## HIGHWAY RESEARCH BOARD
## Special Report 61E

# The AASHO Road Test

## Report 5

## Pavement Research

**National Academy of Sciences—**
**National Research Council**

publication 954

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# The AASHO Road Test

## Report 5

## Pavement Research

By the

**HIGHWAY RESEARCH BOARD**

of the

NAS-NRC Division of Engineering and Industrial Research

## Special Report 61E

Publication No. 954
National Academy of Sciences—National Research Council
Washington, D.C.
1962

This is one of a series of reports of work done under a fiscal agreement of June 10, 1955, between the National Academy of Sciences and the Bureau of Public Roads relating to AASHO Road Test Project; and under individual agreements covering Cooperative Highway Research Project (AASHO Road Test) made between the National Academy of Sciences and the several participating state highway departments, members of the American Association of State Highway Officials.

Included in the series are the following reports:

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# Preface

The AASHO Road Test was conceived and sponsored by the American Association of State Highway Officials as a study of the performance of pavement and bridge structures of known characteristics under moving loads of known magnitude and frequency. It was administered by the Highway Research Board of the National Academy of Sciences—National Research Council, and was considerably larger and more comprehensive than any previous highway research study.

This is the fifth of a series of major reports on the AASHO Road Test. The first four reports are "History and Description of Project", "Materials and Construction", "Traffic Operations and Pavement Maintenance", and "Bridge Research". Additional reports in the series include "Special Studies" and "Final Summary".

This report is a comprehensive summarization of all research related to the test pavements. It describes briefly the experiments and experiment designs, test traffic, measurement programs and data collection procedures, methods of analysis, and the results of the analyses.

It is presented in three major parts. The first is general in nature, describing the background and objectives of the research, facilities and methods of operation employed, and the "present serviceability" concept of pavement performance evaluation. The second and third parts describe the flexible and rigid pavement experimental designs and research and report the findings.

# Acknowledgments

Personnel from many organizations, industrial firms, and institutions of higher learning assisted in carrying out the AASHO Road Test. It is impractical to list the names of all individuals who participated in this report. However, the efforts of the following are particularly acknowledged:

The Bureau of Public Roads of the U. S. Department of Commerce, together with the Department of Defense, for technical advice and services in a great many areas.

The Illinois Division of Highways for technical advice and services of personnel from its headquarters in Springfield, Illinois, and District 3 office in Ottawa, Illinois, and for providing its Resident Task Force.

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Purdue University, the University of Illinois, and Lehigh University for technical advice and services.

The Portland Cement Association, The Asphalt Institute, and the several States for participation in materials testing programs.

The following organizations for the services of resident observer-consultants: The Asphalt Institute, the Portland Cement Association, the American Trucking Association, the Canadian Good Roads Association, the Department of Highways, Province of Ontario, Canada, and the German Highway Research Board.

The American Petroleum Industries for technical advice and services.

General Motors Corporation for equipment, personnel and technical advice in performing skid resistance experiments.

Shell Oil Company for equipment, personnel and technical advice in dynamic testing of flexible pavements.

# Definitions of Terms and Symbols

The following definitions are for terms and symbols that appear frequently or that may have special connotations in this report. Terms in parentheses represent abbreviated or alternative versions that are sometimes used for the defined term. Wherever appropriate, symbols for the term are given after the definition.

## Loop Subdivision

*Loop* (Test Loop): A section of four-lane divided highway about a mile long, the ends of which are connected with large-radius turnarounds.

*Main Loops:* The four loops (Nos. 3, 4, 5 and 6) subjected to tractor-semitrailer traffic.

*Tangent* (straightaway): That portion of any loop excluding turnarounds that lies on one side of the loop median. (All test sections were located on tangents.)

*Lane:* That portion of a tangent that lies on one side of the tangent centerline. (The paved surface of one lane was 12 ft wide.)

*Inner Lane* (lane 1): The lane nearest the loop median. (Single axle tractor-semitrailers operated in the inner lane in the main loops; pick-up trucks with 2-kip single axle loads operated in the inner lane of Loop 2.)

*Outer Lane* (lane 2): The lane farthest from the loop median. (Tandem axle tractor-semitrailers operated in the outer lane of the main loops; single axle trucks with 6-kip axle loads operated in the outer lane of Loop 2.)

*Wheelpath:* The portion of any lane bounded by a pavement edge and an imaginary line parallel to the centerline half way between the edge and centerline. (A wheelpath was considered to be 6 ft wide.)

*Inner Wheelpath:* The wheelpath bounded by the tangent centerline. .............IWP

*Outer Wheelpath:* The wheelpath bounded by the pavement edge. ...............OWP

## Time Identification

*AASHO Calendar* (AASHO day): A four-digit code that increases by one every 24 hr. (July 1, 1956 = 0000; November 3, 1958 = 0855; November 30, 1960 = 1613.)

*Index Day:* A two-digit code that increases by one every two weeks. (Regular measurements pertaining to serviceability were associated with index days.) ....................$t$
($t = 1$ on AASHO day 0855; $t = 55$ on AASHO day 1613.)

*Index Period:* The two-week interval between successive index days.

## Vehicles and Applications

*Axle Arrangement* (Axle configuration, axle spacing, axle type): A qualitative variable used to distinguish between single axle loads and tandem axle loads. ......................$L_2$
($L_2 = 1$ for single axle configuration and $L_2 = 2$ for tandem axle configuration.)

*Tandem Axle:* A two axle unit whose individual axles are approximately 4 ft apart. T or TA

*Single Axle:* A load axle that is not part of a tandem axle unit. .................S or SA

*Steering Axle:* The front axle of a vehicle, not considered a load axle except in the case of the vehicles in Loop 2, lane 1.

*Axle Load:* The total load carried by either a single or tandem axle, usually expressed in thousands of pounds (kips). .............$L_1$

*Vehicle Speed:* The average speed at which the test vehicles traveled (mph). ...........$v$

*Index Period Applications:* The number of load axles that crossed a pavement section during an index period. (Unless otherwise specified the number of applications is the average number in all traffic lanes.) ..............$n_t$

*Seasonal Weighting Function:* A function used to describe the relative serviceability loss potential of a pavement during an index period. ..................................$q_t$

*Weighted Applications for an Index Period:* The product of the seasonal weighting function and the number of applications for an index period; i.e., $q_t\, n_t$. ......................$w_t$

*Axle Load Applications* (Cumulative load applications, load applications, applications): The total number of axle loads that have crossed the pavement sections from Day 836 to any later day. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . $W$

*Axle Load Applications on an Index Day:* $W_t$

*Weighted or Unweighted Applications:* If $W$ has been determined with the use of a seasonal weighting function, $W$ represents weighted applications; if the seasonal weighting function is not used, $W$ represents unweighted applications. Unweighted applications can be considered to be determined by a seasonal weighting function whose value is always 1. Reference to applications implies that the applications are unweighted unless the context specifies weighted applications.

**Pavement Structure**

*Pavement Structure* (pavement): One or more layers of specially processed materials overlying the embankment soil.

*Flexible Pavement:* A pavement structure generally consisting of asphaltic concrete surfacing, base and/or subbase.

*Rigid Pavement:* A pavement structure consisting of portland cement concrete surfacing, with or without subbase.

*Surface:* The visible portion of a pavement.

*Surfacing* (surface): The layers of asphaltic concrete or portland cement concrete material upon which traffic operates.

*Surface Course:* The uppermost layer of asphaltic concrete surfacing.

*Binder Course:* The layer of asphaltic concrete underlying the surface course.

*Surfacing Thickness* (surface thickness, surface, slab thickness (rigid)): The thickness of surfacing material, usually expressed in inches. . . . . . . . . . . . . . . . . . . . . . . . . $D_1$ (Flex.) $D_2$ (Rigid)

*Reinforcement* (surfacing reinforcement): A qualitative variable for rigid pavement used to distinguish between plain portland cement concrete and surfacing reinforced with wire mesh. . . . . . . . . . . . . . . . . . . . . . . . . $D_1$ (Rigid)

*Reinforced Pavement:* Portland cement concrete pavement with doweled transverse contraction joints spaced at 40 ft and containing welded wire fabric in amounts varying from 21 to 81 lb per 100 sq ft, the amount depending upon slab thickness (see Table 38). No expansion joints were provided except adjacent to structures.

*Nonreinforced Pavement:* Plain portland cement concrete pavement with doweled transverse contraction joints spaced at 15 ft (see Table 38). No expansion joints were provided.

*Base* (base course in Road Test usage): Crushed stone, gravel, cement-treated or asphalt-treated sand-gravel material (subbase material) immediately under the surfacing material. (At the Road Test base was used only in the flexible pavements.)

*Base Thickness* (base): The thickness of base, expressed in inches. . . . . . . . . . . $D_2$ (Flex.) (Where no base is specified the material immediately under the surfacing course is either subbase or embankment soil.)

*Subbase* (subbase course in Road Test usage): The layer of graded sand-gravel material between the surface of the embankment soil and the base course (or surfacing course when there is no base course).

*Subbase Thickness* (subbase): The thickness of subbase, expressed in inches. . . . . $D_3$ (Flex. or Rigid)

*Embankment* (embankment soil): The prepared soil underlying the pavement structure.

*Pavement Design* (design, structure design): The specifications for materials and thicknesses of the pavement components (for flexible pavements usually abbreviated $D_1$, $D_2$, $D_3$).

*Thickness Index:* A linear combination of pavement components (flexible pavements) that expresses pavement design as a single number . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . $D$

$D = a_1D_1 + a_2D_2 + a_3D_3$ (Coefficients $a_1$, $a_2$ and $a_3$ depend on the analysis in which the thickness index is to be used.) In certain cases a subscript has been used with $D$; e.g., a cracking index. . . . . . . . . . . . . . . . . . . . . . . . . . . . $D_c$

**Pavement Sections, Experiment Designs**

*Structural Section:* A two-lane section of test pavement of the same design on both sides of the centerline.

*Test Section* (section): A one-lane section of test pavement that has the same load assignment for its full length, and the same design throughout (except in the case of wedge sections and flexible paved shoulder sections).

*Subsection:* One of four 40-ft segments of 160-ft test sections in the special flexible pavement experiments.

*Wedge Section* (special base section): A flexible pavement structural section whose base course varies in thickness at a uniform rate throughout its length.

*Replicate Sections:* Two test sections or subsections having the same pavement design and load assignment.

*Experiment Design:* A set of test sections that form the basic units for controlled variation in pavement design or load factors.

*Factorial Experiment* (Design 1, factorial sections): A set of test sections (flexible or rigid) for which, in each loop, all possible combinations of selected levels appear for the three pavement design factors, $D_1$, $D_2$ and $D_3$.

*Paved Shoulder Studies* (Design 2): A set of test sections (flexible pavement) in which asphaltic concrete shoulder paving decreases in width uniformly from 8 ft to zero from end to end in the direction of traffic.

*Paved Shoulder—Subbase Studies* (Design 3): A factorial experiment (rigid pavement) in each main loop for which the design variables (and their respective levels) are paved shoulders (either present or absent), a 6-in. subbase (either present or absent), and surfacing thickness (at two levels).

*Special Base Studies* (Design 4): The set of wedge sections (flexible pavement) where the thickness and type of base material were varied.

*Subsurface Studies* (Design 5): a set of sections (flexible and rigid) in the non-traffic loop provided for determining seasonal changes in subsurface conditions.

*Surface Treatment Study* (Design 6): The set of flexible pavement sections whose surfacing was a bituminous treatment.

## Accumulated Behavior of Pavements

*Cracking:* The amount of cracking in the pavement surface that existed at any given time, expressed in square feet of cracked area per 1,000 sq ft of surface area (flexible) or in linear feet of projection (see Section 3.2.3.1) per 1,000 sq ft of surface area (rigid). Usually classified according to severity, as follows:

*Cracking,* for serviceability indexes. . . . . $C$

*Cracking Index, Flexible Pavement:* The number of axle load applications before Class 2 cracking appeared (see Section 3.2.3.1). . . . $W_c$

*Cracking Index, Rigid Pavement:* The total cracking in the surface of a test section. . . . $C'$

*Patching:* The area of a test section, patched with asphaltic concrete, expressed in square feet of patching per 1,000 sq ft of surfacing. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . $P$

*Pumping:* The ejection of water and subbase material or embankment soil from beneath the pavement surfacing.

*Pumping Index:* An index used classifying the severity of edge pumping, expressed in cubic inches of material per inch of pavement edge. (The term "pumping score"—Equivalent to 100 × the pumping index—was used for convenience in record keeping.)

*Rut Depth* (rut): The maximum vertical displacement of a point of the surface measured from the center of a 4-ft transverse straightedge . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . $RD$
(The mean rut depth, $\overline{RD}$, taken in both wheelpaths at several points longitudinally along a test section was used in most analyses).

*Slope:* A profilometer estimate of the angle between a horizontal plane and a line joining two surface points 9 in. apart longitudinally in the wheelpaths.

*Slope Variance:* The variance (mean square deviation) of a set of slopes about the mean slope . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . $SV$
(The mean slope variance in the two wheelpaths of a section, $\overline{SV}$, was used in most analyses).

*Faulting:* The vertical displacement of the surface of a portland cement concrete pavement at one side of a joint or crack relative to the slab surface on the other side of the joint or crack measured at the center of each wheelpath and expressed in tenths of inches per 1,000 ft of wheelpath.

*Frost Heave:* The vertical displacement of the surface of the embankment soil or of any of the structural pavement components associated with volume change due to freezing.

*Serviceability Rating:* The judgment of an observer as to the current ability of a pavement to serve the traffic it is meant to serve. PSR

*Serviceability Index:* An estimate of the mean of serviceability ratings made by a panel of judges. A present serviceability index formula is used to determine the estimate of the serviceability rating of a section. . . . . . . . $p$

*Serviceability Index on an Index Day.* . . . $p'_t$

*Smoothed Serviceability Index:* An average of serviceability values for several weeks before and after a given index day. . . . . . . . . . $p_t$

*Serviceability Trend:* A continuous graph of smoothed serviceability values plotted against axle load applications.

*Roughness Index, Flexible:* The logarithm of (1 + slope variance).

*Performance:* The serviceability trend of a test section with increasing number of axle applications.

*Performance Data:* Selected pairs of coordinates from a serviceability trend, usually equally spaced on either a time basis or on a serviceability basis. . . . . . . . . . . . . . . . . $p$, $W$ or $p$, log $W$

*Out-of-Test Section* (failed section): Any section whose serviceability trend fell to 1.5 before the end of the test traffic (1.0 for Design 6).

*In-Test Section:* Any section whose serviceability index was greater than 1.5 at the time of observation (1.0 for Design 6).

**Transient Behavior of Pavements**

*Corner Movement:* Maximum vertical displacement, in inches, of a point on a rigid pavement edge at a joint, occurring as the air temperature changes from a maximum to the next minimum, or from a minimum to the next maximum. . . . . . . . . . . . . . . . . . . . . . . . . . . . . $m_c$

*Curling* (in Road Test usage): Changes in the shape of a rigid pavement surface over a period of maximum movement found to be about 12 hours.

*Deflection:* The difference in elevation of a point on or in the pavement before and after a specified condition of loading.

*Beam Deflection:* Deflection taken with a Benkelman beam whose probe is at the point of measurement.

*Creep Speed Deflection:* Deflection recorded when the load approaches and leaves the probe point at creep speed (2 to 3 mph) (flex.)

*Normal Procedure Deflection:* The difference between the probe elevation before loading and the probe elevation when the load is opposite the probe (flex.)

*Rebound Procedure Deflection:* The difference between the probe elevation after removal of the load and the probe elevation when the load is opposite the probe (flex.)

*Static Rebound Deflection:* The difference in elevation of the probe when the load is static and opposite the probe and when the load is removed. (Used in all rigid pavement tests with the beam reference on the shoulder.)

*Static Rebound Edge Deflection:* A test with the probe midway between 15-ft transverse joints in nonreinforced pavement and 10 ft from joints in reinforced pavement, and with the load (center of the dual wheels of the test vehicles) 20 in. from the pavement edge. $d'_e$

*Static Rebound Corner Deflection:* A test with the probe on a rigid pavement edge at a joint and with the load 20 in. from the edge (see Fig. 145) . . . . . . . . . . . . . . . . . . . . . . . . $d'_c$

*Dynamic Deflection:* Deflection caused by a moving vehicle and measured at a point with a linear variable differential transformer. . . . $d$

*Partial Deflection:* The deflection measured under a 2-ft longitudinal chord at the bottom of the deflection basin (flex.)

*Corner Deflection:* Deflection of a rigid pavement edge 6 in. from a joint with the center of the wheel load 20 in. from the edge (see Fig. 138) . . . . . . . . . . . . . . . . . . . . . . . . $d_c$

*Temperature:* Unless otherwise specified, temperature refers to temperature, in °F, of a point within a pavement structure as measured with a thermocouple.

*Air Temperature:* Temperature of air, in °F, at a point 5 ft above the ground. . . . . . . . $U$

*Temperature Differential* (in Road Test usage): The difference in temperature at the top and bottom of a 6½-in. concrete slab. . . . $T$

*Strain:* The unit change in length of an element of the pavement surface between the loaded and unloaded conditions. Strain may be tensile or compressive. It is usually expressed in microinches per inch . . . . . . . . . . . . . . . . . . $e$

*Pressure* (embankment pressure): The unit pressure, in lb per sq in., transmitted through a pavement structure under dynamic load to a cell located in the surface of the embankment soil. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . $P$

**Data and Analysis**

*Data System:* A collection of data that may contain initial observations, summarized data, or results from analyses. Data in a particular system are generally in one or more of three forms: analog records, IBM cards and printouts, or folders containing basic data and summaries. A four-digit code is used to identify each Road Test data system.

*Mathematical Model* (model): An assumed algebraic form for the relationship among particular experimental variables. The model includes constants whose values are to be determined by analysis procedures, and may also include constants whose values are assumed. In many cases the models involve logarithms. Throughout this report logarithms are always to the base 10.

*Residual:* The difference between the observed value of an experimental variable and the value computed for this variable from a model in which all constants are determined and specific values are assigned to all remaining variables.

*Root Mean Square Residual:* The square root of the average squared residual. In general the divisor for this average is equal to the number of residuals less the number of constants determined for the model by the data. rms$r$ or rms error

*Average Residual* (mean residual): The average of the absolute values of all residuals. In general, the divisor for this average is equal to the number of residuals. . . . . . . . . . . . . . . . . $r$

*Mean Log Residual:* Whenever an equation is derived for the logarithm of a variable, $Y$, instead of for $Y$ itself, residuals and mean residuals represent discrepancies between observed and calculated logarithms of $Y$. Because it is generally assumed that about 90 percent of individual residuals are less than twice the mean residual, nine-tenths of the scatter of the observations log $Y$, around the calculated values, $\log \hat{Y}$, is contained in the band whose limits are $\log Y = \log \hat{Y} + 2\bar{r}$, where $\log \hat{Y}$ is calculated from the derived equation and where $\bar{r}$ is the mean log residual.

It is often useful to express the error limits in the original units of $Y$. By taking antilogarithms these limits are given by $Y = (10^{\pm 2r})\ (\hat{Y})$. Thus nine-tenths of the scatter of $Y$ around $\hat{Y}$ is expressed as two percentages of $\hat{Y}$, $(10^{-2\bar{r}})\ (Y)$ and $(10^{2\bar{r}})\ (\hat{Y})$. For example, if $\bar{r} = 0.16$, then $10^{-0.32} = 0.48$ and $10^{0.32} = 2.09$, so that approximately nine-tenths of the observed values for $Y$ are found between 0.48 and 2.09 times the corresponding calculated values for $Y$. Roughly speaking, it would be unusual, in this example, to find an observation less than one-half or more than twice the corresponding value calculated from the equation.

If only one mean log residual is used to establish the error band, it can be expected that the band will contain about 60 percent of the residuals in log $Y$.

*Effects* (explained effects): Changes, or average changes, in an observed variable that are attributed to changes in one or more of the controlled factors of an experiment.

*Residual Effects* (unexplained effects, residual variation): Changes in an observed variable that are attributed to changes in unidentified variables. Usually expressed in terms of average residuals.

*Statistical Significance:* An (explained) effect is said to be statistically significant if its magnitude relative to an appropriate average residual is so large that there is little risk that the explained effect is actually a residual effect. The assumed risk that the explained effect is really a residual effect is called the significance level, usually selected to be no more than 5 percent.

*Linear Model:* A model whose general form is $A_0 + A_1X_1 + A_2X_2 \ldots + A_kX_k = 0$, where $X_1, X_2, \ldots, X_k$ are functions of one or more experimental variables, and at least one of the constants $A_0, A_1, \ldots, A_k$ is to be determined through data analysis.

*Least Squares Linear Regression Analysis* (regression analysis): A mathematical procedure for evaluating the undetermined constants in a linear model when it is assumed that the best coefficients are those which lead to a minimum for the sum of squared residuals for a particular experimental variable.

*Total Variation:* For a particular experimental variable, the sum of squared deviations of the values for the variable from the mean value of the variable.

*Squared Correlation Coefficient:* For linear models the difference between unity and the ratio of total squared residuals to total variation for a particular variable. Sometimes said to be that fraction of the total variation which is explained by the regression equation. . . . . $r^2$

*Correlation Index:* For the case of nonlinear models the correlation index serves to indicate the degree of correlation between observed values of an experimental variable and corresponding values predicted from a derived equation. Thus, the correlation index is a generalization of the squared correlation coefficient that is used for linear models. The correlation index is computed by subtracting from one the ratio of sum of squared residuals to the total variation in the observations for the variable.

*Beta:* In the Road Test model for performance, a function of pavement design and load variables ($D_1$, $D_2$, $D_3$, $L_1$, $L_2$) that determines the shape of a computed serviceability trend. If $\beta = 1$ the trend is linear; if $\beta > 1$ the trend decreases more rapidly with increasing applications; if $\beta < 1$ the trend decreases less rapidly with increasing applications. ....... $\beta$

*Rho:* In the Road Test model for performance, a function of ($D_1$, $D_2$, $D_3$, $L_1$, $L_2$) that equals the (computed) number of load applications required to bring the serviceability level of a pavement to 1.5. ........................ $\rho$

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# THE AASHO ROAD TEST
# Report 5
# Pavement Research

## Chapter 1

## General Information

### 1.1 BACKGROUND AND OBJECTIVES

#### *1.1.1 History*

The events leading to the three most recent large-scale highway research projects, Road Test 1–MD, the WASHO Road Test and the AASHO Road Test, are described in detail in AASHO Road Test Report 1, "History and Description of the Project" (HRB Special Report 61A). The following is a summary of these events and the activities of the AASHO Road Test.

For many years the member states of the American Association of State Highway Officials had been confronted with the dual problem of constructing pavements to carry a growing traffic load and establishing an equitable policy for vehicle sizes and weights. The Association recognized the common need for factual data for use in resolving the problem. Therefore, in September 1948, it set up a procedure for initiating and administering research projects to be jointly financed by two or more states.

In December of the following year a meeting was held at Columbus, at the request of the Governor of Ohio, to consider the problem of vehicle weight and its effect upon existing and future pavements. The conference was attended by representatives of the Council of State Governments and highway officials of 14 eastern and midwestern states. The need for more factual data concerning the effect of axle loads of various magnitudes on pavements was confirmed.

As a result, Road Test 1–MD was conducted in 1950. An existing concrete pavement in Maryland was tested under repeated application of two single- and two tandem-axle loads. The Highway Research Board administered the test and published the results as HRB Special Report 4.

Concurrently, the Committee on Highway Transport of the American Association of State Highway Officials recommended that additional road tests be initiated by the regional members of the Association. As a result, the Western Association of State Highway Officials sponsored the WASHO Road Test, consisting of a number of specially-built flexible pavements in Idaho tested in 1953-54 under the same loads used in the Maryland test. The results of this test, also conducted by the Highway Research Board, were published as Special Reports 18 and 22.

In March 1951, the Mississippi Valley Conference of State Highway Engineers had started planning a third regional project. However, the idea of another regional project of limited extent was abandoned in favor of a more comprehensive road test to be sponsored by the entire Association. In October, complying with a request by the Association, a Highway Research Board task committee submitted a report, "Proposal for Road Tests," after which the Association appointed a working committee to prepare a prospectus on the project. By December it had been decided to include bridges in the research.

In June 1952, the Working Committee produced a report, "AASHO Road Test Project Statement." In July it selected a site for the project near Ottawa, Ill. In January 1953, it submitted a second report, "AASHO Road Test Project Program," and in August 1954, a third entitled "Project Program Supplement." In May 1955, this committee produced its fourth and final report "Statement of Fundamental Principles, Project Elements and Specific Directions."

Meanwhile, in March 1953, AASHO had formulated a plan for prorating the cost of the project among its member departments and, later, had received assurances of participation from the States, the Automobile Manufacturers Association, the Bureau of Public Roads and the American Petroleum Institute, while the Department of Defense had agreed to furnish military personnel for driving the vehicles.

On February 22, 1955, the Highway Research Board with the approval of its parent organization, the National Academy of Sciences —National Research Council, accepted from the Association the responsibility to administer and direct the new project. The Board opened a field office at Ottawa, Ill., in July 1955; and in August a task force of the Illinois Division of Highways moved to the site to undertake the preparation of plans and to prepare for the construction of the test facilities.

In March 1956, the Board appointed the National Advisory Committee as its senior advisory group and in April selected a project director.

In June 1956, the National Advisory Committee passed a resolution recommending that the Executive Committee of the Highway Research Board consider the inclusion in the facility of a fifth test loop to be subjected to light axle loads. This resolution, recommended by the Bureau of Public Roads, was based on the pending enactment of the Federal Aid Highway Act of 1956. In July, the Executive Committee of the Board approved this change and made additional changes involving special studies areas. The final layout of the test facilities is described in Section 1.2.2.

Construction of the test facilities began in August 1956, and test traffic was inaugurated on October 15, 1958. Test traffic was operated until November 30, 1960, at which time 1,114,000 axle loads had been applied to the pavement and the bridges.

A special studies program was conducted in the spring and early summer of 1961 over some of the remaining test sections. Strains, deflections and pressures were measured in these studies under a wide variety of vehicle types, load suspensions, tires and tire pressures. Special military vehicles, included at the request of the Army, as well as highway construction equipment, were included in these tests. The results of the studies are presented in Road Test Report 6.

During 1961, the research staff concentrated on analysis of the test data and the preparation of reports. Each of the major reports was approved by a review subcommittee of the National Advisory Committee and later submitted to the entire National Advisory Committee and the Regional Advisory Committees prior to its publication by the Highway Research Board. All reports were completed by the project staff, reviewed by the various committees, and submitted to the Board.

The field office for the project was closed in January 1962. However, the Highway Research Board agreed to continue certain studies associated with the Road Test pavement performance analyses in its Washington office. The results of these studies will be reported by the Highway Research Board.

### *1.1.2 Intent of the AASHO Road Test*

The following formal statement of the intent of the Road Test was approved by the Executive Committee of the Highway Research Board January 13, 1961:

> The AASHO Road Test plays a role in the total engineering and economic process of providing highways for the nation. It is important that this role be understood.
>
> The Road Test is composed of separate major experiments, one relating to asphalt concrete pavement, one relating to portland cement concrete pavement, and one to short span bridges. There are numerous secondary experiments. In each of the major experiments, the objective is to relate design to performance under controlled loading conditions.
>
> In the asphalt concrete and portland cement concrete experiments some of the pavement test sections are underdesigned and others overdesigned. Each experiment requires separate analysis. Eventually the collection and analysis of additional engineering and economic data for a local environment are necessary in order to develop final and meaningful relations between pavement types.
>
> All of the short span bridges are underdesigned. Each is a separate case study.
>
> Failures and distress of the pavement test sections and the beams of the short span bridges are important to the success of each of the experiments.
>
> The Highway Research Board of the National Academy of Sciences—National Research Council has the responsibility of administering the project for the sponsor, the American Association of State Highway Officials, within the bounds of the objectives of the test. The Board is also responsible for collecting engineering data, developing methods of analysis and presentation of data, preparing comprehensive reports describing the tests, and drawing valid findings and conclusions. It is here that the role of the Highway Research Board ends.
>
> As the total engineering and economic process of providing highways for the nation is developed, engineering data from the AASHO Road Test and engineering and economic data from many other sources will flow to the sponsor and its member departments. It is here that studies will be made and final conclusions drawn that will be helpful to the executive and legislative branches of our several levels of government and to the highway administrator and engineer.

### *1.1.3 Objectives*

The objectives of the AASHO Road Test as stated by the National Advisory Committee were as follows:

> 1. To determine the significant relationships between the number of repetitions of specified axle loads of different magnitude and arrangement and the performance of different thick-

nesses of uniformly designed and constructed asphaltic concrete, plain portland cement concrete, and reinforced portland cement concrete surfaces on different thicknesses of bases and subbases when on a basement soil of known characteristics.

2. To determine the significant effects of specified vehicle axle loads and gross vehicle loads when applied at known frequency on bridges of known design and characteristics.
3. To make special studies dealing with such subjects as paved shoulders, base types, pavement fatigue, tire size and pressures, and heavy military vehicles, and to correlate the findings of these special studies with the results of the basic research.
4. To provide a record of the type and extent of effort and materials required to keep each of the test sections or portions thereof in a satisfactory condition until discontinued for test purposes.
5. To develop instrumentation, test procedures, data, charts, graphs, and formulas, which will reflect the capabilities of the various test sections; and which will be helpful in future highway design, in the evaluation of the load-carrying capabilities of existing highways and in determining the most promising areas for further highway research.

This report deals primarily with work done in connection with Objectives 1 and 5 and with some of the special studies mentioned in Objective 3. Material relating to Objective 2 will be found in Road Test Report 4 and Objective 4 is discussed in Report 3. Other special studies suggested in Objective 3 are discussed in Report 6.

### *1.1.4 Objectivity of Findings*

Discussion of the results given in this report has generally been limited to specific relationships derived from the data. Restraint has been exercised in expressing opinions, conjectures, and speculations. Conclusions have been drawn only when supported by data acquired during the tests.

At the request of the National Academy of Sciences a panel of statisticians was appointed in 1955 so that professional advice was available for both the designs of the Road Test experiments and for the procedures by which the experimental data would be analyzed. It was not the function of this group to select variables nor levels for variables to be included in the Road Test. This was the responsibility of the National Advisory Committee, acting upon the recommendations of the original AASHO Transport Committee's Working Committee. The Statistical Panel played an important role in influencing the experimental layout through its recommendations for complete factorial designs, randomization, and replication. Its recommendations, accepted by the Advisory Committee, made possible effective studies of the relationships sought by the objectives.

Within the space, time and funds available, only a few variables could be studied thoroughly. The experiment was designed and the test facilities built specifically for the study of these variables. In general, mathematical models were used to represent associations among experimental variables, then statistical methods were employed to determine constants for the models as well as to describe the reliability of the evaluated models. Thus experimental designs and analytical procedures were developed in order to obtain unbiased estimates of the effects (and the statistical significance of many of the effects) of controlled experimental factors. The designs and procedures did not, however, make it possible to obtain effects for other factors that were either held constant or that varied in an uncontrolled fashion, for example, embankment soil, strength of materials, and environmental conditions. Although estimates were obtained for the effects of axle load and axle configuration, it was not possible to determine the statistical significance of these effects because replication of load or configuration was not provided. Nevertheless, particularily in the cases of load effect on both pavement types and axle configuration effect on rigid pavement the differences observed were so great as to leave practically no doubt that the effects were significantly greater than zero.

Basic data will be made available to other groups equipped to perform independent analyses. Further analyses are to be encouraged by the Highway Research Board in the expectation that the over-all usefulness of the project will be enhanced.

### *1.1.5 Applicability of Findings*

The findings of the AASHO Road Test, as stated in the relationships shown by formulas, graphs, and tables throughout this report, relate specifically to the physical environment of the project, to the materials used in the pavements, to the range of thicknesses and loads and number of load applications included in the experiments, to the construction techniques employed, to the specific times and rates of application of test traffic, and to the climatic cycles that occurred during construction and testing of the experimental pavements. More specific limitations on certain of the findings are given in the discussion of results in various sections of this report. *Generalizations and extrapolations of these findings to conditions other than those that existed at the Road Test should be based upon experimental or other evidence of the effects on pavement performance of variations in climate, soil type, materials, construction practices and traffic.*

## 1.2 FACILITIES AND OPERATIONS

### *1.2.1 Site Location*

The location of the AASHO Road Test was near Ottawa, Ill., in LaSalle County, about 80 mi southwest of Chicago (Fig. 1). The test

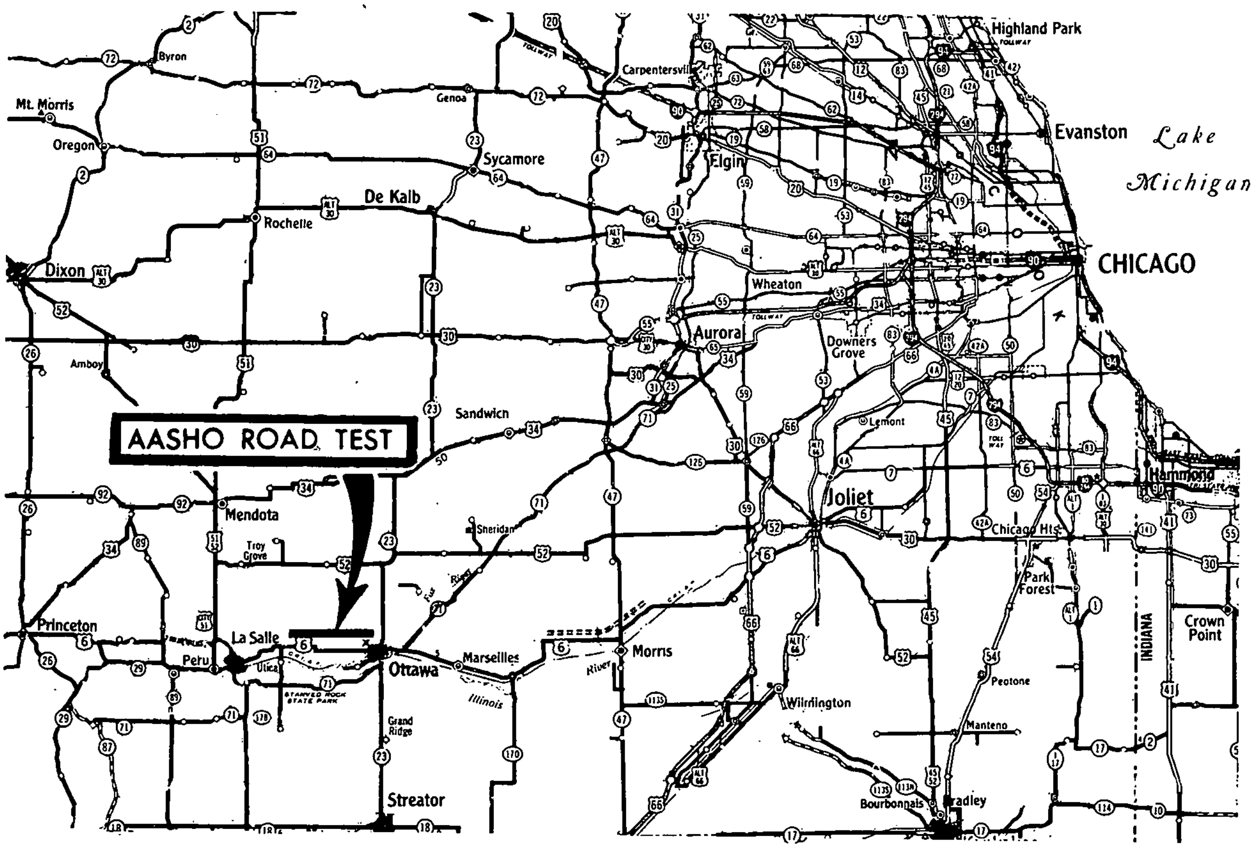


Figure 1. Site location.

facility was constructed along the alignment of Interstate Route 80. The site was chosen because the soil within the area was uniform and of a type representative of that found in large areas of the country, because the climate was typical of that found throughout much of the northern United States, and because much of the earthwork and pavement construction could ultimately be utilized in the construction of a section of the National System of Interstate and Defense Highways.

### 1.2.2 *Test Facilities*

The test facilities consisted of four large loops, numbered 3 through 6, and two smaller loops, 1 and 2. Test bridges were at four locations in two of the large loops. The layout of the six test loops, the administration area and the Army barracks is shown in Figure 2.

Each loop was a segment of a four-lane divided highway whose parallel roadways, or tangents, were connected by a turnaround at each end. Tangent lengths were 6,800 ft in Loops 3 through 6, 4,400 ft in Loop 2 and 2,000 ft in Loop 1. Turnarounds in the major loops had 200-ft radii and were superelevated so that the traffic could operate over them at 25 mph with little or no side thrust. Loop 2 had superelevated turnarounds with 42-ft radii. Centerlines divided the pavements into inner and outer lanes, called lane 1 and lane 2 respectively.

All vehicles assigned to any one traffic lane of Loops 2 through 6 had the same axle arrangement-axle load combinations. No traffic operated over Loop 1. In all loops, the north tangents were surfaced with asphaltic concrete and south tangents with portland cement concrete. All variables for pavement studies were concerned with pavement designs and loads within each of the 12 tangents. Each tangent was constructed as a succession of pavement sections called structural sections. Pavement designs, as a rule, varied from section to section. The minimum length of a section was 100 ft in Loops 2 through 6, and 15 ft in Loop 1. Sections were separated by short transition pavements. Each structural section was separated into two pavement test sections by the centerline of the pavement. Figure 3 shows the layout of two typical test loops and locations of the test bridges.

Details of the experiment designs are given in Report 1 and are summarized in Sections 2.1.1 and 3.1.1 of this report. Details concerning all features of bridge research are given in Road Test Report 4.

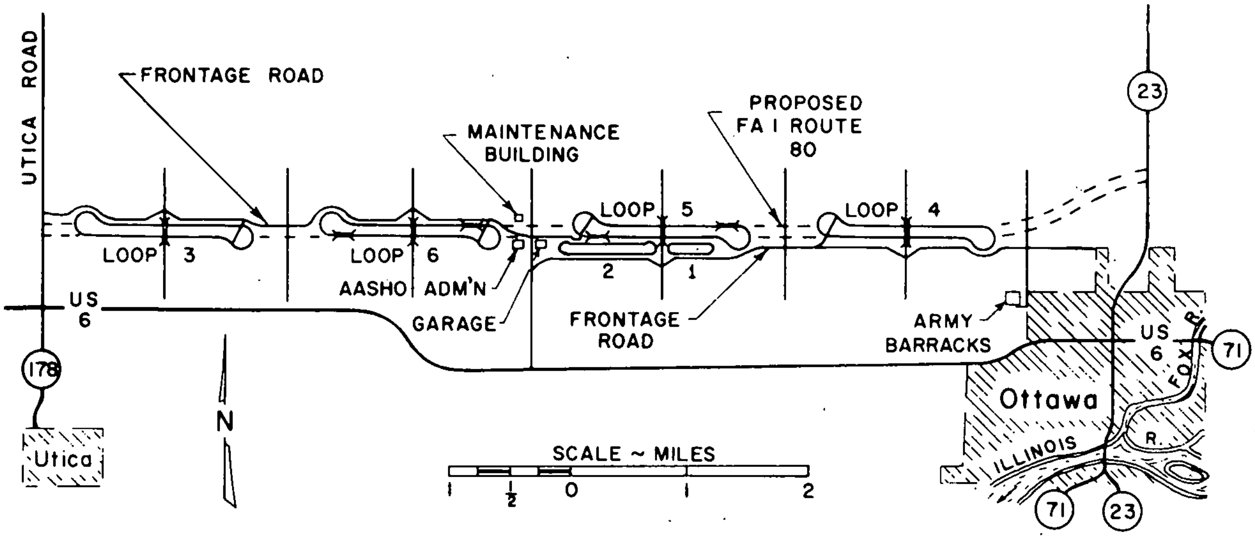


Figure 2. Layout of AASHO Road Test.

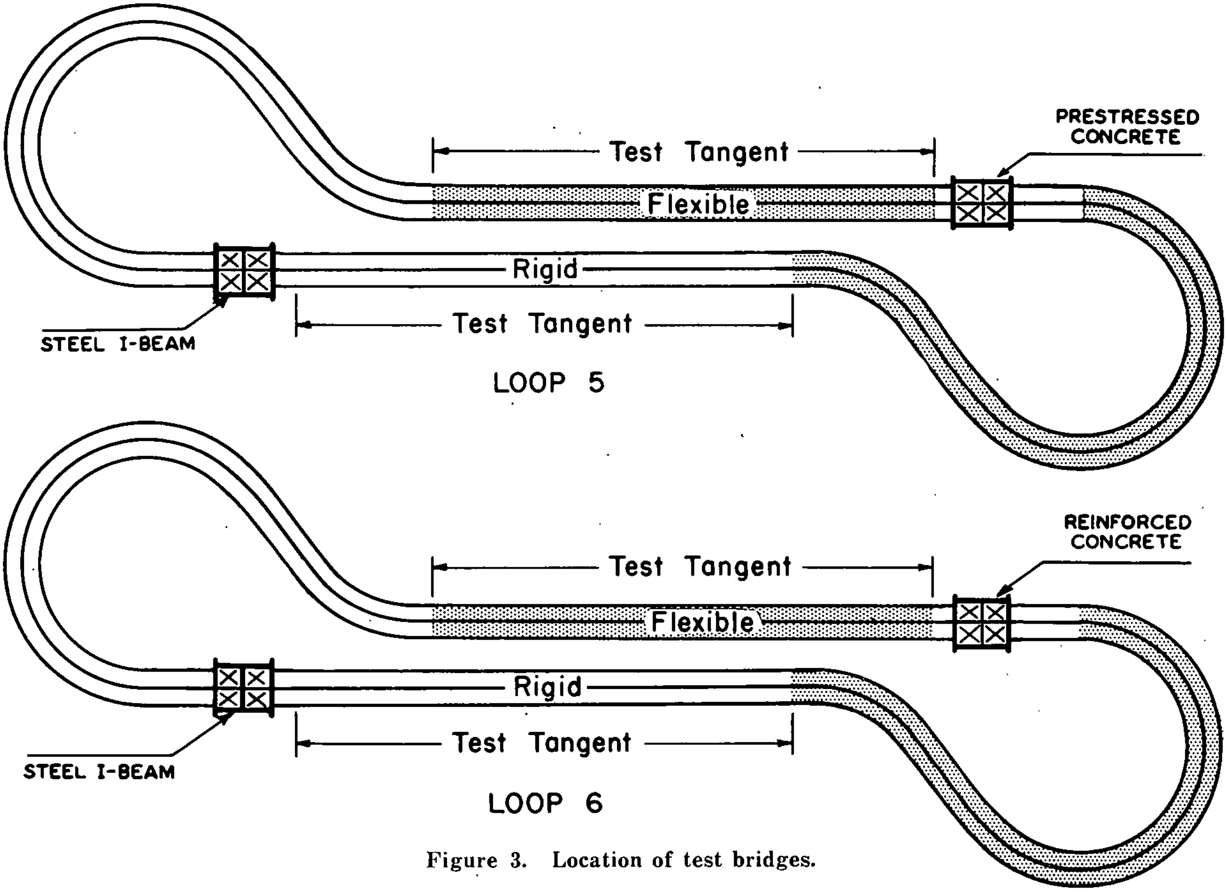


Figure 3. Location of test bridges.

Figure 4. Administration building.

Figure 5. Vehicle maintenance garage.

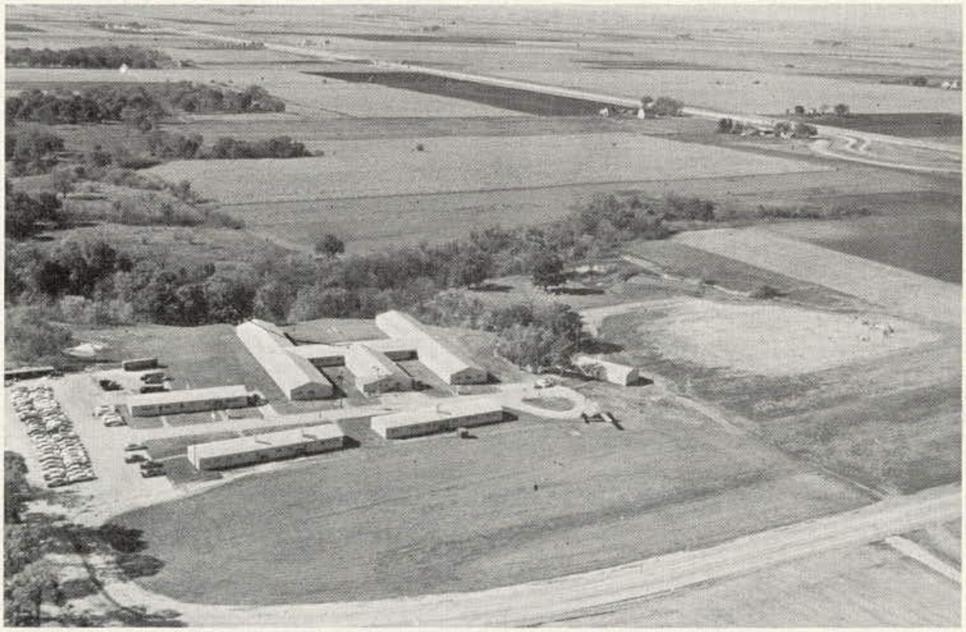


Figure 6. Army driver quarters (Wallace Barracks).

An administrative area was located at the center of the project. Laboratories and offices were located in the building shown in Figure 4. Shop facilities for vehicle maintenance were provided in the building shown in Figure 5. A military installation called Wallace Barracks (Fig. 6) was provided by the National Academy of Sciences to house the Army Transportation Corps Road Test Support Activity.

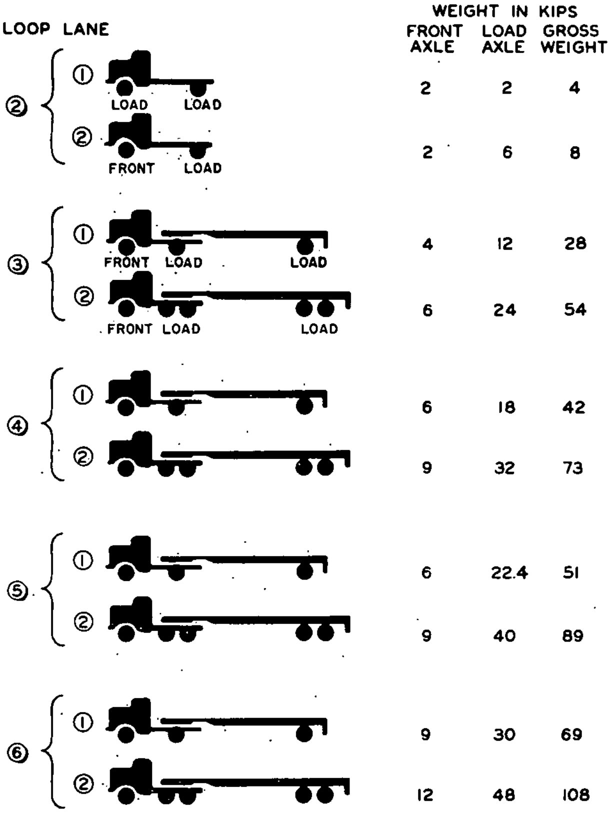
### *1.2.3 Construction*

A comprehensive description of the construction of the AASHO Road Test facilities is given in Road Test Report 2. Construction was supervised by the task force of the Illinois Division of Highways. On-site materials control and testing were provided by the Highway Research Board Staff on the project. Conventional techniques for construction were used except that extraordinary effort was put forth to insure uniformity of all pavement components. For example, no construction equipment other than that necessary for compaction was permitted to operate in the center 24-ft width of the roadway, and all turning operations on the grade were limited to specially designated transition areas. Specifications for density of compacted embankment soil, subbase and base materials included stipulations of maximum densities as well as the conventional minimums.

Construction was performed under contracts negotiated through normal Illinois contractual channels. It was started in late summer 1956 and completed in time for test traffic to begin in the fall of 1958. S. J. Groves and Sons was the principal contractor in a joint venture with Arcole Midwest, Inc., in the embankment construction and with Rock Roads, Inc., as a subcontractor for asphaltic concrete surfacing. Valley Builders, Inc., built the bridges.

### *1.2.4 Test Traffic*

A detailed description of the operation of the test traffic is presented in Road Test Report 3. As previously stated, Loop 1 was not subjected to test traffic. One lane of this loop was used for subsurface and special load studies, the other for observing the effect of environment on pavements not subjected to traffic. The remaining five loops, 2 through 6, were subjected to traffic for slightly more than two years. Every vehicle in any one of the ten traffic lanes had the same axle load and axle configuration. The assignment of axle loads and vehicle types to the various lanes is shown in Figure 7.



| LOOP | LANE | WEIGHT IN KIPS FRONT AXLE | WEIGHT IN KIPS LOAD AXLE | WEIGHT IN KIPS GROSS WEIGHT |
|---|---|---|---|---|
| ② | ① | 2 | 2 | 4 |
| | ② | 2 | 6 | 8 |
| ③ | ① | 4 | 12 | 28 |
| | ② | 6 | 24 | 54 |
| ④ | ① | 6 | 18 | 42 |
| | ② | 9 | 32 | 73 |
| ⑤ | ① | 6 | 22.4 | 51 |
| | ② | 9 | 40 | 89 |
| ⑥ | ① | 9 | 30 | 69 |
| | ② | 12 | 48 | 108 |

**Figure 7. Typical test vehicle axle loadings.**

The vehicles were loaded with concrete blocks that were anchored down with steel bands and chains. Although the traffic phase was inaugurated on October 15, 1958, early operation indicated the need to readjust the test loads. This delayed full-scale traffic until November 5, 1958. From November 1958 to January 1960 controlled test traffic consisted of six vehicles in each lane of Loops 3 through 6, four vehicles in lane 1 of Loop 2 and eight vehicles in lane 2 of Loop 2. In January 1960, the traffic was increased to ten vehicles in each lane of Loops 3 through 6, six in lane 1 and 12 in lane 2 of Loop 2. These vehicle distributions were selected in order that axle load applications could be accumulated at the same rate in each of the ten traffic lanes.

All lanes had identical specifications for transverse placement, speed, and rate of axle load accumulation. Tire pressure and steering axle loads were representative of normal practice. Some of the vehicles were gasoline and others diesel powered. Further information concerning the vehicles is contained in Road Test Reports 1 and 3.

Whenever possible, traffic was operated at 35 mph on the test tangents. Traffic was scheduled to operate over an 18-hr, 40-min period each day, 6 days a week, except that during the first 6 months of 1960 the schedule was extended to 7 days a week. The schedule was maintained except when pavement distress, truck breakdowns, bad weather and certain other causes made it impossible. A total accumulation of 1,114,000 axle load applications was attained during the 25-month traffic testing period. To accomplish this, soldiers of the U. S. Army Transportation Corps Road Test Support Activity drove more than 17 million miles.

### *1.2.5 Measurement Programs*

Each measurement program was designed to accomplish one or more of the following purposes: (1) to furnish information at regular and frequent intervals concerning the roughness and visible deterioration of the surfacing of each section; (2) to record early in the life of each section transient load effects that might be directly correlated with the ultimate performance of the section; and (3) to furnish a limited amount of additional information which might contribute to a better understanding of pavement mechanics.

Programs falling in the first category were concerned with measurements of permanent changes in the pavement profile along and across the wheelpaths, as well as the extent of cracking and patching of the surfacing. These measurements were given major emphasis since they were used to define the performance of each section as required by the first Road Test objective.

Programs falling in the second category included the measurement of strains and deflections which became the basis for estimating pavement capability, as required by the fifth objective.

Finally, programs of the third category encompassed such measurements as the severity of pumping of rigid pavements, changes in layer thickness in flexible pavements, pavement temperatures, subsurface conditions, and numerous other measurements.

In general, measurements were restricted to those variables that had been demonstrated by previous research to be related significantly to pavement performance. A further restriction, applying especially to subsurface studies, was imposed by the overriding necessity to keep the test traffic moving.

In spite of these restrictions, a formidable amount of data was accumulated, and special electronic systems were evolved to facilitate the storage and initial processing of the data. For example, in the case of some programs, means were provided to record automatically in the field the desired information directly on perforated paper tape, thus eliminating the task of the manual reading of analog records. In another case, an electronic device was used to read field analog records and to punch the information on paper tape for immediate transference to an electronic computer. In general, automatic data handling was used wherever possible and the majority of the data were stored on IBM cards.

Data from the various measurement systems were classified into data systems, and a particular system was identified by a four digit code. Appendix I lists major Road Test data systems concerned with pavement research and notes how the systems may be obtained from the Highway Research Board. Major data systems from the bridge research are listed in Appendix A, Road Test Report 4.

The text of this report contains many references to data systems whose contents are pertinent to the discussion. These references are explained in Appendix I. For example, a reference to Data System 5121, or simply DS 5121, is explained in Appendix I as containing all routine Benkelman beam deflection data for flexible pavement sections on the traffic loops with an IBM printout of the data available on request.

Specific measurement programs are described in the appropriate sections of Parts 2 and 3.

### *1.2.6 Pavement Maintenance*

Detailed descriptions of maintenance criteria and procedures are given in Road Test Report 3. Complete maintenance histories of each test section are available in DS 6300.

The objectives of the Road Test were concerned with the performance of the test sections as constructed. Consequently, maintenance operations were held to a minimum in any section that was still considered under study. When the "present serviceability" (see Section 1.3) of any section dropped to a specified level the section was considered to be out of test and maintenance or reconstruction was performed as needed.

Since the prime objective of the maintenance work was to keep test traffic operating as much as possible, minor repairs were made when required regardless of weather or time of day. The use of pierced steel landing mats permitted traffic to operate through a complete driving period so that more conventional repairs could be made during the daily 5-hr, 20-min traffic break.

All repairs were made with flexible-type pavement material. Deep patches and reconstruction consisted of compacted crushed stone base material surfaced with hot-mixed asphaltic concrete. Overlays consisted of asphaltic concrete. Thin patches were made either with hot-mix or cold-mix materials. Crushed stone base material and cold-mix surfacing were stockpiled at several locations on the project, and hot-mix asphaltic concrete was generally purchased from a nearby contractor.

As a general rule, pavement maintenance was done by project forces with project-owned equipment. However, in the critical spring periods of 1959 and 1960, it was necessary to augment the project maintenance forces with additional men and equipment.

### *1.2.7 Environmental Conditions*

The topography of the Road Test area is level to gently undulating with elevations varying from 605 to 635 ft. Drainage is provided by several small creeks which are tributaries of the Illinois River. Surface drainage, how-

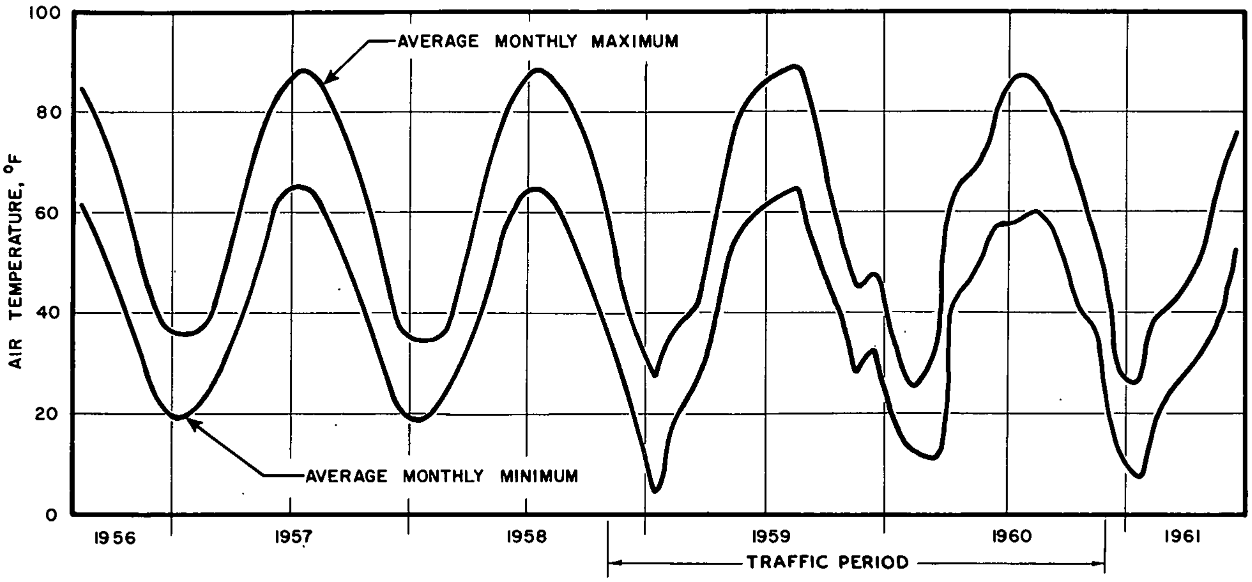


Figure 8. Average monthly air temperature at project.

ever, is generally slow. Geologic information indicates that the area was covered by ice during several glacial periods and that the subsurface soils were deposited or modified during these periods. Surface soils were subsequently derived from a thin mantle of loess deposited during a post-glacial period and were reasonably uniform in the area of the project. Soil drainage is generally poor. Bed rock is found 10 to 30 ft below the surface.

The upper layer of soil was from 1 to 2 ft thick and consisted generally of A-6 or A-7-6 soil with similar characteristics. The adjacent underlying stratum was usually from 1 to 2 ft thick and most of this material was fairly plastic A-7-6 soil. Substratum layers were usually represented by samples exhibiting A-6 characteristics.

In the interest of uniformity, soil making up the top 3 ft of embankment directly under the test pavements was taken from borrow areas near the project. This soil, underlying the surface stratum, was shown by tests to have a plasticity index from 11 to 15, a liquid limit from 27 to 32, and a grain size distribution of 80 to 85 percent finer than the 200 mesh sieve, 58-70 percent finer than 0.02 mm and 34-40 percent finer than 0.005 mm. Maximum dry densities were in the range 114 to 118 lb per cu ft and optimum moisture contents in the range of 14 to 16 percent when compacted in accordance with standard procedure, AASHO T99–49.

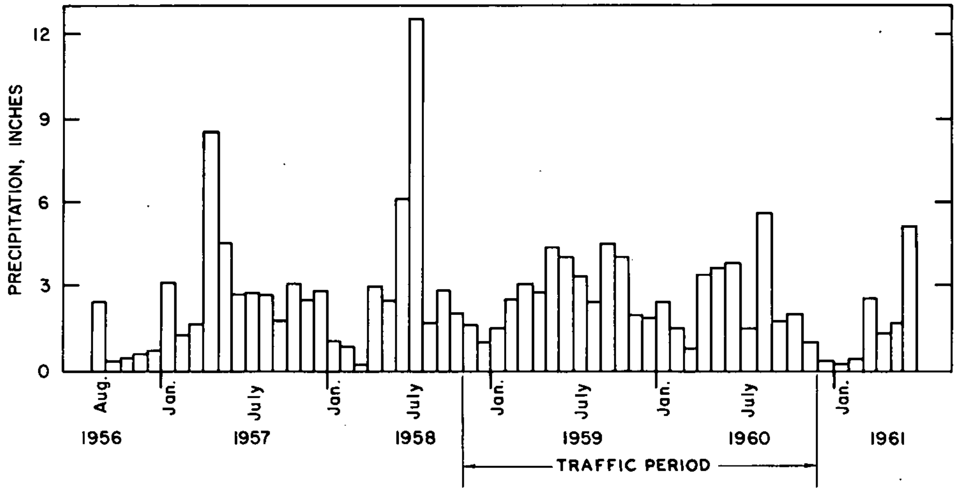


Figure 9. Precipitation at project.

The climate of the Road Test area is temperate with an average annual precipitation of about 34 in. of which about 2.5 in. occurs as 25 in. of snow. The average mean summer temperature is 76 F and the average mean winter temperature is 27 F. The soil usually remains frozen during the winter with alternate thawing and freezing of the immediate surface. Normally the average depth of frost penetration in the area is about 28 in.

Summaries of climatological data observed at weather stations on the project are given in Figures 8 through 10 and frost depth information in Figure 11. Depth of frost under the test pavements was obtained by means of special instrumentation involving the measurement of electrical resistance of the soil as described in *Highway Research Abstracts,* Vol. 27, No. 4. More detailed climatological and frost information is available in the form of IBM listings in Data Systems 3300, 3301, 3140 and 3240. Figure 12 summarizes the observations made at the project on the elevation of the water table under the test pavements and adjacent natural ground.

## 1.3 PAVEMENT SERVICEABILITY AND PERFORMANCE

### *1.3.1 Relation to Objectives*

The first objective of the Road Test (see Section 1.1.3) asks for relationships between the performance of the pavement and the pavement design variables for various loads. In order to define performance, a new concept was evolved founded on the principle that the prime function of a pavement is to serve the traveling public. Briefly, it was considered that a pavement which maintained a high level of ability to serve traffic over a period of time was superior in performance to one whose riding qualities and general condition deteriorated at a more rapid rate under the same traffic. The term "present serviceability" was adopted to represent the momentary ability of a pavement to serve traffic, and the performance of the pavement was represented by its serviceability history in conjunction with its load application history.

Though the serviceability of a pavement is patently a matter to be determined subjectively, a method for converting it to a quantity based on objective measurements is given in the next two sections. Since the Road Test was concerned only with the structural features of the pavement, such items as grade, alignment, access, condition of shoulders, slipperiness and glare were excluded from consideration in arriving at a value for pavement serviceability.

The serviceability of each test section was determined every two weeks during the traffic testing phase, and performance analyses were based on the trend of serviceability with increasing number of load applications. The serviceability-performance concept is described in detail in Appendix F.

### *1.3.2 Rating of Pavements in Service*

Serviceability was found to be influenced by longitudinal and transverse profile as well as the extent of cracking and patching. The amount of weight to assign to each element in

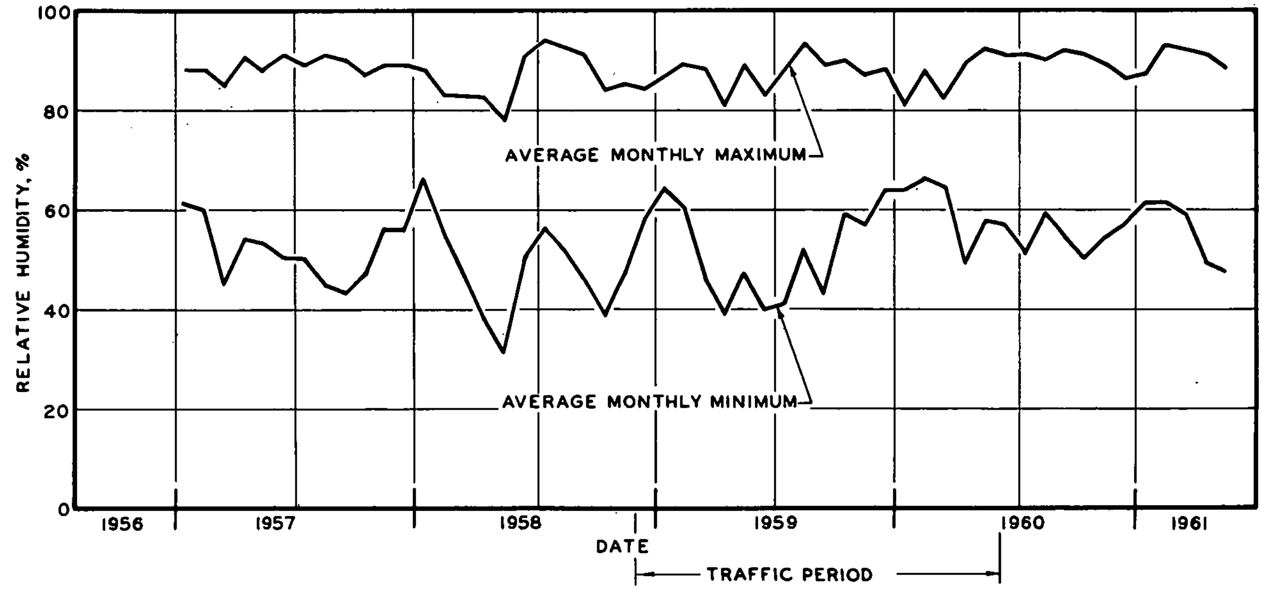


**Figure 10. Relative humidity, weather station at Peoria, Ill.**

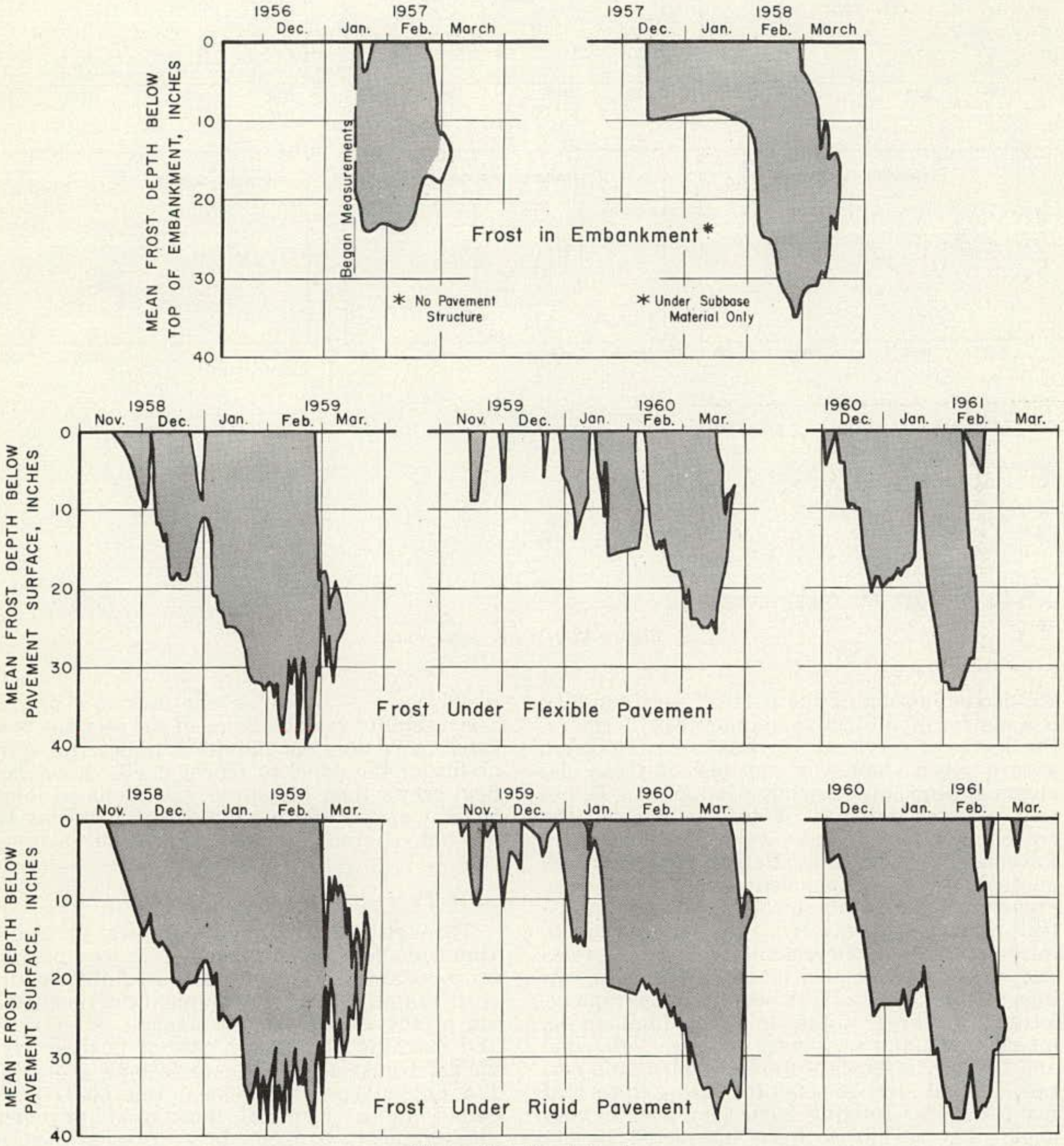


Figure 11. Frost depth.

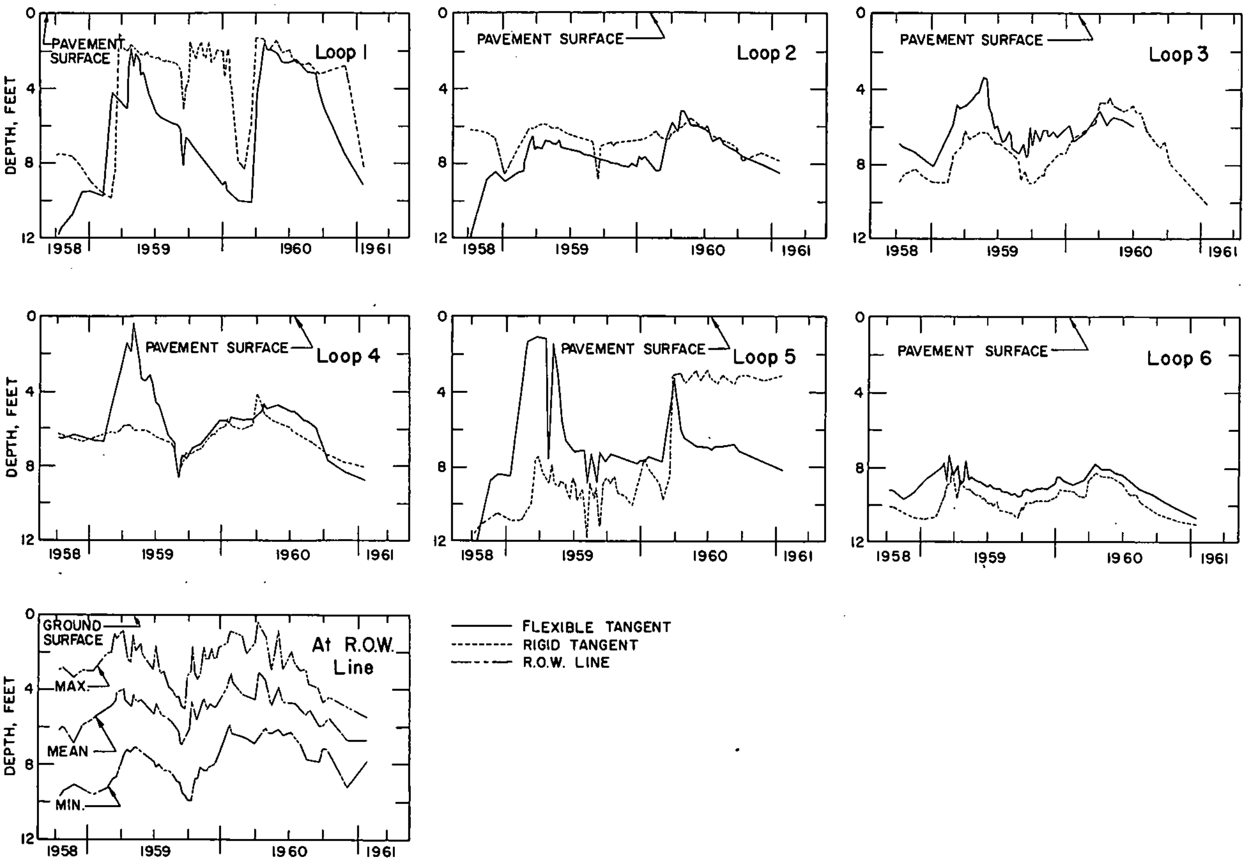


Figure 12. Water table data.

the determination of the over-all serviceability is a matter of subjective opinion. Furthermore, the degree of serviceability loss to be associated with a given change in any one of these elements depends on subjective judgment. To obtain a good estimate of the opinion of the traveling public in these subjective matters a Pavement Serviceability Rating Panel was appointed. This panel included highway designers, highway maintenance men, highway administrators, men with materials interests, trucking interests, automobile manufacturing interests and others. These men made independent ratings of the ability of 138 sections of pavement, located in three states, to serve high speed, mixed truck and passenger traffic. Both rigid and flexible pavements were included, and certain sections were selected for rating in each of five categories ranging from very poor to very good. The members were instructed to use whatever system they wished in rating each pavement and to indicate their opinions of the ability of the pavement to serve traffic at the time of rating on a scale ranging from 0 to 5 with adjective designations of very poor (0–1), poor (1–2), fair (2–3), good (3–4), and very good (4–5). For each section the mean of the independent ratings of the individual panel members was taken as the section's present serviceability rating. Some of the sections were rated more than once in order to determine the ability of the panel to repeat itself. Road Test field crews then measured variations in longitudinal and transverse profiles, as well as the amount of cracking and patching of each section.

### *1.3.3 Present Serviceability Index*

Through a conventional statistical procedure (multiple regression analysis) it was possible to correlate the present serviceability rating with the objective measurements of longitudinal profile variations, the amount of cracking and patching and, in the case of flexible pavements, transverse profile variations (rutting). For either type of pavement this analysis resulted in a formula that used pavement measurements to compute a "present serviceability index" which closely approximated the mean rating of the panel.* The necessary measurements and serviceability index compu-

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* A detailed discussion of the work of the Rating Panel, including the ratings, the data obtained in the measurements of the sections that were rated, and the derivation of the present serviceability indexes is presented in Appendix F.

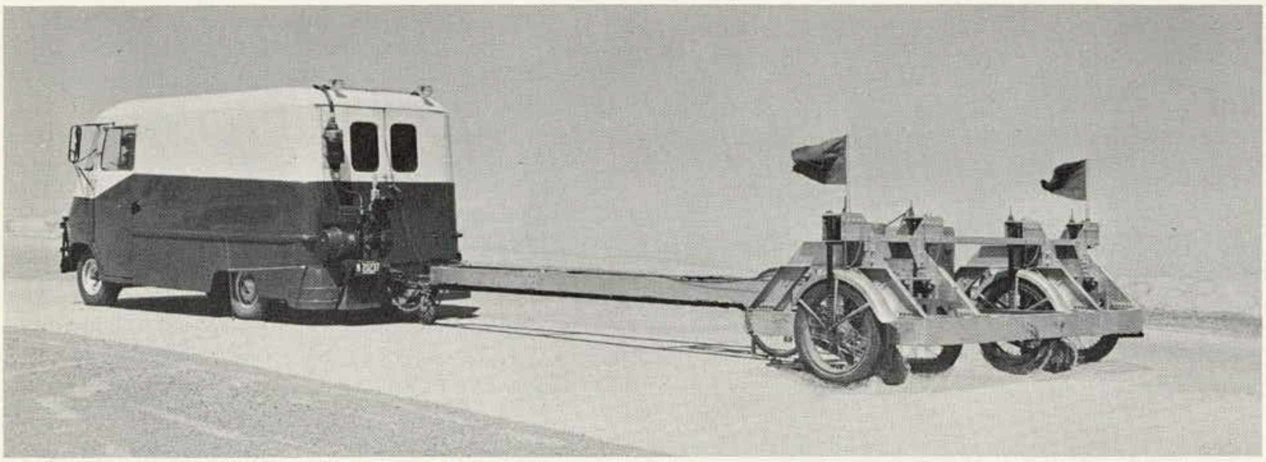


Figure 13. Longitudinal profilometer.

tations were made for each Road Test section at two-week intervals throughout the traffic phase.

Formulas for the present serviceability index, together with descriptions of the measurements entering into them, will be found in Chapters 2 and 3 for flexible and rigid pavement, respectively. The method of measuring longitudinal profile variations was the same for both pavement types and is described below.

The instrument used for recording longitudinal profile variations was the longitudinal profilometer pictured in Figure 13 and shown schematically in Figure 14. This instrument, moving at a speed of 5 mph, recorded continuously the angle, A, formed by the line of the support wheels G and H, and the line CD that connects the centers of two small (8-in. diameter) hard-rubber tired wheels, E, arranged in tandem. One pair of these wheels traveled in the center of each wheelpath.

Since the distance between the centers of the wheels, E, was small (9 in.) the line, CD, was assumed to be approximately parallel to the tangent to the road surface at the point, F, midway between the wheels.

The distance between the supports, G and H, of the tongue being relatively large (25.5 ft), the line GH was regarded as being approximately parallel to the pavement surface had it been perfectly smooth. Thus, the angle, A, between CD and GH represents a departure from a smooth pavement surface and variations in A represent variations in the longitudinal profile. It was this angle that the instrument was designed to measure. The effect of vibration of the tires and springs at G and H was held to a low level by restricting the operating speed and by electrically filtering out high frequencies so that they did not appear on the record.

It was recognized that line GH was not a stable reference and that as a consequence the instrument could not respond correctly to gradual changes in the true pavement slope occurring over relatively long distances. Therefore, considerable effort was expended to develop a means to detect and correct for rotations of the line GH with respect to a horizontal reference. An inertial reference system was devised that would accomplish this purpose for short runs (that is, 2,000 ft). But tests of the effectiveness of the instrument with and without the reference indicated that the inconvenience of operation with the reference far outweighed the small increases in the over-all system effectiveness. Consequently, the inertial reference was abandoned.

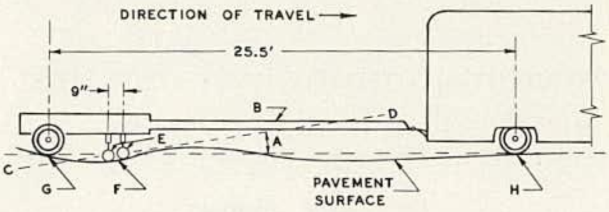
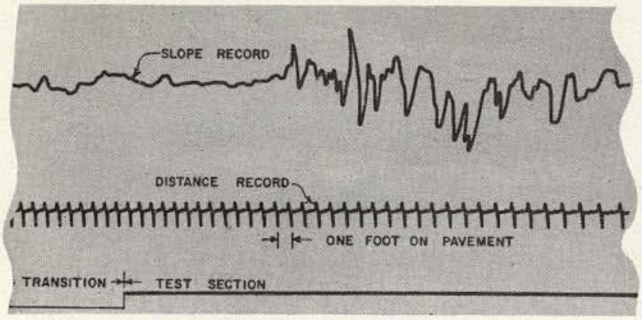


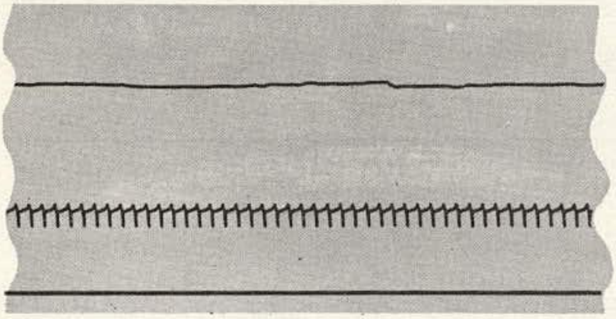
Figure 14. Schematic of longitudinal profilometer.

The angle A rarely exceeded 3 deg even on rough pavements. Within the range of ±3 deg, the tangent of an angle is virtually equal to the radian measure of the angle, and thus the record of angle A could be interpreted as the slope of the pavement. In this report the profilometer output will be referred to as the pavement slope.

The instrument output on paper tape was a continuous analog of the slope of the pavement in each wheelpath, together with 1-ft distance marks along the margin of the tape (Fig. 15). The tapes were fed into an automatic electronic chart reader (Fig. 16) which measured the ordinate of the chart at intervals equivalent to



For Rough Pavement



For Smooth Pavement

Figure 15. Typical longitudinal profilometer record.

1 ft on the pavement, digitized this information and punched it on perforated paper tape suitable for use as an input to the project's digital computer.

To correlate profile variation with serviceability ratings made by the panel the hundreds of slope measurements taken in each section were reduced to a single statistic intended to represent the roughness of the section. Investigation of several alternative statistics led to the choice of the variance of the slope measurements computed from:

$$SV = \frac{\sum_{i=1}^{n} X_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)^2}{n-1} \qquad (1)$$

in which

$SV$ = slope variance;
$X_i$ = the $i^{\text{th}}$ slope measurement; and
$n$ = total number of measurements.

The slope variance for each section was calculated by the digital computer directly from the tape output of the chart reader. For use by other agencies, the Road Test staff has developed a simplified profilometer (Fig. 17), designated the CHLOE Profilometer, whose

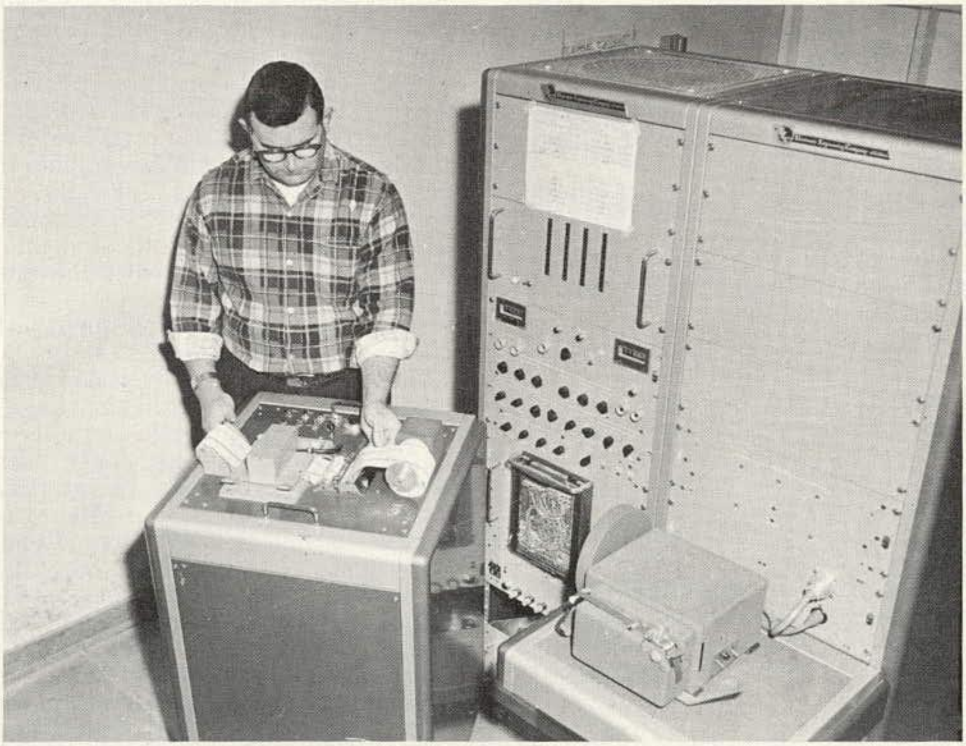


Figure 16. Electronic analog chart reader.

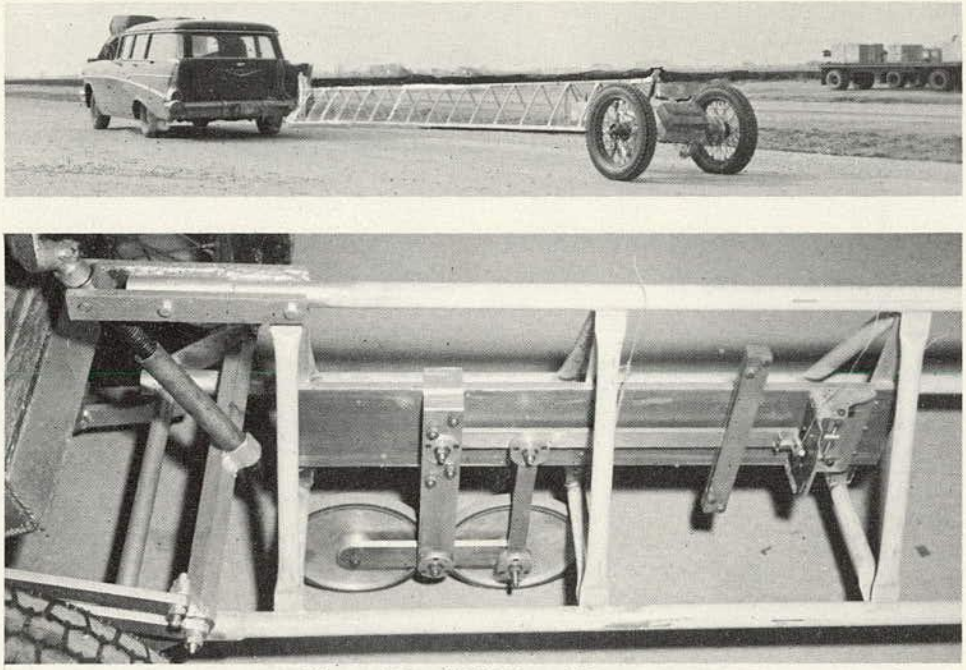


Figure 17. CHLOE profilometer.

output is slope variance. Thus, neither a chart reader nor a digital computer is required when the CHLOE Profilometer is used.

It was found that of the several types of measurements used in the serviceability index formulas, longitudinal profile variation of a section of pavement when represented by the logarithm of the slope variance correlated most highly with the rating of that section by the panel.

### *1.3.4 Pavement Performance Data*

As stated in Section 1.3.1, pavement performance analyses were based on the trend of the serviceability index (determined at intervals of two weeks, or more often when required) with increasing axle applications. Prior to use in the analyses, performance data were identified and processed.

Each 2-week period was termed an "index period", and the last day of each period was called an "index day". Index days were numbered sequentially from 1 to 55, the first occurring on November 3, 1958, and the fifty-fifth on November 30, 1960. Because all sections had been subjected to almost the same number of applications of axle loads on any given date, the pairing of an index value with an index day was equivalent to specifying the serviceability index corresponding to a given number of axle applications. The symbol $p_t'$ was used to represent the serviceability index of any section as determined by measurements made on the $t^{\text{th}}$ index day, and the plot of $p_t'$ versus time was termed the "serviceability history" of a section. (Usually the last three days of an index period were required to make the measurements on all sections for determining $p_t'$.)

The serviceability history of each section was converted to a "smoothed serviceability history" by a moving average that included at least three (generally five) successive index values except that the end values for the history were sometimes taken as end values for the smoothed history. Typical serviceability data and smoothed serviceability histories are shown in Figure 18.

The number of axle applications applied during the $t^{\text{th}}$ index period, averaged over the ten traffic lanes, was represented by $n_t$, and the total number accumulated through that period by $N_t$; thus,

$$N_t = n_1 + n_2 + \ldots + n_t \qquad (2)$$

It was observed early in the traffic phase of the Road Test, confirming experience elsewhere, that for sections of insufficient design relative to load, the rate at which pavement damage accumulated with applications of load was affected by seasonal changes, especially in the case of flexible pavements. The design of the Road Test experiment did not permit a clearcut comparison of the damage rate in the various seasons since sections which failed in one season were not available for observation during subsequent seasons. Nevertheless Table 1, giving the percentage of failures occurring in each season for each type of pavement, suggests that the damage rate was relatively low in winter for both types of pavement and relatively high in spring for flexible pavements.

Changes in the effect of load with seasons

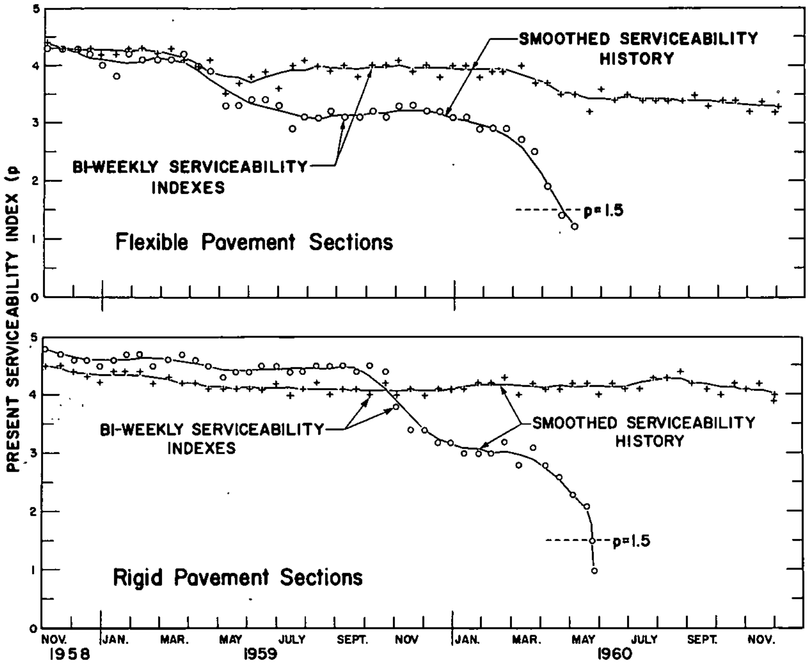


Figure 18. Typical serviceability histories.

TABLE 1
PAVEMENT FAILURE, BY SEASONS

| Season | Axle Load Applications (× 10³) | Seasonal Distribution Section Failure[1] (%) | |
|---|---|---|---|
| | | Rigid | Flexible |
| Fall | | | |
| 1958 Oct., Nov. | 9 | 0 | 3 |
| 1959 Sept., Oct., Nov. | 109 | 28 | 1 |
| 1960 Sept., Oct., Nov. | 173 | 12 | 1 |
| All | 291 | 40 | 5 |
| Winter | | | |
| 1958-59 Dec., Jan., Feb. | 64 | 0 | 4 |
| 1959-60 Dec., Jan., Feb. | 167 | 11 | 5 |
| All | 231 | 11 | 9 |
| Spring | | | |
| 1959 March, April, May | 59 | 0 | 57 |
| 1960 March, April, May | 215 | 22 | 23 |
| All | 274 | 22 | 80 |
| Summer | | | |
| 1959 June, July, Aug. | 109 | 3 | 3 |
| 1960 June, July, Aug. | 209 | 24 | 3 |
| All | 318 | 27 | 6 |
| Total | 1,114 | 100 | 100 |

[1] A section was considered to have failed when its serviceability index dropped to 1.5. Table includes only factorial sections (first replicates) in Design 1.

suggested the use of a "seasonal weighting function," $q_t$, to be multiplied by the number of load applications made during each index period, with the value of $q_t$ depending on some measurement designed to reflect the general variation above and below a "normal" value in the strength of the test sections. The function $q_t$ presumably would take on values greater than unity during periods when the pavement was weaker than normal, and between 0 and 1 when stronger than normal. The product, $q_tn_t$, would then yield "weighted applications," $w_t$, corresponding to the actual application, $n_t$, made on each test section during an index period. The total number of weighted applications, $W_t$, would be given by

$$W_t = q_1n_1 + q_2n_2 + \ldots + q_tn_t \tag{3}$$

Weighted application, $W_t$, could then be substituted for actual applications, $N_t$, in the performance analyses. (Hereafter $W$ will be used to represent either weighted or unweighted axle applications, the meaning of the symbol being specified wherever used.)

A seasonal weighting function, dependent on the periodic measurement of flexible pavement deflections in Loop 1, was developed and used in an analysis of flexible pavement performance described in Section 2.2. In the case of rigid pavements, although all rigid pavement distress was associated with pumping and although pumping must be associated with periods of high rainfall, the seasonal variations in damage rate were less pronounced, and no effective function was developed.

For the analyses of pavement performance it was assumed that the trend of serviceability, $p$, with increasing axle application, $W$, could be satisfactorily represented by five pairs of coordinates. For sections that failed during the test period, simultaneous values of $p$ and $W$ were taken at $p = 3.5, 3.0, 2.5, 2.0$ and $1.5$. For sections that survived the traffic testing period, the coordinates were chosen from the smoothed serviceability history at 11, 22, 33, 44 and 55 index days. Sets of coordinates from the serviceability trend, that is, performance data, for each Road Test section are given in Appendix A.

### 1.3.5 *Procedures for Analysis*

The analyses of performance resulted in empirical formulas wherein performance was associated with load and pavement design variables. To use mathematical procedures for the analyses it was necessary to assume some analytical form or model for these associations. In addition to the experimental variables the models include constants whose values were either to be specified or to be estimated from the data. Thus the analytical procedures were for the estimation of constants whose values were unspecified in the model—constants that indicate the effects of design and load variables upon performance. The procedures also included methods for estimating the precision with which the data fit the assumed model. The procedures used in the Road Test analyses are set forth in detail in Appendix G.

There are many different mathematical forms that could be used as models for serviceability trends, and several of these may fit the data with more or less the same precision. Different models were tested for goodness of fit to the Road Test performance data. Preference for one model over another was governed mainly by relative goodness of fit, but consideration was also given to relative agreement with highway design practice and experience for traffic conditions beyond the Road Test.

The mathematical model ultimately chosen for both the flexible and rigid pavement analyses is of the form

$$p = c_o - (c_o - c_1)\left(\frac{W}{\rho}\right)^{\beta} \qquad (4)$$

in which

$c_1 \leqq p \leqq c_0;$

$p$ = the serviceability trend value;

$c_o$ = the initial serviceability trend value (for the Road Test $c_o = 4.5$ for rigid pavements, and 4.2 for flexible pavements—these values were the means of the initial serviceability of test sections);

$c_1$ = the serviceability level at which a test section was considered out of test and no longer observed (for the Road Test $c_1 = 1.5$);

$W$ = the accumulated axle load applications at the time when $p$ is to be observed and may represent either weighted or unweighted applications.

$\rho$ and $\beta$ are functions of design and load to be discussed later. Rearranging Eq. 4 in logarithmic form, and defining $G$, a function of serviceability loss, as $\log\ (c_o - p)/(c_o - c_1)$ gives

$$G = \beta\ (\log W - \log \rho) \qquad (5)$$

Plotting $G$ against $\log W$ for Eq. 5 gives a straight line whose slope is $\beta$ and whose intercept on the $\log W$ axis is $\log \rho$. For each Road Test section the performance data given in Appendix A were converted into values for $G$ and $\log W$ and a straight line was fitted to the $G$, $\log W$ points. From these straight lines, estimates of $\beta$ and $\log \rho$ were obtained for each test section. For the cases where the serviceability loss was very small over the traffic testing period $\beta$ may be nearly zero and $\log \rho$ extremely large. Special rules were applied for these cases in order to obtain logical values of $\beta$ and $\log \rho$ (see Appendix G).

The assumed relationship between $\beta$ and the design and load variables was

$$\beta = \beta_0 + \frac{B_o\ (L_1 + L_2)^{B_2}}{(a_1D_1 + a_2D_2 + a_3D_3 + a_4)^{B_1}\ L_2^{B_3}} \qquad (6)$$

in which

$\beta_o$ = a minimum value assigned to $\beta$;

$L_1$ = the nominal load axle weight in kips (*e.g.*, for 18,000-lb single axle load, $L_1 = 18$; for 32,000-lb tandem axle load, $L_1 = 32$);

$L_2$ = 1 for single axle vehicles, 2 for tandem axle vehicles;

$D_1$, $D_2$ and $D_3$ = the three pavement design factors surfacing, base and subbase thickness for flexible pavement and reinforcement, slab thickness and subbase thickness for rigid pavement.

The remaining symbols of Eq. 6 are positive constants whose values were either to be assigned as was done for $\beta_o$ or to be estimated by means of the analysis.

Equations in this same form were determined from analysis of the rigid pavement data and the flexible pavement data, respectively.

The analysis rationale assumes that estimates for $\beta$ from the equation are better than estimates based only on the individual section performance data. Consequently, the values of $\beta$ estimated from the equation were used in conjunction with the data to obtain new estimates of log $\rho$ for every test section.

The algebraic form assumed for the association of $\rho$ with the design and load variables is

$$\rho = \frac{A_0 (D + a_4)^{A_1} L_2^{A_3}}{(L_1 + L_2)^{A_2}} \qquad (7)$$

where $D$ $(=a_1 D_1 + a_2 D_2 + a_3 D_3)$ represents a "thickness index" of the pavement, $L_1$ and $L_2$ are as defined for Eq. 6, and the remaining symbols are constants whose values are either to be assumed or to be estimated from the analysis.

Evaluation of the constants in Eqs. 6 and 7 is reported in Section 2.2.2 for flexible and 3.2.2 for rigid pavements.

Eqs. 6 and 7 when evaluated and used in conjunction with Eq. 5 thus represent the first goal of the Road Test—to associate performance with design and load variables.

At various stages in the development of the equations, tests were made for the significance of pavement design factors, and statistics were computed to express the degree of correlation between observations and corresponding predictions from the equations. Finally, average residuals were used to indicate the extent to which observations were scattered from the corresponding calculated values of $p$ and log $W$. Average residuals, correlation indexes, and inferences from the significance tests are summarized after presentation of derived equations in Sections 2.2.2 and 3.2.2.

Many different models and fitting procedures were studied and one selected from which the performance equations fit the Road Test data with satisfactory precision. In time, other models may be found that also fit the data satisfactorily and which may prove equally or more useful.

## 1.4 NEEDED RESEARCH—GENERAL

### *1.4.1 Modification of Performance Relationships*

Any further effort by the Highway Research Board to fit a mathematical model to the Road Test performance data will likely involve modifications either in the basic models for $p$, $\beta$, and $\rho$, or in the fitting procedures, or in both. It is the purpose of this section to mention several possibilities for both types of modification that are contemplated in further work with the performance data.

Even if no changes are made in Eq. 4, it is possible to modify the formulas for $\beta$ and $\rho$. For example, it might be assumed that $\beta$ is a constant,

$$\beta = b_0 \qquad (8)$$

or that $\beta$ is a simple function of $\rho$, for example,

$$\beta = b_0 + \frac{b_1}{\rho\, b_2} \qquad (9)$$

The concept of a thickness index for flexible pavements might be generalized after further research to a "structural index," $S$, where $S$ would account for all pavement layers (their thicknesses and strengths) as well as the embankment soil. A single index for vehicle load, $L$, might be introduced so that $L$ could account for all axle loads (including steering axles) and their spacing. Then it might be assumed that

$$\rho = \left(\frac{S}{\sqrt{L}}\right)^A \qquad (10)$$

so that the structural index is squared relative to the load index. It may be noted that the ratio of $A_1$ to $A_2$ in Eqs. 18 and 21 (see Section 2.2) is already of the order two to one, so that Eq. 10 appears to be a reasonable assumption at least for flexible pavements.

As is explained in Appendix G, performance equations developed for the present report result from a step-by-step fitting procedure where the results of one step are used as input for the next step. Modification of the fitting procedures will likely take the form of an over-all procedure that determines all unassigned constants simultaneously as a particular residual criterion is minimized. Once the over-all fitting procedure is developed, the residual criterion can include both residuals from log $W$ estimates and residuals from $p$ estimates. Moreover, performance data from experiments that have been analyzed separately in this report may be combined in an effort to obtain a more general analysis.

Although it was not possible to investigate modifications of the type just described in time for inclusion in this report, the Highway Research Board will undertake these studies. It is hoped that further effort will produce modified equations that can represent all the Road Test performance data with at least the same precision as given in this report and that simplifications can be introduced with little sacrifice in precision over the equations reported herein.

### *1.4.2 Generalization and Extension of Relationships*

Discussion in the preceding subsection relates to the need for additional study of the data obtained in the Road Test. A larger area for future research involves the extension of the performance equations to include parameters that were not varied in the project. It is important to know, for example, the effects on pavement performance of variations in the characteristics of the soil and the materials used in the pavement structure. The effects of environment need study. Not only the differences in performance associated with the existence of heavy rainfall, desert conditions, frost, etc., must be considered, but also the differences that may be associated with different rates of traffic application and distribution of axle loads in the traffic stream. (For example, at the Road Test a million axle loads of one weight were applied in two years to each section. What would have been the situation had these loads, accompanied by several million lighter loads, been applied in 20 years?)

Studies designed to fill these gaps may fall in four categories: (1) theoretical studies, (2) major satellite studies, (3) field tests, and (4) laboratory tests.

There should be continuing encouragement of research into the mechanical and physical laws involved in pavement performance. Only through such theoretical work will there be developed rational mathematical models by which performance can be related to the fundamental properties of materials and to the dynamic characteristics of the loading.

Since the completion of such theoretical work appears to be years away, immediate attention should also be given to means for extending the empirical models developed at the Road Test to include additional important parameters. A most effective device for this purpose is the so-called satellite study. These studies have been described* as relatively small road tests in different parts of the country (and other countries) involving consideration of variables most of which were not included in the AASHO Road Test. A very important finding of the Road Test was that, within the range of precision of measurements systems and estimation techniques available, no significant interactions were found among the design variables. Therefore, in the design of satellite experiments where the variables are like those in the Road Test (structure thickness, base type, etc.) balance in the experiment can be attained through the use of partial rather than full factorials.** This means that to test a given number of variables any satellite experiment will require only a small fraction of the test sections that would have been required had the AASHO Road Test shown that significant interactions existed.

Such satellite experiments are also different from the Road Test in that traffic is not a variable. The test sections would be constructed as part of the regular highway system and their serviceability trends observed under the normal traffic using the facility. A careful record of the number and magnitudes of axle loads over the test sections would be required.

These experiments would provide for verification of the coefficients in the Road Test performance equations and for the inclusion of terms in the equations relating to variables that were not under study in the AASHO Road Test. More specific areas for study in the satellite experiments are discussed at the ends of Chapters 2 and 3.

Field tests would be simple pavement performance experiments, with 2 or 3 test sections each, constructed as part of normal highway construction in a large number of locations where only one or two variations from normal pavement design would be observed along with the normal design. These studies would prove very useful to engineers who must use judgment in the application of Road Test findings and in their attempts to evaluate new designs and new materials. However, the field tests would not be designed in such a way as to permit analyses that would result in important modification of the Road Test equations themselves. Many states have constructed test pavements in the field test category in the past. If traffic records are available, further study of these pavements would be extremely useful.

Laboratory tests are those needed in the study of materials characteristics as they might affect pavement performance. Here again more detailed recommendations are given at the ends of Chapters 2 and 3.

### *1.4.3 Serviceability of Pavements*

It is believed that the serviceability-performance concept developed at the Road Test has added a new technique of value in the design and maintenance of highway pavement. It is emphasized, however, that the specific serviceability indexes developed for the Road Test, were based on very small samples of the American highway network by a very small group of highway engineers. There is no reason to think that more extensive sampling will result in major modification of these indexes, but if the system is to receive widespread use, it is imperative that other groups, working under the same rules as the Road Test Rating Panel, make subjective ratings of many sections of pavement over the entire country containing many types of distress leading to loss of serviceability. Accompanying these rating sessions should be objective measurements of those elements that may be involved in serviceability such as, slope variance (roughness), rut depth, cracking, faulting, patching, and slipperiness. Regression analyses of the ratings in terms of the objective measurement data will produce new more generally applicable serviceability indexes.

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* "Extending the Findings of the AASHO Road Test" before the Design Committee, AASHO, at the AASHO meeting in Denver, Colo., October 1961.

** See Hain, R. C., and Irick, P. E., "Fractional Factorial Analysis," HRB Road Test Conference, May 1962.

# Chapter 2

# Flexible Pavement Research

## 2.1 DESCRIPTION OF FLEXIBLE PAVEMENTS

Detailed descriptions of the flexible pavement experiments may be found in Road Test Report 1. (Highway Research Board Special Report 61A). A brief summarization is included in the following paragraphs.

### *2.1.1 Experiment Designs and Layout*

The north tangent of each of the six loops in the AASHO Road Test was constructed of flexible pavement. The six tangents included a total of 234 structural sections or 468 test sections. A majority of the sections in each flexible pavement tangent comprised a complete factorial experiment, the design factors of which were surfacing thickness, base thickness and subbase thickness. These experiments were referred to as the main factorial designs (Design 1). The dimensions of the main factorial designs (Table 2) in each of Loops 3 through 6 were 3x3x3, that is, three levels of surfacing thickness existed in combination with three levels of base thickness and each of these nine combinations existed for the three levels of subbase thickness. The dimensions of the factorial design for Loop 2 were 3x3x2, and for Loop 1, 3x2x3 levels of surfacing, base and subbase thickness, respectively. In the traffic loops (2 through 6) surfacing thickness varied in 1-in. increments, base thickness in 3-in. increments, and subbase thickness in 4-in. increments.

The structural design of the sections in each test tangent of the traffic loops was varied by the National Advisory Committee about a nominal design determined from designs submitted by four highway departments. Although the nominal design increased in thickness as the load increased from loop to loop (Table 2), considerable overlap was provided so that many structural designs were common to two loops, several structural designs appeared across three loops and a few appeared in four loops. This arrangement made it possible to study the effect of different loads on identical designs of pavements. In each loop a certain number of the designs were repeated once or replicated. These are shown as shaded areas in Table 2. Variation in the performance of sections constructed to identical designs in a given lane provides a measure of the effects of uncontrolled variables.

In addition to the main factorial design in Loop 1, sixteen test sections were included for special subsurface studies (Design 5) with base and subbase thickness as the principal variables. A special experiment was also included in the flexible tangent of Loop 2 which involved a study of bituminous surface treatments (two cover coats and one seal coat). This experiment (Design 6) was a 3x2 factorial design with base and subbase thickness as the only variables. The experiment was completely replicated, requiring 24 test sections.

Two special experiments were included in the main loops (3 through 6). The first involved a study of paved shoulders and the second a study of type of base material (Table 2). In the first of these studies (Design 2) the shoulders of three structural sections having relatively thin combinations of surfacing, base and subbase were paved. The sections were 160 ft long with the shoulder paving consisting of a uniform 3-in. thickness of asphaltic concrete that varied in width from 8 to 0 ft in the direction of traffic throughout the length of each section. The sections in Design 2 in each of the major loops were replicated, resulting in a total of 48 test sections. In the second study (Design 4), four different types of base course material were used: crushed stone, gravel, cement-treated and bituminous-treated gravel. Three of these base materials were selected for study in each of the four major loops. These sections were of the wedge type, that is, the thickness of the base material decreased in the direction of traffic at a uniform rate from one end of the 160-ft section to the other. The base study sections were also replicated, resulting in a total of 48 test sections per loop, the same number as for the paved shoulder experiment.

### *2.1.2 Materials and Construction*

The materials used in the flexible test pavements and the methods of construction are described in detail in Report 2 along with comprehensive summarizations of materials control tests. Basic data concerning materials are available in the form of IBM listings. A brief summarization of the characteristics of the materials used follows.

The 3 ft of the embankment upon which the test pavement sections were constructed was made up of material taken from three borrow areas located along the right-of-way of the project. This material was hauled onto the grade, brought to uniform moisture content slightly above optimum, thoroughly mixed with

# Loop 1

### Axle Load

| Lane 1 | Lane 2 |
|---|---|
| None | None |

### Main Factorial Design
### Design 1

| Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| 1 | 0 | 0 | 857 | 858 |
| | | 8 | 867 | 868 |
| | | 16 | 833 | 834 |
| | | | 841 | 842 |
| | 6 | 0 | 827 | 828 |
| | | 8 | 847 | 848 |
| | | 16 | 839 | 840 |
| 3 | 0 | 0 | 859 | 860 |
| | | | 863 | 864 |
| | | 8 | 869 | 870 |
| | | | 829 | 830 |
| | | 16 | 837 | 838 |
| | 6 | 0 | 825 | 826 |
| | | | 851 | 852 |
| | | 8 | 875 | 876 |
| | | | 819 | 820 |
| | | 16 | 821 | 822 |
| 5 | 0 | 0 | 823 | 824 |
| | | 8 | 865 | 866 |
| | | 16 | 877 | 878 |
| | 6 | 0 | 871 | 872 |
| | | 8 | 849 | 850 |
| | | 16 | 879 | 880 |
| | | | 873 | 874 |

### Subsurface Studies
### Design 5

| Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| 3 | 0 | 0 | 861 | 862 |
| | | 8 | 831 | 832 |
| | | | 853 | 854 |
| | | 16 | 817 | 818 |
| | 6 | 0 | 855 | 856 |
| | | 8 | 845 | 846 |
| | | 16 | 843 | 844 |
| | | | 835 | 836 |

Note: Shaded sections are replicates

# Loop 2

### Axle Load

| Lane 1 | Lane 2 |
|---|---|
| 2,000-S | 6,000-S |

### Main Factorial Design
### Design 1

| Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| 1 | 0 | 0 | 721 | 722 |
| | | 4 | 727 | 728 |
| | 3 | 0 | 743 | 744 |
| | | 4 | 717 | 718 |
| | 6 | 0 | 755 | 756 |
| | | 4 | 719 | 720 |
| 2 | 0 | 0 | 771 | 772 |
| | | 4 | 729 | 730 |
| | 3 | 0 | 759 | 760 |
| | | | 731 | 732 |
| | | 4 | 741 | 742 |
| | | | 709 | 710 |
| | 6 | 0 | 775 | 776 |
| | | | 757 | 758 |
| | | 4 | 737 | 738 |
| | | | 711 | 712 |
| 3 | 0 | 0 | 769 | 770 |
| | | 4 | 739 | 740 |
| | 3 | 0 | 773 | 774 |
| | | 4 | 745 | 746 |
| | 6 | 0 | 749 | 750 |
| | | 4 | 763 | 764 |

### Surface Treatment Study
### Design 6

| Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| Surface Treatment | 0 | 0 | 733 | 734 |
| | | | 751 | 752 |
| | | 4 | 753 | 754 |
| | | | 723 | 724 |
| | 3 | 0 | 725 | 726 |
| | | | 767 | 768 |
| | | 4 | 765 | 766 |
| | | | 715 | 716 |
| | 6 | 0 | 747 | 748 |
| | | | 735 | 736 |
| | | 4 | 761 | 762 |
| | | | 713 | 714 |

# Loop 3

### Axle Load

| Lane 1 | Lane 2 |
|---|---|
| 12,000-S | 24,000-T |

### Main Factorial Design
### Design 1

| Surface Thickness | Base Thickness | Subbase Thickness | Factorial Block | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| 2 | 0 | 0 | 1 | 165 | 166 |
| | | 4 | 3 | 125 | 126 |
| | | 8 | 2 | 143 | 144 |
| | | | 2 | 133 | 134 |
| | 3 | 0 | 3 | 113 | 114 |
| | | 4 | 2 | 135 | 136 |
| | | 8 | 1 | 159 | 160 |
| | 6 | 0 | 2 | 127 | 128 |
| | | 4 | 1 | 157 | 158 |
| | | 8 | 3 | 111 | 112 |
| 3 | 0 | 0 | 2 | 137 | 138 |
| | | 4 | 1 | 163 | 164 |
| | | 8 | 3 | 109 | 110 |
| | 3 | 0 | 1 | 147 | 148 |
| | | 4 | 3 | 107 | 108 |
| | | | 3 | 115 | 116 |
| | | 8 | 2 | 129 | 130 |
| | 6 | 0 | 3 | 117 | 118 |
| | | 4 | 2 | 131 | 132 |
| | | 8 | 1 | 155 | 156 |
| 4 | 0 | 0 | 3 | 119 | 120 |
| | | 4 | 2 | 141 | 142 |
| | | 8 | 1 | 153 | 154 |
| | 3 | 0 | 2 | 145 | 146 |
| | | 4 | 1 | 151 | 152 |
| | | 8 | 3 | 121 | 122 |
| | 6 | 0 | 1 | 161 | 162 |
| | | | 1 | 149 | 150 |
| | | 4 | 3 | 123 | 124 |
| | | 8 | 2 | 139 | 140 |

### Shoulder Paving Study
### Design 2

| Shoulder Paving | Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| With | 2 | 3 | 0 | 177 | 178 |
| | | | | 179 | 180 |
| | 2 | 3 | 8 | 175 | 176 |
| | | | | 183 | 184 |
| | 4 | 3 | 0 | 173 | 174 |
| | | | | 181 | 182 |

### Base Type Study.
### Design 4

| Base Type | Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| Crush. Stone | 3 | 2-14 | 0 | 169 | 170 |
| | | | | 105 | 106 |
| Gravel | 3 | 2-14 | 0 | 171 | 172 |
| | | | | 103 | 104 |
| Bit. Treat. | 3 | 2-11 | 0 | 167 | 168 |
| | | | | 101 | 102 |

# Loop 4

### Axle Load

| Lane 1 | Lane 2 |
|---|---|
| 18,000-S | 32,000-T |

### Main Factorial Design
### Design 1

| Surface Thickness | Base Thickness | Subbase Thickness | Factorial Block | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| 3 | 0 | 4 | 1 | 633 | 634 |
| | | 8 | 2 | 607 | 608 |
| | | 12 | 3 | 571 | 572 |
| | | | 3 | 569 | 570 |
| | 3 | 4 | 2 | 599 | 600 |
| | | 8 | 3 | 573 | 574 |
| | | 12 | 1 | 617 | 618 |
| | 6 | 4 | 3 | 585 | 586 |
| | | 8 | 1 | 623 | 624 |
| | | 12 | 2 | 601 | 602 |
| 4 | 0 | 4 | 3 | 583 | 584 |
| | | 8 | 1 | 619 | 620 |
| | | 12 | 2 | 603 | 604 |
| | 3 | 4 | 1 | 627 | 628 |
| | | 8 | 2 | 589 | 590 |
| | | | 2 | 597 | 598 |
| | | 12 | 3 | 575 | 576 |
| | 6 | 4 | 2 | 595 | 596 |
| | | 8 | 3 | 577 | 578 |
| | | 12 | 1 | 625 | 626 |
| 5 | 0 | 4 | 2 | 605 | 606 |
| | | 8 | 3 | 587 | 588 |
| | | 12 | 1 | 621 | 622 |
| | 3 | 4 | 3 | 579 | 580 |
| | | 8 | 1 | 631 | 632 |
| | | 12 | 2 | 593 | 594 |
| | 6 | 4 | 1 | 629 | 630 |
| | | | 1 | 615 | 616 |
| | | 8 | 2 | 591 | 592 |
| | | 12 | 3 | 581 | 582 |

### Shoulder Paving Study
### Design 2

| Shoulder Paving | Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| With | 3 | 0 | 4 | 637 | 638 |
| | | | | 609 | 610 |
| | 3 | 6 | 4 | 635 | 636 |
| | | | | 611 | 612 |
| | 5 | 0 | 4 | 639 | 640 |
| | | | | 613 | 614 |

### Base Type Study
### Design 4

| Base Type | Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| Crush. Stone | 3 | 2-16 | 4 | 567 | 568 |
| | | | | 561 | 562 |
| Gravel | 3 | 2-16 | 4 | 565 | 566 |
| | | | | 559 | 560 |
| Cem. Treat. | 3 | 2-10 | 4 | 563 | 564 |
| | | | | 557 | 558 |

# Loop 5

### Axle Load

| Lane 1 | Lane 2 |
|---|---|
| 22,400-S | 40,000-T |

### Main Factorial Design
### Design 1

| Surface Thickness | Base Thickness | Subbase Thickness | Factorial Block | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| 3 | 3 | 4 | 1 | 485 | 486 |
| | | 8 | 2 | 451 | 452 |
| | | 12 | 3 | 415 | 416 |
| | | | 3 | 429 | 430 |
| | 6 | 4 | 2 | 449 | 450 |
| | | 8 | 3 | 419 | 420 |
| | | 12 | 1 | 487 | 488 |
| | 9 | 4 | 3 | 413 | 414 |
| | | 8 | 1 | 471 | 472 |
| | | 12 | 2 | 441 | 442 |
| 4 | 3 | 4 | 3 | 411 | 412 |
| | | 8 | 1 | 481 | 482 |
| | | 12 | 2 | 443 | 444 |
| | 6 | 4 | 1 | 473 | 474 |
| | | 8 | 2 | 455 | 456 |
| | | | 2 | 453 | 454 |
| | | 12 | 3 | 425 | 426 |
| | 9 | 4 | 2 | 437 | 438 |
| | | 8 | 3 | 417 | 418 |
| | | 12 | 1 | 477 | 478 |
| 5 | 3 | 4 | 2 | 439 | 440 |
| | | 8 | 3 | 421 | 422 |
| | | 12 | 1 | 479 | 480 |
| | 6 | 4 | 3 | 423 | 424 |
| | | 8 | 1 | 469 | 470 |
| | | 12 | 2 | 445 | 446 |
| | 9 | 4 | 1 | 475 | 476 |
| | | | 1 | 483 | 484 |
| | | 8 | 2 | 447 | 448 |
| | | 12 | 3 | 427 | 428 |

### Shoulder Paving Study
### Design 2

| Shoulder Paving | Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| With | 3 | 3 | 4 | 435 | 436 |
| | | | | 407 | 408 |
| | 3 | 9 | 4 | 431 | 432 |
| | | | | 405 | 406 |
| | 5 | 3 | 4 | 433 | 434 |
| | | | | 409 | 410 |

### Base Type Study
### Design 4

| Base Type | Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| Gravel | 3 | 3-18 | 4 | 467 | 468 |
| | | | | 457 | 458 |
| Bit. Treat | 3 | 3-16 | 4 | 463 | 464 |
| | | | | 459 | 460 |
| Cem. Treat. | 3 | 3-12 | 4 | 465 | 466 |
| | | | | 461 | 462 |

# Loop 6

### Axle Load

| Lane 1 | Lane 2 |
|---|---|
| 30,000-S | 48,000-T |

### Main Factorial Design
### Design 1

| Surface Thickness | Base Thickness | Subbase Thickness | Factorial Block | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| 4 | 3 | 8 | 3 | 269 | 270 |
| | | 12 | 2 | 299 | 300 |
| | | 16 | 1 | 317 | 318 |
| | | | 1 | 329 | 330 |
| | 6 | 8 | 2 | 303 | 304 |
| | | 12 | 1 | 323 | 324 |
| | | 16 | 3 | 253 | 254 |
| | 9 | 8 | 1 | 321 | 322 |
| | | 12 | 3 | 267 | 268 |
| | | 16 | 2 | 309 | 310 |
| 5 | 3 | 8 | 1 | 319 | 320 |
| | | 12 | 3 | 261 | 262 |
| | | 16 | 2 | 315 | 316 |
| | 6 | 8 | 3 | 259 | 260 |
| | | 12 | 2 | 307 | 308 |
| | | | 2 | 305 | 306 |
| | | 16 | 1 | 327 | 328 |
| | 9 | 8 | 2 | 313 | 314 |
| | | 12 | 1 | 331 | 332 |
| | | 16 | 3 | 265 | 266 |
| 6 | 3 | 8 | 2 | 297 | 298 |
| | | 12 | 1 | 335 | 336 |
| | | 16 | 3 | 255 | 256 |
| | 6 | 8 | 1 | 325 | 326 |
| | | 12 | 3 | 257 | 258 |
| | | 16 | 2 | 301 | 302 |
| | 9 | 8 | 3 | 263 | 264 |
| | | | 3 | 271 | 272 |
| | | 12 | 2 | 311 | 312 |
| | | 16 | 1 | 333 | 334 |

### Shoulder Paving Study
### Design 2

| Shoulder Paving | Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| With | 4 | 3 | 8 | 291 | 292 |
| | | | | 275 | 276 |
| | 4 | 3 | 16 | 293 | 294 |
| | | | | 273 | 274 |
| | 6 | 3 | 8 | 295 | 296 |
| | | | | 277 | 278 |

### Base Type Study
### Design 4

| Base Type | Surface Thickness | Base Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| Crush. Stone | 4 | 3-19 | 8 | 287 | 288 |
| | | | | 279 | 280 |
| Bit. Treat. | 4 | 3-18 | 4 | 285 | 286 |
| | | | | 283 | 284 |
| Cem. Treat. | 4 | 3-13 | 4 | 289 | 290 |
| | | | | 281 | 282 |

Table 2 Designs for Flexible Pavement Experiments

rotary mixers and compacted in nine 4-in. lifts. To maintain control of the construction operations the contractor was required to work in short blocks approximately 600 ft long. The moisture content and density of the soil in each lift was determined and the contractor was not permitted to proceed with the construction of the next block-lift until certain criteria had been met. These criteria are described in Report 2. Table 3 summarizes the engineering characteristics of the embankment soil.

The subbase for the flexible pavement consisted of a locally available sand-gravel material modified by the addition of small amounts of fine sand and friable fine-grained soil. The material and methods of placement are described in detail in Report 2. The material was produced in a washing and screening plant and mixed with the fines in a concrete mixer. In the summer of 1957, the subbase was placed in 4- or 8-in. lifts to protect the embankment soil during the winter months. Additional material to complete placement of the subbase for sections having 12- or 16-in. thickness of the material was placed in 4- and 8-in. lifts, respectively.

The subbase material was also placed in short blocks. Engineering characteristics of the material are given in Table 4.

TABLE 3

CHARACTERISTICS OF EMBANKMENT SOIL

| | |
|---|---|
| Classification (AASHO M-145) .............. | A-6 |
| Average values, borrow pit samples: | |
| Max. dry density, AASHO T-99-49 (pcf) | 116 |
| Optimum moisture content (%) ......... | 15 |
| Liquid limit (%) ........................ | 29 |
| Plasticity index ........................ | 13 |
| Grain size, finer than (%): | |
| No. 200 .................................. | 81 |
| 0.02 mm .................................. | 63 |
| 0.005 mm ................................. | 42 |
| Specific gravity ............................ | 2.71 |
| Average of construction tests: | |
| Density (% max. dry dens.) .............. | 97.7 |
| Moisture content (%) ................... | 16 |
| Constructed embankment tests: | |
| Laboratory CBR, soaked .................. | 2-4 |
| Field in-place CBR, spring .............. | 2-4 |
| Modulus of subgrade reaction, spring, *k* .... | 45 |

The base material for the factorial sections and for the limestone base sections in Design 4 was a crushed dolomitic limestone (Table 4). The material was delivered to the project in two sizes, proportioned by weight, and mixed in a concrete mixer with as much water as necessary to bring it to optimum moisture content. It was

TABLE 4

CHARACTERISTICS OF MATERIALS, FLEXIBLE PAVEMENTS[1]

| Item | Subbase | Crushed Stone Base | Gravel Base | Cement Treated Base | Asphalt Treated Base | Asphaltic Concrete | |
|---|---|---|---|---|---|---|---|
| | | | | | | Surface Mix | Binder Mix |
| Aggregate gradation, % passing: | | | | | | | |
| 1½-in. sieve | | 100 | 100 | | | | |
| 1-in. sieve | 100 | 90 | 98 | 100 | 100 | | 100 |
| ¾-in. sieve | 96 | 80 | | 96 | 96 | 100 | |
| ½-in. sieve | 90 | 68 | 74 | 90 | 90 | 92 | 75 |
| No. 4 sieve | 71 | 50 | 49 | 71 | 71 | 65 | 36 |
| No. 40 sieve | 25 | 21 | 23 | 25 | 25 | 22 | 13 |
| No. 200 sieve | 7 | 11 | 9 | 7 | 7 | 5 | 4 |
| Plasticity index, minus No. 40 material | N.P. | N.P. | 3.5 | | | | |
| Max. dry density[2] (pcf) | 138 | 139 | 140 | 138 | 149[3] | 151[3] | 154[3] |
| Field density (% max. dry dens.) | 102[4] | 102 | 104 | 101 | 97 | 97 | 97 |
| Asphalt[5] content (% total mix) | | | | | 5.2 | 5.4 | 4.5 |
| Cement[6] content (% by wt.) | | | | 4.0 | | | |
| 7-Day compressive strength (psi) | | | | 840 | | | |
| Laboratory tests: | | | | | | | |
| Marshall stability | | | | | 1,600 | 2,000 | 1,800 |
| Marshall flow | | | | | 10 | 11 | 11 |
| Total voids (%) | | | | | 6.2 | 3.6 | 4.8 |

[1] Identification: Subbase, uncrushed natural sand-gravel; Crushed stone base, crushed dolomitic limestone; Gravel base, uncrushed natural gravel; Treated bases, asphalt cement or portland cement and subbase material.

[2] AASHO T99-57.

[3] Laboratory density using Marshall procedure.

[4] Before subgrading.

[5] 85-100 penetration grade asphalt.

[6] Type I portland cement.

placed on the roadway and rolled in 3-in. lifts to the required density. Construction operations were limited to short blocks as in the case of the subbase and embankment soil.

Data concerning the materials used in the construction of the special bases for Design 4 are also given in Table 4. Certain of these sections had gravel bases, some cement-treated and some bituminous-treated. The gravel used for cement and bituminous treatment was essentially the subbase material as used in the flexible pavement experiments. The gravel base material was slightly coarser than the subbase and contained some plastic soil fines. It was obtained from a local source.

The asphaltic concrete binder course was a mixture of dense-graded crushed dolomitic limestone aggregate 1-in. maximum size and natural sand with about 4.5 percent of 85–100 penetration grade paving asphalt. The asphaltic concrete surface course (the uppermost layer) was a mixture of dense-graded crushed dolomitic limestone aggregate, ¾-in. maximum size, and natural sand with about 5.4 percent of 85–100 penetration grade paving asphalt (Table 2). Details relating to the materials, the construction testing and construction operation are given in Report 2.

## 2.2 PAVEMENT PERFORMANCE

The serviceability concept and the derivation of the serviceability indexes are described briefly in Section 1.3 of this report and in detail in Appendix F.

This section describes the flexible pavement present serviceability index. As required by the first objective of the Road Test, it gives the principal relationships showing flexible pavement performance as a function of design and load variables. It also presents the results obtained from the paved shoulder and the special base experiments (Designs 2 and 4). A summary of the material contained in each major subsection precedes the text of the subsection.

### *2.2.1 Serviceability Index for Flexible Pavement*

This subsection contains the equation used to determine the present serviceability index of each flexible pavement test section (Eq. 11). It also includes tables giving for each design the number of axle load applications sustained before the section's serviceability fell to 1.5 for unweighted applications (Table 5), to 1.5 for weighted applications (Table 6), to 2.5 for unweighted applications (Table 7), and to 2.5 for weighted applications (Table 8).

Eq. 11 was used to determine the level of serviceability of the surviving flexible pavement sections every two weeks during the period of traffic operation.

$$p = 5.03 - 1.91 \log (1 + \overline{SV}) - 0.01\sqrt{C + P} - 1.38\overline{RD}^2 \qquad (11)$$

in which

$p$ = the present serviceability index;

$\overline{SV}$ = the mean of the slope variance in the two wheelpaths;

$C + P$ = a measure of cracking and patching in the pavement surface; and

$\overline{RD}$ = a measure of rutting in the wheelpaths.

(In this equation and throughout this report, logarithms are to the base 10.)

Slope variance was discussed in Section 1.3. Cracking, $C$, in Eq. 11 is defined as the area, in square feet per 1,000 sq ft of pavement surface, exhibiting class 2 or class 3 cracking. Class 2 cracking is defined as that which has progressed to the stage where cracks have connected together to form a grid-type pattern. Class 3 cracking is that in which the bituminous surfacing segments have become loose. Patching, $P$, is the repair of the pavement surface by skin patching or deep patching expressed in square feet per 1,000 sq ft of pavement surfacing. Rut depth, $\overline{RD}$, is defined as the mean depth of rut in both wheelpaths of the pavement where the rut is the depression under the center of a 4-ft straightedge. The mean rut depth was estimated by sampling in each wheelpath at 25-ft intervals. The relative significance of these terms is discussed in Appendix F.

During critical periods it was often apparent that a section had reached a present serviceability level of 1.5 or that it would reach this level prior to the next regularly scheduled index day. Where this was the case it was sometimes necessary to determine the serviceability index by expedient methods. Cracking and patching were measured in the usual way, but since it was not feasible to obtain slope variance with the project profilometer, a special present serviceability index equation was developed that included a rut depth variance term instead of slope variance. The variance in rut depth was determined by measuring the depth of rutting at 5-ft intervals in both wheelpaths. It is emphasized that this expedient was used only in cases where sections were nearing failure and it appeared that major maintenance would be required before the next regular 2-week index day.

DS 7322 gives the complete serviceability history of each section as well as cracking, patching, rut depth and slope variance data by wheelpaths. Section history charts showing the trends of cracking, patching, serviceability, roughness index, deflection and other items of information are also available for every test

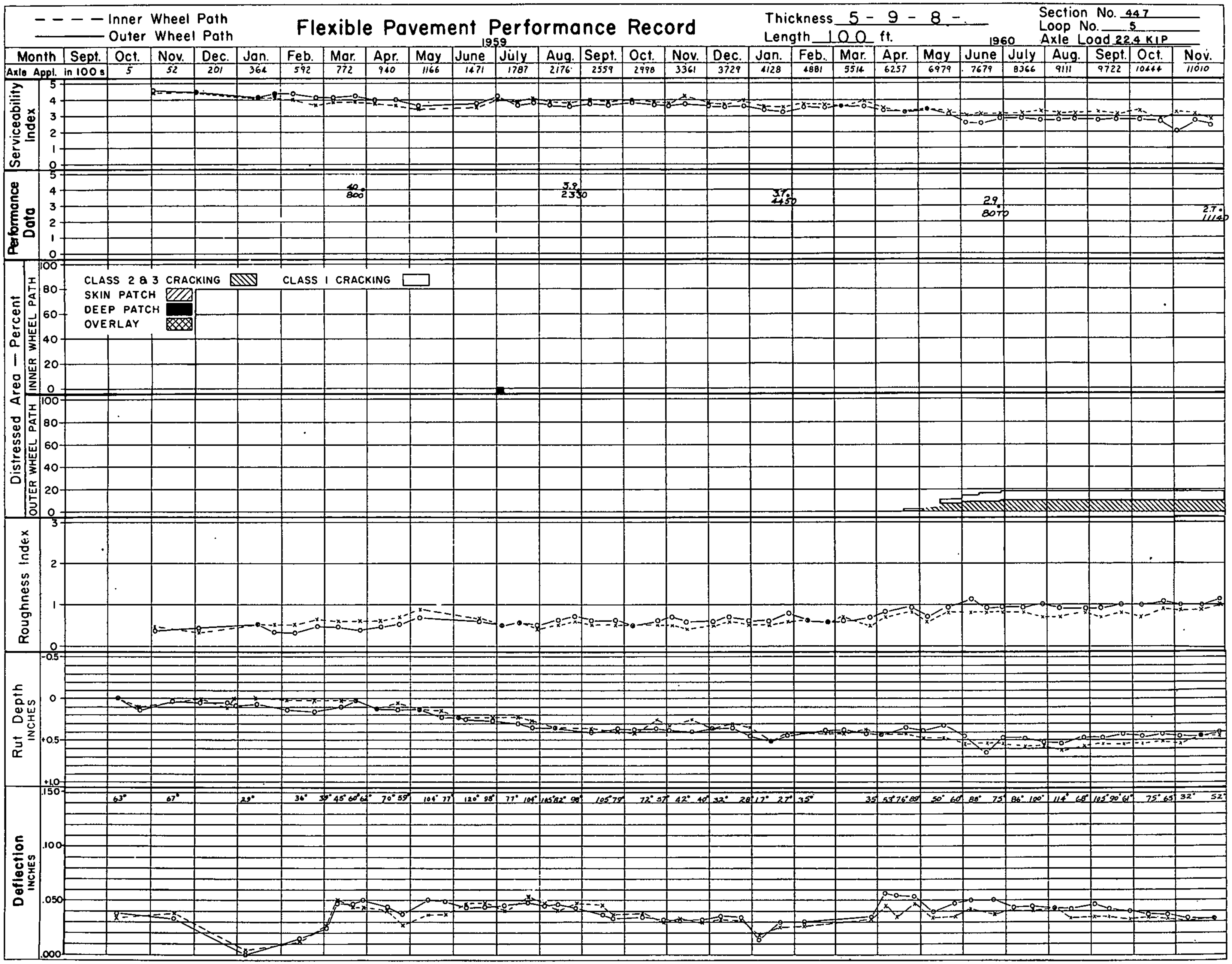

Figure 19. Typical test section history.

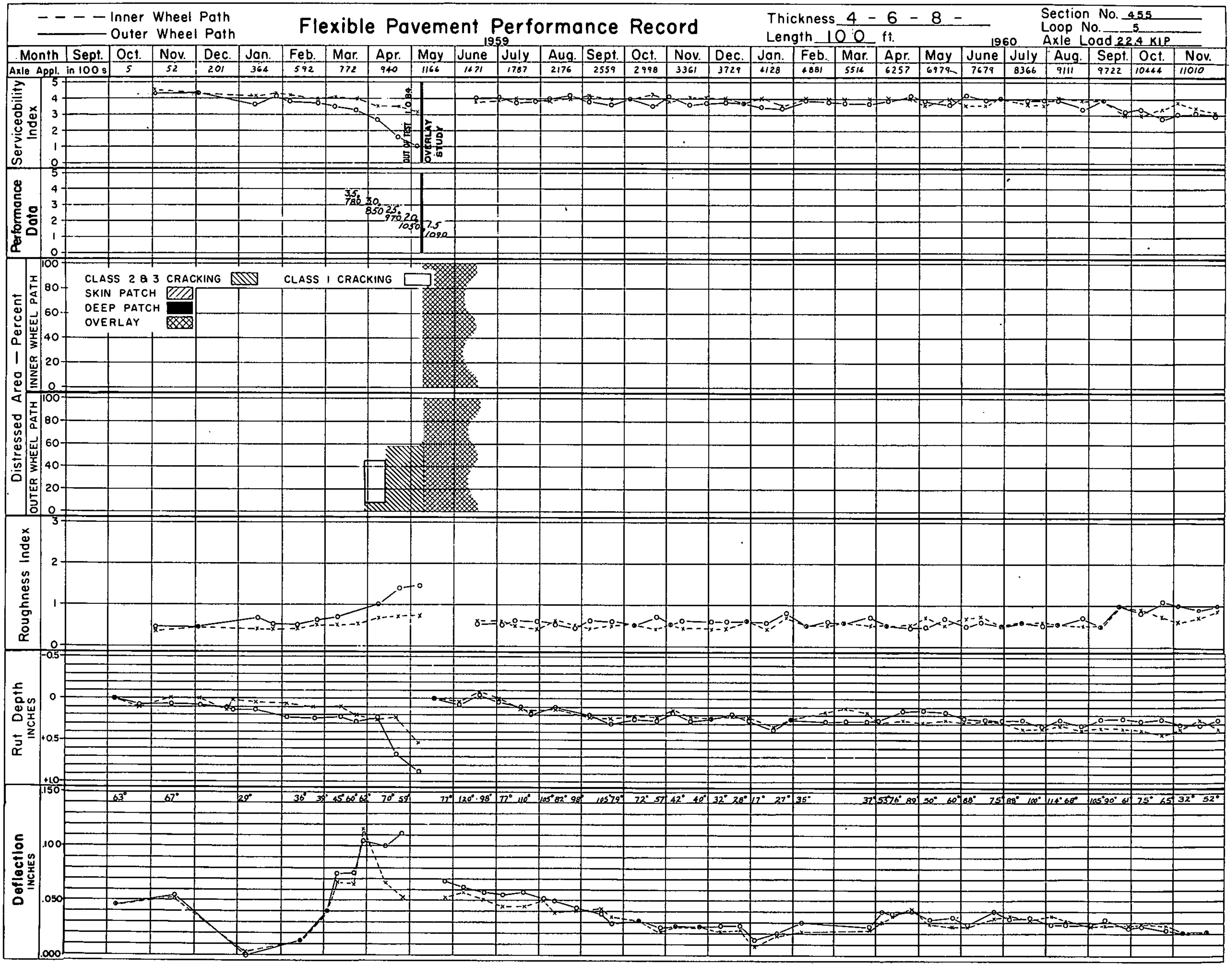

Figure 20. Typical test section history.

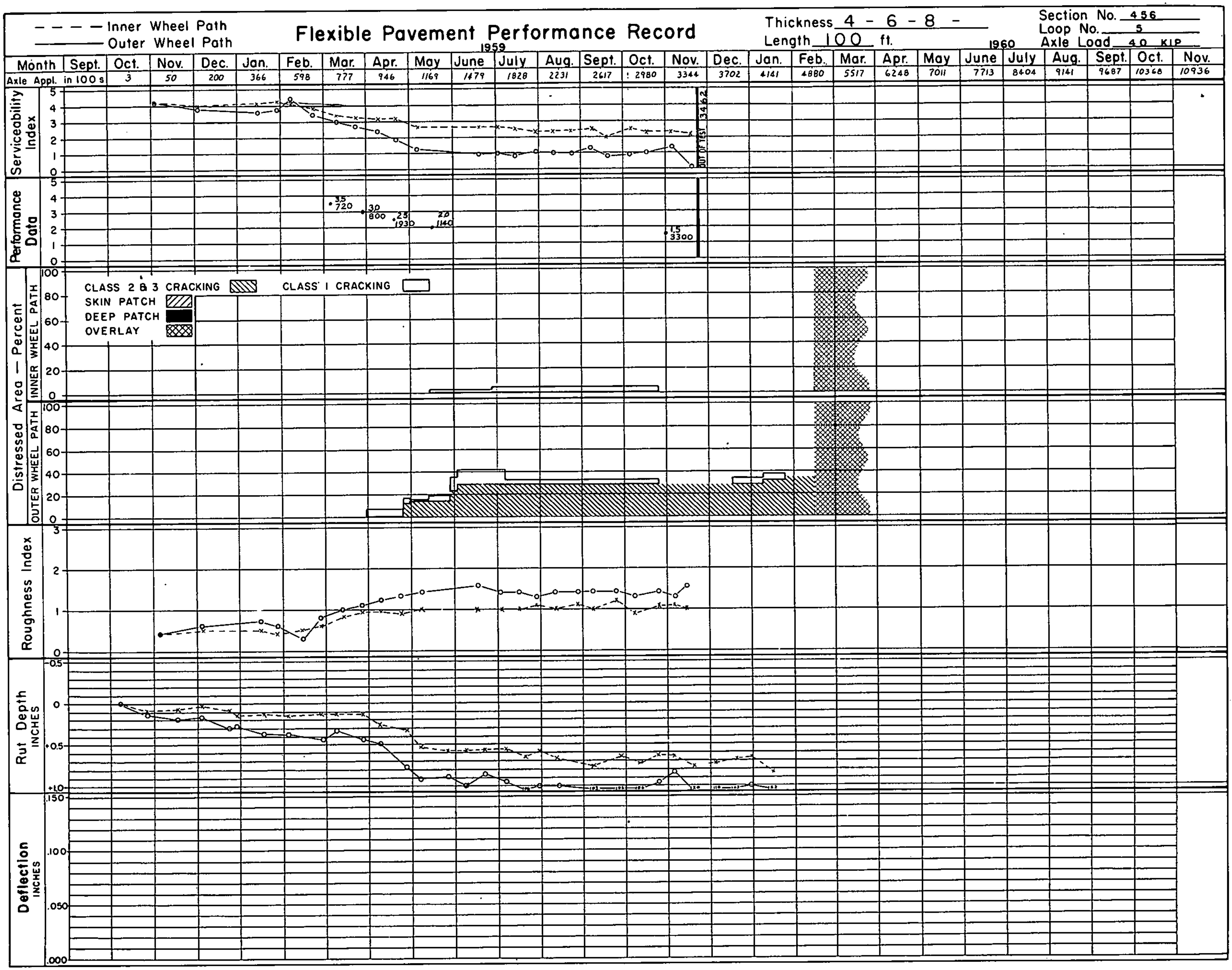

Figure 21. Typical test section history.

section. Figures 19, 20 and 21 are examples of these charts as they may be found for each section in DS 4199.

Basic data relative to the performance of the factorial sections for both weighted and unweighted application are given in Appendix A. Data for a present serviceability level of 1.5 and 2.5, are also given in Tables 5, 6, 7 and 8. Load applications for each design of pavement are given for those sections that were removed from the test and *p* values for those sections that survived the test.

### *2.2.2 Performance as a Function of Design and Load*

This subsection gives relationships between flexible pavement performance and variables that describe load and pavement design. Performance data, models, and analytical procedures described in Section 1.3 are used to obtain specific performance-design-load equations for the factorial experiments. This section also includes associations of performance with design and load variables for the paved shoulder studies and for the special base type studies.

*2.2.2.1 Main Factorial Experiments (Design 1).*—This subsection contains the results of the major Road Test flexible pavement analysis, the pavement performance analysis, and develops the relationships for flexible pavement sought in the first objective. These relationships have been reduced to four equations containing terms for the variables included in the test. Eqs. 13, 17, 18, and 19 are for the case where load applications have been adjusted by the seasonal weighting function; similar equations are given for unweighted applications.

Graphs and tables were constructed from the equations for use in the study of performance over the wide range of designs and loads included in the Road Test.

A convenient presentation of the relationships for the axle loadings of the Road Test is shown in Figure 22. For example, to determine what pavement structure would have survived a million 22.4-kip single axle loads at the Road Test before its serviceability level dropped to 2.5, the chart is entered at 1,000,000 applica-

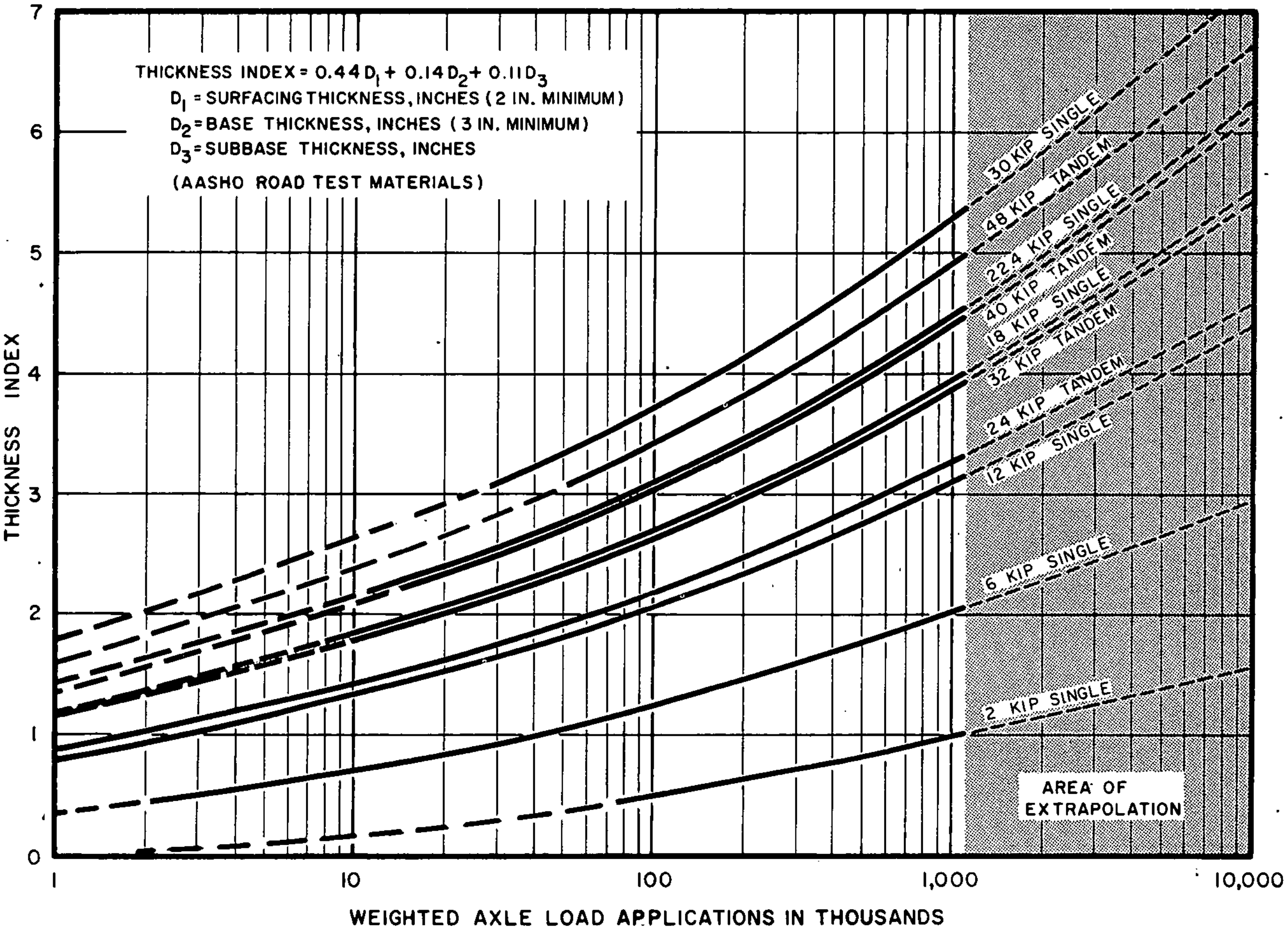

**Figure 22. Main factorial experiment, relationship between design and axle application at $p = 2.5$ (from Road Test equations).**

### TABLE 5

### PERFORMANCE DATA, EXPERIMENT DESIGN 1, UNWEIGHTED AXLE APPLICATIONS TO $p = 1.5$ OR $p$ AT END OF TRAFFIC TEST[1]

Unweighted Axle Applications ($\times 10^3$)

(*a*) LOOP 2

| Axle Load (kips) | Subbase Thick. (in.) | 1-In. Surface |  |  | 2-In. Surface |  |  | 3-In. Surface |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base |
| 2S | 0 | 52 | 552 | (2.8) | 645 | (3.8) | (3.4) | (3.0) | (3.8) | (3.6) |
|  | 0 |  |  |  |  | (2.4) | (3.7) |  |  |  |
|  | 4 | 80 | (2.5) | (3.2) | (1.7) | (3.5) | (3.6) | (3.3) | (3.8) | (3.9) |
|  | 4 |  |  |  |  | (3.3) | (3.3) |  |  |  |
| 6S | 0 | 2 | 70 | 106 | 74 | 250 | (3.5) | 104 | 710 | (3.1) |
|  | 0 |  |  |  |  | 120 | (2.5) |  |  |  |
|  | 4 | 2 | 73 | 570 | 87 | 582 | (3.2) | 106 | (2.7) | (3.6) |
|  | 4 |  |  |  |  | (1.8) | (2.6) |  |  |  |

(*b*) LOOP 3

| Axle Load (kips) | Subbase Thick. (in.) | 2-In. Surface |  |  | 3-In. Surface |  |  | 4-In. Surface |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base |
| 12S | 0 | 64 | 65 | 77 | 77 | 72 | 87 | 78 | 80 | 178 |
|  | 0 |  |  |  |  |  |  |  |  | 109 |
|  | 4 | 4 | 73 | 90 | 87 | 87 | 589 | 78 | 109 | (2.3) |
|  | 4 |  |  |  |  | 87 |  |  |  |  |
|  | 8 | 73 | 88 | 722 | 100 | 561 | (1.6) | 109 | 611 | (3.6) |
|  | 8 | 77 |  |  |  |  |  |  |  |  |
| 24T | 0 | 64 | 70 | 72 | 72 | 75 | 80 | 72 | 88 | 175 |
|  | 0 |  |  |  |  |  |  |  |  | 95 |
|  | 4 | 3 | 76 | 81 | 80 | 86 | 102 | 80 | 100 | 627 |
|  | 4 |  |  |  |  | 82 |  |  |  |  |
|  | 8 | 74 | 80 | 555 | 91 | 111 | 614 | 88 | 558 | (3.3) |
|  | 8 | 74 |  |  |  |  |  |  |  |  |

(*c*) LOOP 4

| Axle Load (kips) | Subbase Thick. (in.) | 3-In. Surface |  |  | 4-In. Surface |  |  | 5-In. Surface |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base |
| 18S | 4 | 2 | 74 | 80 | 78 | 87 | 90 | 88 | 125 | 641 |
|  | 4 |  |  |  |  |  |  |  |  | 611 |

|  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | 8 | 72 | 82 | 92 | 107 | 100 | (1.9) | 119 | 589 | (3.6) |
|  | 8 |  |  |  |  | 111 |  |  |  |  |
|  | 12 | 82 | 583 | (1.6) | 426 | 1110 | (1.9) | 676 | 592 | (3.3) |
|  | 12 | 115 |  |  |  |  |  |  |  |  |
| 32T | 4 | 12 | 76 | 80 | 83 | 93 | 120 | 102 | 151 | 734 |
|  | 4 |  |  |  |  |  |  |  |  | 621 |
|  | 8 | 74 | 86 | 570 | 102 | 151 | (2.0) | 126 | 752 | (2.7) |
|  | 8 |  |  |  |  | 138 |  |  |  |  |
|  | 12 | 106 | 601 | 618 | 576 | 796 | (3.1) | 850 | (2.2) | (2.7) |
|  | 12 | 115 |  |  |  |  |  |  |  |  |

(*d*) Loop 5

|  |  | 3-In. Surface |  |  | 4-In. Surface |  |  | 5-In. Surface |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 3-In. Base | 6-In. Base | 9-In.. Base | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base |
| 22.4S | 4 | 70 | 72 | 81 | 71 | 80 | 102 | 78 | 101 | 624 |
|  | 4 |  |  |  |  |  |  |  |  | 589 |
|  | 8 | 72 | 76 | 87 | 82 | 109 | 490 | 103 | 652 | (2.7) |
|  | 8 |  |  |  |  | 102 |  |  |  |  |
|  | 12 | 87 | 408 | (2.9) | 104 | 605 | (2.4) | 756 | (2.0) | (3.5) |
|  | 12 | 77 |  |  |  |  |  |  |  |  |
| 40T | 4 | 4 | 75 | 82 | 66 | 82 | 111 | 90 | 113 | 627 |
|  | 4 |  |  |  |  |  |  |  |  | 601 |
|  | 8 | 74 | 77 | 106 | 82 | 330 | 401 | 129 | (1.9) | (2.6) |
|  | 8 |  |  |  |  | 540 |  |  |  |  |
|  | 12 | 114 | 555 | 655 | 102 | 549 | (3.0) | (1.9) | (2.4) | (3.2) |
|  | 12 | 82 |  |  |  |  |  |  |  |  |

(*e*) Loop 6

|  |  | 4-In. Surface |  |  | 5-In. Surface |  |  | 6-In. Surface |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base |
| 30S | 8 | 72 | 82 | 82 | 78 | 100 | 595 | 141 | 106 | 624 |
|  | 8 |  |  |  |  |  |  |  |  | (2.1) |
|  | 12 | 373 | 83 | 353 | 101 | 634 | 719 | 113 | (1.6) | (2.8) |
|  | 12 |  |  |  |  | 411 |  |  |  |  |
|  | 16 | 134 | 552 | (2.0) | 573 | (1.8) | (3.3) | 627 | (3.2) | (2.7) |
|  | 16 | 91 |  |  |  |  |  |  |  |  |
| 48T | 8 | 80 | 373 | 242 | 103 | 105 | 624 | 579 | 250 | (2.6) |
|  | 8 |  |  |  |  |  |  |  |  | (1.7) |
|  | 12 | 573 | 100 | 737 | 419 | 595 | 722 | 485 | (3.0) | (2.6) |
|  | 12 |  |  |  |  | 618 |  |  |  |  |
|  | 16 | 621 | 621 | (3.2) | 652 | 809 | (3.5) | (2.4) | (3.9) | (3.6) |
|  | 16 | 104 |  |  |  |  |  |  |  |  |

[1] Values in parentheses are values of *p*.

## TABLE 6

### PERFORMANCE DATA, EXPERIMENT DESIGN 1, WEIGHTED AXLE APPLICATIONS TO $p = 1.5$ OR $p$ AT END OF TRAFFIC TEST[1]

| Axle Load (kips) | Subbase Thick. (in.) | Weighted Axle Applications ( × 10$^3$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (a) LOOP 2 | | | | | | | | |
| | | 1-In. Surface | | | 2-In. Surface | | | 3-In. Surface | | |
| | | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base |
| 2S | 0 | 13 | 448 | (2.8) | 738 | (3.8) | (3.4) | (3.0) | (3.8) | (3.6) |
| | 0 | | | | | (2.4) | (3.7) | | | |
| | 4 | 78 | (2.5) | (3.2) | (1.7) | (3.5) | (3.6) | (3.3) | (3.8) | (3.9) |
| | 4 | | | | | (3.3) | (3.3) | | | |
| 6S | 0 | 2 | 28 | 145 | 49 | 306 | (3.5) | 141 | 802 | (3.1) |
| | 0 | | | | | 164 | (2.5) | | | |
| | 4 | 3 | 43 | 477 | 105 | 530 | (3.2) | 145 | (2.7) | (3.6) |
| | 4 | | | | | (1.8) | (2.6) | | | |
| | | (b) LOOP 3 | | | | | | | | |
| | | 2-In. Surface | | | 3-In. Surface | | | 4-In. Surface | | |
| | | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base |
| 12S | 0 | 21 | 22 | 63 | 60 | 40 | 105 | 65 | 78 | 232 |
| | 0 | | | | | | | | | 148 |
| | 4 | 4 | 43 | 110 | 105 | 105 | 557 | 67 | 148 | (2.3) |
| | 4 | | | | | 105 | | | | |
| | 8 | 43 | 108 | 814 | 133 | 462 | (1.6) | 148 | 645 | (3.6) |
| | 8 | 60 | | | | | | | | |
| 24T | 0 | 21 | 28 | 40 | 37 | 52 | 78 | 37 | 108 | 229 |
| | 0 | | | | | | | | | 124 |
| | 4 | 4 | 58 | 80 | 78 | 102 | 138 | 75 | 133 | 702 |
| | 4 | | | | | 83 | | | | |
| | 8 | 49 | 78 | 452 | 113 | 152 | 657 | 108 | 457 | (3.3) |
| | 8 | 46 | | | | | | | | |
| | | (c) LOOP 4 | | | | | | | | |
| | | 3-In. Surface | | | 4-In. Surface | | | 5-In. Surface | | |
| | | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base |
| 18S | 4 | 2 | 49 | 75 | 68 | 105 | 110 | 108 | 169 | 734 |
| | 4 | | | | | | | | | 645 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 8 | 40 | 86 | 116 | 146 | 133 | (1.9) | 162 | 557 | (3.6) |
| | 8 | | | | | 152 | | | | |
| | 12 | 86 | 530 | (1.6) | 396 | 1224 | (1.9) | 775 | 571 | (3.3) |
| | 12 | 157 | | | | | | | | |
| 32T | 4 | 11 | 55 | 78 | 91 | 119 | 164 | 138 | 200 | 826 |
| | 4 | | | | | | | | | 679 |
| | 8 | 49 | 102 | 477 | 136 | 200 | (2.0) | 171 | 859 | (2.7) |
| | 8 | | | | | 187 | | | | |
| | 12 | 145 | 611 | 668 | 504 | 928 | (3.1) | 1012 | (2.2) | (2.7) |
| | 12 | 157 | | | | | | | | |

(*d*) Loop 5

| | | 3-In. Surface | | | 4-In. Surface | | | 5-In. Surface | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base |
| 22.4S | 4 | 31 | 40 | 80 | 34 | 78 | 136 | 67 | 135 | 691 |
| | 4 | | | | | | | | | 557 |
| | 8 | 40 | 55 | 105 | 86 | 148 | 419 | 140 | 747 | (2.7) |
| | 8 | | | | | 138 | | | | |
| | 12 | 105 | 391 | (2.9) | 141 | 622 | (2.4) | 866 | (2.0) | (3.5) |
| | 12 | 60 | | | | | | | | |
| 40T | 4 | 4 | 52 | 83 | 24 | 86 | 152 | 110 | 153 | 702 |
| | 4 | | | | | | | | | 611 |
| | 8 | 46 | 60 | 145 | 86 | 352 | 390 | 175 | (1.9) | (2.6) |
| | 8 | | | | | 428 | | | | |
| | 12 | 155 | 452 | 752 | 138 | 443 | (3.0) | (1.9) | (2.4) | (3.2) |
| | 12 | 83 | | | | | | | | |

(*e*) Loop 6

| | | 4-In. Surface | | | 5-In. Surface | | | 6-In. Surface | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base |
| 30S | 8 | 37 | 86 | 83 | 68 | 133 | 584 | 190 | 145 | 691 |
| | 8 | | | | | | | | | (2.1) |
| | 12 | 385 | 89 | 367 | 135 | 725 | 811 | 153 | (1.6) | (2.8) |
| | 12 | | | | | 392 | | | | |
| | 16 | 183 | 448 | (2.0) | 490 | (1.8) | (3.3) | 702 | (3.2) | (2.7) |
| | 16 | 113 | | | | | | | | |
| 48T | 8 | 75 | 385 | 298 | 140 | 143 | 691 | 517 | 306 | (2.6) |
| | 8 | | | | | | | | | (1.7) |
| | 12 | 490 | 133 | 832 | 394 | 584 | 814 | 418 | (3.0) | (2.6) |
| | 12 | | | | | 668 | | | | |
| | 16 | 679 | 679 | (3.2) | 747 | 948 | (3.5) | (2.4) | (3.9) | (3.6) |
| | 16 | 141 | | | | | | | | |

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[1] Values in parentheses are values of $p$.

### TABLE 7

### PERFORMANCE DATA, EXPERIMENT DESIGN 1, UNWEIGHTED AXLE APPLICATIONS TO $p = 2.5$ OR $p$ AT END OF TRAFFIC TEST[1]

| Axle Load (kips) | Subbase Thick. (in.) | Unweighted Axle Applications ($\times 10^3$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (a) LOOP 2 | | | | | | | | |
| | | 1-In. Surface | | | 2-In. Surface | | | 3-In. Surface | | |
| | | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base |
| 2S | 0 | 26 | 543 | (2.8) | 634 | (3.8) | (3.4) | (3.0) | (3.8) | (3.6) |
| | 0 | | | | | 803 | (3.7) | | | |
| | 4 | 74 | (2.5) | (3.2) | 592 | (3.5) | (3.6) | (3.3) | (3.8) | (3.9) |
| | 4 | | | | | (3.3) | (3.3) | | | |
| 6S | 0 | 2 | 45 | 81 | 72 | 165 | (3.5) | 101 | 708 | (3.1) |
| | 0 | | | | | 109 | (2.5) | | | |
| | 4 | 1 | 70 | 408 | 80 | 576 | (3.2) | 102 | (2.7) | (3.6) |
| | 4 | | | | | 628 | (2.6) | | | |
| | | (b) LOOP 3 | | | | | | | | |
| | | 2-In. Surface | | | 3-In. Surface | | | 4-In. Surface | | |
| | | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base |
| 12S | 0 | 61 | 63 | 73 | 76 | 70 | 86 | 77 | 80 | 119 |
| | 0 | | | | | | | | | 107 |
| | 4 | 2 | 71 | 87 | 85 | 86 | 573 | 77 | 100 | 716 |
| | 4 | | | | | 79 | | | | |
| | 8 | 72 | 78 | 621 | 98 | 506 | 638 | 100 | 582 | (3.6) |
| | 8 | 75 | | | | | | | | |
| 24T | 0 | 61 | 58 | 71 | 71 | 73 | 80 | 70 | 86 | 139 |
| | 0 | | | | | | | | | 90 |
| | 4 | 2 | 71 | 77 | 80 | 83 | 94 | 80 | 94 | 614 |
| | 4 | | | | | 80 | | | | |
| | 8 | 72 | 78 | 500 | 85 | 95 | 493 | 86 | 503 | (3.3) |
| | 8 | 72 | | | | | | | | |
| | | (c) LOOP 4 | | | | | | | | |
| | | 3-In. Surface | | | 4-In. Surface | | | 5-In. Surface | | |
| | | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base | 0-In. Base | 3-In. Base | 6-In. Base |
| 18S | 4 | 1 | 72 | 80 | 77 | 86 | 86 | 87 | 119 | 605 |
| | 4 | | | | | | | | | 582 |

|  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | 8 | 71 | 81 | 83 | 103 | 98 | 760 | 111 | 289 | (3.6) |
|  | 8 |  |  |  |  | 105 |  |  |  |  |
|  | 12 | 81 | 570 | 621 | 146 | 659 | 680 | 589 | 576 | (3.3) |
|  | 12 | 97 |  |  |  |  |  |  |  |  |
| 32T | 4 | 11 | 73 | 80 | 82 | 88 | 102 | 100 | 133 | 673 |
|  | 4 |  |  |  |  |  |  |  |  | 592 |
|  | 8 | 72 | 86 | 138 | 100 | 109 | 716 | 122 | 634 | (2.7) |
|  | 8 |  |  |  |  | 115 |  |  |  |  |
|  | 12 | 98 | 582 | 573 | 570 | 624 | (3.1) | 631 | 815 | (2.7) |
|  | 12 | 102 |  |  |  |  |  |  |  |  |

(*d*) Loop 5

|  |  | 3-In. Surface |  |  | 4-In. Surface |  |  | 5-In. Surface |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base |
| 22.4S | 4 | 64 | 71 | 80 | 67 | 80 | 83 | 77 | 98 | 608 |
|  | 4 |  |  |  |  |  |  |  |  | 485 |
|  | 8 | 70 | 73 | 79 | 80 | 97 | 169 | 101 | 561 | (2.7) |
|  | 8 |  |  |  |  | 91 |  |  |  |  |
|  | 12 | 86 | 78 | (2.9) | 90 | 506 | 1099 | 611 | 701 | (3.5) |
|  | 12 | 74 |  |  |  |  |  |  |  |  |
| 40T | 4 | 2 | 72 | 80 | 62 | 81 | 99 | 87 | 102 | 242 |
|  | 4 |  |  |  |  |  |  |  |  | 462 |
|  | 8 | 72 | 76 | 85 | 80 | 93 | 123 | 107 | 373 | 800 |
|  | 8 |  |  |  |  | 151 |  |  |  |  |
|  | 12 | 85 | 459 | 153 | 98 | 182 | (3.0) | 611 | 764 | (3.2) |
|  | 12 | 80 |  |  |  |  |  |  |  |  |

(*e*) Loop 6

|  |  | 4-In. Surface |  |  | 5-In. Surface |  |  | 6-In. Surface |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base | 3-In. Base | 6-In. Base | 9-In. Base |
| 30S | 8 | 70 | 80 | 80 | 78 | 91 | 441 | 111 | 102 | 512 |
|  | 8 |  |  |  |  |  |  |  |  | 705 |
|  | 12 | 133 | 80 | 109 | 92 | 586 | 558 | 95 | 713 | 669 |
|  | 12 |  |  |  |  | 126 |  |  |  |  |
|  | 16 | 98 | 452 | 1022 | 498 | 676 | (3.3) | 552 | (3.2) | (2.7) |
|  | 16 | 85 |  |  |  |  |  |  |  |  |
| 48T | 8 | 77 | 114 | 119 | 101 | 101 | 595 | 573 | 120 | (2.6) |
|  | 8 |  |  |  |  |  |  |  |  | 618 |
|  | 12 | 473 | 88 | 233 | 115 | 506 | 271 | 111 | (3.0) | (2.6) |
|  | 12 |  |  |  |  | 601 |  |  |  |  |
|  | 16 | 576 | 217 | (3.2) | 592 | 576 | (3.5) | 1099 | (3.9) | (3.6) |
|  | 16 | 101 |  |  |  |  |  |  |  |  |

---

[1] Values in parentheses are values of *p*.

## TABLE 8

### PERFORMANCE DATA, EXPERIMENT DESIGN 1, WEIGHTED AXLE APPLICATIONS TO $p = 2.5$ OR $p$ AT END OF TRAFFIC TEST[1]

Weighted Axle Applications ($\times 10^3$)

(*a*) LOOP 2

| Axle Load (kips) | Subbase Thick. (in.) | 1-In. Surface | | | 2-In. Surface | | | 3-In. Surface | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0-In. Base | 3-In. Base | 6-In. Base | 0–In. Base | 3–In. Base | 6–In. Base | 0–In. Base | 3–In. Base | 6–In. Base |
| 2S | 0 | 12 | 433 | (2.8) | 725 | (3.8) | (3.4) | (3.0) | (3.8) | (3.6) |
| | 0 | | | | | 938 | (3.7) | | | |
| | 4 | 49 | (2.5) | (3.2) | 571 | (3.5) | (3.6) | (3.3) | (3.8) | (3.9) |
| | 4 | | | | | (3.3) | (3.3) | | | |
| 6S | 0 | 2 | 12 | 80 | 40 | 218 | (3.5) | 135 | 799 | (3.1) |
| | 0 | | | | | 148 | (2.5) | | | |
| | 4 | 2 | 31 | 391 | 75 | 504 | (3.2) | 136 | (2.7) | (3.6) |
| | 4 | | | | | 702 | (2.6) | | | |

(*b*) LOOP 3

| Axle Load (kips) | Subbase Thick. (in.) | 2-In. Surface | | | 3-In. Surface | | | 4-In. Surface | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0-In. Base | 3-In. Base | 6-In. Base | 0–In. Base | 3–In. Base | 6–In. Base | 0–In. Base | 3–In. Base | 6–In. Base |
| 12S | 0 | 17 | 20 | 43 | 58 | 31 | 102 | 60 | 78 | 162 |
| | 0 | | | | | | | | | 146 |
| | 4 | 3 | 34 | 105 | 99 | 102 | 490 | 62 | 133 | 808 |
| | 4 | | | | | 73 | | | | |
| | 8 | 37 | 67 | 679 | 130 | 423 | 729 | 133 | 530 | (3.6) |
| | 8 | 52 | | | | | | | | |
| 24T | 0 | 17 | 14 | 34 | 34 | 43 | 75 | 31 | 102 | 188 |
| | 0 | | | | | | | | | 110 |
| | 4 | 2 | 34 | 62 | 75 | 89 | 121 | 75 | 121 | 657 |
| | 4 | | | | | 78 | | | | |
| | 8 | 40 | 65 | 422 | 99 | 124 | 420 | 102 | 422 | (3.3) |
| | 8 | 37 | | | | | | | | |

(*c*) LOOP 4

| Axle Load (kips) | Subbase Thick. (in.) | 3-In. Surface | | | 4-In. Surface | | | 5-In. Surface | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0-In. Base | 3-In. Base | 6-In. Base | 0–In. Base | 3–In. Base | 6–In. Base | 0–In. Base | 3–In. Base | 6–In. Base |
| 18S | 4 | 1 | 40 | 75 | 63 | 102 | 102 | 105 | 162 | 622 |
| | 4 | | | | | | | | | 530 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 8 | 34 | 80 | 89 | 140 | 130 | 872 | 152 | 332 | (3.6) |
| | 8 | | | | | 143 | | | | |
| | 12 | 80 | 477 | 679 | 195 | 756 | 778 | 557 | 504 | (3.3) |
| | 12 | 127 | | | | | | | | |
| 32T | 4 | 11 | 43 | 75 | 83 | 108 | 138 | 133 | 181 | 773 |
| | 4 | | | | | | | | | 571 |
| | 8 | 40 | 102 | 187 | 133 | 148 | 808 | 165 | 725 | (2.7) |
| | 8 | | | | | 157 | | | | |
| | 12 | 130 | 530 | 490 | 477 | 691 | (3.1) | 713 | 958 | (2.7) |
| | 12 | 136 | | | | | | | | |

### (*d*) Loop 5

| | | 3-In. Surface | | | 4-In. Surface | | | 5-In. Surface | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3-In. Base | 6-In. Base | 9-In. Base | 3–In. Base | 6–In. Base | 9-In. Base | 3–In. Base | 6–In. Base | 9-In. Base |
| 22.4S | 4 | 21 | 34 | 75 | 25 | 75 | 89 | 62 | 130 | 634 |
| | 4 | | | | | | | | | 418 |
| | 8 | 31 | 43 | 72 | 78 | 127 | 222 | 135 | 462 | (2.7) |
| | 8 | | | | | 113 | | | | |
| | 12 | 102 | 65 | (2.9) | 110 | 423 | 1219 | 645 | 794 | (3.5) |
| | 12 | 49 | | | | | | | | |
| 40T | 4 | 3 | 40 | 78 | 18 | 80 | 131 | 105 | 138 | 424 |
| | 4 | | | | | | | | | 409 |
| | 8 | 37 | 58 | 99 | 78 | 119 | 167 | 146 | 385 | 980 |
| | 8 | | | | | 200 | | | | |
| | 12 | 97 | 408 | 202 | 130 | 236 | (3.0) | 645 | 879 | (3.2) |
| | 12 | 75 | | | | | | | | |

### (*e*) Loop 6

| | | 4-In. Surface | | | 5-In. Surface | | | 6-In. Surface | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3-In. Base | 6-In. Base | 9-In. Base | 3–In. Base | 6–In. Base | 9-In. Base | 3–In. Base | 6–In. Base | 9–In. Base |
| 30S | 8 | 31 | 78 | 75 | 65 | 113 | 400 | 152 | 138 | 424 |
| | 8 | | | | | | | | | 797 |
| | 12 | 181 | 78 | 143 | 116 | 544 | 457 | 124 | 805 | 770 |
| | 12 | | | | | 171 | | | | |
| | 16 | 130 | 405 | 1181 | 421 | 775 | (3.3) | 448 | (3.2) | (2.7) |
| | 16 | 99 | | | | | | | | |
| 48T | 8 | 63 | 155 | 162 | 135 | 135 | 584 | 490 | 164 | (2.6) |
| | 8 | | | | | | | | | 668 |
| | 12 | 414 | 108 | 290 | 157 | 423 | 318 | 152 | (3.0) | (2.6) |
| | 12 | | | | | 611 | | | | |
| | 16 | 504 | 276 | (3.2) | 571 | 504 | (3.5) | 1219 | (3.9) | (3.6) |
| | 16 | 135 | | | | | | | | |

---

[1] Values in parentheses are values of $p$.

tions on the abscissa and the thickness index (4.5) is read on the ordinate scale. Asphaltic concrete surfacing, base and subbase may be combined in any combination for an index of 4.5, provided it meets the conditions for use of the thickness index equation stated on the chart. Many combinations of structural layers will meet these conditions. One, for example, is 4 in. of surfacing, 10 in. of base and 12 in. of subbase.

Since these equations represent serviceability trend data observed in the test, some Road Test sections failed sooner and some later than indicated by the smooth curves. Thus, some allowance should be made for the scatter of the data as shown, for example, in Figure 25. Through a residual analysis it was found that the scatter corresponds to approximately ±14 percent of the thickness index values given by the curves. If comparisons are made with observed performance of actual highways in service, additional allowance should be made to account for differences between the Road Test and the actual highway in materials, environment, and loading history.

These relationships are not intended to be design equations. However, they can serve as a basis for design procedures in which variables not included in the Road Test, such as soil type, are considered.

Tables and discussion are included to show the basis for determining the significance or nonsignificance of the various effects. Correlation indexes show the degree of correlation found in the relationships; mean residuals, the degree of scatter of the observed performance data from the predictions of the performance equations.

The thickness index found to apply to Road Test flexible pavements is of interest in itself. For the weighted applications case the thickness index equation (Eq. 19) indicates that an inch of surfacing was about three times as effective as an inch of base and four times as effective as an inch of subbase in improving pavement performance within the range of design studied.

The use of the seasonal weighting function on axle load applications was found to increase the correlation index from 0.48 to 0.70 and to reduce the mean residuals by 15 percent.

The general model used to represent pavement performance was Eq. 4. For flexible pavement test sections in the factorial experiments the average initial serviceability trend value was $c_0 = 4.2$, and since $c_1 = 1.5$, $c_0 - c_1 = 2.7$, and the trend curves are represented by

$$p = 4.2 - 2.7 \left(\frac{W}{\rho}\right)^{\beta} \qquad (12)$$

Both $\beta$ and $\rho$ are positive functions of the design variables, $D_1$ (surfacing thickness, in.), $D_2$ (base thickness, in.), and $D_3$ (subbase thickness, in.), and of the load variables, $L_1$ (nominal axle load, kips*) and $L_2$ (1 for single axles or 2 for tamdem axles).

The function $\beta$ determines the general shape of the serviceability trend with increasing axle load applications, $W$. If $\beta = 1$, the trend is a straight line; if $\beta > 1$, the serviceability loss rate increases with applications; and if $\beta < 1$, the loss rate decreases with axle load repetitions. Graphs of the performance data for flexible pavements in Appendix A indicated that designs failing early in the Road Test tended to have an increasing rate of serviceability loss ($\beta > 1$), while more adequate designs as a rule had a decreasing loss rate ($\beta < 1$). Estimates of $\beta$ were obtained from the performance data of a number of sections that experienced relatively little serviceability loss in the Road Test. The average of these values was approximately 0.4, and this value was assigned to $\beta_0$, the assumed minimum value for $\beta$ in Eq. 6.

The function $\rho$ is equal to the number of load applications at which $p = 1.5$, and is assumed to increase as design increases and to decrease as load increases. The over-all aim of the performance analysis is to arrive at formulas for $\beta$ and $\rho$ in terms of $D_1$, $D_2$, $D_3$, $L_1$ and $L_2$ so that Eq. 12 may be used to predict the value of $p$ after a specified number of applications, $W$. Or if Eq. 12 is solved for log $W$,

$$\log W = \log \rho + \frac{\log\left(\frac{4.2 - p}{2.7}\right)}{\beta} \qquad (13)$$

then Eq. 13 may be used to predict the number of applications required to reduce $p$ to a specified value.

For the flexible pavements, $\beta$ and $\rho$ are given by particular cases of Eqs. 6 and 7 of Section 1.3.5, as follows:

$$\beta = 0.4 + \frac{B_0(L_1 + L_2)^{B_2}}{(D + 1)^{B_1} L_2^{B_3}} \qquad (14)$$

$$\rho = \frac{A_0(D + 1)^{A_1} L_2^{A_3}}{(L_1 + L_2)^{A_2}} \qquad (15)$$

in which $D$ is a thickness index given by

$$D = a_1 D_1 + a_2 D_2 + a_3 D_3 \qquad (16)$$

If the coefficients $a_1$, $a_2$ and $a_3$ in Eq. 16 are each assigned a value of one, $D$ is the total structure thickness. In the Road Test analyses,

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* For example, for single axle loads of 18 or 22.4 kips, $L_1$ = 18 or 22.4; for tandem axle loads of 32 or 40 kips, $L_1$ = 32 or 40.

however, these coefficients were permitted to vary so that the three elements of the pavement structure might each enter into the thickness index with a different weight per unit thickness.

Several analyses of variance were made in order to infer how $D_1$, $D_2$ and $D_3$ might be brought into the expressions for $\beta$ and $\rho$. Partial results from one such analysis are given in Tables 9 and 10, which show first the number of test sections that entered the analysis for each loop. The second part gives mean squares that can be used to determine the relative significance of various effects. Because there were complete factorial experiments with replication in each loop, analysis of variance could be used to separate out and determine mean squares for the separate linear effects of $D_1$, $D_2$ and $D_3$; mean squares for the separate and combined non-linear effects of $D_1$, $D_2$ and $D_3$; mean squares for the separate and combined interaction effects of $D_1$, $D_2$ and $D_3$; and mean squares for unexplained effects represented by replicate differences. For each of

TABLE 9

ANALYSIS OF VARIANCE FOR LOG $\rho$ ESTIMATES[1] WITHIN LOOPS, UNWEIGHTED APPLICATIONS

| Item | Loop 2 | | Loop 3 | | Loop 4 | | Loop 5 | | Loop 6 | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of test sections | 44 | | 60 | | 60 | | 60 | | 60 | |
| No. of replicate sections | 8 | | 6 | | 6 | | 6 | | 6 | |
| Effects[2]: | | | | | | | | | | |
| Lane mean difference | | 13.75 | | 0.28 | | 0.14 | | 0.02 | | 1.81 |
| $D_1$ (surface) linear: | | | | | | | | | | |
| Lanes combined | 14.47 | | 4.10 | | 5.48 | | 5.76 | | 4.00 | |
| Lane interaction | | 0.02 | | 0.00 | | 0.00 | | 0.01 | | 0.08 |
| $D_2$ (base) linear: | | | | | | | | | | |
| Lanes combined | 11.18 | | 6.75 | | 6.97 | | 5.77 | | 4.80 | |
| Lane interaction | | 0.27 | | 0.07 | | 0.01 | | 0.01 | | 0.01 |
| $D_3$ (subbase) linear: | | | | | | | | | | |
| Lanes combined | 0.71 | | 4.60 | | 7.76 | | 6.38 | | 7.97 | |
| Lane interaction | | 0.12 | | 0.07 | | 0.02 | | 0.02 | | 0.04 |
| $D_1$, $D_2$, $D_3$ non-linear: | | | | | | | | | | |
| Lanes combined | 0.87 | | 0.21 | | 0.01 | | 0.11 | | 0.07 | |
| Lane interaction | | 0.42 | | 0.02 | | 0.00 | | 0.01 | | 0.15 |
| $D_1$, $D_2$, $D_3$ interactions: | | | | | | | | | | |
| Lanes combined | 0.07 | | 0.20 | | 0.12 | | 0.07 | | 0.13 | |
| Lane interaction | | 0.07 | | 0.01 | | 0.01 | | 0.02 | | 0.02 |
| Replicate differences: | | | | | | | | | | |
| Lanes combined | 0.28 | | 0.02 | | 0.01 | | 0.01 | | 0.06 | |
| Lane interaction | | 0.14 | | 0.01 | | 0.01 | | 0.01 | | 0.06 |
| Within loop regression coefficient: | | | | | | | | | | |
| For $D_1$ | 0.78 | | 0.34 | | 0.39 | | 0.40 | | 0.33 | |
| $D_2$ | 0.23 | | 0.14 | | 0.15 | | 0.13 | | 0.12 | |
| $D_3$ | 0.07 | | 0.09 | | 0.12 | | 0.11 | | 0.12 | |
| Within lane | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Coefficient for log $(D+1)$ | 8.12 | 9.07 | 6.23 | 5.38 | 8.83 | 9.07 | 9.14 | 9.50 | 9.87 | 11.57 |
| Percent of variation explained by regression | 68 | 88 | 66 | 69 | 83 | 89 | 84 | 86 | 82 | 75 |
| Mean square for unexplained variation | 0.32 | 0.12 | 0.16 | 0.11 | 0.08 | 0.05 | 0.07 | 0.06 | 0.06 | 0.12 |

[1] Data from which this table arose are the estimates log $\hat{\rho}$ as described in Appendix G.

[2] Mean squares for effects; underlined values considered to be significant relative to replicate differences pooled with interaction effects.

these effects, Tables 9 and 10 show mean squares for the two lanes combined in any loop and also mean squares for lane interactions that bring about dissimilar effects in the two lanes of any loop. In any column of the tables, significance is attained for a stated effect if the mean square for the effect is a sufficient multiple of the mean square for an unexplained or residual effect. For example, $D_1$, $D_2$ and $D_3$ interaction effects must have mean squares about eight times the mean square for replicate effects if the interaction effects are to be significant at the 5 percent level. Although a few scattered interactions did reach this level of significance, the general finding was that $D_1$, $D_2$ and $D_3$ interactions were similar to replicate effects and could be pooled with the replicate effects. Moreover, mean squares for non-linear effects of $D_1$, $D_2$ and $D_3$ on log $\rho$ estimates were generally of the same size as the interaction effects, and since the linear effects of these variables were highly significant in almost every case, the linear expression $a_1D_1 + a_2D_2 + a_3D_3$ accounts for practically all

## TABLE 10

### Analysis of Variance for Log $\rho$ Estimates[1] Within Loops, Weighted Applications

| Item | Loop 2 | | Loop 3 | | Loop 4 | | Loop 5 | | Loop 6 | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of test sections | 44 | | 60 | | 60 | | 60 | | 60 | |
| No. of replicate sections | 8 | | 6 | | 6 | | 6 | | 6 | |
| Effects[2]: | | | | | | | | | | |
| Lane mean difference | | $\underline{13.25}$ | | $\underline{0.32}$ | | $\underline{0.14}$ | | 0.04 | | $\underline{1.55}$ |
| $D_1$ (surface) linear: | | | | | | | | | | |
| Lanes combined | $\underline{16.58}$ | | $\underline{6.89}$ | | $\underline{6.94}$ | | $\underline{7.87}$ | | $\underline{3.83}$ | |
| Lane interaction | | 0.00 | | 0.00 | | 0.00 | | 0.00 | | 0.01 |
| $D_2$ (base) linear: | | | | | | | | | | |
| Lanes combined | $\underline{11.04}$ | | $\underline{7.78}$ | | $\underline{6.16}$ | | $\underline{6.11}$ | | $\underline{4.04}$ | |
| Lane interaction | | 0.14 | | 0.07 | | 0.03 | | 0.01 | | 0.00 |
| $D_3$ (subbase) linear: | | | | | | | | | | |
| Lanes combined | 0.62 | | $\underline{6.94}$ | | 7.51 | | $\underline{7.20}$ | | $\underline{7.07}$ | |
| Lane interaction | | 0.08 | | 0.08 | | 0.01 | | 0.01 | | 0.00 |
| $D_1$, $D_2$, $D_3$ non-linear: | | | | | | | | | | |
| Lanes combined | $\underline{0.90}$ | | 0.13 | | 0.05 | | 0.09 | | 0.04 | |
| Lane interaction | | $\underline{0.45}$ | | 0.04 | | 0.01 | | 0.01 | | 0.09 |
| $D_1$, $D_2$, $D_3$ interactions: | | | | | | | | | | |
| Lanes combined | 0.10 | | 0.07 | | 0.09 | | 0.03 | | 0.11 | |
| Lane interaction | | 0.03 | | 0.01 | | 0.01 | | 0.02 | | 0.01 |
| Replicate differences: | | | | | | | | | | |
| Lanes combined | 0.27 | | 0.01 | | 0.01 | | 0.02 | | 0.05 | |
| Lane interaction | | 0.13 | | 0.01 | | 0.01 | | 0.01 | | 0.05 |
| Within loop regression coefficient: | | | | | | | | | | |
| For $D_1$ | 0.83 | | 0.44 | | 0.44 | | 0.47 | | 0.33 | |
| $D_2$ | 0.25 | | 0.16 | | 0.14 | | 0.14 | | 0.11 | |
| $D_3$ | 0.09 | | 0.11 | | 0.11 | | 0.11 | | 0.11 | |
| Within lane | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Coefficient for log $(D+1)$ | 8.39 | 9.07 | 7.47 | 6.52 | 9.27 | 9.10 | 10.30 | 10.14 | 10.09 | 10.41 |
| Percent of variation explained by regression | 71 | 88 | 81 | 84 | 87 | 93 | 91 | 93 | 85 | 77 |
| Mean square for unexplained variation | 0.32 | 0.13 | 0.11 | 0.07 | 0.06 | 0.03 | 0.04 | 0.03 | 0.05 | 0.09 |

[1] Data from which this table arose are the estimates log $\hat{\rho}$ as described in Appendix G.

[2] Mean squares for effects; underlined values considered to be significant relative to replicate differences pooled with interaction effects.

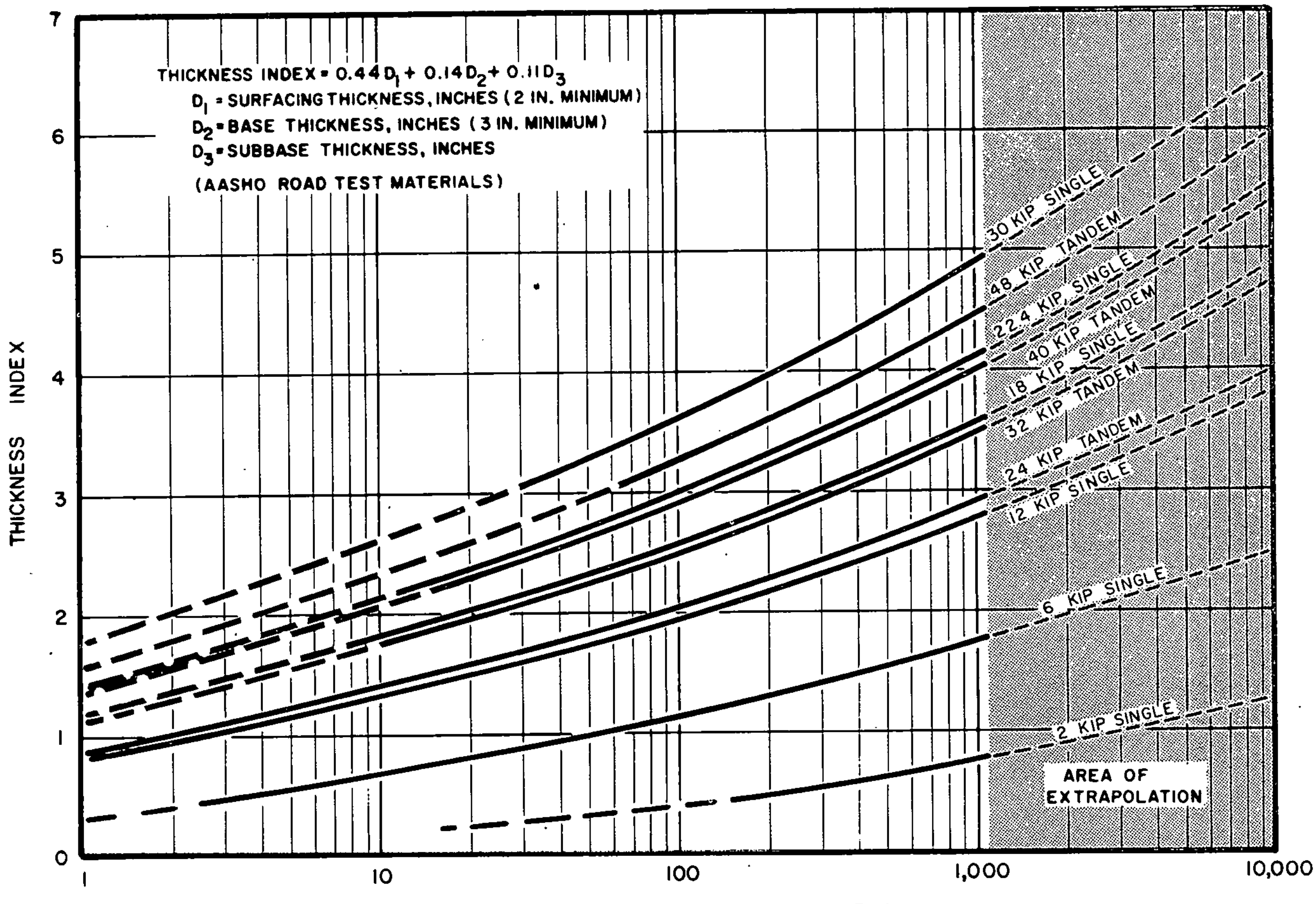

**Figure 23.** Main factorial experiment, relationship between design and axle load applications at $p = 1.5$ (from Road Test equations).

significant effects. Thus this and similar analyses of variance all pointed to the use of a thickness index as given by Eq. 16.

The third part of Tables 9 and 10 shows within loop estimates for $a_1$, $a_2$, and $a_3$ that were obtained from the variance analyses. Weighted averages of these estimates gave the values shown in Eqs. 19 and 22. The last part shows the results of within lane regression analyses that were used to determine values for $A_1$ in Eq. 15. In the logarithmic form, $A_1$ is the coefficient of log $(a_1D_1 + a_2D_2 + a_3D_3 + 1)$, and estimates for this coefficient are shown for each lane at the bottom of the table. Weighted average values for $A_1$ are 9.36 and 8.94 for the two cases represented by Eqs. 18 and 21. The remaining constants in Eqs. 14 and 15 were determined by applying procedures described in Appendix G to the performance data of Appendix A.

If $W$ represents weighted applications obtained through the use of seasonal weighting

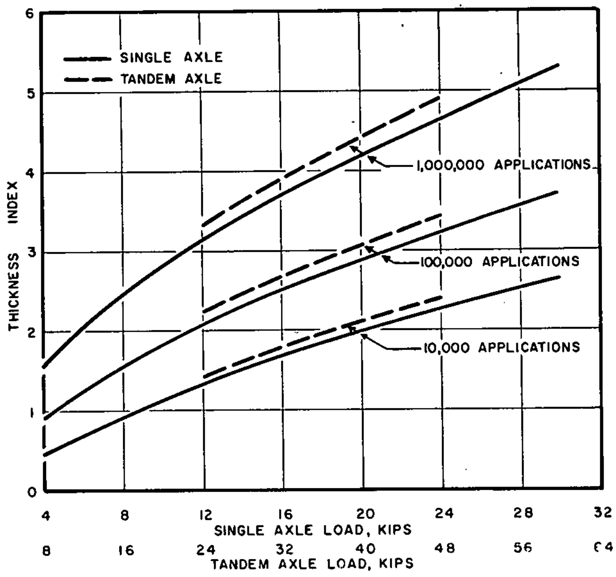

**Figure 24.** Main factorial experiment, relationship between design and load at $p = 2.5$.

function described in Section 2.2.2.1.1, then the analysis gives the following equations:

$$\beta = 0.4 + \frac{0.081(L_1 + L_2)^{3.23}}{(D+1)^{5.19} L_2^{3.23}} \tag{17}$$

$$\rho = \frac{10^{5.93}(D+1)^{9.36} L_2^{4.33}}{(L_1 + L_2)^{4.79}} \tag{18}$$

$$D = 0.44D_1 + 0.14D_2 + 0.11D_3 \tag{19}$$

If the applications are unweighted, then the performance equations are as follows:

$$\beta = 0.4 + \frac{0.083(L_1 + L_2)^{4.87}}{(D+1)^{8.73} L_2^{4.87}} \tag{20}$$

$$\rho = \frac{10^{6.16}(D+1)^{8.94} L_2^{4.17}}{(L_1 + L_2)^{4.54}} \tag{21}$$

$$D = 0.37D_1 + 0.14D_2 + 0.10D_3 \tag{22}$$

Thus for a particular pavement design and axle load, either Eqs. 17, 18 and 19 or Eqs. 20, 21 and 22 give values for $\beta$ and $\rho$ that may be substituted in Eq. 12 if $p$ is to be estimated from $W$, or in Eq. 13 if $W$ is to be estimated when $p$ is given. Figures 22 and 23 show how $W$ varies with $D$ in Eq. 13 when $p$ is fixed at 2.5 and 1.5, respectively. Each figure has ten curves, one curve for each test load used in the Road Test.

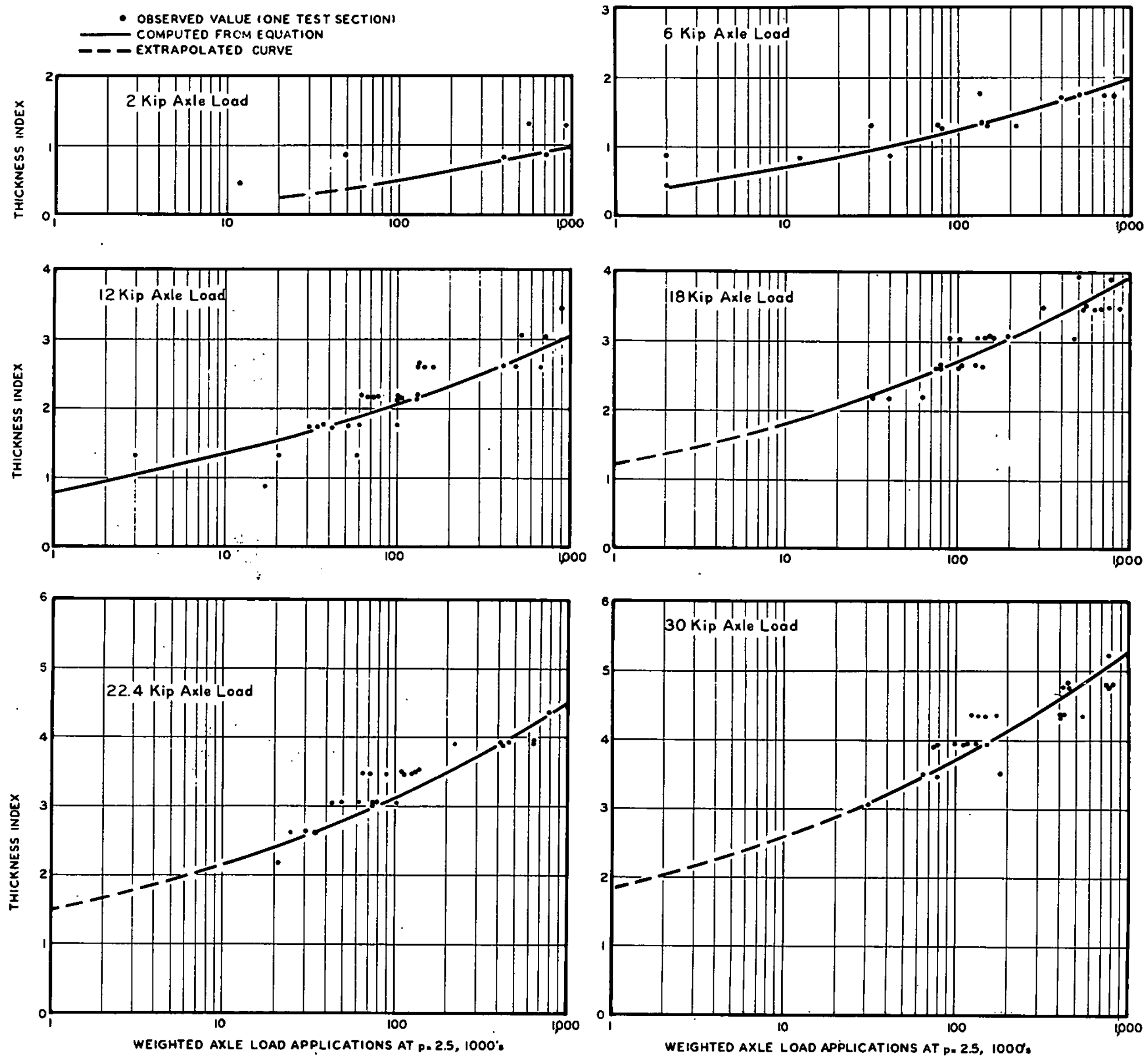

**Figure 25. Main factorial experiment, relationship between design and single axle load applications at $p$ = 2.5.**

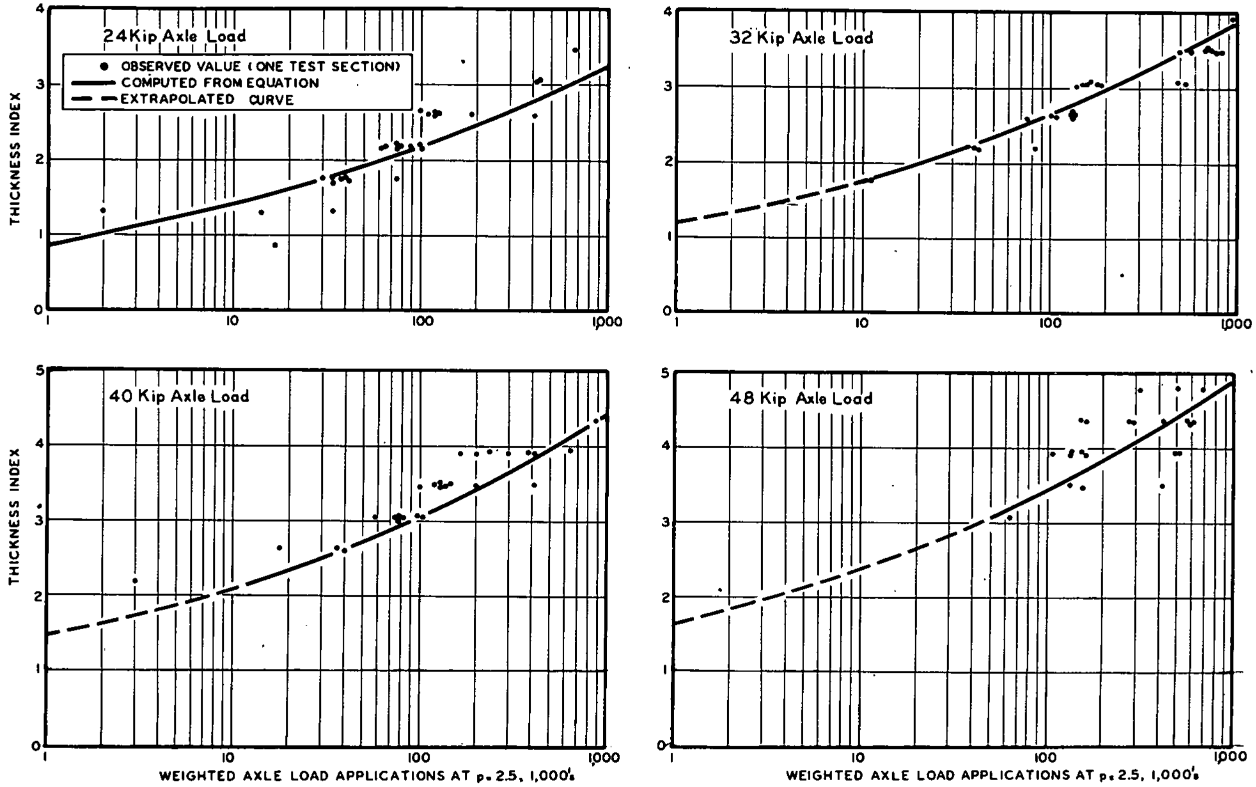

**Figure 26. Main factorial experiment, relationship between design and tandem axle load applications at $p = 2.5$.**

Figure 24 shows design requirements when the final serviceability value is $p = 2.5$ for a range of single and tandem axle loads at three levels of load applications. In this and the remaining graphs for flexible pavement performance (Figs. 24, 25 and 26), the final serviceability level is $p = 2.5$. The choice of 2.5 for final serviceability was arbitrary. The level of serviceability at which states actually perform major maintenance will be established by a survey of pavements scheduled for overlay or reconstruction.

Figures 25 and 26 show the correspondence between the individual curves of Figure 22 and performance data from Appendix A for each of the ten traffic lanes. Each point represents the observed number of weighted applications at which the serviceability of a test section was 2.5. Horizontal deviations of the points from the curves represent prediction errors or residuals when Eqs. 13, 14, 15, and 16 are used to predict the life of a section (to $p = 2.5$) whose design and load values are specified.

Points shown (Figs. 25 and 26) represent only those sections whose serviceability fell to 2.5 by the end of the test. All remaining sections would be represented by points whose abscissas are to the right of 1,114,000 applications. The number of such sections for any lane can be found by subtracting the number of points shown from 22 in Loop 2 and from 30 in all remaining loops. Although these sections do not appear in the graphs, their performance data were used in the development of the performance equations.

The performance data in Appendix A, Design 1, give a minimum of 5 and a maximum of 10 ($p$, log $W$) pairs for each test section. When $p$ is fixed at 3.5, 3.0, 2.5, 2.0 and 1.5 there can be as many as 5 log $W$ observations, and when log $W$ is fixed at $t = 11, 22, 33, 44$ and 55 index days there can be as many as 5 observed values for $p$. Corresponding to each observation, log $W$ or $p$, is a calculated value, $\log\hat{W}$ or $\hat{p}$, obtained from the performance equations. Differences between calculated and observed values are the residuals $\Delta \log W = \log\hat{W} - \log W$ and $\Delta p = \hat{p} - p$. Absolute values of these residuals are summarized in the first part of Table 11 which shows for each lane the number of residuals of each type as well as mean absolute residuals. Mean absolute values for $\Delta$ log $W$ in Loop 2, lane 1 were found to be extreme relative to the other lanes and were omitted from the grand means. Table 11 thus shows that mean values for $\Delta p$ and $\Delta$ log $W$ were 0.53 and 0.27 for unweighted applications, and 0.46 and 0.23 for weighted applications.

Log $W$ residuals are horizontal deviations from the performance equation curves and are thus of special interest in the use of these curves. The second part of Table 11 shows a further summary of log $W$ residuals. The cor-

## TABLE 11

### SUMMARY OF PERFORMANCE EQUATION RESIDUALS AND REPLICATE DIFFERENCES

| Loop | Lane | Load | | Number of Sections | *p* Residuals | | | Log *W* Residuals | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Number of Residuals | Mean Absolute | | Number of Residuals | Mean Absolute | |
| | | $L_1$ | $L_2$ | | | Unwtd. App. | Wtd. App. | | Unwtd. App. | Wtd. App. |
| 2 | 1 | 2 | 1 | 22 | 97 | 0.39 | 0.41 | 42 | 0.85 | 0.92 |
| | 2 | 6 | 1 | 22 | 55 | 0.44 | 0.51 | 83 | 0.40 | 0.36 |
| 3 | 1 | 12 | 1 | 30 | 37 | 0.53 | 0.46 | 138 | 0.34 | 0.28 |
| | 2 | 24 | 2 | 30 | 31 | 0.57 | 0.44 | 146 | 0.37 | 0.29 |
| 4 | 1 | 18 | 1 | 30 | 62 | 0.58 | 0.53 | 136 | 0.23 | 0.19 |
| | 2 | 32 | 2 | 30 | 66 | 0.44 | 0.41 | 138 | 0.18 | 0.16 |
| 5 | 1 | 22.4 | 1 | 30 | 56 | 0.57 | 0.46 | 137 | 0.24 | 0.20 |
| | 2 | 40 | 2 | 30 | 63 | 0.52 | 0.39 | 138 | 0.26 | 0.21 |
| 6 | 1 | 30 | 1 | 30 | 77 | 0.75 | 0.56 | 133 | 0.23 | 0.18 |
| | 2 | 48 | 2 | 30 | 94 | 0.54 | 0.46 | 122 | 0.25 | 0.21 |
| All | All | — | — | — | 638 | 0.53 | 0.46 | 1171[1] | 0.27[1] | 0.23[1] |

| Log *W* residual summary[1] | | Unwtd. App. | Wtd. App. |
|---|---|---|---|
| | Correlation index | 0.48 | 0.70 |
| | Root mean square residual | 0.36 | 0.31 |
| | Percent of residuals within one mean residual | 0.60 | 0.61 |
| | Percent of residuals within two mean residuals | 0.92 | 0.90 |

| Replicate differences[2] | *No. Replicate Section Pairs* | p *Differences* | | Log W *Differences* | | |
|---|---|---|---|---|---|---|
| | | | | | *Mean* | |
| | | No. | Mean | No. | Unwtd. | Wtd. |
| | 32 | 78 | 0.46 | 126 | 0.15 | 0.17 |

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[1] Excluding Loop 2, lane 1.
[2] All lanes.

relation indexes are given as 0.48 and 0.70 for unweighted and weighted applications, respectively, and corresponding root mean square residuals are 0.36 and 0.31.

The general nature of the over-all $\Delta$ log $W$ distribution (except for Loop 2, lane 1) is indicated by the fact that about 60 percent of all $\Delta$ log $W$ is contained within one mean absolute residual and about 90 percent within two mean absolute residuals. The distributions support the statement that in about nine out of ten cases, observations agree with corresponding performance equation estimates to within plus or minus two mean residuals. In other words there is approximately 90 percent confidence (Table 11 includes root mean square residuals, twice whose value can be used to set limits with approximately 95 percent confidence.) that log $W$ will be observed between log $\hat{W} \pm 0.54$ for unweighted applications and between log $\hat{W} \pm 0.46$ for weighted applications. In terms of the thickness index, $D$, these bands correspond approximately to $\hat{D} \pm 0.14\ (\hat{D} + 1)$ for unweighted applications and to $\hat{D} \pm 0.11\ (\hat{D} + 1)$ for weighted applications, where $\hat{D}$ is obtained by entering the appropriate performance equation (or curve) with fixed $W$ and calculating $D$. For relatively heavy designs, the uncertainty represented by two mean residuals in log $W$ is approximately $0.18\hat{D}$ using the unweighted applications formulas and approximately $0.14\hat{D}$ using the weighted application formulas. All confidence limits such as these are relative to the Road Test conditions and range of variables.

The last part of Table 11 summarizes log $W$ and $p$ differences observed between replicate test sections. In all there were 32 pairs of replicate sections in Design 1, and the mean replicate difference is 0.46 for $p$, 0.15 for unweighted log $W$ differences and 0.17 for weighted log $W$ differences. In those pairs where one section was out of test before the second, replicate differences were provided at the missing points by assuming that the remaining differences would be as large as when the first section went out of test.

For whatever reasons two replicate sections do not show the same performance, it can be expected that the performance data will deviate from any fitted equation. For a particular lane a satisfactory model and fitting procedure should result in residuals that average about the same as deviations of replicate observations from their own mean. For two replicates, then, estimation errors should average to be about one-half the replicate differences if the fit is to be judged adequate. Since the performance equations were developed across lanes and loops it is expected that the average residual will be more than one-half the average replicate difference, but how much greater cannot be determined in the absence of replicate lanes and loops. In the Road Test performance analyses it has been supposed that a satisfactory model and fit is indicated whenever mean absolute residuals are about equal to replicate mean differences. Table 11 gives this comparison for unweighted applications to be 0.53 vs 0.46 for $p$ and 0.27 vs 0.15 for log $W$. For weighted applications the comparison is 0.46 vs 0.46 for $p$ and 0.23 vs 0.17 for log $W$. It is quite possible that other models and fitting procedures may do equally well, and that some will represent better the long-time performance of highways in actual service.

2.2.2.1.1 Seasonal Weighting Function.—The concept of a seasonal weighting function to allow for changing load effects in a changing environment was discussed in Section 1.3.4. The weighting function, $q_t$, used in flexible pavement analyses is given by

$$q_t = \left[\frac{2d_t - d_{t-1}}{\bar{d}}\right]^2 \qquad (23)$$

in which $d_t$ is an estimate of the average deflection under a 6-kip wheel load of eight sections in Loop 1 (the non-traffic loop) during index period $t$. Deflections were generally taken twice during each index period and averaged, then a 3-point moving average was used to smooth the deflection history of the eight sections. The deflection $d_{t-1}$ is the smoothed deflection for index period $t - 1$.

Division by $\bar{d}$, the 2-yr average of $d_t$, makes $q_t$ a unitless factor and also makes the weighting function relative to the Road Test conditions. Whenever $d_t = d_{t-1} = \bar{d}$, then $q_t = 1$, so that the weighting function is unity if deflections in Loop 1 are unchanging and are at the 2-yr average value.

The exponent 2 in Eq. 23 has been assumed as an appropriate factor for increasing the amplitude of $q_t$ in periods of high increasing deflection relative to periods of low constant deflection. Data and values for $q_t$ are given in Appendix B.

In Table 11, the use of the seasonal weighting function increased the correlation index from 0.48 to 0.70 and reduced the mean residuals in log $W$ from 0.27 to 0.23.

*2.2.2.2 Paved Shoulder Studies.*—A study of the effectiveness of paved shoulders (Design 2) was included in the Road Test. A total of 48 test sections was provided in this study.

Unfortunately, the pavements selected for the tests were underdesigned to the extent that 42 of the sections failed during the first spring of traffic operation and little information of value was disclosed by the experiment. An attempt was made to obtain additional information by studying the differences in performance of the outer and inner wheelpaths of the test sections of the main experiment.

The results of these studies pointed to the fact that the pavement needed to maintain a certain serviceability at a given number of axle load applications would be considerably thinner in the inner than in the outer wheelpath.

2.2.2.2.1 Design 2.—The paved shoulder study (Design 2) involved six structural sections (12 test sections) in each flexible pavement tangent of Loops 3, 4, 5 and 6. The sections were 160 ft long with shoulders paved with 3 in. of asphaltic concrete varying in width from 8 ft to 0 in the direction of traffic. The six structural sections in each tangent included three different pavement designs and three replicate sections.

The objective of the study was to determine the effect of width of paved shoulder on the performance of the pavement.

Since the procedures used on the Road Test did not produce objective measures of the serviceability of pavements on a foot-by-foot basis, each paved shoulder section was divided into four 40-ft subsections. In the analysis of performance each subsection was considered to have a paved shoulder whose width was represented by its average width (that is, 7, 5, 3 and 1 ft in the direction of traffic).

Data concerning the performance of the paved shoulder subsections are shown graphically in Figures 27 and 28. The values are averages of the total number of the axle loads applied to corresponding subsections in each pair of replicate sections at the time the subsection's serviceability had dropped to 2.5. Also shown are similar values for the 100-ft factorial sections with equivalent structural designs.

Of the 48 160-ft paved shoulder sections, 42 were removed from the test during the first spring of traffic operation when the serviceability of their subsections had been reduced to 1.5. The exceptions were the 2-3-8 design (thickness, in inches, of surfacing, base and subbase, respectively) in lane 1 of Loop 3 and the 4-3-16 design in both lanes of Loop 6. These were the thickest structures included in the paved shoulder test in these loops. Only three subsections remained in test for the entire traffic period. They were the first three subsections in the 4-3-16 structure in lane 2 of Loop 6.

As shown by Figures 27 and 28, there was no clear evidence of any effect of width of paved shoulder on the performance of the section that failed during the first spring. In the other three sets of replicate sections, there was some indication of an effect, but it was neither orderly nor consistent.

Of the 24 sets of replicate sections, 17 indicated no effect of paved shoulders on performance. The average performance of these sections agreed closely with the performance of the factorial sections having the same structural design. For the remaining 7 sets, the

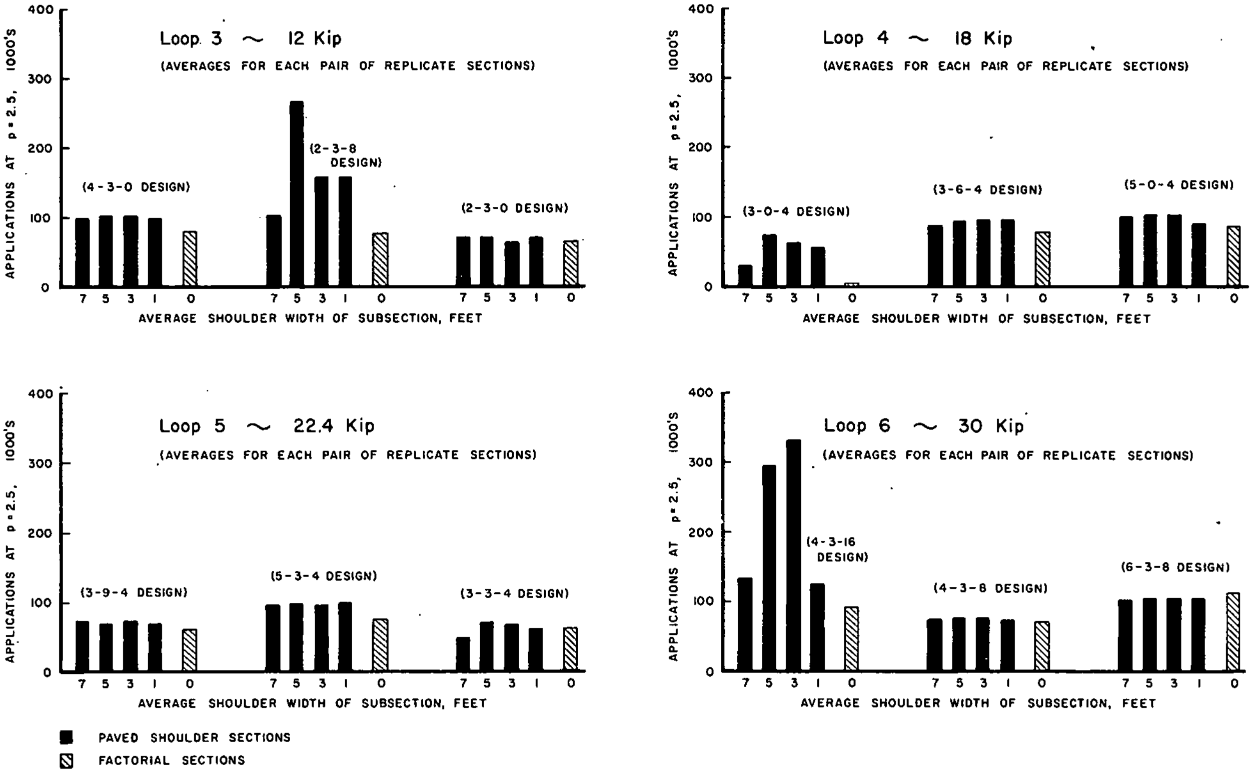
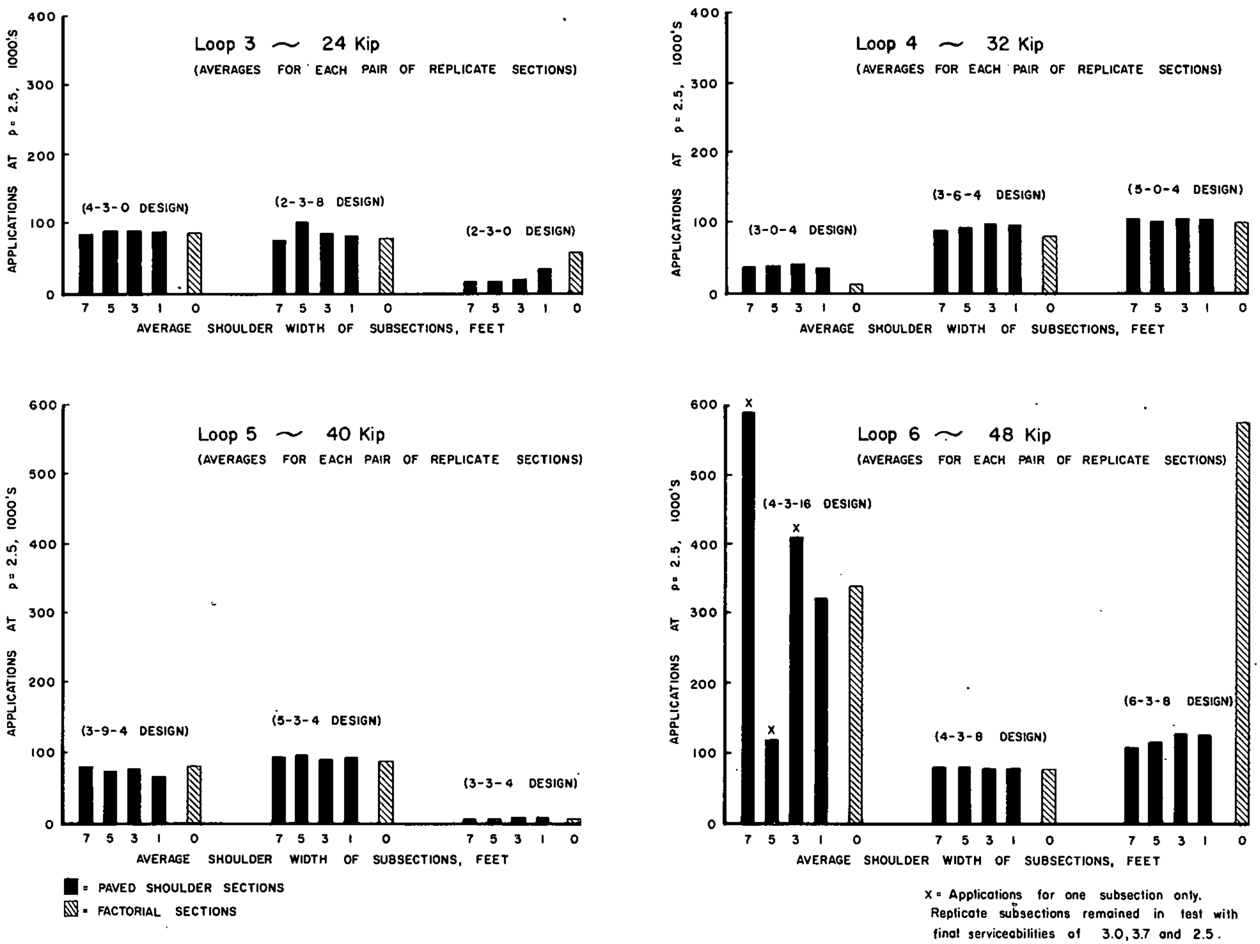


**Figure 27.** **Paved shoulder experiment, performance data for single axle loads, unweighted applications.**



X = Applications for one subsection only. Replicate subsections remained in test with final serviceabilities of 3.0, 3.7 and 2.5.

Figure 28. Paved shoulder experiment, performance data for tandem axle loads, unweighted applications.

performance of the paved shoulder subsections, on an average, was appreciably better in five cases than it was for the counterpart factorial sections, and not as good in two cases. However, there was no clear indication of the effect of varying width.

Additional study of the condition of the pavement in each paved shoulder section just prior to maintenance work on the section indicated that subsection serviceability decreased with increase in paved shoulder width in about as many cases as it increased. This also applied to the depth of rutting. There were as many sections showing an increase in depth of rutting in the outer wheelpath with an increase in width of paved shoulder as there were showing a decrease.

Records of deflections in the outer wheelpath of the subsections also failed to reveal any potential benefit from the presence of the paved shoulders.

Failure of the experiment to provide conclusive evidence of the effect of width of paved shoulders on pavement performance can be attributed at least in part to the selection of the designs included in the test. The pavements were underdesigned to the extent that all four subsections in 42 of the 160-ft test sections went out-of-test in the first spring of traffic operation, with pavement distress and failure occurring quite rapidly. However, the six test sections that survived the test beyond the first spring were benefited to some extent by the presence of the paved shoulder although they provided little indication of the effect of its width on their performance. These sections represented the thickest pavement design included in the paved shoulder test on Loops 3 and 6. If thicker designs had been used, the effect of the width of paved shoulders on pavement performance might have been more evident.

2.2.2.2.2 Performance, by Wheelpaths.—Because all biweekly measurements that entered into the serviceability index for each flexible pavement section were made by wheelpaths, it was possible to make a complete analysis of the performance of each wheelpath. The analyses were identical to those described in Section 2.2.2.1 except that the slope variance, cracking and patching, and rut depth observed in the inner wheelpath were used in computing the inner wheelpath serviceability index for each 2-week period and those observed in the outer wheelpath were used in computing indexes for the outer wheelpath.

To simplify this analysis it was assumed that the thickness index for each wheelpath would be the same as that determined for the entire section (for weighted applications) as in Eq. 19. The other coefficients and constants in the performance equations for each wheelpath were determined for weighted applications by the same techniques as described in Section 2.2.2.1 and in Appendix G. The resulting equations for $\beta$ and $\log \rho$ for the inner wheelpaths are

$$\beta = 0.4 + \frac{0.028(L_1 + L_2)^{2.60}}{(D + 1)^{3.62} L_2^{2.60}} \tag{24}$$

$$\log \rho = 6.63 + 9.20 \log(D + 1) - 5.02 \log (L_1 + L_2) + 4.47 \log L_2 \tag{25}$$

The resulting equations for the outer wheelpaths are

$$\beta = 0.4 + \frac{0.087(L_1 + L_2)^{2.72}}{(D + 1)^{4.35} L_2^{2.72}} \tag{26}$$

$$\log \rho = 5.82 + 8.72 \log(D + 1) - 4.47 \log (L_1 + L_2) + 4.01 \log L_2 \tag{27}$$

The equations may be compared with those (Eqs. 17 and 18) obtained for the entire section. All terms in the equations are defined as they were for the previous equations. There is perhaps more reliability associated with the outer wheelpath performance equations than with those for the inner wheelpath since the serviceability loss in the inner wheelpath was generally less than for the outer wheelpath. As a result the serviceability trends of inner wheelpaths for many sections had not been well established at the time the section was removed from test.

Figure 29 shows plots of *W* against *D* for each axle load of the Road Test. Each graph includes a plot from the outer wheelpath equation, one from the inner wheelpath equation, and one from the over-all section equation (see Section 2.2.2.1). The over-all section equation gives very nearly the same relationship as does the analysis of outer wheelpath alone. This indicates that since most distress in flexible pavement occurs first in the outer wheelpath, pavement structure designs based on the requirements for the outer wheelpath alone may be nearly the same as the structure design needed for an entire pavement.

These plots show that the requirements for pavement structure in terms of thickness index necessary to maintain a serviceability of 2.5 after one million applications of axle load averaged considerably greater for the outer wheelpath than for the inner wheelpath. This thickness index differential could be made up of asphaltic concrete, crushed stone base, or subbase, or by any combination of the three materials. This is of interest because it indicates that for a given quantity of material in the pavement structure, the expected life of the pavement would be greater if the inner wheelpath were constructed thinner than the outer wheelpath than it would be if both wheelpaths had identical structural thicknesses. Or, a structural design for a specified life would require less material if the outer wheelpath were thicker and the inner wheelpath thinner than it would be if a conventional uniform thickness design were used. These comments relate to quantities of materials only; the cost of building unconventional sections may outweigh the savings in materials.

*2.2.2.3 Special Base Type Experiments.*—An important investigation within the flexible pavement experiment involved the study of the relative effectiveness of certain treated and untreated bases. Four base types were studied: crushed stone, gravel, cement-treated and bituminous-treated gravel. There were 48 test sections in this study.

The base experiment was designed so that no mathematical analysis of the performance of the sections was attempted. The analysis was essentially graphical. However, it is anticipated that the Highway Research Board and others will later incorporate the special base data into the data from the main factorial experiment in an effort to produce performance equations containing terms for the special base materials.

The results of the analysis are presented in graphs (See Figs. 35 and 36), which permit comparison of the performance of the stone, cement-treated and bituminous-treated bases; that is, comparison of the thickness of the materials that was necessary to maintain a level of serviceability of 2.5 at a specified number of load applications. For example, for the 18-kip single axle load at 1,000,000 applications, the required thickness of base (where the surfacing thickness was 3 in. and the subbase 4 in.) is shown to be approximately 13, 8 and 6 in. of stone, cement-treated and bituminous-treated base, respectively. These values suggest that there was considerable difference in the performance of the treated bases and the crushed stone bases. In fact, in all loops and at all levels of serviceability the performance of the treated gravel bases was definitely superior to that of the untreated crushed stone.

Most of the sections containing the untreated gravel base failed early in the test (Figs. 30 and 31); their performance was definitely inferior to that of the sections with crushed stone base.

The performance of four different types of base course was studied in Design 4: crushed stone, gravel, cement-treated and bituminous-

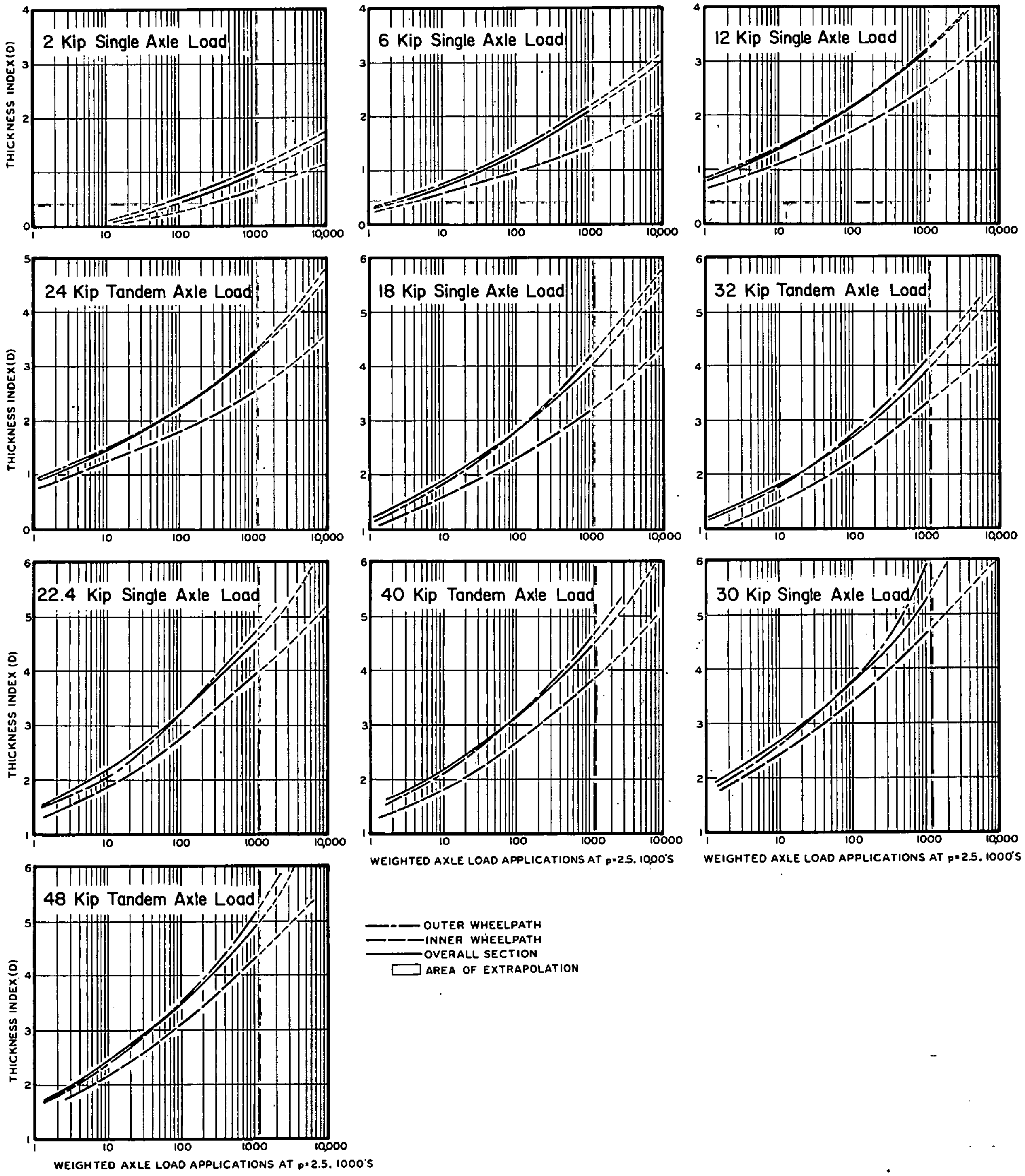


**Figure 29.** Main factorial experiment, relationship between design and axle load applications at $p = 2.5$.

treated material. The crushed stone base was the same as that used in the factorial sections; the gravel base consisted of a well-graded uncrushed material; the cement-treated base consisted of the sand-gravel subbase material combined in a paving mixer with 4.0 percent by weight of Type I portland cement; and the bituminous-treated base was a hot mix consisting of the subbase material and 5.2 percent of 85–100 penetration grade paving asphalt (see Table 4). Three of the four types were included in six structural sections in each flexible tangent of the four major loops (two replicate sections for each base type). The sections were 160 ft long, and the base was constructed as a wedge, that is, the thickness of the base material decreased at a uniform rate from one end of the section to the other in the direction of traffic.

As in the case of the paved shoulder experiment, the 160-ft wedge sections were divided into 40-ft subsections, and each subsection was considered in the major analysis of performance to be represented by its mean thickness of base. Table 12 gives the pavement designs, base types and average base thickness of the subsections included in each of the four major loops. The main objectives of the study were to relate thickness of the four types of base course material to pavement performance and pavement capability (see Section 2.3.2) for various levels of single and tandem axle loading and number of applications.

Basic information on performance of each subsection is given in Table 13 and Appendix A. The values listed for each subsection are either the number of unweighted axle load applications to a serviceability of 1.5 or the final serviceability if the subsection was still in test at the termination of traffic. Similar information for a serviceability level of 2.5 is given in Table 14, and average values for pairs of replicate sections are shown in Figures 30 and 31. The effect of the thickness of the base on performance can be clearly seen except in the case of the gravel base sections in Loop 5.

The gravel base wedge sections failed early in the test and are omitted from the analysis of performance. The data in Tables 13 and 14 show that on Loops 3 and 4 there was a fairly orderly effect of thickness of the gravel material. However, on Loop 5, the serviceability of all gravel subsections dropped to 1.5 at practically the same number of axle load applications (less than 100,000), indicating that increasing the base thickness within the range

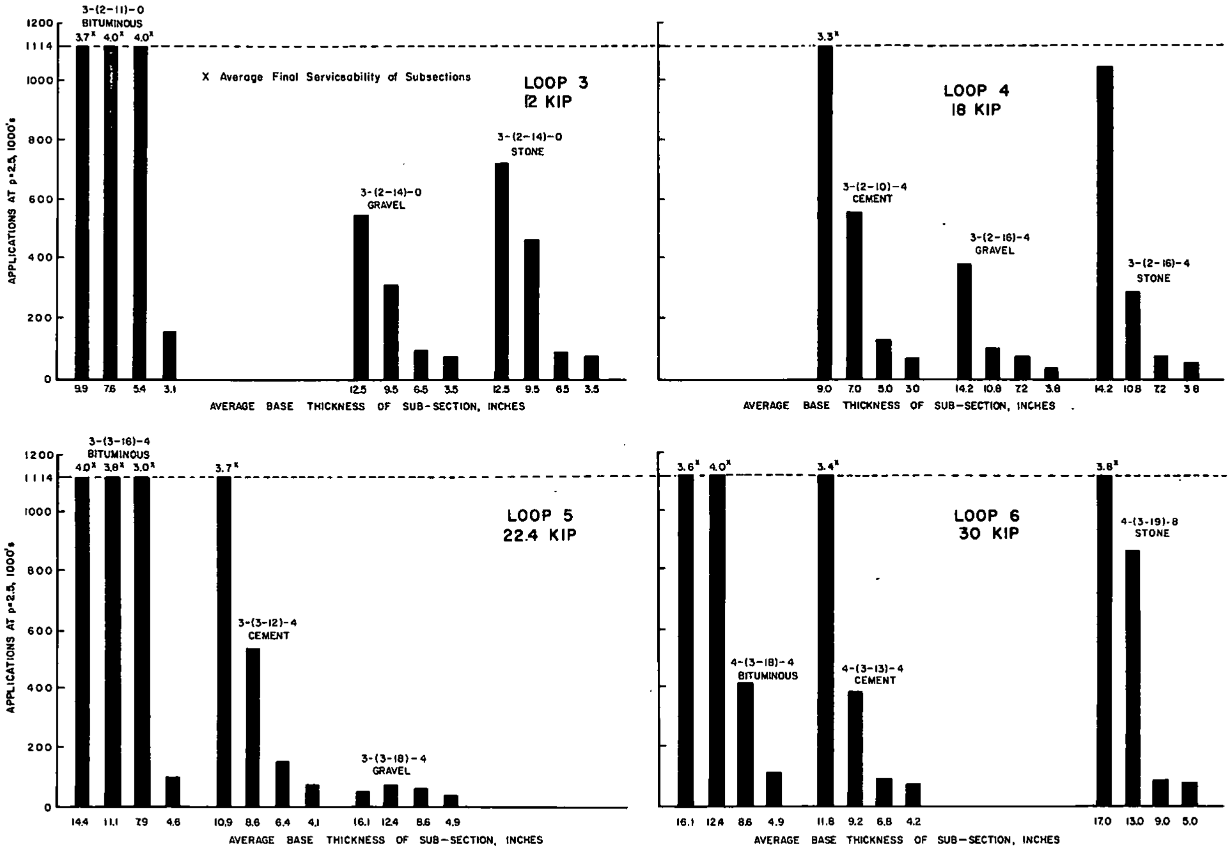


**Figure 30. Special base type experiment, performance data for single axle loads (averages for each pair of replicate sections).**

## TABLE 12

### DESIGN OF SPECIAL-BASE TYPE WEDGE SECTIONS

| Loop | Base Type | Thickness (in.) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Surfacing | Subbase | Base | | | | |
| | | | | Range | Average for Subsection | | | |
| | | | | | 1 | 2 | 3 | 4 |
| 3 | Bituminous | 3 | 0 | 2–11 | 9.9 | 7.6 | 5.4 | 3.1 |
| | Stone | 3 | 0 | 2–14 | 12.5 | 9.5 | 6.5 | 3.5 |
| | Gravel | 3 | 0 | 2–14 | 12.5 | 9.5 | 6.5 | 3.5 |
| 4 | Cement | 3 | 4 | 2–10 | 9.0 | 7.0 | 5.0 | 3.0 |
| | Stone | 3 | 4 | 2–16 | 14.3 | 10.8 | 7.3 | 3.8 |
| | Gravel | 3 | 4 | 2–16 | 14.3 | 10.8 | 7.3 | 3.8 |
| 5 | Bituminous | 3 | 4 | 3–16 | 14.4 | 11.1 | 7.9 | 4.6 |
| | Cement | 3 | 4 | 3–12 | 10.9 | 8.6 | 6.4 | 4.1 |
| | Gravel | 3 | 4 | 3–18 | 16.1 | 12.4 | 8.6 | 4.9 |
| 6 | Bituminous | 4 | 4 | 3–18 | 16.1 | 12.4 | 8.6 | 4.9 |
| | Cement | 4 | 4 | 3–13 | 11.8 | 9.3 | 6.8 | 4.3 |
| | Stone | 4 | 8 | 3–19 | 17.0 | 13.0 | 9.0 | 5.0 |

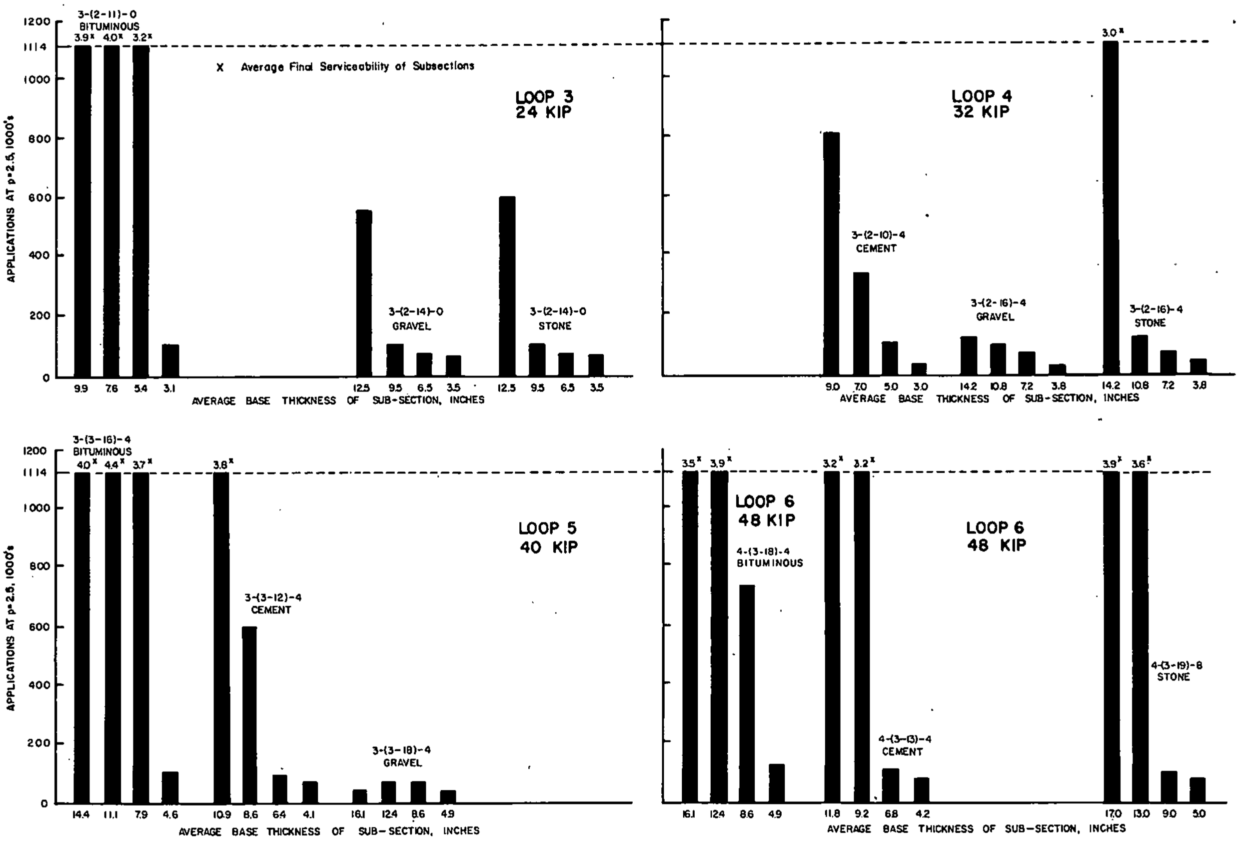


**Figure 31.** Special base type experiment, performance data for tandem axle loads (averages for each pair of replicate sections).

## TABLE 13

### PERFORMANCE DATA TO $p$ = 1.5, BASE TYPE STUDY

| Loop | Pavement Design and Base Type | Subsection Base Thickness (in.) | | Applications ($\times 10^3$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Lane 1 | | | Lane 2 | | |
| | | Range | Avg. | Rep. 1 | Rep. 2 | Avg. | Rep. 1 | Rep. 2 | Avg. |
| 3 | 3–(2–11)–0 Bituminous | 8.8–11.0 | 9.9 | 3.7 | 3.7 | 3.7 | 3.9 | 3.9 | 3.9 |
| | | 6.5– 8.8 | 7.6 | 3.9 | 4.2 | 4.0 | 4.0 | 4.0 | 4.0 |
| | | 4.2– 6.5 | 5.4 | 4.1 | 3.9 | 4.0 | 3.8 | 2.7 | 3.3 |
| | | 2.0– 4.2 | 3.1 | 1.7 | 309 | | 765 | 142 | 454 |
| | 3–(2–14)–0 Gravel | 11.0–14.0 | 12.5 | 578 | 557 | 568 | 573 | 552 | 562 |
| | | 8.0–11.0 | 9.5 | 554 | 110 | 332 | 124 | 108 | 116 |
| | | 5.0– 8.0 | 6.5 | 126 | 78 | 102 | 81 | 79 | 80 |
| | | 2.0– 5.0 | 3.5 | 78 | 73 | 76 | 69 | 69 | 69 |
| | 3–(2–14)–0 Stone | 11.0–14.0 | 12.5 | 2.4 | 1.9 | 2.2 | 687 | 735 | 711 |
| | | 8.0–11.0 | 9.5 | 615 | 559 | 587 | 147 | 124 | 136 |
| | | 5.0– 8.0 | 6.5 | 101 | 85 | 93 | 97 | 85 | 91 |
| | | 2.0– 5.0 | 3.5 | 86 | 70 | 78 | 76 | 71 | 74 |
| 4 | 3–(2–10)–4 Cement | 8.0–10.0 | 9.0 | 3.9 | 2.7 | 3.3 | 4.2 | 2.5 | 3.4 |
| | | 6.0– 8.0 | 7.0 | 774 | 557 | 666 | 580 | 348 | 464 |
| | | 4.0– 6.0 | 5.0 | 274 | 98 | 186 | 147 | 119 | 133 |
| | | 2.0– 4.0 | 3.0 | 84 | 78 | 81 | 77 | 79 | 78 |
| | 3–(2–16)–4 Gravel | 12.5–16.0 | 14.2 | 500 | 450[1] | 475 | 160 | 148[1] | 154 |
| | | 9.0–12.5 | 10.8 | 118 | 105 | 112 | 116 | 103 | 110 |
| | | 5.5– 9.0 | 7.2 | 85 | 87 | 86 | 87 | 85 | 86 |
| | | 2.0– 5.5 | 3.8 | 6 | 70 | 38 | 58 | 68 | 63 |
| | 3–(2–16)–4 Stone | 12.5–16.0 | 14.2 | 2.5 | 3.9 | 3.2 | 2.9 | 3.0 | 3.0 |
| | | 9.0–12.5 | 10.8 | 519 | 551 | 535 | 420 | 338 | 379 |
| | | 5.5– 9.0 | 7.2 | 81 | 86 | 84 | 80 | 80 | 80 |
| | | 2.0– 5.5 | 3.8 | 77 | 70 | 74 | 77 | 66 | 72 |
| 5 | 3–(3–18)–4 Gravel | 14.2–18.0 | 16.1 | 66 | 84 | 75 | 59 | 80[1] | 70 |
| | | 10.5–14.2 | 12.4 | 70 | 85 | 78 | 71 | 74 | 72 |
| | | 6.8–10.5 | 8.6 | 68 | 74 | 71 | 71 | 79 | 75 |
| | | 3.0– 6.8 | 4.9 | 63 | 67 | 65 | 6 | 73 | 40 |
| | 3–(3–16)–4 Bituminous | 12.8–16.0 | 14.4 | 3.9 | 4.2 | 4.0 | 4.2 | 3.8 | 4.0 |
| | | 9.5–12.8 | 11.1 | 4.4 | 3.3 | 3.8 | 4.4 | 4.3 | 4.4 |
| | | 6.2– 9.5 | 7.9 | 3.4 | 2.7 | 3.0 | 3.9 | 3.5 | 3.7 |
| | | 3.0– 6.2 | 4.6 | 120 | 122 | 121 | 104 | 134 | 119 |
| | 3–(3–12)–4 Cement | 9.8–12.0 | 10.9 | 3.7 | 3.7 | 3.7 | 4.0 | 3.6 | 3.8 |
| | | 7.5– 9.8 | 8.6 | 563 | 604 | 584 | 707 | 580 | 644 |
| | | 5.2– 7.5 | 6.4 | 89 | 274 | 182 | 110 | 144 | 127 |
| | | 3.0– 5.2 | 4.1 | 70 | 80 | 75 | 71 | 78 | 74 |
| 6 | 4–(3–19)–8 Stone | 15.0–19.0 | 17.0 | 3.4 | 4.1 | 3.8 | 4.0 | 3.7 | 3.9 |
| | | 11.0–15.0 | 13.0 | 2.7 | 1.9 | 2.3 | 3.8 | 3.5 | 3.6 |
| | | 7.0–11.0 | 9.0 | 84 | 117 | 100 | 453 | 583 | 518 |
| | | 3.0– 7.0 | 5.0 | 80 | 78 | 79 | 87 | 81 | 84 |
| | 4–(3–13)–4 Cement | 10.5–13.0 | 11.8 | 3.4 | 3.3 | 3.4 | 3.2 | 3.2 | 3.2 |
| | | 8.0–10.5 | 9.2 | 418 | 1095 | 756 | 2.1 | 2.4 | 2.2 |
| | | 5.5– 8.0 | 6.8 | 92 | 130 | 111 | 124 | 156 | 140 |
| | | 3.0– 5.5 | 4.2 | 71 | 80 | 76 | 77 | 90 | 84 |
| | 4–(3–18)–4 Bituminous | 14.2–18.0 | 16.1 | 3.9 | 3.4 | 3.6 | 3.5 | 3.5 | 3.5 |
| | | 10.5–14.2 | 12.4 | 4.1 | 4.0 | 4.0 | 3.7 | 4.1 | 3.9 |
| | | 6.8–10.5 | 8.6 | 741 | 852 | 796 | 1.9 | 3.0 | 2.4 |
| | | 3.0– 6.8 | 4.9 | 107 | 144 | 126 | 108 | 179 | 144 |

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[1] Estimated applications.

## TABLE 14

### PERFORMANCE DATA TO $p = 2.5$, BASE TYPE STUDY

| Loop | Pavement Design and Base Type | Subsection Base Thickness (in.) | | Applications (× 10³) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Lane 1 | | | Lane 2 | | |
| | | Range | Avg. | Rep. 1 | Rep. 2 | Avg. | Rep. 1 | Rep. 2 | Avg. |
| 3 | 3–(2–11)–0 | 8.8–11.0 | 9.9 | 3.7 | 3.7 | 3.7 | 3.9 | 3.9 | 3.9 |
| | Bituminous | 6.5– 8.8 | 7.6 | 3.9 | 4.2 | 4.0 | 4.0 | 4.0 | 4.0 |
| | | 4.2– 6.5 | 5.4 | 4.1 | 3.9 | 4.0 | 3.8 | 2.7 | 3.2 |
| | | 2.0– 4.2 | 3.1 | 130 | 178 | 154 | 114 | 100 | 107 |
| | 3–(2–14)–0 | 11.0–14.0 | 12.5 | 573 | 519 | 546 | 576 | 540 | 558 |
| | Gravel | 8.0–11.0 | 9.5 | 523 | 102 | 312 | 108 | 101 | 104 |
| | | 5.0– 8.0 | 6.5 | 106 | 76 | 91 | 77 | 77 | 77 |
| | | 2.0– 5.0 | 3.5 | 77 | 72 | 74 | 71 | 70 | 70 |
| | 3–(2–14)–0 | 11.0–14.0 | 12.5 | 762 | 668 | 715 | 586 | 624 | 605 |
| | Stone | 8.0–11.0 | 9.5 | 445 | 483 | 464 | 110 | 98 | 104 |
| | | 5.0– 8.0 | 6.5 | 90 | 78 | 84 | 79 | 77 | 78 |
| | | 2.0– 5.0 | 3.5 | 82 | 70 | 76 | 76 | 71 | 74 |
| 4 | 3–(2–10)–4 | 8.0–10.0 | 9.0 | 3.9 | 2.7 | 3.3 | 4.2 | 816 | 816[1] |
| | Cement | 6.0– 8.0 | 7.0 | 618 | 493 | 556 | 526 | 163 | 344 |
| | | 4.0– 6.0 | 5.0 | 162 | 95 | 128 | 111 | 104 | 108 |
| | | 2.0– 4.0 | 3.0 | 65 | 71 | 68 | 4 | 77 | 40 |
| | 3–(2–16)–4 | 12.5–16.0 | 14.2 | 401 | 383 | 392 | 128 | 125 | 126 |
| | Gravel | 9.0–12.5 | 10.8 | 111 | 94 | 102 | 108 | 101 | 104 |
| | | 5.5– 9.0 | 7.2 | 81 | 80 | 80 | 79 | 77 | 78 |
| | | 2.0– 5.5 | 3.8 | 5 | 61 | 33 | 8 | 60 | 34 |
| | 3–(2–16)–4 | 12.5–16.0 | 14.2 | 1056 | 3.9 | 1085[1] | 2.9 | 3.0 | 3.0 |
| | Stone | 9.0–12.5 | 10.8 | 107 | 483 | 295 | 116 | 134 | 125 |
| | | 5.5– 9.0 | 7.2 | 80 | 78 | 79 | 79 | 75 | 77 |
| | | 2.0– 5.5 | 3.8 | 76 | 41 | 58 | 76 | 10 | 43 |
| 5 | 3–(3–18)–4 | 14.2–18.0 | 16.1 | 24 | 80 | 52 | 24 | 70 | 47 |
| | Gravel | 10.5–14.2 | 12.4 | 66 | 80 | 73 | 70 | 71 | 70 |
| | | 6.8–10.5 | 8.6 | 60 | 72 | 66 | 70 | 77 | 70 |
| | | 3.0– 6.8 | 4.9 | 20 | 63 | 42 | 6 | 72 | 73 |
| | 3–(3–16)–4 | 12.8–16.0 | 14.4 | 3.9 | 4.2 | 4.0 | 4.2 | 3.8 | 4.0 |
| | Bituminous | 9.5–12.8 | 11.1 | 4.4 | 3.3 | 3.8 | 4.4 | 4.3 | 4.4 |
| | | 6.2– 9.5 | 7.9 | 3.4 | 2.7 | 3.0 | 3.9 | 3.5 | 3.7 |
| | | 3.0– 6.2 | 4.6 | 85 | 114 | 100 | 91 | 112 | 102 |
| | 3–(3–12)–4 | 9.8–12.0 | 10.9 | 3.7 | 3.7 | 3.7 | 4.0 | 3.6 | 3.8 |
| | Cement | 7.5– 9.8 | 8.6 | 523 | 546 | 534 | 614 | 570 | 592 |
| | | 5.2– 7.5 | 6.4 | 87 | 208 | 148 | 102 | 90 | 96 |
| | | 3.0– 5.2 | 4.1 | 60 | 80 | 70 | 64 | 77 | 70 |
| 6 | 4–(3–19)–8 | 15.0–19.0 | 17.0 | 3.4 | 4.1 | 3.8 | 4.0 | 3.8 | 3.9 |
| | Stone | 11.0–15.0 | 13.0 | 2.7 | 631 | 872[1] | 3.8 | 3.5 | 3.6 |
| | | 7.0–11.0 | 9.0 | 80 | 88 | 84 | 114 | 94 | 104 |
| | | 3.0– 7.0 | 5.0 | 77 | 77 | 77 | 78 | 79 | 78 |
| | 4–(3–13)–4 | 10.5–13.0 | 11.8 | 3.4 | 3.3 | 3.4 | 3.2 | 3.2 | 3.2 |
| | Cement | 8.0–10.5 | 9.2 | 265 | 503 | 384 | 2.1 | 2.4 | 2.2 |
| | | 5.5– 8.0 | 6.8 | 82 | 111 | 96 | 105 | 127 | 116 |
| | | 3.0– 5.5 | 4.2 | 70 | 77 | 74 | 77 | 87 | 82 |
| | 4–(3–18)–4 | 14.2–18.0 | 16.1 | 3.9 | 3.4 | 3.6 | 3.5 | 3.5 | 3.5 |
| | Bituminous | 10.5–14.2 | 12.4 | 4.1 | 4.0 | 4.0 | 3.7 | 4.1 | 3.9 |
| | | 6.8–10.5 | 8.6 | 240 | 589 | 414 | 348 | 3.0 | 731[1] |
| | | 3.0– 6.8 | 4.9 | 102 | 116 | 109 | 90 | 160 | 125 |

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[1] Average assumes 1,114 thousand applications for the replicate that did not fall to $p = 2.5$ by end of test.

provided in Loop 5 did not improve its performance. It appears that the gravel material possessed internal stability that was adequate for the loads operating on Loop 3 and nearly so for Loop 4 but certainly not for the loads on Loop 5.

In a graphical analysis of performance of the stone, cement and bituminous base wedge sections, the relationships between changes in serviceability and changes in thickness of the base material were first developed for each pair of replicate sections at several levels of axle load applications (Figs. 32, 33 and 34). The plotted points represent mean serviceability vs mean base thickness for each pair of replicate subsections. The family of curves was formed by connecting the plotted points for each of the six selected levels of axle load applications.

Considerable judgment had to be exercised in developing these performance relationships. In many cases, especially at the lower levels of axle load applications, the relationships were well established by the plotted points. In other cases, it was necessary to examine the field condition survey records in order to establish the trends of the curves.

For example, in lane 1 of Loop 4 two subsections having a 3-in. mean thickness of cement-treated base were removed from the test at fewer than 100,000 applications. Thus, no points could be plotted for this thickness at 100,000 applications. The two subsections with 5-in. mean base thickness had a mean serviceability at 100,000 applications of 1.65, but were removed from test before 300,000 applications. The condition survey records showed that prior to 300,000 applications the surface of these subsections had been maintained back into the subsections to a point where the base thickness was 5.6 in. Therefore, the trend of the serviceability-base thickness relationship at 300,000 axle load applications was established by extending the curve through a point plotted at $p = 1.5$ and 5.6 in. of base thickness. The end points for the relationships at 700,000 and 1,114,000 applications were obtained in the same manner. The curves at 500,000 and 900,000 applications were drawn to fit the other relationships.

From curves constructed in this manner it was possible to estimate values of base course thickness for various levels of axle load applications at any desired serviceability level. Table 15 gives these values for 100, 300, 500, 700, 900 and 1,114 thousand axle load applications at a serviceability level of 2.5. The actual thicknesses listed are not directly comparable across loops, or within Loop 6, since the thickness of surfacing and subbase was not the same for all sections included in the study. Therefore, the base thicknesses for Loops 3 and 6 have been adjusted to correspond with the thicknesses of surfacing and subbase used in Loops 4 and 5. In making the assumptions necessary to specify the following relationships consideration was given to the strength characteristics of the various materials. For example, the Marshall stability of the bituminous-treated base was nearly as high as that for the surface and binder courses (1600 vs 2000 and 1800) and the compressive strength at seven days for the cement-treated base was 840 psi.

The adjustments were made on the following basis:

From Eq. 19: 1-in. bituminous surface = 3-in. stone base, approximately; 1-in. bituminous surface = 4-in. subbase, approximately; and 3-in. stone base = 4-in. subbase, approximately. It is assumed that 1-in. bituminous surface = 1-in. bituminous base; and 1-in. bituminous base = 4-in. subbase. From average ratios of thickness of bituminous base and cement base given in Table 15 for Loops 5 and 6: 1-in. bituminous base = 1.30-in. cement base; 1-in. bituminous surface = 1.30-in. cement base.

The relationships shown in Figure 35 were developed from Table 15 (adjusted thicknesses for Loops 3 and 6). Because there was no consistent indication of curvilinearity, straight lines were fitted to the plotted points. These relationships compare the three types of base with respect to their ability to give the same level of performance under a range of single and tandem axle loads and at six levels of axle load applications. The thicknesses of base are those needed when the surfacing thickness is 3 in. and the subbase thickness is 4 in.

Figure 36 shows a similar comparison of the three types of base under a range of axle load applications for each single and tandem axle load included in the test. The values used to plot the curves were taken directly from the relationships in Figure 35. Extrapolation or interpolation were used when necessary. For example, a curve is shown for each of four loads in Figure 35 even though only three loads were actually applied to a particular base type.

Additional information on the performance of the special base type sections is given in Tables 16 and 17. The thicknesses of base represent the amount necessary to prevent Class 2 cracking of the surfacing at two levels of axle load applications. The values are applicable for the basic designs of the sections (Table 12).

Because no preconceived mathematical form was used in the graphical analysis of the base study data, the curves shown in Figures 32 through 36 do not necessarily follow the shapes that would be given were the models of Section 2.2.2.1 fitted to the performance data of Tables 13 and 14. It is interesting, however, to superimpose the crushed stone base data from Table 14 upon the data and curves obtained from the performance analysis of the factorial sections (Design 1), all of which had crushed stone base.

Figure 37 shows this superposition, and it may be inferred that the crushed stone base data from Design 4 generally agree with the corresponding data from Design 1. For the subsections having the thickest base, however, it would appear that the curves from the performance equation may tend to overestimate the thickness index requirements when the thickness index involves a considerably greater proportion of base thickness than was present in the factorial experiment designs. Thus if the factorial performance data are augmented by data from the crushed stone base study of this section, it is likely that certain coefficients in the performance equations will be modified. However, in Figure 37 it was not possible to show data points for those subsections whose serviceability had not dropped to 2.5 by the end of the test. Many of these points would fall to the right of the curves and tend to reduce the apparent bias. A systematic procedure for fitting the augmented data to the models of Section 2.2.2.1 was under study when this report was written. It was expected that application of this procedure would result in a somewhat modified performance equation that would fit both the factorial and wedge section data for crushed stone base, and would provide for the differential effects on performance of the three base types that were discussed in the graphical analysis of this section.

### *2.2.3 Structural Deterioration*

In Section 2.2.2 performance was considered to be the trend of pavement serviceability with applications of load. The three principal elements that detract from serviceability of the flexible pavements were slope variance (a measure of longitudinal roughness), rut depth, and cracking and patching.

TABLE 15

SPECIAL BASE TYPE STUDY,
THICKNESS OF BASES CORRESPONDING TO A SERVICEABILITY LEVEL OF 2.5

| Applications | Base Type | Lane | Thickness (in.) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Actual | | | | Adjusted[1] | |
| | | | Loop 3 | Loop 4 | Loop 5 | Loop 6 | Loop 3 | Loop 6 |
| 100,000 | Stone | 1 | 7.6 | 10.1 | .... | 10.6 | 4.6 | 16.6 |
| | | 2 | 9.5 | 10.3 | .... | 8.8 | 6.5 | 14.8 |
| | Cement | 1 | .... | 5.6 | 6.8 | 7.4 | .... | 8.7 |
| | | 2 | .... | 4.7 | 6.4 | 6.2 | .... | 7.5 |
| | Bituminous | 1 | 2.6 | .... | 4.7 | 4.7 | 1.6 | 5.7 |
| | | 2 | 3.0 | .... | 4.7 | 4.3 | 2.0 | 5.3 |
| 300,000 | Stone | 1 | 8.9 | 10.6 | .... | 11.1 | 5.9 | 17.1 |
| | | 2 | 10.9 | 11.4 | .... | 9.4 | 7.9 | 15.4 |
| | Cement | 1 | .... | 6.1 | 7.4 | 8.9 | .... | 10.2 |
| | | 2 | .... | 6.3 | 7.3 | 8.1 | .... | 9.8 |
| | Bituminous | 1 | 3.2 | .... | 5.5 | 7.8 | 2.2 | 8.8 |
| | | 2 | 3.8 | .... | 5.2 | 5.6 | 2.8 | 6.6 |
| 500,000 | Stone | 1 | 9.9 | 11.8 | .... | 11.7 | 6.9 | 17.7 |
| | | 2 | 11.8 | 12.0 | .... | 10.1 | 8.8 | 16.1 |
| | Cement | 1 | .... | 6.9 | 8.2 | 10.2 | .... | 11.5 |
| | | 2 | .... | 7.5 | 8.0 | 8.8 | .... | 10.1 |
| | Bituminous | 1 | 3.7 | .... | 6.0 | 8.8 | 2.7 | 9.8 |
| | | 2 | 4.0 | .... | 5.6 | 6.6 | 3.0 | 7.6 |
| 700,000 | Stone | 1 | 11.6 | 12.8 | .... | 12.5 | 8.6 | 18.5 |
| | | 2 | 13.4 | 12.6 | .... | 10.7 | 10.4 | 16.7 |
| | Cement | 1 | .... | 7.9 | 8.7 | 10.6 | .... | 11.9 |
| | | 2 | .... | 8.1 | 8.6 | 9.2 | .... | 10.5 |
| | Bituminous | 1 | 3.7 | .... | 6.4 | 9.2 | 2.7 | 10.2 |
| | | 2 | 4.3 | .... | 6.0 | 7.9 | 3.3 | 8.9 |
| 900,000 | Stone | 1 | 12.7 | 13.1 | .... | 13.1 | 9.7 | 19.1 |
| | | 2 | 14.1 | 13.1 | .... | 11.1 | 11.1 | 17.1 |
| | Cement | 1 | .... | 8.3 | 9.1 | 10.9 | .... | 12.2 |
| | | 2 | .... | 8.3 | 9.3 | 9.7 | .... | 11.0 |
| | Bituminous | 1 | 3.8 | .... | 6.9 | 9.5 | 2.8 | 10.5 |
| | | 2 | 4.5 | .... | 6.3 | 8.5 | 3.5 | 9.5 |
| 1,114,000 | Stone | 1 | 13.2 | 13.4 | .... | 13.6 | 10.2 | 19.6 |
| | | 2 | 14.4 | 13.7 | .... | 11.5 | 11.4 | 17.5 |
| | Cement | 1 | .... | 8.6 | 9.6 | 11.1 | .... | 12.4 |
| | | 2 | .... | 8.6 | 9.7 | 10.2 | .... | 11.5 |
| | Bituminous | 1 | 3.9 | .... | 7.3 | 9.8 | 2.9 | 10.8 |
| | | 2 | 4.6 | .... | 6.8 | 8.9 | 3.6 | 9.9 |

[1] Adjusted to correspond with thicknesses of surfacing and subbase used in Loops 4 and 5.

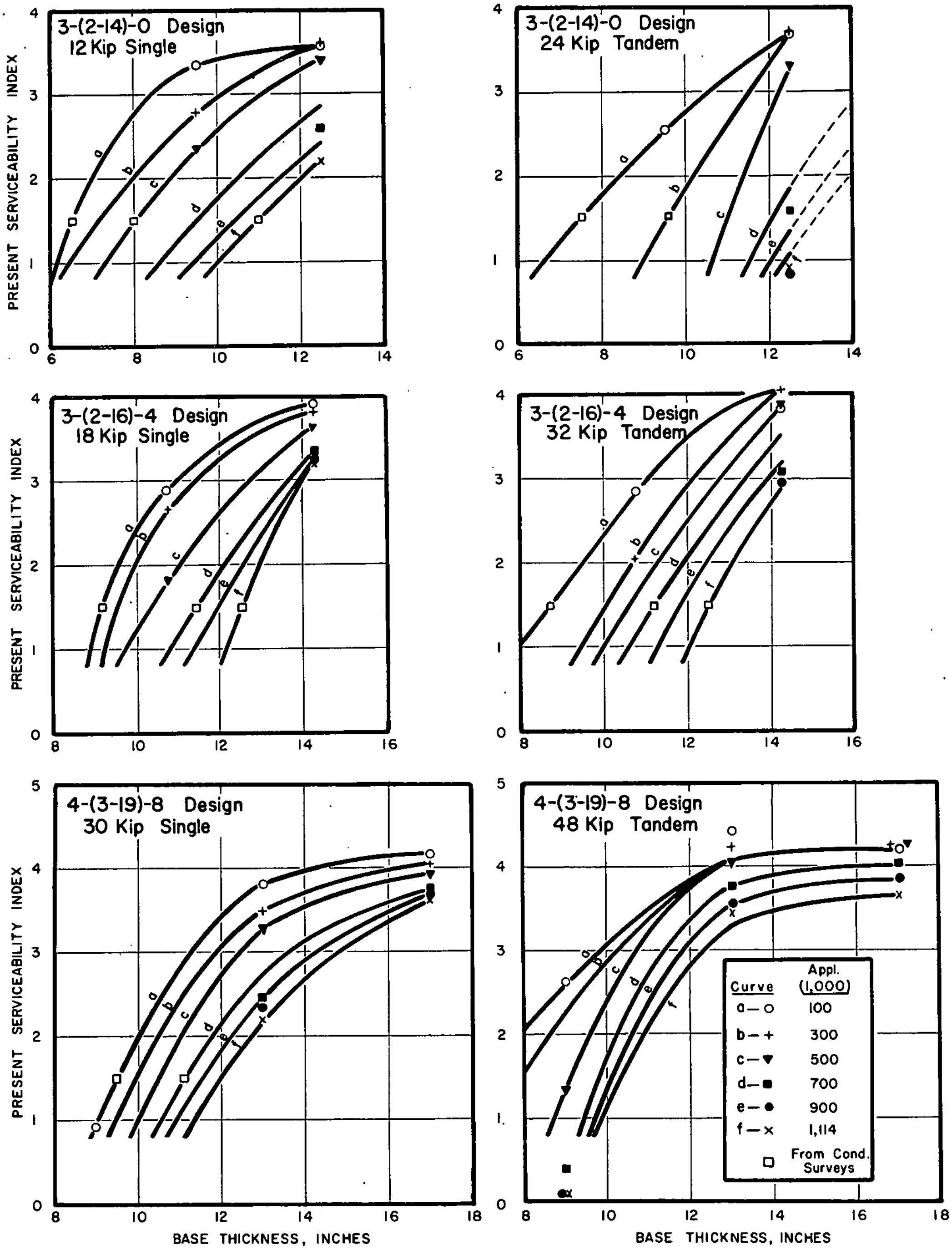

Figure 32. Special base type experiment, crushed stone base performance data (averages of two replicate sections).

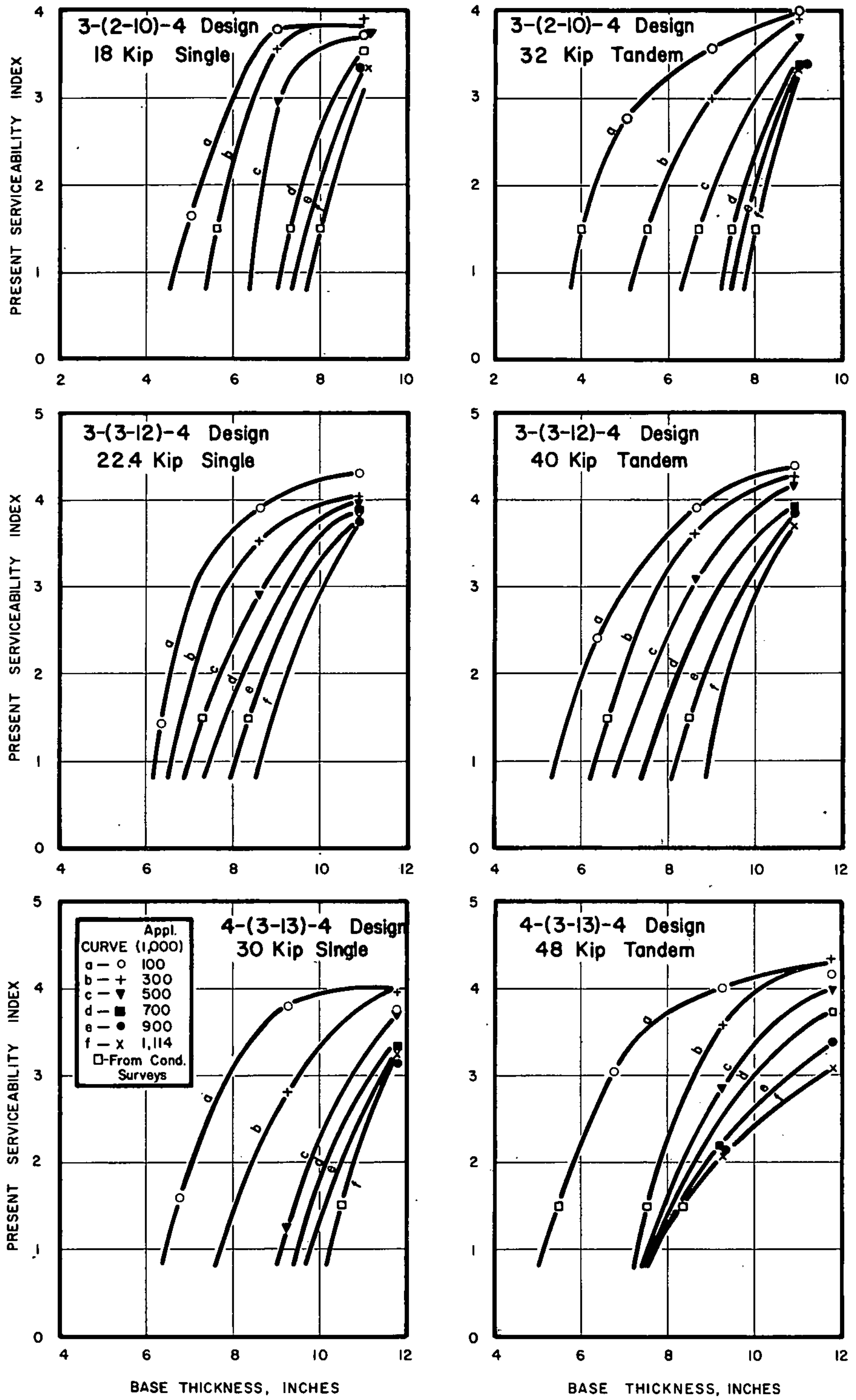

Figure 33. Special base type experiment, cement-treated base performance data (averages of two replicate sections).

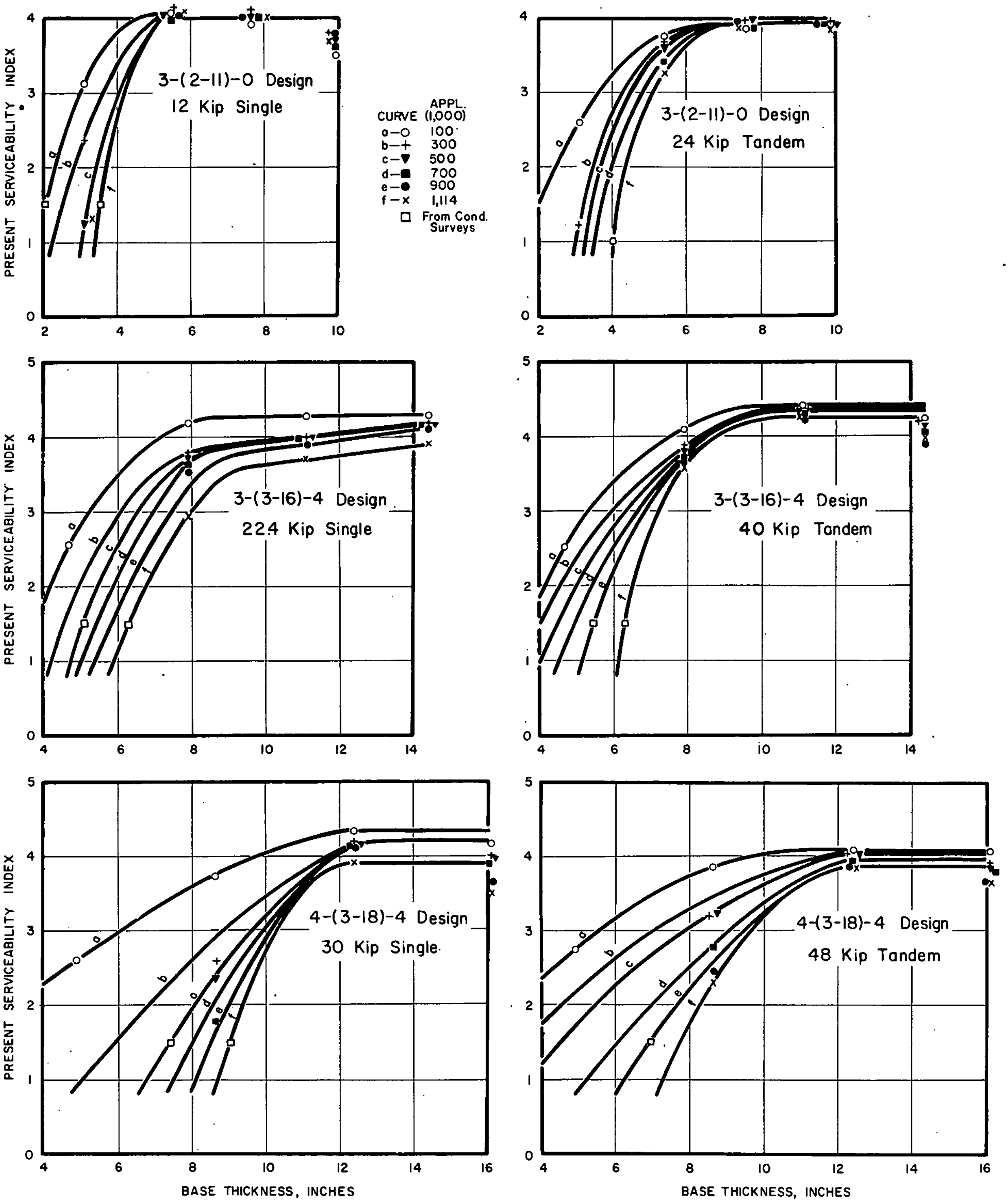

Figure 34. Special base type experiment, bituminous-treated base performance (averages of two replicate sections).

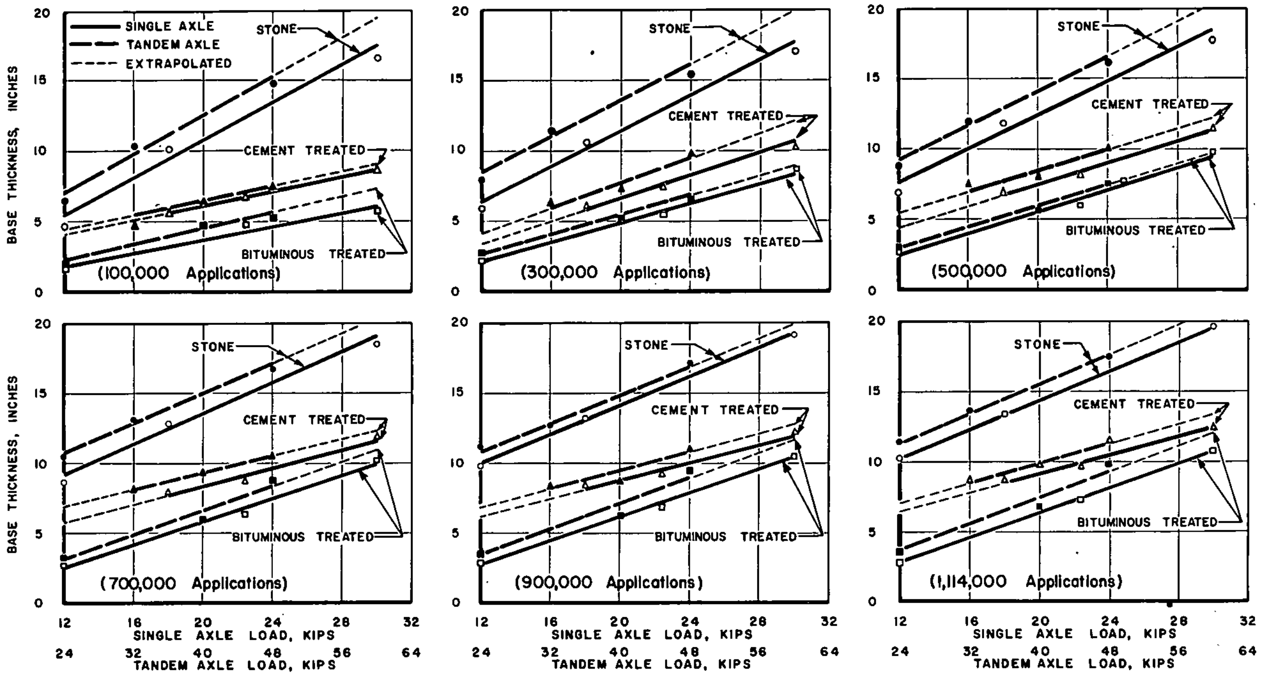

**Figure 35. Special base type experiment, relationship between base thickness and axle load at $p$ = 2.5 (surfacing, 3 in.; subbase, 4 in.).**

### TABLE 16

### Special Base Section Performance Data, Base Thickness Not Associated with Class 2 Surface Cracking, February 20, 1960, 500,000 Axle Applications

| Type of Base | Lane | Base Thickness[1] (in.) | | | |
|---|---|---|---|---|---|
| | | Loop 3 | Loop 4 | Loop 5 | Loop 6 |
| Gravel | 1 | 9.3 | OT | OT | — |
| | | 9.5 | OT | OT | — |
| | 2 | 10.4 | OT | OT | — |
| | | 11.3 | OT | OT | — |
| Stone | 1 | 7.7 | 9.2 | — | 11.0 |
| | | 7.7 | 9.2 | — | 11.0 |
| | 2 | 9.4 | 9.1 | — | 7.6 |
| | | 10.4 | 9.2 | — | 7.6 |
| Cement | 1 | — | 6.2 | 6.9 | 9.1 |
| | | — | 6.3 | 7.0 | 9.1 |
| | 2 | — | 6.2 | 6.9 | 7.7 |
| | | — | 6.4 | 6.9 | 7.7 |
| Bituminous | 1 | 2.4 | — | 5.3 | 6.7 |
| | | 2.6 | — | 5.3 | 6.7 |
| | 2 | 3.1 | — | 5.3 | 5.7 |
| | | 3.1 | — | 5.3 | 5.7 |

[1] OT = out of test. Thickness is average of two subsections; for thickness of surfacing and subbase see Table 12.

### TABLE 17

### Special Base Section Performance Data, Base Thickness Not Associated with Class 2 Surface Cracking, November 30, 1960, 1,114,300 Axle Applications

| Type of Base | Lane | Base Thickness[1] (in.) | | | |
|---|---|---|---|---|---|
| | | Loop 3 | Loop 4 | Loop 5 | Loop 6 |
| Gravel | 1 | OT | OT | OT | — |
| | | OT | OT | OT | — |
| | 2 | OT | OT | OT | — |
| | | OT | OT | OT | — |
| Stone | 1 | 11.4 | 11.0 | — | 11.0 |
| | | 13.0 | 13.2 | — | 11.2 |
| | 2 | 13.4 | 11.6 | — | 8.0 |
| | | 13.5 | 12.6 | — | 9.2 |
| Cement | 1 | — | 7.8 | 8.0 | 9.5 |
| | | — | 7.5 | 8.8 | 10.2 |
| | 2 | — | 7.5 | 8.2 | 8.0 |
| | | — | 7.5 | 8.2 | 8.1 |
| Bituminous | 1 | 2.6 | — | 5.3 | 7.6 |
| | | 2.8 | — | 6.0 | 8.0 |
| | 2 | 3.2 | — | 5.6 | 6.8 |
| | | 3.8 | — | 5.6 | 6.8 |

[1] OT = out of test. Thickness is average of two subsections; for thickness of surfacing and subbase see Table 12.

*2.2.3.1 Transverse Profile Changes.*—Studies were made of the seasonal changes in elevation of the pavements and of the rutting in the wheelpaths. The studies of rutting included such factors as the extent to which changes in thickness of the structural components affected the depth of rut, and how much of the thickness change was due to densification and how much was due to lateral displacement. Studies were made also of the seasonal changes in physical condition and strength of the pavement components.

On an average, the pavement in the various loops heaved approximately 0.4 in. during the winter with the edges rising about 0.6 in. and the interior portion about 0.3 in. (see Fig. 44). Most of this heaving was attributed to expansion of the embankment soil.

Rutting of the pavement was due principally to decreases in thickness of the component layers. Based on average data from 51 sections that were trenched in 1960 (see Tables 19, 20 and 21), a rut could be attributed to changes in thickness of 32 percent, 14 percent and 45 percent, respectively, in surfacing, base and subbase, and to a rut in the embankment soil equal to 9 percent of the total rut.

Only 20 percent of the change in thickness of the surfacing and 4 percent of the change in subbase thickness could be accounted for by increases in density of the materials. In the case of the base only 30 percent of the change in thickness determined in the summer of 1960 could be accounted for by increases in density. However, the increase in the density determined

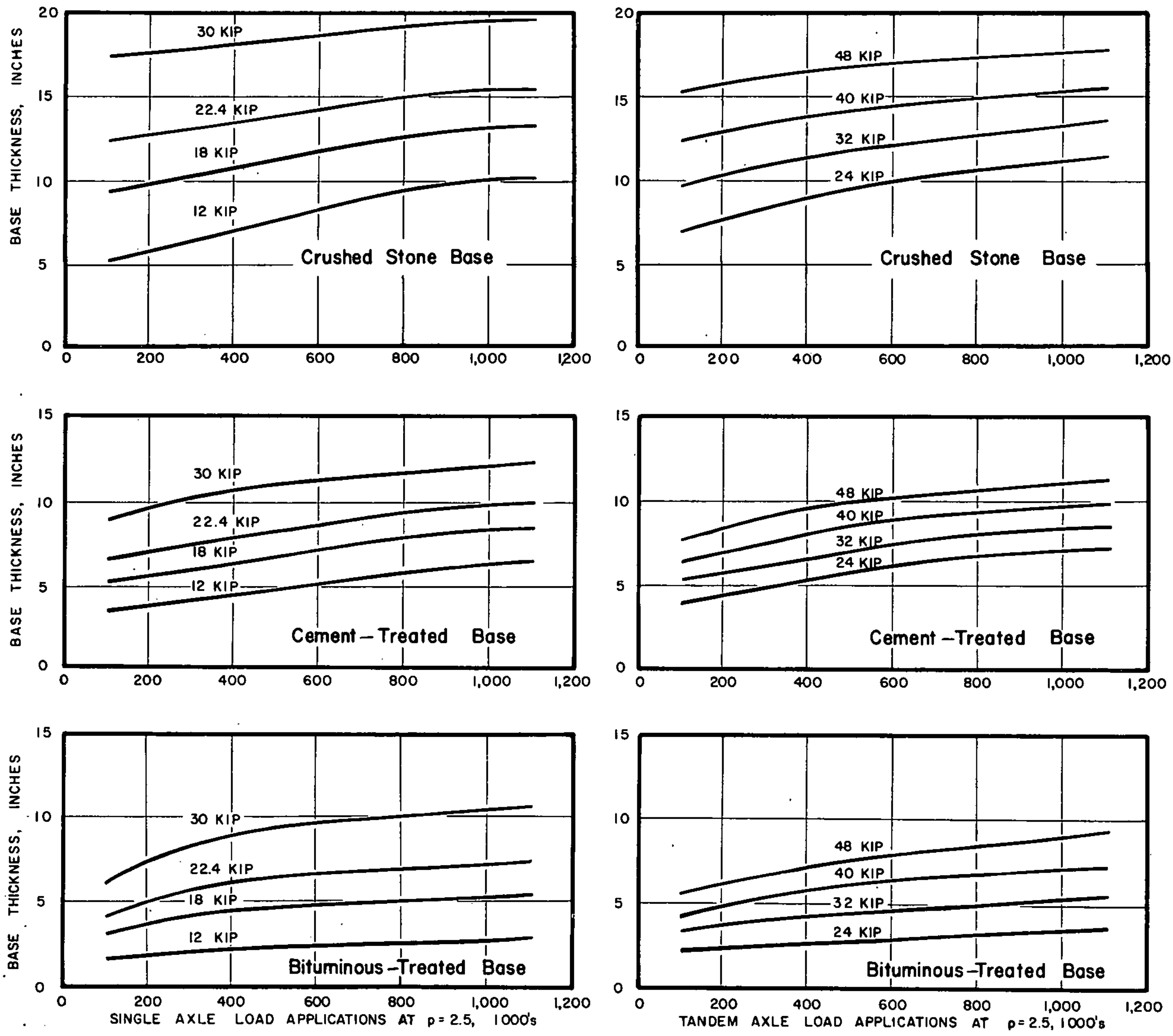

Figure 36. Special base type experiment, relationship between base thickness and axle load applications at $p$ = 2.5 (surfacing, 3 in.; subbase, 4 in.).

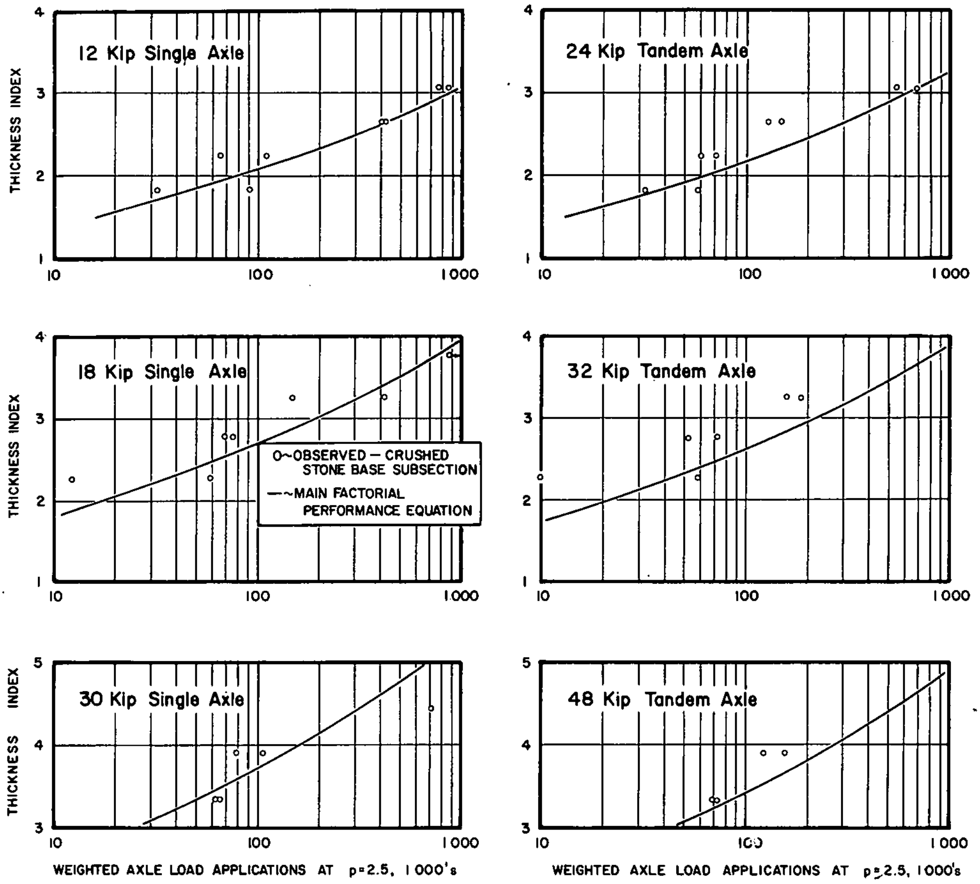

Figure 37. Special base type experiment, comparison of observed performance of crushed stone base wedge subsections with that predicted from the main factorial experiment performance equations.

in the spring of 1960 accounted for all of the decrease in thickness of the material.

In sections that survived the test, the rate of development of rutting during the first year of traffic generally exceeded the rate observed during the second year.

In the special base studies there was a level of base thickness above which the surface rut depth remained constant with increase in base thickness and below which it increased rapidly with decrease in thickness.

The bituminous-treated base and surfacing material offered greater resistance to consolidation and displacement at low temperature than at high temperature.

In nearly all of the flexible pavement test sections ruts were formed in the wheelpaths during the course of the traffic tests (see Fig. 66). Since there appeared negligible loss of surface material due to abrasion or other causes, the observed rutting must be attributed to one or both of two conditions: (1) additional consolidation under traffic of one or more layers of the pavement structure and/or the embankment material; and (2) displacement outward from the center of the wheelpath of material in one or more layers of the pavement structure and/or the embankment material. Since corrective measures appropriate to the prevention of rutting must depend to a large extent on the reasons for the rutting, considerable effort was expended in the study of these matters.

Information for use in these studies was obtained from a number of different types of measurement, as follows: (1) Six sets of surface elevation data in which conventional precise level surveying techniques were used to establish the transverse profile from measurements at three locations per test section. (2) Transverse profile measurements with the automatic recording electronic device shown in Figures 38 and 39. The continuous profile traces were used with the precise level measurements to establish the elevation at every foot across the pavement. (3) Settlement rod measurements. After construction, vertical rods were installed in the pavement and anchored to plates previously placed at the various pavement layer interfaces and in the embankment. Layer thickness changes were determined from measurements of the surface elevations with reference to the tops of the rods as shown in Figure 40. (A full description of the settlement rods, their installation and the measurement program is contained in Appendix 4.) (4) Pre-

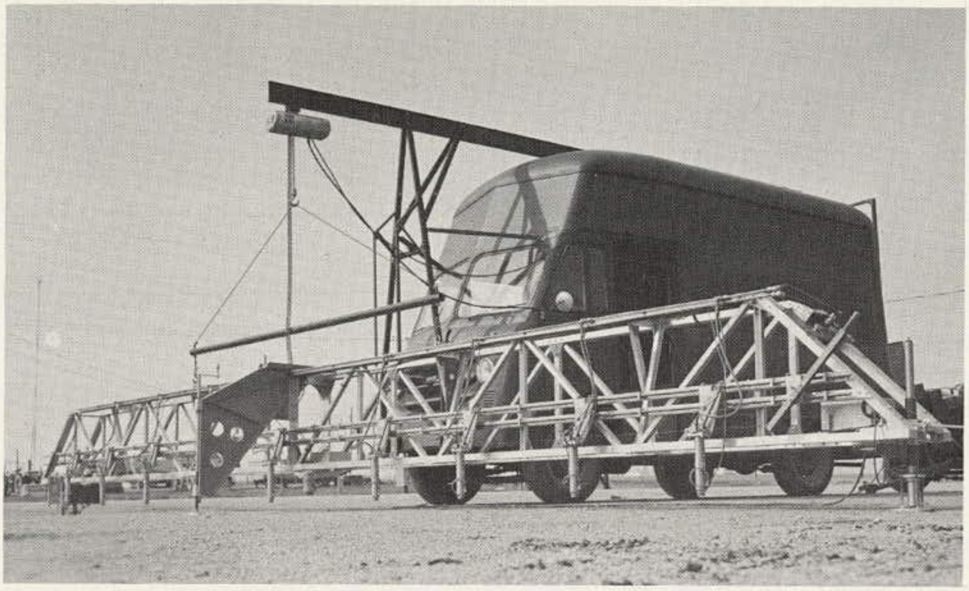

Figure 38. Transverse profilometer truss and van.

cise level measurements made on the surfaces and the tops of the subsurface layers during the trenching program. From these measurements made every foot across the section, cross-sections of the pavement and embankment surface were obtained. (5) Routine biweekly rut measurements using the device shown in Figure 41. (6) Measurements of rut depth at 5-ft intervals in the special (wedge) base sections, made with the same device, five times during the test period.

Transverse profiles of the pavement surface taken with precise levels at different times during the traffic test are summarized in Table 18 and are shown graphically in Figures 42 and 43. For any one section comparison of the profiles taken in the three periods demonstrates the magnitude of the absolute change in elevation in the entire pavement with seasons. For example, the 3-6-4 pavement under the 2- and 6-kip axle loads of Loop 2 rather consistently went up about 0.04 ft between October 1959 and March 1960. By October 1960, the pavement had gone down to about 0.01 ft below the October 1959 level. Although the magnitude of this rise and fall varied from section to section, the same general trend was observed in most of the pavements. The rise of the pavement surface noted in the early spring (March) of 1960 is attributed to the presence of frost in the structure and embankment.

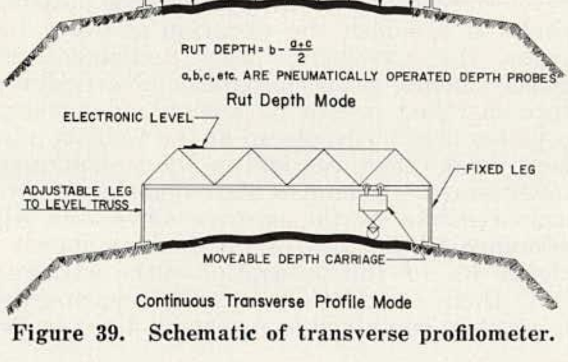

Figure 39. Schematic of transverse profilometer.

The changes in elevation at the edge, outer wheelpath, between wheelpaths, inner wheelpath and at the center of the pavement between the fall of 1959 and spring of 1960 are shown in Figure 44. There was almost twice as much heaving at the extreme edges of the pavements as in the interior portions. This situation was much the same for all loops although the actual amount of heaving varied appreciably from loop to loop. The greater heaving at the pavement edge was attributed to the presence of more moisture in the base, subbase and embankment soil beneath the shoulders. Heaving decreased from Loop 1 through Loop 4, the reverse trend occurred from Loop 4 through Loop 6 (Fig. 44). To this extent the data are inconsistent insofar as the effect of pavement thickness on frost heaving is concerned.

Data concerning the condition of the embankment soil in the spring for Loops 3, 4, 5 and 6 in 1960 and for Loops 2 and 4 in 1961 are given in Table 19. (The data from the 1960 study were obtained from the trenching program described in detail later in this discussion. Data from the 1961 trenches were obtained during the post-traffic special study program de-

Figure 40. Electrical device used to measure vertical movement of pavement.

Figure 41. Manual rut depth gage.

## TABLE 18

### TRANSVERSE PROFILE DATA (1 OF 4) CHANGE IN ELEVATION OF PAVEMENT SURFACE

| Loop | Design (in.) | Date | Surface Elevation Change ($10^{-1}$ in.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Single Axle Lane | | | | Center-line | Tandem Axle Lane | | | |
| | | | 12 Ft | 9 Ft | 6 Ft | 3 Ft | | 3 Ft | 6 Ft | 9 Ft | 12 Ft |
| 2 | 3–6–0 | July 1959 | +4 | 0 | 0 | −2 | −1 | −4 | −1 | −2 | +1 |
| | | October 1959 | +1 | −1 | −1 | −2 | −1 | −4 | −1 | −4 | −1 |
| | | March 1960$^1$ | +12 | +6 | +5 | .. | +4 | 0 | +2 | 0 | +8 |
| | | March 1960$^2$ | +11 | +7 | +6 | .. | +5 | +4 | +3 | +4 | +9 |
| | | August 1960 | 0 | −2 | −2 | −5 | −4 | −5 | −4 | −7 | −4 |
| | | October 1960 | 0 | −2 | −1 | −5 | −4 | −5 | −2 | −5 | −2 |
| | 3–6–4 | July 1959 | +2 | 0 | +2 | +1 | +1 | 0 | +1 | −1 | +1 |
| | | October 1959 | −1 | −4 | −1 | −1 | −1 | −4 | −2 | −4 | −2 |
| | | March 1960$^1$ | +6 | +1 | +2 | +2 | +2 | 0 | +1 | −1 | +6 |
| | | March 1960$^2$ | +7 | +5 | +3 | +3 | +3 | +4 | +3 | +3 | +8 |
| | | August 1960 | −1 | −2 | −1 | −2 | −2 | −4 | −2 | −4 | −4 |
| | | October 1960 | −2 | −4 | −1 | −4 | −2 | −5 | −4 | −5 | −4 |
| 3 | 4–6–4 | July 1959 | −1 | −2 | +1 | 0 | +2 | −1 | +2 | 0 | +5 |
| | | October 1959 | 0 | −5 | −1 | −2 | 0 | −4 | +1 | +2 | +2 |
| | | March 1960$^1$ | −1 | −5 | +4 | +2 | +5 | 0 | +5 | +1 | +11 |
| | | March 1960$^2$ | −1 | 0 | +5 | +4 | +5 | +4 | +4 | −1 | +9 |
| | 4–6–8 | July 1959 | +1 | −1 | 0 | −2 | 0 | −2 | 0 | −2 | +1 |
| | | October 1959 | 0 | −2 | 0 | −2 | 0 | −5 | −1 | −2 | 0 |
| | | March 1960$^1$ | +5 | −1 | +2 | −1 | +1 | −4 | +1 | −2 | +7 |
| | | March 1960$^2$ | +5 | +1 | +2 | +1 | +1 | +1 | +2 | 0 | +7 |
| | | August 1960 | −2 | −5 | 0 | −5 | −1 | −5 | −1 | −6 | −1 |
| | | October 1960 | −2 | −5 | −1 | −5 | −1 | −5 | −1 | −6 | 0 |
| 4 | 5–6–12 | July 1959 | −2 | −6 | −1 | −5 | −2 | −8 | −2 | −6 | −1 |
| | | November 1959 | −1 | −6 | −1 | −6 | −2 | −8 | −2 | −6 | −1 |
| | | March 1960$^1$ | +4 | −4 | 0 | −5 | 0 | −7 | 0 | −5 | +4 |
| | | March 1960$^2$ | +5 | +2 | +1 | +1 | +2 | +1 | +2 | +1 | +5 |
| | | August 1960 | −8 | −12 | −5 | −11 | −6 | −11 | −5 | −11 | −6 |
| | | October 1960 | −5 | −10 | −2 | −10 | −4 | −8 | −2 | −7 | −2 |
| | 3–6–12 | July 1959 | −2 | −7 | −1 | −4 | −1 | −6 | −2 | −8 | −6 |
| | | November 1959 | −2 | −7 | −1 | −6 | −1 | −6 | −4 | −8 | −4 |
| | | March 1960$^1$ | 0 | −7 | −2 | −6 | −1 | −7 | −2 | −8 | 0 |
| | | March 1960$^2$ | +2 | 0 | −1 | 0 | 0 | −1 | +2 | 0 | +4 |
| | 5–6–4 | July 1959 | −5 | −8 | −1 | −5 | −1 | −10 | −1 | −8 | −1 |
| | | October 1959 | −2 | −6 | 0 | −4 | +1 | −6 | +1 | −5 | +1 |
| | | March 1960$^1$ | +4 | −4 | +2 | −1 | +4 | −5 | +4 | −2 | +7 |
| | | March 1960$^2$ | +6 | +2 | +2 | +3 | +3 | +1 | +3 | +3 | +6 |
| | 5–0–12 | July 1959 | −4 | −10 | −1 | −5 | −1 | .. | 0 | −5 | +1 |
| | | October 1959 | −4 | −10 | −2 | −6 | −1 | −6 | −1 | −5 | 0 |
| | | March 1960$^1$ | +1 | −8 | 0 | −5 | 0 | −5 | +1 | −4 | +6 |
| | | March 1960$^2$ | +5 | +2 | +2 | +1 | +1 | +1 | +2 | +1 | +6 |
| | 5–6–4 | July 1959 | +1 | −4 | +2 | −1 | +1 | −4 | +4 | 0 | +5 |
| | | November 1959 | −1 | −5 | +1 | −5 | +1 | −4 | +2 | 0 | +5 |
| | | March 1960$^1$ | +5 | −5 | +2 | −2 | +1 | −4 | +2 | −1 | +8 |
| | | March 1960$^2$ | +6 | 0 | +1 | +3 | 0 | 0 | 0 | −1 | +3 |
| 5 | 4–6–12 | July 1959 | −4 | −11 | −2 | −11 | −2 | −11 | −2 | −11 | −4 |
| | | March 1960$^1$ | +2 | −8 | 0 | −8 | +1 | −10 | 0 | −10 | +4 |
| | | March 1960$^2$ | +6 | +3 | +2 | +3 | +3 | +1 | +2 | +1 | +8 |
| | 5–9–12 | July 1959 | −1 | −5 | 0 | −4 | 0 | −4 | −1 | −7 | −5 |
| | | November 1959 | −2 | −6 | −1 | −6 | −1 | −7 | −5 | −10 | −6 |
| | | March 1960$^1$ | +7 | −2 | +1 | −2 | +1 | −5 | −1 | −7 | +2 |
| | | March 1960$^2$ | +9 | +4 | +2 | +4 | +2 | +2 | +4 | +3 | +8 |
| | | August 1960 | −7 | −8 | −2 | −7 | −2 | −10 | −6 | −12 | −7 |
| | | October 1960 | −8 | −10 | −2 | −7 | −2 | −8 | −5 | −12 | −8 |
| | 3–9–12 | July 1959 | −1 | −7 | −1 | −7 | −1 | −10 | −4 | −13 | −6 |
| | | November 1959 | −2 | −8 | −2 | −8 | −1 | −10 | −4 | −13 | −5 |
| | | March 1960$^1$ | +4 | −6 | 0 | −6 | 0 | −10 | −1 | −13 | 0 |
| | | March 1960$^2$ | +6 | +2 | +2 | +2 | +1 | 0 | +3 | 0 | +5 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5-6-12 | November 1959 | -1 | -8 | -1 | -7 | -1 | -10 | -2 | -11 | -4 |
| | | March 1960[1] | +5 | -5 | +1 | -5 | +2 | -7 | 0 | -8 | +2 |
| | | March 1960[2] | +6 | +3 | +2 | +2 | +3 | +3 | +2 | +3 | +6 |
| | | August 1960 | -10 | -13 | -4 | -11 | -2 | -10 | -4 | -13 | -5 |
| | | October 1960 | -8 | -14 | -4 | -12 | -2 | -10 | -4 | -12 | -5 |
| | 5-9-8 | November 1959 | 0 | -5 | 0 | -5 | -1 | -5 | -1 | -8 | -7 |
| | | March 1960[1] | +8 | 0 | +4 | -1 | +2 | -4 | +1 | -5 | +5 |
| | | March 1960[2] | +8 | +5 | +4 | +4 | +3 | +1 | +2 | +3 | +12 |
| | | August 1960 | -6 | -7 | -1 | -8 | -2 | -8 | -2 | -12 | -6 |
| | | October 1960 | -6 | -10 | -1 | -10 | -2 | -10 | -4 | -13 | -6 |
| | 5-6-8 | July 1959 | -1 | -7 | 0 | -5 | -1 | -7 | -2 | -10 | -1 |
| | | November 1959 | -2 | -10 | -1 | -8 | -2 | -10 | -2 | -12 | -2 |
| | | March 1960[1] | +5 | -4 | +2 | -4 | 0 | -7 | 0 | -10 | +5 |
| | | March 1960[2] | +7 | +6 | +3 | +4 | +2 | +3 | +2 | +2 | +7 |
| | 5-9-4 | July 1959 | -2 | -8 | -1 | -7 | -1 | -10 | -2 | -10 | -4 |
| | | November 1959 | 0 | -6 | +2 | -4 | 0 | -6 | 0 | -8 | -4 |
| | | March 1960[1] | +4 | -5 | +1 | -5 | +1 | -7 | +1 | -8 | +4 |
| | | March 1960[2] | +4 | +1 | -1 | -1 | +1 | -1 | +1 | 0 | +8 |
| | 4-9-12 | July 1959 | 0 | -7 | 0 | -6 | 0 | -6 | 0 | -7 | -1 |
| | | November 1959 | | | | | | | | | |
| | | March 1960[1] | +4 | -6 | +1 | -4 | 0 | -6 | +1 | -6 | +6 |
| | | March 1960[2] | +4 | +1 | +1 | +2 | 0 | 0 | +1 | +1 | +7 |
| | | June 1960 | -7 | -13 | -3 | -8 | -3 | -9 | -3 | -12 | -4 |
| | | August 1960 | -11 | -16 | -7 | -17 | -5 | -14 | -6 | -14 | -5 |
| | | October 1960 | -6 | -12 | -1 | -8 | -1 | -7 | -1 | -12 | -2 |
| | 5-3-12 | July 1959 | -1 | -10 | -2 | -8 | -4 | -7 | -4 | -11 | -4 |
| | | November 1959 | +1 | -7 | +1 | -6 | 0 | -7 | 0 | -8 | -1 |
| | | March 1960[1] | +7 | -2 | +4 | -4 | +5 | -5 | +2 | -5 | +8 |
| | | March 1960[2] | +6 | +5 | +3 | +2 | +5 | +2 | +2 | +3 | +9 |
| | | June 1960 | -7 | -15 | -2 | -8 | -1 | -10 | -2 | -11 | -1 |
| | | August 1960 | -11 | -17 | -6 | -13 | -5 | -12 | -5 | -16 | -5 |
| | | October 1960 | -8 | -16 | -2 | -11 | 0 | -8 | -1 | -12 | -1 |
| | 5-9-4 | July 1959 | -1 | -7 | 0 | -10 | -2 | -8 | -4 | -11 | -5 |
| | | November 1959 | +1 | -5 | +1 | -6 | -1 | -6 | -1 | -8 | -4 |
| | | March 1960[1] | +8 | -1 | +5 | 0 | +4 | -5 | +2 | -5 | +5 |
| | | March 1960[2] | +7 | +4 | +4 | +6 | +5 | +1 | +3 | +3 | +9 |
| 6 | 6-3-16 | July 1959 | -8 | -11 | -2 | -6 | -1 | -7 | 0 | -7 | +1 |
| | | October 1959 | -7 | -10 | -2 | -6 | 0 | -7 | 0 | -7 | -2 |
| | | March 1960[1] | -6 | -13 | -3 | -8 | +1 | -7 | +1 | -6 | +6 |
| | | March 1960[2] | +1 | -3 | -1 | -2 | +1 | 0 | +1 | +1 | +8 |
| | 6-9-8 | July 1959 | -5 | -12 | -1 | -10 | -2 | -8 | -1 | -10 | +1 |
| | | October 1959 | -7 | -14 | -4 | -12 | -4 | -11 | -4 | -12 | -4 |
| | | March 1960[1] | 0 | -10 | 0 | -7 | +1 | -7 | +1 | -7 | +5 |
| | | March 1960[2] | +7 | +4 | +4 | +5 | +5 | +4 | +5 | +5 | +9 |
| | 6-9-8 | July 1959 | -4 | -11 | -2 | -7 | -2 | -6 | 0 | -4 | +2 |
| | | October 1959 | -6 | -12 | -4 | -10 | -4 | -8 | -1 | -7 | 0 |
| | | March 1960[1] | +1 | -7 | 0 | -6 | 0 | -4 | +2 | -1 | +8 |
| | | March 1960[2] | +7 | +5 | +4 | +4 | +4 | +4 | +3 | +6 | +8 |
| | | June 1960 | -10 | -14 | -4 | -11 | -4 | -8 | -1 | -7 | +4 |
| | | August 1960 | -12 | -14 | -5 | -12 | -5 | -8 | -2 | -12 | -4 |
| | | October 1960 | -11 | -16 | -4 | -12 | -4 | -5 | -1 | -5 | +1 |
| | 4-9-16 | July 1959 | -5 | -11 | -2 | -6 | -2 | -7 | -2 | -7 | -1 |
| | | October 1959 | -6 | -11 | -2 | -7 | -2 | -7 | -4 | -8 | -5 |
| | | March 1960[1] | -1 | -10 | -1 | -5 | 0 | -5 | 0 | -5 | +5 |
| | | March 1960[2] | +5 | +1 | +1 | +2 | +2 | +2 | +4 | +3 | +10 |
| | | June 1960 | -10 | -13 | -3 | -8 | -2 | -7 | -2 | -10 | -3 |
| | | August 1960 | -12 | -13 | -4 | -11 | -2 | -8 | -2 | -12 | -4 |
| | | October 1960 | -13 | -17 | -4 | -12 | -4 | -8 | -4 | -12 | -4 |
| | 6-9-16 | July 1959 | -4 | -10 | -2 | -7 | -4 | -8 | -4 | -7 | -1 |
| | | October 1959 | -6 | -11 | -4 | -10 | -4 | -8 | -5 | -10 | -3 |
| | | March 1960[1] | 0 | -10 | -4 | -8 | -4 | -8 | -5 | -8 | 0 |
| | | March 1960[2] | +6 | +1 | 0 | +2 | 0 | 0 | 0 | +2 | +3 |
| | | June 1960 | -12 | -16 | -5 | -11 | -6 | -11 | -7 | -10 | -5 |
| | | August 1960 | -12 | -13 | -5 | -10 | -6 | -10 | -5 | -12 | -5 |
| | | October 1960 | -13 | -18 | -6 | -12 | -7 | -10 | -6 | -12 | -6 |

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[1] Change from initial elevation.
[2] Change from previous fall elevation.

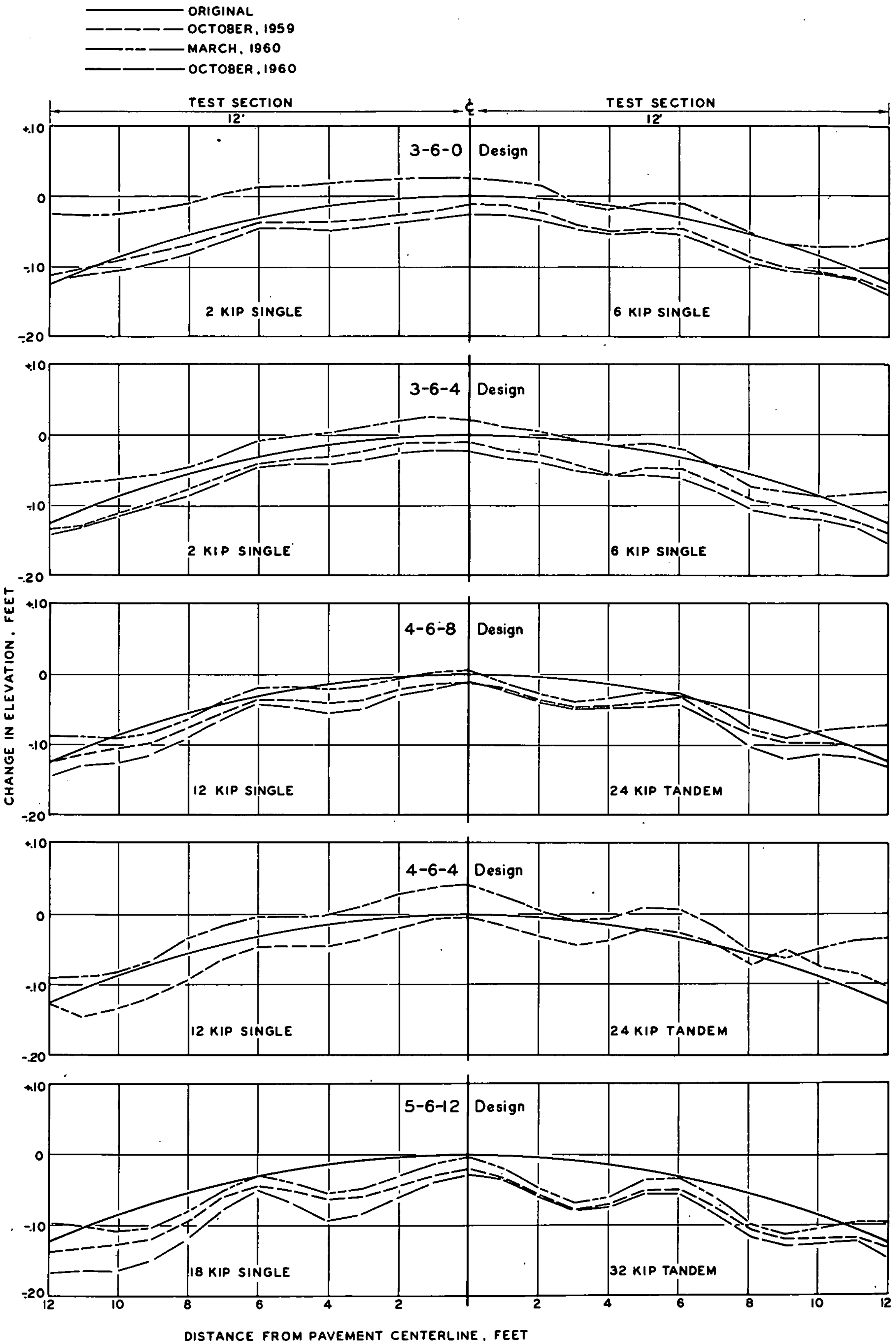


Figure 42. Transverse profiles of pavement surface (obtained by precise level and profilometer measurements).

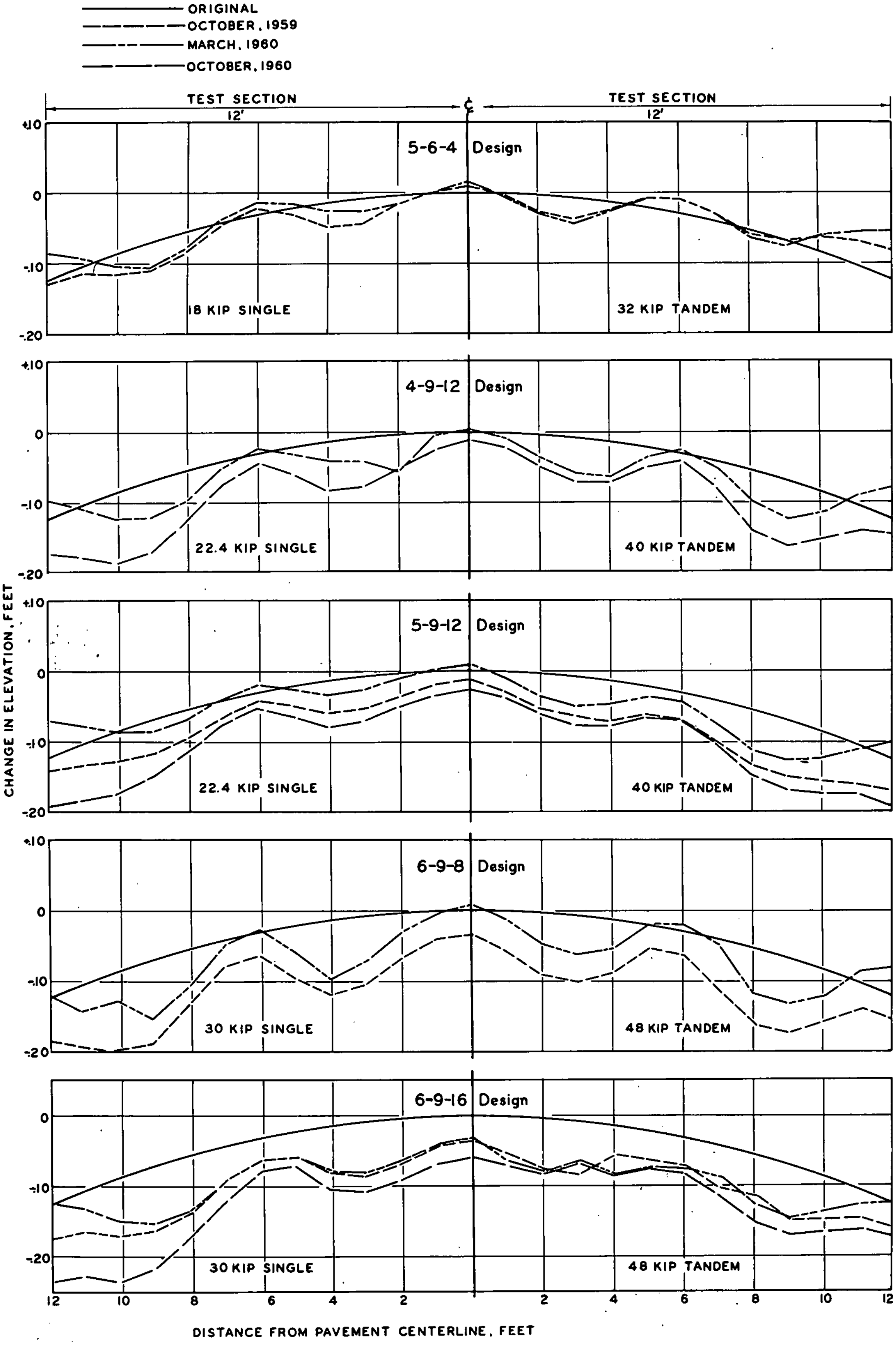


Figure 43. Transverse profiles of pavement surface (obtained by precise level and profilometer measurements).

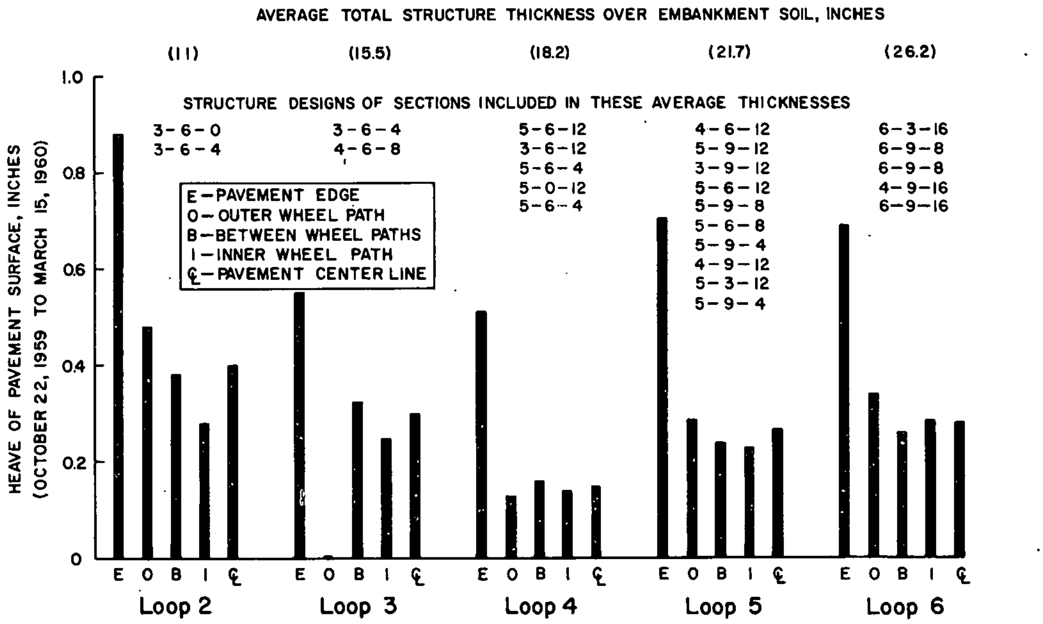


Figure 44. Heave of pavement surface.

scribed in AASHO Road Test Report 6.) The computed value of saturation of the soil for Loop 2 (OWP, spring 1961) was the highest (82.3 percent). Also its density was appreciably lower and its moisture content higher than these values for the other loops.

Information on the frost potential of the embankment soil reported by the Corps of Engineers (DS 2300) shows that when frozen in the laboratory the material at 72 percent saturation, 114-pcf density and 13 percent moisture exhibited no heave. However, at 85 percent saturation, 15.5 percent moisture and at the same density the soil heaved about 1.7 percent. Since soil conditions in Loop 2 were more adverse than those in the other loops (nearly 85 percent saturation was noted) a greater degree of heaving was expected in this loop.

Additional data regarding vertical movements of the flexible pavement structure are shown in Figures 45 and 46. They were ob-

TABLE 19

CONDITION OF EMBANKMENT SOIL, SPRING MONTHS

| Loop | 1960 | | | | | 1961 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Sections | Moisture Content (%) | Density (pcf) | Saturation (%) | CBR | Number of Sections | Moisture Content (%) | Density (pcf) | Saturation (%) | CBR |
| | | | | | (*a*) OUTER WHEELPATH | | | | | |
| 2 | — | — | — | — | — | 6 | 17.1 | 109.2 | 82.3 | 1.8 |
| 3 | 3 | 15.1 | 113.3 | 80.7 | 2.5 | — | — | — | — | — |
| 4 | 3 | 14.1 | 115.4 | 79.6 | 4.0 | 2 | 14.1 | 116.8 | 81.3 | 5.0 |
| 5 | 3 | 16.1 | 110.2 | 79.5 | 2.7 | — | — | — | — | — |
| 6 | 3 | 13.1 | 115.1 | 73.4 | 6.6 | — | — | — | — | — |
| All | | 14.6 | 113.5 | 78.4 | — | — | — | — | — | — |
| | | | | | (*b*) BETWEEN WHEELPATHS | | | | | |
| 2 | — | — | — | — | — | 6 | 16.8 | 108.6 | 79.6 | 2.8 |
| 3 | 3 | 15.0 | 112.5 | 78.5 | 2.7 | — | — | — | — | — |
| 4 | 3 | 14.3 | 113.8 | 78.9 | 3.7 | 2 | 13.8 | 116.0 | 79.6 | 3.8 |
| 5 | 3 | 16.2 | 109.4 | 78.3 | 3.0 | — | — | — | — | — |
| 6 | 3 | 13.9 | 115.1 | 77.9 | 3.9 | — | — | — | — | — |
| All | | 14.9 | 112.7 | 78.4 | — | — | — | — | — | — |

tained from measurements taken in the fall and spring periods of the traffic testing phase. The figures show the seasonal changes in elevation in the wheelpaths of the pavement surface and of the top of the embankment soil in ten test sections. Although some heaving took place within the pavement structure during the winter, the greater part of the heaving observed at the top of the pavement originated in the embankment soil and the major part of the settlement of the pavement surface occurred as a result of movements within the structure. This is in agreement with the findings of the trench studies that are discussed later in this section.

The transverse profiles shown in Figures 42 and 43 not only present a clear picture of the magnitude of the ruts in the surface of these particular pavements but show the location of the ruts with respect to the pavement edge. These locations for the 18 test sections are summarized in Table 20. For these particular sections ruts average 2.9 and 8.9 ft from the edge in the single axle lane and 3.2 and 9.0 ft from the edge in the tandem lane. There is reasonable consistency among the means for the group of sections in each loop. In these sections the tandem axle vehicles were apparently driven closer to the centerline of the pavement than the single axle vehicles (6 in. on the average).

During 1959, a number of trenches were cut into sections, whose conditions had deteriorated to the point where their removal from the test was imminent. In fact, the serviceability of some of these sections had dropped below 1.5, the level at which they were normally removed from test. The purposes of this work was to develop some preliminary information concerning the amount of wheelpath rutting at the top of each of the component structure layers as well as to obtain information on the existing condition and strength of the materials. Also, since a comprehensive program of trenching work was being planned for 1960, another objective of the work was to develop an acceptable procedure for executing the program.

While the trenches were being made, precise levels were taken at 1-ft intervals on the top of each of the layers. The trenches were 3 ft in width and the levels were taken on both faces. In addition, cores for density determinations were taken of the surfacing course, and in-place density, CBR, and moisture content determinations of the granular materials and embankment soil were made. In some cases plate load tests were made on the embankment soil.

Transverse profiles of three of the 1959 trenches are shown in Figure 47, two from Loop 6 and one from Loop 4. Those in Loop 6 were cut when the serviceability of the pavements was about 1.5, and that in Loop 4 when its serviceability was about 0.5 and failure was in a more advanced stage. In the two Loop 6 sections, although pronounced rutting had developed in both wheelpaths of the pavement surface, very little of it was apparent in the embankment soil. This was considered to be evidence that reduction in thickness of the surfacing, base and subbase courses was to a very large degree, responsible for the rutting observed in the wheelpaths of the pavement surface. If sections that were failing at a rapid rate were not maintained, rutting or distortion of the pavement in the wheelpaths would probably extend into the embankment soil as was the case in the 5-3-4 section.

Layer thickness changes were also measured by means of settlement rods anchored to plates located at various levels in the pavement structure and on the embankment. Examples of these data are shown in Figures 48 and 49 for the crushed stone base and the bituminous-treated base. Generally, for all bituminous-treated base thicknesses and for all stone base thicknesses greater than 11 in., very little thickness change was found in the material underlying the base. Sections with these thicknesses of base also had small losses in serviceability over the test period. This is considered evidence that the rutting in pavement designs of substantial thickness can be attributed primarily to reduction in thicknesses of the pavement layers.

Further information was obtained from trenches cut into 12 sections in the spring and summer of 1960 and from 27 more trenches cut in the fall of 1960. Data from these tests are given in Tables 21, 22 and 23, and a summary of the data is shown graphically in Figures 50 and 51. Values of the actual change in thickness and those computed due to densification are listed for each section trenched, for the mean of the sections in each loop and for all loops combined. Also listed are initial values of thickness and density of each component and similar values determined at the time of trenching. The means of the sections for each loop (Fig. 50 and 51) are for measurements made in the outer wheelpath and between the wheelpaths. In addition to the change of thickness data for the pavement layers, the depth of rut reflected in the subgrade is indicated for the outer wheelpath in Figure 50. A comparison of the magnitude of the embankment rut to the total pavement thickness change serves as further evidence that most of the observed surface rut can be attributed to changes of thickness of the pavement layers.

Comparison of the as-constructed densities and the densities measured in the trenches in the three programs provide a means for assigning portions of the change in thickness of each component to densification. The amount of change of thickness that would be expected due to the measured change in density is shown for each loop and each structural component in the solid bars (except that densities of base and subbase were not determined in case of the fall group of trenches). The total observed thick-

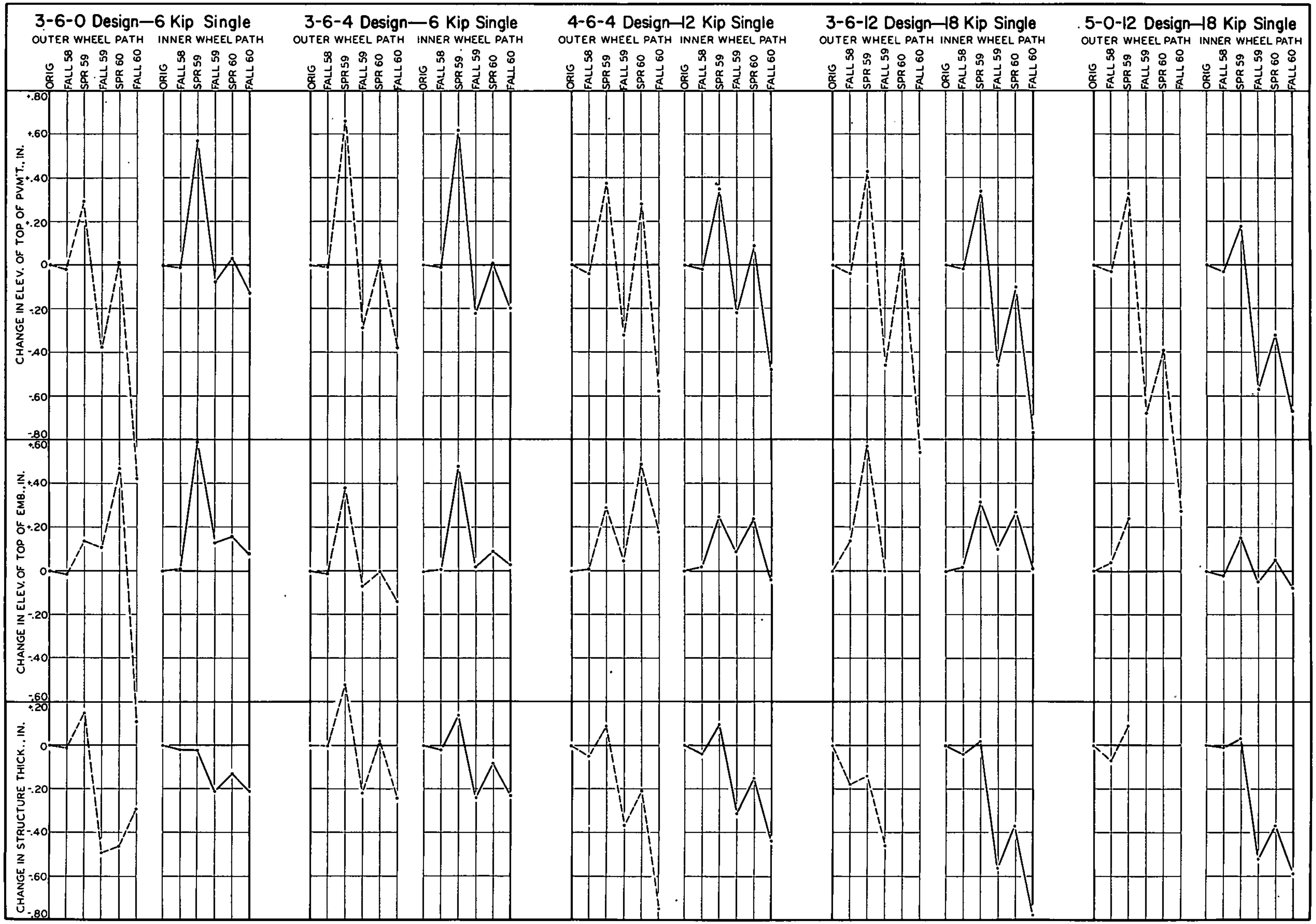


Figure 45. Vertical movement data from settlement rod measurements.

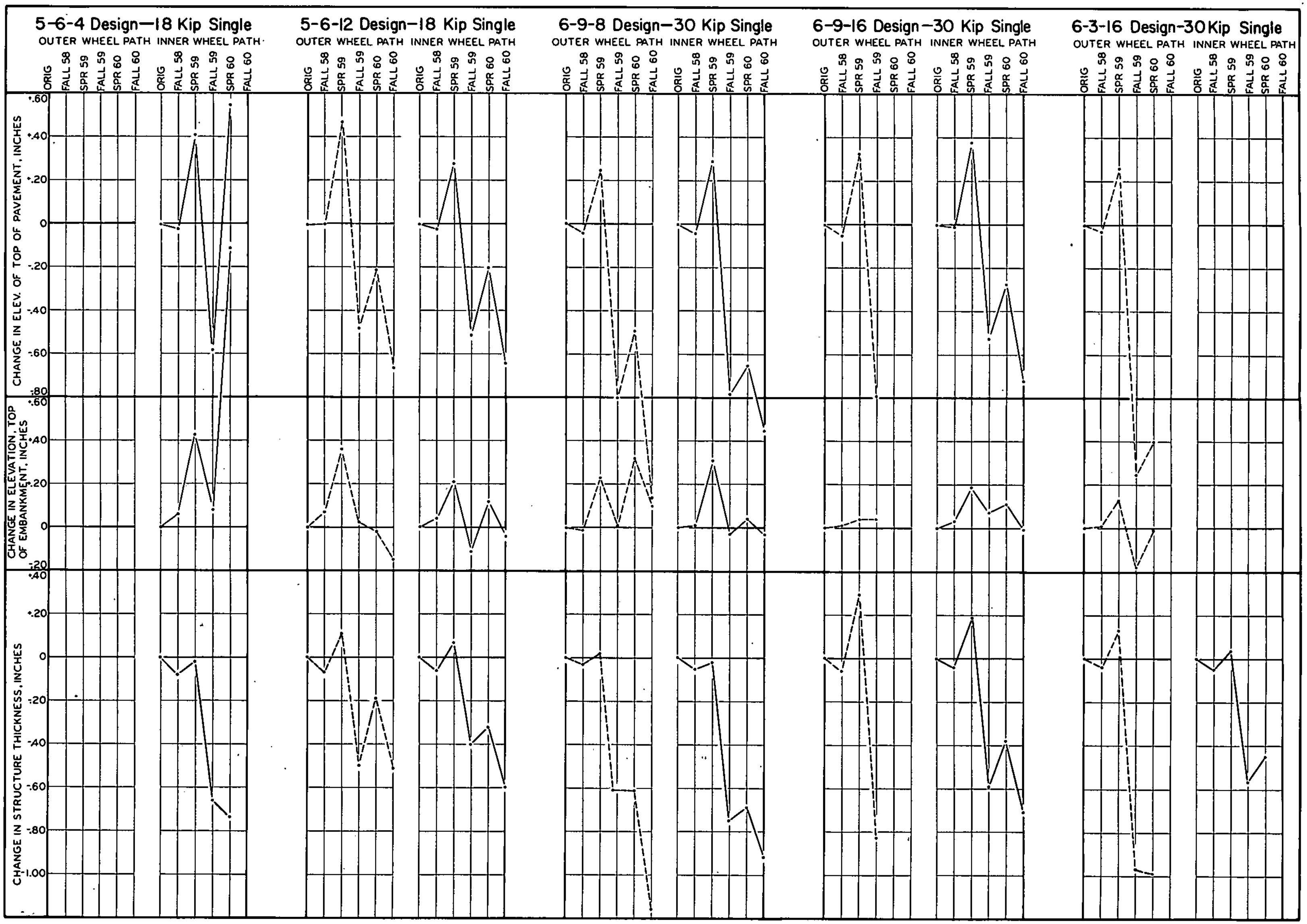


Figure 46. Vertical movement data from settlement rod measurements.

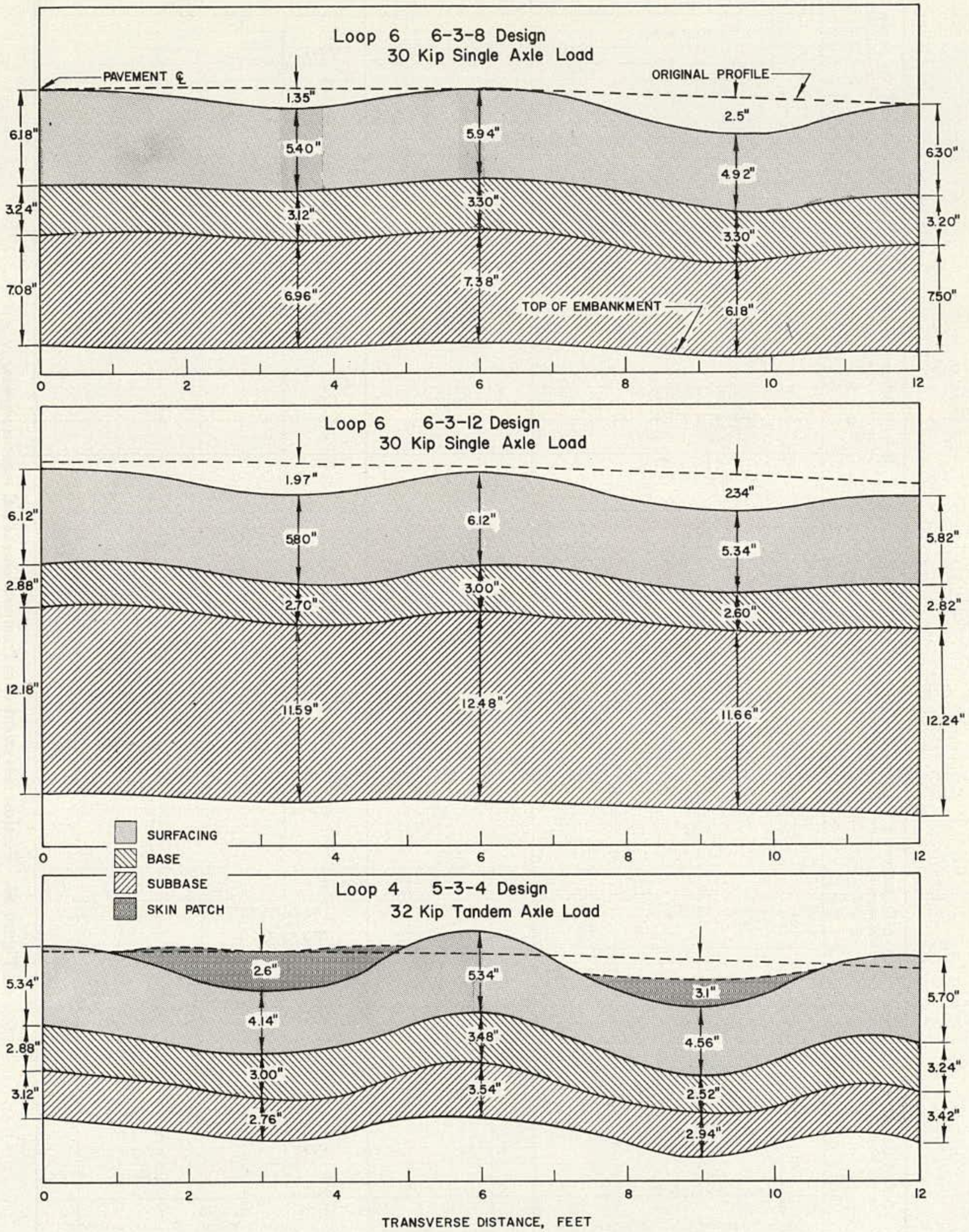
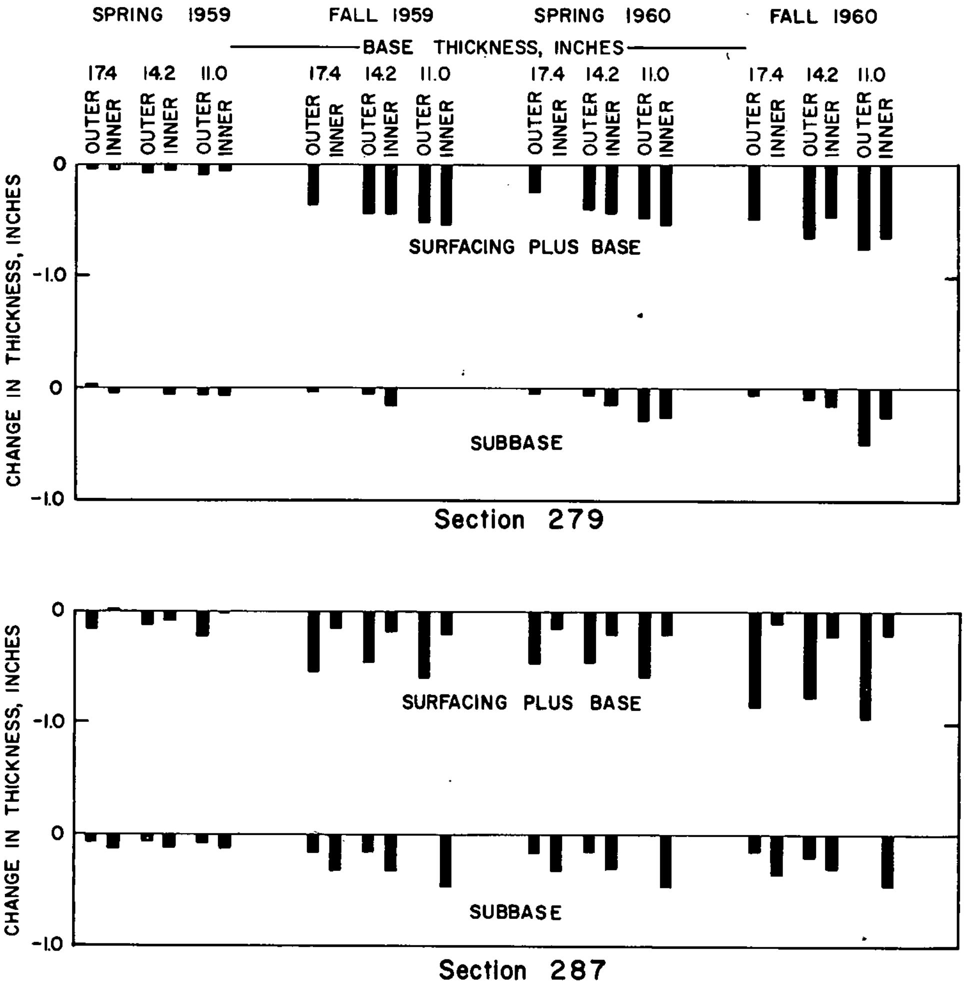


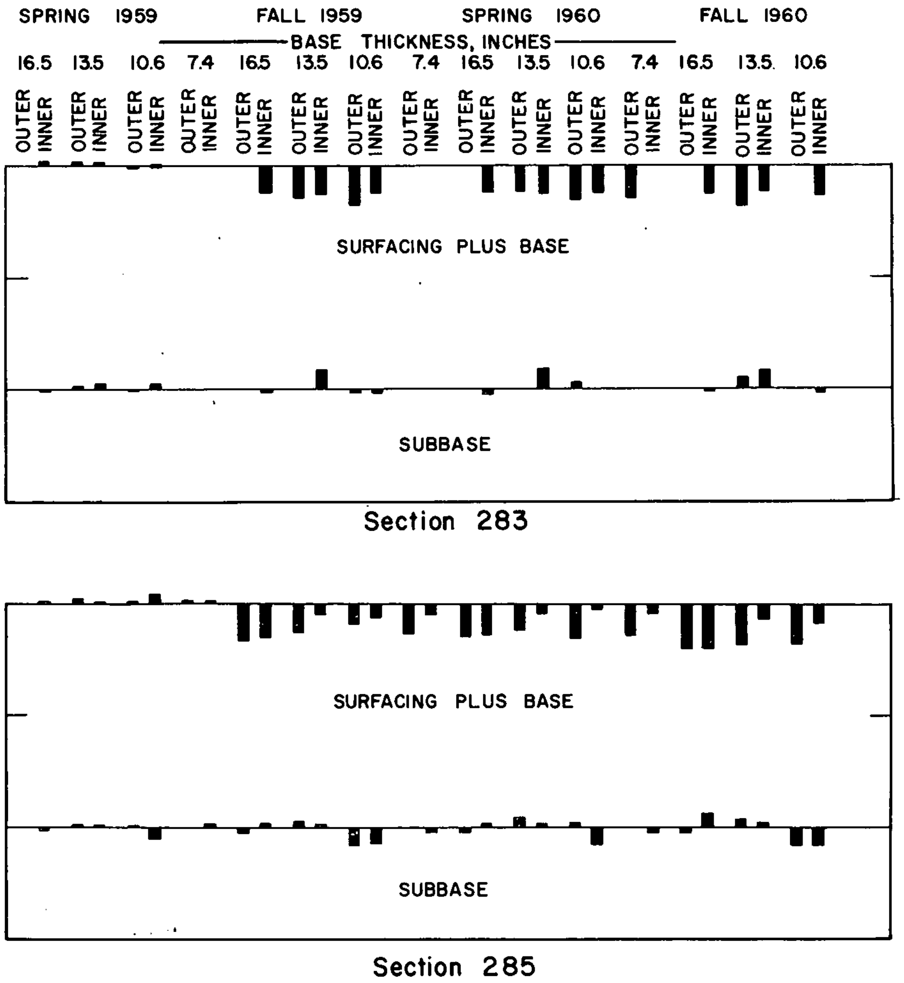
Figure 47. Transverse profiles, 1959 trench study.



Section 279

Section 287

Figure 48. Change in thickness of pavement in wheelpaths of stone base wedge sections, 4–(3–19)–8 design, 30-kip single axle load.



Section 283

Section 285

Figure 49. Change in thickness of pavement in wheelpaths of bituminous-treated base wedge sections, 4–(3–18)–4 design, 30-kip single axle load.

ness change, for whatever cause, is shown for each loop and structural component in the hatched bars. The fall 1960 trenches (near the end of the traffic test) indicated that only about 25 percent of the thickness change in the surfacing in the outer wheelpath of these sections could be assigned to densification of the material. The summer trenches indicated that about 25 percent of the thickness change in the subbase under the outer wheelpath and less than 50 percent of the thickness change in the base material of these sections could be assigned to densification.

Data taken from between the wheelpaths in the trenches are shown summarized by loops in Figure 51. (Values for each section are available in DS 4180.) Densification of the asphaltic concrete accounted for all of the total thickness change in the surfacing material. The base course in nearly all the trenches became thicker rather than thinner between the wheelpaths without undergoing much change in density. Presumably the material was forced into this position from the wheelpath locations. Thus between the wheelpaths there was considerable reduction in subbase thickness accompanied by a reduction on the average in subbase density.

The data from all the trenching studies lead to the conclusion that changes in thickness of the components of the flexible pavements at the AASHO Road Test were due primarily to lateral movement of the materials.

In connection with the data given in Tables 21, 22 and 23, in the outer wheelpath there was

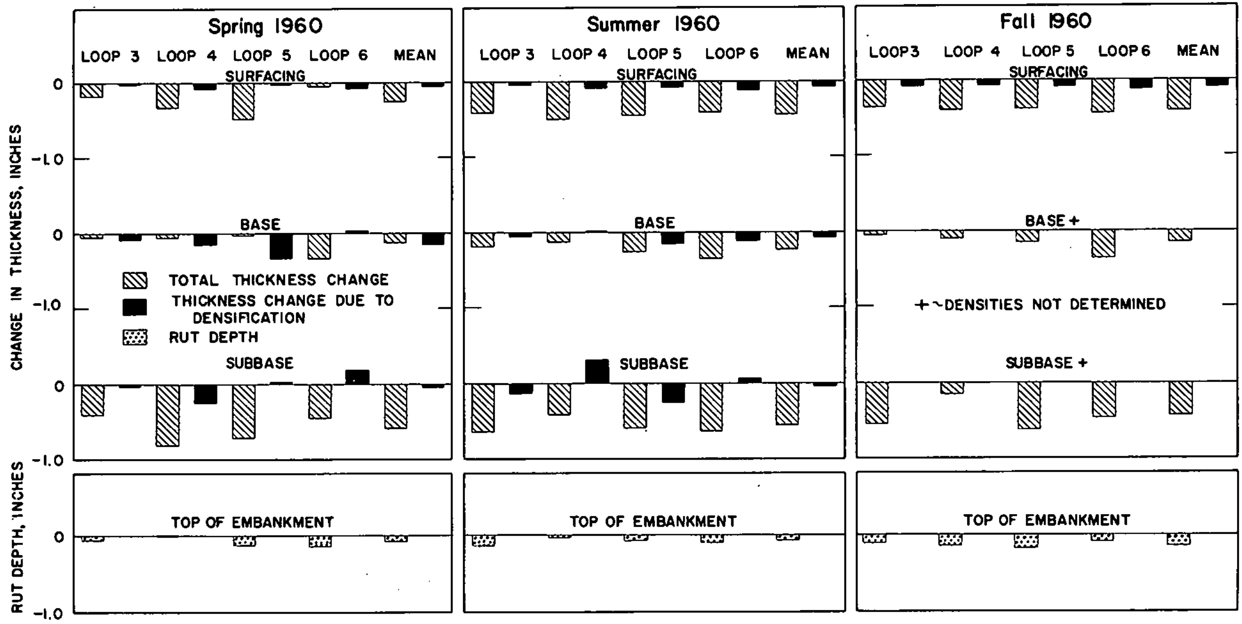


Figure 50. Summary of layer thickness changes in outer wheelpath, 1960 trench study.

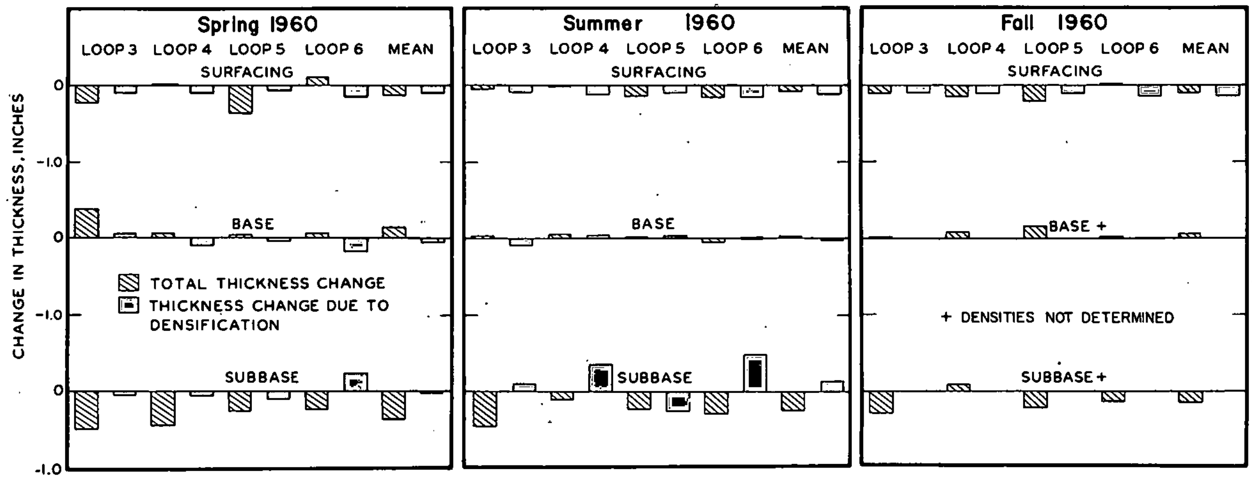


Figure 51. Summary of layer thickness changes between wheelpaths, 1960 trench study.

# TABLE 20

## LOCATION OF RUTS FROM TRANSVERSE PROFILES; DISTANCE TO CENTROID OF RUT FROM PAVEMENT EDGE

| Loop | Design | Distance from Pavement Edge (ft) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Single Axle Lane | | | | | | | | Tandem Axle Lane | | | | | | | |
| | | Inner Wheelpath | | | | Outer Wheelpath | | | | Inner Wheelpath | | | | Outer Wheelpath | | | |
| | | Oct. 1959 | Mar. 1960 | Oct. 1960 | Mean | Oct. 1959 | Mar. 1960 | Oct. 1960 | Mean | Oct. 1959 | Mar. 1960 | Oct. 1960 | Mean | Oct. 1959 | Mar. 1960 | Oct. 1960 | Mean |
| 2 | 3–6–4 | 8.6 | None | 8.1 | 8.4 | 2.6 | 3.5 | 4.0 | 3.4 | 8.0 | 8.1 | 8.0 | 8.1 | 4.0 | 3.0 | 4.0 | 3.7 |
| 3 | 4–6–4 | 8.1 | 8.0 | — | 8.1 | 2.0 | 2.5 | — | 2.3 | 9.0 | 9.0 | — | 9.0 | 4.0 | 3.0 | — | 3.5 |
| | 4–6–8 | 8.5 | 8.5 | 8.5 | 8.5 | 3.0 | 3.0 | 3.0 | 3.0 | 9.0 | 9.0 | 9.0 | 9.0 | 4.0 | 3.0 | 3.0 | 3.4 |
| *Mean* | | | | | *8.3* | | | | *2.7* | | | | *9.0* | | | | *3.5* |
| 4 | 5–6–12 | 8.5 | 8.1 | 8.0 | 8.2 | 3.0 | 3.0 | 3.0 | 3.0 | 9.0 | 9.0 | 9.0 | 9.0 | 3.5 | 3.0 | 4.0 | 3.5 |
| | 3–6–12 | 8.7 | 8.3 | 8.0 | 8.3 | 3.0 | 3.0 | 3.0 | 3.0 | 9.0 | 9.0 | 9.0 | 9.0 | 3.2 | 3.7 | 3.5 | 3.5 |
| | 4–6–12 | 8.7 | 8.7 | — | 8.7 | 3.0 | 3.0 | — | 3.0 | 8.7 | 8.8 | — | 8.8 | 3.3 | 3.0 | — | 3.2 |
| | 5–0–12 | 8.2 | 8.3 | 8.0 | 8.2 | 3.0 | 3.0 | 3.0 | 3.0 | 8.7 | 9.0 | 9.0 | 8.9 | 3.0 | 3.8 | 3.0 | 3.3 |
| | 5–6–4 | 9.0 | 9.0 | — | 9.0 | 3.0 | 3.0 | — | 3.0 | 9.0 | 9.0 | — | 9.0 | 4.0 | 3.0 | — | 3.5 |
| *Mean* | | | | | *8.5* | | | | *3.0* | | | | *8.9* | | | | *3.4* |
| 5 | 4–9–8 | 9.0 | 8.7 | — | 8.9 | 3.2 | 3.0 | — | 3.1 | 8.2 | 8.3 | — | 8.3 | 3.3 | 3.3 | — | 3.3 |
| | 5–9–12 | 8.5 | 8.5 | 8.3 | 8.4 | 3.0 | 3.0 | 2.5 | 2.8 | 9.0 | 9.0 | 9.0 | 9.0 | 3.0 | 3.5 | 3.0 | 3.2 |
| | 3–9–12 | 9.0 | 8.7 | 8.7 | 8.8 | 3.0 | 3.0 | 3.0 | 3.0 | 8.5 | 8.7 | 9.0 | 8.7 | 3.0 | 3.0 | 3.0 | 3.0 |
| | 5–9–4 | 9.0 | 8.8 | 8.5 | 8.8 | 3.0 | 3.0 | 3.0 | 3.0 | 8.7 | 9.0 | 9.0 | 8.9 | 3.2 | 3.5 | 3.0 | 3.2 |
| | 5–9–4 | 8.7 | 8.7 | 8.7 | 8.7 | 3.0 | 3.0 | 3.0 | 3.0 | 8.0 | 9.0 | 8.7 | 8.6 | 3.0 | 3.3 | 3.0 | 3.1[1] |
| *Mean* | | | | | *8.7* | | | | *3.0* | | | | *8.7* | | | | *3.2* |
| 6 | 6–3–16 | 8.0 | 8.0 | 8.0 | 8.0 | 2.3 | 2.3 | 2.3 | 2.3 | 9.0 | 9.0 | 9.0 | 9.0 | 3.5 | 3.7 | 3.0 | 3.4[2] |
| | 6–9–8 | 8.0 | 8.0 | — | 8.0 | 3.0 | 3.0 | — | 3.0 | 9.0 | 9.0 | — | 9.0 | 3.0 | 3.0 | — | 3.0 |
| | 6–9–8 | 8.0 | 8.0 | 8.0 | 8.0 | 2.5 | 3.0 | 2.7 | 2.7 | 9.0 | 9.0 | 9.0 | 9.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| | 4–9–16 | 8.7 | 8.5 | 8.3 | 8.5 | 3.0 | 3.0 | 3.0 | 3.0 | 9.0 | 9.0 | 9.0 | 9.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| | 6–9–16 | 9.0 | 9.0 | 9.0 | 9.0 | 3.0 | 3.0 | 3.0 | 3.0 | 9.0 | 10.0 | 10.0 | 9.7 | 3.0 | 3.0 | 3.0 | 3.0[1] |
| *Mean* | | | | | *8.3* | | | | *2.8* | | | | *9.1* | | | | *3.1* |
| *Total mean* | | | | | *8.4* | | | | *3.0* | | | | *8.8* | | | | *3.4* |

[1] Near end tangent.
[2] Near start tangent.

## TABLE 21

### CHANGES IN THICKNESS AND DENSITY, OUTER WHEELPATH, TRENCH PROGRAM, SPRING 1960

| Loop | Design | Thickness (in.) | | Density (pfc) | | Change in Thickness (in.) | |
|---|---|---|---|---|---|---|---|
| | | Initial[1] | Trench[2] | Initial[3] | Trench[4] | Total Observed | Due to Densification |
| (*a*) SURFACING | | | | | | | |
| 3 | 4–3–8 | 4.04 | 3.81 | 149.3 | 150.8 | −0.23 | −0.04 |
| | 4–6–4 | 4.17 | 3.65 | 148.9 | 148.3 | −0.52 | +0.02 |
| | 4–6–8 | 3.93 | 4.07 | 149.2 | 149.9 | +0.14 | −0.02 |
| *Mean* | | *4.04* | *3.84* | *149.1* | *149.7* | *−0.20* | *−0.02* |
| 4 | 5–6–12 | 5.31 | 4.73 | 149.2 | 151.6 | −0.58 | −0.09 |
| | 5–6–8 | 4.87 | 4.94 | 149.1 | 150.9 | +0.07 | −0.06 |
| | 5–3–12 | 4.90 | 4.40 | 148.6 | 152.5 | −0.50 | −0.13 |
| *Mean* | | *5.03* | *4.69* | *149.0* | *151.7* | *−0.33* | *−0.09* |
| 5 | 5–9–12 | 5.03 | 4.29 | 150.5 | 150.8 | −0.74 | −0.01 |
| | 5–6–12 | 5.03 | 4.83 | 149.0 | 150.8 | −0.20 | −0.06 |
| | 5–9–8 | 5.06 | 4.53 | 149.3 | 149.6 | −0.53 | −0.01 |
| *Mean* | | *5.04* | *4.55* | *149.6* | *150.4* | *−0.49* | *−0.03* |
| 6 | 6–6–16 | 5.66 | 5.90 | 149.5 | 153.0 | +0.34 | −0.13 |
| | 6–9–12 | 5.84 | 5.48 | 149.6 | 150.3 | −0.36 | −0.03 |
| | 6–9–16 | 5.94 | 5.80 | 148.1 | 151.2 | −0.14 | −0.12 |
| *Mean* | | *5.78* | *5.73* | *149.1* | *151.5* | *−0.05* | *−0.09* |
| *Over-all Mean* | | *4.97* | *4.70* | *149.2* | *150.8* | *−0.27* | *−0.05* |
| (*b*) BASE | | | | | | | |
| 3 | 4–3–8 | 3.32 | 3.13 | 145.0 | 143.4 | −0.19 | +0.04 |
| | 4–6–4 | 5.60 | 5.66 | 142.6 | 145.8 | +0.06 | −0.13 |
| | 4–6–8 | 5.96 | 5.96 | 143.5 | 149.1 | 0.00 | −0.23 |
| *Mean* | | *4.96* | *4.92* | *143.7* | *146.1* | *−0.04* | *−0.08* |
| 4 | 5–6–12 | 6.50 | 6.45 | 140.6 | 146.3 | −0.05 | −0.26 |
| | 5–6–8 | 6.00 | 6.09 | 140.7 | 149.0 | +0.09 | −0.35 |
| | 5–3–12 | 3.10 | 2.87 | 139.9 | 137.2 | −0.23 | +0.06 |
| *Mean* | | *5.20* | *5.14* | *140.4* | *144.2* | *−0.06* | *−0.14* |
| 5 | 5–9–12 | 9.24 | 9.53 | 137.1 | 147.8 | +0.29 | −0.72 |
| | 5–6–12 | 6.14 | 6.09 | 143.1 | 140.5 | −0.05 | +0.11 |
| | 5–9–8 | 9.02 | 8.74 | 138.6 | 146.9 | −0.28 | −0.54 |
| *Mean* | | *8.13* | *8.12* | *139.6* | *145.1* | *−0.01* | *−0.32* |
| 6 | 6–6–16 | 6.16 | 5.77 | 138.1 | 141.5 | −0.39 | −0.15 |
| | 6–9–12 | 9.22 | 8.66 | 141.9 | 136.2 | −0.56 | +0.37 |
| | 6–9–16 | 8.60 | 8.57 | 140.2 | 141.4 | −0.03 | −0.07 |
| *Mean* | | *7.99* | *7.67* | *140.1* | *139.7* | *−0.33* | *+0.02* |
| *Over-all Mean* | | *6.57* | *6.46* | *140.9* | *143.8* | *−0.11* | *−0.14* |
| (*c*) SUBBASE | | | | | | | |
| 3 | 4–3–8 | 7.98 | 7.37 | 131.7 | 134.0 | −0.61 | −0.14 |
| | 4–6–4 | 3.74 | 3.72 | 133.6 | 137.4 | −0.02 | −0.11 |
| | 4–6–8 | 8.14 | 7.56 | 134.0 | 128.3 | −0.58 | +0.35 |
| *Mean* | | *6.62* | *6.22* | *133.1* | *133.2* | *−0.40* | *−0.01* |
| 4 | 5–6–12 | 11.38 | 11.04 | 130.3 | 143.4 | −0.34 | −1.14 |
| | 5–6–8 | 7.98 | 7.19 | 136.8 | 135.2 | −0.79 | +0.09 |
| | 5–3–12 | 12.32 | 11.02 | 137.3 | 135.2 | −1.30 | +0.19 |
| *Mean* | | *10.56* | *9.75* | *134.8* | *137.9* | *−0.81* | *−0.24* |
| 5 | 5–9–12 | 12.12 | 11.54 | 136.7 | 131.2 | −0.58 | +0.49 |
| | 5–6–12 | 11.96 | 10.84 | 135.9 | 134.7 | −1.12 | +0.11 |
| | 5–9–8 | 7.88 | 7.46 | 129.3 | 135.3 | −0.42 | −0.37 |
| *Mean* | | *10.65* | *9.95* | *134.0* | *133.7* | *−0.71* | *+0.02* |
| 6 | 6–6–16 | 15.60 | 14.91 | 139.5 | 131.3 | −0.69 | +0.92 |
| | 6–9–12 | 11.88 | 11.48 | 136.9 | 134.8 | −0.40 | +0.18 |
| | 6–9–16 | 16.54 | 16.27 | 136.6 | 141.3 | −0.27 | −0.57 |
| *Mean* | | *14.67* | *14.22* | *137.6* | *135.8* | *−0.45* | *+0.19* |
| *Over-all Mean* | | *10.63* | *10.03* | *134.9* | *135.2* | *−0.59* | *−0.02* |

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[1] Cores taken at 1, 6 and 11 ft from pavement centerline at third points in section; data are interpolations from these measurements.

[2] Thickness determined from transverse profile plot at maximum depth of rut; surface profiles prepared from 25 precise level measurements at 1-ft intervals.

[3] Average of two tests made at randomly selected locations.

[4] Average of two tests in outer wheelpath, one from each side of trench.

### TABLE 22
### CHANGES IN THICKNESS AND DENSITY, OUTER WHEELPATH, TRENCH PROGRAM, SUMMER 1960

| Loop | Design | Thickness (in.) | | Density (pcf) | | Change in Thickness (in.) | |
|---|---|---|---|---|---|---|---|
| | | Initial[1] | Trench[2] | Initial[3] | Trench[4] | Total Observed | Due to Densification |
| | (*a*) SURFACING | | | | | | |
| 3 | 4–3–8 | 3.90 | 3.45 | 149.3 | 150.2 | −0.45 | −0.02 |
| | 4–6–4 | 3.79 | 3.29 | 148.9 | 151.9 | −0.50 | −0.08 |
| | 4–6–8 | 3.93 | 3.66 | 149.2 | 151.2 | −0.27 | −0.05 |
| *Mean* | | *3.88* | *3.47* | *149.1* | *151.1* | *−0.41* | *−0.05* |
| 4 | 5–6–12 | 5.31 | 4.94 | 149.2 | 152.5 | −0.37 | −0.12 |
| | 5–6–8 | 4.87 | 4.36 | 149.1 | 152.8 | −0.51 | −0.12 |
| | 5–3–12 | 4.91 | 4.28 | 148.6 | 150.2 | −0.63 | −0.05 |
| *Mean* | | *5.03* | *4.53* | *149.0* | *151.8* | *−0.50* | *−0.09* |
| 5 | 5–9–12 | 5.04 | 4.57 | 150.5 | 152.4 | −0.47 | −0.06 |
| | 5–6–12 | 5.03 | 4.54 | 149.0 | 152.1 | −0.49 | −0.10 |
| | 5–9–8 | 5.06 | 4.63 | 149.3 | 151.3 | −0.43 | −0.07 |
| *Mean* | | *5.04* | *4.58* | *149.6* | *151.9* | *−0.46* | *−0.08* |
| 6 | 6–6–16 | 5.56 | 5.18 | 149.5 | 152.9 | −0.38 | −0.13 |
| | 6–9–12 | 5.84 | 5.37 | 149.6 | 151.6 | −0.47 | −0.08 |
| | 6–9–16 | 5.94 | 5.57 | 148.1 | 151.7 | −0.37 | −0.14 |
| *Mean* | | *5.78* | *5.37* | *149.1* | *152.3* | *−0.41* | *−0.12* |
| *Over-all Mean* | | *4.93* | *4.49* | *149.2* | *151.7* | *−0.45* | *−0.08* |
| | (*b*) BASE | | | | | | |
| 3 | 4–3–8 | 3.31 | 2.98 | 145.0 | 148.2 | −0.33 | −0.07 |
| | 4–6–4 | 5.78 | 5.44 | 142.6 | 146.4 | −0.34 | −0.15 |
| | 4–6–8 | 5.96 | 6.10 | 143.5 | 141.0 | +0.14 | +0.10 |
| *Mean* | | *5.02* | *4.84* | *143.7* | *145.2* | *−0.18* | *−0.05* |
| 4 | 5–6–12 | 6.44 | 6.12 | 140.6 | 145.0 | −0.32 | −0.20 |
| | 5–6–8 | 6.00 | 5.86 | 140.7 | 133.6 | −0.14 | +0.30 |
| | 5–3–12 | 3.06 | 3.18 | 139.9 | 142.0 | +0.12 | −0.05 |
| *Mean* | | *5.17* | *5.05* | *140.4* | *140.2* | *−0.12* | *+0.01* |
| 5 | 5–9–12 | 9.20 | 8.80 | 137.1 | 141.9 | −0.40 | −0.32 |
| | 5–6–12 | 5.86 | 5.64 | 143.1 | 144.9 | −0.22 | −0.07 |
| | 5–9–8 | 8.89 | 8.73 | 138.6 | 140.2 | −0.16 | −0.10 |
| *Mean* | | *7.98* | *7.72* | *139.6* | *142.3* | *−0.26* | *−0.15* |
| 6 | 6–6–16 | 6.16 | 6.02 | 138.1 | 142.2 | −0.14 | −0.18 |
| | 6–9–12 | 9.16 | 8.44 | 141.9 | 142.0 | −0.72 | −0.01 |
| | 6–9–16 | 8.60 | 8.42 | 140.2 | 141.9 | −0.18 | −0.10 |
| *Mean* | | *7.97* | *7.63* | *140.1* | *142.1* | *−0.34* | *−0.11* |
| *Over-all Mean* | | *6.54* | *6.31* | *140.9* | *142.4* | *−0.23* | *−0.07* |
| | (*c*) SUBBASE | | | | | | |
| 3 | 4–3–8 | 7.71 | 6.85 | 131.7 | 136.2 | −0.86 | −0.26 |
| | 4–6–4 | 3.80 | 3.70 | 133.6 | 137.9 | −0.10 | −0.12 |
| | 4–6–8 | 8.14 | 7.24 | 134.0 | 132.7 | −0.90 | +0.08 |
| *Mean* | | *6.55* | *5.93* | *133.1* | *135.6* | *−0.62* | *−0.12* |
| 4 | 5–6–12 | 11.40 | 11.12 | 130.3 | 129.0 | −0.28 | +0.11 |
| | 5–6–8 | 7.98 | 7.48 | 136.8 | 130.4 | −0.50 | +0.37 |
| | 5–3–12 | 11.76 | 11.30 | 137.3 | 132.9 | −0.46 | +0.38 |
| *Mean* | | *10.38* | *9.97* | *134.8* | *130.8* | *−0.41* | *+0.31* |
| 5 | 5–9–12 | 12.16 | 11.98 | 136.7 | 139.9 | −0.18 | −0.28 |
| | 5–6–12 | 11.98 | 10.80 | 135.9 | 134.8 | −1.18 | +0.10 |
| | 5–9–8 | 7.78 | 7.38 | 129.3 | 136.9 | −0.40 | −0.46 |
| *Mean* | | *10.64* | *10.05* | *134.0* | *137.2* | *−0.59* | *−0.25* |
| 6 | 6–6–16 | 15.60 | 15.00 | 139.5 | 138.6 | −0.60 | +0.10 |
| | 6–9–12 | 12.08 | 11.12 | 136.9 | 130.3 | −0.96 | +0.58 |
| | 6–9–16 | 16.54 | 16.20 | 136.6 | 142.5 | −0.34 | −0.71 |
| *Mean* | | *14.74* | *14.11* | *137.7* | *137.1* | *−0.63* | *+0.06* |
| *Over-all Mean* | | *10.58* | *10.01* | *134.9* | *135.2* | *−0.56* | *−0.02* |

[1] Cores taken at 1, 6 and 11 feet from pavement centerline at third points in section; data are interpolations from these measurements.

[2] Thickness determined from transverse profile plot at maximum depth of rut; surface profiles prepared from 25 precise level measurements at 1-ft intervals.

[3] Average of two tests at randomly selected locations.

[4] Average of two tests in outer wheelpath, one from each side of trench.

more consistency in the behavior of the surfacing than of the base and subbase components. In fact, the thickness of the surfacing of all the sections that were trenched had decreased in 94 percent of the cases and the density had increased in 98 percent. For the base course these values were 75 and 76 percent and for the subbase course 42 and 94 percent, respectively.

The summary of the data (Fig. 50) serves as further evidence that there was more uniformity in the changes in thickness of the surfacing in the wheelpaths particularly for the summer and fall trenches than in case of the granular courses. This is also shown for the between wheelpaths data (Fig. 51). Here, as expected, there was less reduction in the thickness of the layers than in the wheelpaths; and as far as the surfacing is concerned, it was all accounted for by changes in the density of the material. Actually since a large part of the change (reduction) in thickness of the surfacing in the wheelpaths was apparently due to lateral movement, it is not clear why this material did not exhibit an increase in thickness between the wheelpaths rather than a decrease.

In connection with the data in the tables and figures, the sum of the thickness changes in each layer plus the rut measured on the top of

TABLE 23

CHANGES IN THICKNESS AND DENSITY, OUTER WHEELPATH, TRENCH PROGRAM, FALL 1960

| Loop | Design | Thickness (in.) | | Density (pcf) | | Change in Thickness (in.) | |
|---|---|---|---|---|---|---|---|
| | | Initial[1] | Trench[2] | Initial[3] | Trench[4] | Total Observed | Due to Densification |
| | | | | *(a)* SURFACING | | | |
| 3 | 3–3–8 | 2.99 | 2.64 | 149.0 | 152.7 | −0.35 | −0.07 |
| 4 | 4–3–12 | 3.90 | 3.48 | 148.5 | 151.9 | −0.42 | −0.09 |
| | 4–6–8 | 4.03 | 3.54 | 148.8 | 152.3 | −0.49 | −0.09 |
| | 3–6–12 | 2.72 | 2.49 | 149.9 | 152.9 | −0.23 | −0.05 |
| | 5–3–8 | 4 81 | 4.35 | 149.5 | 151.3 | −0.46 | −0.06 |
| *Mean* | | *3.86* | *3.46* | *149.2* | *152.1* | *−0.40* | *−0.07* |
| 5 | 3–6–8 | 2.93 | 2.61 | 148.4 | 151.0 | −0.32 | −0.05 |
| | 3–6–12 | 2.68 | 2.42 | 148.1 | 152.3 | −0.26 | −0.08 |
| | 3–9–8 | 3.03 | 2.76 | 148.0 | 151.1 | −0.27 | −0.06 |
| | 3–9–12 | 3.10 | 2.70 | 149.3 | 153.4 | −0.40 | −0.09 |
| | 4–6–8 | 3.97 | 3.51 | 146.4 | 150.1 | −0.46 | −0.10 |
| | 4–6–12 | 3.97 | 3.30 | 147.6 | 152.4 | −0.67 | −0.13 |
| | 4–9–8 | 4.03 | 3.64 | 148.5 | 152.1 | −0.39 | −0.10 |
| | 4–9–12 | 4.03 | 3.45 | 148.6 | 153.6 | −0.58 | −0.14 |
| | 5–6–4 | 4.87 | 4.47 | 148.0 | 150.4 | −0.40 | −0.08 |
| | 5–6–8 | 5.09 | 4.91 | 150.1 | 151.6 | −0.19 | −0.05 |
| *Mean* | | *3.77* | *3.38* | *148.3* | *151.8* | *−0.39* | *−0.09* |
| 6 | 4–3–16 | 3.70 | 3.12 | 144.9 | 151.2 | −0.58 | −0.16 |
| | 4–6–12 | 3.61 | 3.12 | 148.5 | 150.6 | −0.49 | −0.05 |
| | 4–6–16 | 3.62 | 3.42 | 149.2 | 152.5 | −0.20 | −0.08 |
| | 4–9–12 | 3.85 | 3.33 | 149.9 | 153.4 | −0.52 | −0.09 |
| | 4–9–16 | 3.75 | 3.49 | 148.9 | 153.2 | −0.26 | −0.11 |
| | 5–6–12 | 4.90 | 4.11 | 150.3 | 152.7 | −0.79 | −0.08 |
| | 5–6–16 | 4.87 | 4.60 | 149.1 | 152.7 | −0.27 | −0.12 |
| | 5–9–12 | 4.78 | 4.16 | 150.2 | 153.1 | −0.62 | −0.09 |
| | 5–9–16 | 4.65 | 4.36 | 151.4 | 153.9 | −0.29 | −0.08 |
| | 6–3–12 | 5.81 | 5.16 | 148.0 | 154.0 | −0.65 | −0.24 |
| | 6–6–8 | 5.78 | 5.36 | 149.7 | 152.5 | −0.42 | −0.11 |
| | 6–6–12 | 5.72 | 5.52 | 149.4 | 154.4 | −0.20 | −0.19 |
| *Mean* | | *4.59* | *4.15* | *149.1* | *152.9* | *−0.44* | *−0.12* |
| *Over-all Mean* | | *4.12* | *3.70* | *148.8* | *152.3* | *−0.41* | *−0.10* |
| | | | | *(b)* BASE | | | |
| 3 | 3–3–8 | 3.56 | 3.54 | 142.0 | No trench densities taken | −0.02 | |
| 4 | 4–3–12 | 3.24 | 3.42 | 143.9 | | +0.18 | |
| | 4–6–8 | 6.44 | 6.18 | 144.1 | | −0.26 | |
| | 3–6–12 | 5.72 | 5.82 | 143.9 | | +0.10 | |
| | 5–3–8 | 3.22 | 2.82 | 143.7 | | −0.40 | |
| *Mean* | | *4.66* | *4.56* | *143.9* | | *−0.10* | |
| 5 | 3–6–8 | 6.40 | 6.36 | 144.6 | | −0.04 | |
| | 3–6–12 | 6.14 | 5.63 | 141.9 | | −0.51 | |
| | 3–9–8 | 9.14 | 9.20 | 143.2 | | +0.06 | |
| | 3–9–12 | 9.06 | 8.80 | 141.7 | | −0.26 | |
| | 4–6–8 | 6.74 | 6.31 | 138.1 | | −0.43 | |
| | 4–6–12 | 6.16 | 6.26 | 139.6 | | +0.10 | |
| | 4–9–8 | 9.11 | 9.16 | 145.0 | | +0.05 | |

the embankment soil does not always equal the depth of the existing rut on the pavement surface. This is because any uplift of the surfacing on either side of the rut will add to the depth of the rut. However, if this is ignored an approximation of the extent to which changes of thickness of each of the layers of the pavement contributed to the rut can be made. For example, in the 51 sections trenched in 1960, changes in thickness of the surfacing, base, subbase and the embankment soil contributed 32, 14, 45 and 9 percent, respectively, to the total rut.

Figure 52 shows the increase in the density of the asphaltic concrete with axle applications for the thickest pavement designs in the factorial experiment, Loops 5 and 6. As a reference, the 50-blow Marshall density is shown as the horizontal line on each plot. Initial data were taken from the as-constructed density measurements. Later, data were obtained from special tests during the period of test traffic. Figure 53 shows the effect of type of base material on the void content of the asphaltic concrete surface with axle applications. The greatest change in void content took place in case of the stone base sections and the least change in the bituminous-treated base sections.

| | | | | | | |
|---|---|---|---|---|---|---|
| | 4–9–12 | 8.66 | 8.26 | 142.5 | No trench densities taken | −0.40 |
| | 5–6–4 | 6.07 | 6.25 | 140.6 | | +0.18 |
| | 5–6–8 | 5.91 | 5.92 | 141.9 | | +0.01 |
| *Mean* | | *7.34* | *7.22* | *141.9* | | *−0.12* |
| 6 | 4–3–16 | 2.52 | 2.48 | 146.9 | | −0.04 |
| | 4–6–12 | 6.18 | 5.85 | 141.7 | | −0.83 |
| | 4–6–16 | 6.12 | 5.88 | 141.0 | | −0.24 |
| | 4–9–12 | 9.04 | 8.37 | 141.0 | | −0.67 |
| | 4–9–16 | 9.24 | 8.70 | 141.6 | | −0.54 |
| | 5–6–12 | 6.01 | 5.34 | 138.1 | | −0.67 |
| | 5–6–16 | 6.04 | 5.46 | 138.8 | | −0.58 |
| | 5–9–12 | 8.82 | 8.83 | 139.0 | | +0.01 |
| | 5–9–16 | 8.98 | 8.42 | 138.8 | | −0.56 |
| | 6–3–12 | 2.77 | 2.67 | 141.3 | | −0.10 |
| | 6–6–8 | 5.94 | 5.55 | 142.5 | | −0.39 |
| | 6–6–12 | 5.70 | 5.28 | 141.0 | | −0.42 |
| *Mean* | | *6.45* | *6.07* | *141.0* | | *−0.38* |
| *Over-all Mean* | | *5.50* | *5.35* | *141.8* | | *−0.16* |
| | | | (*c*) SUBBASE | | | |
| 3 | 3–3–8 | 7.52 | 6.99 | 131.0 | No trench densities taken | −0.53 |
| 4 | 4–3–12 | 11.73 | 11.37 | 135.7 | | −0.36 |
| | 4–6–8 | 7.94 | 7.80 | 136.7 | | −0.14 |
| | 3–6–12 | 12.20 | 11.70 | 137.4 | | −0.50 |
| | 5–3–8 | 7.97 | 8.37 | 138.2 | | +0.40 |
| *Mean* | | *9.96* | *9.81* | *137.0* | | *−0.15* |
| 5 | 3–6–8 | 7.88 | 7.20 | 135.8 | | −0.68 |
| | 3–6–12 | 12.54 | 11.72 | 138.7 | | −0.82 |
| | 3–9–8 | 7.71 | 7.48 | 131.3 | | −0.23 |
| | 3–9–12 | 12.03 | 10.88 | 133.7 | | −1.15 |
| | 4–6–8 | 7.90 | 7.30 | 137.6 | | −0.60 |
| | 4–6–12 | 11.86 | 11.55 | 133.7 | | −0.31 |
| | 4–9–8 | 7.86 | 6.57 | 136.3 | | −1.29 |
| | 4–9–12 | 12.24 | 11.87 | 133.9 | | −0.37 |
| | 5–6–4 | 3.40 | 3.21 | 133.5 | | −0.19 |
| | 5–6–8 | 8.08 | 7.59 | 135.1 | | −0.49 |
| *Mean* | | *9.15* | *8.54* | *135.0* | | *−0.61* |
| 6 | 4–3–16 | 16.28 | 15.47 | — | | −0.81 |
| | 4–6–12 | 11.36 | 11.40 | 139.4 | | +0.04 |
| | 4–6–16 | 15.92 | 15.10 | 135.9 | | −0.82 |
| | 4–9–12 | 12.00 | 11.31 | 132.2 | | −0.69 |
| | 4–9–16 | 15.12 | 14.82 | 137.6 | | −0.30 |
| | 5–6–12 | 11.81 | 10.94 | 134.6 | | −0.87 |
| | 5–6–16 | 15.56 | 15.59 | 136.7 | | +0.03 |
| | 5–9–12 | 12.08 | 11.43 | 138.6 | | −0.65 |
| | 5–9–16 | 15.38 | 15.07 | 129.3 | | −0.31 |
| | 6–3–12 | 12.29 | 11.74 | 135.2 | | −0.55 |
| | 6–6–8 | 7.76 | 7.67 | 139.5 | | −0.09 |
| | 6–6–12 | 12.24 | 12.01 | 139.1 | | −0.23 |
| *Mean* | | *13.15* | *12.71* | *136.2* | | *−0.44* |
| *Over-all Mean* | | *9.95* | *9.50* | *135.7* | | *−0.43* |

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[1] Cores taken at 1, 6 and 11 ft from pavement centerline at third points in section; data are interpolations from these measurements.

[2] Thickness determined from transverse profile plot at maximum depth of rut; surface profiles prepared from 25 precise level measurements at 1-ft intervals.

[3] Average of two tests made at randomly selected locations; nuclear probe used to determine base density, Rainhart equipment to determine subbase density.

[4] Average of two tests in outer wheelpath, one from each side of trench.

Because rut depths were measured every two weeks throughout the period of traffic testing, it was possible to develop plots for the many different designs of pavement, showing the progression of rutting with axle applications. Such plots are included on the historical records of each factorial section and for each subsection of the paved shoulder and the special base experiment. (The basic data used in the development of these plots is in DS 4120 and 4123.) For the purpose of this discussion, certain plots of this type are presented here. Those in Figure 54 are for factorial sections and those in Figure 55 for certain of the special base sections. They are for designs, all of which survived the 1,114,000 axle applications of the test loads. All plotted points are means of the rut depth in the inner and outer wheelpaths. The data indicate that a greater increase in the progression of rutting occurred for the first year of test traffic than for the second year. Thus, there is definite evidence that the rate of the rut development was decreasing with load applications.

A representation of rutting versus load applications for sections having the three types of base material is shown in Figure 56. This was developed after examining the trend of rutting with load applications of sections that survived the test in the factorial and the special base experiments (Figs. 54 and 55). It is intended to show the trend of rut development with time during the course of the Road Test and the relative level of the depth of rutting in the surface for sections containing the three types of base. According to Figure 56, rutting of stone base sections began early in the spring, continued at a somewhat slower rate during the summer and remained fairly constant during the fall and winter months. In contrast, rutting of bituminous-treated base sections did not begin until warm weather when it developed at a relatively rapid rate until the fall and winter when it remained fairly constant. The difference in the trend of rutting for equivalent thicknesses of crushed stone and of bituminous-treated base during the spring months is considered to be due to the added strength of the bituminous material at low temperatures, its consequent lower deflections and its greater resistance to consolidation and displacement. It is emphasized that this schematic representation is for pavements that survived the Road Test. The lower level of rutting of the sections with cement-treated bases is accounted for by the fact that all of the rutting took place in the surfacing course itself. This situation is considered to exist as long as the thickness of the cement-treated base is sufficient to prevent cracking of the base material into small pieces with subsequent vertical or transverse displacement of the pieces themselves.

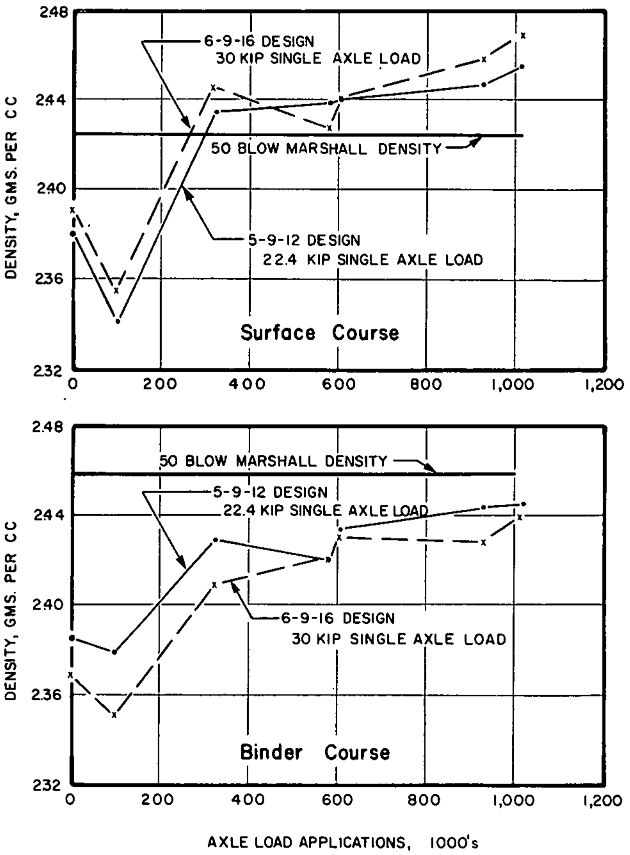


**Figure 52. Change in surfacing density with axle load applications.**

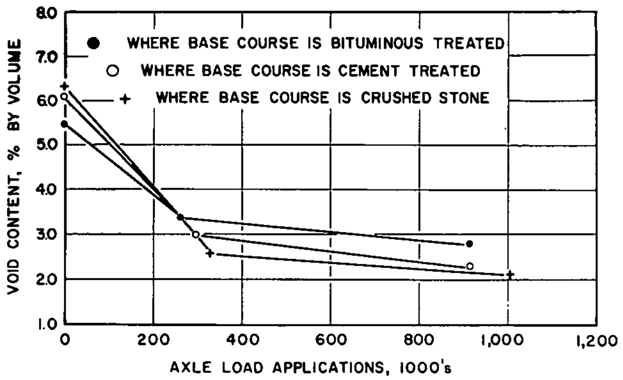


**Figure 53. Effect of base type on void content of surface course material.**

Because of the wide range in base thicknesses provided in the special base study, it was possible to relate rut depth to base thickness for each base type and for several levels of axle loadings. These relationships are shown in Figures 57, 58 and 59 for bituminous-treated, cement-treated and crushed stone bases. All data are for the single axle lanes and the plotted points are means of the rut depth in the inner and outer wheelpaths of the two replicates, that is, the mean of four values. Measurements of the rut depths were made periodically at 5-ft intervals during the test traffic phase. The lines fitted to the points by eye indicate that there was a level of base thickness above which the surface rut depth remained essentially constant and below which it increased rapidly.

Disregarding the variations in surfacing and subbase thickness from loop to loop and interpolating or extrapolating for the loops where each base type was not represented, estimated values of minimum base thickness above which little or no reduction in surface rutting was noted with increase in base thickness are as follows:

| Single Axle (kips) | Design Thickness (in.) | | | Base (in.) | | |
|---|---|---|---|---|---|---|
| | Surf. | Base | Subbase | Bitum. | Cement | Stone |
| 12 | 3 | Variable | 0 | 4 | 5[1] | — |
| 18 | 3 | Variable | 4 | 6[1] | 8 | 14 |
| 22.4 | 3 | Variable | 4 | 7 | 10 | 14[1] |
| 30 | 4 | Variable | 4 | 9.5 | 12 | — |
| 30 | 4 | Variable | 8 | — | — | 13 |

[1] Interpolated or extrapolated.

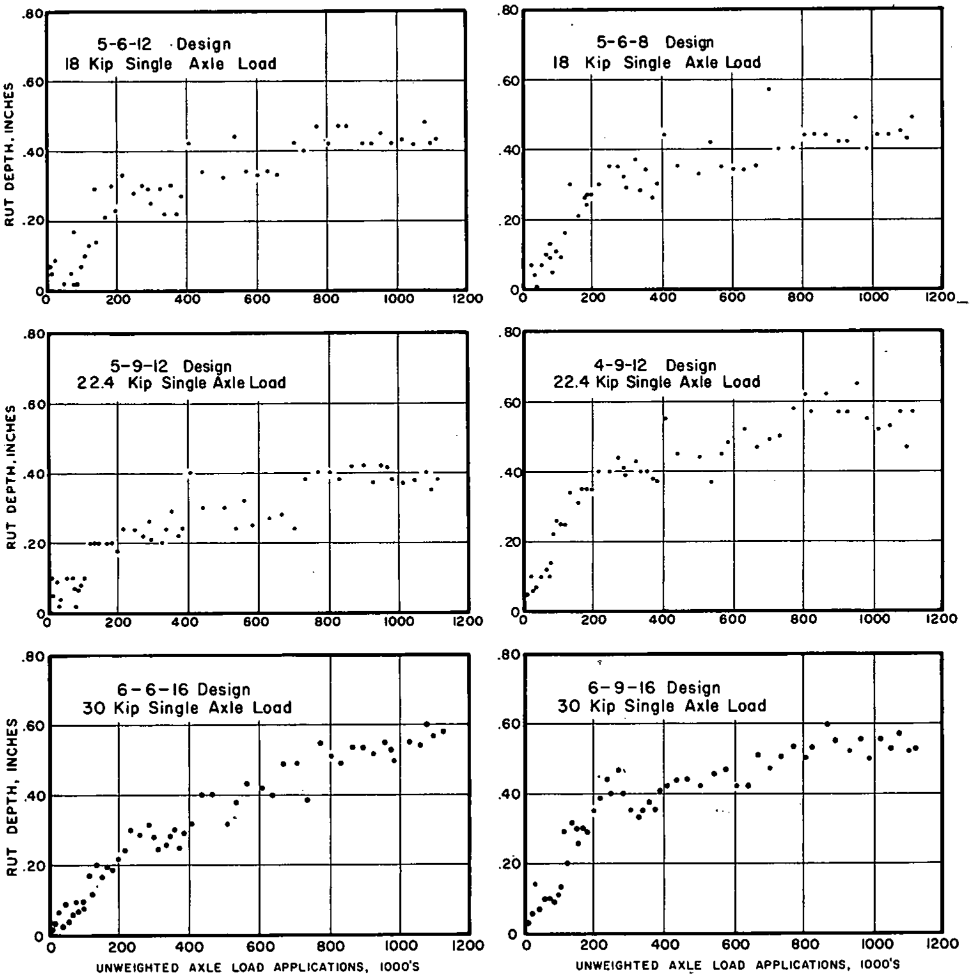


Figure 54. Effect of axle load application on depth of rut; typical sections from main factorial experiment.

Relationships between rut depth and axle load for the late summer of 1959 and for the fall of 1960 are given in Figures 60 and 61. The values of rut depths are for thicknesses of the bases where rutting was no longer reduced with further increase in thickness. Relationships of this type for the crushed stone base are not shown since it was not possible to determine the thickness of this material beyond which the depth of rut for the 12-kip single and the 24-kip tandem axle loads remained constant (Fig. 59).

*2.2.3.2 Cracking.*—Cracking was also an element of structural deterioration that detracted from serviceability and performance of flexible pavement. Records were maintained of the development of cracks in order that relationships could be established between cracking, pavement design and load applications.

Eq. 29 was developed from which the number of axle loads sustained by the pavement before Class 2 cracking of the surface occurred could be computed for any design and load. By including a deflections term in the equation it was found that a somewhat better prediction of load application could be obtained (Eq. 30 and 31).

More surface cracking occurred during periods when the pavement structure was in a relatively cold state than during periods of warm weather.

Generally, cracking was more prevalent in sections having deeper ruts than in sections with shallower ruts.

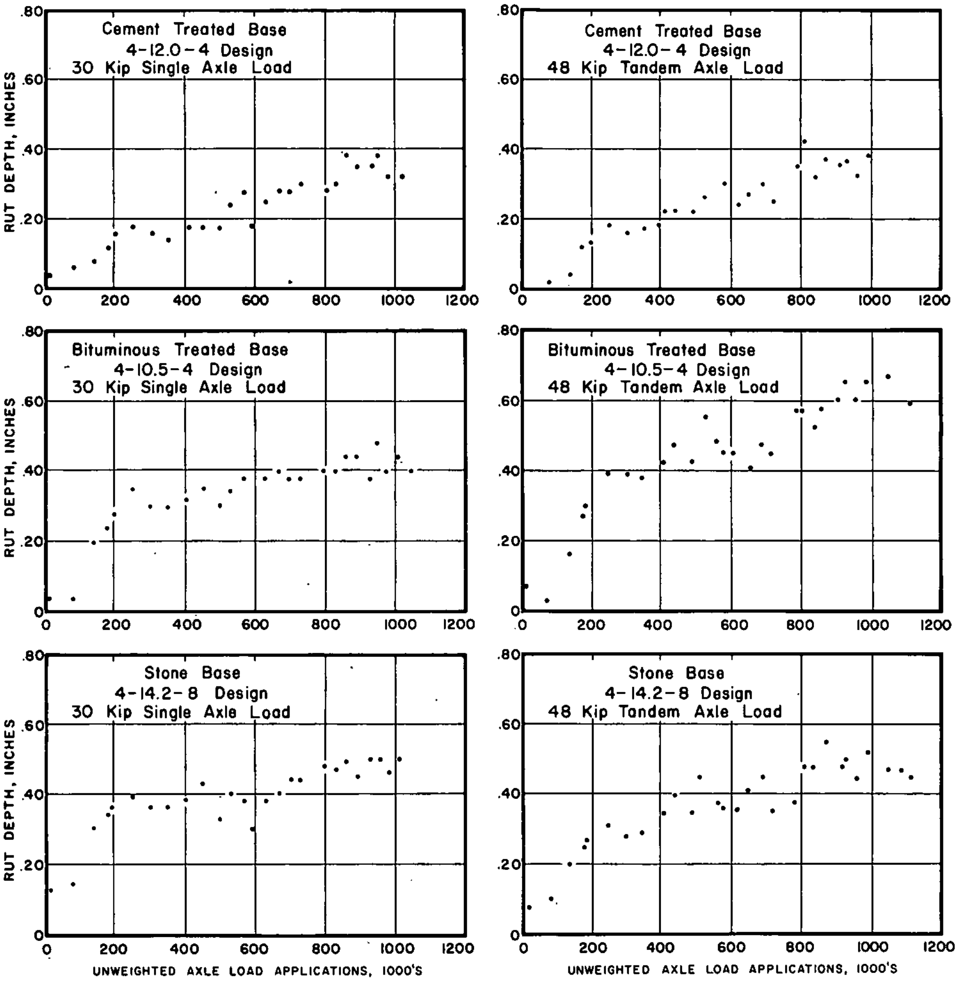


Figure 55. Effect of axle application on depth of rut; typical sections from special base experiment.

An important element of the serviceability and the performance of flexible pavements was cracking of the surfacing material. Although cracks do not in themselves have much effect on the ability of the pavement to serve traffic, they serve as indications that something about the pavement design is inadequate and that failure of the pavement is likely to occur at an earlier date than would be the case if no cracking appeared.

For purpose of classification, cracking was

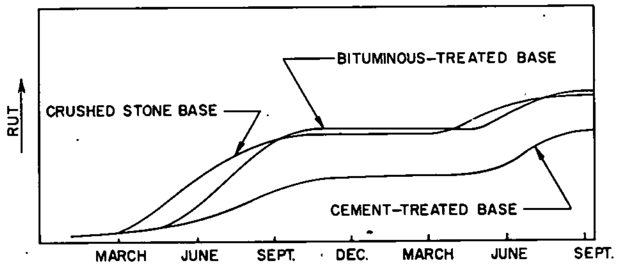


Figure 56. Relative effect of seasons on rutting.

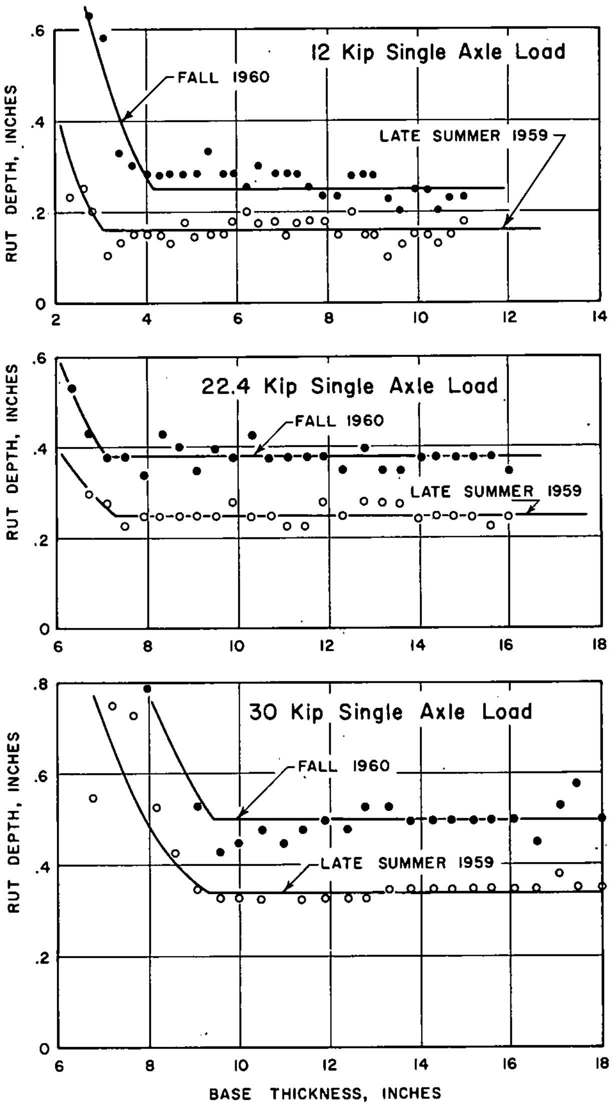


Figure 57. Effect of thickness of bituminous-treated base on depth of rut.

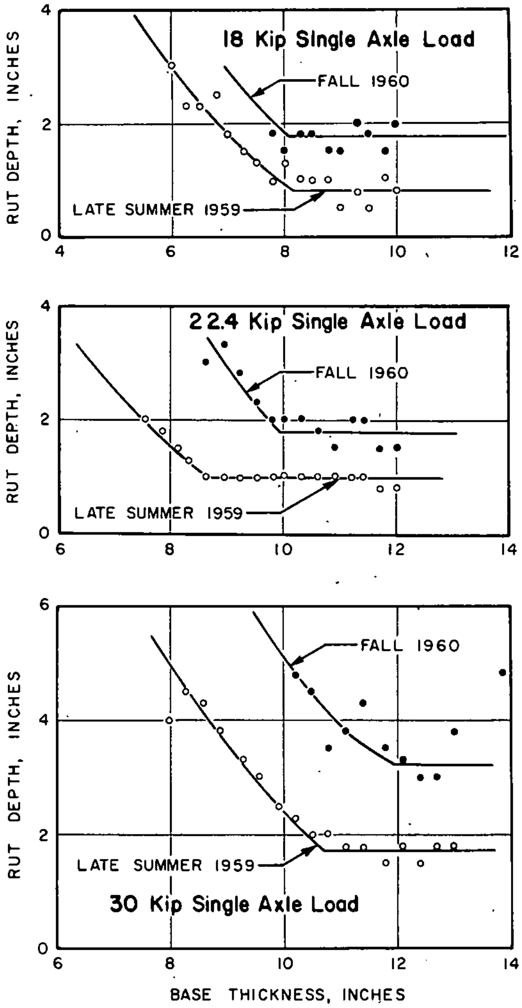


Figure 58. Effect of thickness of cement-treated base on depth of rut.

divided into three categories, namely: Class 1, Class 2 and Class 3 (see Fig. 66). Class 1 cracking was the earliest type observed and consisted of fine disconnected hairline cracks. As distress increased the cracks in the Class 1 type lengthened and widened until cells were formed into what is commonly called alligator cracking. Such cracking was called Class 2 cracking. A small amount of surface spalling at the crack was usually evident.

When the segments of the Class 2 cracks spalled more severely at the edges and loosened until the cells rocked under traffic, the situation was called Class 3 cracking.

Much of the Class 1 cracking which appeared in the spring "healed" (that is, the cracks were no longer visible at the pavement surface) during the summer months when pavement temperatures rose to over 120 F. Class 1 cracking was not included in the evaluation of serviceability of the pavement. Only when the cracking was so severe as to be classified Class 2 or Class 3 was it considered in the serviceability index.

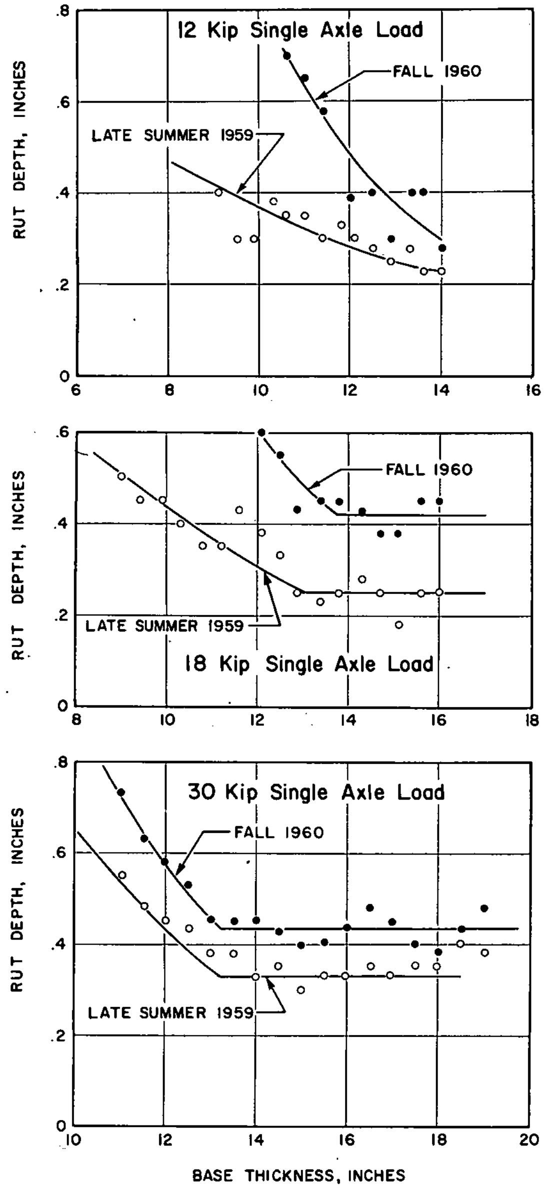


Figure 59. Effect of thickness of crushed stone base on depth of rut.

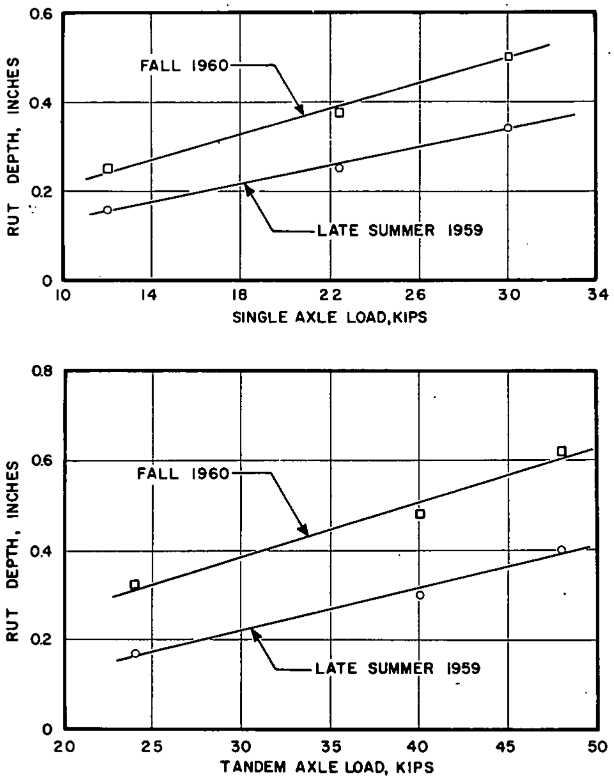


Figure 60. Relationship between axle load and minimum rut depth in bituminous-treated base wedge sections.

A mathematical analysis was undertaken in which the number of axle load applications sustained by a flexible pavement before the appearance of Class 2 cracking was expressed as a function of the pavement structure design and axle load. The mathematical model selected for the analysis was the same as the model for log $\rho$ used in the pavement performance analyses.

$$W_c = \frac{A_0(a_1D_1+a_2D_2+a_3D_3+a_4)^{A_1}\,L_2^{A_3}}{(L_1+L_2)^{A_2}} \tag{28}$$

in which

$W_c$ = number of weighted axle applications sustained by the pavement before appearance of Class 2 cracking;

$D_1, D_2$ and $D_3$ = thicknesses of surfacing, base and subbase, in inches;

$L_1$ = nominal axle load (*e.g.*, for an 18-kip single axle load $L_1 = 18$, for a 32-kip tandem axle load $L_1 = 32$); and

$L_2$ = 1 for single axle configuration and 2 for tandem axle configuration.

The coefficients and exponents designated $A_0 \ldots a_1 \ldots$ are either to be assigned or determined by analysis of the data. For these analyses the cofficient $a_4$ was assigned the value of 1.

Analysis of the factorial experiment data of the number of weighted applications sustained prior to Class 2 cracking made on the basis of Eq. 28 resulted in

$$\log W_c = 5.484 + 7.275 \log (0.33D_1 + 0.10D_2 + 0.08D_3 + 1) + 2.947 \log L_2 - 3.136 \log (L_1 + L_2) \qquad (29)$$

The mean absolute residual (that is, the difference between the logarithm of the observed number of applications, $W_c$, and the logarithm of applications estimated by Eq. 29 was 0.18; the squared correlation coefficient was 0.79.

Figure 62 shows, as a curved line, the relationships from Eq. 29 between cracking thickness index $(0.33D_1 + 0.10D_2 + 0.08D_3)$ and the weighted applications sustained prior to Class 2 cracking for the single axle lanes of Loops 4 and 5. Also plotted are points showing the number of applications at which time Class 2 cracking was actually observed to occur in the test sections in these lanes. The fit of Eq. 29 to the data in the other Road Test lanes was about the same.

Eq. 29 may be used to predict $W_c$ for pavements similar to those in the Road Test; however, in case of pavements in service, a somewhat better prediction of $W_c$ can be made by a slightly different approach. At the Road Test this involved the measurement in each test section of creep speed deflection under a 12-kip single axle load in the fall of 1958, shortly after pavement construction was completed and again in the spring of 1959, during the period of adverse environmental conditions for flexible pavements. It was assumed that the as-constructed fall deflection, $d_f$, or the spring deflection, $d_s$, would help in the prediction of $W_c$ when used in conjunction with design and load information. The model chosen for analysis was identical to Eq. 28 except that a term, $d^{A_4}$, was included in the denominator.

Evaluation of the constants in this model resulted in Eq. 30 when fall deflections $d_f$ (in 0.001 in.) were used and in Eq. 31 when spring deflections, $d_s$, were used:

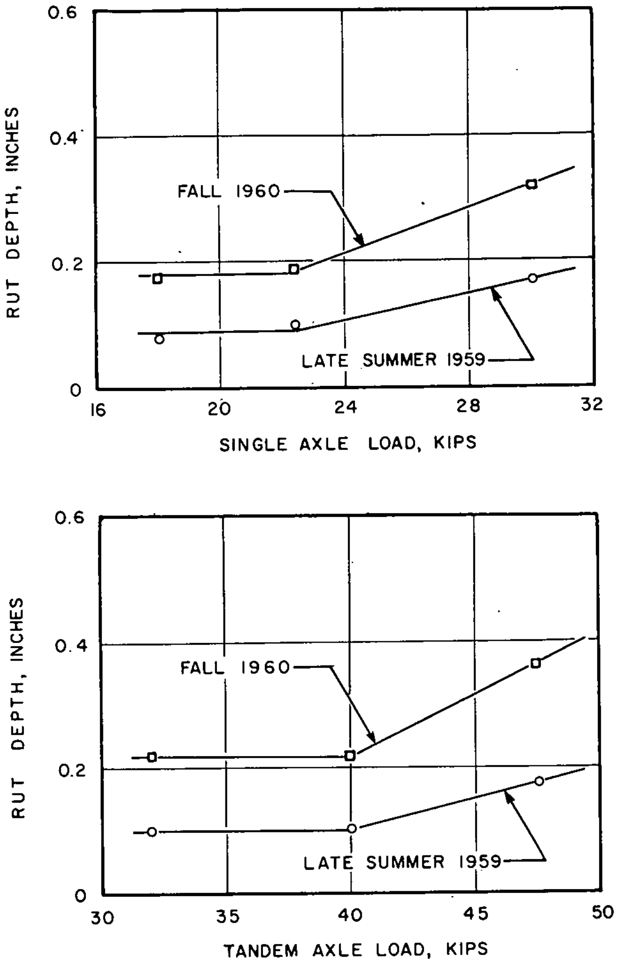


**Figure 61. Relationship between axle load and minimum rut depth in cement-treated base wedge sections.**

$$\log W_c = 7.847 + 5.919 \log (0.33D_1 + 0.10D_2 + 0.08D_3 + 1) + 2.850 \log L_2 - 3.204 \log (L_1 + L_2) - 1.106 \log d_f \qquad (30)$$

The mean absolute residual was 0.16 and $r^2 = 0.84$.

$$\log W_c = 8.131 + 4.526 \log (0.33D_1 + 0.10D_2 + 0.08D_3 + 1) + 2.185 \log L_2 - 2.434 \log (L_1 + L_2) - 1.296 \log d_s \qquad (31)$$

The mean absolute residual was 0.16 and $r^2 = 0.85$.

The improvement in the squared correlation coefficient, from 0.79 in Eq. 29 to 0.84 and 0.85 in Eqs. 30 and 31 means that it is possible to explain about 5 percent more of the variation

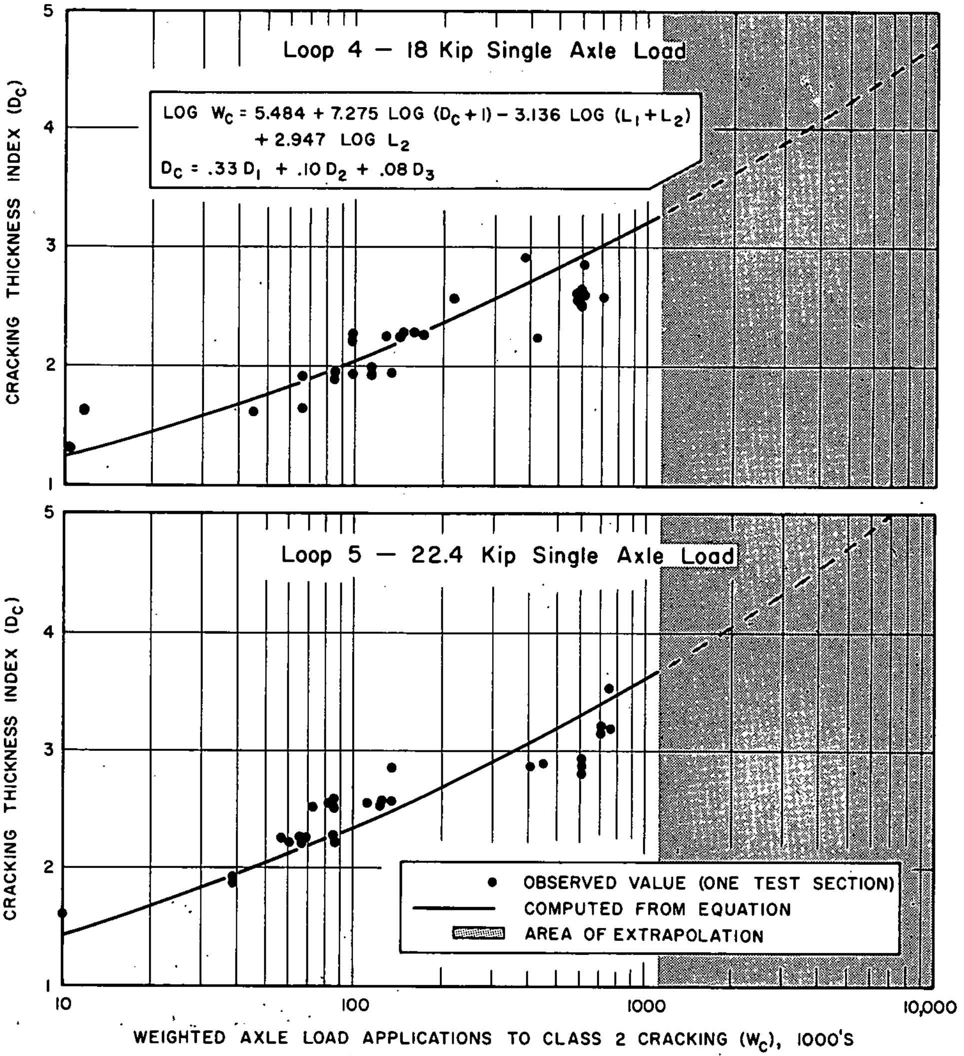


**Figure 62. Relationship between pavement design, axle load applications and Class 2 cracking.**

in log $W_c$ if the deflection (either $d_f$ or $d_s$) is used than can be explained in terms of load and design alone. The mean residual of 0.18 for log $W_c$ predictions from Eq. 29 indicates that observations whose residuals are less than the mean residual will range from 64 percent to 151 percent of the corresponding prediction. With the addition of the deflection term, however, the mean residual of 0.16 corresponds to the narrower range of 69 percent to 144 percent. Although these gains are probably not great enough to warrant the time and expense required for taking deflection measurements, it must be remembered that Road Test construction was exceptionally uniform. In normal highway construction a greater spread in deflection for a given design may be expected and thus a prediction of $W_c$ by Eq. 30 or Eq. 31 may be considerably more precise than one from Eq. 29 without the deflection term.

Figure 63 shows the fit to the observation attained by Eq. 30. The fit of Eq. 31 is very similar and the other lanes were similar to those shown. To show a smooth curve for the relationship it was necessary to adjust the predicted number of applications by the deflection term from the equation. Thus the plots in Figure 63 are for cracking thickness index, $D_c$, on the ordinate and for log $W_c$ + 1.106 log $d_f$ on the abscissa. The extrapolated portion of the curve was computed assuming a 12-kip axle load deflection of 0.012 in. (approximately the minimum deflection to be expected regardless of thickness).

A bar graph showing the time of appearance of Class 2 cracking as it occurred in the test sections of the main factorial experiment is shown in Figure 64. Most cracking occurred during periods when the pavement structure was in a relatively cold state, slightly above freezing. The peak period for the appearance of Class 2 cracking was in April for both spring seasons. Rutting on the other hand occurred more during warm weather (see Fig. 56, Section 2.2.3).

Figure 65 shows the number of sections, cracked and uncracked, for different levels of rutting. Among sections having deeper ruts, a greater proportion of the sections also had cracking than was the case among sections having shallower ruts.

## 2.3 DEFLECTION AS RELATED TO DESIGN, LOAD, SPEED AND TEMPERATURE

Relationships were developed between flexible pavement deflection and pavement design, load, vehicle speed and pavement temperature to provide a basis for the deflection vs pavement performance studies reported in Section 2.4. Findings were as follows:

In the main factorial experiment the asphaltic concrete surfacing was much more effective, inch for inch, in reducing pavement deflection, particularly during the spring, than was the base or subbase.

The subbase was somewhat more effective than the base in restricting deflection in both the spring and fall (see Section 2.3.1).

In the special base experiment the level of deflection was considerably greater at each season (spring, summer and fall) in the sections with gravel and stone base (9 in. thick) than in sections with bituminous- and cement-treated base of the same thickness.

The deflection of the sections with 9-in. gravel and stone bases reached a maximum during the spring, decreased during the summer and continued to decrease until late in the fall.

The deflection of the sections with 9-in. bituminous- and cement-treated bases increased only to a slight degree in the spring, reached a maximum during the summer, and decreased during the fall.

The high level of deflection of the sections with stone and gravel bases in the spring was considered due to adverse subsurface conditions at this time; the lower level in the fall, to an improvement in these conditions.

The deflections of the sections with gravel base were somewhat lower than those for sections with stone base, although the performance of the stone base was considerably better than that of the gravel base sections (Section 2.3.2).

The deflection occurring within the pavement structure (surface, base and subbase), as well as that at the top of the embankment soil, was greater in the spring than during the succeed-

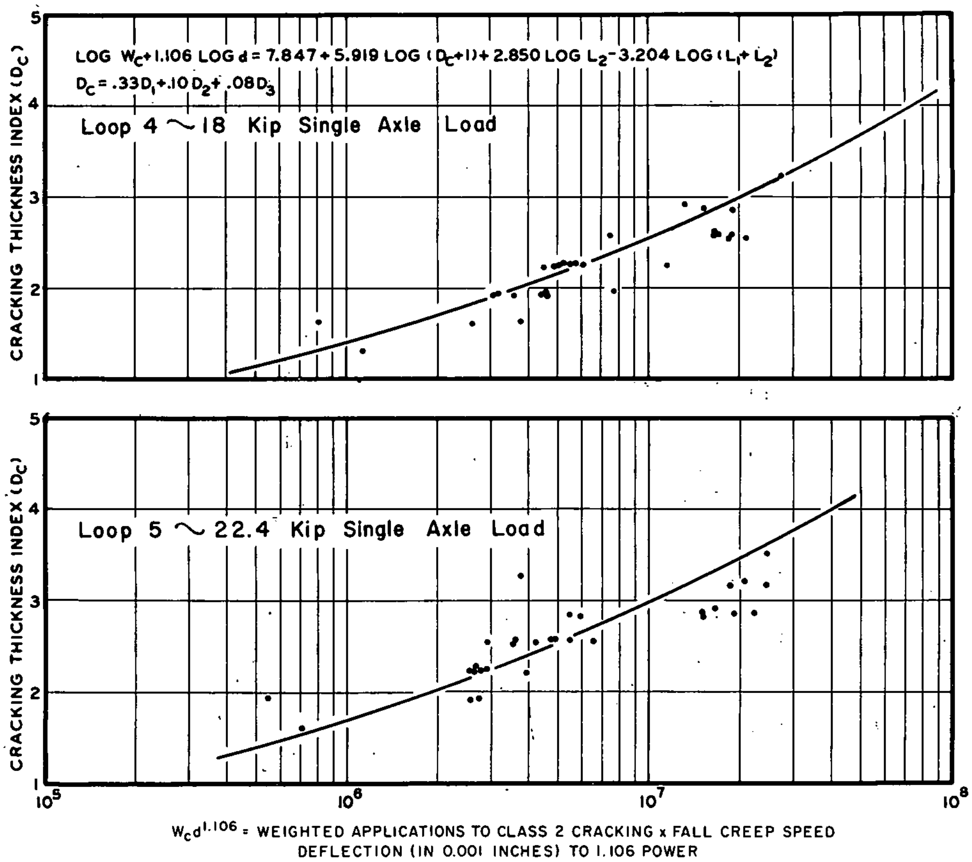


**Figure 63. Relationship of design to axle load applications at Class 2 cracking and fall creep speed deflection.**

ing summer months. This was considered to be due to the higher moisture contents of the base and subbase that existed in the spring.

A high degree of correlation was found to exist between the deflection at the top of the embankment and the total deflection (Section 2.3.3).

A pronounced reduction in deflection accompanied an increase in vehicle speed. Increasing the speed from 2 to 35 mph reduced the total deflection 38 percent, the embankment deflection 35 percent, and the partial deflection 67 percent (see Fig. 78, Section 2.3.4 for definition of partial deflection).

In the studies of the effect of the temperature of the asphaltic concrete surfacing upon deflection, it was found that between 80 and 120 F the deflection was essentially constant. At about 80 F it began to decrease as the temperature decreased. As shown by Figures 87 through 91, the extent of the decrease varied, depending upon such factors as the age and traffic history of the pavement, the speed of the vehicles, the design of the pavement, the type of base, and the time of the year when the tests were made.

An extensive program was conducted in which deflections of the flexible pavement sections under moving loads were measured periodically throughout the traffic testing phase of the Road Test. The principal purposes of this program were (1) to provide information that could be used in the fulfillment of objective 5 which called for, ". . . test procedures, data, charts, graphs, and formulas which will reflect the capabilities of the various test sections. . . ." (these studies are reported in Section 2.4), and (2) to develop relationships showing how deflection is influenced by pavement design, load, vehicle speed, etc. (these studies are discussed in this section). Data upon which the deflection studies are based are given in Appendix C.

Taken together, the studies showing how deflection is influenced by design and load and the studies showing how performance may be predicted by deflection, may add to the understanding of the mechanics of load support of flexible pavements. This should prove helpful to engineers in pavement design work and in the evaluation of the capabilities of existing pavements.

### *2.3.1 Deflection as a Function of Design and Load, Factorial Experiments*

Deflections of the surface of the pavement were measured with the Benkelman beam under

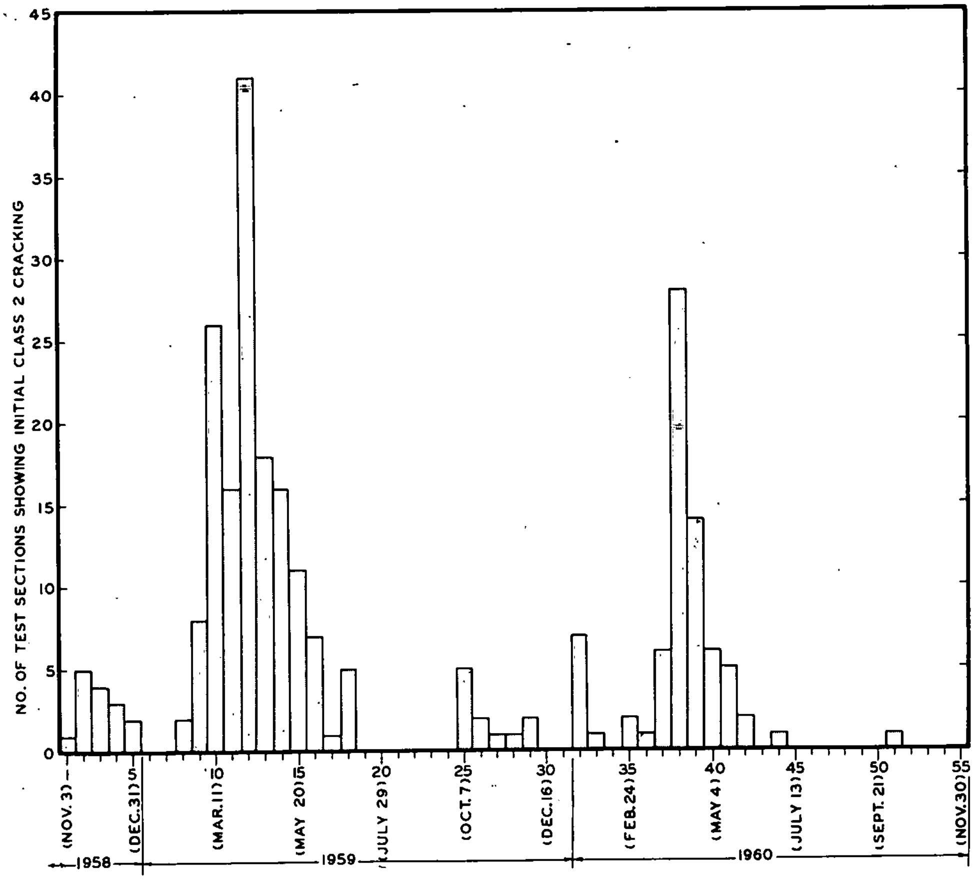


Figure 64. Main factorial experiment, development of Class 2 cracking.

vehicle wheels moving at creep speed (approximately 2 mph). For each section in the factorial experiment (Design 1) the deflection reported for each date consisted of the mean of four measurements; two in the inner and two in the outer wheelpath.

Two series of deflection measurements were used in the development of relationships among deflection, design and load. The first series included deflections of each Road Test section measured in the fall of 1958 shortly after construction of the pavement was completed. The second included those measured in the spring of 1959 after the disappearance of frost. Each series consisted of the means of two complete sets of measurements.

The fall period was selected for study because many highway pavements are completed and opened to traffic at this time. The spring period was selected because, in the frost susceptible areas of the country, flexible-type pavements are most likely to undergo distress at this time. In view of this, it was expected that spring deflections would be more highly correlated with pavement performance than those of other periods. This proved to be the case.

Table 24 shows load assignments for the deflection program in each traffic lane.

All routine flexible pavement deflection data for the traffic loops appear in DS 5121.

Spring and fall normal and rebound deflections were analyzed to determine the influence of design and load on deflection. Equations were developed for each of the single axle lanes for the spring and fall normal and rebound deflections. The mathematical model used for these analyses was:

$$d = 10^{a_0 + a_1D_1 + a_2D_2 + a_3D_3 + a_4L_1} \qquad (32)$$

in which

$d$ = deflection, in 0.001 in.;

$D_1, D_2, D_3$ = thickness of surfacing, base and subbase, respectively;

$L_1$ = axle load in kips; and

$a_0, a_1, a_2, a_3$, and $a_4$ = coefficients to be determined from the analysis.

The equations resulting from these analyses were used to determine the relative effect of the thickness of surfacing, base and subbase courses on deflection. Although there was considerable variation among the coefficients from one loop to the next, there was no consistent trend that indicated the need of including a load-design interaction term in the across-loop equations. Consequently, it was assumed that the best estimates for $a_1$, $a_2$, and $a_3$ were the means of the values from the individual loop equations. Coefficients from the Loop 2, lane 2 equation were not included.

TABLE 24

LOADS USED IN DEFLECTION STUDIES

| Loop | Lane | Single Axle Load (kips) |
|---|---|---|
| 2 | 1 | — |
| | 2 | 6 |
| 3 | 1 | 6, 12 |
| | 2 | 6, 12 |
| 4 | 1 | 12, 18 |
| | 2 | 12 |
| 5 | 1 | 12, 22.4 |
| | 2 | 12 |
| 6 | 1 | 12, 30 |
| | 2 | 12 |

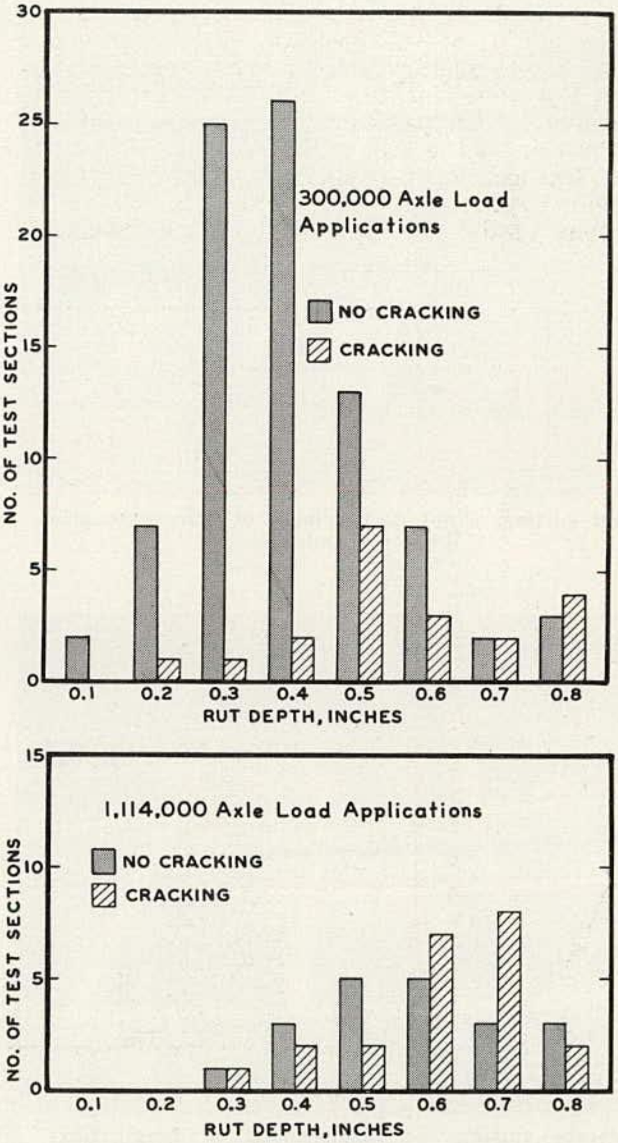
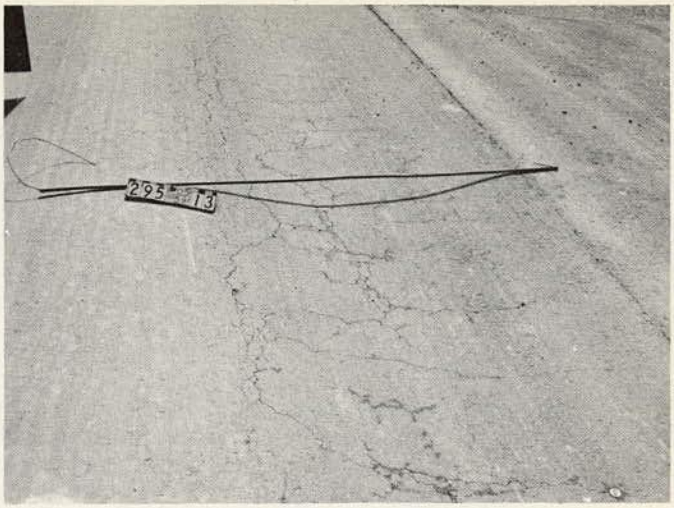
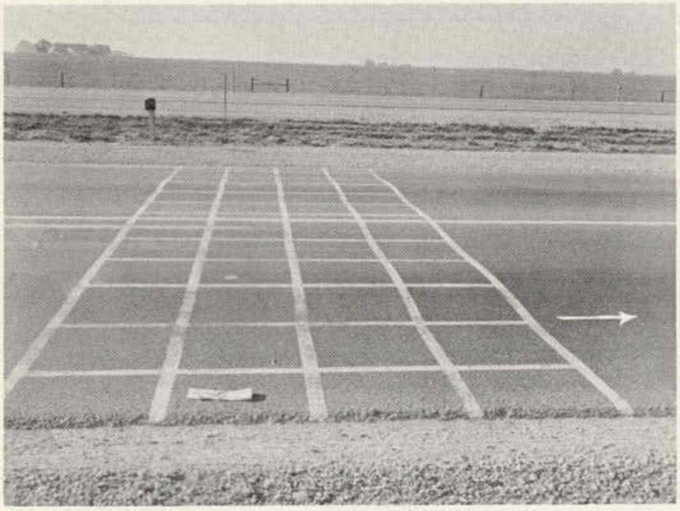


Figure 65. Main factorial experiment, relationship between cracking and rut depth (Loops 3, 4, 5 and 6, all test sections in test).

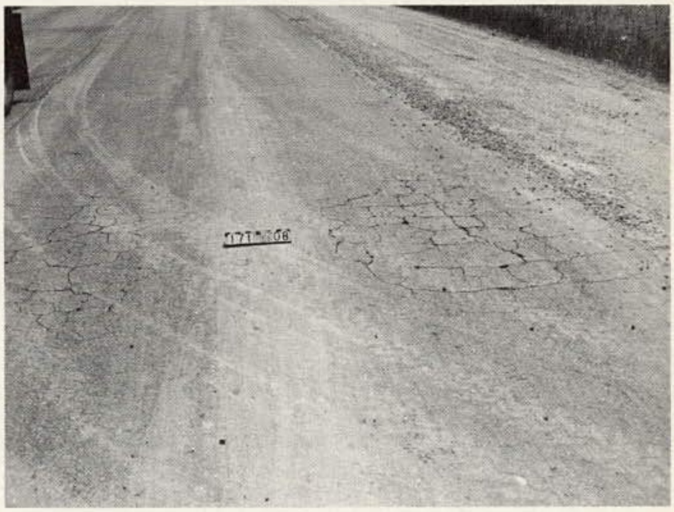
Evidence of longitudinal rutting, water in wheelpaths after a rain in a no-traffic period.



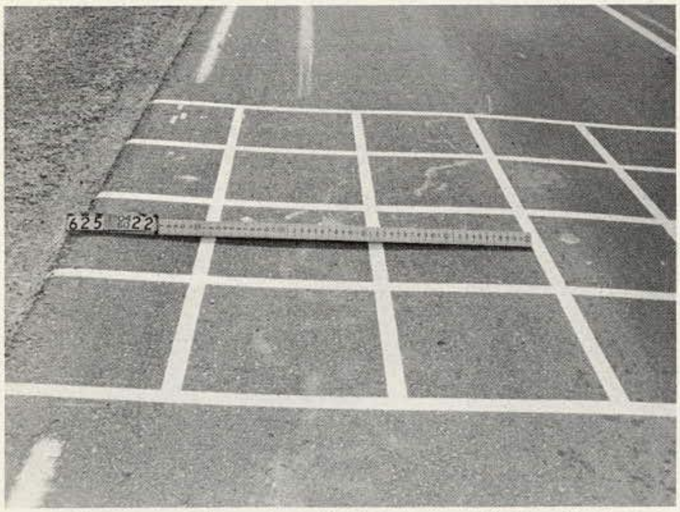
Pronounced rutting, Class 2 cracking.



Minor rutting, slight displacement of transverse grid lines in wheelpaths.



Class 2 cracking.



Moderate rutting, no displacement of longitudinal grid line.

Class 3 cracking.

Figure 66. Typical distress in flexible pavement.

These coefficients made it possible to express pavement design as a single number (thickness index, $D$) insofar as its affect on log $d$ was concerned. These indexes were:

$$D = 0.049D_1 + 0.014D_2 + 0.023D_3 \quad \text{(fall normal deflections)} \tag{33}$$

$$D = 0.125D_1 + 0.020D_2 + 0.028D_3 \quad \text{(spring normal deflections)} \tag{34}$$

$$D = 0.056D_1 + 0.016D_2 + 0.026D_3 \quad \text{(fall rebound deflections)} \tag{35}$$

$$D = 0.140D_1 + 0.021D_2 + 0.031D_3 \quad \text{(spring rebound deflections)} \tag{36}$$

Examination of the coefficients for surfacing, base and subbase thickness in Eqs. 33 through 36 disclosed that the surfacing was much more effective in reducing pavement deflection, particularly during the spring period of the year, than was the base or subbase. This is evident from the ratios of the coefficients in each thickness index to the base coefficient as follows:

| Period | Procedure | Ratio | | | Surf. Temp. (°F) |
|---|---|---|---|---|---|
| | | Base | Surfacing | Subbase | |
| Fall | Normal | 1.0 | 3.5 | 1.6 | 70 |
| Spring | Normal | 1.0 | 6.2 | 1.4 | 59 |
| Fall | Rebound | 1.0 | 3.5 | 1.6 | 70 |
| Spring | Rebound | 1.0 | 6.7 | 1.5 | 59 |

The greater effectiveness of the surfacing during the spring months can be attributed to the lower temperatures that prevailed at this time, a condition under which the asphaltic material is better able to support and distribute load.

The values of equivalence of the materials listed also show that the subbase was somewhat more effective than the base in restricting deflection in both the fall and spring periods. However, in this connection it should be pointed out that the subbase material underlaid the base and was at a level in the pavement structure where the vertical stresses were considerably lower than they were nearer the surface.

Normal and rebound deflections were analyzed across single axle loads using the model

$$d = \frac{B_0 L_1^{B_1}}{(D + 1)^{B_2}} \tag{37a}$$

or

$$\log d = \log B_0 + B_1 \log L_1 - B_2 \log (D + 1) \tag{37b}$$

in which

$d = d_{fn}, d_{fr}, d_{sn}$, or $d_{sr}$ = fall normal, fall rebound, spring normal, or spring rebound deflection, in 0.001 in.;

$L_1$ = axle load, in kips;

$D$ = thickness index, previously given for each of the four cases; and

$B_0, B_1, B_2$ = constants derived through the analysis.

The logarithmic equations resulting from the analysis, together with the correlation index $c^2$ that expresses the goodness of fit of the respective equation to the data, and a mean log residual $\bar{r}$ that indicates the average discrepancy between log $d$ as observed and as calculated from the equation, are as follows:

*For the fall normal procedure deflection:*

$$\log d_{fn} = 0.74 + 1.13 \log L_1 - 3.61 \log (0.049\,D_1 + 0.014\,D_2 + 0.023D_3 + 1) \tag{38}$$

$$c^2 = 0.55, \quad \bar{r} = 0.09$$

*For the spring normal procedure deflection:*

$$\log d_{sn} = 1.07 + 1.46 \log L_1 - 4.42 \log (0.125D_1 + 0.020D_2 + 0.028D_3 + 1) \tag{39}$$

$$c^2 = 0.79, \quad \bar{r} = 0.07$$

*For the fall rebound procedure deflection:*

$$\log d_{fr} = 0.76 + 1.09 \log L_1 - 3.32 \log (0.056D_1 + 0.016D_2 + 0.026D_3 + 1) \tag{40}$$

$$c^2 = 0.51, \quad \bar{r} = 0.10$$

*For the spring rebound procedure deflection:*

$$\log d_{sr} = 1.06 + 1.54 \log L_1 - 4.60 \log (0.140D_1 + 0.021D_2 + 0.031D_3 + 1) \tag{41}$$

$$c^2 = 0.80, \quad \bar{r} = 0.07$$

Figure 67 shows the spring and fall normal deflections for each of the five single axle loads used in the analysis. Figures 68 and 69 show the equations for individual loads, as well as the scatter of observed data about the curves.

Only small differences exist between the normal and rebound procedure with respect to coefficients, correlation indexes, or mean residuals. Spring deflections are more closely associated with pavement design factors and load than are the fall deflections as is evidenced by higher correlation indexes and lower mean residuals.

Since the mean residual when calculating either log $d_{sn}$ or log $d_{sr}$ is 0.07, approximately 90 percent of the observed spring deflections lie between 0.72 and 1.38 times the corresponding deflections calculated from Eqs. 39 and 41. Using 0.10 as the mean residual for fall deflection equations, about 90 percent of the observed fall deflections lie between 0.63 and 1.59 times the corresponding calculated deflections.

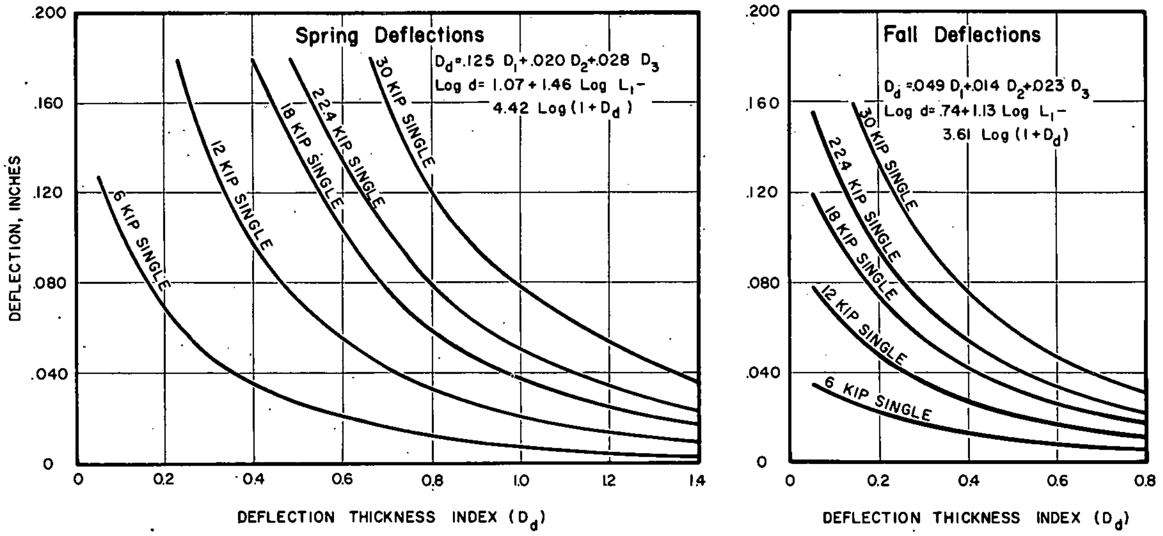


Figure 67. Relationship between pavement design and creep speed deflection (from Road Test equations).

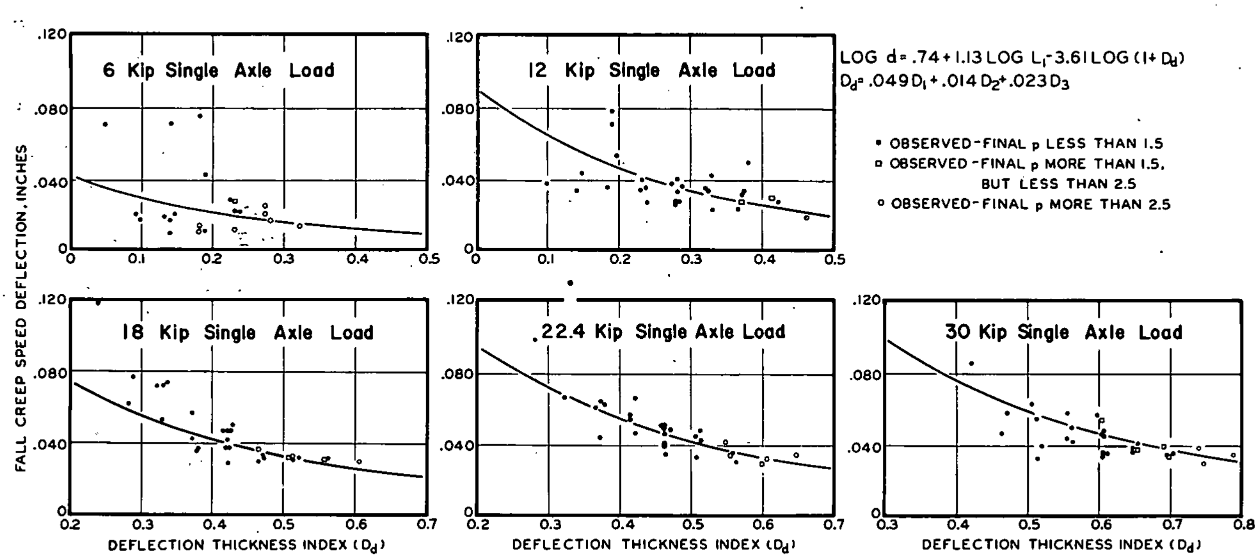


Figure 68. Main factorial experiment, relationship between design and fall creep speed deflection.

### *2.3.2 Deflection as a Function of Design and Load, Base Type Experiment*

Creep speed deflection tests were made every two weeks during the period of traffic operation on the special base sections (Design 4). Single axle loads were employed as follows:

| Loop | Single Axle Lane (kips) | Tandem Axle Lane (kips) |
|---|---|---|
| 3 | 6 and 12 | 6 |
| 4 | 12 and 18 | 12 |
| 5 | 12 and 22.4 | 12 |
| 6 | 12 and 30 | 12 |

Measurements were taken in both wheelpaths at the midpoint of each 40-ft subsection. The procedures used were the same as those outlined in Section 2.3.1.

The results of tests made in the fall of 1958 (before start of test traffic), and in the spring, summer and fall of 1959 are shown in Figures 70 through 73. The values given are the means of the deflection in both wheelpaths for two to four series of tests. The test dates for the selected periods were as follows:

| Season | Test Dates | Avg. Temp. of Surfacing (°F) |
|---|---|---|
| Fall 1958 | Oct. 5; Nov. 8 | 72 |
| Spring 1959 | March 20, 31;<br>April 16, 27 | 68 |
| Summer 1959 | Aug. 3, 17, 31 | 96 |
| Fall 1959 | Oct. 12, 26; Nov. 8 | 55 |

After examining a number of deflection histories, these dates were selected to represent the associated seasons. However, they do not necessarily correspond to the maximum or minimum values of deflection for each base type. Generally, deflections were greater in the spring in the stone and gravel base sections; they were greater in the summer for the bituminous and cement base sections.

Curves were constructed by eye through the data of Figures 70 and 73, and the values of deflection for 9-in. thicknesses of each type of base were obtained from the curves. These values are plotted in Figure 74, which shows the differences in level of deflection of each base type for the four periods of testing. For each period, the level of deflection of the gravel and stone base sections was considerably greater than that for the bituminous and cement base sections.

The deflection of the gravel and stone bases reached a maximum during the spring, decreased during the summer, and continued to decrease during the fall; the pattern being much the same as for the factorial sections.

The deflection of the bituminous- and cement-treated bases increased only to a slight degree in the spring; and for some unknown reasons reached a maximum during the summer, and decreased during the fall.

The high level of deflection of the stone and gravel sections in the spring was due to adverse subsurface conditions that exist at this time; the lower level in the fall months was due to improved subsurface conditions.

Asphaltic concrete is more able to support and distribute load at low temperature than at high (see Section 2.3.1). The relatively low deflections of the bituminous base sections in the spring and the higher values in the summer may be attributed to this fact. The relatively low deflections in the fall months may be partially due to the temperature of the bituminous base and surfacing, and to better subsurface conditions.

Although the deflections of the gravel base sections were somewhat less than those of the stone base sections, the performance of the stone base was considerably better than the gravel. Perhaps the gravel possessed less internal stability than the stone; yet, it may have been somewhat less resilient.

### *2.3.3 Deflection at Embankment Level*

In Sections 2.3.1 and 2.3.2, all references have been to deflections of the pavement surface measured at creep speed with the Benkelman beam. Additional studies were conducted in which deflections were measured with electronic devices at speeds ranging from creep speed to 50 mph. Small linear variable differential transformers (hereafter designated LVDT) were used as transducers that translated movements into changes in electric current which were recorded by conventional means. These devices were used to measure

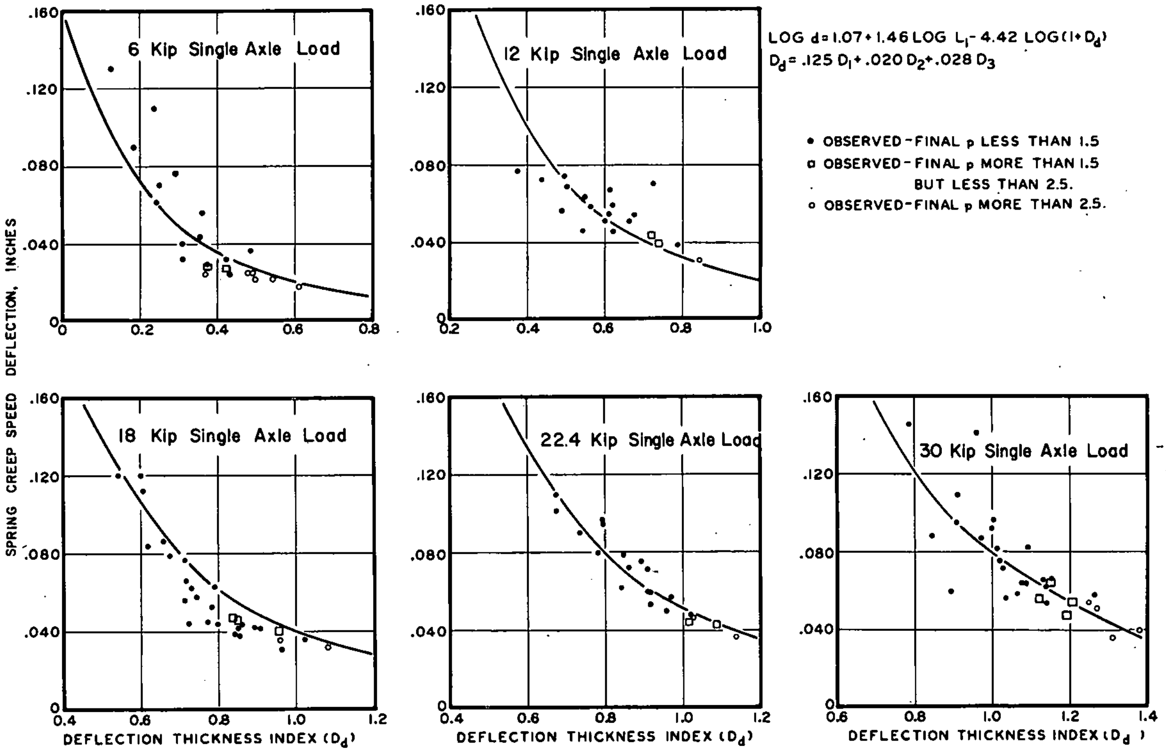


Figure 69. Main factorial experiment, relationship between pavement design and spring creep speed deflection.

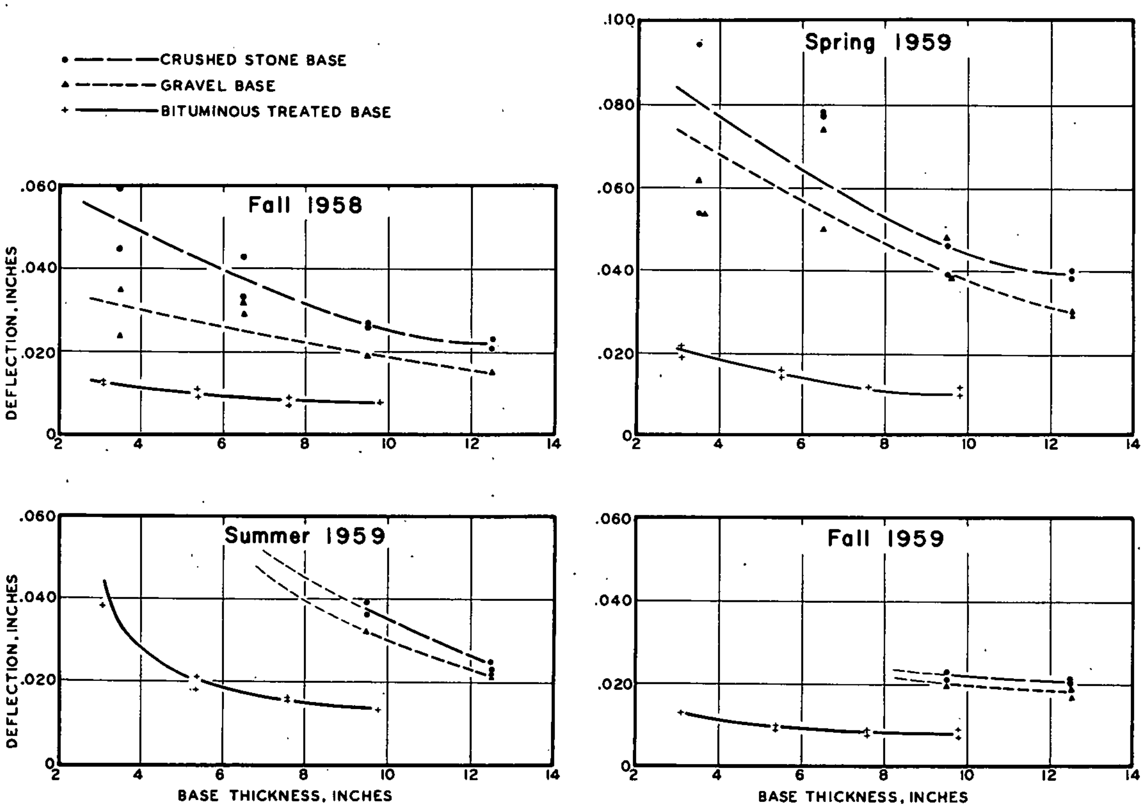


Figure 70. Special base type experiment, relationship between base thickness and deflection, 12-kip single axle load, Loop 3.

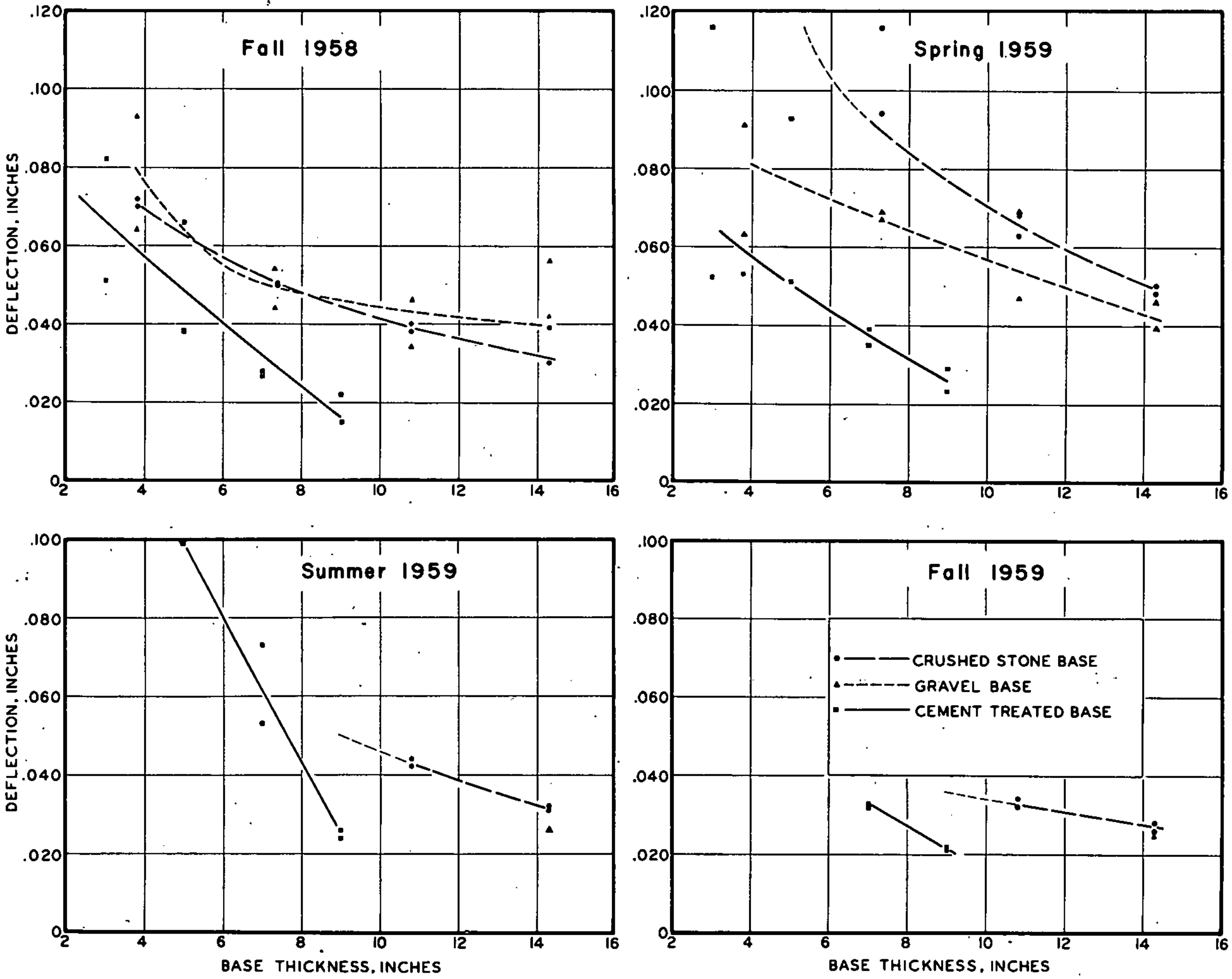


Figure 71. Special base type experiment, relationship between base thickness and deflection, 18-kip single axle load, Loop 4.

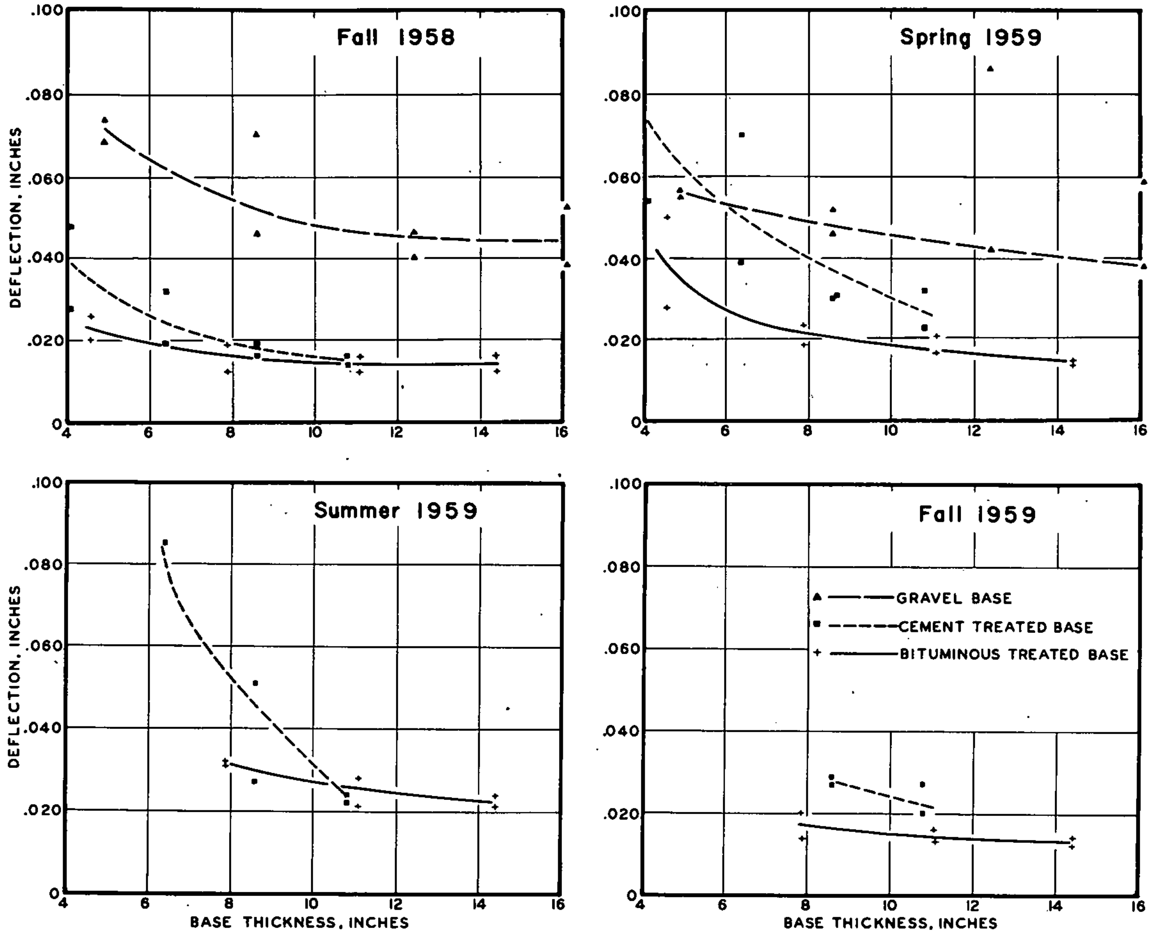


Figure 72. Special base type experiment, relationship between base thickness and deflection, 22.4-kip single axle load, Loop 5.

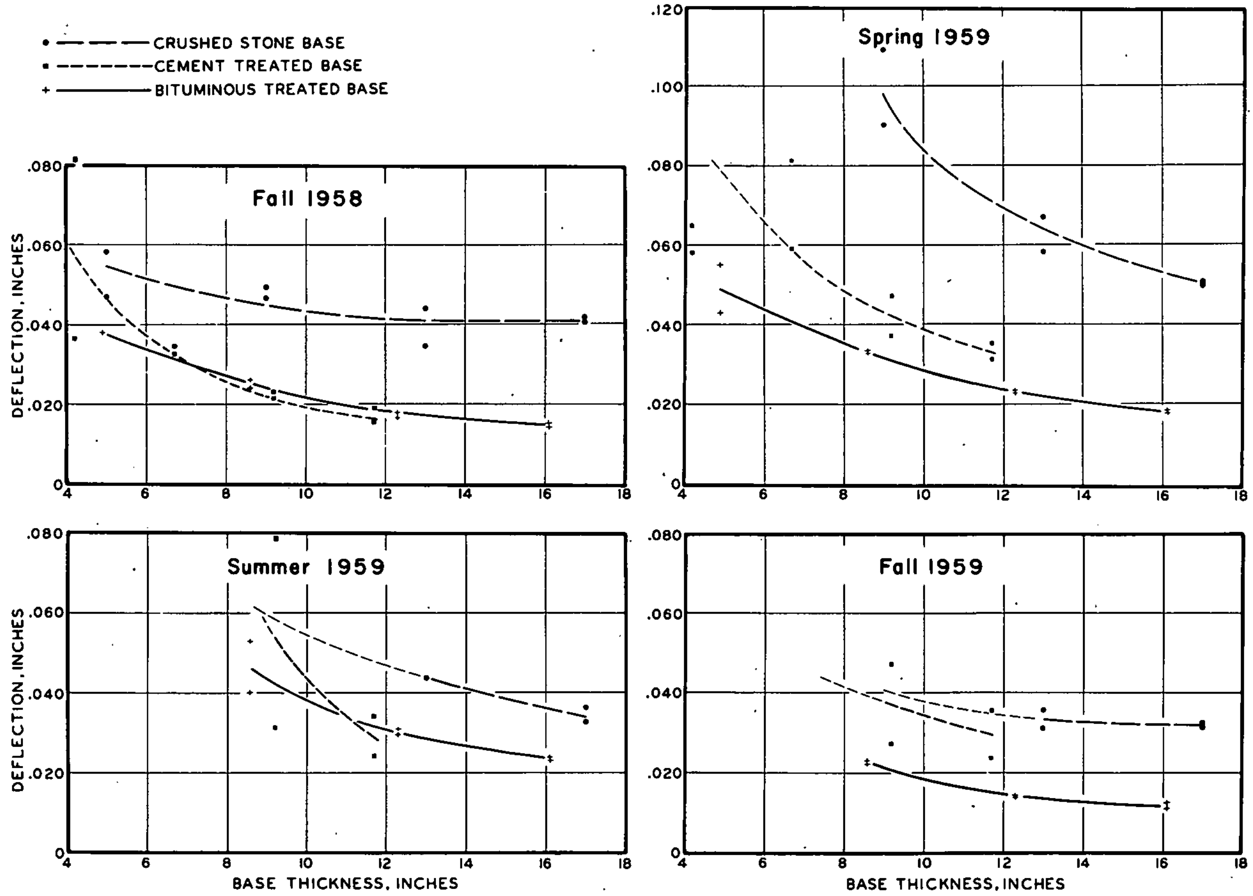


Figure 73. Special base type experiment, relationship between base thickness and deflection, 30-kip single axle load, Loop 6.

deflections at various levels beneath the pavement surface as well as on the surface (see Appendix D for a description of the test equipment and procedures).

Because dynamic deflections could be measured in only one test section at a time, nearly two weeks were required to obtain a complete set of readings in all of the instrumented sections. These tests were normally made during scheduled traffic operations under the regular traffic test vehicles. Except during the winter months, these measurements were taken continuously throughout the traffic testing phase. Basic data from these tests may be obtained from the Highway Research Board in DS 5141, which defines deflection as the mean of the five highest readings taken during any individual observation period. Readings were not recorded unless the center of the dual wheels passed within 5½ in. of the center of the LVDT installation.

Deflections of the pavement surface were referenced to plates installed 6 ft below the top of the embankment, on the embankment surface and on the top of the subbase. The difference between the deflections referenced to the deep plates (total deflection) and those referenced to the plates on the top of the embankment (deflection within the pavement structure only) was the deflection of the surface of the embankment. Figure 75 shows relationships between deflection and total structure thickness for five of the traffic lanes at four periods during the traffic testing phase. The data shown include manual Benkelman beam deflections taken at creep speed on the surface, and surface deflections and embankment deflections taken at the regular test traffic speeds of 35 mph (no beam deflections were taken under the 32-kip tandem axle load). The four periods correspond to four seasons and the data for each season represents the averages of the biweekly deflection measuring series. The selected series for each season are as follows: spring 1959—May 1 and May 19; summer 1959—June 16, July 2, July 15 and August 12; spring 1960—April 8, April 19, and May 4; summer 1960—May 31, June 23, and July 13. The average absolute deviation from the plotted means (dynamic tests) for each of these periods was spring 1959, 0.0035 in.; summer 1959, 0.0029 in.; spring 1960, 0.0034 in.; summer 1960, 0.0033 in. It may be noted that the creep speed deflections are considerably greater than the high speed deflections. Data concerning the effect of speed on deflection are presented in Section 2.3.6.

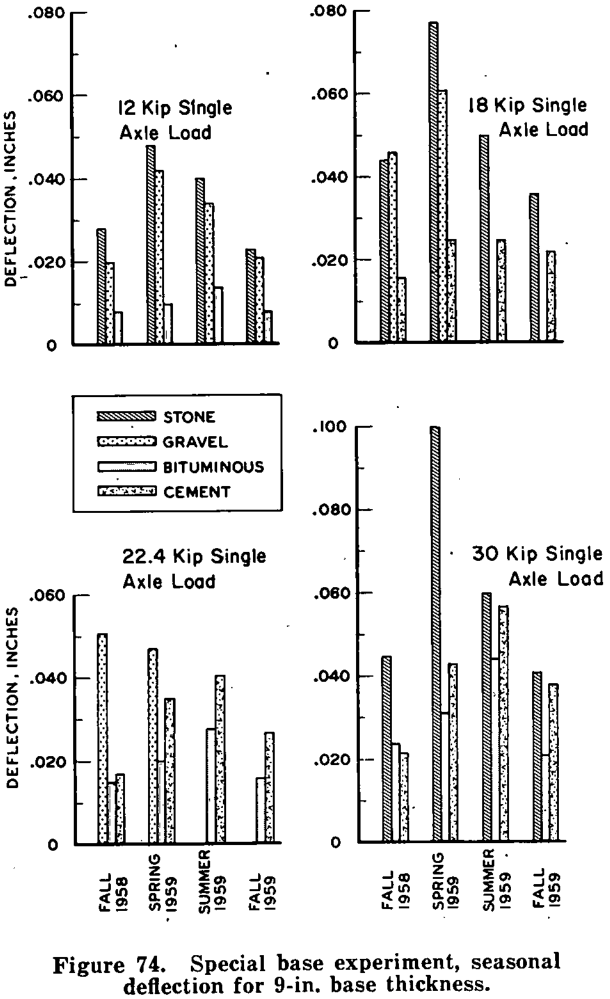


**Figure 74. Special base experiment, seasonal deflection for 9-in. base thickness.**

The lines in Figure 75 were constructed through the data by eye. Furthermore, no attempt was made to separate the effects of the three individual layers of structure—deflection is plotted against total thickness (that is, $D = D_1 + D_2 + D_3$ in the notation of Section 2.3.1).

Table 25 gives the total deflection, structure deflection and embankment deflection of five axle loads for four periods of time. The values were taken directly from Figure 75 and indicate that deflections (total, structure, and embankment) in general were greater during the spring than during the succeeding summer periods.

Of interest in this connection are the data in Section 2.5.6 (see Table 34) on the condition of the embankment soil and base and subbase courses in the spring and summer of 1960. These data, obtained from the trenching program, show that for base and subbase materials the moisture contents were higher in the spring and for all three materials the CBR values were higher in summer. In fact, the summer CBR values of the subbase and base were double those of the spring and those for the embankment soil were 40 percent higher. In view of this, it was expected that the densities of the materials would be greater in the summer. However, this was the case only for the sub-

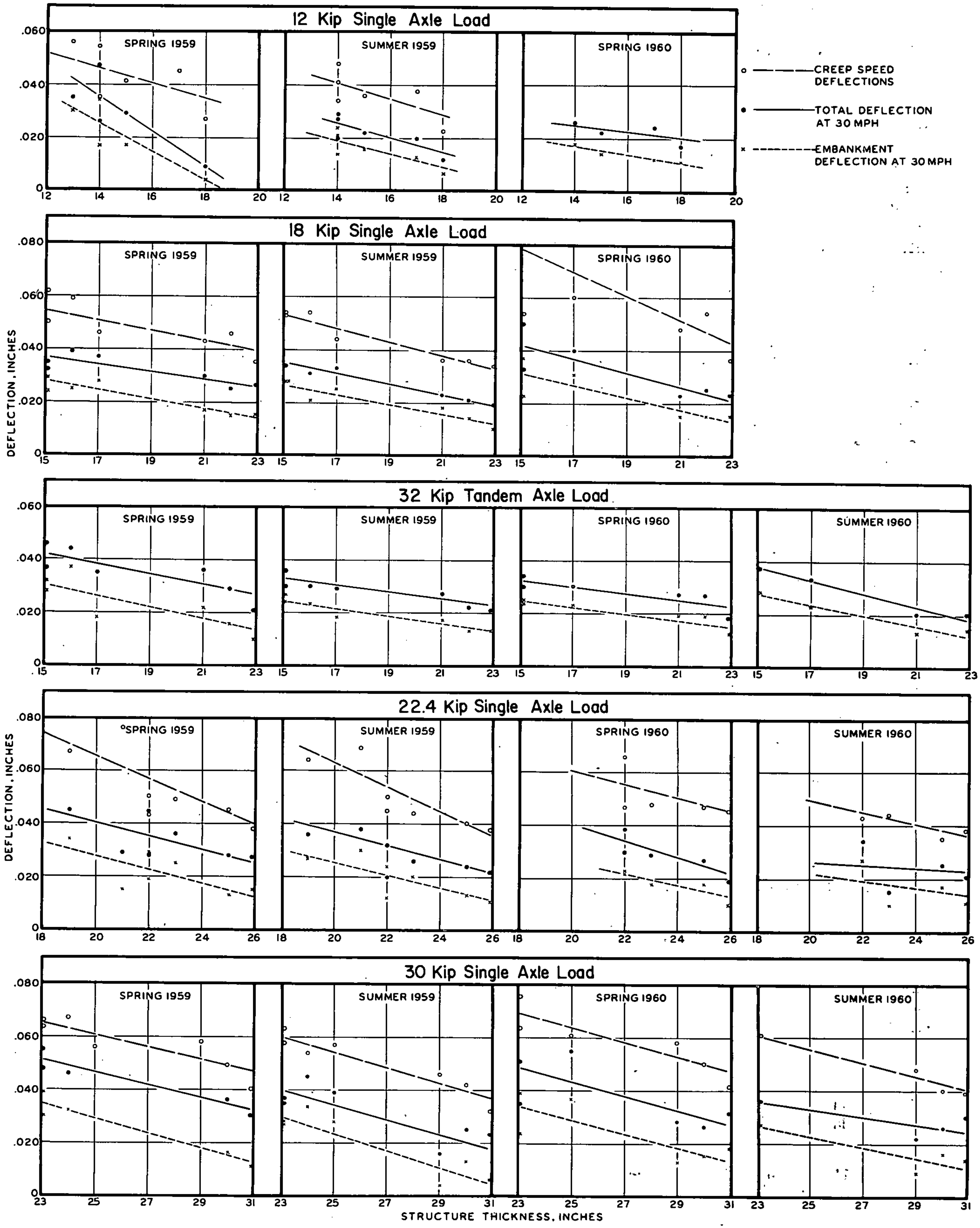


Figure 75. Main factorial experiment, relationship between design and deflection.

base (Table 34). The increase in moisture content was probably responsible for the higher structure deflections that occurred in the spring months.

Figure 76 includes plots of embankment deflection against total deflection for the dynamic deflection data obtained in the spring and summer of 1959. A high level of correlation existed. Extrapolation of the relationships indicates that the embankment deflection would approach zero when the total deflection is about 0.008 in. for both the spring and summer period.

### *2.3.4 Deflection Basin*

Several side studies produced the information concerning the configuration of the deflection basin. The deflections used in these studies were measured either with the electronic recording devices (LVDT's) or with Benkelman beams especially equipped to record complete analogs of the deflection traces.

Data on distribution of deflection were developed from the traces of deflection by conventional influence line techniques. These traces were obtained from placements of the vehicle wheel to the left, right, and directly over the deflection measuring point. This made it possible to develop contours of equal deflection, ranging from the maximum at the center of the basin to zero around the periphery. Figure 77 shows typical deflection contours of the pavement surface and of the top of the embankment under a single and a tandem axle load.

Use of total deflection as a measure of the capabilities of flexible pavements has been subject to question, because total deflection alone does not show the sharpness of bend or curvature of the surfacing. At the Road Test attempts to measure the curvature of the surfacing directly with curvature strips (plastic strips with strain gages cemented to their surfaces) placed between the layers of asphaltic concrete produced no useful data. However, a simple statistic ("partial deflection") related to maximum curvature of the surfacing was obtained from the analog traces of deflection. The partial deflection was simply the depth of the deflection basin measured under a 2-ft chord at the bottom of the basin. Figure 78 shows the manner in which partial deflections were obtained from the deflection traces.

Figure 79 shows plots of partial deflection against total deflection under single axle loads for all six test loops, indicating the degree of correlation between partial and total deflection. Within each loop, the ratio of partial deflection to total deflection decreased as the load increased.

### *2.3.5 Deflection-Load Relationships*

In Eqs. 38 and 39 in Section 2.3.1, it was shown that, based on a wide range of structure designs and loads, the deflections measured at creep speed in fall 1958 and spring 1959 increased with load with upward curvature (Fig. 80). Specifically, fall deflections, $d_f$, in-

TABLE 25

ESTIMATES OF DYNAMIC DEFLECTION

(from Figure 75)

| Loop | Test Load (kips) | Structure Thickness (in.) | Period | Deflection[1] (in.) | | |
|---|---|---|---|---|---|---|
| | | | | Total | Structure | Embankment |
| 3 | 12 S | 15 | Spring 1959 | 0.029 | 0.009 | 0.020 |
| | | | Summer 1959 | 0.022 | 0.007 | 0.015 |
| | | | Spring 1960 | 0.024 | 0.008 | 0.016 |
| | | | Summer 1960 | 0.025 | 0.005 | 0.020 |
| 4 | 18 S | 19 | Spring 1959 | 0.031 | 0.010 | 0.021 |
| | | | Summer 1959 | 0.027 | 0.007 | 0.020 |
| | | | Spring 1960 | 0.031 | 0.009 | 0.022 |
| | | | Summer 1960 | — | — | — |
| 4 | 32 T | 19 | Spring 1959 | 0.034 | 0.012 | 0.022 |
| | | | Summer 1959 | 0.028 | 0.009 | 0.019 |
| | | | Spring 1960 | 0.027 | 0.008 | 0.019 |
| | | | Summer 1960 | 0.028 | 0.008 | 0.020 |
| 5 | 22.4 S | 24 | Spring 1959 | 0.030 | 0.013 | 0.017 |
| | | | Summer 1959 | 0.026 | 0.010 | 0.016 |
| | | | Spring 1960 | 0.028 | 0.011 | 0.017 |
| | | | Summer 1960 | 0.024 | 0.008 | 0.016 |
| 6 | 30 S | 27 | Spring 1959 | 0.042 | 0.018 | 0.024 |
| | | | Summer 1959 | 0.029 | 0.012 | 0.017 |
| | | | Spring 1960 | 0.038 | 0.014 | 0.024 |
| | | | Summer 1960 | 0.030 | 0.012 | 0.018 |

[1] At 30 mph.

creased in proportion to $L_1^{1.13}$ and spring deflections, $d_s$, varied with $L_1^{1.46}$.

As a further check on the effect of wheel load on deflection, special studies were made where load was varied and other variables were kept constant. This program included three series of tests. The first two were made on the single axle lane of Loop 6, one during the spring and one during the fall of 1959. The third series was made on the single axle lane of Loop 4 during the fall of 1959. There were six test sections in each series.

The sections in Loop 6 for series 1 and 2 were of the following designs (inches of surfacing, base and subbase, respectively): 5-9-12, 5-9-16, 6-6-12, 6-9-12, 6-6-16 and 6-9-16. The six sections in Loop 4 included in the third series of tests had the following designs: 4-6-8, 4-6-12, 5-3-8, 5-6-8, 5-3-12 and 5-6-12.

Both single and tandem axle vehicles were included in these studies. Axle loads for test series 1 and 2 were 6, 12, 18, 22.4 and 30 kips single axle and 24, 32, 40 and 48 kips tandem axle. For series 3 they were 6, 12 and 18 kips single axle and 24 and 32 kips tandem axle.

Benkelman beam deflections were taken at eight locations (4 in each wheelpath) in each section using an improvised form of the rebound procedure, involving placement of the probe tip about 1 ft ahead of the rear axle (in case of tandem axles this was the second or rear axle of the assembly). The truck was then driven forward at creep speed and a load reading obtained as the wheels passed the probe. The final reading, as in case of the normal deflection procedure, was taken when the load had passed out of the range of influence. The test loads were passed over all the deflection measuring points in randomized order. Dynamic deflections with the electronic devices were taken in one section only of Loop 6. As for the beam test, these deflections were recorded at creep speed only.

The load-deflection relationships shown in Figures 81, 82 and 83 were computed from regression equations developed for each of the sections included in the three series of tests. The squared correlation coefficients, the standard errors of estimate and the ratios of the single and tandem axle loads that produced the same deflection are also shown.

The mathematical model used in the analysis was

$$d = A_0 \, L_1^{A_1} \, L_2^{A_2} \qquad (42)$$

in which

$d$ = the deflection, in inches;

$L_1$ = the axle load, in kips; and

$L_2$ = the number of axles (*i.e.*, 1 for single axle configuration and 2 for tandem axle configuration)

The constants $A_0$, $A_1$ and $A_2$ were determined by regression analysis.

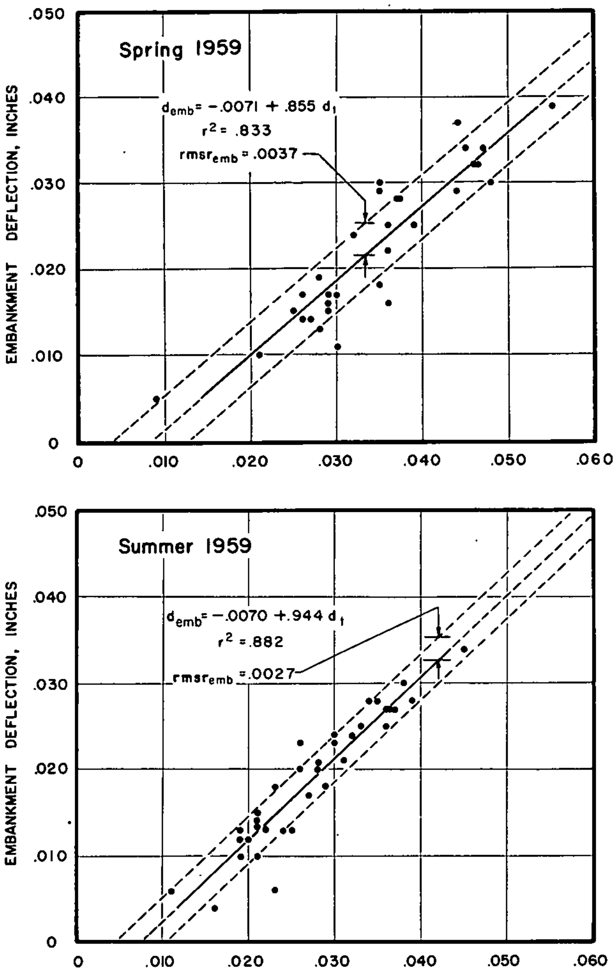


Figure 76. Main factorial experiment, relationship between total deflection and embankment deflection.

As previously stated, one section was tested during the fall only, utilizing the dynamic equipment, which made it possible to measure the total deflection and the deflection occurring within the structure (see Fig. 84). Regression equations corresponding to the curves are as follows:

*For total deflection:*

$$\log d = 0.242 + 0.835 \log L_1 - 0.651 \log L_2 \qquad (43)$$

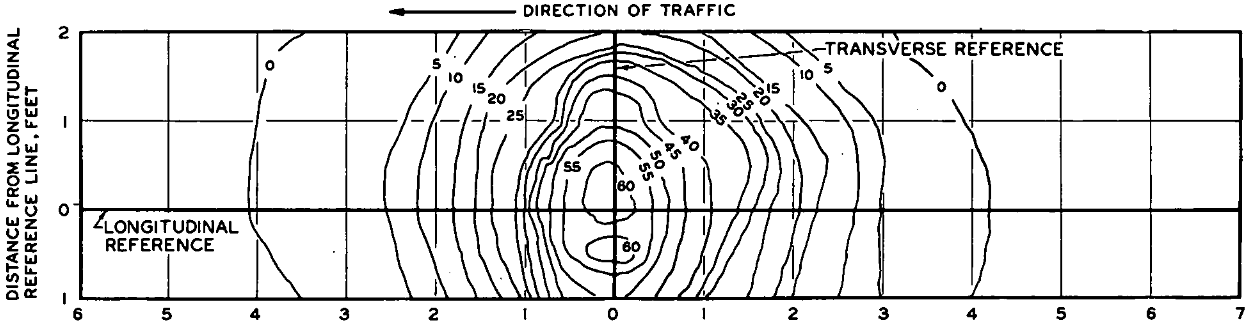
$$r^2 = 0.98 \text{ and rms error} = 0.022.$$

In Eq. 43, if $L_1 = L_{1S}$ and $L_2 = 1$ gives the same log $d$ as when $L_1 = L_{1T}$ and $L_2 = 2$, then the loads $L_{1S}$ and $L_{1T}$ are equivalent as far as deflection is concerned. The equivalency ratio is $L_{1S}/L_{1T}$.

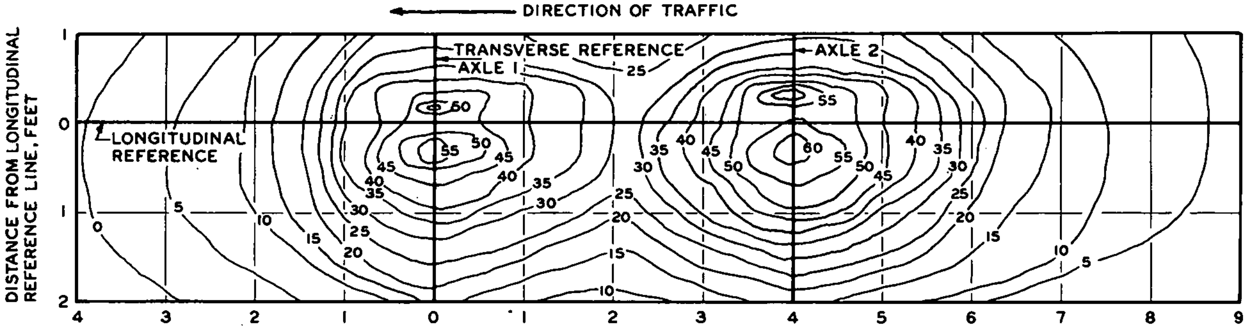
$$\log \, (L_{1S}/L_{1T}) = 0.301 \, A_2/A_1$$

and for total deflection $L_{1S}/L_{1T} = 0.583$.

Deflection Contours on Pavement Surface
4-6-4 Design - 18 Kip Single Axle Load



Deflection Contours on Pavement Surface
5-6-4 Design - 32 Kip Tandem Axle Load



Deflection Contours on Top of Embankment
5-6-4 Design - 32 Kip Tandem Axle Load

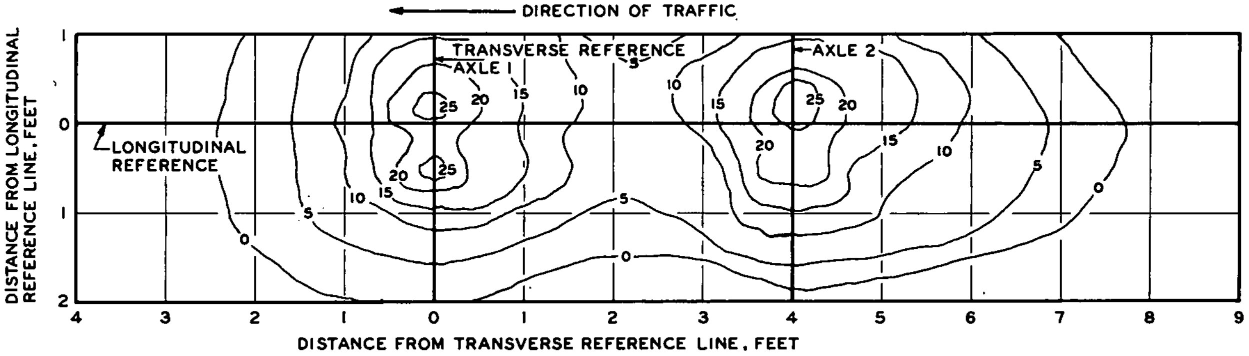


Figure 77. Deflection contours, March 1959.

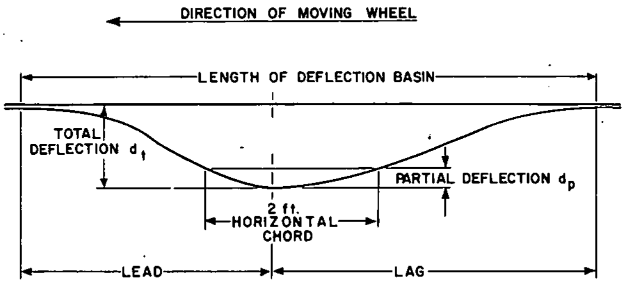


Figure 78. Relationship between partial and total deflection.

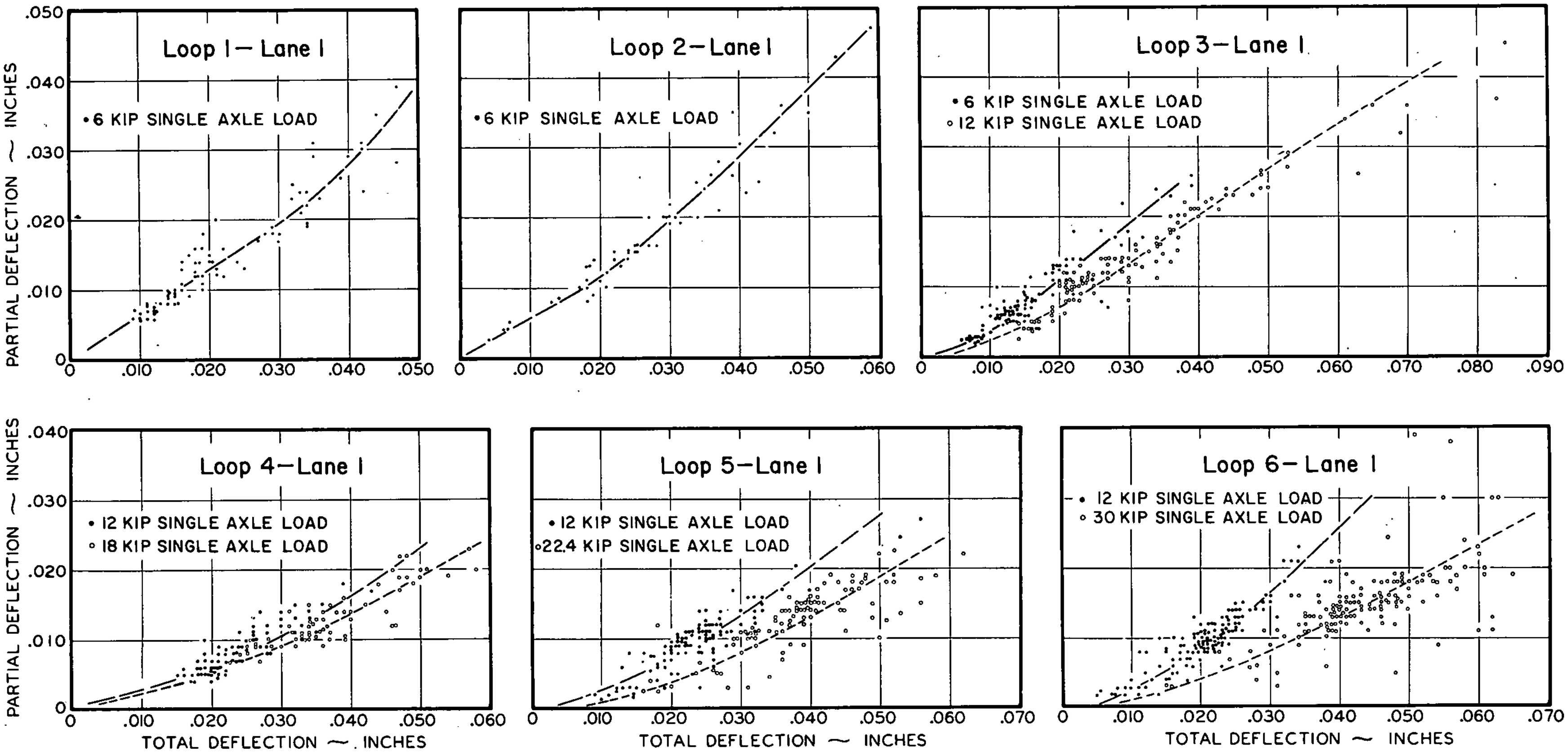


**Figure 79.** Main factorial experiment, relationship between partial deflection and total deflection.

*For structure deflection:*

$$\log d_{str} = 0.336 + 0.611 \log L_1 - 0.534 \log L_2 \quad (44)$$

$r^2 = 0.83$, rms error $= 0.055$, and $L_{1S}/L_{1T} = 0.546$.

In only two sections (5-3-12 and 5-6-8 in Loop 4), and then only in the fall test series, were the deflection-load relationships curved upward; *i.e.*, the exponent of $L_1$ was greater than unity. The others curved downward. The disagreement between this and the clear upward curvature shown in the studies reported in Section 2.3.1 was not explained.

### *2.3.6 Deflection-Speed Relationships*

Because vehicle speed was not a variable in the Road Test its effect upon pavement performance was not determined. However, considerable information associated with this question was obtained from special studies of the effect of speed on pavement deflection.

The objectives of the tests were to determine the effect of load, pavement design and temperature of the surfacing upon the deflection-speed relationships. Three series of tests were made, the first in August, the second in September, and the third in December 1959. The following shows that all the sections included in the tests were in good condition at the time of study:

| Loop | Design | Fall Thickness Index[1] | Serviceability Value, $p$ | | |
|---|---|---|---|---|---|
| | | | Aug. | Sept. | Dec. |
| 4 | 3–6–12 | 0.51 | 3.5 | 3.2 | 3.5 |
| 4 | 5–6–12 | 0.61 | 3.5 | 3.4 | 3.5 |
| 4 | 5–6–4 | 0.42 | 3.4 | 3.3 | 3.3 |
| 4 | 5–6–4 | 0.42 | 4.0 | 3.9 | 3.9 |
| 6 | 4–9–16 | 0.69 | 3.7 | 3.6 | 3.7 |
| 6 | 6–9–8 | 0.60 | 2.8 | 2.8 | 2.7 |
| 6 | 6–9–8 | 0.60 | 3.6 | 3.4 | 3.4 |
| 6 | 6–9–16 | 0.79 | 3.6 | 3.3 | 3.2 |

[1] Fall thickness indexes were computed from the fall normal procedure deflection Eq. 33.

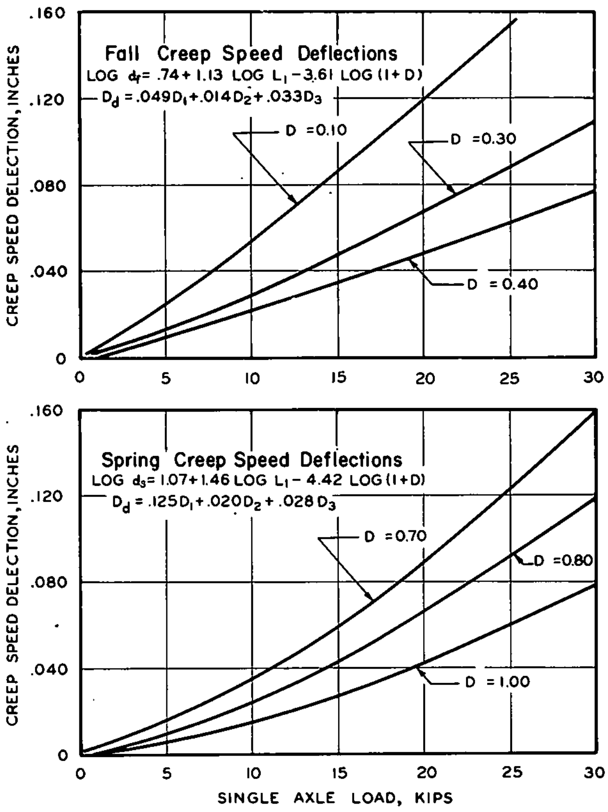


**Figure 80. Main factorial experiment, relationship between spring and fall creep speed deflection and axle load (from Road Test equations).**

The deflections were measured using the electronic devices and recording equipment described in Section 2.3.3. They were taken at speeds ranging from creep speed to 50 mph using two single axle wheel loads, 6 and 9 kips on Loop 4 and under 6 and 15 kips on Loop 6. The loads of the test trucks were randomized but all trips necessary for one speed were run in sequence before progressing to another speed level.

The deflection of the pavement and that of the structure alone (surfacing, base and subbase) was recorded on paper tape and for these records the total deflection and the partial deflection (see Section 2.3.4) was obtained.

In the analysis of the data, equations were developed for each section included in the tests, for each load used, and for each date tested. The model selected to fit the observed data was

$$d = 10^{A_0 + A_1 v} \quad (45a)$$

in which

$d$ = deflection;

$v$ = vehicle speed;

$A_0$ = test section constant; and

$A_1$ = speed coefficient.

The regression was performed on the log transformation

$$\log d = A_0 + A_1 v \quad (45b)$$

Good agreement was found between observed values of deflection and those computed with the equations. Examples of the level of agreement for the tests made in September 1959 on the 5–6–12 design in Loop 4 and on the 6–9–16 design in Loop 6 are shown in Figure 85.

In a study of the speed-deflection data for the sections under the same load no consistent or orderly effect of design on the speed coefficient was disclosed. Consequently, equations were developed for the means of the four sections in each loop. This was done by averaging the values of $A_0$ and $A_1$ appearing in the individual equations. These values, for the total

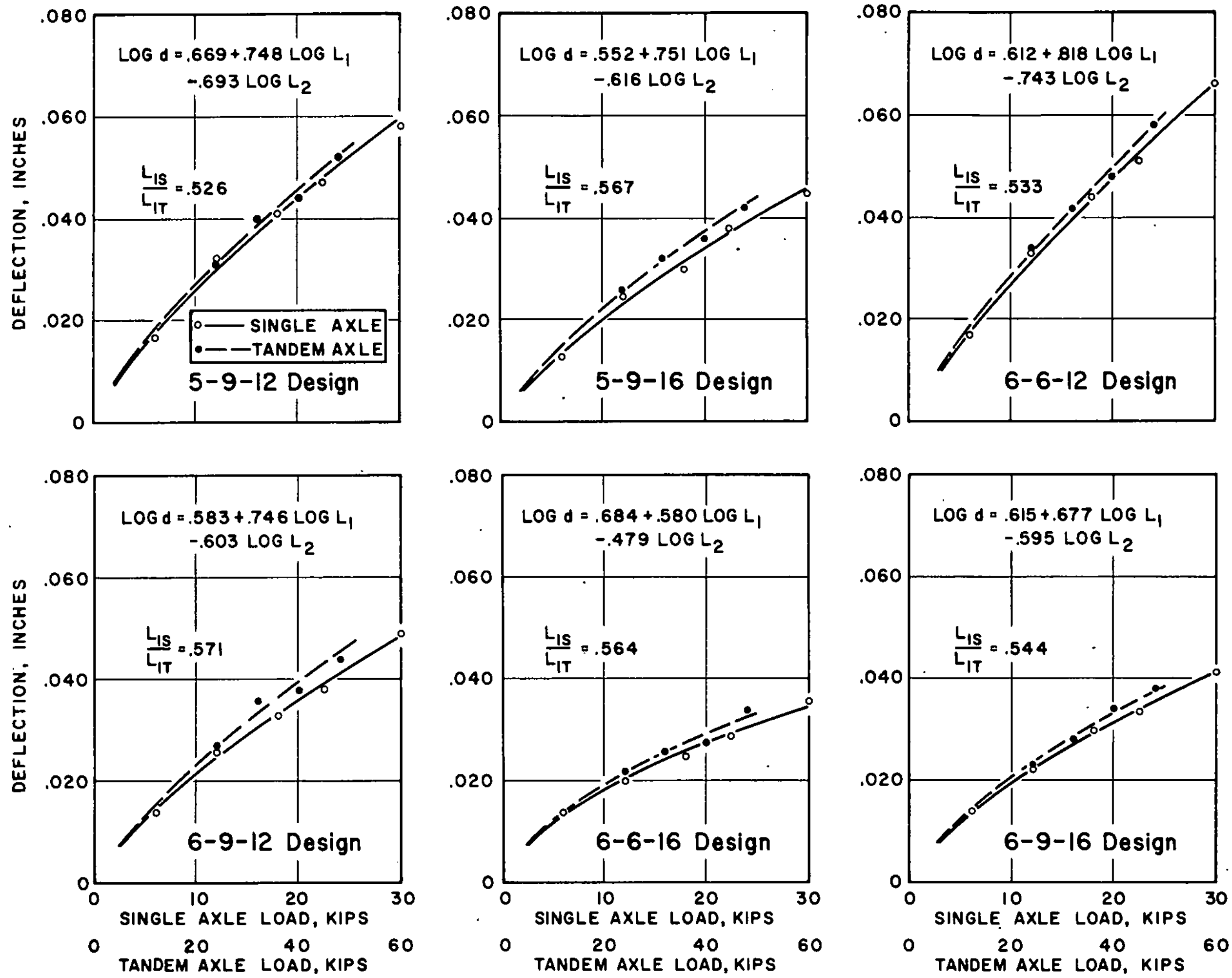


Figure 81. Variable load study, Loop 6, effect of axle load on creep speed deflection, spring tests.

deflection, the embankment deflection and the partial deflection, are given in Table 26 for each date of testing and for each of the loads used in the two loops.

All analyses indicate a marked reduction in deflection with increase in vehicle speed. Since most Road Test deflections were measured at creep speed (2 mph), and since normal Road Test traffic operated at 35 mph it is of interest to consider the influence of design, speed and surfacing temperature on the reduction in deflections between these speeds.

The percentage reduction in deflection as speed is varied from 2 to 36 mph is equal to 100 (1 — $10^{33A_1}$) where $A_1$ is the speed coefficient. Information from Table 26 is repeated in Table 27 along with computed values of these percentage reductions. These data indicate no consistent variation of percentage reduction with surface temperature between 87 and 40 F, and none with pavement structure design over the range of average deflection thickness index from 0.49 to 0.67. (Loop 4 sections may be compared with Loop 6 sections only under the 12-kip axle load). However, Table 26 indicates clearly that the speed coefficient ($A_1$) is reduced as load is increased.

If partial deflection is considered a measure of curvature of the deflected surface, then the data in Table 27 show that there was a much greater reduction in curvature with speed than in case of the total or embankment deflection. If curvature is considered a better measure of performance of flexible pavements than total deflection the apparent benefits of increasing speed are greater than indicated by the reduction in total deflection.

### *2.3.7. Deflection-Temperature Relationships*

*2.3.7.1 Non-Traffic Loop 1.*—During traffic operations creep speed deflections were measured weekly on the non-traffic loop using a 6-kip axle load except during the winter when the pavement was frozen. The results of these tests are shown in Figure 86. Each line represents the average deflection (outer and inner wheelpaths) of three groups of sections, whose surfacing, base and subbase thickness were as follows:

| Group 1 | Group 2 | Group 3 |
|---|---|---|
| 1–0–8 | 3–0–8 | 5–0–8 |
| 1–0–16 | 3–0–16 | 5–0–16 |
| 1–6–0 | 3–6–9 | 5–6–0 |
| 1–6–8 | 3–6–8 | 5–6–8 |
| 1–6–16 | 3–6–16 | 5–6–16 |

Included are those eight sections whose deflections were used to determine the seasonal weighting function described in Section 2.2. Deflections in these sections are listed in Appendix B.

Figure 86 shows clearly the effect of seasons of the year. Initial deflections taken during the fall of 1958 were relatively low, increased somewhat subsequently, then decreased to a very low level when freezing occurred. Spring tests showed a high level of deflection after frost left the pavement; tests during the summer revealed a gradual decrease. The deflections for the second fall increased somewhat erratically. Deflections taken during the second year followed approximately the same trends as during the first.

During the summer months, when the temperature of the surface was relatively high and the subsurface conditions good, the difference in deflection of the 1-, 3- and 5-in. surfacing groups of sections were of a low order of magnitude. These differences increased appreciably when the surfacing temperature was low and the subsurface conditions adverse, as during the spring months.

The data plotted in Figure 87 represent an attempt to smooth out the variations in the level of the observed deflections with seasons by

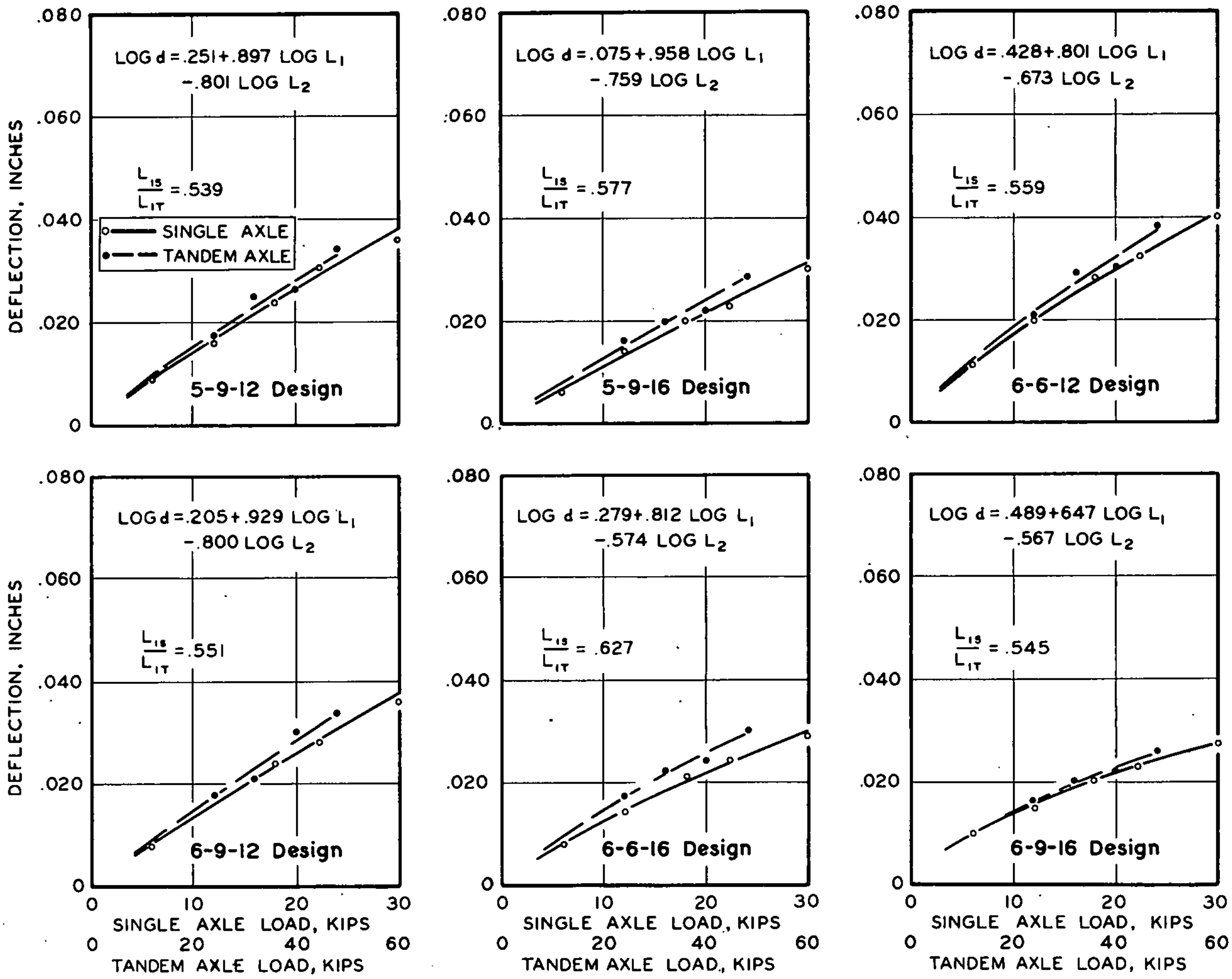


Figure 82. Variable load study, Loop 6, effect of axle load on creep speed deflection, fall tests.

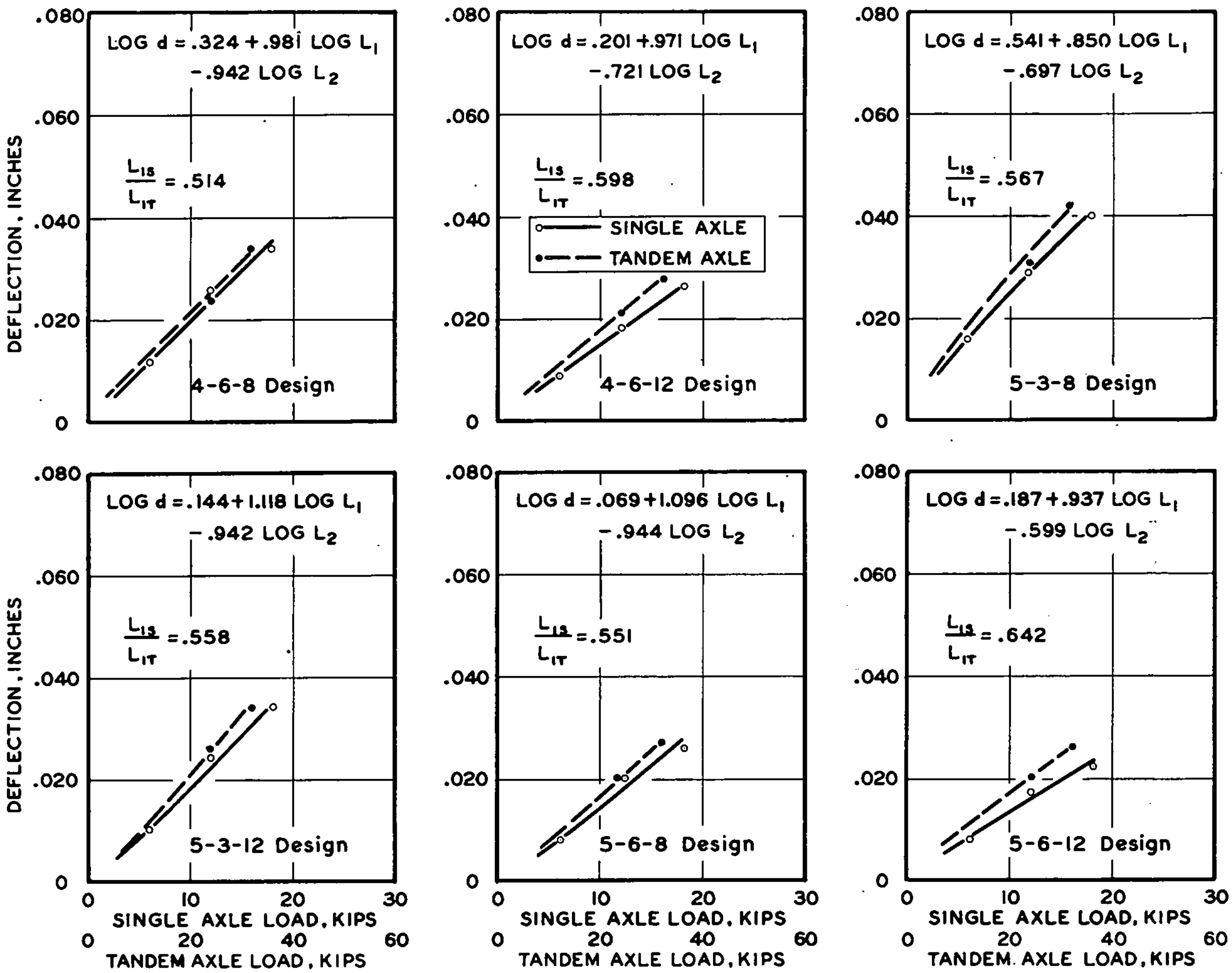


Figure 83. Variable load study, Loop 4, effect of axle load on creep speed deflection, fall tests.

plotting the ratios of deflection; that is, the 1- to 3-in., the 1- to 5-in. and the 3- to 5-in. surfacing groups of sections against surfacing temperature. This was done to obtain an indication of the effect of temperature alone.

In all three plots, the ratio values begin to increase as the temperature decreases below 80 F and those for the 1- to 5-in. group increase at a more rapid rate than those for the 1- to 3-in. or the 3- to 5-in. There is no change indicated in the ratio values above 80 F. The ratios never reach a value of one because of the addi-

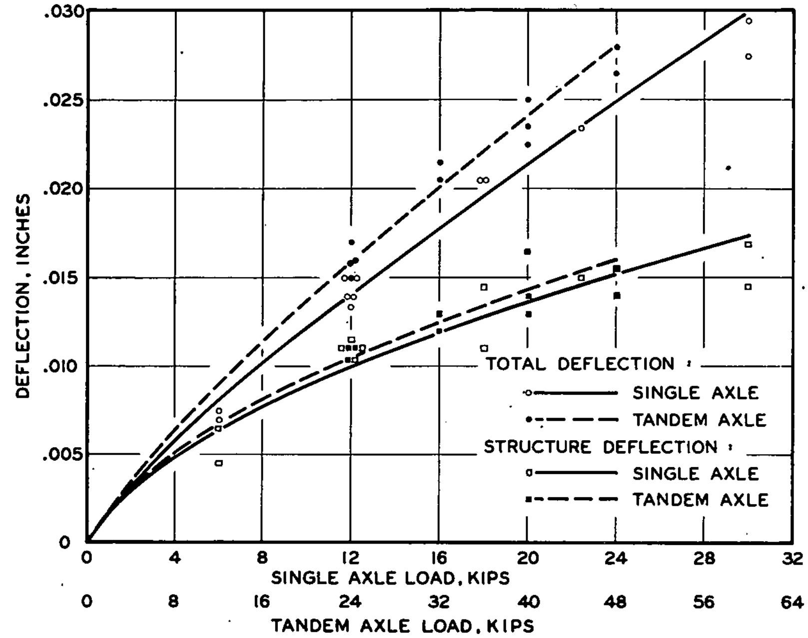


Figure 84. Variable load study, effect of axle load on creep speed LVDT deflection, fall tests (6–9–16 design, Loop 6).

tional total thickness of pavement. For example, sections having 5-in. surfacing were 4 in. thicker than those having 1-in. surfacing.

Additional information concerning the effect of surfacing temperature (mean of temperature at top, middle and bottom of surfacing) on deflection was obtained from seven special series of tests on the non-traffic loop. Deflections were taken periodically over 24-hr periods on days when it was anticipated that there would be appreciable changes in temperature of the surfacing. In each test from 13 to 16 observations were made. Dates of the tests and range of the surfacing temperature were as follows:

| Date | Temp. Range (°F) |
|---|---|
| May 22, 1959 | 59–78 |
| June 26, 1959 | 88–124 |
| August 14, 1959 | 83–120 |
| October 2, 1959 | 62–77 |
| December 3, 1959 | 31–50 |
| May 6, 1960 | 50–67 |
| August 19, 1960 | 70–94 |

For each series of tests the average deflections of the sections having the 1-, 3-, and 5-in.

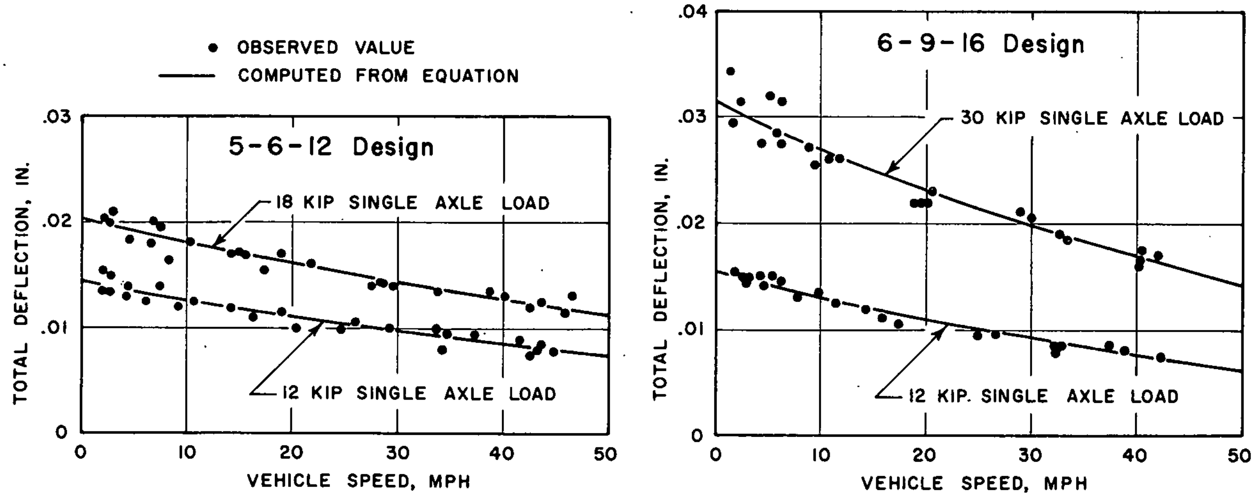


Figure 85. Variable speed study, effect of vehicle speed on total deflection.

## TABLE 26

### CONSTANTS AND COEFFICIENTS OF SPEED, DEFLECTION EQUATIONS[1]

| Loop | Single Axle Load (kips) | Total Deflection | | | Embankment Deflection | | | Partial Deflection | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $A_0$ | $A_1$ | $r^2$ | $A_0$ | $A_1$ | $r^2$ | $A_0$ | $A_1$ | $r^2$ |
| | | (*a*) AUG. 26, 1959—SURFACING TEMPERATURE, 87 F | | | | | | | | |
| 4 | 12 | 1.386 | 0.0072 | 0.86 | 1.192 | 0.0065 | 0.65 | 1.017 | 0.0160 | 0.91 |
| 4 | 18 | 1.559 | 0.0058 | 0.79 | 1.360 | 0.0040 | 0.40 | 1.149 | 0.0130 | 0.83 |
| 6 | 12 | 1.278 | 0.0070 | 0.84 | 1.823 | 0.0035 | 0.30 | 0.924 | 0.0155 | 0.85 |
| 6 | 30 | 1.638 | 0.0055 | 0.86 | 1.337 | 0.0052 | 0.40 | 1.225 | 0.0138 | 0.91 |
| | | (*b*) SEPT. 30, 1959—SURFACING TEMPERATURE, 62 F | | | | | | | | |
| 4 | 12 | 1.287 | 0.0070 | 0.94 | 1.124 | 0.0065 | 0.80 | 0.878 | 0.0165 | 0.90 |
| 4 | 18 | 1.440 | 0.0062 | 0.93 | 1.300 | 0.0055 | 0.82 | 0.969 | 0.0145 | 0.88 |
| 6 | 12 | 1.183 | 0.0075 | 0.93 | 0.865 | 0.0085 | 0.54 | 0.769 | 0.0170 | 0.90 |
| 6 | 30 | 1.534 | 0.0058 | 0.91 | 1.322 | 0.0058 | 0.68 | 0.998 | 0.0150 | 0.92 |
| | | (*c*) DEC. 2, 1959—SURFACING TEMPERATURE, 40 F | | | | | | | | |
| 4 | 12 | 1.277 | 0.0062 | 0.89 | 1.071 | 0.0058 | 0.60 | 0.818 | 0.0152 | 0.87 |
| 4 | 18 | 1.420 | 0.0058 | 0.93 | 1.261 | 0.0058 | 0.78 | 0.926 | 0.0142 | 0.86 |
| 6 | 12 | 1.128 | 0.0060 | 0.86 | 0.765 | 0.0062 | 0.34 | 0.645 | 0.0138 | 0.76 |
| 6 | 30 | 1.491 | 0.0058 | 0.86 | 1.278 | 0.0050 | 0.56 | 0.878 | 0.0118 | 0.85 |

[1] $r^2$ = square correlation coefficient.

## TABLE 27

### REDUCTION IN DEFLECTION AS SPEED VARIES FROM 2 TO 35 MPH

| Loop | Load (kips) | Temp. (°F) | Total Defl. | | Emb. Defl. | | Partial Defl. | |
|---|---|---|---|---|---|---|---|---|
| | | | $A_1$ | % Red. | $A_1$ | % Red. | $A_1$ | % Red. |
| 4 | 12 S | 87 | 0.0072 | 42 | 0.0065 | 39 | 0.0160 | 70 |
| 4 | 18 S | 87 | 0.0058 | 36 | 0.0040 | 26 | 0.0130 | 63 |
| 6 | 12 S | 87 | 0.0070 | 41 | 0.0035 | 23 | 0.0155 | 69 |
| 6 | 30 S | 87 | 0.0055 | 34 | 0.0052 | 33 | 0.0138 | 65 |
| 4 | 12 S | 62 | 0.0070 | 41 | 0.0065 | 39 | 0.0165 | 71 |
| 4 | 18 S | 62 | 0.0062 | 38 | 0.0055 | 34 | 0.0145 | 67 |
| 6 | 12 S | 62 | 0.0075 | 43 | 0.0085 | 48 | 0.0170 | 73 |
| 6 | 30 S | 62 | 0.0058 | 36 | 0.0058 | 36 | 0.0150 | 68 |
| 4 | 12 S | 40 | 0.0062 | 38 | 0.0058 | 36 | 0.0152 | 68 |
| 4 | 18 S | 40 | 0.0058 | 36 | 0.0058 | 36 | 0.0142 | 66 |
| 6 | 12 S | 40 | 0.0060 | 37 | 0.0062 | 38 | 0.0138 | 65 |
| 6 | 30 S | 40 | 0.0058 | 36 | 0.0050 | 32 | 0.0118 | 59 |

thicknesses of surfacing were plotted against temperature. Curves fitted to the plotted points by eye are shown in Figure 88.

From season to season the level of deflections changed; however, the change in deflection per degree change in temperature was much the same. Above about 80 F the deflection was practically constant. Below 50 F to about 30 F the change, with one exception, was most pronounced. The lone exception was in the group of sections having 5-in. surfacing, tested on December 3, 1959. Before this date, air temperatures as low as 15 F had been recorded with several minor cycles of freezing and thawing. These conditions may have influenced the deflections of the thicker surfaced sections in a different way than they did those having the thinner surfaces. If the deflection of the 5-in. sections in the December 3 tests had decreased from 50 to 30 F at the rate shown by the dashed curve (Fig. 88), the ratios of deflection of the group of sections having the different surfacing thicknesses would be of much the same order of magnitude as those shown in Figure 87. (Data for the non-traffic loop temperature-deflection study are in DS 5190 and DS 5191.)

*2.3.7.2 Traffic Loops.*—In addition to the two complete routine creep-speed deflection coverages in the fall of 1958 before traffic, a limited program of deflection-temperature tests was conducted on sections of Loops 3, 5 and 6, both in the single and tandem axle load lanes, as follows:

| Loop 3 | | | Loop 5 | | | Loop 6 | | |
|---|---|---|---|---|---|---|---|---|
| Surf. (in.) | Base (in.) | Sub. (in.) | Surf. (in.) | Base (in.) | Sub. (in.) | Surf. (in.) | Base (in.) | Sub. (in.) |
| 2 | 0 | 8 | 3 | 3 | 8 | 4 | 3 | 12 |
| 2 | 0 | 8* | 3 | 6 | 4 | 4 | 6 | 8 |
| 2 | 3 | 4 | 3 | 9 | 12 | 4 | 9 | 16 |
| 2 | 6 | 0 | — | — | — | — | — | — |
| 3 | 0 | 0 | 4 | 3 | 12 | 5 | 6 | 12 |
| 3 | 3 | 8 | 4 | 6 | 8 | 5 | 6 | 12* |
| 3 | 6 | 4 | 4 | 6 | 8* | 5 | 9 | 8 |
| — | — | — | 4 | 9 | 4 | 5 | 3 | 16 |
| 4 | 0 | 4 | 5 | 3 | 4 | 6 | 3 | 8 |
| 4 | 3 | 0 | 5 | 6 | 12 | 6 | 6 | 16 |
| 4 | 6 | 8 | 5 | 9 | 8 | 6 | 9 | 12 |

* Replicate section.

In each loop, average base and subbase thickness is the same for each surfacing thickness. For example, in Loop 5 sections with 3-in. surfacing average 14 in. of base and subbase, as do the sections with 4-in. or 5-in. surfacing. The tests were made over 24-hr periods on three dates—October 2, October 13, and October 31, 1958—at either two or three levels of surfacing temperature. Creep speed normal deflections were taken under a 12-kip single axle load.

The results of the tests are shown in Figure 89, in which curves a, b and c represent the average deflection for each of the three groups of sections having the same thickness of surfacing, and curves d are averages of the deflection of the three groups of sections in each of the loops. The same axle load (12 kips) was used in all tests. All thicknesses increased from Loop 3 to Loop 5 to Loop 6. The deflections were greater for the sections of Loop 3 than for those of Loop 5 and of Loop 5 than for those of Loop 6.

The results of these tests indicate that deflection was decreasing at 85 F, whereas on the non-traffic loop deflection did not begin to decrease until the temperature reached 70 to 80 F. The rate and extent of reduction of deflection with temperature to about 45 F appears more pronounced than in the non-traffic loop study, possibly because of the lack of oxidation of the asphaltic cement at the time these early tests were made, at least to the point where the response of the asphaltic concrete surface to temperature changes was more pronounced.

One series of deflection-temperature tests was conducted on the special base sections of Loop 6 in October 1960. Measurements were made extending over a 24-hr period at three levels of thickness of the bituminous-treated base, 8.6, 12.4 and 16.1 in., at two levels of the cement-treated base, 9.3 and 11.8 in., and at two levels of thickness of the stone base, 13.0 and 17 in. The surfacing thickness over all three base types was 4 in., the subbase thickness beneath the bituminous and cement base, 4 in., and beneath the stone base, 8 in.

The results of the tests are shown in Figure 90. In all three base types the reduction in deflection with temperature change was somewhat more pronounced for the thinner cross-sections. This is in agreement with the test described previously. Also, the percentage reduction was the greatest in case of the 16.1-in. bituminous base.

In the previously discussed tests, the deflections were measured with the Benkelman beam

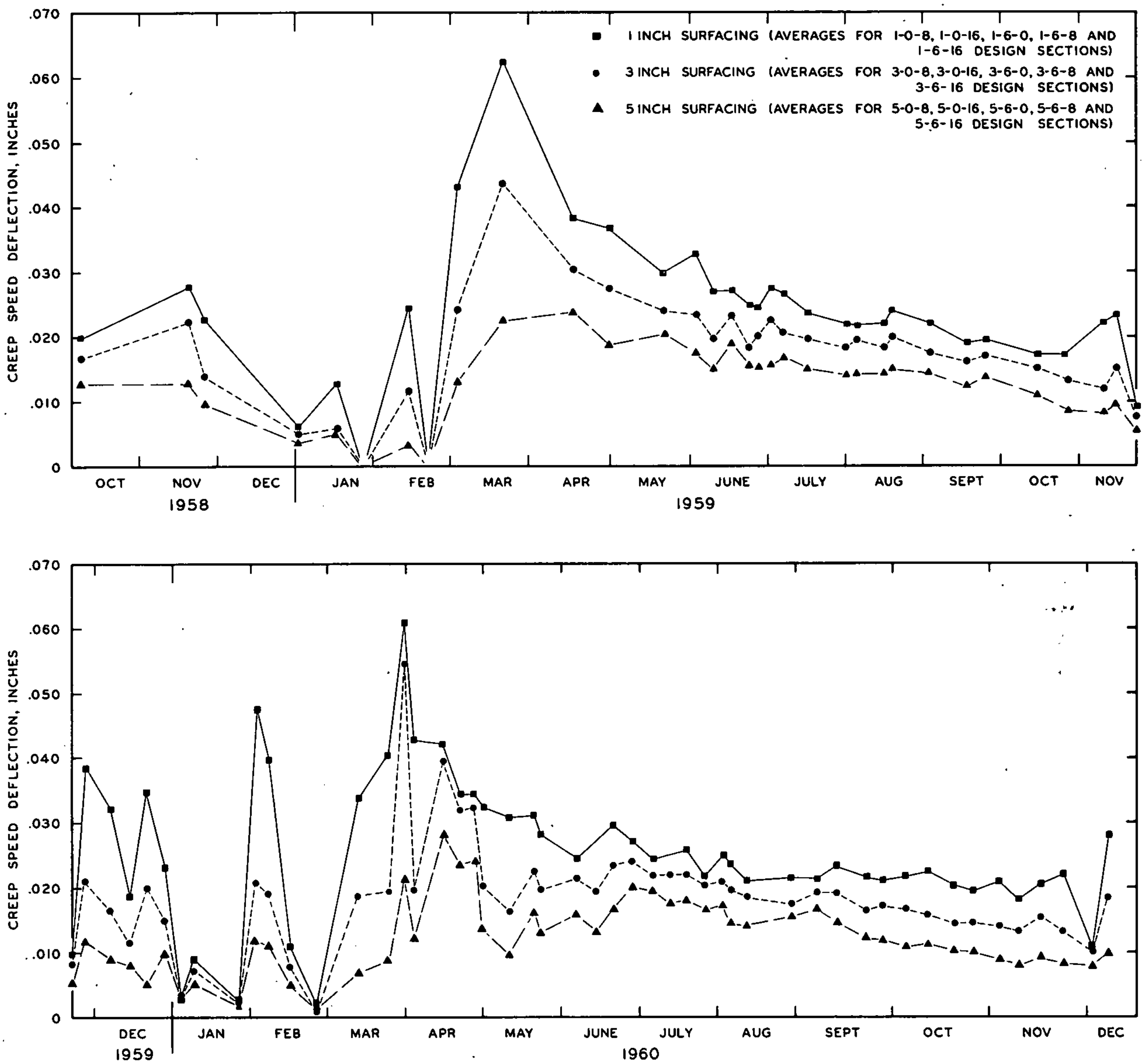


Figure 86. Seasonal deflection on non-traffic loop, 6-kip single axle load.

at creep speed. One series of tests was made on a single section of Loop 4 (5-6-12 design) where the deflection was recorded electronically under an 18-kip single axle load at a vehicle speed of 35 mph (the speed at which test traffic operated). The tests were carried out in one day in September 1960 when temperatures of the surfacing ranged from about 60 to 90 F. Figure 91 shows the results of a straight line regression analysis. The reduction in deflection with temperature was of a low order of magnitude, about 0.0012 in. per 30 deg temperature change.

Obviously more data are needed before it can be said that the effect of temperature on deflection is less at moderate than at slow speeds of vehicle travel.

## 2.4 PREDICTION OF PERFORMANCE FROM DEFLECTION

The fifth Road Test objective asked for relationships that would employ information from dynamic measurements in the prediction of future pavement performance. Deflections in flexible pavements under moving loads proved to be highly effective for this purpose.

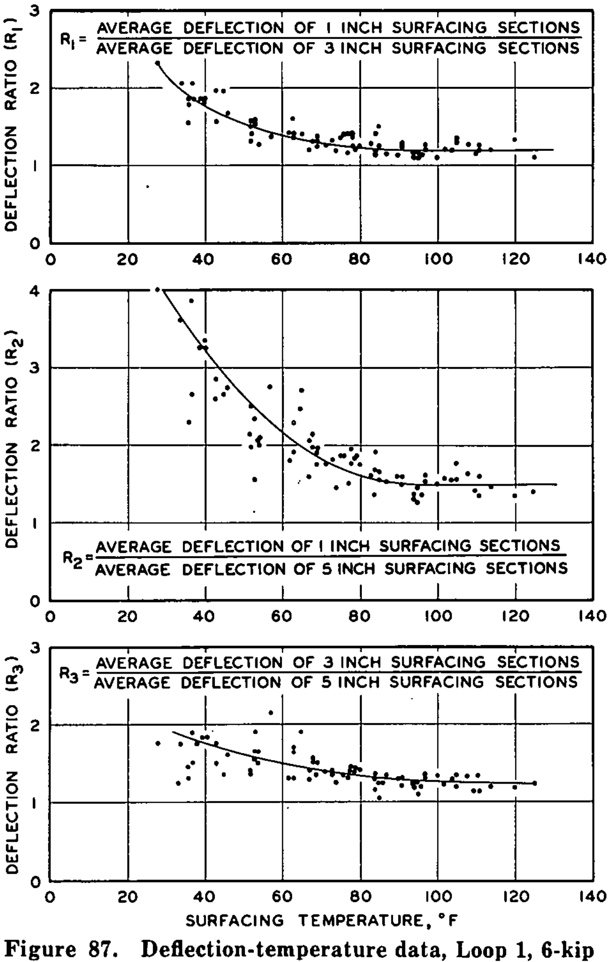


**Figure 87. Deflection-temperature data, Loop 1, 6-kip single axle load.**

The performance of the flexible pavements was predicted with essentially the same precision from load-deflection data as from load-design information.

Deflections taken during the spring when the subsurface conditions were adverse gave a better prediction of pavement life than those taken in the fall.

There was a high degree of correlation between deflection and rutting.

### *2.4.1 Performance-Deflection Relationships*

The principal purpose for the measurement and study of deflections under load in flexible pavement (Section 2.3) was to find relationships between deflection measured at a given time and the future performance of the pavement. It was assumed that the deflection of a given pavement under a particular load would serve as a better measure of the pavement's ability to survive many applications of the load than knowledge of the pavement structure design alone. For example, the deflection may be expected to reflect the strength of the embankment soil and the strength of the surfacing, base and subbase as they were actually constructed regardless of how they may have been specified.

Original Road Test efforts were based on the assumption that deflection might serve as a satisfactory substitute for both design and load, so that the future performance of a pavement under a given load might be predicted from deflection of the pavement measured, for example, when construction was completed.

After several alternatives were considered, a model was found by which the life of a pavement to a given level of serviceability could be estimated satisfactorily provided both load and deflection were included in the function.

$$W_p = \frac{A_0 \, L_1^{A_1}}{d^{A_2}} \qquad (46)$$

in which

$W_p$ = number of applications of axle load $L_1$ sustained by the pavement at the time the serviceability was at level $p$;

$L_1$ = single axle load, in kips; and

$d$ = normal deflection in 0.001 in. measured under a wheel load equal to $L_1/2$.

The constant terms $A_0$, $A_1$ and $A_2$ in Eq. 46 were to be determined by the analysis. To perform the analysis by linear regression techniques, logarithms of both sides of Eq. 46 were taken:

$$\log W_p = A_0 + A_1 \log L_1 - A_2 \log d \qquad (47)$$

The deflection data used in the derivation of the performance equations were those obtained

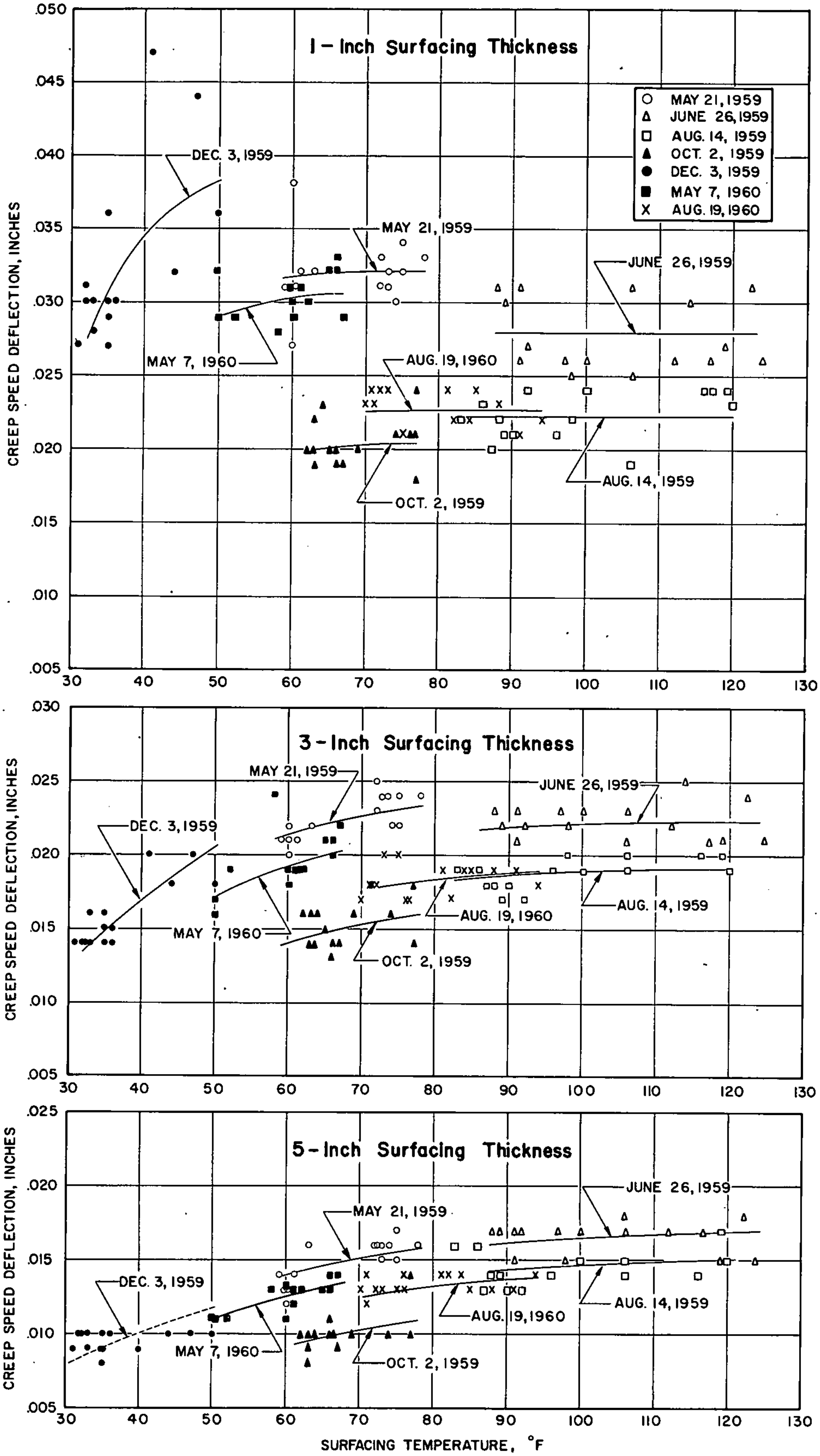


Figure 88. Deflection-temperature data, Loop 1, 6-kip single axle load.

in the fall of 1958 and spring of 1959 (see Section 2.3.1) under the loads normally assigned to the single axle lanes of Loops 3, 4, 5 and 6 and lane 2 of Loop 2. The life data for these relationships in most cases were observed values of $W$ at the level of $p$ specified. In several cases, where the specified level of $p$ was not attained during the course of the Road Test, estimates for $W$ were obtained from the performance equations given in Section 2.2.2.

To obtain common coefficients for all loops the coefficients for log $d$ for the individual loops were averaged. An adjusted lane mean was then determined for each loop. These adjusted means were then regressed on log $L_1$ to obtain a coefficient for log $L_1$ and a constant term $A_0$. Subsequently an analysis was made across all loops in which the coefficients $A_0$, $A_1$ and $A_2$ were determined in one step. Very little difference in the coefficients was found indicating that significant design-load interactions were not present. Therefore, in Eqs. 48-51 the coefficients are those obtained from the analysis made across loops.

Equations were derived for predicting log $W_p$ from log $L$ and log $d$; both when $d = d_{fn}$ (fall normal deflection) and when $d = d_{sn}$ (spring normal deflection). For each case the terminal serviceability level was set at both $p = 2.5$ and $p = 1.5$.

*For the fall normal deflections:*

$$\log W_{2.5} = 7.98 + 1.72 \log L_1 - 3.07 \log d_{fn} \quad (48)$$

$$c^2 = 0.47, \quad \bar{r} = 0.33$$

$$\log W_{1.5} = 8.48 + 1.76 \log L_1 - 3.32 \log d_{fn} \quad (49)$$

$$c^2 = 0.39, \quad \bar{r} = 0.34$$

*For the spring normal deflections:*

$$\log W_{2.5} = 9.40 + 1.32 \log L_1 - 3.25 \log d_{sn} \quad (50)$$

$$c^2 = 0.78, \quad \bar{r} = 0.21$$

$$\log W_{1.5} = 10.18 + 1.36 \log L_1 - 3.64 \log d_{sn} \quad (51)$$

$$c^2 = 0.66, \quad \bar{r} = 0.24$$

Correlation indexes and mean residuals for these equations show that log $W$ predictions are closer to the observations when spring deflections are used rather than fall deflections, and also that better predictions are made for applications to $p = 2.5$ than to $p = 1.5$.

Curves computed from Eqs. 48 and 50 are

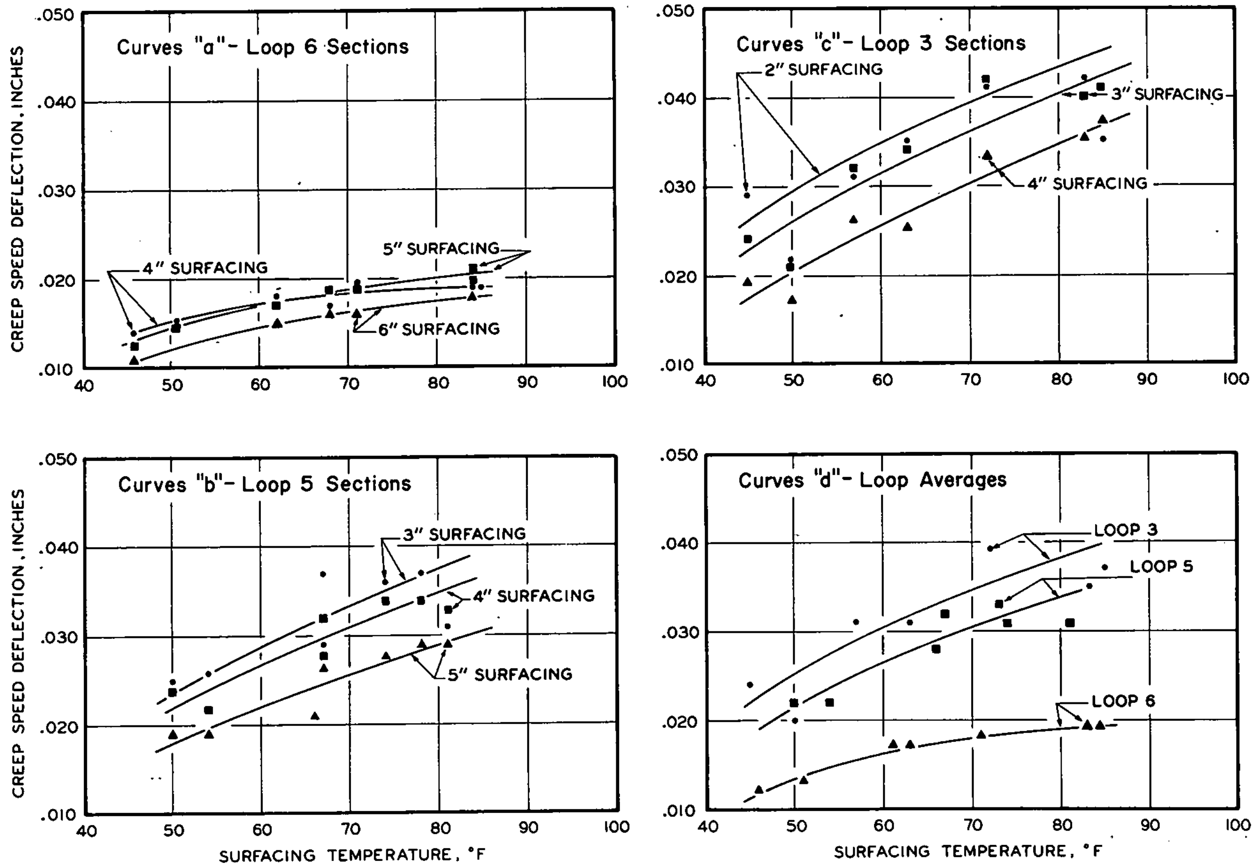


Figure 89. Deflection-temperature data, traffic loops, 12-kip single axle load.

shown for each load in Figures 92 and 93, respectively, along with the scatter of individual test section deflections about the computed curves. The equations were derived from sections whose serviceability had reached $p = 2.5$ by the end of test traffic. These sections are represented by solid points if terminal serviceability was 1.5 before the end of the test and by squares if final serviceability was between 2.5 and 1.5. Sections represented by open circles had serviceability indexes greater than 2.5 at the end of the test, and are plotted at points estimated from the performance equations (see Section 2.2) for log $W_{2.5}$. Summary plots of Eqs. 48 through 51 are shown in Figure 94.

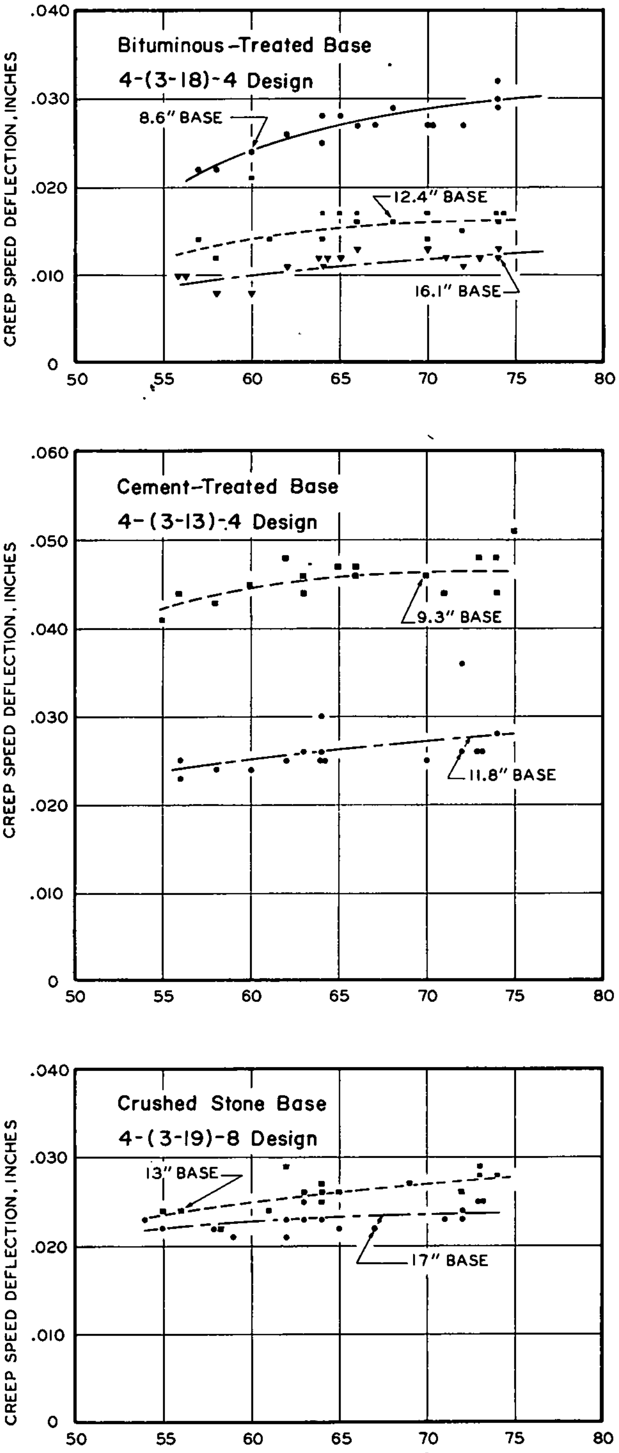


**Figure 90.** Deflection-temperature data, special base type wedge sections, 30-kip single axle load.

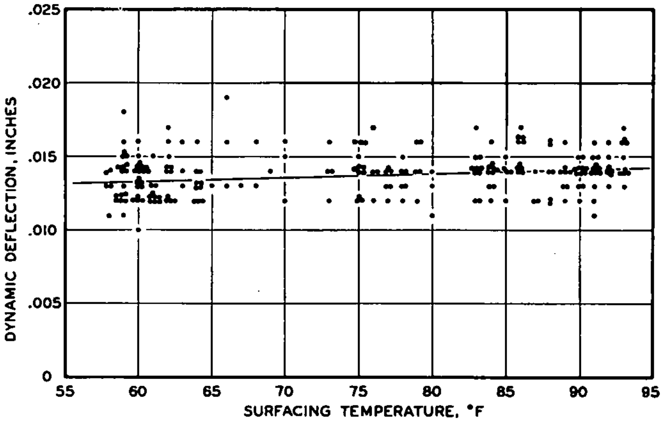


**Figure 91.** Deflection-temperature data, 18-kip single axle load (5–6–12 design)

Because normal deflections could not be obtained with the Benkelman beam under tandem axle loads, Eqs. 48 through 51 must be used in conjunction with single-tandem relationships (see Section 2.2.2) in order to predict life under tandem axle loads.

Mean residuals for log $W$ are about the same whether log $W$ is predicted from the performance equation with given pavement design and load or predicted from the equations involving load and spring deflections. Therefore, under the conditions of the Road Test, flexible pavement performance was predicted with essentially the same precision from load-spring deflection information as from load-design information. In actual highway practice it may be that the load-deflection equations are better predictors since they can reflect non-uniformity of construction as well as differences between Road Test materials and those used in the actual construction.

The relationships in Figure 94 might be used to indicate the magnitude of deflection, measured in the fall or spring, that could be considered "safe" for any specified number of load applications before $p = 2.5$ or $p = 1.5$. If, for example, it is assumed that there is little risk

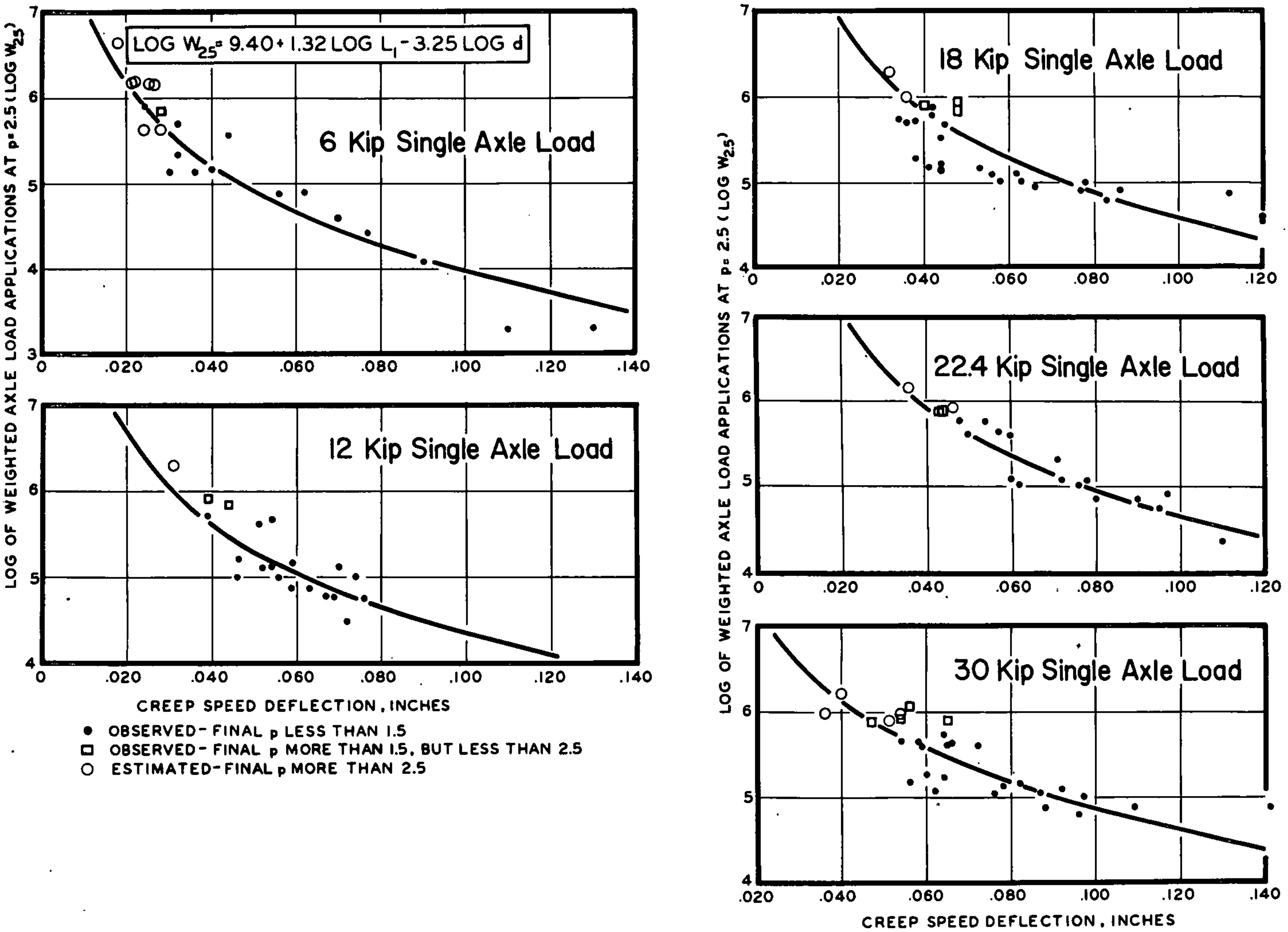


Figure 92. Main factorial experiment, relationship between axle load application at $p = 2.5$ and spring 1959 creep speed deflections.

that a pavement life will fall much more than two mean residuals below the curves, then safe curves would be parallel to those of Figure 94 at a distance of about 0.50 units below the curves as shown. For example, this rule would determine that a spring deflection of 0.025 is safe for a pavement that is expected to carry one million 18-kip axle loads without dropping below $p = 2.5$.

### *2.4.2 Rutting-Deflection Relationships*

Because serviceability, and therefore pavement performance, was affected by the degree of rutting and because a high level of correlation was found to exist between deflection and performance, deflection was expected to correlate with rutting. Figure 95 shows this to be the case.

The analyses involved the spring normal deflections (see Section 2.4.1) and the mean of the rut depths in both wheelpaths of the main factorial sections in lane 1 of Loops 3, 4, 5 and 6 and in lane 2 of Loop 2. Regression analyses were made of data obtained at 140,000 and 610,000 axle load applications and at the end of traffic testing (1,114,000 applications). The regression lines and equations are shown (Fig. 95) along with plotted values of the observed data. Also shown are the correlation coefficient and the standard error of estimate for each case. The dotted lines are located at a distance of one standard error of estimate from each regression line.

## 2.5 AUXILIARY STUDIES

### *2.5.1. Overlays*

A study of the effectiveness of asphaltic concrete overlays included 99 flexible pavement test sections. It was clear that overlays were highly effective as a means for extending the service life of these pavements.

Attempts at mathematical analysis designed to establish specific relationships between performance and overlay design were unsuccessful, because the outcome of each analysis proved to be highly dependent on the assumptions made concerning the mathematical model for the analysis. Further work will be attempted by the Highway Research Board.

In the flexible pavement factorial experiment, 83 of the 288 sections failed early in the test. Each was rebuilt to a thickness considered adequate to carry the remaining test traffic. Their subsequent performance was no longer observed. In another group of 129 sections, structural deterioration occurred at a much slower rate. Many sections in this category were overlaid, and observations and studies of their performance were continued in the same manner as for in-test sections. Thus, for each of these sections the loss in serviceability with load applications could be determined from the time it was overlaid until further maintenance was necessary, or until the end of the traffic test. It was intended to use trends in loss of serviceability of these sections to develop information regarding the effectiveness of the overlays.

The study included 5 sections from Loop 2, 12 from Loop 3, 23 from Loop 4, 30 from Loop 5 and 29 from Loop 6. Basic data obtained from the study (Table 28) include (a) original design of each section; (b) thickness, date placed and type of overlay and percent asphalt from extraction tests; (c) data from Marshall tests on the overlay material; (d) weighted axle load application sustained before and after overlaying; (f) rut depths before overlaying and on final observation date; (g) cracking and patching; (h) level of serviceability trend before and after overlaying and on the final observation date; and (i) deflections.

Not all of the sections had reached a serviceability level of 1.5 when they were overlaid. Some were overlaid when one wheelpath only (usually the outer) had attained this level. Generally, these were sections having such severe distress in one wheelpath that they were considered unsafe for the test vehicles at their normal speeds, despite over-all serviceabilities over 1.5. In some sections, the rate of deterioration of serviceability was so rapid that they

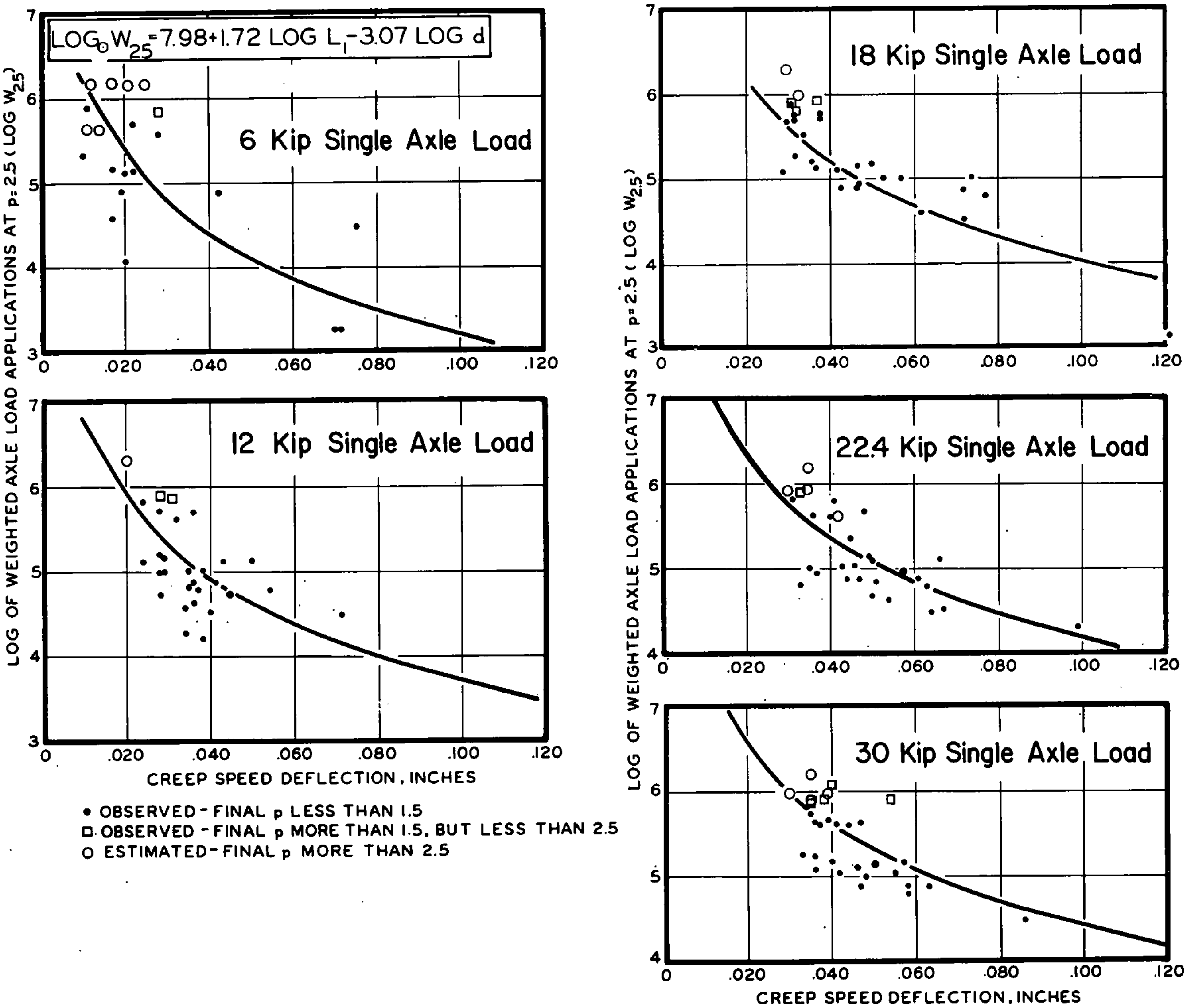


**Figure 93.** Main factorial experiment, relationship between axle load application at $p = 2.5$ and fall 1958 creep speed deflections.

were not actually overlaid until their condition was below the 1.5 level. In many cases, this was because of the established policy under which the placement of overlays was often delayed until two or more sections had fallen below the 1.5-serviceability level. (It is important to keep in mind that the analysis of performance of the sections in the main experiment was based on the entire serviceability trend of each section, and that after a downward trend was established for any section, the actual level of serviceability at which the section was removed from test had little bearing on the results.)

Moreover, the data (Table 28) show that the level of serviceability of the overlays after placement was not as high as the average (4.2) of the sections when originally constructed. This was not surprising in view of the short lengths (100 ft) of the individual sections, and the necessity for placing many of the overlays at low temperature and during inclement weather.

The data in Table 28 have been further summarized in Table 29, which gives weighted applications of axle loads that the sections, averaged by lanes, withstood before and after overlaying, together with average values of the initial and final overlay serviceabilities. The overlaid sections sustained an average of 671,000 weighted load applications, with an average loss in serviceability of 0.5 (3.4 initial, 2.9 final). Before overlaying, the same sections had sustained a lower average number of weighted applications (348,000) with a higher loss in serviceability, 2.7 (4.2 original, 1.5 final). For all the sections, the average depth of rut before overlaying was 0.69 in. From the time of overlaying until the end of test traffic the ruts developed averaged 0.38 in. Although there are appreciable differences in the values for the individual lanes and those for all lanes combined, the over-all trends were much the same.

Several attempts were made at the Road Test to analyze mathematically the performance of the flexible pavement overlays. In these analyses the overlay was considered to be a fourth layer in the pavement system. It was assumed that the following model, similar to

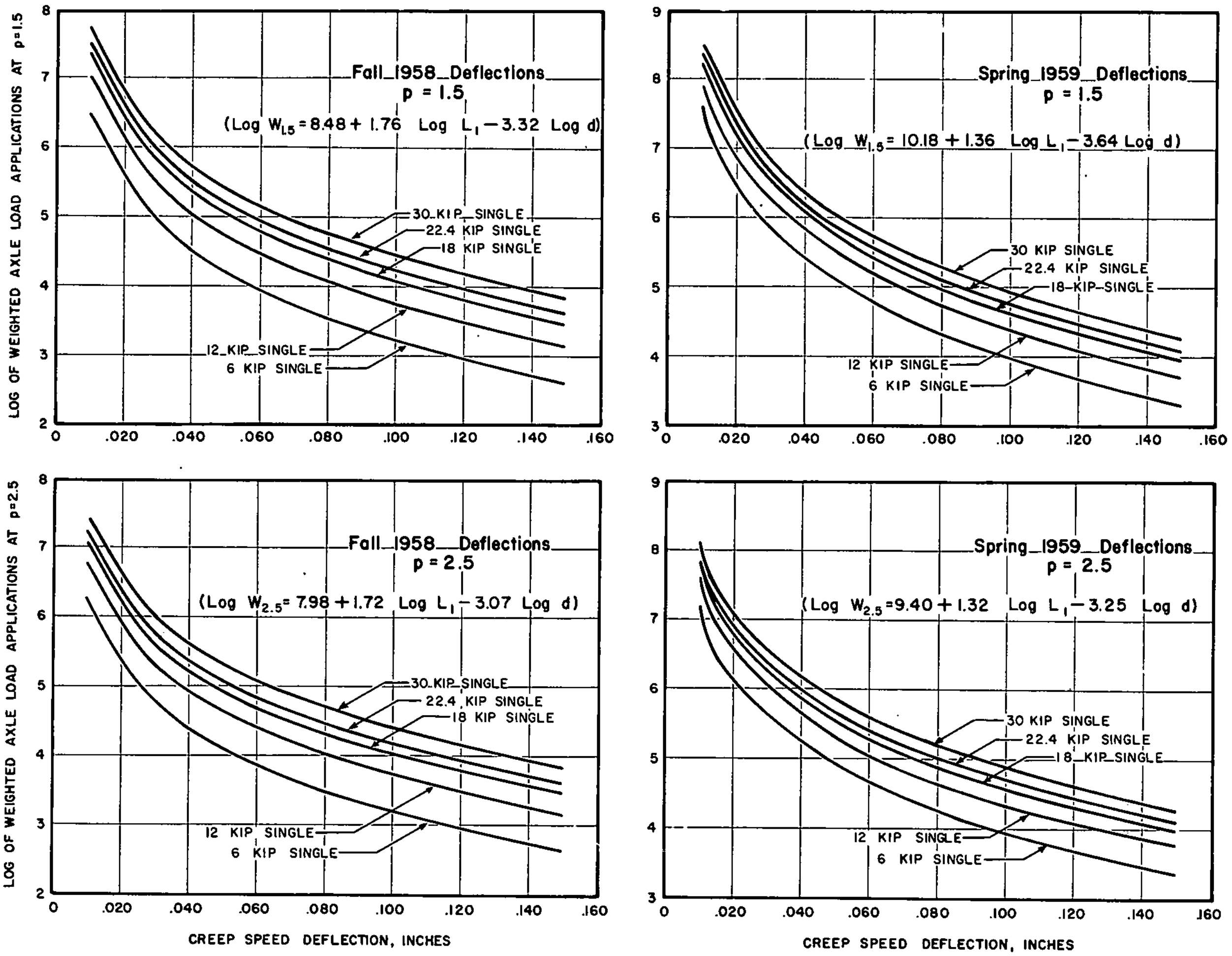


Figure 94. Main factorial experiment, relationship between performance and creep speed deflection (from Road Test equations).

that reported in Section 2.2 for performance, would apply:

$$G' = \beta' (\log W' - \log \rho') \qquad (52)$$

in which

$G'$ = a function of serviceability loss in the overlaid pavement, $\log \frac{4.2 - p}{2.7}$;

$W'$ = weighted axle application on the overlaid pavement;

$\beta'$ and $\rho'$ = functions of design and load, identical to $\beta$ and $\rho$ (see Eqs. 14 and 15) except that $D$ is now $D'$ and is defined as

$$D' = a'_1 D'_1 + a_1 D_1 + a_2 D_2 + a_3 D_3 \qquad (53)$$

in which

$D'_1$ = overlay thickness, in inches.

This approach to the analysis of overlaid pavement performance was tried using several alternative definitions for $G'$. The different assumptions involved different interpretations of the initial serviceability of the overlaid pavement, $p'_0$, and different hypotheses as to the rate of serviceability loss in pavements that did not start at a serviceability of $c_0 = 4.2$ as did the average pavement in the main performance analysis.

It was clear from these studies that the coefficient $a'_1$ for overlay thickness was highly dependent on these assumptions. Consequently, it was decided that additional studies by the Highway Research Board and others must be undertaken before mathematical statements as to overlay effect should be released.

### *2.5.2 Subsurface in Non-Traffic Loop (Loop 1)*

Loop 1 was included as part of the AASHO Road Test to provide a group of traffic free representative sections (designs) of pavement that would be continually available for a number of different studies. These included (1) periodic observations of the condition of the subsurface components, (2) measurements of vertical volume change, (3) temperature distribution, and (4) serviceability changes of pavements not subject to traffic.

The condition of the subsurface components in the non-traffic loop was more adverse than in the loops where traffic was a factor.

Little information of significance was found from the vertical volume change studies.

The rate and depth of heat penetration was greater in the pavement than in the granular shoulders.

There was virtually no loss of serviceability of the pavements in the non-traffic loop over the 2-yr period of the test.

*2.5.2.1 Strength and Condition Data, Non-Traffic Loop.*—No traffic was permitted to op-

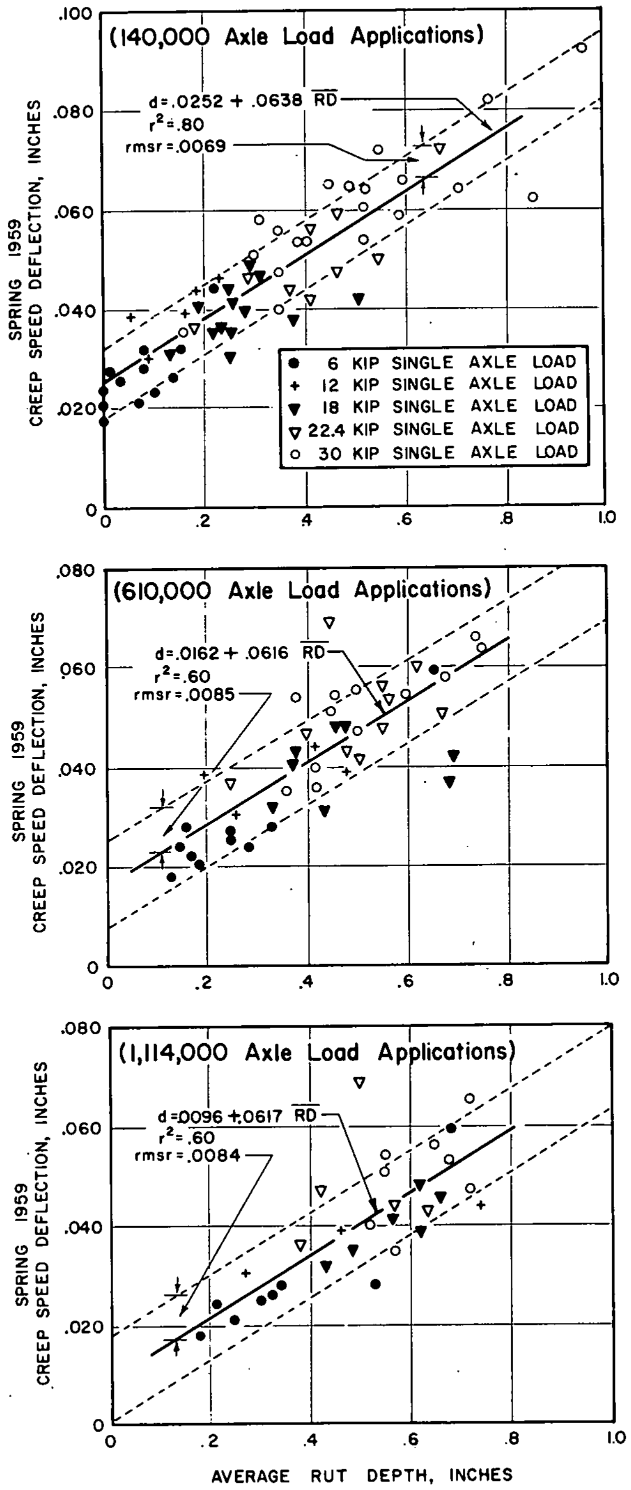


Figure 95. Main factorial experiment, relationship between rut depth and creep speed deflection.

## TABLE 28

### BASIC DATA, OVERLAY STUDY, FLEXIBLE PAVEMENT

| Loop | Axle Load (kips) | Orig. Design (in.) | Overlay |  |  |  | Marshall Stab. Data |  |  |  | Wtd. Applic. to $p = 1.5$ (1,000's) |  | Deflection[2] ($10^{-3}$ in.) |  | Rut Depth (in.) |  | Cracking and Patching (sq ft/ 1,000 sq ft) |  | Serviceability Rating |  |  | Date of End of Study | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Thickness (in.) | Date | Type[1] | Asphalt (%) | Stab. | Flow | Voids (%) |  | Before Overlay | After Overlay | Before Overlay | After Overlay | Before Overlay | End of Study | Before Overlay | End of Study | Before Overlay | After Overlay | End of Study |  |  |
|  |  |  |  |  |  |  |  |  | Total | Filled |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 | 6S | 1–6–4 | 2 | 4/ 6/60 | II | 4.5 | 2084 | 10.0 | 7.08 | 59.97 | 477 | 479 | 66 | 36 | 0.68 | 0.08 | 551 | 0 | 1.0 | 2.50 | 2.35 | 11/30/60 |  |
|  | 6S | 2–3–4 | 2 | 4/ 6/60 | II | 4.5 | 2084 | 10.0 | 7.08 | 59.97 | 530 | 457 | 34 | 28 | 0.40 | 0.10 | 300 | 0 | 1.1 | 2.40 | 2.15 | 11/30/60 | 4/6/60, 20 ft of surface replaced |
|  | 6S | 1–6–0 | 2 | 5/25/59 | II | 4.4 | 1573 | 9.0 | 5.99 | 63.30 | 145 | 1035 | 50 | 34 | 0.14 | 0.17 | 388 | 0 | 0.0 | 2.70 | 2.45 | 11/30/60 | 5/1/59, 25 ft ¼-in. binder overlay |
|  | 6S | 2–3–0 | 2 | 9/10/59 | II | 4.3 | 2403 | 10.0 | 5.14 | 66.70 | 306 | 895 | 76 | 48 | 0.28 | 0.26 | 234 | 0 | 1.7 | 2.23 | 2.00 | 11/30/60 |  |
|  | 6S | 3–3–0 | 2 | 6/ 2/60 | II |  | No Data |  |  |  | 802 | 283 | 18 | 28 | 0.33 | 0.15 | 172 | 0 | 2.2 | 3.17 | 3.20 | 11/30/60 | 5/24/60, 33 ft of surface replaced[3] |
| 3 | 24T | 2–6–8 | 3 | 3/29/60 | III | 4.6 | 2304 | 11.0 | 7.08 | 60.31 | 452 | 502 | 33 | 26 | 0.55 | 0.15 | 244 | 0 | 0.9 | 3.33 | 3.35 | 11/30/60 | —[3] |
|  | 12S | 4–3–8 | 3½ | 4/20/60 | III | 4.6 | 2526 | 12.0 | 4.55 | 71.16 | 645 | 430 | 54 | 35 | 0.65 | 0.18 | 192 | 0 | 1.6 | 3.35 | 3.55 | 11/30/60 | —[3] |
|  | 24T | 4–3–8 | 3½ | 4/ 7/60 | III | 4.6 | 2304 | 11.0 | 7.08 | 60.31 | 457 | 479 | 32 | 48 | 0.66 | 0.23 | 60 | 0 | 0.8 | 3.10 | 2.75 | 11/30/60 | 3/22/60, 13 ft of surface replaced |
|  | 24T | 4–6–4 | 3 | 4/27/60 | III |  | No Data |  |  |  | 702 | 430 | 78 | 20 | 0.70 | 0.28 | 442 | 0 | 1.0 | 3.73 | 3.65 | 11/30/60 |  |
|  | 24T | 3–3–8 | 3 | 5/12/59 | I | 4.6 | 1800 | 8.5 | 5.18 | 68.10 | 152 | 1044 | 124 | 38 | 0.66 | 0.38 | 399 | 0 | 1.7 | 3.97 | 3.80 | 11/30/60 |  |
|  | 12S | 3–6–4 | 4 | 4/ 6/60 | III | 4.5 | 2084 | 10.0 | 7.08 | 59.97 | 557 | 457 | 104 | 42 | 0.68 | 0.22 | 496 | 0 | 1.5 | 2.97 | 2.55 | 11/30/60 |  |
|  | 24T | 3–6–4 | 3 | 5/ 6/59 | I | 4.8 | 1817 | 9.5 | 4.55 | 71.50 | 138 | 216 | 91 | 37 | 0.25 | 0.23 | 150 | 200 | 2.1 | 3.30 | 2.00[4] | 1/ 6/60 | 21 ft skin patch |
|  | 12S | 4–0–8 | 3½ | 5/13/59 | I | 4.8 |  | No Data |  |  | 148 | 1044 | 84 | 66 | 0.84 | 0.28 | 250 | 0 | 1.3 | 3.50 | 3.30 | 11/30/60 |  |
|  | 24T | 3–6–8 | 3½ | 4/ 7/60 | III | 4.5 | 2771 | 12.0 | 6.07 | 64.66 | 657 | 457 | 58 | 28 | 0.48 | 0.15 | 158 | 0 | 1.7 | 3.77 | 3.80 | 11/30/60 | —[3] |
|  | 12S | 2–6–4 | 3 | 4/15/59 | I | 5.1 | 2138 | 10.5 | 4.33 | 73.50 | 110 | 1063 | 60 | 36 | 0.27 | 0.30 | 383 | 0 | 1.1 | 3.80 | 3.45 | 11/30/60 |  |
|  | 24T | 2–6–4 | 3 | 4/ 8/59 | I | 5.1 | 1657 | 10.0 | 4.28 | 72.70 | 80 | 76 | 138 | 52 | 0.50 | 0.43 | 834 | 325 | 0.5 | 2.90 | 2.00[4] | 6/10/59 | —[3] |
|  | 12S | 2–3–8 | 3 | 4/15/59 | I | 5.1 | 2138 | 10.5 | 4.33 | 73.50 | 108 | 73 | 112 | 35 | 0.25 | 0.28 | 296 | 200 | 1.2 | 2.20 | 2.00[4] | 7/ 1/59 |  |
| 4 | 18S | 3–0–12 | 3 | 5/18/59 | I | 4.6 | 1955 | 9.2 | 4.72 | 69.80 | 157 | 1044 | 37 | 34 | 0.62 | 0.30 | 396 | 0 | 1.6 | 3.87 | 3.90 | 11/30/60 | —[3] |
|  | 32T | 3–0–12 | 3 | 5/18/59 | I | 4.6 | 1955 | 9.0 | 4.72 | 69.80 | 157 | 1044 | 68 | 34 | 0.80 | 0.48 | 221 | 0 | 1.5 | 3.97 | 3.50 | 11/30/60 |  |
|  | 18S | 3–0–12 | 3 | 3/31/59 | I | 5.2 | 2274 | 12.0 | 3.55 | 77.30 | 86 | 1111 | 46 | 35 | 0.28 | 0.45 | 266 | 30 | 1.2 | 3.70 | 2.70 | 11/30/60 |  |
|  | 32T | 3–0–12 | 3 | 5/18/59 | I | 4.6 | 1955 | 9.0 | 4.72 | 69.80 | 145 | 1044 | 85 | 36 | 0.98 | 0.48 | 262 | 0 | 0.7 | 3.40 | 3.10 | 11/30/60 |  |
|  | 18S | 3–3–8 | 3 | 3/31/59 | I | 5.2 | 2274 | 12.0 | 3.55 | 77.30 | 86 | 76 | 65 | 40 | 0.28 | 0.50 | 458 | 485 | 1.4 | 3.85 | 2.00[4] | 6/10/59 |  |
|  | 18S | 5–0–8 | 3 | 5/19/59 | I | 4.7 |  | No Data |  |  | 162 | 1026 | 43 | 60 | 0.62 | 0.30 | 118 | 0 | 1.1 | 3.43 | 3.45 | 11/30/60 | 3/18/59, 40 ft of surface replaced[3] |
|  | 32T | 5–0–8 | 3 | 5/29/59 | I | 5.2 | 2345 | 13.0 | 3.60 | 77.70 | 171 | 1026 | 88 | 68 | 0.28 | 0.57 | 138 | 60 | 0.5 | 2.73 | 2.30 | 11/30/60 |  |
|  | 32T | 4–3–8 | 3 | 6/24/59 | I |  | No Data |  |  |  | 200 | 991 | 84 | 60 | 1.46 | 0.25 | 48 | 0 | 1.4 | 2.90 | 2.85 | 11/30/60 |  |
|  | 18S | 5–3–12 | 3 | 4/ 7/60 | I | 4.5 | 2771 | 12.0 | 6.07 | 64.66 | 571 | 479 | 38 | 24 | 0.35 | 0.22 | 180 | 0 | 1.5 | 3.35 | 2.35 | 11/30/60 |  |
|  | 32T | 4–6–4 | 3 | 5/21/59 | I | 4.8 |  | No Data |  |  | 164 | 1026 | 90 | 44 | 0.68 | 0.57 | 76 | 0 | 1.3 | 3.37 | 2.25 | 11/30/60 |  |
|  | 18S | 4–3–8 | 3 | 5/19/59 | I | 4.7 |  | No Data |  |  | 152 | 1026 | 126 | 46 | 0.45 | 0.34 | 70 | 0 | 1.1 | 3.77 | 3.25 | 11/30/60 |  |
|  | 32T | 4–3–8 | 3 | 6/ 8/59 | I | 4.8 | 2446 | 12.0 | 3.30 | 77.50 | 187 | 1004 | 76 | 60 | 1.15 | 0.68 | 72 | 0 | 1.4 | 3.97 | 3.25 | 11/30/60 |  |
|  | 32T | 3–6–12 | 3 | 5/12/60 | III | 4.7 | 2031 | 11.0 | 6.46 | 63.44 | 668 | 401 | 27 | 23 | 0.76 | 0.22 | 198 | 0 | 0.5 | 3.67 | 3.50 | 11/30/60 |  |
|  | 32T | 4–0–12 | 3 | 4/ 2/60 | I | 4.6 | 1928 | 11.0 | 6.05 | 64.46 | 504 | 502 | 25 | 16 | 0.44 | 0.25 | 208 | 0 | 0.0 | 3.67 | 3.15 | 11/30/60 | 4/1/60, 47 ft of surface replaced |
|  | 18S | 5–6–4 | 3½ | 4/19/60 | IB | 4.8 | 1975 | 11.0 | 5.40 | 68.08 | 645 | 430 | 92 | 29 | 0.66 | 0.20 | 338 | 0 | 1.1 | 3.83 | 2.90 | 11/30/60 |  |
|  | 32T | 5–6–4 | 3½ | 4/19/60 | III | 4.8 | 1975 | 11.0 | 5.40 | 68.08 | 679 | 430 | 56 | 30 | 0.52 | 0.34 | 130 | 0 | 2.1 | 3.70 | 3.55 | 11/30/60 |  |
|  | 18S | 3–3–12 | 3 | 4/ 2/60 | I | 4.6 | 1928 | 11.0 | 6.05 | 64.46 | 530 | 559 | 30 | 28 | 0.48 | 0.27 | 408 | 0 | 1.1 | 3.15 | 2.80 | 11/30/60 | 4/1/60, 1-in. scratch coat[5] |
|  | 32T | 3–3–12 | 3 | 4/ 7/60 | IB | 4.5 | 2771 | 12.0 | 6.07 | 64.66 | 611 | 479 | 40 | 29 | 0.36 | 0.26 | 304 | 0 | 2.2 | 3.50 | 3.20 | 11/30/60 |  |
|  | 18S | 5–0–12 | 3 | 5/12/60 | III | 4.7 | 2031 | 11.0 | 6.46 | 63.44 | 775 | 416 | 29 | 22 | 0.68 | 0.20 | 226 | 0 | 1.1 | 3.35 | 3.15 | 11/30/60 |  |
|  | 18S | 3–6–8 | 3 | 4/20/59 | I |  | No Data |  |  |  | 116 | 648 | 59 | 28 | 0.40 | 0.34 | 204 | 272 | 1.3 | 3.30 | 2.00[4] | 5/25/60 |  |
|  | 32T | 3–6–8 | 3½ | 4/ 2/60 | I | 4.6 | 1928 | 11.0 | 6.05 | 64.46 | 477 | 502 | 36 | 22 | 0.72 | 0.32 | 365 | 0 | 0.0 | 3.40 | 3.35 | 11/30/60 |  |
|  | 18S | 5–6–4 | 3 | 4/25/60 | III |  | No Data |  |  |  | 734 | 430 | 158 | 16 | 0.72 | 0.22 | 408 | 0 | 1.9 | 3.00 | 2.65 | 11/30/60 |  |
|  | 18S | 5–3–8 | 3½ | 4/ 5/60 | I | 4.5 | 2064 | 10.0 | 7.33 | 59.39 | 557 | 457 | 24 | 24 | 0.65 | 0.25 | 244 | 0 | 1.2 | 3.37 | 2.50 | 11/30/60 |  |
| 5 | 22.4S | 3–9–4 | 3 | 3/30/59 | I | 5.2 | 1994 | 11.0 | 3.61 | 77.20 | 80 | 1080 | 36 | 28 | 0.55 | 0.40 | 792 | 0 | 0.6 | 3.23 | 3.65 | 11/29/60 | —[3] |
|  | 40T | 3–9–4 | 3 | 3/30/59 | I | 5.2 | 1994 | 11.0 | 3.61 | 77.20 | 83 | 1097 | 60 | 36 | 0.65 | 0.52 | 924 | 0 | 1.4 | 2.97 | 2.85 | 11/29/60 |  |
|  | 22.4S | 3–3–12 | 3 | 4/15/59 | I | 5.1 | 2138 | 10.5 | 4.33 | 73.50 | 105 | 1080 | 78 | 19 | 0.58 | 0.36 | 452 | 0 | 1.2 | 3.20 | 2.35 | 11/29/60 |  |
|  | 40T | 3–3–12 | 3 | 5/ 7/59 | I | 4.6 | 1909 | 8.5 | 4.08 | 73.10 | 155 | 1044 | 34 | 24 | 0.55 | 0.45 | 188 | 0 | 1.6 | 3.27 | 2.85 | 11/29/60 |  |
|  | 22.4S | 3–6–8 | 3 | 3/19/59 | I | 5.2 | 1562 | 10.75 | 4.41 | 73.40 | 55 | 109 | 90 | 32 | 0.83 | 0.46 | 458 | 150 | 0.9 | 3.83 | 2.00[4] | 6/24/59 |  |
|  | 40T | 3–6–8 | 3 | 3/19/59 | I | 5.2 | 1562 | 10.75 | 4.41 | 73.40 | 60 | 123 | 54 | 36 | 0.37 | 0.68 | 215 | 160 | 1.4 | 3.10 | 2.00[4] | 6/24/59 |  |
|  | 22.4S | 5–3–8 | 3 | 5/ 7/59 | I | 4.6 | 1909 | 8.5 | 4.08 | 73.10 | 140 | 1044 | 32 | 36 | 1.22 | 0.30 | 104 | 0 | 0.4 | 3.80 | 2.60 | 11/29/60 |  |
|  | 40T | 5–3–8 | 3 | 6/ 8/59 | I | 4.8 | 2446 | 12.0 | 3.30 | 77.50 | 175 | 1004 | 76 | 40 | 1.50 | 0.62 | 172 | 0 | 1.5 | 3.80 | 3.65 | 11/29/60 |  |
|  | 22.4S | 5–6–4 | 3 | 4/29/59 | I | 4.5 | 1700 | 10.0 | 4.74 | 69.50 | 135 | 1063 | 59 | 40 | 0.36 | 0.38 | 219 | 0 | 0.9 | 3.00 | 2.00 | 11/29/60 |  |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 40T | 5–6–4 | 3 | 5/15/59 | I | 4.7 | | No Data | | | 153 | 1044 | 48 | 46 | 0.76 | 0.45 | 144 | 0 | 1.7 | 3.17 | 2.50 | 11/29/60 | |
| | 22.4S | 4–6–12 | 3 | 4/15/60 | IB | 4.5 | 1943 | 10.0 | 6.38 | 62.77 | 622 | 457 | 38 | 22 | 0.67 | 0.14 | 326 | 0 | 0.1 | 3.40 | 2.45 | 11/29/60 | |
| | 40T | 4–6–12 | 3 | 4/15/60 | IB | 4.5 | 1943 | 10.0 | 6.38 | 62.77 | 443 | 479 | 31 | 18 | 0.68 | 0.24 | 100 | 0 | 1.4 | 3.10 | 2.85 | 11/29/60 | |
| | 22.4S | 3–3–12 | 3 | 3/19/59 | I | 5.2 | 1562 | 10.75 | 4.41 | 73.40 | 60 | 123 | 59 | 30 | 0.58 | 0.58 | 248 | 99 | 1.5 | 3.60 | 2.00[4] | 6/24/59 | |
| | 40T | 3–3–12 | 3 | 3/30/59 | I | 5.2 | 1994 | 11.0 | 3.61 | 77.20 | 83 | 76 | 46 | 42 | 0.48 | 0.54 | 334 | 340 | 1.1 | 3.75 | 1.55 | 6/24/59 | |
| | 22.4S | 4–9–4 | 3 | 4/29/59 | I | 4.5 | 1700 | 10.0 | 4.74 | 69.50 | 136 | 1063 | 95 | 74 | 0.60 | 0.38 | 542 | 0 | 1.4 | 3.50 | 3.60 | 11/30/60 | —[3] |
| | 40T | 4–9–4 | 3 | 5/15/59 | I | 4.7 | | No Data | | | 152 | 109 | 52 | 35 | 0.76 | 0.54 | 454 | 200 | 1.7 | 2.90 | 2.00[4] | 8/19/59 | |
| | 40T | 3–9–12 | 3 | 5/23/60 | III | 4.6 | 2392 | 10.0 | 6.38 | 63.32 | 752 | 334 | 32 | 23 | 0.80 | 0.14 | 298 | 0 | 1.4 | 3.50 | 3.60 | 11/30/60 | —[3] |
| | 22.4S | 4–3–12 | 3 | 5/ 7/59 | I | 4.6 | 1909 | 8.5 | 4.08 | 73.10 | 141 | 1044 | 48 | 28 | 0.88 | 0.28 | 268 | 0 | 1.6 | 3.63 | 3.85 | 11/30/60 | —[3] |
| | 40T | 4–3–12 | 3 | 5/ 7/59 | I | 4.6 | 1909 | 8.5 | 4.08 | 73.10 | 138 | 1044 | 60 | 30 | 1.22 | 0.45 | 220 | 0 | 1.7 | 3.30 | 2.55 | 11/30/60 | |
| | 22.4S | 4–6–8 | 3 | 5/12/59 | I | 4.6 | 1800 | 8.5 | 5.18 | 68.10 | 138 | 1044 | 38 | 30 | 0.84 | 0.34 | 252 | 0 | 1.3 | 4.07 | 3.95 | 11/30/60 | |
| | 40T | 4–6–8 | 3 | 4/ 6/60 | I | 4.5 | 2084 | 10.0 | 7.08 | 59.97 | 428 | 479 | 39 | 33 | 0.95 | 0.32 | 300 | 6 | 1.1 | 3.55 | 2.50 | 11/30/60 | 4/4/60, 1-in. scratch course |
| | 22.4S | 4–6–8 | 3 | 5/12/59 | I | 4.6 | 1800 | 8.5 | 5.18 | 68.10 | 148 | 1044 | 55 | 35 | 0.72 | 0.35 | 314 | 0 | 1.5 | 4.00 | 3.10 | 11/30/60 | |
| | 22.4S | 5–6–8 | 3 | 5/23/60 | IB | 4.6 | 2392 | 10.0 | 6.38 | 63.32 | 747 | 334 | 38 | 27 | 0.80 | 0.20 | 264 | 0 | 0.9 | 3.53 | 2.15 | 11/30/60 | |
| | 22.4S | 3–9–8 | 3 | 4/16/59 | I | 4.8 | 1748 | 9.5 | 5.91 | 65.40 | 105 | 1080 | 70 | 30 | 0.72 | 0.24 | 526 | 0 | 1.0 | 3.00 | 2.55 | 11/30/60 | |
| | 40T | 3–9–8 | 3 | 5/25/59 | I | 4.4 | 1573 | 9.0 | 5.99 | 63.30 | 145 | 1026 | 55 | 38 | 0.92 | 0.40 | 712 | 0 | 1.6 | 3.37 | 2.20 | 11/30/60 | |
| | 22.4S | 5–9–4 | 3 | 4/29/60 | IB | 4.5 | 2357 | 10.0 | 5.49 | 66.45 | 691 | 430 | 58 | 18 | 0.70 | 0.20 | 388 | 0 | 0.8 | 3.30 | 3.30 | 11/30/60 | —[3] |
| | 40T | 5–9–4 | 3 | 5/12/60 | III | 4.7 | 2031 | 11.0 | 6.46 | 63.44 | 702 | 401 | 39 | 22 | 1.02 | 0.28 | 220 | 0 | 0.6 | 2.97 | 2.95 | 11/30/60 | |
| | 22.4S | 5–9–4 | 3½ | 4/15/60 | III | 4.5 | 1943 | 10.0 | 6.38 | 62.77 | 557 | 479 | 43 | 28 | 0.62 | 0.18 | 382 | 0 | 1.5 | 3.30 | 3.15 | 11/30/60 | |
| | 40T | 5–9–4 | 3 | 4/29/60 | III | 4.5 | 2357 | 10.0 | 5.49 | 66.45 | 611 | 430 | 48 | 17 | 0.68 | 0.25 | 305 | 0 | 1.2 | 3.33 | 3.45 | 11/30/60 | —[3] |
| | 40T | 3–6–12 | 2 | 4/ 6/60 | I | 4.5 | 2084 | 10.0 | 7.08 | 59.97 | 452 | 457 | 37 | 32 | 1.12 | 0.12 | 718 | 0 | 1.0 | 3.67 | 3.60 | 11/30/60 | |
| 6 | 48T | 4–6–16 | 3 | 5/14/60 | I | 4.7 | 2160 | 10.0 | 5.31 | 67.85 | 679 | 401 | 20 | 18 | 0.90 | 0.38 | 72 | 0 | 1.1 | 3.90 | 3.90 | 12/ 3/60 | —[3] |
| | 30S | 6–3–16 | 3 | 5/14/60 | III | 4.7 | 2160 | 10.0 | 5.31 | 67.85 | 702 | 401 | 28 | 18 | 0.74 | 0.30 | 235 | 0 | 1.2 | 3.67 | 3.55 | 11/30/60 | |
| | 30S | 5–6–8 | 3 | 4/30/59 | I | 4.5 | 1700 | 10.0 | 4.74 | 69.50 | 133 | 1063 | 60 | 26 | 0.44 | 0.62 | 358 | 0 | 1.0 | 2.93 | 2.50 | 12/ 3/60 | |
| | 48T | 5–6–8 | 3 | 5/18/59 | I | 4.6 | 1955 | 9.0 | 4.72 | 69.80 | 143 | 1044 | 55 | 32 | 1.05 | 0.56 | 108 | 0 | 1.4 | 2.90 | 2.60 | 11/30/60 | |
| | 30S | 5–3–12 | 3 | 4/30/59 | I | 4.5 | 1700 | 10.0 | 4.74 | 69.50 | 135 | 1063 | 54 | 22 | 0.38 | 0.56 | 200 | 0 | 1.3 | 3.57 | 3.40 | 12/ 3/60 | |
| | 30S | 6–9–8 | 3 | 5/14/60 | III | 4.7 | 2160 | 10.0 | 5.31 | 67.85 | 691 | 416 | 36 | 19 | 0.87 | 0.25 | 236 | 0 | 1.0 | 3.35 | 3.00 | 11/30/60 | |
| | 30S | 6–3–8 | 3 | 6/19/59 | III | 4.9 | 1876 | 10.0 | 5.38 | 68.50 | 190 | 991 | 62 | 38 | 0.87 | 0.27 | 128 | 0 | 1.6 | 2.97 | 2.85 | 11/30/60 | |
| | 48T | 6–3–8 | 3 | 3/ 2/60 | I | 4.6 | 1928 | 11.0 | 6.05 | 64.46 | 517 | 502 | 22 | 19 | 0.76 | 0.32 | 94 | 0 | 0.4 | 3.47 | 3.70 | 12/ 3/60 | —[3] |
| | 30S | 4–3–12 | 3 | 1/20/60 | III | 4.4 | 2357 | 11.0 | 5.92 | 64.14 | 385 | 809 | 4 | 15 | 0.78 | 0.44 | 274 | 102 | 1.5 | 2.97 | 1.75 | 11/30/60 | |
| | 48T | 4–3–12 | 3½ | 3/ 2/60 | I | 4.6 | 1928 | 11.0 | 6.05 | 64.46 | 490 | 559 | 28 | 20 | 0.75 | 0.38 | 255 | 0 | 1.0 | 3.30 | 3.15 | 12/ 3/60 | |
| | 30S | 4–6–8 | 3 | 4/ 4/59 | I | 5.3 | 1742 | 11.5 | 3.59 | 78.10 | 86 | 1111 | 89 | 30 | 0.29 | 0.65 | 497 | 0 | 0.9 | 3.40 | 2.00 | 11/30/60 | |
| | 48T | 5–6–12 | 3 | 4/28/60 | IB | 4.5 | 2323 | 10.0 | 6.13 | 63.95 | 668 | 430 | 34 | 14 | 0.87 | 0.25 | 244 | 0 | 1.7 | 3.83 | 3.85 | 12/ 3/60 | —[3] |
| | 30S | 5–6–12 | 2½ | 4/22/60 | III | 4.7 | 2220 | 10.0 | 5.05 | 69.20 | 725 | 430 | 43 | 20 | 0.80 | 0.25 | 396 | 0 | 1.5 | 3.30 | 3.00 | 11/30/60 | |
| | 48T | 5–6–12 | 3½ | 4/10/60 | IB | 4.5 | 1724 | 9.0 | 7.91 | 57.35 | 584 | 457 | 42 | 23 | 0.85 | 0.22 | 292 | 0 | 1.6 | 2.97 | 2.95 | 12/ 3/60 | |
| | 30S | 5–9–8 | 3½ | 3/ 1/60 | III | 4.6 | 2495 | 13.0 | 5.79 | 65.40 | 584 | 502 | 34 | 24 | 0.72 | 0.25 | 320 | 0 | 1.6 | 3.40 | 3.15 | 11/30/60 | |
| | 48T | 5–9–8 | 3 | 4/22/60 | IB | 4.7 | 2220 | 10.0 | 5.05 | 69.20 | 691 | 430 | 34 | 25 | 0.65 | 0.25 | 335 | 0 | 1.4 | 3.50 | 3.65 | 12/ 3/60 | —[3] |
| | 30S | 5–3–16 | 3 | 4/ 2/60 | III | 4.6 | 1928 | 11.0 | 6.05 | 64.46 | 490 | 502 | 28 | 23 | 0.75 | 0.24 | 372 | 0 | 0.7 | 2.50 | 2.65 | 11/30/60 | 4/1/60, 2-in. scratch course[5] |
| | 48T | 5–3–16 | 3 | 5/14/60 | I | 4.7 | 2160 | 10.0 | 5.31 | 67.85 | 747 | 401 | 22 | 20 | 0.66 | 0.32 | 84 | 0 | 1.3 | 3.97 | 3.85 | 12/ 3/60 | |
| | 30S | 4–3–16 | 3 | 7/ 9/59 | III | 5.0 | 2312 | 12.0 | 4.40 | 73.00 | 183 | 981 | 47 | 24 | 1.00 | 0.35 | 453 | 0 | 1.7 | 2.50 | 2.20 | 11/30/60 | |
| | 48T | 4–3–16 | 3½ | 4/18/60 | I | 4.6 | 1955 | 11.0 | 5.98 | 64.65 | 679 | 457 | 49 | 23 | 0.84 | 0.32 | 368 | 0 | 1.5 | 4.07 | 4.25 | 12/ 3/60 | —[3] |
| | 30S | 4–9–8 | 3 | 4/ 4/59 | III | 5.3 | 1742 | 11.5 | 3.59 | 78.10 | 83 | 1111 | 86 | 26 | 0.39 | 0.50 | 446 | 0 | 0.5 | 3.80 | 3.70 | 11/30/60 | |
| | 48T | 4–9–8 | 3 | 9/10/59 | I | 4.3 | 2403 | 10.0 | 5.14 | 66.70 | 417 | 909 | 34 | 20 | 0.75 | 0.15 | 274 | 0 | 1.9 | 3.47 | 3.35 | 12/ 3/60 | |
| | 30S | 4–6–12 | 3 | 4/ 4/59 | III | 5.3 | 1742 | 11.5 | 3.59 | 78.10 | 89 | 150 | 65 | 30 | 0.50 | 0.62 | 696 | 140 | 1.1 | 3.40 | 2.00[4] | 8/ 5/59 | |
| | 48T | 4–6–12 | 3 | 4/30/59 | I | 4.5 | 1700 | 10.0 | 4.74 | 69.50 | 133 | 198 | 49 | 26 | 0.68 | 0.26 | 200 | 248 | 1.2 | 2.93 | 2.00[4] | 11/25/59 | |
| | 30S | 6–6–8 | 3 | 5/28/59 | III | 4.4 | 2300 | 15.0 | 3.60 | 74.80 | 145 | 1035 | 55 | 34 | 1.06 | 0.55 | 242 | 0 | 1.1 | 3.50 | 2.10 | 11/30/60 | |
| | 48T | 6–6–8 | 3 | 1/ 5/60 | I | 4.4 | 1587 | 10.0 | 7.25 | 58.97 | 306 | 825 | 29 | 17 | 1.23 | 0.40 | 494 | 0 | 0.1 | 3.67 | 2.90 | 12/ 3/60 | |
| | 30S | 4–3–16 | 3 | 4/15/59 | III | 5.1 | 2138 | 10.5 | 4.33 | 73.50 | 113 | 1089 | 50 | 36 | 0.55 | 0.38 | 588 | 0 | 1.3 | 3.35 | 2.55 | 11/30/60 | |
| | 48T | 4–3–16 | 3 | 5/20/59 | I | 4.9 | 1790 | 9.5 | 4.90 | 70.60 | 141 | 1044 | 48 | 29 | 1.25 | 0.65 | 446 | 0 | 1.0 | 2.87 | 2.05 | 12/ 3/60 | |
| | 30S | 6–3–12 | 3 | 9/ 3/59 | III | 4.4 | 2340 | 10.0 | 4.36 | 71.12 | 153 | 909 | 38 | 24 | 0.81 | 0.17 | 227 | 0 | 1.6 | 3.47 | 2.10 | 11/30/60 | |

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| [1] Overlay | | | Rolling | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Breakdown | | Intermediate | | Final | |
| Type | Thickness (in.) | Method | Wt. (tons) | Roller | Wt. (tons) | Roller | Wt. (tons) | Roller |
| I | 3 | Scratch coat; 2 lifts | 10 | 3-wheel steel | 12–15 | Pneumatic | 8 | Tandem |
| IB | 3 | Scratch coat; 2 lifts | 10 | Tandem | 19 | 100-psi pneu. | 8 | Tandem |
| II | 2 | Scratch coat; 1 lift | 5 | Tandem | — | — | 5 | Tandem |
| III | 3 | Scratch coat; 2 lifts | 10 | Tandem | — | — | 8 | Tandem |

[2] 6-kip axle load, Loop 2; 12-kip axle load, Loops 3, 4, 5, 6.

[3] Initial overlay serviceability lower than final value; for analysis these sections were assigned initial serviceability equal to final serviceability plus 0.1.

[4] Observations terminated prior to end of traffic due to maintenance; serviceability assumed to be 2.0.

[5] Scratch coat—a level course used to fill ruts and depressions before placing first lift. This course placed either by hand or asphalt paver without vibrating screed in operation. In general, this course was compacted with 5-ton tandem roller.

TABLE 29

PERFORMANCE DATA, SUMMARY OF OVERLAID SECTIONS

| Loop | Lane | Overlays | | Original Sections | | | | | | Overlaid Sections | | | | Rut Depth (in.) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No. | Thickness (in.) | Thickness (in.) | | | Weighted Applic. to $p = 1.5$[1] (1000's) | Serviceability | | Weighted Applic. (1000's) | Serviceability | | | Before Overlay | After Overlay to End of Test |
| | | | | Surf. | Base | Subb. | | Init. | Loss | | Init. | Final | Loss | | |
| 2 | 1 | 5 | 2.0 | 1.8 | 4.2 | 1.6 | 452 | 3.9 | 2.4 | 630 | 2.60 | 2.43 | 0.17 | 0.37 | 0.15 |
| 3 | 1 | 5 | 3.4 | 3.0 | 3.6 | 6.4 | 314 | 3.8 | 2.3 | 613 | 3.16 | 2.97 | 0.19 | 0.54 | 0.25 |
| | 2 | 7 | 3.1 | 3.0 | 5.1 | 6.3 | 377 | 4.0 | 2.5 | 458 | 3.40 | 3.05 | 0.35 | 0.54 | 0.26 |
| 4 | 1 | 12 | 3.1 | 3.7 | 3.0 | 9.1 | 381 | 4.2 | 2.7 | 642 | 3.50 | 2.80 | 0.70 | 0.52 | 0.30 |
| | 2 | 11 | 3.1 | 4.1 | 2.8 | 9.0 | 360 | 4.2 | 2.7 | 768 | 3.48 | 3.09 | 0.39 | 0.74 | 0.40 |
| 5 | 1 | 15 | 3.0 | 4.0 | 6.2 | 7.7 | 257 | 4.4 | 2.9 | 765 | 3.49 | 2.85 | 0.64 | 0.71 | 0.32 |
| | 2 | 15 | 3.0 | 3.8 | 6.4 | 8.3 | 302 | 4.3 | 2.8 | 610 | 3.32 | 2.74 | 0.58 | 0.83 | 0.40 |
| 6 | 1 | 16 | 3.0 | 4.9 | 5.1 | 11.3 | 305 | 4.2 | 2.7 | 785 | 3.26 | 2.66 | 0.60 | 0.68 | 0.40 |
| | 2 | 13 | 3.1 | 4.7 | 5.3 | 11.7 | 477 | 4.2 | 2.7 | 589 | 3.45 | 3.25 | 0.20 | 0.86 | 0.34 |
| All | | 99 | 3.0 | 4.0 | 4.9 | 8.7 | 348 | 4.2 | 2.7 | 671 | 3.40 | 2.90 | 0.50 | 0.69 | 0.38 |

[1] Extrapolated for those sections that did not reach $p = 1.5$ (see text).

erate in the lane other than that necessary every two weeks to tow the longitudinal profilometer. A discussion of the changes in serviceability in the no-traffic lane is given in Section 2.5.7. The outside lane was used in the deflection and subsurface condition studies. The deflection studies are discussed in Section 2.3.7. The results of subsurface studies are presented in this section.

The study included eight sections making up a 2 by 3 factorial experiment (Design 5) with one level of surfacing thickness (3 in.) two levels of base (0 and 6 in.) and three levels of subbase (0, 8 and 16 in.). Two of the designs, 3–0–8 and 3–6–6, were replicated. The sections were 125 ft in length and were divided into 5- by 12-ft panels. Panels were selected in random order for trenches that were cut at periodic intervals (except in winter) beginning in the spring of 1959. Before cutting a trench, Benkelman beam tests, using a 6-kip axle load, were made on the surface at three points, 3, 6 and 9 ft from the pavement edge at the centerline of the trench, and on lines 5 ft both sides of the trench centerline. Plate load tests using a 12-in. diameter plate, were also made on the surface before opening the trench. Plate load, CBR, moisture content, and density tests were made on each subsurface layer and the embankment.

The transverse locations of the tests within the trench were varied so that the tests would not be made one on top of another. Embankment tests were made in the outer wheelpath. One CBR test was made on the base and one on the subbase course in each wheelpath (3 and 9 ft from the pavement edge) and two were made at these locations on the embankment soil. Two density tests and moisture content determinations were made in each wheelpath on the base and two on the subbase. Four of each test were made in each wheelpath on the embankment. In addition, at each of two depths (16 in. and 32 in. below the level of the embankment) one moisture determination was made.

Details of testing procedures and data reduction are described in Appendix D. The results of the tests made in the subsurface study are given in DS 4150. In this report the data are presented in summary form only. Figures 96 and 97 show the trends in condition and indicated strength (CBR and plate load tests) of all the pavement components against time. Figure 98 shows the observed differences in these two characteristics for the spring and summer periods.

The data indicate that recovery in strength of the materials following the spring periods is at a slower rate and lower in degree than that observed in the traffic loop studies. The densities of the embankment soil, the subbase and base materials were practically the same in the spring and summer periods. This finding was identical to that for these materials in the traffic loops, and the increases in CBR and elastic modulus from spring to summer are attributed to moisture changes rather than to density changes (see Section 2.5.6). However, in case of the subbase and base materials, the increases in indicated strength are not as pronounced as those for the traffic loops.

Benkelman beam deflection data provided further evidence that flexible pavements under traffic possess higher strengths and recover strength more quickly than pavements without traffic. For equivalent designs, beam deflections on no-traffic pavement are higher and decrease from spring to fall at a slower rate. This is evidence that some traffic during the spring and early summer will hasten the restoration of pavement strength following the conditions associated with spring thaw.

Data obtained from the trench studies on Loop 1 were used to develop correlations between Benkelman beam deflection and the results of the plate load tests. A sample of these correlations is shown in Figure 99. Within the range of the test data the relationships are practically linear for 12- and 18-in. diameter plates and slightly curvilinear for the 24-in. plate. In these tests the beam deflection values were obtained under a 6-kip axle load, and

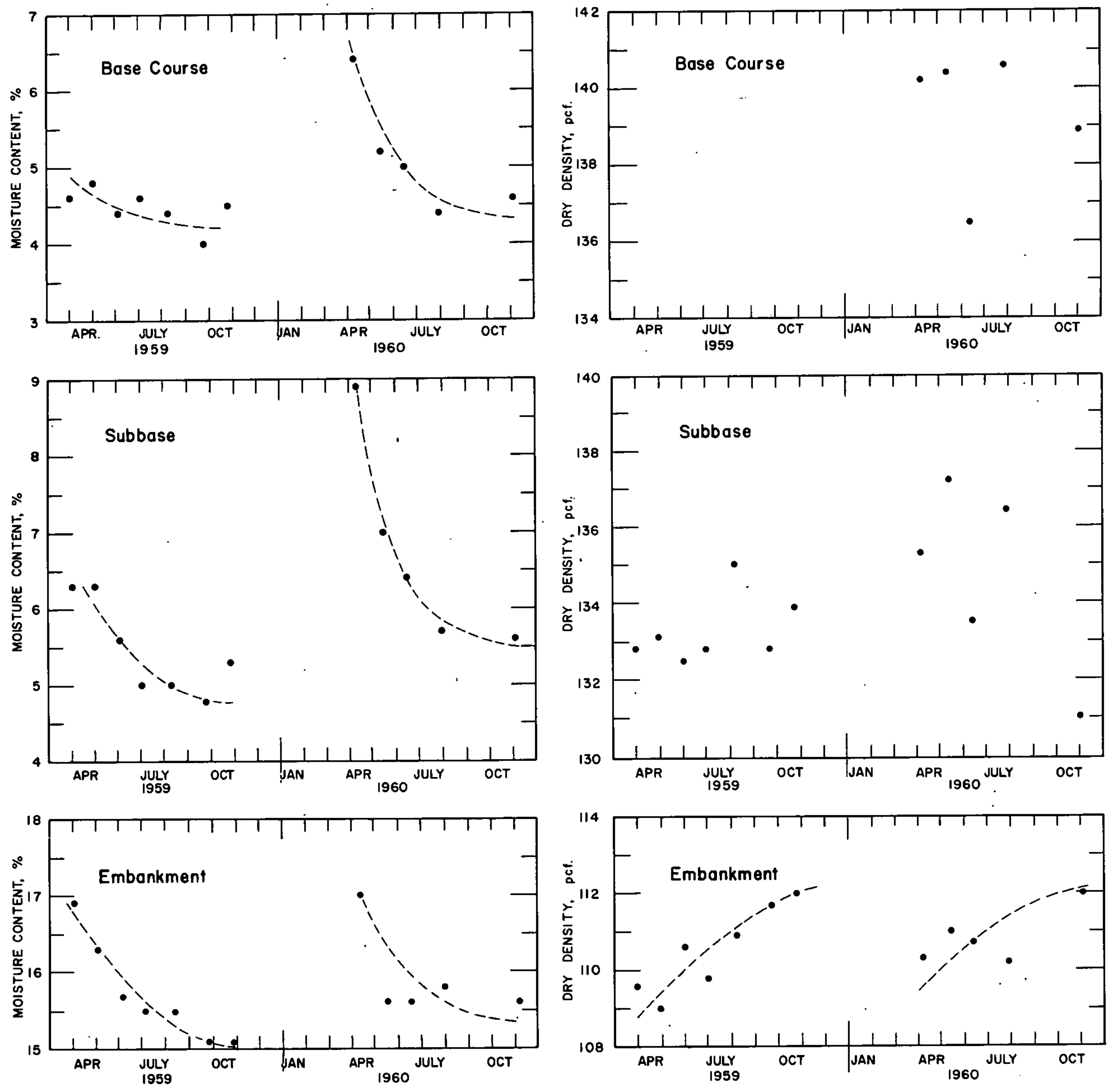

Figure 96. Seasonal subsurface conditions, Loop 1.

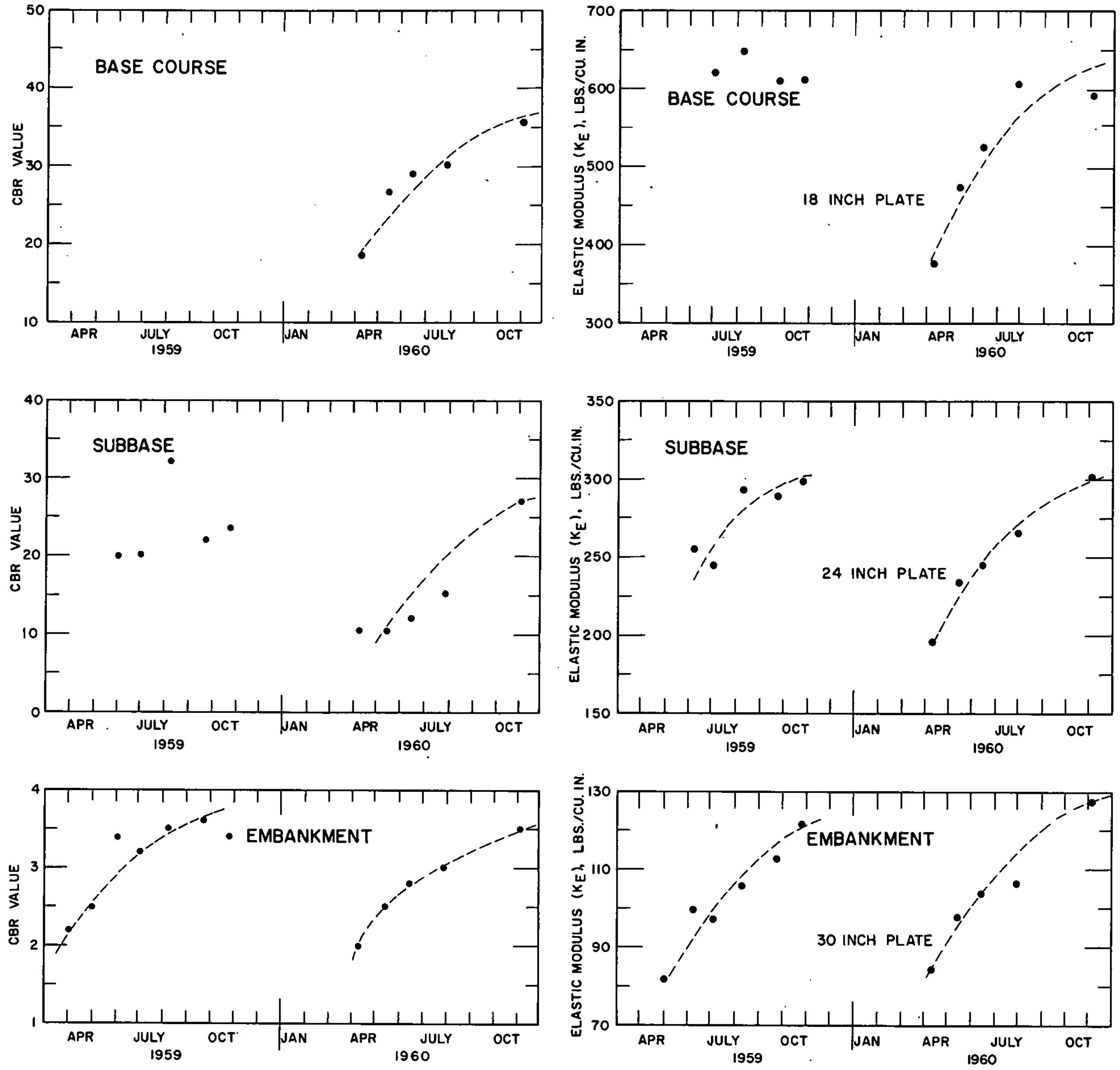

Figure 97. Seasonal strength tests, Loop 1.

the plate values are for a 16-psi unit load. Other investigators have found essentially the same correlation between the results of beam and plate load tests on flexible pavement surfaces.*

A considerable amount of effort was expended in developing relationships between the conditions of the embankment soil (moisture content, density and percent saturation) and the strength of the material (CBR and plate load tests). Since relationships of this type are of interest to many pavement research engineers, those developed in connection with the Loop 1 studies are given in Appendix H.

*2.5.2.2 Vertical Volume Changes.*—Instrumentation installed in selected sections of the non-traffic loop (Loop 1) produced information concerning the seasonal changes in elevation at the pavement surface at the top of the embankment soil, and at 4 ft below the top of the pavement. (Relevant information from the traffic loops is reported at the end of Section 2.2.3.1.)

Table 30 summarizes the data obtained from sections of the following designs: 5-0-0, 5-6-0, 5-0-16 and 5-6-16. Figure 100 shows the changes in elevation that were found at the three levels in the winter and fall of 1959 and

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* Sebastyan, C. Y., "The Benkelman Beam Deflections as a Measure of Pavement Strength." *Proceedings*, Canadian Good Road Association, 1960.

1960. The values plotted for the five sections represent the changes in elevation that occurred from the fall of 1958 when the initial readings were taken.

In the 5-0-0 section the vertical movements of the surface (up in both winters; down in both falls) were practically the same in degree as those of the embankment surface. At the 4-ft level, however, the movements were in the reverse order. In the other three sections, the movements of the pavement surface were similar, that is, up in the winter and down in the fall periods; however, the heave at the pavement surface was appreciably greater in the 5-6-0 section than in the other two. At the embankment level the movements followed those of the surface, except that in the second winter the movements were downward in case of the 5-0-16 and the 5-6-16 sections. At the 4-ft level below the pavement surface the movements in these three sections were of a low order of magnitude, except that in the second winter they were downward in the 5-0-16 and the 5-6-16 sections to about the same degree as the top of the embankment. In all four sections no heaving due to frost was found at the 4-ft level.

As expected, the movements at the embankment surface of the 5-0-0 section accounted for all the movements at the pavement surface. In the remaining three sections the movements at the pavement surface were accounted for by those at the embankment level plus those within the granular layers.

Of special interest is the fact that after disappearance of frost, the pavement sections settled appreciably (in most cases to a level below their original elevation even though they were not subjected to traffic).

*2.5.2.3 Temperature.*—In two sections of Loop 1 a sufficient number of thermocouples were installed to make it possible to study the distribution of temperature in the pavement structure and underlying embankment soil. Figure 101 shows the data for March 25 and May 25, 1960. When the temperature of the surfacing was at the minimum level on either date, the temperature of the underlying granular material was at a higher level; when the temperature of the surfacing was at its maximum level, the temperature of the material beneath was at a lower level. In all cases the "penetration" of a given temperature beneath the surfacing was appreciably different from that beneath the crushed stone shoulders. When the temperature of the surfacing was at its maximum level on either day, heat penetrated

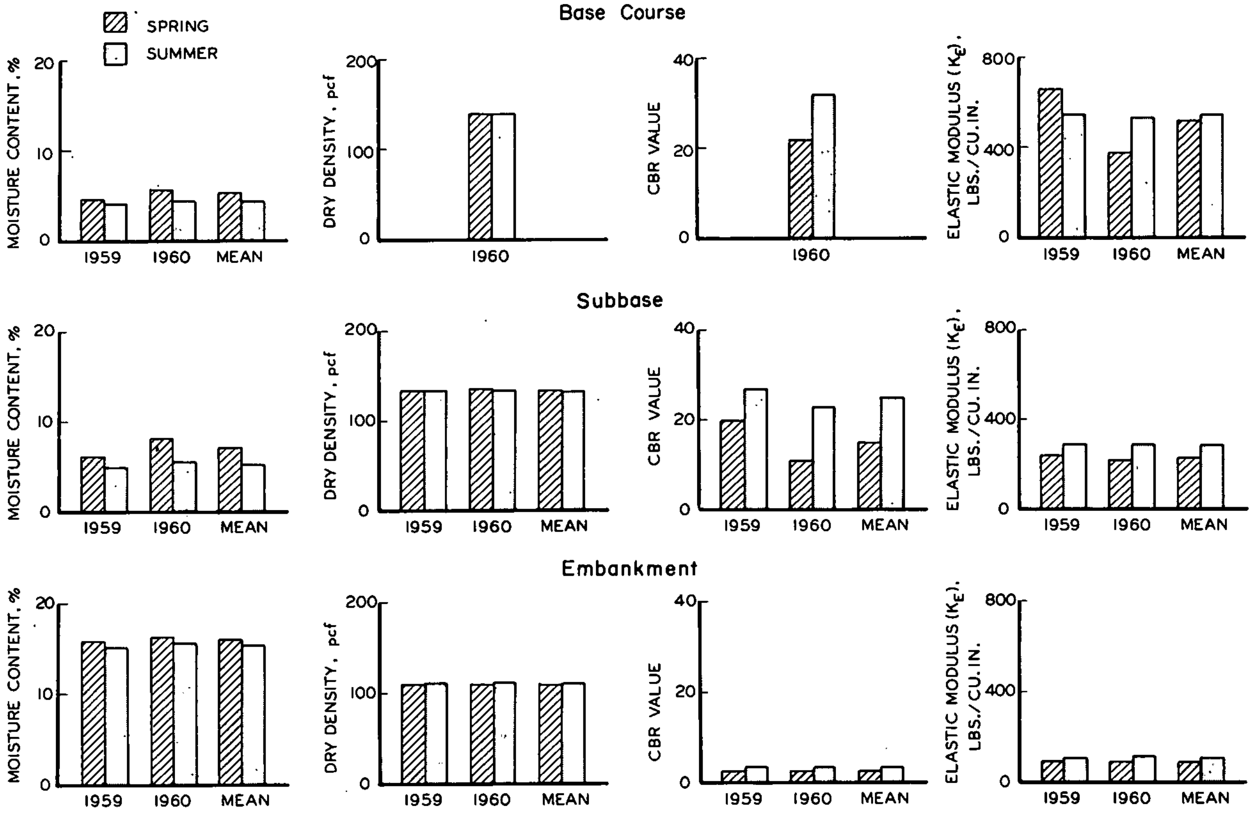

Figure 98. Spring and summer subsurface conditions, Loop 1.

TABLE 30

SEASONAL ELEVATION CHANGES[1] NON-TRAFFIC LOOP

| Date | Elevation Change (in.) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Surface of Pavement | | | | Surface of Embankment | | | | 4 Feet Below Surface | | | |
| | 5-0-0 Design | 5-6-0 Design | 5-0-16 Design | 5-6-16 Design | 5-0-0 Design | 5-6-0 Design | 5-0-16 Design | 5-6-16 Design | 5-0-0 Design | 5-6-0 Design | 5-0-16 Design | 5-6-16 Design |
| Dec. 1958 | +0.10 | +0.39 | −0.13 | +0.12 | +0.10 | +0.24 | +0.03 | −0.03 | +0.01 | 0 | −0.04 | 0 |
| Feb. 1959 | +0.09 | +0.52 | +0.33 | +0.13 | +0.09 | +0.43 | +0.18 | +0.01 | −0.05 | +0.02 | −0.05 | −0.10 |
| May 1959 | −0.09 | +0.16 | −0.17 | −0.16 | −0.09 | +0.12 | −0.18 | −0.06 | +0.14 | −0.02 | −0.02 | +0.07 |
| Aug. 1959 | −0.09 | +0.19 | −0.17 | −0.16 | −0.09 | +0.11 | −0.16 | −0.07 | +0.15 | −0.02 | −0.04 | +0.09 |
| Oct. 1959 | −0.06 | +0.12 | −0.25 | −0.21 | −0.06 | +0.05 | −0.22 | −0.11 | +0.18 | −0.04 | −0.07 | +0.04 |
| Jan. 1960 | +0.27 | +0.40 | +0.33 | +0.31 | +0.27 | +0.13 | −0.10 | −0.12 | +0.17 | −0.01 | −0.06 | +0.01 |
| Mar. 1960 | +0.27 | +0.74 | +0.24 | +0.37 | +0.27 | +0.48 | −0.24 | −0.40 | +0.15 | 0 | −0.31 | −0.26 |
| Apr. 1960 | −0.15 | +0.23 | −0.33 | −0.27 | −0.15 | +0.16 | −0.30 | −0.30 | +0.10 | −0.02 | −0.20 | −0.12 |
| Oct. 1960 | −0.20 | +0.08 | −0.31 | −0.25 | −0.20 | −0.02 | −0.24 | −0.20 | +0.23 | −0.11 | −0.11 | −0.02 |

[1] Values given are changes from initial readings obtained in fall 1958.

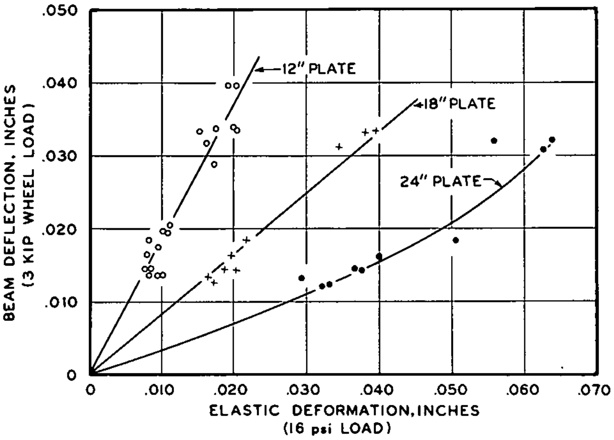

**Figure 99. Relationship between Benkelman beam and plate load deflections.**

into the granular material and embankment soil to a greater depth than beneath the shoulders. Conversely, when the temperature of the surfacing was at the minimum level, the temperature at a given depth was greater beneath the shoulders than beneath the surfacing.

*2.5.2.4 Serviceability Changes, Non-Traffic Loop.*—Pavements in Loop 1 were not subjected to the test traffic. Over the 2-yr test period no significant loss in serviceability was noted in these sections.

One of the purposes of Loop 1 was to determine the performance of pavements subjected to the effects of weather and time in the absence of traffic. Consequently, lane 1 of this loop was kept free of traffic during the entire test period. Because the flexible pavement sections in this lane were extremely short (25 ft) it was difficult to ascertain their serviceabilities without relatively large measurement error. Small localized irregularities played inordinately large parts in the serviceability determination. In longer sections such irregularities were "averaged out."

Another limitation of this experiment was its short duration. Obviously, the probable effects of environment and time on serviceability over the normal life span of a pavement could not be estimated satisfactorily from a 2-yr study. Nonetheless, a direct comparison was available between pavements subjected to traffic and those in Loop 1 that were not. Even though only two years had elapsed, several cycles of freezing and thawing occurred, and the normal central Illinois precipitation and temperature ranges were encountered.

The serviceability trend values for the sections in Loop 1 are included along with the other performance data in Appendix A. Excluding Section 857, which was inadvertently damaged, the serviceability trend values for the remaining 23 sections in the study averaged on index days 11, 22, 33, 44 and 55 were 3.47, 3.46, 3.37, 3.45 and 3.44. The differences among these values are well below the magnitude of experimental error associated with the serviceability determining system. Thus, it is concluded that no significant serviceability loss was found in the flexible pavements of Loop 1 that were not subjected to traffic over the 2-yr period of the Road Test.

### *2.5.3 Embankment Pressure*

In connection with the problem of the mechanics of load support of flexible pavements, pressures that are transmitted through the structure to the supporting soil were subjected to a limited study. In Loop 4, 20 pressure cells were installed in certain sections.

The variations in transmitted pressure with seasons and speed were of the same character as those shown for creep speed deflections.

The transmitted pressures were found to vary approximately as a linear function of the applied load in the same manner as deflections.

In the routine program of pressure distribution tests, observations of the pressure transmitted to the surface of the embankment were taken weekly except during the winter. Details of the test procedures and equipment used are given in Appendix D. The basic data obtained in these tests are given in DS 5162 and 5163.

One special study was made to determine the effect of vehicle speed on transmitted pressure to the surface of the embankment. The tests were conducted simultaneously with those made on December 2, 1959, to determine the effect of speed on deflection (see Section 2.3). Included were four sections of Loop 4 (3–6–12, 5–6–12, and the 5–6–4 section and its replicate) tested under four single axle loads (2, 6, 12 and 18 kips).

Variations in embankment pressure with seasons of the year are shown in Figure 102. The pressure reached a maximum value during the spring and early summer and decreased subsequently. The pattern of pressure variation with seasons was similar to that observed for creep speed deflections.

The effect of design (total thickness) of the pavement on transmitted pressure is shown in Figure 103. A fairly orderly effect is evident for the spring and summer periods. For the fall, the 3–6–12 (21-in. pavement) appears to be out-of-line. No explanation was found.

The pressure contours at the embankment level (Fig. 104) also show the effect of design of the pavement. The contours for one wheel of the tandem axle load show a slight effect of the adjacent second wheel.

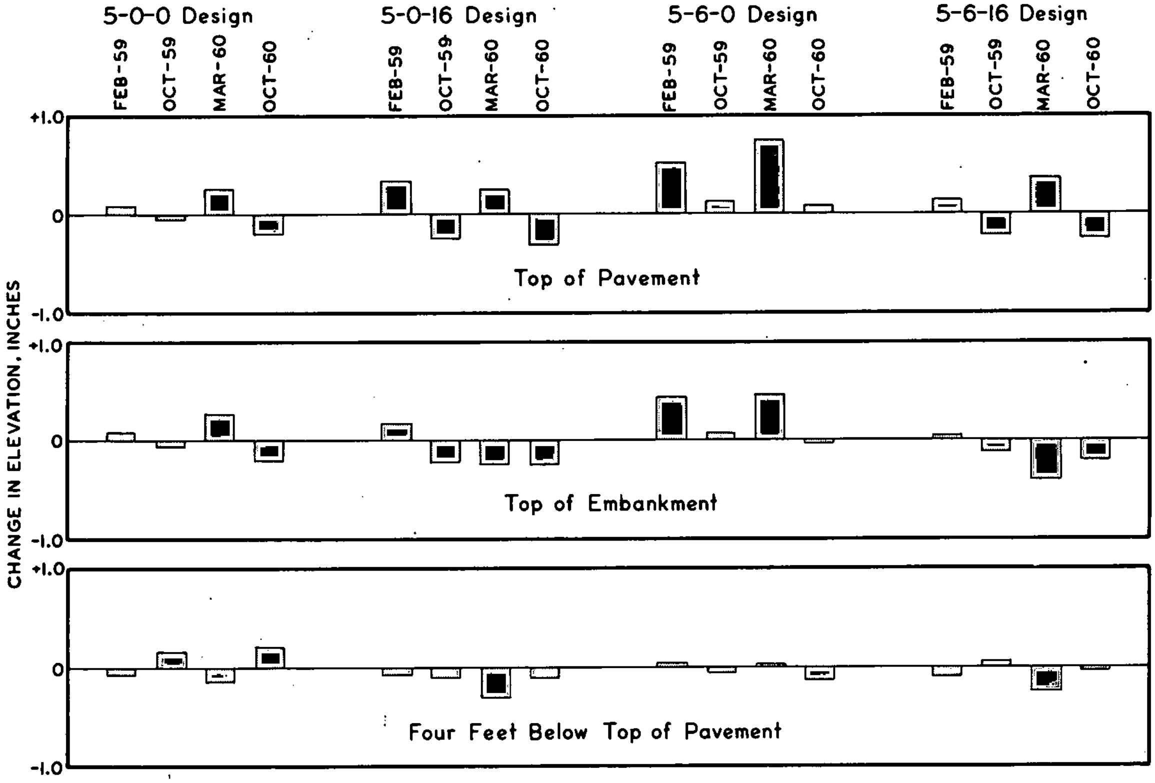

**Figure 100.** Vertical movement data, Loop 1 (elevation changes from initial elevation).

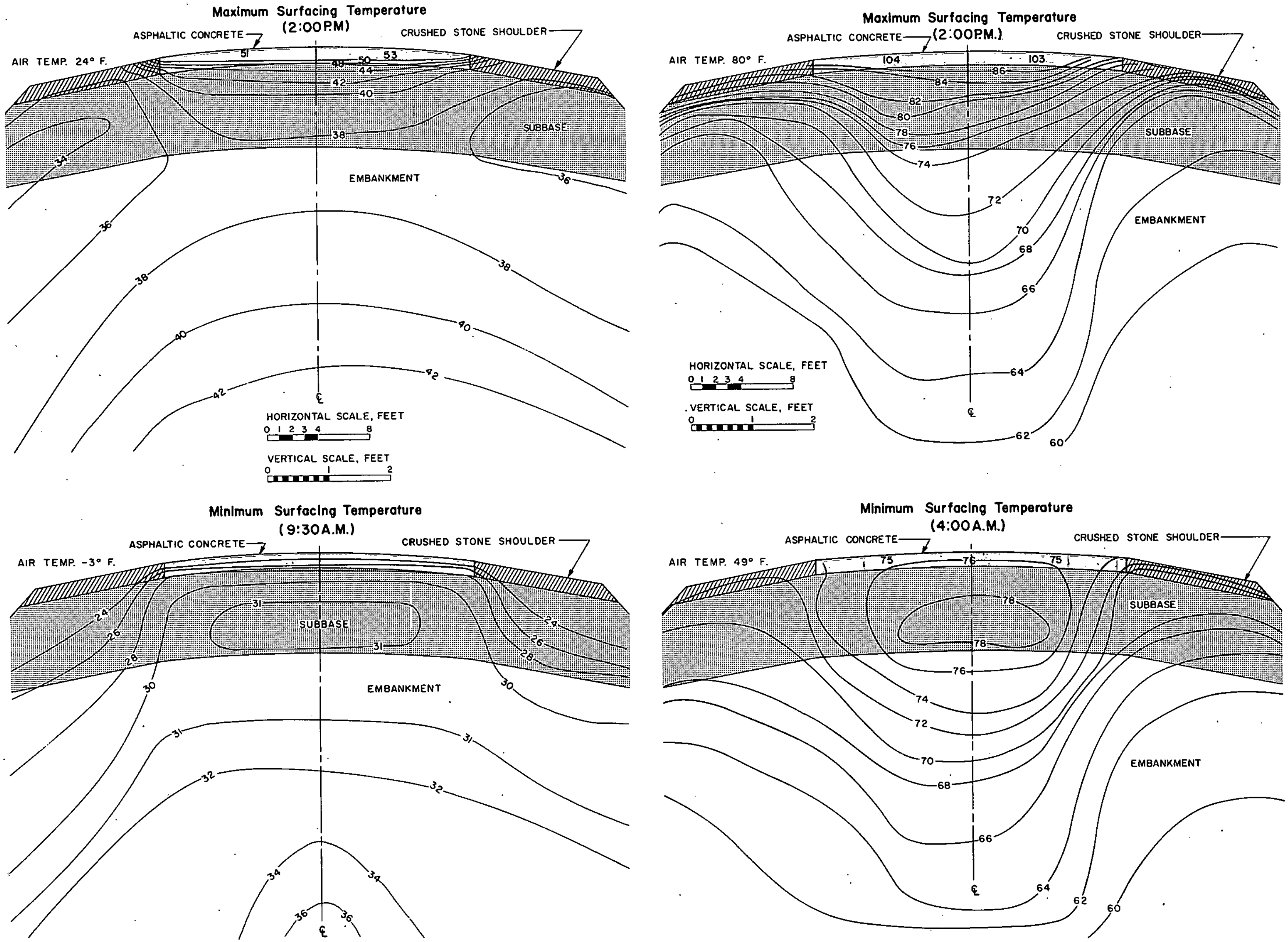

Figure 101. Isothermal lines, 3–0–16 design, Loop 1, March 25, 1960 (left) and May 25, 1960 (right).

The model used for regression analysis of the speed-pressure data was

$$P = 10^{A_0 - A_1 v} \quad (54)$$

in which

$P$ = transmitted pressure in psi; and

$v$ = vehicle speed, in mph.

The coefficients determined for the four sections are given in Table 31.

Examples of the analytical results are given in Figure 105. Embankment pressures are plotted as a function of vehicle speed. The points represent observed values, and the dashed lines represent computed values. The marked effect of load and speed is clearly shown by these data.

Table 32 gives computed values of the coefficient $A_1$ and the percent reduction in deflection and pressure for two loads, 12 and 18 kips, and two designs of pavement. The percentage values are for a speed range from 2 to 35 mph.

There was close agreement between the percent reduction of deflection and pressure with speed for the 5-6-12 design, but the reduction in transmitted pressure was much less than that for the deflection for the 3-6-12 design.

In Figure 106, embankment pressure is plotted against wheel load. It appears that the transmitted pressure at the embankment level varies as a near linear function of the load.

### *2.5.4 Marshall Stability* vs *Temperature*

The apparent greatest strength of the asphaltic concrete surfacing at low temperatures has been frequently mentioned in this report. Some pertinent information on this question was obtained in a limited series of tests in the project laboratory utilizing Marshall stability equipment. Molded specimens of the material were tested over a temperature range from 40 to 160 F.

A well-defined effect of temperature was found both for the surface and binder course mixture. In each case the log log of Marshall stability was shown to vary as a linear function of the temperature of the material at the time of testing (Fig. 107).

A small study was conducted in the project laboratory to determine the effect of temperature of asphaltic concrete on Marshall stability. Laboratory-prepared specimens of binder and surface course mixtures having design characteristics the same as those in the flexible pavement surfacing were tested over a temperature range between 40 and 160 F.

The aggregates were heated to 350 F and the asphalt cement to 275 F before being mixed. The specimens were molded at 225 F using 70 blows of a mechanical compactor. All other procedures followed the "Marshall Method of Mix Design," Asphalt Institute Manual No. 2, p. 19 (April 1956).

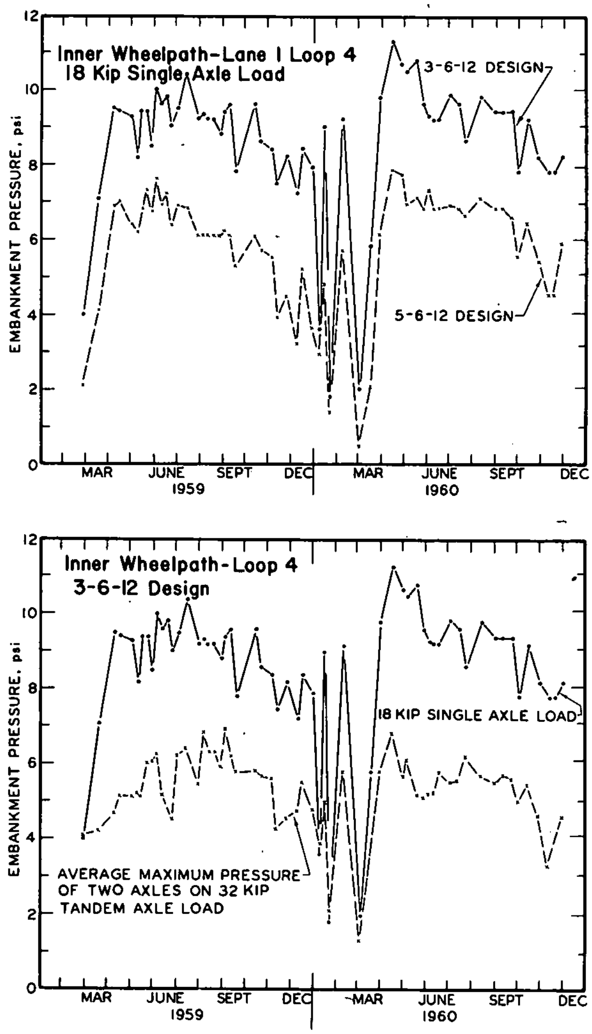

Figure 102. Embankment pressure histories.

Two sets of tests were made for each type of mixture (binder and surface course). In each set, two specimens were tested at each of five designated temperatures. The averages of the test results of each pair of specimens were used in the analysis. Table 33 gives the results of the tests on the individual specimens and the averages of each pair of specimens at the various test temperatures.

Work done at Purdue University* suggested that the relationship among test temperature,

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* Goetz, W. H., McLaughlin, J. F., and Woods, K. B., "Load-Deformation Characteristics of Bituminous Mixtures Under Various Conditions of Loading." *Proceedings*, February 1957 Annual Meeting of the AAPT, 26: 237.

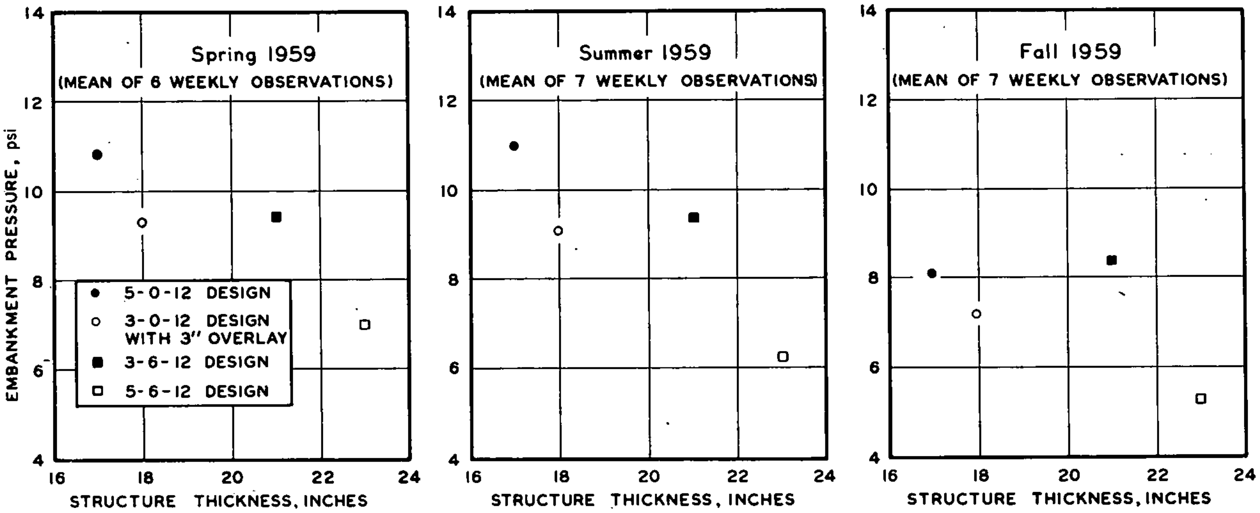

Figure 103. Relationship between design and embankment pressure under 18-kip single axle load.

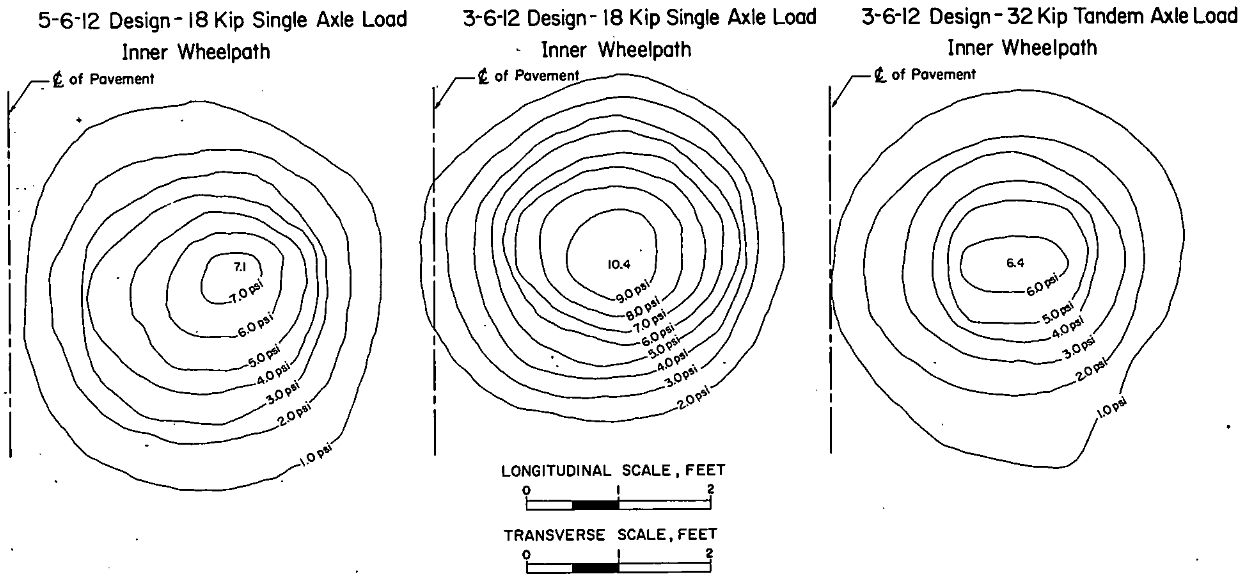

Figure 104. Embankment pressure contours.

TABLE 31

COEFFICIENTS FOR PRESSURE-SPEED RELATIONSHIP

| Section | Load (kips) | $A_0$ | $A_1$ | $r^2$ (%) |
|---|---|---|---|---|
| 3–6–12 | 1 | −0.100 | −0.0037 | 84 |
| | 3 | 0.407 | −0.0041 | 83 |
| | 6 | 0.657 | −0.0026 | 58 |
| | 9 | 0.785 | −0.0016 | 42 |
| 5–6–12 | 1 | −0.486 | −0.0059 | 75 |
| | 3 | −0.015 | −0.0082 | 73 |
| | 6 | 0.258 | −0.9941 | 81 |
| | 9 | 0.474 | −0.0045 | 73 |
| 5–6–4 | 1 | −0.255 | −0.0028 | 28 |
| | 3 | 0.234 | −0.0076 | 94 |
| | 6 | 0.511 | −0.0037 | 67 |
| | 9 | 0.671 | −0.0034 | 66 |
| 5–6–4 | 1 | −0.192 | −0.0035 | 65 |
| | 3 | 0.203 | −0.0015 | 71 |
| | 6 | 0.547 | −0.0036 | 76 |
| | 9 | 0.706 | −0.0035 | 78 |

rate of loading and the maximum compressive stress takes the form

$$X_0 = A^{BX_1}{}^{(CX^2 + D)} \qquad (55)$$

in which

$X_0$ = maximum compressive stress;
$X_1$ = rate of loading; and
$X_2$ = test temperature.

For this study, it was assumed that the rate of loading was constant. Thus, the above relationship suggested that the log log of Marshall stability is a linear function of the test temperature. That is,

$$\log \log S = aT + b \qquad (56)$$

in which

$S$ = Marshall stability, in lb; and
$T$ = test temperature in ° F.

Using this model, a regression analysis was made of the data obtained for both mixes.

*For surface course mixture:*

$$\log \log S = 0.6692 — 0.001216T \qquad (57)$$

*For binder course mixture:*

$$\log \log S = 0.6581 — 0.001146T \qquad (58)$$

Figure 107 shows how well the regression lines fit the observed data. The $r^2$ was greater than 95 percent for both equations.

### *2.5.5 Turnaround Surfacing Stability*

Inasmuch as the test pavements were confined to the tangents of the test loops, the turnarounds were available for a limited study of the problem of stability of asphaltic concrete mixtures. Unfortunately failure of the basic pavement on the turnarounds occurred at an early date and no information of significance was obtained from the studies.

The turnarounds of the five traffic loops were divided into short sections and paved with three separate asphaltic concrete mixtures: the standard mix used on the test tangents, a mix having a lower stability, and one having a higher stability. It was intended to observe the performance of the three mixtures relative to their resistance to displacement under load and vehicle movement. The experiment is described in detail and the measurements of rutting and cracking are summarized in DS 4170 available from the Highway Research Board.

### *2.5.6 Physical Test Data*

A great deal more structural deterioration of the flexible pavement sections took place during the spring months of the year than in the summer and fall months (Table 1). The increase in strength from spring to summer of the base and subbase material was attributed to changes in moisture content rather than to changes in density. The increase in strength of the embankment soil was not accompanied by explainable differences in moisture or density.

Considerable data bearing on the question of structural deterioration of flexible pavements were obtained from the 1960 trenching program, mentioned in Section 2.2.3.1. These studies included determination of moisture contents, densities and CBR's on all materials and

TABLE 32

PERCENT REDUCTION IN DEFLECTION WITH SPEED

| Load (kips) | 5–6–12 | | | | 3–6–12 | | | |
|---|---|---|---|---|---|---|---|---|
| | Deflection | | Pressure | | Deflection | | Pressure | |
| | $A_1$ | Percent Reduction | $A_1$ | Percent Reduction | $A_1$ | Percent Reduction | $A_1$ | Percent Reduction |
| 12 | −0.0046 | 29 | −0.0041 | 27 | −0.0062 | 38 | −0.0026 | 18 |
| 18 | −0.0049 | 31 | −0.0045 | 29 | −0.0057 | 35 | −0.0016 | 11 |

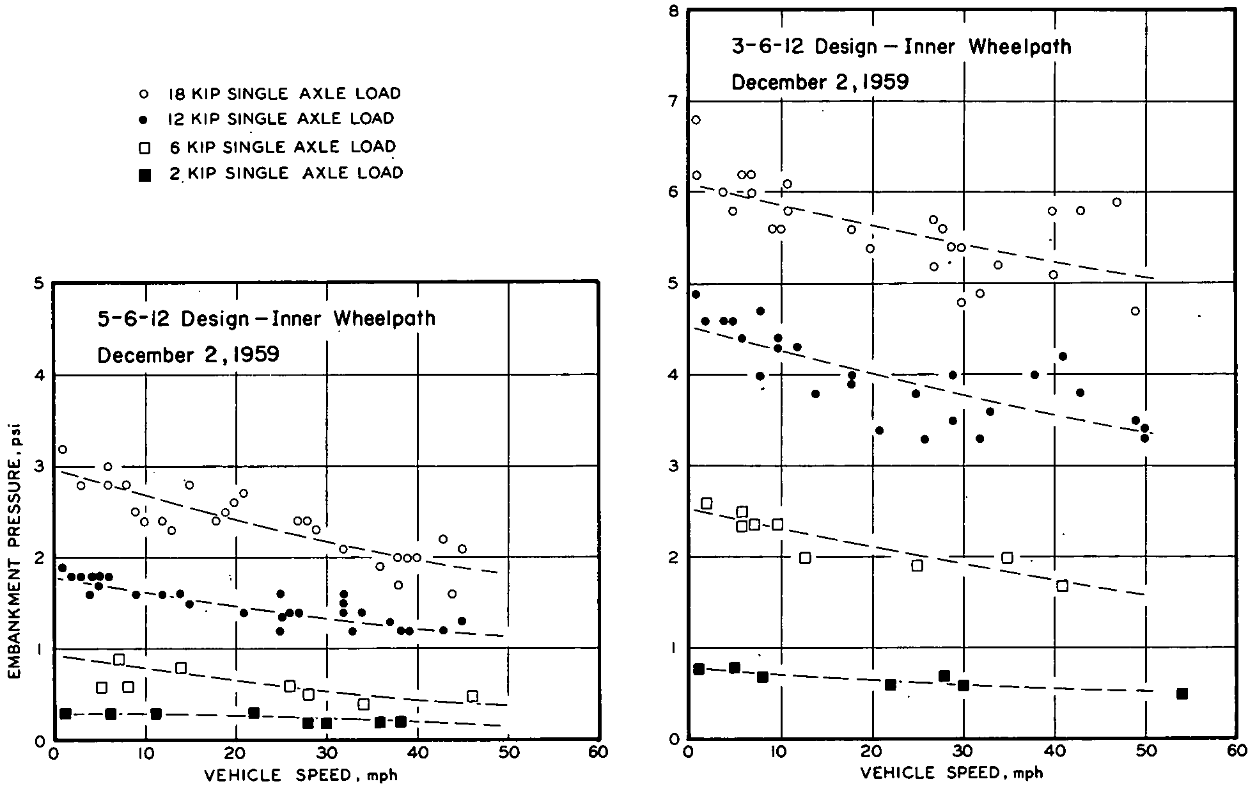

**Figure 105. Effect of vehicle speed on embankment pressure.**

elastic subgrade moduli from 30-in. diameter plate load tests on the embankment. These data are presented in detail in Table 34 and in summary form in Figures 108, 109 and 110. The strength (plate load and CBR tests) of the granular layers and of the embankment soil was greater in the summer than in the spring. Furthermore, the elastic subgrade modulus of the embankment soil in both of the periods was somewhat higher beneath the thick than the thin pavement sections.

This increase in strength or stability of the embankment material is not explained by increases in density or by decreases in moisture content as these changes were neither orderly nor consistent. However, the increase in strength may have resulted from a drying cycle during the summer and a wetting cycle during the spring.* The marked increase in the indicated strength of the base and subbase materials from spring to summer was apparently caused by decreases in moisture content because changes in density were small and inconsistent.

In the study of the physical test data of the embankment soil obtained from the trenches in the main traffic loops, relationships, similar to those for Loop 1, were developed (Appendix H).

### *2.5.7 Bituminous Surface Treatment*

A limited program of tests involving surface treatments was conducted on Loop 2 as a part of the over-all study of pavement design. The performance of the surface-treated sections was inferior to that of sections with equal thicknesses of base and subbase but with asphaltic concrete surfaces. Their performance was improved appreciably as the thickness of the underlying base and subbase course was increased.

The bituminous surface treatment experiment was included in Loop 2 as a part of the study of pavement design. The experiment (Design 6) was a 3 by 2 factorial experiment with base and subbase thickness as the principal variables. The sections were replicated so that there were 12 sections per lane. Surfacing for all sections consisted of two applications of about ¼ gal per sq yd of MC-5 bituminous material, each covered by crushed stone aggregate (graded from ⅝ in. down), and a similar application of MC-5 with a smaller (⅜ in. down) stone seal coat (see Road Test Report 2).

Basic information on the performance of the

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* "Pore Pressure and Suction in Soils." Conference, British National Society of the International Society of Soil Mechanics and Foundation Engineering, William Clowes and Sons Publishers, London, England.

sections in this experiment is given in Table 35 and in Appendix A. The values for each section are weighted and unweighted load applications to a serviceability of 1.0 or the final serviceability if the section was still in test at the end of test traffic. The applications are for a lower level of serviceability (1.0) than was used in the factorial experiment (1.5 and 2.5). This terminal serviceability value was chosen because the initial serviceabilities of the surface treatment sections were considerably lower than those for sections with hot-mix asphalt concrete surface (2.2 compared to 4.2, on the average). The low initial serviceabilities of these sections may be attributed to the impossibility of maintaining smooth grades during construction of these short sections with thin structures. Also, no paving machine was used to iron out minor irregularities.

If the performances of sections in this experiment and those in the factorial test are to be compared, the comparison should be on a basis of an equal drop in serviceability rather than a drop to the same level of $p$. In the highway system, surface-treated pavements are usually used for relatively low-traffic highways; therefore, these pavements may have lower serviceabilities before major maintenance than high-traffic volume highway pavements.

The performance of the surface-treated sections was appreciably improved as the base thickness was increased in sections with and without subbase for both the 2- and 6-kip axle load lanes (Table 35).

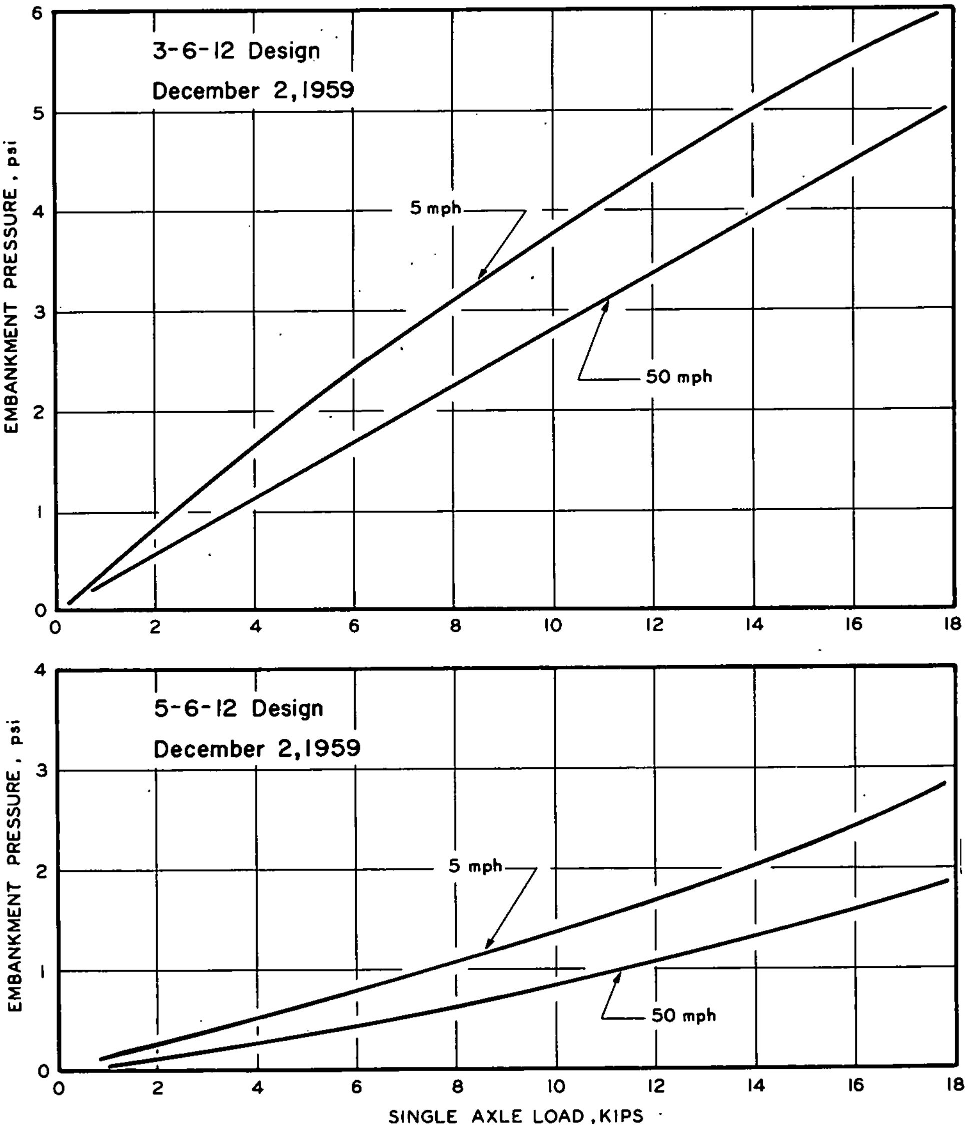

**Figure 106.** **Relationship between embankment pressure and axle load (from Fig. 105).**

## 2.6 SUMMARY OF FINDINGS AND NEEDED RESEARCH

### *2.6.1 Summary of Findings*

The major findings of the flexible pavement research at the AASHO Road Test have been stated in the text and illustrated by means of charts and graphs. Summarization of the material contained in each major subsection precedes the text of the subsection. Here the more important material contained in the summarizations is repeated for the convenience of those who do not wish to study the details of the development of the findings. A similar summarization of the findings of the rigid pavement research may be found in Section 3.6.

The principal objectives of the research at the AASHO Road Test, excluding those dealing with bridge studies and with pavement maintenance, were:

1. To determine the significant relationships between the number of repetitions of specified axle loads of different magnitude and arrangement and the performance of different thicknesses of uniformly designed and constructed asphaltic concrete, plain portland cement concrete, and reinforced portland cement concrete surfaces on different thicknesses of bases and subbases when on a basement soil of known characteristics.

* * *

5. To develop instrumention, test procedures, data, charts, graphs, and formulas, which will re-

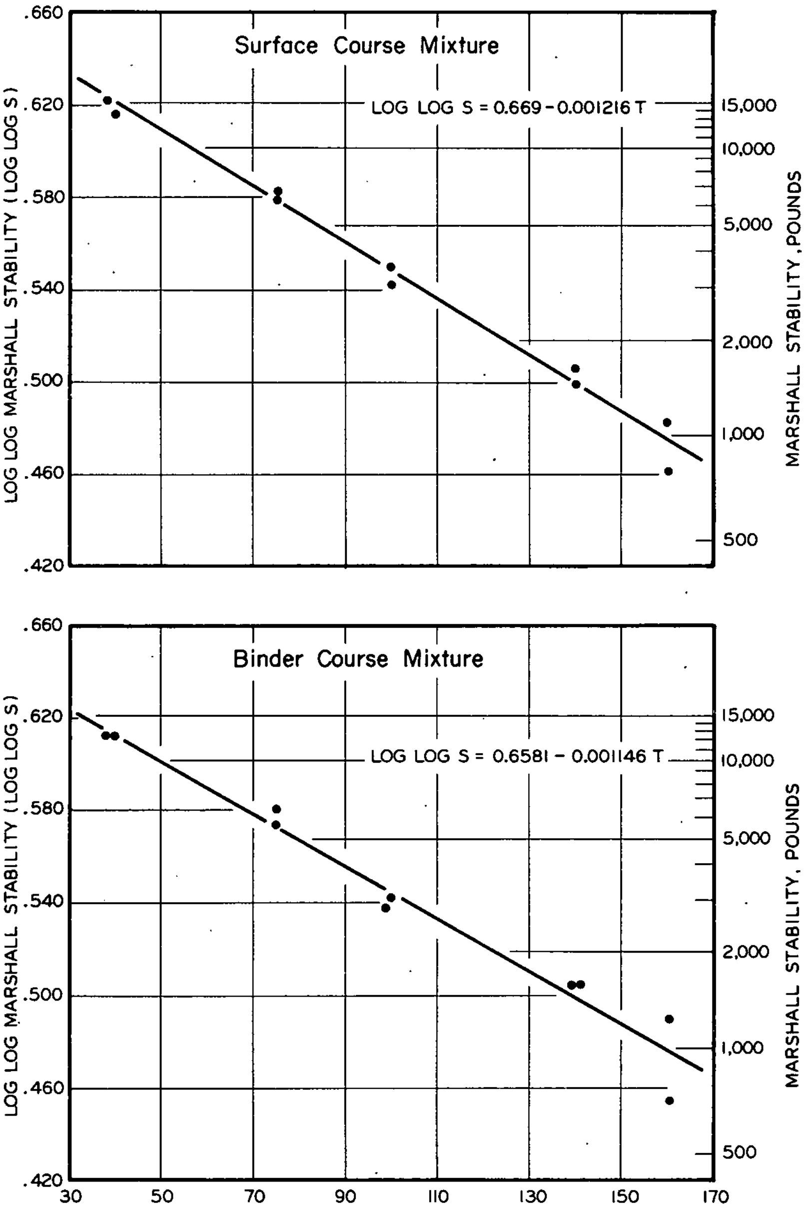

Figure 107. Effect of temperature on Marshall stability.

TABLE 33

RESULTS OF MARSHALL STABILITY TESTS ON ASPHALTIC CONCRETE SPECIMENS AT VARIOUS TEST TEMPERATURES

| Surface Course Mixture | | | | | Binder Course Mixture | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Test | | Marshall Stability (lb) | | | Test | | Marshall Stability (lb) | | |
| No. | Temp. (°F) | Spec. 1 | Spec. 2 | Mean | No. | Temp. (°F) | Spec. 1 | Spec. 2 | Mean |
| 1 | 38 | 15,809 | 15,103 | 15,456 | 1 | 38 | 11,923 | 12,939 | 12,431 |
| | 75 | 6,532 | 6,946 | 6,739 | | 75 | 6,580 | 6,006 | 6,293 |
| | 99 | 3,577 | 3,444 | 3,510 | | 99 | 2,915 | 2,695 | 2,805 |
| | 140 | 1,678 | 1,501 | 1,590 | | 140 | 1,590 | 1,501 | 1,545 |
| | 160 | 1,016 | 1,150 | 1,083 | | 160 | 1,242 | 1,192 | 1,217 |
| 2 | 40 | 13,616 | 13,425 | 13,520 | 2 | 40 | 12,497 | 12,188 | 12,342 |
| | 75 | 6,992 | 6,049 | 6,520 | | 75 | 5,432 | 5,476 | 5,454 |
| | 100 | 3,209 | 2,959 | 3,084 | | 100 | 3,312 | 2,694 | 3,003 |
| | 140 | 1,369 | 1,501 | 1,435 | | 140 | 1,501 | 1,583 | 1,542 |
| | 160 | 707 | 839 | 773 | | 160 | 727 | 642 | 684 |

> flect the capabilities of the various test sections; and which will be helpful in future highway design, in the evaluation of the load-carrying capabilities of existing highways and in determining the most promising areas for further highway research.

Another important objective of the pavement research involved the study of the effectiveness of paved shoulders and various treated base materials. This objective, excluding that portion dealing with material reported in Road Test Report 6, was stated:

> 3. To make special studies dealing with such subjects as paved shoulders, base types, pavement fatigue, . . . , and to correlate the findings of these special studies with the results of the basic research.

Major staff efforts were directed towards the fulfillment of the first objective—to find relationships between pavement performance, on the one hand, and pavement design, loading and number of load applications, on the other.

*Pavement Performance (Section 2.2.2).*—One contribution of the AASHO Road Test was the development of a definition of pavement performance in terms of the trend in pavement serviceability (ability to serve traffic) with increasing number of load applications.

Perhaps the major finding of the flexible pavement research was the set of relationships sought in the first objective. These relationships were reduced to a set of four equations containing terms for the variables that were included in the test. These equations appear in the text as Eqs. 13, 17, 18 and 19 (for the case where load applications were adjusted by a seasonal weighting function). Similar equations are given for unweighted applications.

Graphs and tables were constructed from the equations for use in the study of performance over the wide range of designs and loads included in the Road Test. A convenient presentation of the relationships for the axle loadings of the Road Test is shown in Figure 22. For any axle loading studied it is possible to determine a pavement structure that would carry a specified number of applications before its serviceability dropped to 2.5. Such determinations, of course, are subject to the limitations discussed in Section 1.1.5.

These equations represent empirical, serviceability trend data observed in the test; some Road Test sections failed sooner and some later than indicated by the smooth curves. Therefore, some allowance should be made for the scatter of the data. An example of the scatter is shown in Figure 25. Most of the observed points fall within approximately ± 14 percent of the thickness index given by the curves. If comparisons are made with observed performance of actual highways in service, additional allowance should be made to account for differences in materials, environment, and loading history between the Road Test and the actual highway.

*These relationships are not intended to be design equations.* However, they can serve as a basis for design procedures in which variables, such as soil type, not included in the Road Test, are considered.

Section 2.2.2.1 includes tables and discussion showing the basis for determining the significance or nonsignificance of the various effects, correlation indexes to show the degree of correlation found in the relationships, and mean residuals to show the degree of scatter of the observed performance data from the predictions of the performance equations.

## TABLE 34

### CONDITION DATA OF PAVEMENT COMPONENTS, (FROM TRENCHING PROGRAM, 1960)

| Loop | Design | Outer Wheelpath | | | | | | | | Between Wheelpaths | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Moisture Content (%) | | Density (pcf) | | CBR | | $k_E$ (psi/in.) | | Moisture Content (%) | | Density (pcf) | | CBR | |
| | | Spring[1] | Summer | Spring | Summer | Spring | Summer | Spring | Summer | Spring | Summer | Spring | Summer | Spring | Summer |
| (*a*) EMBANKMENT | | | | | | | | | | | | | | | |
| 3 | 4–3–8 | 15.4 | 15.0 | 113.8 | 113.9 | 2.0 | 6.2 | 115 | 138 | 15.3 | 13.8 | 112.1 | 112.8 | 2.7 | 6.4 |
| | 4–6–4 | 14.5 | 14.2 | 112.5 | 113.7 | 2.8 | 6.8 | 108 | 143 | 14.4 | 13.7 | 112.0 | 115.2 | 2.6 | 5.0 |
| | 4–6–8 | 15.5 | 15.6 | 113.5 | 111.6 | 2.7 | 3.6 | 139 | 149 | 15.2 | 15.0 | 113.3 | 111.7 | 2.8 | 3.8 |
| | *Mean* | *15.1* | *14.9* | *113.3* | *113.1* | *2.5* | *5.5* | *121* | *143* | *15.0* | *14.2* | *112.5* | *113.2* | *2.7* | *5.1* |
| 4 | 5–6–12 | 14.5 | 13.8 | 114.7 | 114.7 | 4.3 | 6.8 | 132 | 169 | 14.1 | 13.6 | 114.3 | 113.7 | 4.5 | 6.3 |
| | 5–6–8 | 14.1 | 14.9 | 114.4 | 112.8 | 3.5 | 5.9 | 131 | 138 | 14.3 | 14.8 | 114.3 | 110.5 | 3.0 | 4.1 |
| | 5–3–12 | 13.8 | 14.9 | 117.0 | 113.8 | 4.3 | 2.4 | 134 | 154 | 14.5 | 15.0 | 112.8 | 110.7 | 3.5 | 3.6 |
| | *Mean* | *14.1* | *14.5* | *115.4* | *113.8* | *4.0* | *5.0* | *132* | *154* | *14.3* | *14.5* | *113.8* | *111.6* | *3.7* | *4.7* |
| 5 | 5–9–12 | 15.2 | 15.2 | 112.6 | 111.2 | 3.2 | 5.3 | 153 | 183 | 15.2 | 15.1 | 111.1 | 109.8 | 3.7 | 5.4 |
| | 5–6–12 | 15.9 | 15.2 | 110.3 | 110.1 | 2.6 | 2.6 | 154 | 164 | 16.5 | 14.8 | 107.3 | 110.6 | 2.2 | 3.0 |
| | 5–9–8 | 17.2 | 16.6 | 107.7 | 106.8 | 2.3 | 4.0 | 127 | 132 | 16.8 | 15.8 | 109.8 | 109.9 | 3.0 | 3.4 |
| | *Mean* | *16.1* | *15.7* | *110.2* | *109.4* | *2.7* | *4.0* | *145* | *160* | *16.2* | *15.2* | *109.4* | *110.1* | *3.0* | *3.9* |
| 6 | 6–6–16 | 13.4 | 12.4 | 118.1 | 115.3 | 6.6 | 8.2 | 192 | 196 | 14.1 | 12.4 | 115.6 | 114.7 | 4.1 | 8.2 |
| | 6–9–12 | 13.1 | 14.3 | 115.9 | 114.7 | 5.9 | 9.7 | 131 | 159 | 13.6 | 13.8 | 115.9 | 113.1 | 4.4 | 5.8 |
| | 6–9–16 | 12.8 | 13.3 | 111.3 | 114.6 | 7.2 | 5.2 | 181 | 240 | 13.9 | 13.6 | 113.8 | 114.3 | 3.3 | 4.8 |
| | *Mean* | *13.1* | *13.3* | *115.1* | *114.9* | *6.6* | *7.7* | *168* | *198* | *13.9* | *13.3* | *115.1* | *114.0* | *3.9* | *6.3* |
| *Over-all Mean* | | *14.6* | *14.6* | *113.5* | *112.8* | *4.0* | *5.6* | *141.5* | *163.8* | *14.9* | *14.3* | *112.7* | *112.2* | *3.3* | *5.0* |
| (*b*) SUBBASE | | | | | | | | | | | | | | | |
| 3 | 4–3–8 | 4.9 | 4.4 | 134.0 | 136.2 | 23.7 | 47.3 | | | 5.1 | 4.2 | 132.8 | 132.0 | 22.6 | 24.2 |
| | 4–6–4 | 5.5 | 4.6 | 137.4 | 137.9 | 9.2 | 30.0 | | | 5.6 | 5.0 | 134.6 | 131.0 | 8.8 | 22.6 |
| | 4–6–8 | 5.2 | 4.7 | 128.3 | 132.7 | 21.4 | 34.2 | | | 5.3 | 4.6 | 134.5 | 130.4 | 24.6 | 56.0 |
| | *Mean* | *5.2* | *4.6* | *133.2* | *135.6* | *18.1* | *37.2* | | | *5.3* | *4.6* | *134.0* | *131.1* | *18.7* | *34.3* |
| 4 | 5–6–12 | 4.8 | 5.2 | 143.4 | 129.0 | 23.2 | 49.8 | | | 4.8 | 4.6 | 135.9 | 126.0 | 14.9 | 65.8 |
| | 5–6–8 | 5.3 | 4.8 | — | 130.4 | 21.6 | 54.4 | | | 5.6 | 4.6 | — | 131.4 | 22.7 | 49.5 |
| | 5–3–12 | 5.4 | 4.6 | — | 132.9 | 9.4 | 45.6 | | | 5.2 | 4.8 | — | 132.5 | 16.8 | 26.3 |
| | *Mean* | *5.2* | *4.9* | *143.4* | *130.8* | *18.1* | *49.9* | | | *5.2* | *4.7* | *135.9* | *130.0* | *18.1* | *47.2* |
| 5 | 5–9–12 | 5.8 | 4.8 | 131.2 | 139.9 | 26.8 | 62.2 | | | 5.9 | 5.1 | 139.3 | 139.7 | 26.7 | 28.8 |
| | 5–6–12 | 5.9 | 4.5 | 134.7 | 134.8 | 18.2 | 42.6 | | | 6.2 | 5.0 | 134.0 | 137.3 | 14.9 | 29.7 |
| | 5–9–8 | 6.3 | 5.4 | 135.3 | 136.9 | 26.2 | 74.7 | | | 7.2 | 5.8 | 132.6 | 134.8 | 18.8 | 52.9 |
| | *Mean* | *6.0* | *4.9* | *133.7* | *137.2* | *23.7* | *59.8* | | | *6.4* | *5.3* | *135.3* | *137.3* | *20.1* | *37.1* |
| 6 | 6–6–16 | 5.7 | 4.8 | 131.3 | 138.6 | 39.1 | 10.3 | | | 6.0 | 4.8 | 134.2 | 131.0 | 23.2 | 74.2 |
| | 6–9–12 | 5.6 | 4.5 | 134.8 | 130.3 | 35.7 | 85.4 | | | 5.8 | 5.0 | 135.2 | 136.0 | 28.7 | 39.0 |
| | 6–9–16 | 5.8 | 5.4 | 141.3 | 142.5 | 36.2 | 60.3 | | | 6.2 | 5.4 | 136.8 | 132.6 | 28.8 | 44.2 |
| | *Mean* | *5.7* | *4.9* | *135.8* | *137.2* | *37.0* | *52.0* | | | *6.0* | *5.1* | *135.4* | *133.2* | *26.9* | *52.5* |
| *Over-all Mean* | | *5.5* | *4.8* | *136.5* | *135.2* | *24.2* | *49.7* | | | *5.7* | *4.9* | *135.2* | *132.9* | *21.0* | *42.8* |

(*c*) BASE

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 4–3–8 | 4.1 | 3.3 | 143.4 | 148.2 | 55 | 142 | 4.1 | 3.4 | 144.7 | 146.3 | 58 | 163 |
| | 4–6–4 | 4.3 | 3.5 | 145.8 | 146.4 | 80 | 145 | 4.5 | 3.6 | 142.7 | 144.2 | 72 | 149 |
| | 4–6–8 | 3.8 | 3.4 | 149.1 | 141.0 | 150 | 103 | 4.2 | 3.4 | 141.2 | 148.0 | 85 | 90 |
| | *Mean* | *4.1* | *3.4* | *146.1* | *145.2* | *95.0* | *130.0* | *4.3* | *3.5* | *142.9* | *146.2* | *71.7* | *134.0* |
| 4 | 5–6–12 | 4.4 | 4.0 | 146.3 | 145.0 | 86 | 200 | 4.6 | 4.1 | 144.3 | 142.7 | 79 | 155 |
| | 5–6–8 | 4.3 | 3.9 | 149.0 | 133.6 | 55 | 109 | 4.8 | 3.6 | 144.9 | 136.6 | 67 | 85 |
| | 5–3–12 | 4.2 | 3.4 | 137.2 | 142.0 | 78 | 124 | 4.4 | 4.0 | 139.8 | 138.2 | 42 | 71 |
| | *Mean* | *4.3* | *3.8* | *144.2* | *140.2* | *73.0* | *144.3* | *4.6* | *3.9* | *143.0* | *139.2* | *62.7* | *103.7* |
| 5 | 5–9–12 | 4.4 | 3.7 | 147.8 | 141.9 | 78 | 150 | 4.5 | 3.9 | 139.2 | 140.3 | 76 | 128 |
| | 5–6–12 | 4.8 | 3.5 | 140.5 | 144.9 | 92 | 150 | 5.0 | 4.0 | 143.2 | 140.2 | 52 | 116 |
| | 5–9–8 | 4.3 | 3.6 | 146.9 | 140.2 | 87 | 150 | 4.6 | 3.8 | 138.1 | 136.8 | 53 | 97 |
| | *Mean* | *4.5* | *3.6* | *145.1* | *142.3* | *85.7* | *150.0* | *4.7* | *3.9* | *140.2* | *139.1* | *60.3* | *113.7* |
| 6 | 6–6–16 | 4.0 | 3.1 | 141.5 | 142.2 | 69 | 82 | 4.3 | 3.4 | 142.5 | 140.2 | 76 | 98 |
| | 6–9–12 | 4.3 | 3.6 | 136.2 | 142.0 | 65 | 104 | 4.8 | 3.5 | 142.2 | 142.0 | 66 | 77 |
| | 6–9–16 | 4.2 | 3.8 | 141.4 | 141.9 | 148 | 116 | 4.3 | 3.8 | 144.4 | 138.1 | 119 | 150 |
| | *Mean* | *4.2* | *3.5* | *139.7* | *142.0* | *94.0* | *100.7* | *4.5* | *3.6* | *143.0* | *140.1* | *87.0* | *108.3* |
| *Over-all Mean* | | *4.3* | *3.6* | *143.8* | *142.4* | *86.9* | *131.3* | *4.5* | *3.7* | *142.3* | *141.2* | *70.4* | *114.9* |

[1] Road Test Report 2 (Materials and Construction), Table 2-C, gives the *R*-value at 300-psi exudation pressure as 21. Hveem stability tests run on in-place samples obtained in the spring of 1959 gave *R*-value in the range 7 to 10, corresponding to an exudation pressure of 220 psi.

The thickness index found to apply to Road Test flexible pavements is of interest in itself. For the weighted applications case the thickness index equation (Eq. 19) indicates that an inch of surfacing was about three times as effective as an inch of base and four times as effective as an inch of subbase in improving pavement performance within the range of design studied.

The use of the seasonal weighting function on axle load applications was found to increase the correlation index from 0.48 to 0.70 and to reduce the mean residuals by 15 percent.

*Special Base Type Experiment (Section 2.2.2.3).*—An important investigation within the flexible pavement experiment involved the study of four types of base: crushed stone, gravel, cement-treated and bituminous-treated gravel.

The design of the base experiment was such that no mathematical analysis of the performance of the sections was attempted. The analysis was essentially graphical. However, it is anticipated that the Highway Research Board and others will incorporate the special base data into the data from the main factorial experiment in an effort to produce performance equations containing terms for the special base materials.

TABLE 35

SURFACE TREATMENT EXPERIMENT PAVEMENT PERFORMANCE DATA AT $p = 1.0$ FOR PAIRS OF REPLICATE SECTIONS[1]

| Axle Load (kips) | Subbase Thickness (in.) | Applications (1,000's) | | |
|---|---|---|---|---|
| | | 0-In. Base | 3-In. Base | 6-In. Base |
| | | (*a*) UNWEIGHTED | | |
| 2S | 0 | 48 | 716 | (1.7) |
| | | 315 | 797 | (1.4) |
| | 4 | 685 | (1.2) | (1.9) |
| | | 25 | (1.1) | (1.9) |
| 6S | 0 | 30 | 30 | 722 |
| | | 20 | 95 | 749 |
| | 4 | 20 | 722 | (1.3) |
| | | 4 | 34 | 755 |
| | | (*b*) WEIGHTED | | |
| 2S | 0 | 50 | 372 | (1.7) |
| | | 124 | 751 | (1.4) |
| | 4 | 268 | (1.2) | (1.9) |
| | | 27 | (1.1) | (1.9) |
| 6S | 0 | 32 | 32 | 402 |
| | | 22 | 92 | 522 |
| | 4 | 22 | 402 | (1.3) |
| | | 5 | 36 | 552 |

[1] Values in parentheses give serviceability at end of test traffic.

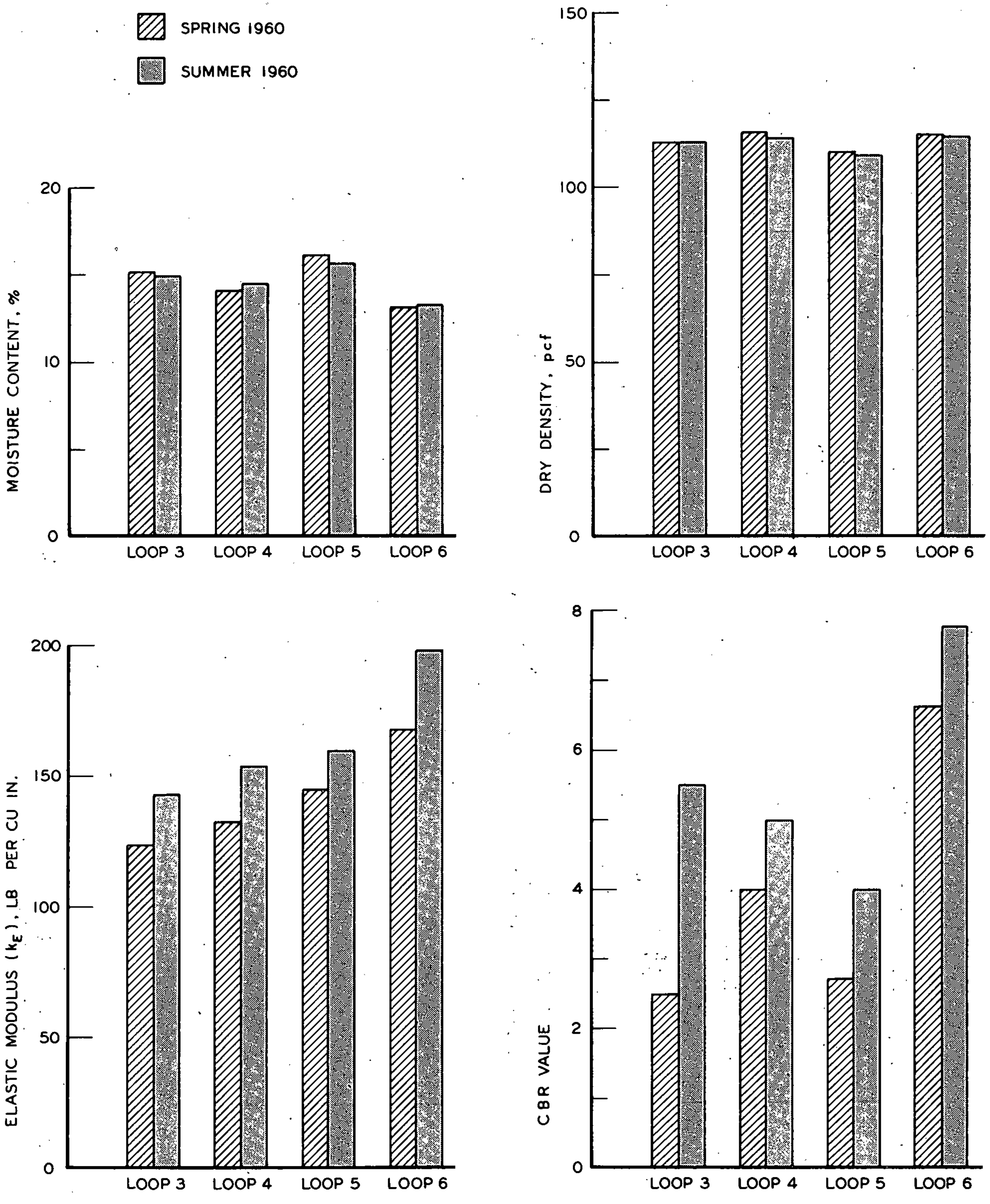

Figure 108. Embankment condition data, spring and summer 1960.

The results of the analysis are presented in graphs (Figs. 35 and 36) which can be used to compare the performance of the stone, cement-treated and bitmuinous-treated bases, that is, to compare the thickness of the materials that was necessary to maintain a level of serviceability of 2.5 at a specified number of load applications. For example, for the 18-kip single axle load at 1,000,000 applications the required thickness of base (where the surfacing thickness was 3 in. and the subbase 4 in.) is shown to be approximately 13, 8 and 6 in. of stone, cement-treated and bituminous-treated base, respectively. These values indicate that there was considerable difference in the performance of the treated bases and the crushed stone bases. In fact, in all loops and at all levels of serviceability the performance of the treated gravel bases was definitely superior to that of the untreated crushed stone.

Most of the sections containing the untreated gravel base failed very early in the test. Data from these sections are shown in Figures 30 and 31 which show that their performance was definitely inferior to that of the sections with crushed stone base.

*Paved Shoulder Studies (Section 2.2.2.2).*—A study of the effectiveness of paved shoulders

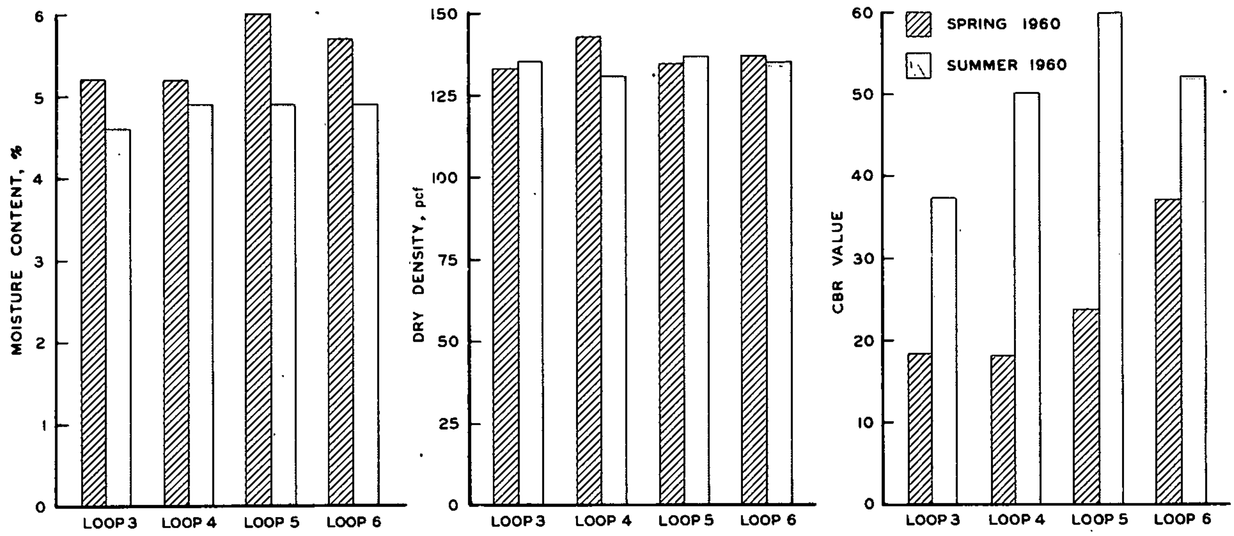

**Figure 109.** Subbase condition data, spring and summer 1960.

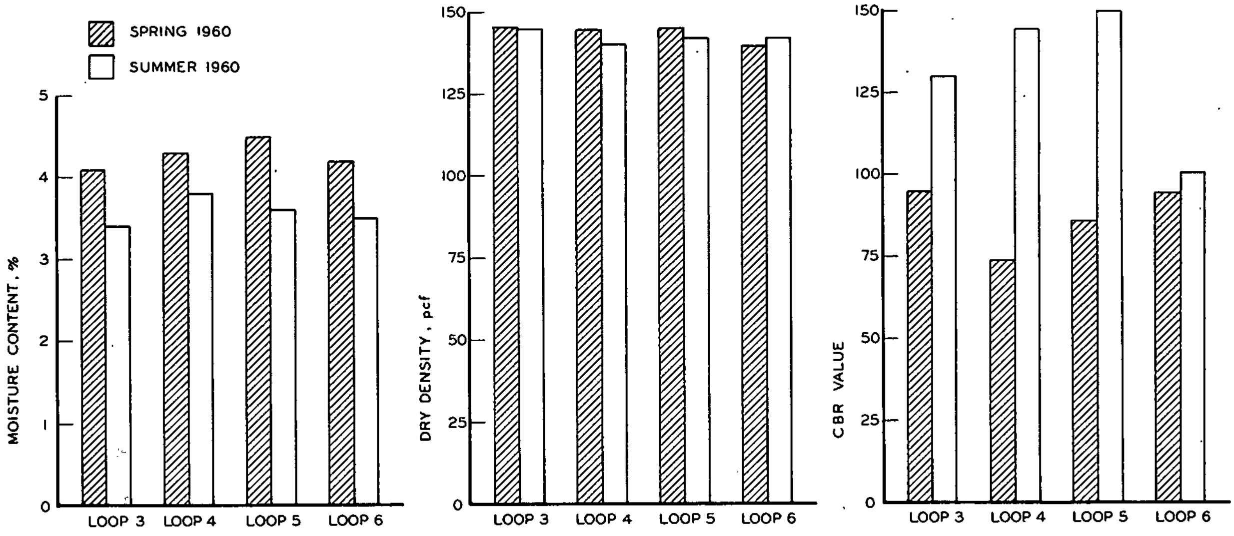

**Figure 110.** Base course condition data, spring and summer 1960.

was included in the Road Test. A total of 48 test sections was provided in this study. Unfortunately, the pavements selected for the tests were underdesigned to the extent that 42 of the sections failed during the first spring of traffic operation and, thus, little information of value was disclosed by the experiment.

An attempt was made to obtain additional information by studying the differences in performance of the outer and inner wheelpaths of the test sections of the main experiment.

The results of these studies indicated that the pavement needed to maintain a certain serviceability at a given number of axle load applications would be considerably thinner in the inner than in the outer wheelpath.

*Structural Deterioration (Section 2.2.3).*—Studies were made of the seasonal changes in elevation of the pavements and of the rutting in wheelpaths. The studies of rutting included such factors as the extent to which changes in thickness of the structural components affected the depth of rut, and how much of the thickness change was due to densification and how much was due to lateral displacement. Studies were made also of the seasonal changes in physical condition and strength of the pavement components.

On an average, the pavement in the various loops heaved approximately 0.4 in. during the winter with the edges rising about 0.6 in. and the interior portion about 0.3 in. (Fig. 44). Most of this heaving was attributed to expansion of the embankment soil.

Rutting of the pavement was due principally to decreases in thickness of the component layers. Based on average data from 51 sections that were trenched in 1960, 32 percent of the depth of rut could be attributed to a reduction in surfacing thickness, 14 percent to a reduction in base thickness and 45 percent to a reduction in subbase thickness—a total of 91 percent. Thus, only 9 percent of a surface rut could be accounted for by rutting of the embankment.

Only 20 percent of the change in thickness of the surfacing and 4 percent of the change in subbase thickness could be accounted for by increases in density of the materials. In the case of the base only 30 percent of the change in thickness determined in the summer of 1960 could be accounted for by increases in density. However, the increase in the density determined in the spring of 1960, accounted for all of the decrease in thickness of the material.

In sections that survived the test the rate of development of rutting during the first year of traffic generally exceeded the rate observed during the second year.

In the special base studies there was a level of base thickness above which the surface rut depth remained constant with increase in base thickness and below which it increased rapidly with decrease in thickness.

The bituminous-treated base and surfacing material offered greater resistance to consolidation and displacement at low than at high temperature.

Cracking was also an element of structural deterioration that detracted from serviceability and performance of flexible pavement. Records were maintained of the development of cracks in order that relationships could be established between cracking, pavement design and load applications.

Eq. 29 was developed, from which the number of axle loads sustained by the pavement before Class 2 cracking of the surface occurred could be computed for any design and load. By including a deflection term, it was found that a somewhat better prediction of load application could be obtained (Eqs. 30 and 31).

More surface cracking occurred during periods when the pavement structure was in a relatively cold state than during periods of warm weather. Generally, cracking was more prevalent in sections having deeper ruts than in sections with shallower ruts.

*Deflection as Related to Design, Load, Speed and Temperature (Section 2.3).*—Relationships were developed between flexible pavement deflection and pavement design, load, vehicle speed and pavement temperature to provide a basis for the deflection vs pavement performance studies reported in Section 2.4.

In the main factorial experiment the asphaltic concrete surfacing was much more effective, inch for inch, in reducing pavement deflection (particularly during the spring months) than was the base or subbase.

The subbase was somewhat more effective than the base in restricting deflection in both the spring and fall (see Section 2.3.1).

In the special base experiment the level of deflection was considerably greater at each season (spring, summer and fall) in the sections with gravel and stone base (9 in. thick) than in sections with bituminous- and cement-treated base of the same thickness.

The deflections of the sections with gravel base were somewhat lower than those for sections with stone base although the performance of the stone base was considerably better than that of the gravel base sections (Section 2.3.2).

The deflection occurring within the pavement structure (surface, base and subbase), as well as that at the top of the embankment soil, was greater in the spring than during the succeeding summer months. This was considered to be due to the higher moisture contents of the base and subbase that existed in the spring.

A high degree of correlation was found to exist between the deflection at the top of the embankment and the total deflection (Section 2.3.3).

A pronounced reduction in deflection accompanied an increase in vehicle speed. Increasing the speed from 2 to 35 mph reduced the total deflection 38 percent, the embankment deflection 35 percent, and the partial deflection 67 percent (see Fig. 78 for definition of partial deflection).

In studies of the effect of the temperature of the asphaltic concrete surfacing upon deflection, it was found that between 80 and 120 F the deflection was essentially constant. At about 80 F, it began to decrease as the temperature decreased. Figures 87 through 91 show that the extent of the decrease varied, depending upon such factors as the age and traffic history of the pavement, the speed of the vehicles, the design of the pavement, the type of base and the time of the year when the tests were made.

*Prediction of Performance from Deflection (Section 2.4).*—The fifth Road Test objective asked for relationships that would employ information from dynamic measurements in the prediction of future pavement performance. Deflections in flexible pavements under loads moving at creep speed proved to be highly effective for this purpose. The performance of the flexible pavements was predicted with essentially the same precision from load-deflection data as from load-design information. Deflections taken during the spring when the subsurface conditions were adverse gave a better prediction of pavement life than those taken in the fall. There was a high degree of correlation between deflection and rutting.

*Overlays (Section 2.5.1).*—A study of the effectiveness of asphaltic concrete overlays included 99 flexible pavement test sections. It was clear that overlays were highly effective as a means for extending the service life of these pavements.

Attempts at mathematical analysis designed to establish specific relationships between performance and overlay design were unsuccessful, because the outcome of each analysis tried proved to be highly dependent upon the assumptions that had to be made concerning the mathematical model for the analyses. Further investigation will be made by the Highway Research Board.

*Subsurface Studies in Non-Traffic Loop (Loop 1) (Section 2.5.2).*—Loop 1 was included as a part of the AASHO Road Test in order to provide a group of traffic-free representative sections (designs) of pavement that would be continually available for a number of different studies.

The condition of the subsurface components in the non-traffic loop was more adverse than in the loops where traffic was a factor. The rate and depth of heat penetration was greater in the pavements than in the granular shoulders. There was virtually no loss of serviceability of the pavements in the non-traffic loop over the 2-yr period of the test.

*Embankment Pressure (Section 2.5.3).*—In connection with the problem of the mechanics of load support of flexible pavements, pressures that are transmitted through the structure to the supporting soil were subjected to limited study in Loop 4, in which 20 pressure cells were installed in certain sections. The variations in transmitted pressure with seasons and speed were of the same character as those shown for creep speed deflections. The transmitted pressures were found to vary approximately as a linear function of the applied load in the same manner as deflections.

*Marshall Stability vs Temperature (Section 2.5.4).*—A limited series of tests was conducted in the project laboratory utilizing Marshall stability equipment in which molded specimens of the asphaltic concrete material were tested over a temperature range from 40 to 160 F. A well-defined effect of temperature was found both for the surface and binder course mixture. In each case the log log of Marshall stability was shown to vary as a linear function of the temperature of the material at the time of testing (Fig. 107).

*Physical Test Data (Section 2.5.6).*—A great deal more structural deterioriation of the flexible pavement sections took place during the spring months of the year than in the summer, fall and winter months (Table 1). In view of this fact, data bearing on changes in the condition of pavement components from season to season were obtained from the 1960 trenching program (Section 2.2.3.1).

The increase in strength from spring to summer of the base and subbase material was attributed to changes in moisture content rather than to changes in density. The increase in strength of the embankment soil was not accompanied by appreciable differences in moisture or density.

*Bituminous Surface Treatment (Section 2.5.7).*—A limited program of tests involving surface treatments was conducted on Loop 2 as a part of the over-all study of pavement design. The performance of the surface treated sections was inferior to that of sections with equal thicknesses of base and subbase but with asphaltic concrete surfaces. Their performance was improved appreciably as the thickness of the underlying base and subbase course was increased.

### *2.6.2 Needed Research*

In Section 1.4 there is a general discussion of research that would be desirable to improve and simplify the relationships found in the AASHO Road Test and to extend the findings of the Road Test to include other soils, materials, and environments. In this subsection the more important areas of research suggested by observations of pavement performance at the Road Test are discussed.

The Road Test performance equations include coefficients that distinguish the relative effectiveness of surfacing, base and subbase in the performance of flexible pavements. These coefficients relate specifically to the type of asphaltic concrete surfacing, the type of crushed stone base and the type of subbase used in the experiment. They also relate, but probably to a lesser degree, to the as-constructed characteristics of these materials (primarily their densities) and to their environment. It is clear that early research is needed in which other typical flexible paving materials are used in conjunction with basement soils similar to the Road Test embankment material, in order that the coefficients for surfacing, base and subbase can be modified for different materials where necessary. These studies can be effectively accomplished in the satellite tests mentioned in Section 1.4. Also, rough checks on the relative effectiveness of different materials may be obtained from the simpler field tests.

Inasmuch as in the Road Test the light axle loads were operated at the same frequency as the heavier loads, additional research is desirable on the effects of very large numbers of applications of passenger loads over long periods of time.

The interrelationship between structure design and load as shown in the performance equations by the exponents of these terms may be somewhat dependent upon the soil type over which the structure is built. Therefore, the satellite and the field tests should also include embankment soils different from that used in the AASHO Road Test. For the same reason, tests should be conducted in environments different from that of Ottawa, Ill.

At the Road Test, rutting in the wheelpaths was largely associated with transverse movement of the component materials. Means to prevent such distortion in flexible pavements should be investigated. In the case of the surfacing material, methods for increasing stability without increasing brittleness should be sought. Extensive research into the mechanism of base failure should be performed.

The clear superiority of the treated over the untreated bases suggests the need for additional experiments permitting direct comparisons between treated and untreated bases on actual highways. The inclusion of treated bases or composite pavements in satellite and field tests is indicated.

The relatively poor performance of the gravel base, coupled with the fact that its deflection under load was no greater than that of the stone base, suggests the need for additional research into the relationship between pavement performance and the resiliency—as well as the strength—of the component layers.

Because the serviceability (and thus the performance) of flexible pavement is highly dependent on the longitudinal profile of the pavement (and because longitudinal roughness existed in the newly-constructed pavements even under extraordinary construction control at the Road Test), means should be sought to improve the uniformity of compaction and of strength of the subsurface materials to minimize differential settlement that may develop along the wheelpaths after traffic has been placed on the pavement.

# Chapter 3

# Rigid Pavement Research

## 3.1 DESCRIPTION OF RIGID PAVEMENTS

A detailed description of the rigid pavement experiments may be found in Road Test Report 1. Materials and construction are covered in Report 2. Some of the information contained in these reports is summarized below.

### *3.1.1 Experiment Designs and Layout*

This subsection describes the grouping of the 368 rigid pavement test sections into three principal experiments. It gives the design factors which were varied within each experiment, and certain details of cross-section, jointing and reinforcing common to all experiments.

*Design Factors.*—The south tangent of each of the six loops in the AASHO Road Test was constructed of portland cement concrete pavement. A majority of the test sections in each loop comprised the "Main Factorial Experiment (Design 1)", the design factors of which were reinforcing, slab thickness and subbase thickness (Table 36). In each of Loops 3 through 6 there was also a "Shoulder Paving—No Subbase Study (Design 3)" for which the design factors were shoulder paving thickness and subbase thickness. In Loop 1, the no-traffic loop, there were "Subsurface Studies (Design 5)" with subbase thickness as the only design factor.

*Design Factor Levels.*—In each rigid pavement tangent of the traffic loops, the pavement thicknesses were varied about one selected thickness which was based on current design criteria for the loading to be applied. The subbase thickness levels were selected to cover a range representing standard practice in a majority of the states.

The subbase thickness (3, 6 and 9 in.) for Design 1 were held the same in each of the main loops (Loops 3, 4, 5, and 6), and the average level of pavement thickness increased by a fixed increment of 1½ in. per loop (Table 36). Furthermore, the same incremental increase of pavement thickness occurred over four levels within each of these loops. On the other hand, subbase thickness levels in Loop 2 were 0, 3 and 6 in. while slab thicknesses were 2½, 3½ and 5 in. In Loop 1, Design 1, subbase thickness was either 0 or 6 in., and the four levels of slab thickness, covering the entire range occurring in the traffic loops, were 2½, 5, 9½ and 12½ in. In all loops in Design 1 there was an equal number of reinforced and nonreinforced test sections.

Each of the design factors of Design 3, which was incorporated in Loops 3 through 6, occurred at two levels: shoulder paving was either present or absent, subbase was present in a thickness of 6 in. or absent, and the slab thickness in each loop corresponded to the thinnest and next to thickest level in Design 1 for that loop. The shoulders were either surfaced with crushed limestone 10 ft wide or paved with bituminous concrete 6 ft wide flanked by 4 ft of crushed limestone, the thickness in both cases being the standard 3 in. used throughout the project. All sections were nonreinforced. Sections shown in the hatched areas of Table 36 appear also in Design 1.

In Design 5 subbase was either present in a thickness of 6 in. or absent. All slabs were 5 in. thick and nonreinforced.

Each of the three experiment designs comprised a complete factorial experiment; that is, all possible combinations of the selected design factor levels were included in the experiment. In addition, certain combinations of design factor levels were repeated in Designs 1 and 5 as indicated by the shaded areas (Table 36) to provide a measure of experimental error.

Table 37 summarizes information regarding the three experiment designs and indicates where data from these designs are discussed and analyzed in this report.

A typical cross-section of the rigid pavement is shown in Figure 111. Reinforced sections were 240 ft long with sawed, doweled transverse contraction joints spaced at 40 ft. Nonreinforced sections were 120 ft long with sawed, doweled transverse contraction joints spaced at 15 feet (no expansion joints were provided). In both pavements the size of the dowels varied with pavement thickness, as did the amount of reinforcing in the reinforced sections. Deformed tie bars, spaced at 30 in., were placed across the longitudinal, sawed joint separating test sections in one lane from those in another. Table 38 gives design details for the pavement.

### *3.1.2 Materials and Construction*

Materials and procedures used in the construction of the rigid pavement test sections are described in detail in Report 2. In Chapter 2 of this report test data and construction pro-

# Table 36 Designs for Rigid Pavement Experiments

## Loop 1

Axle Load

| Lane 1 | Lane 2 |
|---|---|
| None | None |

### Main Factorial Design Design 1

| Slab Type | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| Nonreinforced | 2½ | 0 | 935 | 936 |
| | | 6 | 933 | 934 |
| | 5 | 0 | 889 | 890 |
| | | | 923 | 924 |
| | | 6 | 925 | 926 |
| | | | 891 | 892 |
| | 9½ | 0 | 919 | 920 |
| | | 6 | 917 | 918 |
| | 12½ | 0 | 885 | 886 |
| | | | 881 | 882 |
| | | 6 | 909 | 910 |
| | | | 913 | 914 |
| Reinforced | 2½ | 0 | 895 | 896 |
| | | | 897 | 898 |
| | | 6 | 931 | 932 |
| | | | 899 | 900 |
| | 5 | 0 | 905 | 906 |
| | | 6 | 927 | 928 |
| | 9½ | 0 | 907 | 908 |
| | | | 921 | 922 |
| | | 6 | 915 | 916 |
| | | | 887 | 888 |
| | 12½ | 0 | 883 | 884 |
| | | 6 | 911 | 912 |

### Subsurface Studies Design 5

| Slab Type | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| Non-Reinforced | 5 | 0 | 903 | 904 |
| | | | 893 | 894 |
| | | 6 | 929 | 930 |
| | | | 901 | 902 |

## Loop 2

Axle Load

| Lane 1 | Lane 2 |
|---|---|
| 2,000-S | 6,000-S |

### Main Factorial Design Design 1

| Slab Type | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| Nonreinforced | 2½ | 0 | 805 | 806 |
| | | 3 | 791 | 792 |
| | | 6 | 785 | 786 |
| | 3½ | 0 | 813 | 814 |
| | | 3 | 811 | 812 |
| | | 6 | 787 | 788 |
| | 5 | 0 | 801 | 802 |
| | | 3 | 797 | 798 |
| | | | 777 | 778 |
| | | 6 | 803 | 804 |
| Reinforced | 2½ | 0 | 781 | 782 |
| | | 3 | 799 | 800 |
| | | 6 | 789 | 790 |
| | 3½ | 0 | 793 | 794 |
| | | 3 | 815 | 816 |
| | | | 779 | 780 |
| | | 6 | 783 | 784 |
| | 5 | 0 | 807 | 808 |
| | | 3 | 809 | 810 |
| | | 6 | 795 | 796 |

Note

Shaded sections are replicate sections.

Cross hatched sections are those borrowed from Design 1.

## Loop 3

Axle Load

| Lane 1 | Lane 2 |
|---|---|
| 12,000-S | 24,000-T |

### Main Factorial Design Design 1

| Slab Type | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| Nonreinforced | 3½ | 3 | 195 | 196 |
| | | 6 | 239 | 240 |
| | | 9 | 213 | 214 |
| | 5 | 3 | 225 | 226 |
| | | 6 | 245 | 246 |
| | | | 221 | 222 |
| | | 9 | 219 | 220 |
| | 6½ | 3 | 217 | 218 |
| | | | 193 | 194 |
| | | 6 | 249 | 250 |
| | | 9 | 207 | 208 |
| | 8 | 3 | 201 | 202 |
| | | 6 | 235 | 236 |
| | | 9 | 185 | 186 |
| Reinforced | 3½ | 3 | 209 | 210 |
| | | 6 | 205 | 206 |
| | | 9 | 231 | 232 |
| | 5 | 3 | 251 | 252 |
| | | | 203 | 204 |
| | | 6 | 191 | 192 |
| | | 9 | 233 | 234 |
| | 6½ | 3 | 199 | 200 |
| | | 6 | 247 | 248 |
| | | | 237 | 238 |
| | | 9 | 241 | 242 |
| | 8 | 3 | 211 | 212 |
| | | 6 | 215 | 216 |
| | | 9 | 197 | 198 |

### Shoulder Paving~No Subbase Study Design 3

| Slab Type | Shoulder Paving | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| Nonreinforced | Without | 3½ | 0 | 189 | 190 |
| | | | 6 | 239 | 240 |
| | | 6½ | 0 | 229 | 230 |
| | | | 6 | 249 | 250 |
| | With | 3½ | 0 | 223 | 224 |
| | | | 6 | 243 | 244 |
| | | 6½ | 0 | 227 | 228 |
| | | | 6 | 187 | 188 |

## Loop 4

Axle Load

| Lane 1 | Lane 2 |
|---|---|
| 18,000-S | 32,000-T |

### Main Factorial Design Design 1

| Slab Type | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| Nonreinforced | 5 | 3 | 643 | 644 |
| | | 6 | 647 | 648 |
| | | 9 | 677 | 678 |
| | 6½ | 3 | 649 | 650 |
| | | 6 | 697 | 698 |
| | | | 655 | 656 |
| | | 9 | 703 | 704 |
| | 8 | 3 | 671 | 672 |
| | | | 687 | 688 |
| | | 6 | 683 | 684 |
| | | 9 | 651 | 652 |
| | 9½ | 3 | 675 | 676 |
| | | 6 | 701 | 702 |
| | | 9 | 689 | 690 |
| Reinforced | 5 | 3 | 681 | 682 |
| | | 6 | 661 | 662 |
| | | 9 | 673 | 674 |
| | 6½ | 3 | 641 | 642 |
| | | | 705 | 706 |
| | | 6 | 685 | 686 |
| | | 9 | 653 | 654 |
| | 8 | 3 | 691 | 692 |
| | | 6 | 669 | 670 |
| | | | 707 | 708 |
| | | 9 | 695 | 696 |
| | 9½ | 3 | 645 | 646 |
| | | 6 | 665 | 666 |
| | | 9 | 667 | 668 |

### Shoulder Paving~No Subbase Study Design 3

| Slab Type | Shoulder Paving | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| Nonreinforced | Without | 5 | 0 | 659 | 660 |
| | | | 6 | 647 | 648 |
| | | 8 | 0 | 663 | 664 |
| | | | 6 | 683 | 684 |
| | With | 5 | 0 | 693 | 694 |
| | | | 6 | 679 | 680 |
| | | 8 | 0 | 699 | 700 |
| | | | 6 | 657 | 658 |

## Loop 5

Axle Load

| Lane 1 | Lane 2 |
|---|---|
| 22,400-S | 40,000-T |

### Main Factorial Design Design 1

| Slab Type | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| Nonreinforced | 6½ | 3 | 513 | 514 |
| | | 6 | 517 | 518 |
| | | 9 | 505 | 506 |
| | 8 | 3 | 547 | 548 |
| | | 6 | 539 | 540 |
| | | | 533 | 534 |
| | | 9 | 507 | 508 |
| | 9½ | 3 | 511 | 512 |
| | | | 541 | 542 |
| | | 6 | 525 | 526 |
| | | 9 | 535 | 536 |
| | 11 | 3 | 529 | 530 |
| | | 6 | 497 | 498 |
| | | 9 | 509 | 510 |
| Reinforced | 6½ | 3 | 523 | 524 |
| | | 6 | 491 | 492 |
| | | 9 | 549 | 550 |
| | 8 | 3 | 519 | 520 |
| | | | 521 | 522 |
| | | 6 | 501 | 502 |
| | | 9 | 531 | 532 |
| | 9½ | 3 | 553 | 554 |
| | | 6 | 543 | 544 |
| | | | 503 | 504 |
| | | 9 | 499 | 500 |
| | 11 | 3 | 515 | 516 |
| | | 6 | 545 | 546 |
| | | 9 | 495 | 496 |

### Shoulder Paving~No Subbase Study Design 3

| Slab Type | Shoulder Paving | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| Nonreinforced | Without | 6½ | 0 | 537 | 538 |
| | | | 6 | 517 | 518 |
| | | 9½ | 0 | 493 | 494 |
| | | | 6 | 525 | 526 |
| | With | 6½ | 0 | 555 | 556 |
| | | | 6 | 489 | 490 |
| | | 9½ | 0 | 551 | 552 |
| | | | 6 | 527 | 528 |

## Loop 6

Axle Load

| Lane 1 | Lane 2 |
|---|---|
| 30,000-S | 48,000-T |

### Main Factorial Design Design 1

| Slab Type | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|
| | | | Lane 1 | Lane 2 |
| Nonreinforced | 8 | 3 | 353 | 354 |
| | | 6 | 393 | 394 |
| | | 9 | 369 | 370 |
| | 9½ | 3 | 351 | 352 |
| | | 6 | 367 | 368 |
| | | | 389 | 390 |
| | | 9 | 375 | 376 |
| | 11 | 3 | 377 | 378 |
| | | | 363 | 364 |
| | | 6 | 397 | 398 |
| | | 9 | 365 | 366 |
| | 12½ | 3 | 395 | 396 |
| | | 6 | 349 | 350 |
| | | 9 | 379 | 380 |
| Reinforced | 8 | 3 | 341 | 342 |
| | | 6 | 385 | 386 |
| | | 9 | 347 | 348 |
| | 9½ | 3 | 381 | 382 |
| | | | 371 | 372 |
| | | 6 | 403 | 404 |
| | | 9 | 339 | 340 |
| | 11 | 3 | 391 | 392 |
| | | 6 | 337 | 338 |
| | | | 345 | 346 |
| | | 9 | 343 | 344 |
| | 12½ | 3 | 359 | 360 |
| | | 6 | 355 | 356 |
| | | 9 | 357 | 358 |

### Shoulder Paving~No Subbase Study Design 3

| Slab Type | Shoulder Paving | Slab Thickness | Subbase Thickness | Test Section No. | |
|---|---|---|---|---|---|
| | | | | Lane 1 | Lane 2 |
| Nonreinforced | Without | 8 | 0 | 373 | 374 |
| | | | 6 | 393 | 394 |
| | | 11 | 0 | 383 | 384 |
| | | | 6 | 397 | 398 |
| | With | 8 | 0 | 361 | 362 |
| | | | 6 | 401 | 402 |
| | | 11 | 0 | 399 | 400 |
| | | | 6 | 387 | 388 |

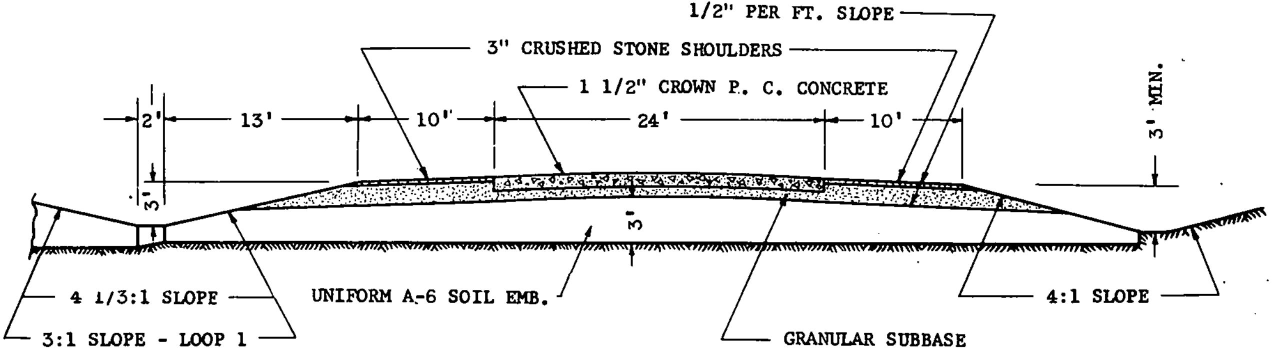

Figure 111. Typical cross-section of rigid pavement test section.

cedures applicable to the embankment and subbase are summarized.

This subsection presents, in tabular form, the results of standard tests made on the cement, water and aggregates used in the portland cement concrete. It also includes proportioning data, the results of tests made on the plastic as well as the hardened concrete, and a summary of changes in flexural and compressive strengths with time.

The mix designs were based on a fixed cement factor of 6 bags per cu yd, a maximum water content of 5 gal per bag of cement, and a sand-to-total-aggregate ratio of about one to three. Average air content was 4 percent. Flexural strengths (AASHO Designation T97–57) averaged about 650 psi at 14 days; compressive strengths (AASHO Designation T22–57) about 3,980 psi at 14 days.

Standard procedures were followed in mixing and placing the concrete, which was spread in both 12-ft lanes simultaneously. Wet straw was used in curing.

The materials used in the rigid pavement test sections and the methods of construction are described in detail in Report 2 along with comprehensive summaries of material control tests. Basic data concerning materials are given in various data systems (see Appendix I). A brief summary of the characteristics of the materials and the methods of construction is presented in this subsection.

The embankment upon which the test sections were constructed is described in Section 2.1.2. The subbase for rigid pavements consisted of the same material used for subbase in the flexible pavements and was a locally available sand-gravel material modified by the addition of small amounts of fine sand and friable fine-grained soil. The material was produced in a washing and screening plant. The soil fines were later added and mixed with the fines in a concrete mixer. In the summer of 1957 the subbase material was placed on the embankment as a means of protecting the underlying soil during the winter. Engineering characteristics of the material are given in Table 4.

The portland cement concrete contained coarse aggregate, a natural sand, Type I portland cement, water, and an air-entraining agent. The coarse aggregate, an uncrushed river gravel, was obtained in two sizes, size A (2½-in. maximum) and size B (1½-in. maximum). Both sizes were used in concrete pavements 5 in. and greater in thickness. Only the size B material was used for the 2½- and 3½-in. thick pavements. A summary of gradation tests made on the coarse and fine aggregates is given in Table 39.

Table 40 gives averages of the results of a number of tests made to determine physical and chemical properties of the portland cement and chemical properties of the mixing water.

The mix designs were based on a fixed cement factor of 1.50 bbl (6 bags) per cu yd, a maximum water content of about 5 gal per bag of cement, a sand-to-total-aggregate ratio of about one to three. Proportioning data are given in Table 41. Properties of the plastic concrete and the flexural and compressive strengths of the hardened concrete at 14 days are given in Table 42.

Standard procedures were followed in the mixing and placing of the concrete. Cement and aggregates, batched at a central plant, were delivered in 4-compartment batch trucks to the 34–E dual drum pavers. Mixing time was not less than 60 sec, and all water had to be added within the first 15 sec. The air-entraining agent was introduced at the mixer.

The concrete was spread mechanically in both lanes simultaneously, and the operation was continuous for the full length of a structural section. Construction joints, when required, were formed in the transition between sections. Pavement fabric for pavements 5 in. and greater in thickness was placed by the double strike-off method; for the 2½- and 3½-in. pavements it was set in place and welded to chairs prior to placing the concrete. The sequence of operations included placing and spreading, strike-off and consolidation, longitudinal floating, straightedging, belting, edging, and final finishing with a burlap drag. Wet straw was used to cure the concrete.

In addition to the beams and cylinders molded during the paving operations for control of construction, specimens were made for determining flexural and compressive strengths at intervals over a period of two years. Table 43 summarizes the results of tests made on these specimens.

## 3.2 PAVEMENT PERFORMANCE

The concept of pavement serviceability, the derivation of the serviceability indexes, and the rationale for the analysis of pavement performance data are described briefly in Section 1.3, and in detail in Appendixes F and G.

Figure 112. Paving on test tangent.

This section describes the rigid pavement present serviceability index, and the relationship of rigid pavement performance to design and load based on data from the main factorial experiment (Design 1). It also presents the results of the shoulder paving—no subbase study (Design 3), and describes elements of pavement deterioration observed during the traffic testing.

### *3.2.1 Serviceability Index for Rigid Pavement*

This subsection contains the equations used to determine the present serviceability index of each rigid pavement section (Eqs. 59 and 60). Also included are Tables 44 and 45 which give, for each section, the number of unweighted applications sustained before the serviceability index fell to 2.5 and 1.5. If the serviceability did not fall to those levels, the tables give the section's index value at the end of the traffic test.

Eq. 59 was used to determine the level of serviceability of the surviving rigid pavement test sections every two weeks during the period of traffic operation.

$$p = 5.41 - 1.80 \log (1 + \overline{SV}) - 0.09 \sqrt{C + P} \qquad (59)$$

in which

$p$ = present serviceability index;

$\overline{SV}$ = mean of the slope variance in the two wheelpaths; and

$C$ and $P$ = measures of cracking and patching in the pavement surface. (In this equation and throughout this report, logarithms are to the base 10.)

$SV$ was discussed in Section 1.3. Cracking, $C$ (Eq. 59), is defined as the total linear feet of Class 3 and Class 4 cracks per 1,000 sq ft of pavement area. The length of a crack is taken as the length of its projection parallel or perpendicular to the pavement centerline, whichever is greater. A Class 3 crack is defined as a crack opened or spalled at the surface to a width of ¼ in. or more over a distance equal to at least one-half the crack length, except that any portion of the crack opened less than ¼ in. at the surface for a distance of 3 ft or more is classified separately. A Class 4 crack is defined as any crack which has been sealed. Patching, $P$, is expressed in square feet per 1,000 sq ft of pavement surfacing.

When it was not feasible to use the project's longitudinal profilometer to determine the serviceability of a test section, the Bureau of Public Roads roughometer (Fig. 113) was used. The roughometer was equipped with a special counter and operated at a speed of 10 mph. Through a study correlating the output of the roughometer with that of the profilometer, a

TABLE 37

SUMMARY OF RIGID PAVEMENT EXPERIMENT DESIGNS

| Experiment Design | Loop | Number of Design Factor Levels | | | | Number of Test Sections | | | Where Reported | Subject Matter |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Reinforcing | Pavement Thickness | Subbase Thickness | Shoulder Material | Basic[1] | Replicates | Total | | |
| 1 | 1 | 2 | 4 | 2 | — | 32 | 16 | 48 | Sect. 3.5.3<br>Sect. 3.5.4<br>Sect. 3.5.6<br>Sect. 3.2.2.1<br>Sect. 3.2.3<br>Sect. 3.3<br>Sect. 3.4 | Curling<br>Load stresses<br>Weathering<br>Performance<br>Structural Deter.<br>Strain, defl.<br>Performance from strain, defl. |
| | 2 | 2 | 3 | 3 | — | 36 | 4 | 40 | | |
| | 3–6 | 2 | 4 | 3 | — | 192 | 32 | 224 | | |
| 3 | 3–6 | — | 2 | 2 | 2 | 64 | 0 | 64[2] | Sect. 3.5.1<br>Sect. 3.2.2.2 | Overlays<br>Performance |
| 5 | 1 | — | — | 2 | — | 4 | 4 | 8 | Sect. 3.5.2 | Plate tests, moisture, density, etc. |

[1] Obtained by multiplying together the design factor levels, then multiplying by two, the number of traffic lanes.
[2] Sixteen of these test sections occur in Design 1; thus, only 48 additional test sections were required for Design 3.

pavement roughness expressed in inches per mile was substituted for $\overline{SV}$ (Eq. 59) with the following result: *

$$p = 5.41 - 1.80 \log (0.40R - 33) - 0.09 \sqrt{C + P} \qquad (60)$$

in which $R$ is the roughometer reading in inches per mile, and the other symbols are as previously defined. The roughometer was used only in cases where sections were nearing failure, and it appeared that maintenance would be required before the next regular 2-week index day period.

DS 7322 gives the complete serviceability history of each section as well as the results of the measurements of cracking, patching and slope variance that were used in Eq. 59 to determine the individual serviceability indexes.

Section history charts, showing the trends of cracking, serviceability and other items, are also available in DS 4292 for every test section. Examples are shown in Figures 114 and 115.

Basic data relative to the performance of Design 1 and Design 3 test sections are given in Appendix A. For Design 1, Tables 44 and 45 give the number of axle applications at which the serviceability level of failed sections dropped to 2.5 and 1.5, and the final serviceability level of every section that survived the two years of traffic testing.

Maintenance criteria permitted repair of the first localized failure in each section. This so-called "free maintenance" is described in Report 3. A table in that report lists the extent of the free maintenance done in each section.

### *3.2.2 Performance as a Function of Design and Load*

This subsection presents, in the form of performance-design-load equations, the results of the application of analytical procedures (described in Section 1.3 and Appendix G) to the performance data given in Appendix A for the main factorial experiments (Design 1). This section also includes associations of performance with design and load variables of the shoulder paving-no subbase study.

*3.2.2.1 Main Factorial Experiments.*—This subsection contains the results of the major rigid pavement analysis, the analysis of performance as a function of design and load, as required by the first objective of the Road Test.

The relationship of pavement performance to design and load resulting from the analysis is expressed by a set of four equations (Eqs. 61, 62, 65 and 66). These are in terms of the serviceability index of the pavement, the magnitude and configuration (single or tandem) of the

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* For a detailed description of the use of the roughometer for the determination of present serviceability see "The Calibration and Use of the Bureau of Public Roads Roughometer at the AASHO Road Test," W. R. Hudson and R. C. Hain, HRB Special Report 66 (1962).

## TABLE 38

### DETAILS OF PORTLAND CEMENT CONCRETE SURFACING

| Pavement Thickness (in.) | Maximum Size of Aggregate (in.) | Depth of Sawing (in.) | Joints[1] |  | Reinforcement in Test Pavements |  |  |
|---|---|---|---|---|---|---|---|
|  |  |  | Transverse Dowels[2] Diam. × Length (in.) | Longitudinal, Deformed Tie Bars[3] Size × Length (no.) (in.) | Fabric Style[4] | Fabric Weight (lb/100 sq ft) | Depth in Pavement (in.) |
| 2½ | 1½ | ¾ | ⅜ x 12 | 3 x 20 | 66–1010 | 21 | 1¼ |
| 3½ | 1½ | 1 | ½ x 12 | 3 x 20 | 66–88 | 30 | 1¾ |
| 5 | 2½ | 1¼ | ⅝ x 12 | 3 x 20 | 612–66 | 32 | 2 |
| 6½ | 2½ | 1½ | ⅞ x 18 | 4 x 24 | 612–44 | 44 | 2 |
| 8 | 2½ | 1¾ | 1 x 18 | 4 x 24 | 612–33 | 51 | 2 |
| 9½ | 2½ | 2 | 1¼ x 18 | 5 x 30 | 612–22 | 59 | 2 |
| 11 | 2½ | 2¼ | 1⅜ x 18 | 5 x 30 | 612–11 | 69 | 2 |
| 12½ | 2½ | 2½ | 1⅝ x 18 | 5 x 30 | 612–00 | 81 | 2 |

[1] All joints formed by sawing groove approximately ⅛-in. wide.

[2] All transverse joints doweled, on 12-in. centers, and spaced at 15 ft in plain sections and at 40 ft in reinforced sections.

[3] At 30-in. centers.

[4] Code:

```
6      12    -    4        4
|      |          |        |__________Gage of transverse wires
|      |          |___________________Gage of longitudinal wires
|      |______________________________Longitudinal spacing of transverse wires (inches)
|_____________________________________Transverse spacing of longitudinal wires (inches)
```

## TABLE 39

### SUMMARY OF GRADATION TESTS ON PORTLAND CEMENT CONCRETE AGGREGATES

| Sieve | Gradation Formula and Tolerances | Mean % of Material Passing | Standard Deviation |
|---|---|---|---|
| (*a*) COARSE AGGREGATE SIZE A (170 TESTS) |  |  |  |
| 2½ in. | 100 | 100 | — |
| 2 in. | 95 ± 5 | 96.3 | 3.45 |
| 1½ in. | 62 ± 7 | 63.5 | 6.11 |
| 1 in. | 10 ± 5 | 10.6 | 3.18 |
| ½ in. | 2.5 ± 2.5 | 3.8 | 2.14 |
| (*b*) COARSE AGGREGATE SIZE B (171 TESTS) |  |  |  |
| 1½ in. | 100 | 100 | — |
| 1 in. | 95 ± 5 | 94.1 | 1.30 |
| ½ in. | 38 ± 5 | 37.9 | 1.65 |
| No. 4 | 5 ± 5 | 1.5 | 0.78 |
| (*c*) PORTLAND CEMENT CONCRETE SAND (80 TESTS) |  |  |  |
| ⅜ in. | 100 | 100 | — |
| No. 4 | 97.5 ± 2.5 | 99.0 | 0.97 |
| No. 8 | 85 ± 5 | 84.1 | 1.55 |
| No. 16 | 67 ± 4 | 67.0 | 1.83 |
| No. 30 | 46 ± 4 | 45.4 | 1.51 |
| No. 50 | 13 ± 3 | 12.3 | 0.73 |
| No. 100 | 3 ± 2 | 2.7 | 0.46 |

## TABLE 40

### CHARACTERISTICS OF PORTLAND CEMENT AND MIXING WATER

| | |
|---|---|
| Physical properties of cement: | |
| Autoclave expansion (%) | 0.21 |
| Time of set (hr): | |
| Initial | 3.28 |
| Final | 5.58 |
| Fineness, Blaine (sq cm per g) | 3413 |
| Compressive strength (psi): | |
| 3 Day | 3200 |
| 7 Day | 4624 |
| 28 Day | 5875 |
| 90 Day | 6241 |
| Air (%) | 6.9 |
| Chemical analysis of cement: | |
| Insoluble residue (%) | 0.17 |
| Ignition loss (%) | 1.78 |
| Sulfuric anhydride (%) | 2.40 |
| Magnesia, MgO (%) | 1.77 |
| Chemical tests of mixing water: | |
| Reaction to: | |
| Litmus | Sl. alk. |
| Methyl orange | Alk. |
| Phenolphthalein | None |
| Tests for sugar | Neg. |
| Total solids (%) | |
| Organic | 0.010 |
| Inorganic | 0.030 |
| Sulfuric anhydride | 0.001 |
| Alkali chloride | Trace |
| Alkalinity | 15.0 ml[1] |

[1] 0.1 N HCl for 200-ml sample.

axle load, the number of applications of the axle load, and the thickness of the pavement slab.

The equations are represented by graphs provided for the purpose of simplifying their interpretation (for an example see Fig. 116) and for displaying their predictions in conjunction with the observed data (Figs. 120 through 123).

An example of using the graph (Fig. 116) follows. It is desired to estimate the number of applications of an 18-kip single axle load associated with a reduction from 4.5 to 2.5 in the serviceability index of a Road Test section having a 5-in. thick slab (on granular subbase). From the figure, the horizontal line representing a slab thickness of 5 in. intersects the "18-kip single" curve at about 400,000 axle load applications. (A comparison of this prediction with the actual performance of the six test sections with a slab thickness of 5 in. subjected to an 18-kip single axle load, is shown in Figure 120.)

Because of random variations in the observed data, there were unavoidable differences be-

TABLE 41

PORTLAND CEMENT CONCRETE PROPORTIONING DATA PER BAG OF CEMENT

| Characteristic | For Pavement Thickness | |
|---|---|---|
| | 5 In. and Greater | 2½ and 3½ In. |
| Total mixing water (gal) | 4.8 | 4.9 |
| Absolute volume (cu ft): | | |
| Sand | 1.02 | 1.08 |
| Coarse aggregate | 2.16 | 2.09 |
| Mortar (cu ft) | 2.34 | 2.41 |
| Yield (cu ft) | 4.5 | 4.5 |
| Proportioning weight (lb): | | |
| Coarse aggregate Size A | 180.5 | — |
| Coarse aggregate Size B | 179.9 | 348.0 |
| Sand | 170.5 | 180.5 |

TABLE 42

SUMMARY OF TEST RESULTS ON PLASTIC AND HARDENED CONCRETE

| Characteristic | Maximum Size Aggregate | |
|---|---|---|
| | 2½ In. | 1½ In. |
| Plastic concrete: | | |
| Slump (in.) | 2.5 | 2.7 |
| Air content (%) | 3.7 | 2.7 |
| Cement factor (bags/cu yd) | 6.08 | .6.07 |
| Water-cement ratio (gal/bag) | 4.65 | 4.81 |
| Hardened concrete: | | |
| Flexural strength at 14 days[1] (psi) | 636 | 668 |
| Compressive strength at 14 days[2] (psi) | 3966 | 4004 |

[1] By AASHO Designation T97–57 ( 6- x 6- x 30-in. beams).

[2] By AASHO Designation T22–57 (6-in. diam. x 12-in. long cylinders).

TABLE 43

SUMMARY OF CONCRETE STRENGTH TESTS

| Age at Testing | Flexural Strength[1] (psi) | | | Compressive Strength[2] (psi) | | |
|---|---|---|---|---|---|---|
| | Number Tests | Mean | Standard Deviation | Number Tests | Mean | Standard Deviation |
| (*a*) 2½-IN. MAXIMUM SIZE AGGREGATE | | | | | | |
| 3 days | 11 | 510 | 23 | 11 | 2670 | 784 |
| 7 days | 11 | 620 | 34 | 11 | 3560 | 396 |
| 21 days | 11 | 660 | 51 | 11 | 4130 | 397 |
| 3 months | 11 | 770 | 66 | 11 | 4680 | 487 |
| 1 year | 11 | 790 | 61 | 11 | 5580 | 509 |
| 2 years | 11 | 787 | 66 | 11 | 5818 | 328 |
| (*b*) 1½-IN. MAXIMUM SIZE AGGREGATE | | | | | | |
| 3 days | 12 | 550 | 37 | 12 | 2860 | 809 |
| 7 days | 12 | 630 | 35 | 12 | 3780 | 289 |
| 21 days | 12 | 710 | 53 | 12 | 4250 | 365 |
| 3 months | 12 | 830 | 41 | 12 | 4930 | 528 |
| 1 year | 10 | 880 | 53 | 12 | 5990 | 379 |
| 2 years | 12 | 873 | 48 | 12 | 6155 | 373 |

[1] By AASHO Designation T97 (third point loading).

[2] By AASHO Designation T22, except that specimens were 6 in. in diameter and 12 in. long.

tween predictions from the equations and the actual performance of individual sections.

Thus, in using the curves, some allowance should be made for the scatter of the data. Analysis of the residuals shows that the scatter corresponds approximately to ±12 percent of the slab thickness given by the performance curves. (If comparisons are made with the observed performance of an actual highway in service, additional allowance should be made to account for differences in materials, environment and loading history between the highway and the Road Test.)

Included in the subsection are tables and discussion showing the basis for determination of the significance or nonsignificance of the load and design variables. Also given are correlation indexes disclosing the degree of correlation found in the relationships, and mean residuals showing the degree of scatter of the observed data from the predictions of the performance equations.

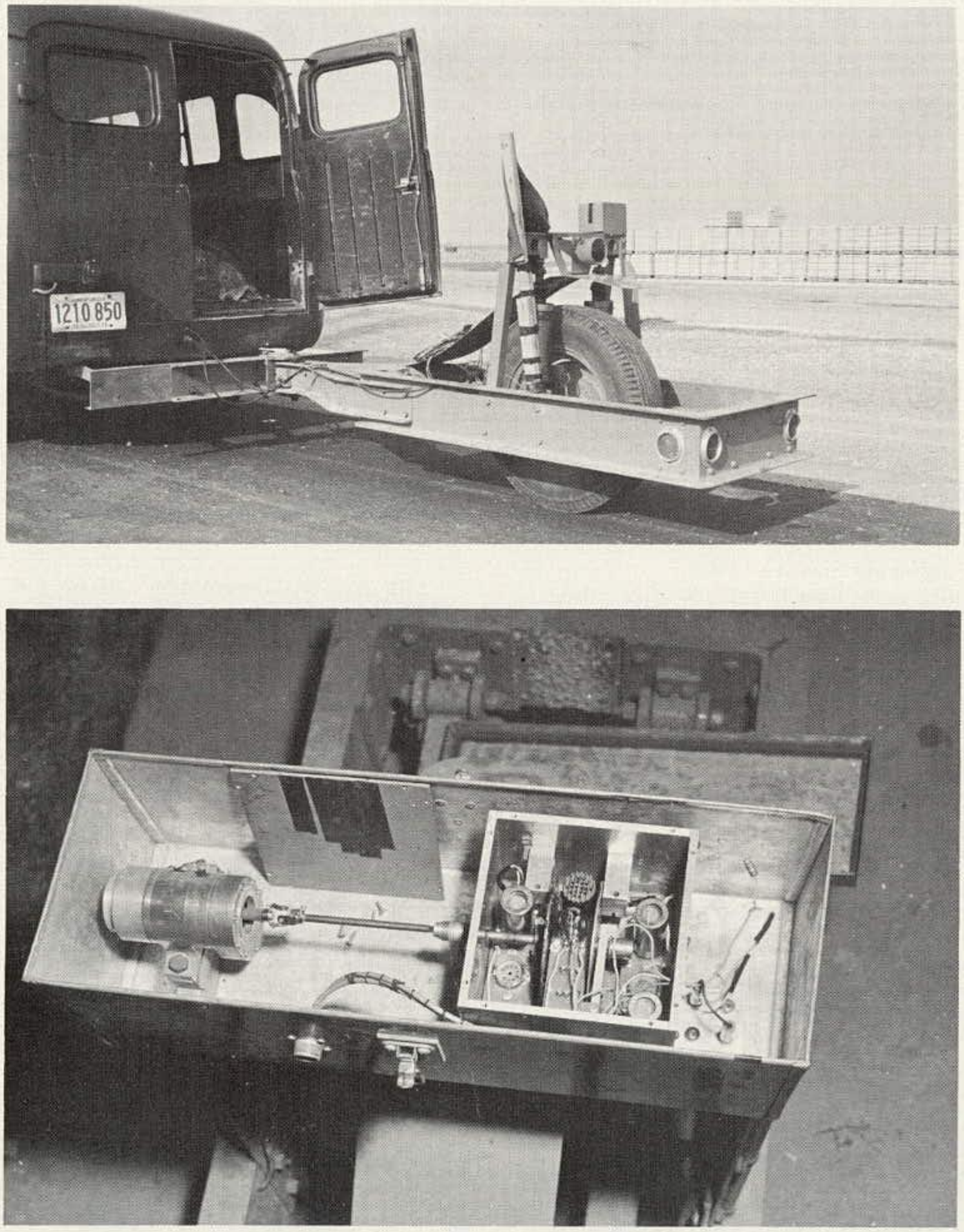

**Figure 113. Bureau of Public Roads roughometer, used to determine serviceability level of sections nearing failure. Special counter (lower photo) was required because of short length of sections.**

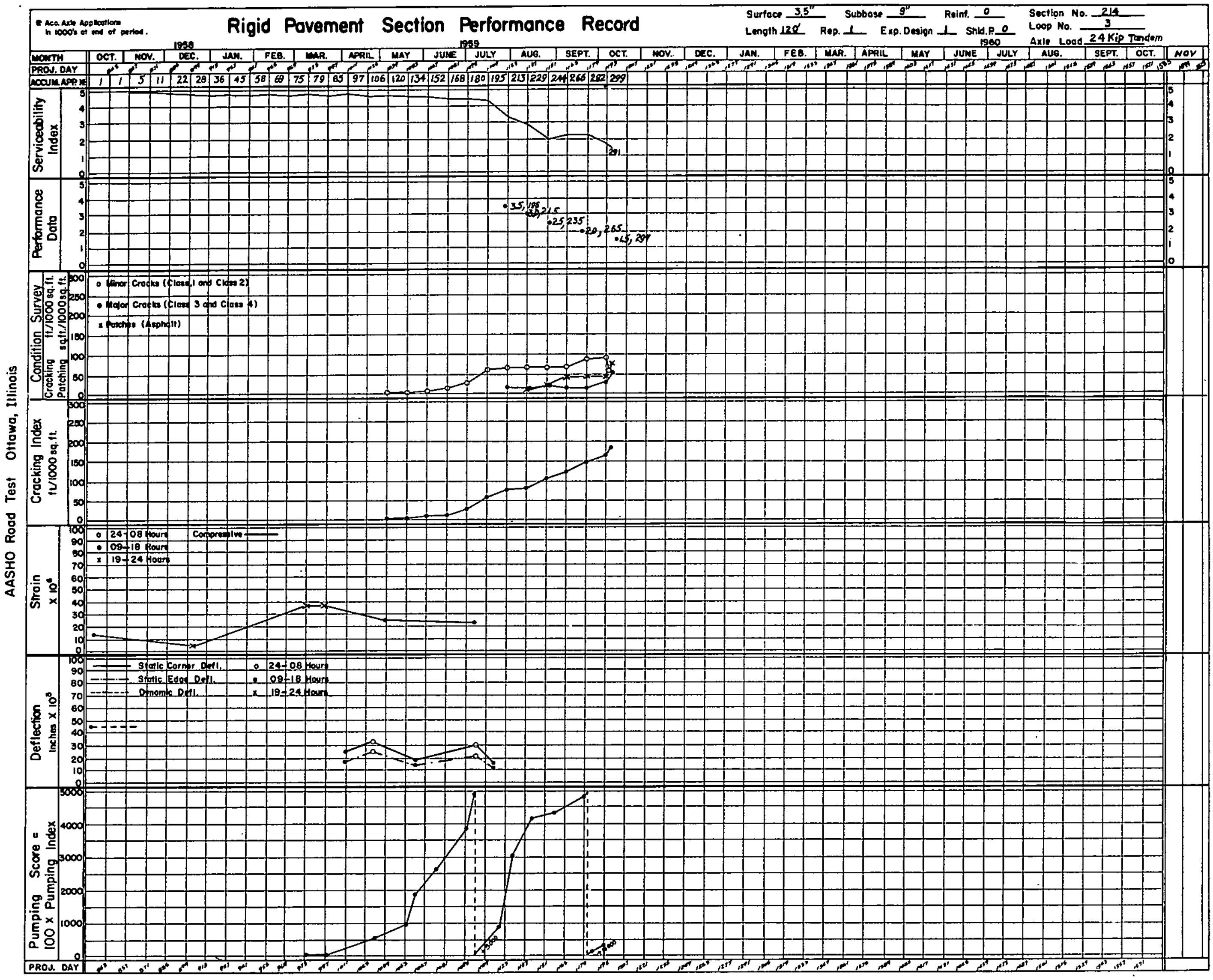

Figure 114. Example of section history chart.

In the course of the development of the performance equations, the following findings resulted from the analysis:

The effect on performance of the pavement design variable, reinforcing (and/or panel length), was not significant; consequently, this variable was excluded from the performance equations. Table 38 includes details of the differences in design between reinforced and nonreinforced sections. The transverse joints were doweled in the nonreinforced as well as in the reinforced slabs.

The effect on performance of varying the thickness of the subbase between 3 and 9 in. also was not significant, and this variable was excluded from the performance equations. However, as shown in Section 3.2.2.2, the performance of sections on 6 in. of subbase was found to be superior to that of sections without subbase.

The general model given in Section 1.3.5 to represent pavement performance was

$$p = c_0 - (c_0 - c_1) \left(\frac{W}{\rho}\right)^{\beta} \tag{4}$$

For rigid pavement test sections, Designs 1 and 3, the average initial serviceability trend value was $c_0 = 4.5$, and since $c_1$ was selected to be 1.5, the trend curves are represented by

$$p = 4.5 - 3 \left(\frac{W}{\rho}\right)^{\beta} \tag{61}$$

Both $\beta$ and $\rho$ are positive functions of the design variables, $D_1$ (0 for nonreinforced sections and 1 for reinforced sections), $D_2$ (slab thickness, in.), and $D_3$ (subbase thickness, in.), and of the load variables, $L_1$ (nominal axle load, kips) and $L_2$ (1 for single axles or 2 for tandem axles).

The function $\beta$ determines the general shape of the serviceability trend with increasing axle load applications, $W$. For example, if $\beta = 1$, the trend is a straight line; if $\beta > 1$, the serviceability loss rate increases with applications. If $\beta < 1$, the loss rate decreases with axle load repetitions. If the serviceability history of a section does not show any definite loss, then the history gives no information about the magnitude of $\beta$. Such was the case for virtually all rigid pavement sections whose slab thickness ($D_2$) was at the highest level in any Road Test traffic lane. Serviceability trends for the lowest and next to lowest levels of $D_2$ were generally well defined, and in certain cases at least the beginning of a loss trend could be detected for sections whose $D_2$ was at the next to highest level. For these reasons the rigid pavement analysis involved only those sections whose slab thickness level was less than the highest level for each lane. For these sections, it was found that data from failed sections always gave estimates for $\beta$ that were greater than one. For those sections whose serviceability loss was relatively small, there was no indication that the loss rate was decreasing. Consequently, it was assumed that $\beta$ was no less than one, and the value 1.0 was assigned to $\beta_0$ in Eq. 6 for rigid pavements.

The function $\rho$ is equal to the number of load applications at which $p$ first equals 1.5 and is

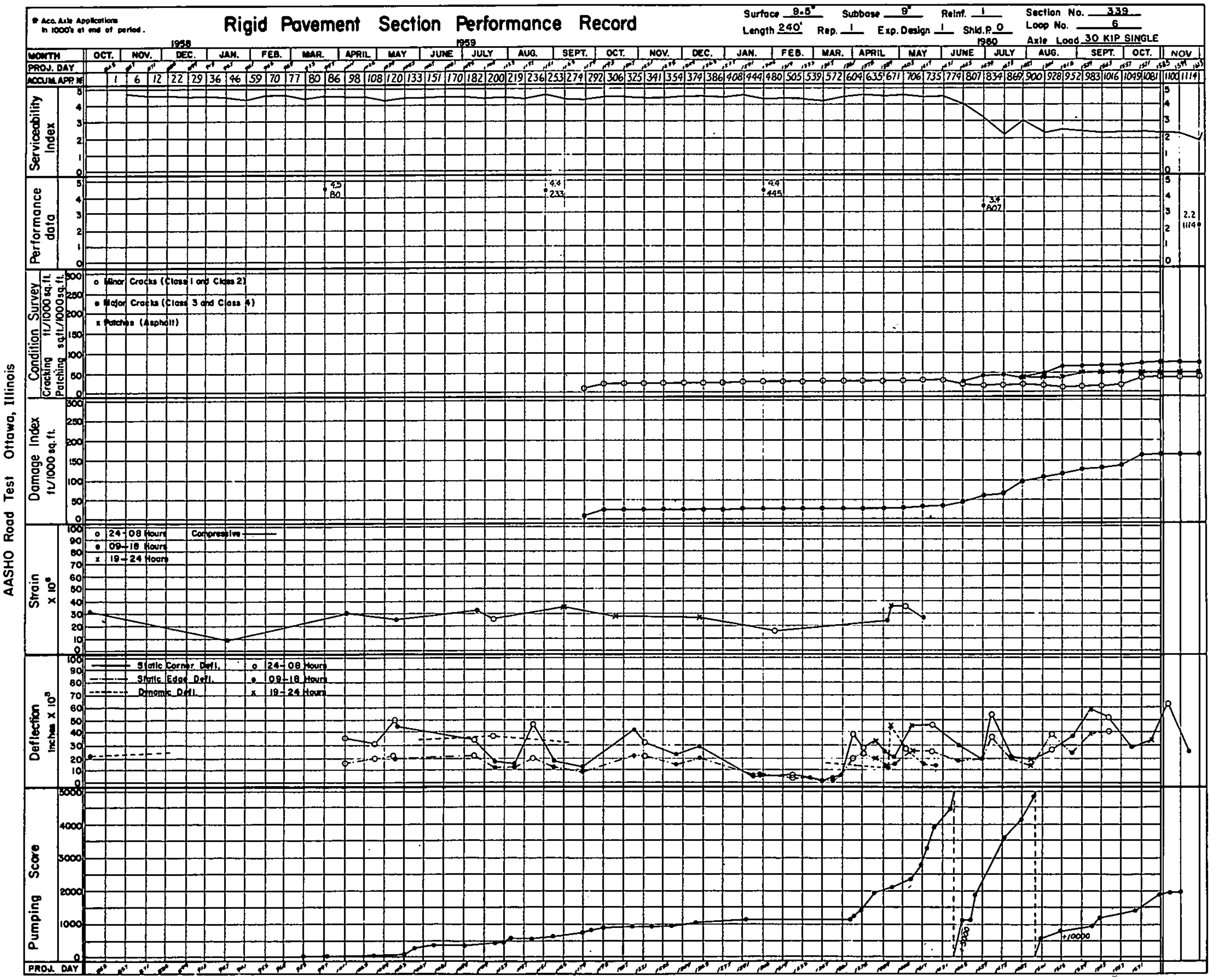

Figure 115. Example of section history chart.

## TABLE 44

PERFORMANCE DATA, EXPERIMENT DESIGN 1, UNWEIGHTED AXLE APPLICATIONS TO $p = 2.5$ OR $p$ AT END OF TRAFFIC TEST[1,2]

| Loop | Axle Load (kips) | Subbase Thickness (in.) | Unweighted Axle Applications (1,000's) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2.5-In. Surface | | 3.5-In. Surface | | 5.0-In. Surface | | 6.5-In. Surface | | 8.0-In. Surface | | 9.5-In. Surface | | 11.0-In. Surface | | 12.5-In. Surface | |
| | | | R | N | R | N | R | N | R | N | R | N | R | N | R | N | R | N |
| 2 | 2S | 0 | (4.2) | (4.3) | (4.4) | (4.2) | (4.3) | (4.1) | | | | | | | | | | |
| | | 3 | | | (4.1) | | | (3.9) | | | | | | | | | | |
| | | | (4.2) | (4.4) | (4.5) | (4.0) | (4.6) | (3.5) | | | | | | | | | | |
| | | 6 | (4.4) | (4.4) | (4.5) | (4.2) | (4.3) | (4.1) | | | | | | | | | | |
| | 6S | 0 | 379 | 309 | (4.1) | (3.7) | (4.5) | (4.1) | | | | | | | | | | |
| | | 3 | | | (4.1) | | | (4.1) | | | | | | | | | | |
| | | | 836 | 1084 | (4.2) | (4.0) | (4.6) | (3.6) | | | | | | | | | | |
| | | 6 | (3.8) | (3.1) | (4.6) | (4.0) | (4.3) | (4.0) | | | | | | | | | | |
| 3 | 12S | 3 | | | | | (2.8) | | | (4.4) | | | | | | | | |
| | | | | | 269 | 309 | (4.0) | (3.7) | (4.2) | (3.9) | (4.3) | (4.4) | | | | | | |
| | | 6 | | | | | | (3.5) | (4.3) | | | | | | | | | |
| | | | | | 254 | 280 | 716 | (3.1) | (4.5) | (4.1) | (4.2) | (4.3) | | | | | | |
| | | 9 | | | 304 | 245 | (3.3) | (3.7) | (4.4) | (4.2) | (4.1) | (4.0) | | | | | | |
| | 24T | 3 | | | | | 1043 | | | (4.2) | | | | | | | | |
| | | | | | 275 | 313 | 1019 | 669 | (4.1) | (4.0) | (4.1) | (4.3) | | | | | | |
| | | 6 | | | | | | (2.8) | (4.3) | | | | | | | | | |
| | | | | | 260 | 205 | 564 | 815 | (4.1) | (4.1) | (4.0) | (4.3) | | | | | | |
| | | 9 | | | 276 | 235 | 775 | 713 | (4.4) | (4.0) | (4.3) | (4.2) | | | | | | |
| 4 | 18S | 3 | | | | | | | (3.8) | | | (4.4) | | | | | | |
| | | | | | | | 378 | 645 | (3.6) | (3.8) | (3.9) | (4.5) | (4.0) | (4.2) | | | | |
| | | 6 | | | | | | | | (4.4) | (4.4) | | | | | | | |
| | | | | | | | 324 | 313 | (3.4) | (4.3) | (3.9) | (4.4) | (4.5) | (4.5) | | | | |
| | | 9 | | | | | 579 | 278 | 1036 | (3.0) | (4.3) | (4.3) | (4.8) | (4.1) | | | | |
| | 32T | 3 | | | | | | | 898 | | | (4.1) | | | | | | |
| | | | | | | | 280 | 328 | 778 | 469 | (4.0) | (4.2) | (4.0) | (4.0) | | | | |
| | | 6 | | | | | | | | (3.4) | (4.4) | | | | | | | |
| | | | | | | | 167 | 291 | 786 | 924 | (3.8) | (4.2) | (4.3) | (4.2) | | | | |
| | | 9 | | | | | 385 | 282 | 968 | 710 | (4.2) | (4.1) | (4.6) | (4.2) | | | | |
| 5 | 22.4S | 3 | | | | | | | | | 881 | | | (4.4) | | | | |
| | | | | | | | | | 828 | 745 | (4.3) | (4.2) | (4.3) | (4.3) | (4.1) | (4.1) | | |
| | | 6 | | | | | | | | | | (4.2) | (4.5) | | | | | |
| | | | | | | | | | 333 | 854 | (4.0) | (4.1) | (4.3) | (3.7) | (4.4) | (4.5) | | |
| | | 9 | | | | | | | 676 | 683 | (4.6) | 1029 | (4.4) | (4.5) | (4.4) | (4.5) | | |
| | 40T | 3 | | | | | | | | | 830 | | | (4.3) | | | | |
| | | | | | | | | | 687 | 316 | (4.3) | (4.2) | (4.1) | (4.2) | (4.3) | (4.3) | | |
| | | 6 | | | | | | | | | | (3.7) | (4.3) | | | | | |
| | | | | | | | | | 292 | 337 | 881 | (4.2) | (4.5) | (4.0) | (4.3) | (4.5) | | |
| | | 9 | | | | | | | 346 | 399 | (3.2) | 885 | (4.6) | (3.8) | (4.4) | (4.4) | | |
| 6 | 30S | 3 | | | | | | | | | | | (4.5) | | | (4.2) | | |
| | | | | | | | | | | | 775 | 871 | 921 | (3.6) | (4.4) | (4.4) | (4.4) | (4.2) |
| | | 6 | | | | | | | | | | | | (4.3) | (4.0) | | | |
| | | | | | | | | | | | 861 | (3.9) | (4.0) | (4.3) | (4.3) | (4.2) | (4.2) | (4.0) |
| | | 9 | | | | | | | | | 710 | (3.4) | 898 | (4.2) | (4.2) | (4.3) | (4.5) | (4.2) |
| | 48T | 3 | | | | | | | | | | | (4.4) | | | (4.3) | | |
| | | | | | | | | | | | 490 | 1086 | (4.1) | (3.1) | (4.4) | (4.3) | (4.3) | (4.3) |
| | | 6 | | | | | | | | | | | | (4.3) | (4.1) | | | |
| | | | | | | | | | | | 408 | (4.1) | (4.0) | (4.3) | (4.2) | (4.3) | (4.4) | (4.2) |
| | | 9 | | | | | | | | | 611 | 1046 | 904 | (4.3) | (4.1) | (4.3) | (4.2) | (4.4) |

---

[1] Numbers in parentheses are values of $p$.

[2] R = reinforced; N = nonreinforced.

TABLE 45

PERFORMANCE DATA, EXPERIMENT DESIGN 1, UNWEIGHTED AXLE APPLICATIONS TO $p$ = 1.5 OR $p$ AT END OF TRAFFIC TEST[1,2]

| Loop | Axle Load (kips) | Subbase Thickness (in.) | Unweighted Axle Applications (1,000's) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2.5-In. Surface | | 3.5-In. Surface | | 5.0-In. Surface | | 6.5-In. Surface | | 8.0-In. Surface | | 9.5-In. Surface | | 11.0-In. Surface | | 12.5-In. Surface | |
| | | | R | N | R | N | R | N | R | N | R | N | R | N | R | N | R | N |
| 2 | 2S | 0 | (4.2) | (4.3) | (4.4) | (4.2) | (4.3) | (4.1) | | | | | | | | | | |
| | | 3 | | | (4.1) | | | (3.9) | | | | | | | | | | |
| | | | (4.2) | (4.4) | (4.5) | (4.0) | (4.6) | (3.5) | | | | | | | | | | |
| | | 6 | (4.4) | (4.4) | (4.5) | (4.2) | (4.3) | (4.1) | | | | | | | | | | |
| | 6S | 0 | 469 | 555 | (4.1) | (3.7) | (4.5) | (4.1) | | | | | | | | | | |
| | | 3 | | | (4.1) | | | (4.1) | | | | | | | | | | |
| | | | 840 | (2.2) | (4.2) | (4.0) | (4.6) | (3.6) | | | | | | | | | | |
| | | 6 | (3.8) | (3.1) | (4.6) | (4.0) | (4.3) | (4.0) | | | | | | | | | | |
| 3 | 12S | 3 | | | | | (2.8) | | | (4.4) | | | | | | | | |
| | | | | | 278 | 315 | (4.0) | (3.7) | (4.2) | (3.9) | (4.3) | (4.4) | | | | | | |
| | | 6 | | | | | | (3.5) | (4.3) | | | | | | | | | |
| | | | | | 273 | 289 | 725 | (3.1) | (4.5) | (4.1) | (4.2) | (4.3) | | | | | | |
| | | 9 | | | 324 | 289 | (3.3) | (3.7) | (4.4) | (4.2) | (4.1) | (4.0) | | | | | | |
| | 24T | 3 | | | | | 1100 | | | (4.2) | | | | | | | | |
| | | | | | 278 | 318 | 1046 | 705 | (4.1) | (4.0) | (4.1) | (4.3) | | | | | | |
| | | 6 | | | | | | (2.8) | (4.3) | | | | | | | | | |
| | | | | | 295 | 210 | 631 | 901 | (4.1) | (4.1) | (4.0) | (4.3) | | | | | | |
| | | 9 | | | 294 | 297 | 793 | 771 | (4.4) | (4.0) | (4.3) | (4.2) | | | | | | |
| 4 | 18S | 3 | | | | | | | (3.8) | | | (4.4) | | | | | | |
| | | | | | | | 415 | 716 | (3.6) | (3.8) | (3.9) | (4.5) | (4.0) | (4.2) | | | | |
| | | 6 | | | | | | | | (4.4) | (4.4) | | | | | | | |
| | | | | | | | 325 | 353 | (3.4) | (4.3) | (3.9) | (4.4) | (4.5) | (4.5) | | | | |
| | | 9 | | | | | 592 | 291 | (1.8) | (3.0) | (4.3) | (4.3) | (4.8) | (4.1) | | | | |
| | 32T | 3 | | | | | | | (2.6) | | | (4.1) | | | | | | |
| | | | | | | | 304 | 343 | 793 | 687 | (4.0) | (4.2) | (4.0) | (4.0) | | | | |
| | | 6 | | | | | | | | (3.4) | (4.4) | | | | | | | |
| | | | | | | | 175 | 328 | 796 | 1000 | (3.8) | (4.2) | (4.3) | (4.2) | | | | |
| | | 9 | | | | | 408 | 289 | 1036 | 722 | (4.2) | (4.1) | (4.6) | (4.2) | | | | |
| 5 | 22.4S | 3 | | | | | | | | | 1104 | | | (4.4) | | | | |
| | | | | | | | | | 898 | 760 | (4.3) | (4.2) | (4.3) | (4.3) | (4.1) | (4.1) | | |
| | | 6 | | | | | | | | | | (4.2) | (4.5) | | | | | |
| | | | | | | | | | 369 | 898 | (4.0) | (4.1) | (4.3) | (3.7) | (4.4) | (4.5) | | |
| | | 9 | | | | | | | 708 | 705 | (4.6) | 1111 | (4.4) | (4.5) | (4.4) | (4.5) | | |
| | 40T | 3 | | | | | | | | | 915 | | | (4.3) | | | | |
| | | | | | | | | | 705 | 335 | (4.3) | (4.2) | (4.1) | (4.2) | (4.3) | (4.3) | | |
| | | 6 | | | | | | | | | | (3.7) | (4.3) | | | | | |
| | | | | | | | | | 305 | 369 | 901 | (4.2) | (4.5) | (4.0) | (4.3) | (4.5) | | |
| | | 9 | | | | | | | 618 | 698 | (3.2) | 898 | (4.6) | (3.8) | (4.4) | (4.4) | | |
| 6 | 30S | 3 | | | | | | | | | | | (4.5) | | | (4.2) | | |
| | | | | | | | | | | | 782 | 878 | (1.6) | (3.6) | (4.4) | (4.4) | (4.4) | (4.2) |
| | | 6 | | | | | | | | | | | | (4.3) | (4.0) | | | |
| | | | | | | | | | | | 974 | (3.9) | (4.0) | (4.3) | (4.3) | (4.2) | (4.2) | (4.0) |
| | | 9 | | | | | | | | | 768 | (3.4) | (2.2) | (4.2) | (4.2) | (4.3) | (4.5) | (4.2) |
| | 48T | 3 | | | | | | | | | | | (4.4) | | | (4.3) | | |
| | | | | | | | | | | | 618 | (1.8) | (4.1) | (3.1) | (4.4) | (4.3) | (4.3) | (4.3) |
| | | 6 | | | | | | | | | | | | (4.3) | (4.1) | | | |
| | | | | | | | | | | | 415 | (4.1) | (4.0) | (4.3) | (4.2) | (4.3) | (4.4) | (4.2) |
| | | 9 | | | | | | | | | 624 | 1114 | 912 | (4.3) | (4.1) | (4.3) | (4.2) | (4.4) |

---

[1] Numbers in parentheses are values of $p$.

[2] R = reinforced; N = nonreinforced.

assumed to increase as design increases and to decrease as load increases. The aim of the performance analysis is to arrive at formulas for $\beta$ and $\rho$ in terms of $D_1$, $D_2$, $D_3$, $L_1$ and $L_2$ so that Eq. 4 may be used to predict the value of $p$ after a specified number of applications, $W$. On the other hand, if Eq. 4 is solved for log $W$, the resulting equation may be used to predict the number of applications required to reduce the serviceability level to a specified value, as follows:

$$\log W = \log \rho + \frac{\log \dfrac{4.5 - p}{3}}{\beta} \qquad (62)$$

Several analyses of variance were made in order to infer how $D_1$, $D_2$ and $D_3$ enter the expressions for $\rho$ and $\beta$ in Eq. 62. Part of one such analysis is given in Table 46 where test section estimates for log $\rho$ have been analyzed within each loop. The number of test sections used in each loop analysis is given. The second part gives mean squares that can be used to determine the relative significance of various effects. Because there were factorial experiments with replication in each loop, analysis of variance could be used to determine mean squares for unexplained effects represented by replicate differences, mean squares for separate effects of $D_1$, $D_2$ and $D_3$ and mean squares for all interaction effects of $D_1$, $D_2$ and $D_3$. For each of these effects, Table 46 gives mean squares for the two lanes combined and for lane interactions that reflect dissimilar effects in the two lanes of any loop. In each column, $D_1$, $D_2$ and $D_3$ interaction mean squares were compared by ratio with replicate effects. Since

TABLE 46

ANALYSIS OF VARIANCE FOR LOG $\rho$ ESTIMATES[1] WITHIN LOOPS

| Item | Loop 2 | Loop 3 | Loop 4 | Loop 5 | Loop 6 |
|---|---|---|---|---|---|
| Total number of test sections[2] | 24 | 36 | 36 | 36 | 36 |
| Number of Replicate Sections in Total | 4 | 8 | 8 | 8 | 8 |
| Effects[3]: | | | | | |
| Lane mean difference | $\underline{3.77}$ | $\underline{0.41}$ | $\underline{0.95}$ | $\underline{0.41}$ | 0.00 |
| $D_1$, reinforcement: | | | | | |
| Lanes combined | 0.01 | 0.03 | 0.00 | 0.00 | 0.07 |
| Lane interaction | 0.00 | 0.03 | 0.05 | 0.00 | 0.02 |
| $D_2$, slab thickness: | | | | | |
| Lanes combined | $\underline{0.74}$ | $\underline{7\ 00}$ | $\underline{6.60}$ | $\underline{3.66}$ | $\underline{2.23}$ |
| Lane interaction | $\underline{0.99}$ | 0.07 | $\underline{0.14}$ | 0.00 | 0.02 |
| $D_3$, subbase thickness: | | | | | |
| Lanes combined | 0.12 | 0 03 | 0.05 | 0.01 | 0.02 |
| Lane interaction | 0.06 | 0.01 | 0.01 | 0.00 | 0.00 |
| Interactions among $D_1$, $D_2$, $D_3$: | | | | | |
| Lanes combined | 0.07 | 0.02 | 0.04 | 0.05 | 0.06 |
| Lane interaction | 0.01 | 0.03 | 0.02 | 0.02 | 0.01 |
| Replicate differences: | | | | | |
| Lanes combined | 0.08 | 0.09 | 0.08 | 0.08 | 0.04 |
| Lane interaction | 0.01 | 0.02 | 0.02 | 0.02 | 0.01 |
| Within loop regression: | | | | | |
| Coefficient for log $(1 + D_2)$ | 6.93[4] | 6.81 | 8.40 | 7.54 | 6.88 |
| Percent of total variation explained by log $(1 + D_2)$ and lane differences | 70 | 94 | 92 | 90 | 81 |
| Mean square for all remaining variation: | | | | | |
| Lanes combined | 0.08 | 0.04 | 0.04 | 0.04 | 0.05 |
| Lane interaction | 0.11 | 0.02 | 0.03 | 0.01 | 0.01 |

[1] Data from which this table arose were estimates log $\hat{\hat{\rho}}$ as described in Appendix G.

[2] Excludes thickest slabs in each lane.

[3] Mean squares for effects (underlined values considered to be significant relative to replicate differences pooled with interaction effects.

[4] Lane 2.

none of the ratios was found to be significantly larger than one, these interactions could be ignored. The ratios of mean squares for $D_1$, $D_2$ or $D_3$ effects to interaction or replicate mean squares were also found not to be significant. Only the $D_2$ and lane effects were significant as indicated by the underlined mean squares. Thus in the expression $a_1D_1 + a_2D_2 + a_3D_3 + a_4$, both $a_1$ and $a_3$ were assigned the value zero so that $D_1$ and $D_3$ terms would not occur in the expression. For convenience it was assumed that $a_2$ and $a_4$ were both 1, and so pavement design was characterized by the expression $D_2 + 1$. With $\beta_0 = 1$, Eqs. 6 and 7 are therefore reduced to the following forms:

$$\beta = 1 + \frac{B_0 (L_1 + L_2)^{B_2}}{(D_2 + 1)^{B_1} L_2^{B_3}} \tag{63}$$

$$\rho = \frac{A_0 (D_2 + 1)^{A_1} L_2^{A_3}}{(L_1 + L_2)^{A_2}} \tag{64}$$

The last part of Table 46 shows the results of within-loop regression analyses that were used to determine a value for $A_1$, the coefficient for log $(D_2 + 1)$ in the logarithmic form of Eq. 64. This coefficient varied from about 6.9 to 8.4 in the various loops, and the weighted average value used for $A_1$ was 7.35 as shown in Eq. 66. The last two lines (Table 46) indicate that the major part of within-loop variation in log $\rho$ estimates was accounted for by slab thickness, and that the residual variation had mean squares quite similar to the replicate difference mean squares. Other variance analyses of rigid pavement performance data consistently gave the same type of results with respect to pavement design effects.

The remaining undetermined constants in Eqs. 63 and 64 were estimated by applying the procedures described in Appendix G to the performance data given in Appendix A for rigid pavements, Design 1.

A weighting function was not used for reasons given in Sections 1.3.4, and the symbol, $W$, in Eq. 62 represents actual (unweighted) axle applications. The expressions for $\beta$ and $\rho$ determined from the analysis were

$$\beta = 1 + \frac{3.63 (L_1 + L_2)^{5.20}}{(D_2 + 1)^{8.46} L_2^{3.52}} \tag{65}$$

$$\rho = \frac{10^{5.85} (D_2 + 1)^{7.35} L_2^{3.28}}{(L_1 + L_2)^{4.62}} \tag{66}$$

Although the subbase thickness term, $D_3$, does not occur in the performance equations, the equations do relate to pavements whose sub-

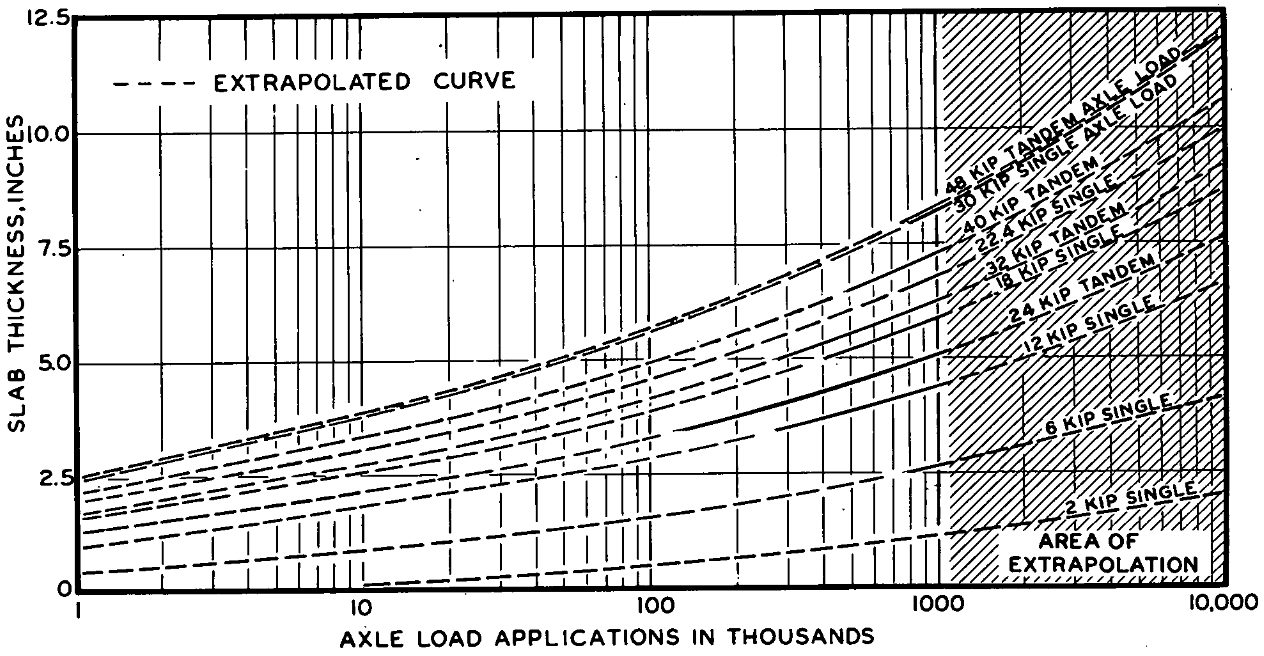

**Figure 116. Rigid pavement performance curves from Road Test equation, experiment design 1, for $p = 2.5$.**

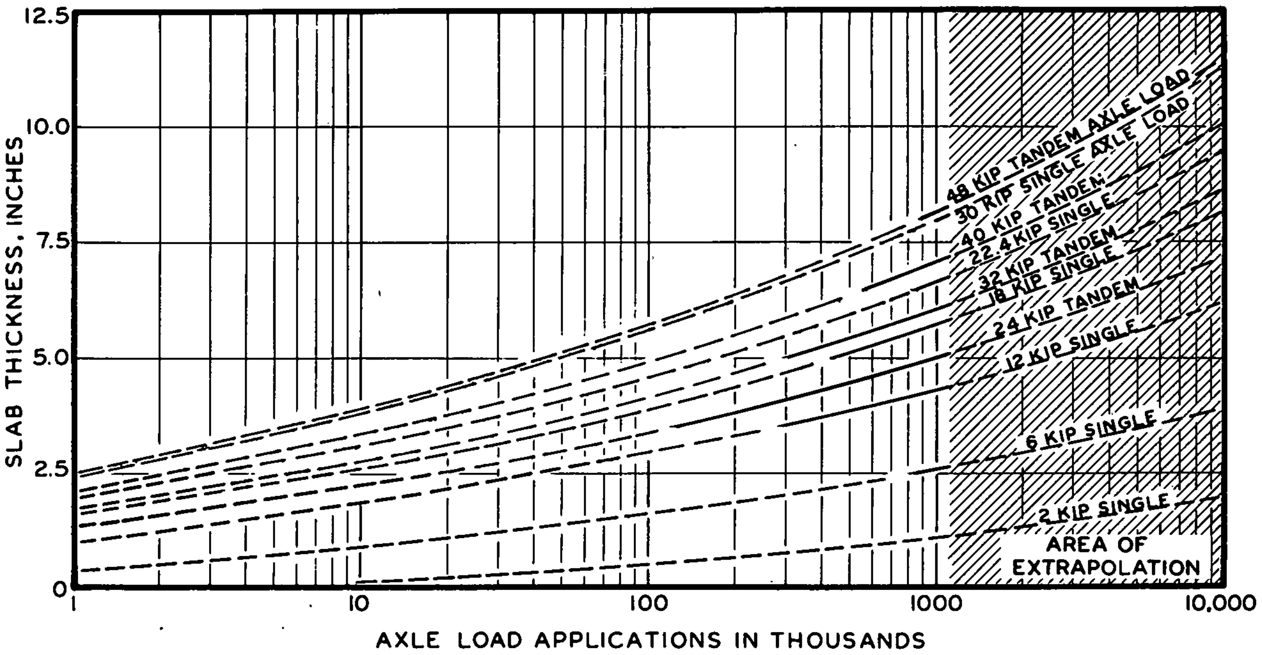

**Figure 117. Rigid pavement performance curves from Road Test equation, experiment design 1, for $p = 1.5$.**

base thickness is in the range of 3 to 9 in. Data from Design 3, described in Section 3.2.2.2, indicated that sections on 6 in. of subbase gave better average performance than sections with no subbase.

For a particular pavement design and axle load, Eqs. 65 and 66 give values for $\beta$ and $\rho$ that may be substituted in Eq. 61 if $p$ is to be estimated from $W$, or in Eq. 62 if $W$ is to be estimated when $p$ is given. Figures 116 and 117 show how $W$ varies with $D_2$ in Eq. 62 when $p$ is fixed at 2.5 and 1.5, respectively. In each figure there are ten curves, one curve for each test load used in the Road Test.

Figure 118 shows design requirements, computed from Eq. 62 when the final serviceability value is $p = 2.5$, for a range of single and tandem axle loads at three levels of load applications. Similar relationships are shown in Figure 119 for a final serviceability level of 1.5.

Figures 120 and 121 show the correspondence between the individual curves of Figure 116 and performance data from Appendix A, Design 1, for each of the ten traffic lanes. Each point represents the observed number of applications at which a test section had a serviceability level of 2.5. Horizontal deviations of the points from the curves represent prediction errors or residuals when Eq. 62 is used to predict the life of a section (to $p = 2.5$) whose design and load values are specified. Figures 122 and 123 are similar except that the terminal serviceability level is 1.5.

Points shown in Figures 120 through 123 represent only those sections whose serviceability fell to 2.5 or to 1.5. All remaining sections would be represented by points on the right of $W = 1{,}114{,}000$ applications. The number of such sections can be deduced from the fact that at each $D_2$ level there were four test sections in Loop 2 lanes and six test sections in each of the Loop 3 through 6 lanes. Although these sections are not shown, their performance data did influence the developed equations and curves.

The performance data in Appendix A, Design 1, give a minimum of 5 and a maximum of 10 ($p$, log $W$) pairs for each test section. When $p$ is fixed at 3.5, 3.0, 2.5, 2.0 and 1.5 there can be as many as five log $W$ observations, and when log $W$ is fixed at $t = 11$, 22, 33, 44 and 55 index days there can be as many as five observed values for $p$. Corresponding to each observation, log $W$, or $p$, is a calculated value, $\log \hat{W}$ or $\hat{p}$, obtained from the performance relationships (Eqs. 61, 62, 65 and 66). Differences between calculated and observed values are the residuals $\Delta \log \hat{W} = \log W - \log W$ and $\Delta p = \hat{p} - p$. Absolute values of these residuals are summarized in the upper part of Table 47. For each lane and for all lanes, the number of residuals of each type as well as mean ab-

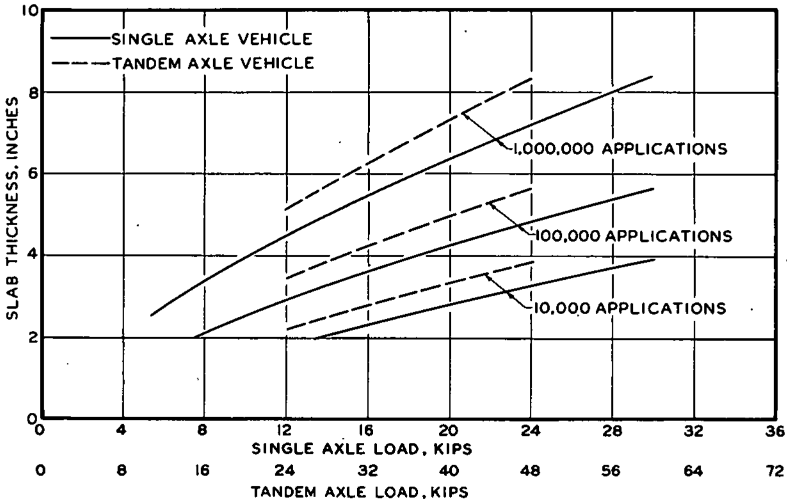

Figure 118. Single-tandem axle load relationship from Road Test equation, experiment design 1, for $p = 2.5$. All curves extrapolated except 1,000,000 applications.

solute residuals are given. The mean absolute residual for log *W* is 0.17 and for *p*, 0.24.

Log *W* residuals are horizontal deviations from the performance equation curves and are thus of special interest. The second part of Table 47 shows a rather low correlation index of 0.16 for the log *W* residual analysis and also gives 0.22 as the root mean square residual. The low correlation index is due in part to the relatively narrow spread in log *W* values. The general nature of the Δ log *W* distribution is indicated by the information that 58 percent and 87 percent of all Δ log *W* are contained, respectively, within bands formed by plus or minus either one or two mean residuals on either side of the performance curves. This distribution supports the statement that the observations, in about nine out of ten cases, agree with the performance curves to within two mean residuals. In other words, there is approximately 90 percent confidence* that log *W* will be found between $\log \hat{W} - 0.34$ and $\log \hat{W} + 0.34$. In terms of the design index, $D_2$, this band corresponds approximately to $\hat{D}_2 \pm 0.11 (\hat{D}_2 + 1)$ where $\hat{D}_2$ is obtained by entering

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* Table 47 includes the root mean square residual so that twice this value can be used to set limits with approximately 95 percent confidence.

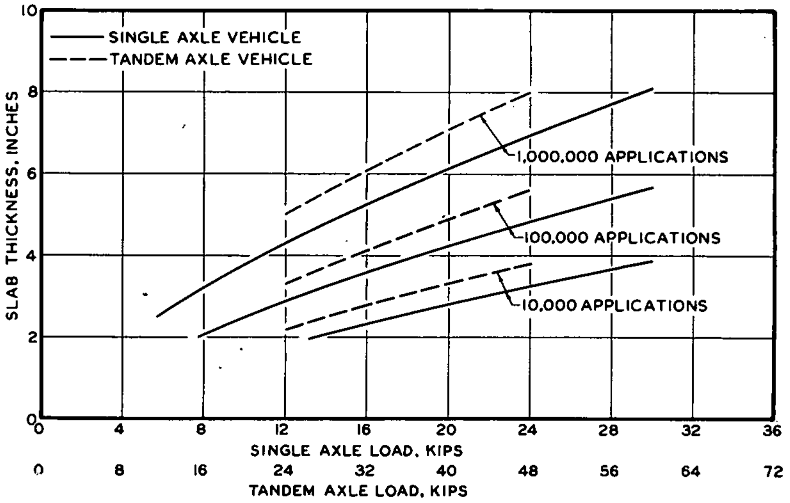

Figure 119. Single-tandem axle load relationship from Road Test equation, experiment design 1, for $p = 1.5$. All curves extrapolated except 1,000,000 applications.

the performance graphs with specified $W$ and reading off $\widehat{D}_2$ on the vertical scale. For the Road Test conditions and range of variables it follows that rigid pavement design requirements are estimated by the performance equations to within about 12 percent of the slab thickness.

The last part of Table 47 summarizes log $W$ and $p$ differences that were observed between replicate test sections. Altogether there were 36 pairs of replicate sections in Design 1, and the mean replicate difference in $p$ and log $W$ is 0.31 and 0.12, respectively.

In six pairs, one replicate was out of test and the other replicate was not at the end of test traffic. The in-test replicate had terminal serviceability above 3.5 in three cases, and above 3.0, 2.5 and 2.0 in the remaining three cases. Replicate differences in these cases were assumed to be at least as large as when the first section went out of test at $p = 1.5$.

For whatever reasons two replicate sections do not show the same performance, it can be expected that the performance data will deviate from any fitted equation. For a particular lane a satisfactory model and fitting procedure should result in residuals that average to be about the same as deviations of replicate observations from their own mean. For two replicates, then, the average estimation error should be about one-half the replicate difference if the fit is to be judged wholly adequate. Since the performance equations were developed across lanes and loops, it is expected that the average residuals will be more than one-half the average replicate difference, but how much greater cannot be determined in the absence of replicate lanes and loops. In the Road Test performance analyses, it has been supposed that a satisfactory model and fit is indicated whenever mean absolute residuals are about equal to replicate mean differences. Table 47 shows this comparison as 0.24 vs 0.31 for $p$ and 0.17 vs 0.12 for log $W$. It is quite possible that other models and fitting procedures may do equally well, and that some will represent better the long-time performance of highways in actual service.

*3.2.2.2 Subbase, Paved Shoulder Experiment.*—This subsection presents the results of comparisons of the performance of sections with and without subbase, and of sections with and without shoulder paving. The subbase was 6 in. in thickness; shoulder paving was a 3-in. layer of asphaltic concrete 6 ft wide. No increase in life resulted from use of paved shoulders. However, the results may have been affected in some cases by damage to the shoulder by test traffic. Sections with subbase had an average life about one-third longer than that of sections without subbase.

TABLE 47

SUMMARY OF PERFORMANCE EQUATION RESIDUALS AND REPLICATE DIFFERENCES

| Loop | Lane | Load | | Number of Sections | $p$ Residuals | | Log $W$ Residuals | |
|---|---|---|---|---|---|---|---|---|
| | | $L_1$ | $L_2$ | | Number | Mean Absolute | Number | Mean Absolute |
| 2 | 1 | 2 | 1 | 22 | 100 | 0.21 | —[1] | —[1] |
| | 2 | 6 | 1 | 22 | 95 | 0.39 | 19 | 0.21 |
| 3 | 1 | 12 | 1 | 28 | 120 | 0.19 | 40 | 0.11 |
| | 2 | 24 | 2 | 28 | 110 | 0.34 | 67 | 0.20 |
| 4 | 2 | 18 | 1 | 28 | 124 | 0.21 | 37 | 0.13 |
| | 2 | 32 | 2 | 28 | 111 | 0.15 | 64 | 0.15 |
| 5 | 1 | 22.4 | 1 | 28 | 127 | 0.20 | 40 | 0.18 |
| | 2 | 40 | 2 | 28 | 122 | 0.21 | 46 | 0.21 |
| 6 | 1 | 30 | 1 | 28 | 134 | 0.30 | 28 | 0.12 |
| | 2 | 48 | 2 | 28 | 131 | 0.23 | 30 | 0.22 |
| All lanes | | | | 268 | 1174 | 0.24 | 371 | 0.17 |

| | | |
|---|---|---|
| Log $W$ residual summary | Correlation index | 0.16 |
| | Root mean square residual | 0.22 |
| | Percent of residuals within one mean absolute residual | 58 |
| | Percent of residuals within two mean absolute residuals | 87 |

| | Number of Replicate Pairs | $p$ Differences | | Log $W$ Differences | |
|---|---|---|---|---|---|
| | | Number | Mean | Number | Mean |
| Replicate differences, all lanes | 36 | 179 | 0.31 | 37 | 0.12 |

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[1] One extreme omitted.

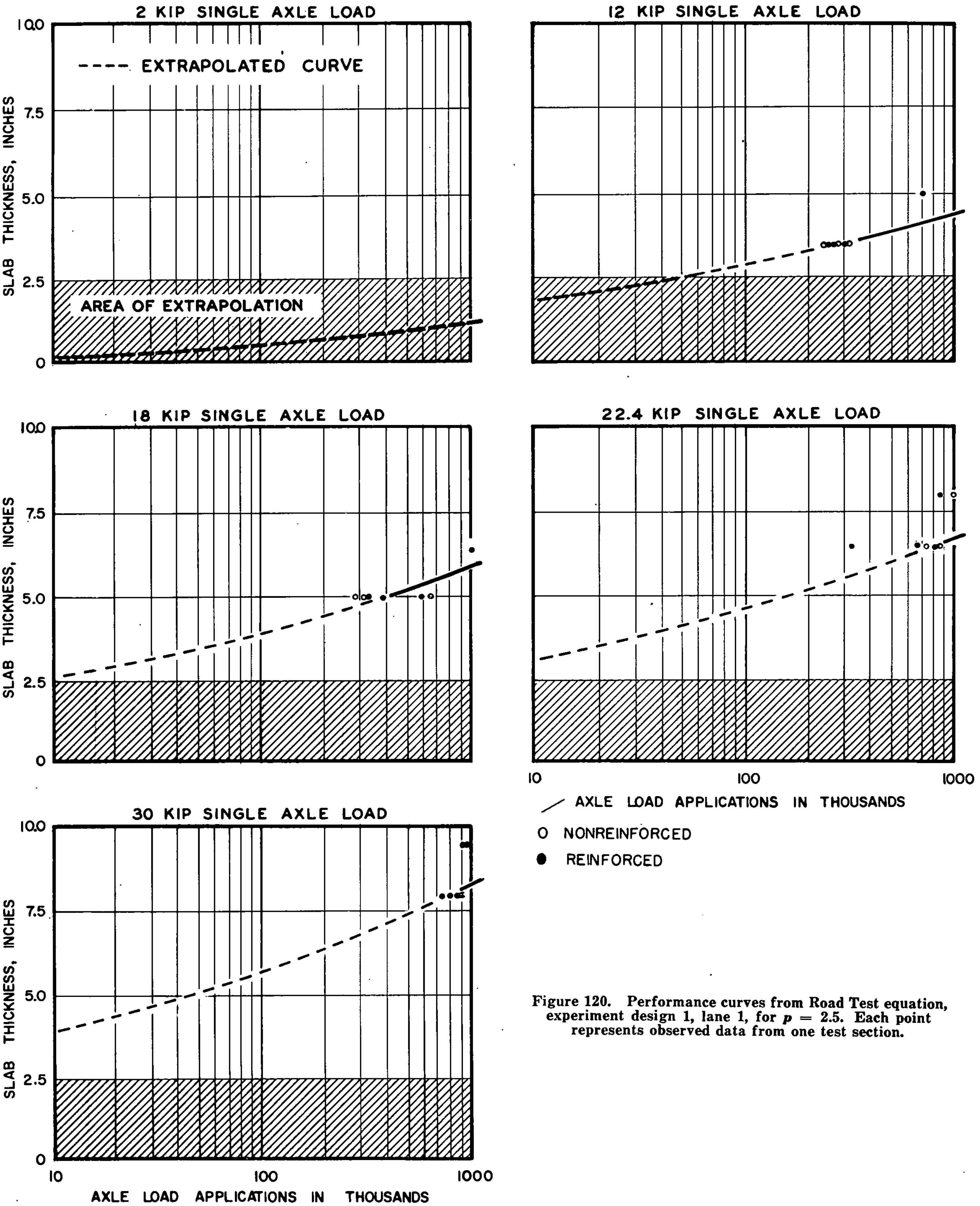


Figure 120. Performance curves from Road Test equation, experiment design 1, lane 1, for $p = 2.5$. Each point represents observed data from one test section.

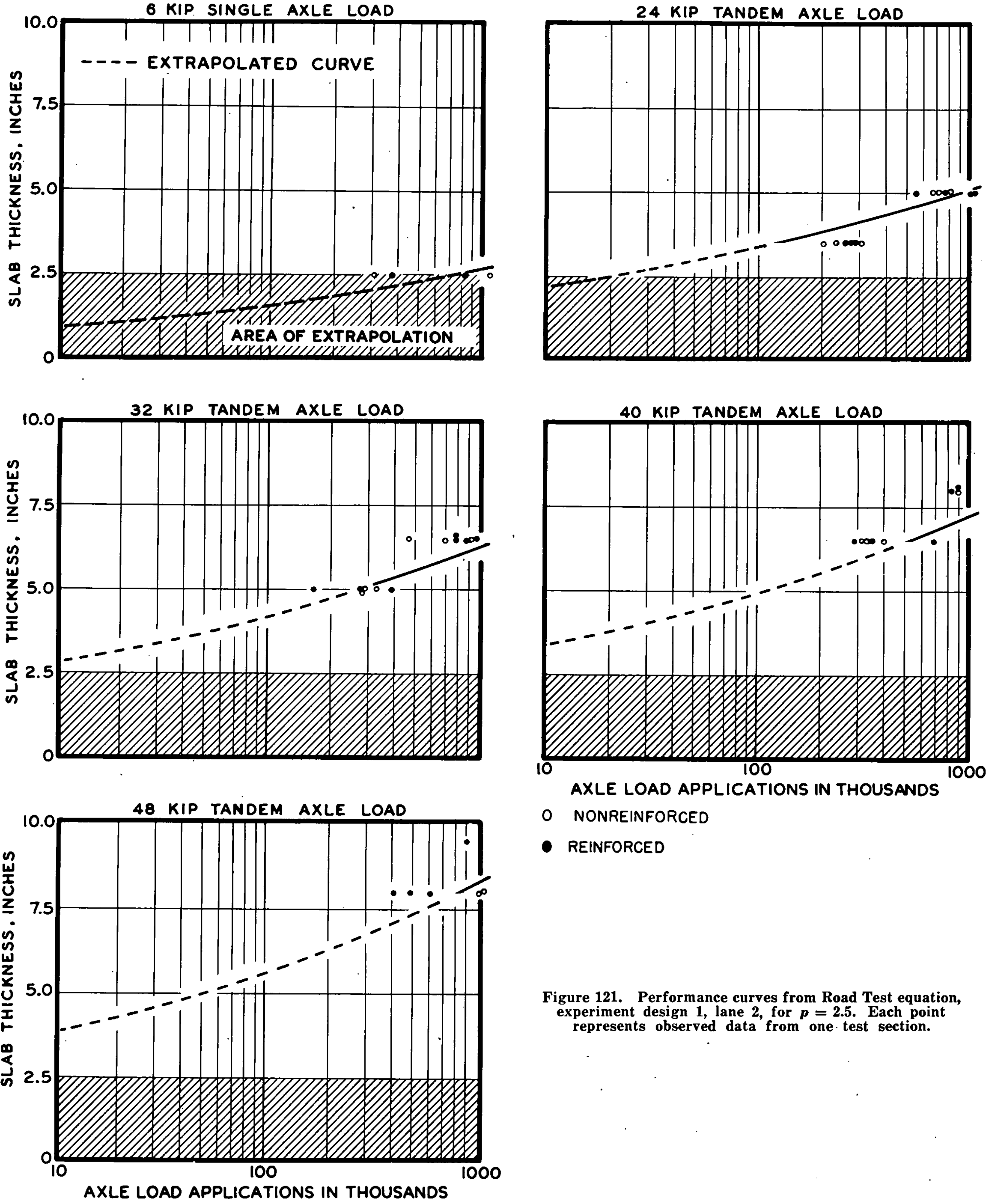


Figure 121. Performance curves from Road Test equation, experiment design 1, lane 2, for $p = 2.5$. Each point represents observed data from one test section.

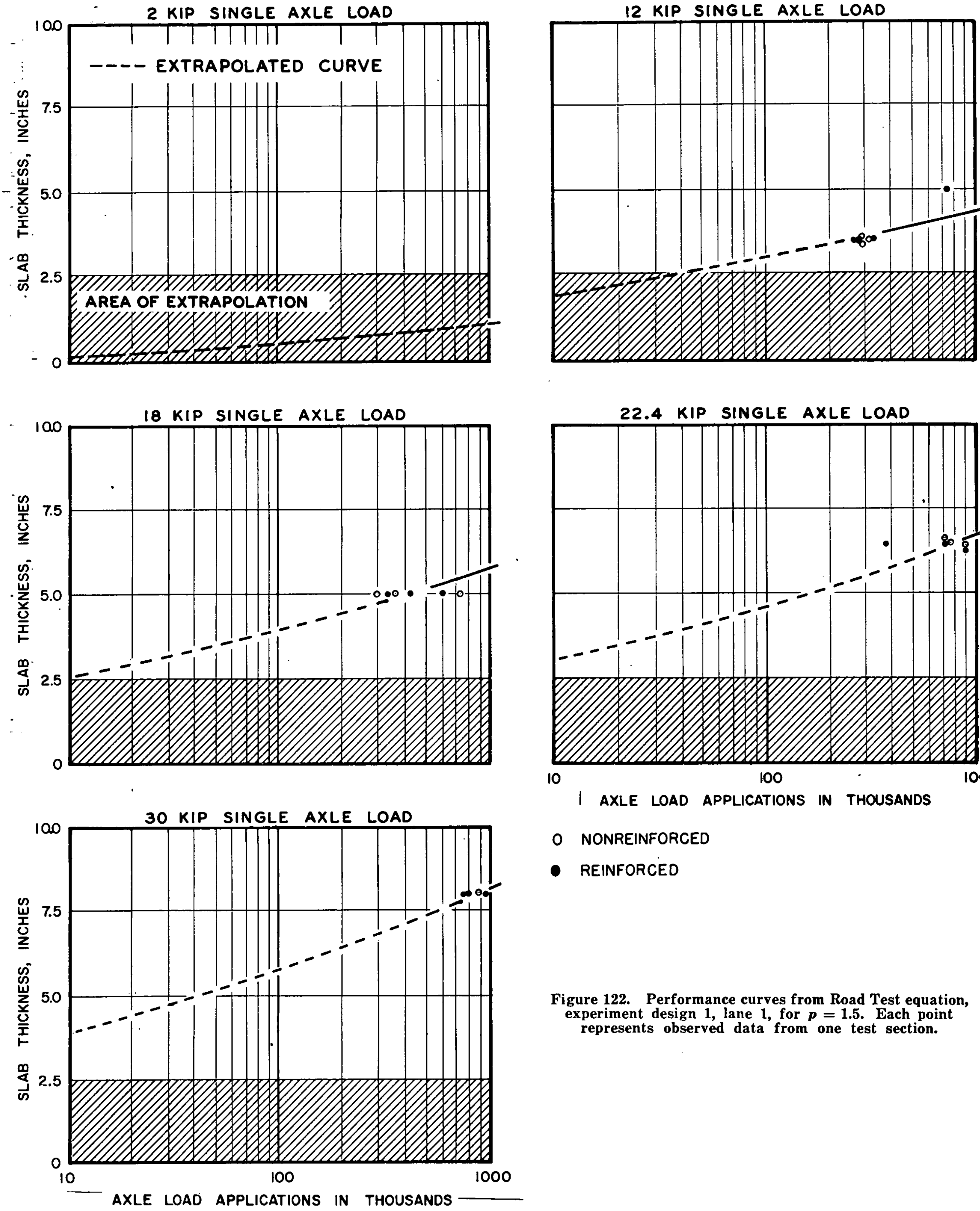


Figure 122. Performance curves from Road Test equation, experiment design 1, lane 1, for $p = 1.5$. Each point represents observed data from one test section.

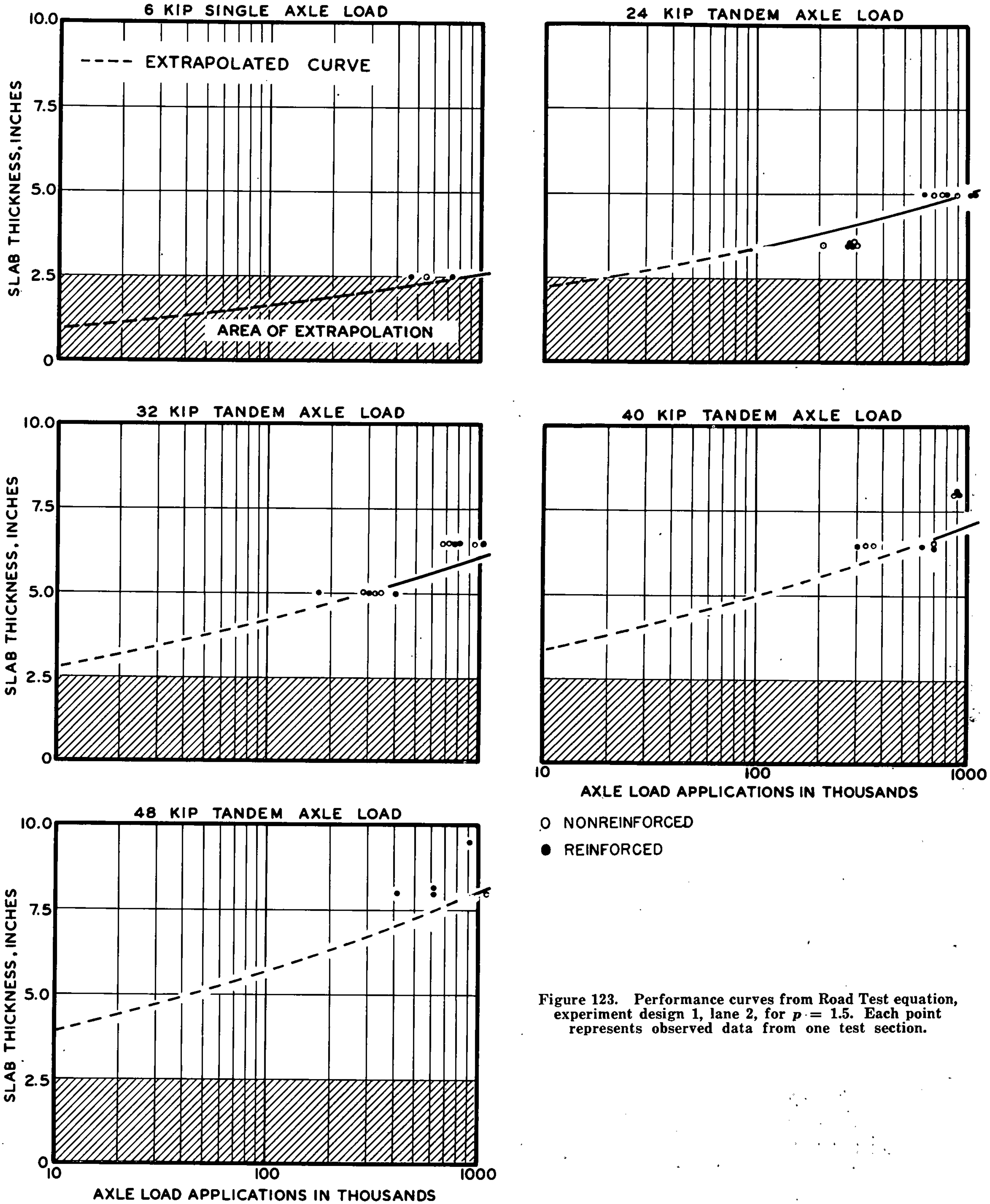


Figure 123. Performance curves from Road Test equation, experiment design 1, lane 2, for $p = 1.5$. Each point represents observed data from one test section.

## TABLE 48

Log $W$ at $p = 2.5$, or $p$ at End of Traffic Test[1]

| Axle Type | Axle Load (kips) | Subbase | Value[2] of Log $W$ or $p$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3.5-In. Slab | | 5.0-In. Slab | | 6.5-In. Slab | | 8.0-In. Slab | | 9.5-In. Slab | | 11.0-In. Slab | |
| | | | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| Single | 12 | No | 5.35 | 5.10 | | | (4.2) | (3.5) | | | | | | |
| | | Yes | 5.45 | 5.47 | | | (4.1) | (4.1) | | | | | | |
| | 18 | No | | | 5.46 | 5.51 | | | (4.2) | (3.6) | | | | |
| | | Yes | | | 5.50 | 5.75 | | | (4.4) | (4.3) | | | | |
| | 22.4 | No | | | | | 5.95 | 5.54 | | | (3.7) | (4.3) | | |
| | | Yes | | | | | 5.93 | 5.94 | | | (3.7) | (4.7) | | |
| | 30 | No | | | | | | | 5.84 | (2.7) | | | (4.2) | (4.2) |
| | | Yes | | | | | | | (3.9) | (3.7) | | | (4.2) | (4.1) |
| Tandem | 24 | No | 5.30 | 5.09 | | | (4.0) | 5.94 | | | | | | |
| | | Yes | 5.31 | 5.40 | | | (4.1) | (4.0) | | | | | | |
| | 32 | No | | | 5.44 | 5.49 | | | (2.4) | 6.00 | | | | |
| | | Yes | | | 5.46 | 5.55 | | | (4.2) | (4.3) | | | | |
| | 40 | No | | | | | 5.83 | 5.46 | | | 5.79 | (4.3) | | |
| | | Yes | | | | | 5.53 | 5.65 | | | (4.0) | (4.5) | | |
| | 48 | No | | | | | | | 5.74 | 5.87 | | | 5.94 | (2.2) |
| | | Yes | | | | | | | (4.1) | 5.85 | | | (4.3) | (4.3) |

[1] Values in parentheses are serviceability ratings, $p$.

[2] No and yes indicate absence or presence of shoulder paving.

The 64 test sections in Design 3 listed in Table 36 comprised an experiment which permitted direct comparisons of the performance of sections (a) without subbase and without paved shoulders, (b) without subbase and with paved shoulders, (c) with subbase and without paved shoulders, and (d) with subbase and with paved shoulders.

Complete performance data for Design 3 sections are in Appendix A. A portion of the data is presented in Table 48. For each section the logarithm of the number of axle applications corresponding to a serviceability level of 2.5 is given if the section fell to that level during the traffic testing, or the final value of *p* is given if the terminal serviceability level of the section exceeded 2.5.

The four comparisons of performance described above may be made within each group of four numbers in the body of Table 48, provided the four numbers represent the same kind of data (log *W* or *p*, but not both). To facilitate making the comparisons, groups which contain data of the same kind have been enclosed in rules. Several reversals of trend are apparent. To determine the average effect of the principal design variables (paved shoulders and subbase) corresponding numbers of the six groups of log *W* data and of the four groups of the serviceability data were averaged and tabulated in Table 49. From significance tests made on the data, it is concluded that paved shoulders did not add to the performance of test sections, while the presence of subbase was, on the average, of benefit. Numerically, the average benefit in increased life (Table 49) was equivalent to 32 percent or about one-third.

The shoulder pavement, consisting of 3 in. of asphaltic concrete, was placed directly on the embankment in the case of those sections without subbase, and on the subbase in the case of the other sections. The shoulder paving was damaged severely by test traffic. Although an effort was made to keep the shoulders in repair, there were instances where rain fell in the interim between damage and maintenance. It is likely that these circumstances had significant influence on the results of the experiment.

### *3.2.3 Structural Deterioration and Deformation*

This section describes elements of pavement deterioration which may have led directly or indirectly to a lowering of the serviceability level and eventual failure of some of the rigid pavement test sections.

Faulting occasionally occurred at cracks, never at transverse joints. (All joints were doweled). There was a tendency for the cracking (per unit of surface area) in reinforced sections with 40-ft panel lengths to exceed that in nonreinforced sections having 15-ft panel lengths. No part of the cracking of pavements in the traffic loops was attributed solely to environmental changes, since no cracks were apparent in the non-traffic loop (Loop 1).

From cracking data, equations were derived from which the number of axle applications associated with any given level of cracking can be computed for a given pavement design and load (see Eqs. 69, 70, 71 and 72). Graphs of the equations for a selected level of cracking are shown in Figure 127.

Longitudinal cracks tended to originate at transverse joints near dowel bars in 2.5-, 3.5- and 5-in. slabs but not in thicker pavements. Pumping of subbase material, including the coarser fractions, was a major factor in the majority of the failures of sections with subbase. Pumping of embankment material was generally confined to those sections constructed without subbase and severe pumping of subbase material was experienced only in the sections with the two thinner slab thicknesses in each loop. The amount of either material pumped through joints and cracks was negligible when compared with the amount ejected along the edge. (See Figure 133.)

*3.2.3.1 Cracking and Faulting.*—Each test section was inspected at least once each week for defects such as cracking, spalling, pop-outs, blowups, and faulting at joints and cracks.

Faulting.—Faulting at cracks sometimes occurred in the later stages of pavement deterioration, but faulting at joints was notably absent throughout the project. One transverse joint faulted seriously, but investigation showed that the joint had been accidentally

TABLE 49

AVERAGED DATA, DESIGN 3

| Average Log *W* at *p* = 2.5 | | | | Average *p* at End of Traffic Test | | | |
|---|---|---|---|---|---|---|---|
| Subbase | Shoulder Paving | | Avg. | Subbase | Shoulder Paving | | Avg. |
| | No | Yes | | | No | Yes | |
| No | 5.55 | 5.36 | 5.46 | No | 4.1 | 3.9 | 4.0 |
| Yes | 5.53 | 5.63 | 5.58 | Yes | 4.1 | 4.3 | 4.2 |
| Avg. | 5.54 | 5.49 | | Avg. | 4.1 | 4.1 | |

sawed at some distance beyond the end of the dowels intended to protect it. Over the 2-yr period of the test there were no other cases of measurable faulting at joints, all of which were doweled (see Table 38 for details of joint construction).

Blowups.—The rigid pavements were constructed without expansion joints except at approaches to the test bridges in Loops 5 and 6. One blowup occurred in Loop 2 at the transverse joint at one end of a structural section with a slab thickness of 2.5 in. At both ends of this section the abutting sections had a slab thickness of 5 in. Two other blowups occurred at transverse joints—one after one-half (12 ft) and the other after three-quarters (18 ft) of the pavement adjacent to the blowup had been removed in the course of maintenance operations.

Classification of Cracks.—Cracks were divided into four classes, depending upon their appearance, as follows: Class 1 included fine cracks not visible under dry surface conditions to a man with good vision standing at a distance of 15 ft. Class 2 cracks were those that could be seen at a distance of 15 ft, but which exhibited only minor spalling such that the opening at the surface was less than ¼ in. Class 3 and 4 cracks were defined in Section 3.2.1. Figure 124 shows cracks of various classifications.

During each weekly survey, maps were pre-

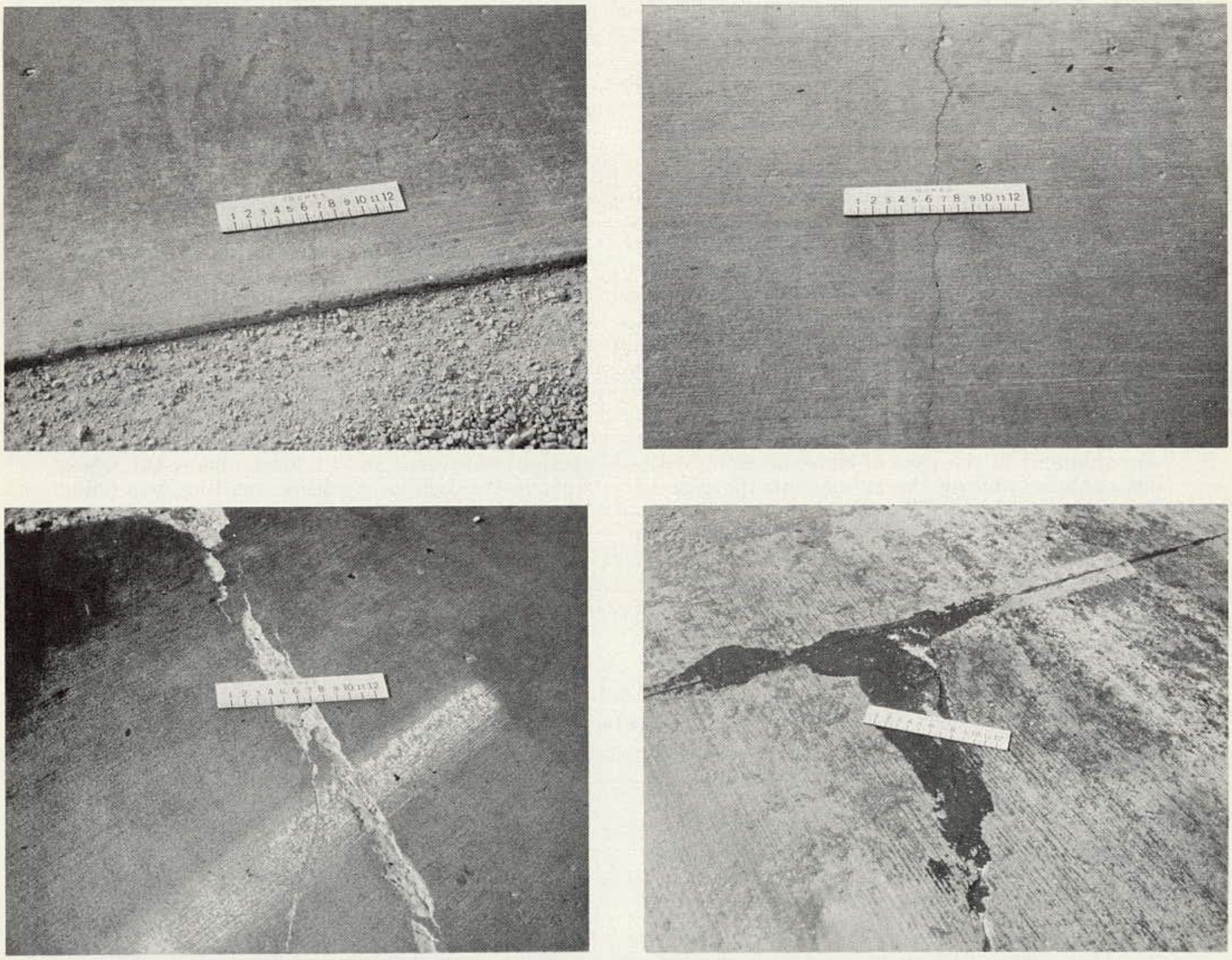


**Figure 124. Examples of the four classes of cracks in rigid pavement at the Road Test: upper left, Class 1; upper right, Class 2; lower left, Class 3; lower right, Class 4. Only Class 3 and 4 cracks entered into the determination of the serviceability index.**

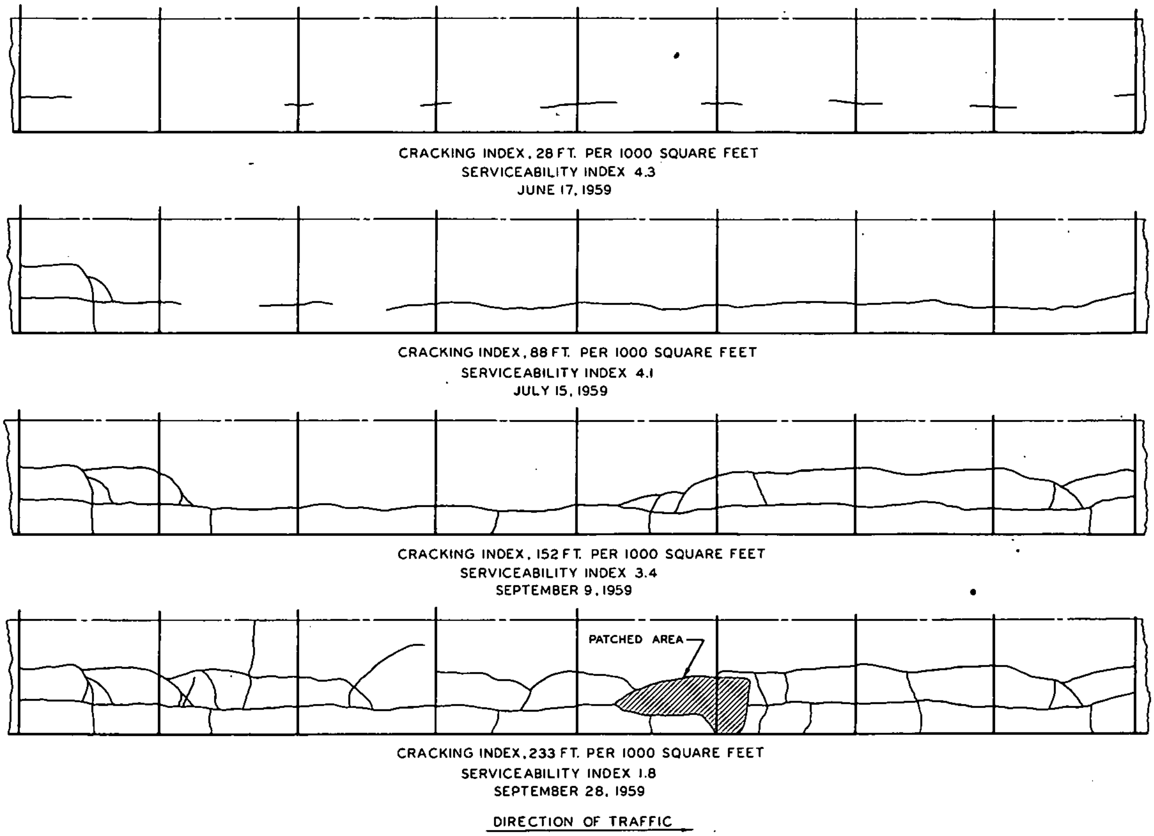


**Figure 125. Progression of cracking in a 3.5-in. nonreinforced section with paved shoulders on 6.0 in. of subbase, 24-kip tandem axle load.**

pared showing the location and classification of each crack, as well as the length of its projection parallel or perpendicular to the centerline of the pavement, whichever projection was greater. Crack lengths in each section were totaled by classes, divided by the area of the pavement, and recorded each index day in units of feet of projected cracks per 1,000 sq ft of pavement surface. These statistics are available in DS 4202 for each test section on each index day for the 2-yr period of traffic testing.

Cracking Index.—In Section 3.2.1 it was stated that only Class 3 and 4 cracking entered into the term, $C$, in the serviceability index from which pavement performance was computed. Another statistic, useful in studies of cracking apart from the pavement serviceability concept, is the total projected length of all cracks, in feet per 1,000 sq ft of pavement area, represented by the symbol, $C'$.* Figures 125 and 126 illustrate the relationship between changes in the value of $C'$ and changes in the general appearance of the pavement as cracking progressed with load applications and age. Different values of $C'$ may occur at about the same serviceability level; for example, when the 3.5-in. pavement of Figure 125 was nearing failure ($p = 1.8$) $C'$ had the value 233, while at $p = 1.5$ the 8-in. pavement of Figure 126 had a cracking index of only 92 (in these figures no attempt has been made to distinguish the various classes of cracking from each other).

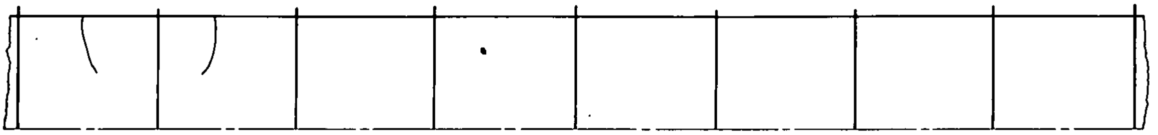
Values of $C'$ determined for each section in Designs 1 and 3 on each index day are available in DS 4202. These data in part are given in Table 50, where $C'$ is given at $W = 1,114,000$ unweighted axle applications for all Design 1 sections that survived the traffic test and at $p = 1.5$ for all sections that failed before the end of the traffic test. Table 51 is similar except that $C'$ is given at a serviceability level of 2.5 (instead of 1.5) for sections that dropped to that level.

The data in Table 50 permitted 27 independent comparisons between reinforced and nonreinforced sections at $p = 1.5$. From Table 51, 29 such comparisons could be made at $p = 2.5$. From either table, the relevant data being the same, 77 comparisons could be made at the end of the traffic testing.

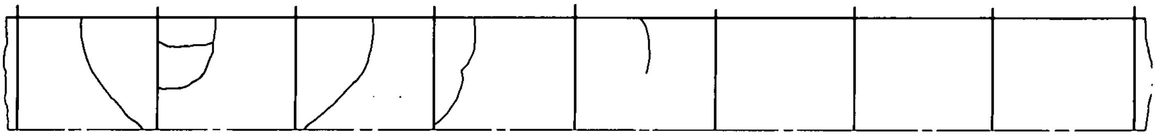
A summary of the results of these three sets of comparisons (each of which included a test of the statistical significance of the difference

---

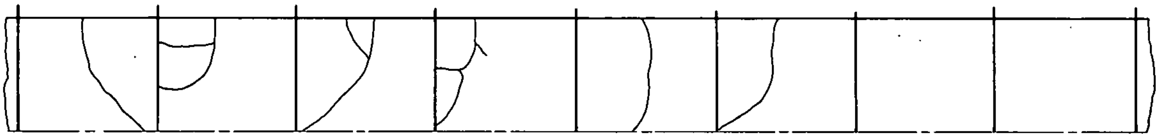
* In arriving at the value of $C'$ for a section that had been patched, the patched area was assigned the cracking equivalent of 1 ft of crack for each square foot of patch. Thus, $C'$ differs from the term $C + P$ occurring in the serviceability index, only in that $C'$ includes all classes of cracks while $C + P$ includes only Class 3 and 4 cracks.



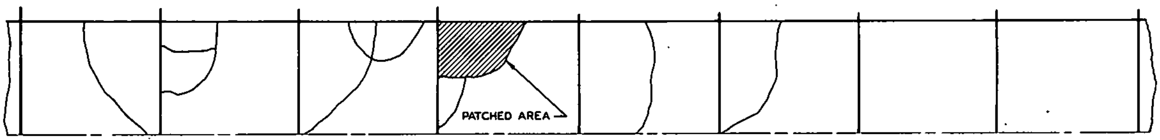
CRACKING INDEX, 9 FT. PER 1000 SQUARE FEET
SERVICEABILITY INDEX 4.0
MAY 23, 1960



CRACKING INDEX, 42 FT. PER 1000 SQUARE FEET
SERVICEABILITY INDEX 3.2
JUNE 16, 1960



CRACKING INDEX, 62 FT. PER 1000 SQUARE FEET
SERVICEABILITY INDEX 2.9
JULY 25, 1960



CRACKING INDEX, 92 FT. PER 1000 SQUARE FEET
SERVICEABILITY INDEX 1.5
AUGUST 1, 1960

DIRECTION OF TRAFFIC →

**Figure 126. Progression of cracking in an 8.0-in. nonreinforced section on 3.0 in. of subbase, 30-kip single axle load.**

in cracking between reinforced and nonreinforced sections) is given in Table 52. From the average data, the cracking in the reinforced sections with 40-ft panel lengths exceeded that in the nonreinforced sections with 15-ft panel lengths by 20 to 24 ft per 1000 sq ft of pavement area. However, the difference was not significant at $p = 1.5$, and was significant only at the 10 percent level at $p = 2.5$. At the end of the traffic test, when the average serviceability level of the 154 sections involved in the comparisons was 4.15, the average difference in cracking was highly significant, although the average values of $C'$ were small (30 and 6).

The observation that cracking in surviving reinforced sections was frequently greater than in nonreinforced sections (other factors being equal) appears to confirm the usual assumption made by concrete pavement engineers that tensile stresses occurring during periods of decreasing temperature tend to increase with panel length. However, no cracking occurred in the Loop 1 pavements not subjected to traffic (see Section 3.5.6.); thus, none of the cracks appearing in the traffic loops can be attributed solely to environment (temperature changes, moisture changes, subgrade restraint, etc.).

The average value of $C'$ at $p = 1.5$ for the 67 failed sections in Design 1 (see Table 50) was 168, and the standard deviation of individual values of $C'$ about their mean was 71. The average value of $C'$ at $p = 2.5$ for the 73 sections which dropped to that level (Table 51) was 103, and the standard deviation was 42.

From the average values of $C'$ given in the preceding paragraph and in Table 52, it was concluded that a value of $C' = 100$ represented a substantial amount of structural deterioration in most cases, and that the relationships between design (including reinforcing), load and load applications at this level of the cracking index would constitute a useful supplement to the performance curves in Figures 116 and 117.

Analysis of Cracking Index.—Plots of $C'$ versus $W$ for individual sections suggested the use of the following model for the analysis of the cracking index:

$$C' = \frac{A_0 \, L_1^{A_1} \, W^2}{D_2^{A_2}} \tag{67}$$

in which, $W$ is unweighted axle applications, $A_0$, $A_1$ and $A_2$ are a set of constants to be determined from analysis of the data given in Table 50, and the other symbols are as previously defined.

The data given in Table 50, together with the corresponding $W$ data given in Appendix A, were used for determining four sets of the constants $A_0$, $A_1$ and $A_2$, in accordance with the following procedure:

## TABLE 50

CRACKING INDEX, $C'$, AT 1,114,000 AXLE APPLICATIONS OR WHEN $p = 1.5$[1], EXPERIMENT DESIGN 1[2]

| Loop | Axle Load (kips) | Subbase Thickness (in.) | Cracking Index, $C'$ | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2.5-In. Surface | | 3.5-In. Surface | | 5.0-In. Surface | | 6.5-In. Surface | | 8.0-In. Surface | | 9.5-In. Surface | | 11.0-In. Surface | | 12.5-In. Surface | |
| | | | R | N | R | N | R | N | R | N | R | N | R | N | R | N | R | N |
| 2 | 2S | 0 | 4 | 0 | 0 | 1 | 1 | 0 | | | | | | | | | | |
| | | 3 | | | 0 | | | 0 | | | | | | | | | | |
| | | | 26 | 2 | 3 | 1 | 1 | 11 | | | | | | | | | | |
| | | 6 | 13 | 3 | 1 | 0 | 4 | 0 | | | | | | | | | | |
| | 6S | 0 | 129* | 183* | 20 | 60 | 0 | 0 | | | | | | | | | | |
| | | 3 | | | 15 | | | 0 | | | | | | | | | | |
| | | | 118* | 115 | 7 | 2 | 1 | 9 | | | | | | | | | | |
| | | 6 | 63 | 115 | 36 | 8 | 4 | 0 | | | | | | | | | | |
| 3 | 12S | 3 | | | | | 51 | | | 1 | | | | | | | | |
| | | | | | 343* | 258* | 60 | 8 | 27 | 1 | 34 | 0 | | | | | | |
| | | 6 | | | | | | 8 | 23 | | | | | | | | | |
| | | | | | 286* | 256* | 211* | 16 | 35 | 1 | 35 | 1 | | | | | | |
| | | 9 | | | 252* | 235* | 48 | 31 | 31 | 0 | 28 | 0 | | | | | | |
| | 24T | 3 | | | | | 126* | | | 0 | | | | | | | | |
| | | | | | 171* | 216* | 169* | 67* | 46 | 0 | 25 | 1 | | | | | | |
| | | 6 | | | | | | 56 | 25 | | | | | | | | | |
| | | | | | 194* | 373* | 143* | 144* | 43 | 0 | 35 | 0 | | | | | | |
| | | 9 | | | 212* | 218* | 152* | 155* | 38 | 0 | 23 | 0 | | | | | | |
| 4 | 18S | 3 | | | | | | | 63 | | | 1 | | | | | | |
| | | | | | | | 178* | 64* | 71 | 8 | 38 | 0 | 39 | 1 | | | | |
| | | 6 | | | | | | | | 0 | 36 | | | | | | | |
| | | | | | | | 112* | 116* | 80 | 0 | 52 | 0 | 25 | 1 | | | | |
| | | 9 | | | | | 77* | 162* | 145 | 26 | 46 | 0 | 29 | 1 | | | | |
| | 32T | 3 | | | | | | | 132 | | | 0 | | | | | | |
| | | | | | | | 250* | 119* | 149* | 154* | 37 | 1 | 37 | 0 | | | | |
| | | 6 | | | | | | | | 21 | 44 | 1 | | | | | | |
| | | | | | | | 391* | 126* | 171* | 155* | 61 | | 33 | 1 | | | | |
| | | 9 | | | | | 131* | 205* | 173* | 193* | 45 | 0 | 30 | 0 | | | | |
| 5 | 22.4S | 3 | | | | | | | | | 150* | | | 0 | | | | |
| | | | | | | | | | 195* | 114* | 30 | 0 | 38 | 0 | 4 | 10 | | |
| | | 6 | | | | | | | | | | 0 | 17 | | | | | |
| | | | | | | | | | 184* | 189* | 47 | 9 | 15 | 42 | 8 | 0 | | |
| | | 9 | | | | | | | 100* | 117* | 44 | 88* | 18 | 1 | 0 | 0 | | |
| | 40T | 3 | | | | | | | | | 179* | | | 0 | | | | |
| | | | | | | | | | 153* | 122* | 34 | 4 | 42 | 4 | 19 | 2 | | |
| | | 6 | | | | | | | | | | 24 | 38 | | | | | |
| | | | | | | | | | 293* | 123* | 157* | 9 | 24 | 17 | 13 | 0 | | |
| | | 9 | | | | | | | 209* | 105* | 82 | 98* | 50 | 19 | 10 | 0 | | |
| 6 | 30S | 3 | | | | | | | | | | | 6 | | | 0 | | |
| | | | | | | | | | | | 93* | 92* | 200 | 28 | 15 | 0 | 4 | 9 |
| | | 6 | | | | | | | | | | | | 4 | 33 | | | |
| | | | | | | | | | | | 126* | 29 | 44 | 1 | 31 | 0 | 21 | 1 |
| | | 9 | | | | | | | | | 246* | 12 | 164 | 0 | 22 | 0 | 0 | 0 |
| | 48T | 3 | | | | | | | | | | | 19 | | | 0 | | |
| | | | | | | | | | | | 195* | 68 | 41 | 30 | 25 | 0 | 8 | 8 |
| | | 6 | | | | | | | | | | | | 9 | 41 | | | |
| | | | | | | | | | | | 74* | 0 | 66 | 0 | 33 | 0 | 26 | 3 |
| | | 9 | | | | | | | | | 58* | 73* | 163* | 2 | 56 | 0 | 11 | 0 |

[1] Values with asterisk are for $p = 1.5$.

[2] R = reinforced; N = nonreinforced.

## TABLE 51

### CRACKING INDEX, $C'$, AT END OF TRAFFIC TEST OR WHEN $p = 2.5$[1], EXPERIMENT DESIGN 1[2]

| Loop | Axle Load (kips) | Subbase Thickness (in.) | Cracking Index, $C'$ | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2.5-In. Surface | | 3.5-In. Surface | | 5.0-In. Surface | | 6.5-In. Surface | | 8.0-In. Surface | | 9.5-In. Surface | | 11.0-In. Surface | | 12.5-In. Surface | |
| | | | R | N | R | N | R | N | R | N | R | N | R | N | R | N | R | N |
| 2 | 2S | 0 | 4 | 0 | 0 | 1 | 1 | 0 | | | | | | | | | | |
| | | 3 | | | 0 | | | 0 | | | | | | | | | | |
| | | | 26 | 2 | 3 | 1 | 1 | 11 | | | | | | | | | | |
| | | 6 | 13 | 3 | 1 | 0 | 4 | 0 | | | | | | | | | | |
| | 6S | 0 | 106* | 52* | 20 | 60 | 0 | 0 | | | | | | | | | | |
| | | 3 | | | 15 | | | 0 | | | | | | | | | | |
| | | | 109* | 112* | 7 | 2 | 1 | 9 | | | | | | | | | | |
| | | 6 | 63 | 115 | 36 | 8 | 4 | 0 | | | | | | | | | | |
| 3 | 12S | 3 | | | | | 51 | | | 1 | | | | | | | | |
| | | | | | 218* | 160* | 60 | 8 | 27 | 1 | 34 | 0 | | | | | | |
| | | 6 | | | | | | 8 | 23 | | | | | | | | | |
| | | | | | 172* | 195* | 115* | 16 | 35 | 1 | 35 | 1 | | | | | | |
| | | 9 | | | 140* | 128* | 48 | 31 | 31 | 0 | 28 | 0 | | | | | | |
| | 24T | 3 | | | | | 97* | | | 0 | | | | | | | | |
| | | | | | 121* | 161* | 145* | 62* | 46 | 0 | 25 | 1 | | | | | | |
| | | 6 | | | | | | 56 | 25 | | | | | | | | | |
| | | | | | 96* | 217* | 113* | 60* | 43 | 0 | 35 | 0 | | | | | | |
| | | 9 | | | 118* | 107* | 96* | 54* | 38 | 0 | 23 | 0 | | | | | | |
| 4 | 18S | 3 | | | | | | | 63 | | | 1 | | | | | | |
| | | | | | | | 92* | 50* | 71 | 8 | 38 | 0 | 39 | 1 | | | | |
| | | 6 | | | | | | | | 0 | 36 | | | | | | | |
| | | | | | | | 112* | 82* | 80 | 0 | 52 | 0 | 25 | 1 | | | | |
| | | 9 | | | | | 64* | 76* | 108* | 26 | 46 | 0 | 29 | 1 | | | | |
| | 32T | 3 | | | | | | | 112* | | | 0 | | | | | | |
| | | | | | | | 163* | 88* | 93* | 125* | 37 | 1 | 37 | 0 | | | | |
| | | 6 | | | | | | | | 21 | 44 | | | | | | | |
| | | | | | | | 47* | 122* | 98* | 84* | 61 | 1 | 33 | 1 | | | | |
| | | 9 | | | | | 90* | 147* | 138* | 98* | 45 | 0 | 30 | 0 | | | | |
| 5 | 22.4S | 3 | | | | | | | | | 98* | | | 0 | | | | |
| | | | | | | | | | 121* | 53* | 30 | 0 | 38 | 0 | 4 | 10 | | |
| | | 6 | | | | | | | | | | 0 | 17 | | | | | |
| | | | | | | | | | 99* | 99* | 47 | 9 | 15 | 42 | 8 | 0 | | |
| | | 9 | | | | | | | 58* | 73* | 44 | 42* | 18 | 1 | 0 | 0 | | |
| | 40T | 3 | | | | | | | | | 105* | | | 0 | | | | |
| | | | | | | | | | 115* | 34* | 34 | 4 | 42 | 4 | 19 | 2 | | |
| | | 6 | | | | | | | | | | 24 | 38 | | | | | |
| | | | | | | | | | 179* | 22* | 113* | 9 | 24 | 17 | 13 | 0 | | |
| | | 9 | | | | | | | 188* | 83* | 82 | 54* | 50 | 19 | 10 | 0 | | |
| 6 | 30S | 3 | | | | | | | | | | | 6 | | | 0 | | |
| | | | | | | | | | | | 93* | 65* | 133* | 28 | 15 | 0 | 4 | 9 |
| | | 6 | | | | | | | | | | | | 4 | 33 | | | |
| | | | | | | | | | | | 64* | 29 | 44 | 1 | 31 | 0 | 21 | 1 |
| | | 9 | | | | | | | | | 135* | 12 | 105* | 0 | 22 | 0 | 0 | 0 |
| | 48T | 3 | | | | | | | | | | | 19 | | | 0 | | |
| | | | | | | | | | | | 110* | 55* | 41 | 30 | 25 | 0 | 8 | 8 |
| | | 6 | | | | | | | | | | | | 9 | 41 | | | |
| | | | | | | | | | | | 74* | 0 | 66 | 0 | 33 | 0 | 26 | 3 |
| | | 9 | | | | | | | | | 55* | 62* | 96* | 2 | 56 | 0 | 11 | 0 |

---

[1] Values with asterisk are for $p = 2.5$.
[2] R = reinforced; N = nonreinforced.

(a) Eq. 67 was transformed as follows:

$$\log \frac{C'}{W^2} = \log A_0 + A_1 \log L_1 - A_2 \log D_2 \quad (68)$$

(b) $\frac{C'}{W^2}$ was computed for each value of $C'$ shown in Table 50, and then averaged over subbase thickness, since there was no consistent trend of $C'$ with subbase thickness. If the average so obtained was zero (*i.e.*, no cracking in any of the sections), the average was not used in the analysis since the logarithm does not exist.

(c) Data from the thickest pavements in each loop were not used in the analysis. (This rule was also followed in the analysis of performance data, see Section 3.2.2.1.)

A set of the constants $A_0$, $A_1$ and $A_2$ was determined from the data corresponding to each of the following combinations of the load variable, $L_2$ (axle type), and the design variable, $D_1$ (reinforcing):

(1) Single axle vehicles, nonreinforced pavement;

(2) Single axle vehicles, reinforced pavement;

(3) Tandem axle vehicles, nonreinforced pavement; and

(4) Tandem axle vehicles, reinforced pavement.

The resulting equations, together with the average absolute error per observation for each, are given in the following in a form suitable for computing log $W$ when $C'$, $D_2$ and $L_1$ are given:

*For single axle vehicles on nonreinforced pavement:*

$$\log W = 4.70 + 0.5 \log C' - 2.62 \log L_1 + 4.84 \log D_2 \pm 0.26 \quad (69)$$

*For single axle vehicles on reinforced pavement:*

$$\log W = 4.95 + 0.5 \log C' - 2.30 \log L_1 + 3.57 \log D_2 \pm 0.17 \quad (70)$$

*For tandem axle vehicles on nonreinforced pavement:*

$$\log W = 6.61 + 0.5 \log C' - 4.38 \log L_1 + 6.33 \log D_2 \pm 0.24 \quad (71)$$

*For tandem axle vehicles on reinforced pavement:*

$$\log W = 6.37 + 0.5 \log C' - 3.13 \log L_1 + 3.96 \log D_2 \pm 0.11 \quad (72)$$

If the curves for tandem axle vehicles on nonreinforced pavement for $C' = 100$ (Fig. 127) are compared with the tandem axle curves of Figures 117 and 118, rather close agreement is found. However, other comparisons of the performance with the cracking index equations show varying degrees of divergence between the two. A difference is to be expected since the serviceability index is heavily weighted by the roughness of the pavement while the cracking index depends solely on the amount of cracking and patching. In addition, analytical procedures were not the same in the two analyses.

Longitudinal Cracks at Transverse Joints.—In the course of the weekly crack surveys, the points at which longitudinal cracks intersected transverse joints were recorded in an effort to determine whether there was a tendency for such cracks to appear more frequently at one location than another. Figure 128 shows histograms showing the frequency with which longitudinal cracks appeared within each 6-in. interval of transverse joint. These graphs represent only failed sections of Designs 1 and 3; and, of those, only the thinnest pavement sections in each loop. To permit comparison between sections having 15-ft transverse joint spacing with those having 40-ft spacing, the number of cracks actually observed has been converted to the average number per panel. The data are further summarized in Table 53, which shows the average number of cracks per panel without regard to the location of the crack-joint intersection.

Figure 128 shows that there was a pronounced tendency in the 2.5-, 3.5- and 5-in.

TABLE 52

COMPARISON OF CRACKING INDEX, $C'$, FOR REINFORCED AND NONREINFORCED SECTIONS

| Item | Number of Pairs of Sections | Number of Cases | | Average $C'$ (ft/1,000 sq ft) | | |
|---|---|---|---|---|---|---|
| | | $C'$ Reinf. $\geq C'$ Nonreinf. | $C'$ Reinf. $< C'$ Nonreinf. | Reinf. Sections | Nonreinf. Sections | Diff. |
| Comparison at $p = 1.5$ | 27 | 13 | 14 | 182 | 161 | 21[1] |
| Comparison at $p = 2.5$ | 29 | 19 | 10 | 114 | 94 | 20[2] |
| Comparison at $W = 1,114,000$[3] | 77 | 68 | 9 | 30 | 6 | 24[4] |

[1] Not significant.

[2] Significant at 10 percent level.

[3] Average $p = 4.15$.

[4] Significant at 1 percent level.

TABLE 53

NUMBER OF LONGITUDINAL CRACKS IN ENDS OF PANELS IN FAILED SECTIONS[1], EXPERIMENT DESIGNS 1 AND 3[2]

| Loop | Slab Thickness (in.) | Panels Observed (no.) | | Average Cracks per Panel (no.) | |
|---|---|---|---|---|---|
| | | Nonreinf. | Reinf. | Nonreinf. | Reinf. |
| 2 | 2.5 | 8 | 12 | 0.9 | 1.7 |
| 3 | 3.5 | 80 | 60 | 1.8 | 3.3 |
| 4 | 5.0 | 80 | 60 | 0.9 | 1.6 |
| 5 | 6.5 | 80 | 60 | 1.1 | 0.6 |
| 6 | 8.0 | 32 | 48 | 0.5 | 0.7 |
| Avg. | | | | 1.0 | 1.6 |

[1] Only sections at lowest level of slab thickness in each loop are included.

[2] Reinforced panels 40 ft; nonreinforced, 15 ft long.

pavements for longitudinal cracks to appear in the outer wheelpath within 3 in. of the third or fourth dowel located 2.5 and 3.5 ft from the pavement edge. On the other hand, this tendency was reduced or absent in the case of the 6.5- and 8-in. pavements. Table 53 shows that the 40-ft panels tended to crack at transverse joints more often than the 15-ft panels.

First Crack in Failed Area.—A study was made of the crack patterns for failed sections to determine (a) the particular area in each section which first required maintenance; (b) the type of crack (longitudinal or transverse) which first appeared in that area; and (c) the point on the transverse joint where the crack originated, if a longitudinal crack, or the point of origin on the pavement edge, if a transverse crack.

Figure 129 shows that among the 32 sections where the first crack in the failed area was longitudinal, the crack in 81 percent of the cases (26 sections) originated within 3 in. of a dowel. Figure 130 indicates that where the first crack in the failed area was transverse, (as was the case in 61 sections), failure usually began with a crack originating at a point on the edge of the pavement at least 5 ft from the transverse joint.

First Panel to Fail.—Changes in pavement design occurred at short intervals in the rigid pavement tangents. It was considered possible that these frequent discontinuities had some effect on the performance of the test sections. Such an effect, if present, would probably be manifested by a different proportion of first failures in panels situated at or near the ends of the sections than would occur by chance alone. To test this hypothesis, data from the study of failed areas were used to determine the frequency with which each panel in the failed sections was the first to require maintenance (Fig. 131).

From Figure 131 it appears that the frequency of early failure in the first 45 ft (*i.e.*, in one or another of the first three panels) traversed by traffic on nonreinforced sections was definitely greater than in the last 75 ft. But it is also indicated that in the reinforced sections early failures were fairly evenly distributed or at the most tended to be more frequent in the last half of the 240-ft sections. An attempt was made to find an explanation

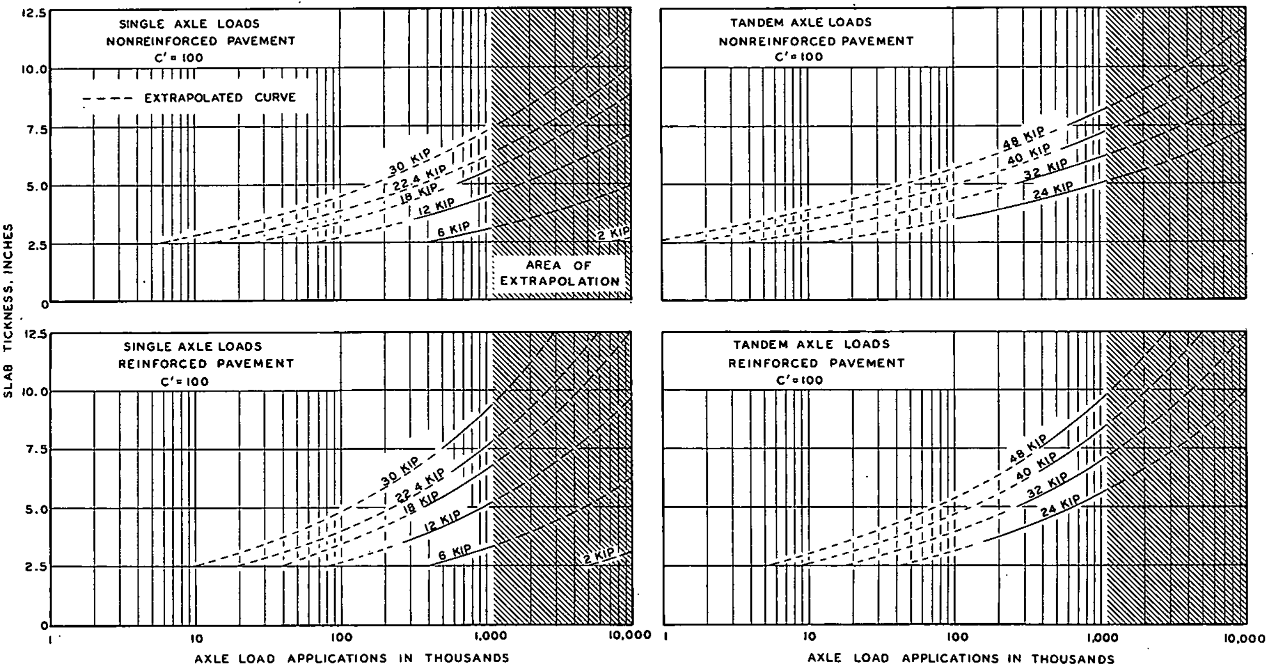


Figure 127. Graphs of equations for cracking index.

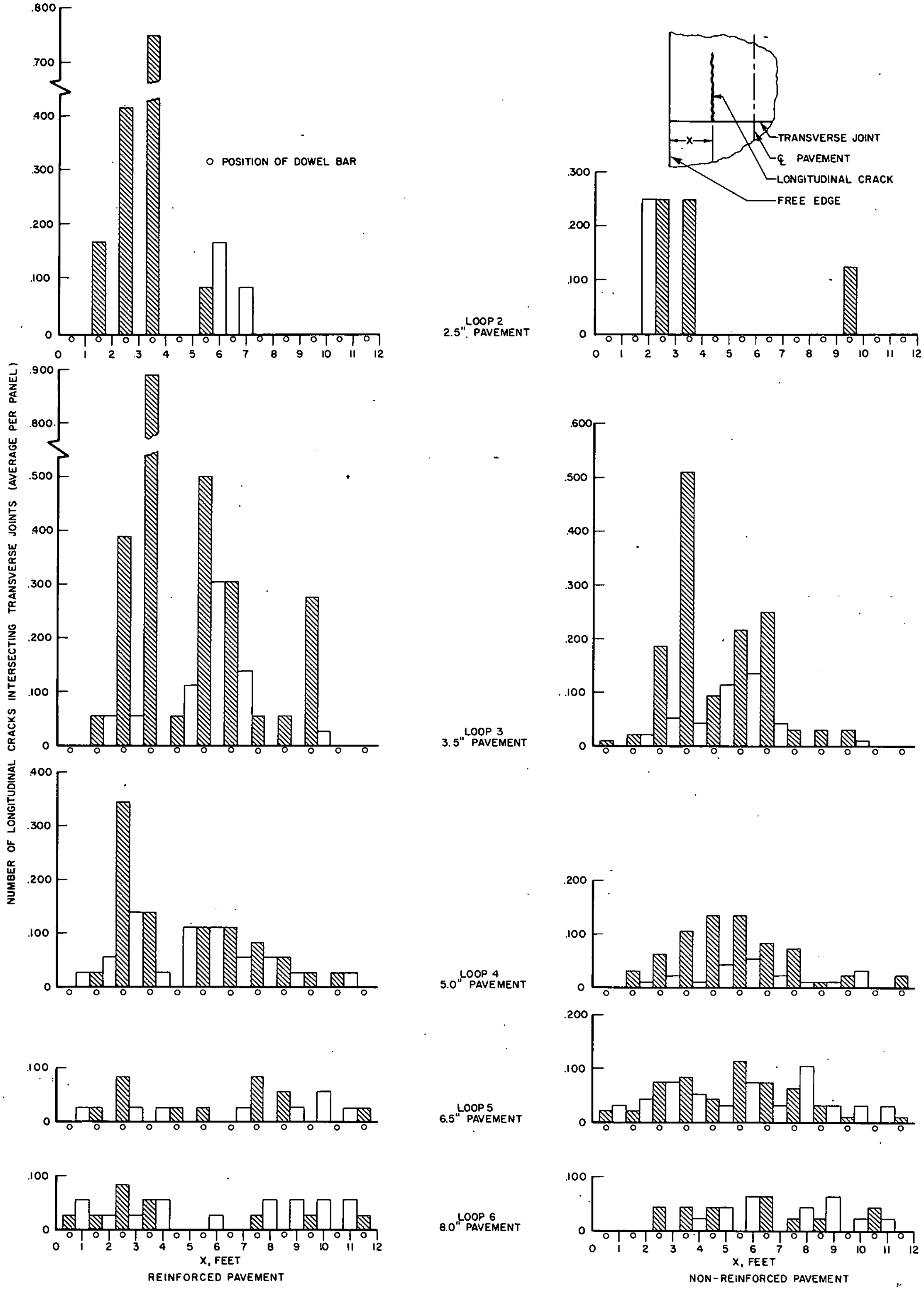


Figure 128. Summary of longitudinal cracks intersecting transverse joints of failed sections at time of removal from test. Data from thinnest sections of each loop, Designs 1 and 3. Shaded bars represent cracks intersecting a joint within 3 in. of a point directly above a dowel bar.

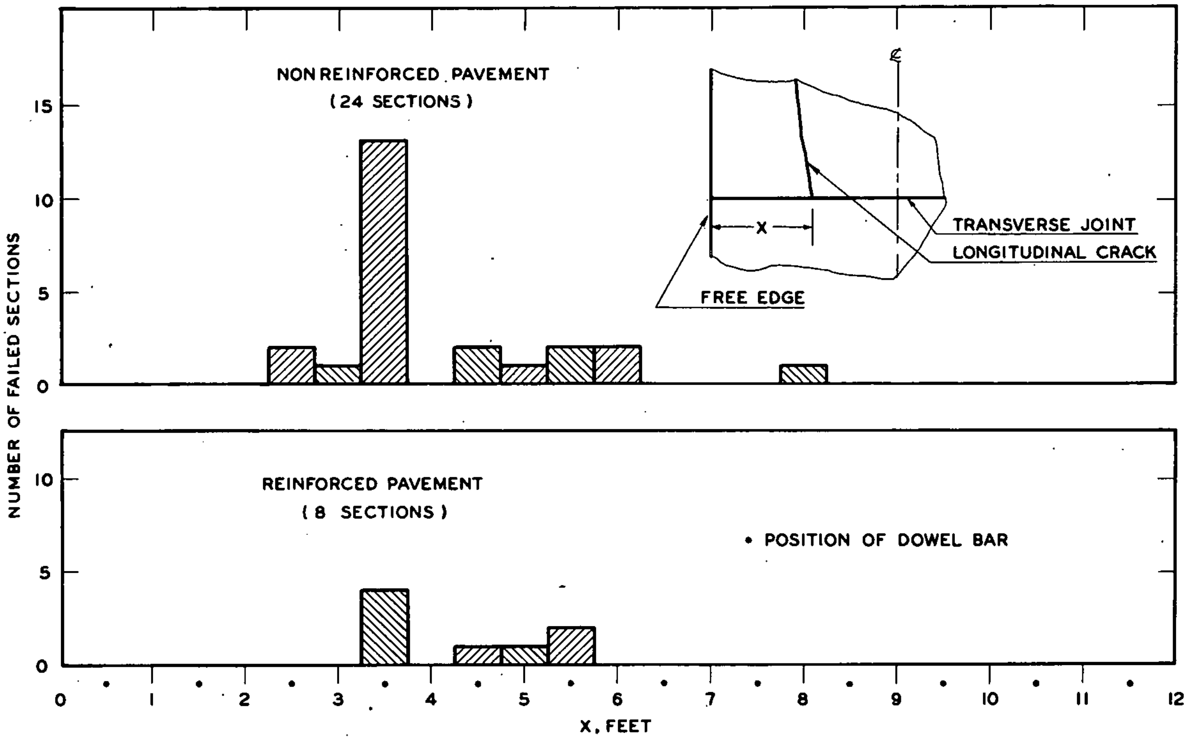


Figure 129. Summary of position of first crack in failed area of 32 failed sections where first crack was longitudinal, Experiment Designs 1 and 3.

for the particular distributions but without success.

Distribution of Cracking in Failed Sections.—In the upper left-hand graph of Figure 132 average values of the cracking index, $C'$, at $p = 1.5$ are shown by panels for the group of nonreinforced sections, Designs 1 and 3, that suffered early failure in panel No. 1. The remaining graphs on the left in the figure give similar distributions for nonreinforced sections where early maintenance was required in the second panel, the third panel and so forth. The graphs on the right present similar data for reinforced sections.*

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* In cases where no patches were applied to a section, first failure was determined by other means. Occasionally two panels were damaged simultaneously, and in these cases panel values of $C'$ were used in more than one graph in Figure 132.

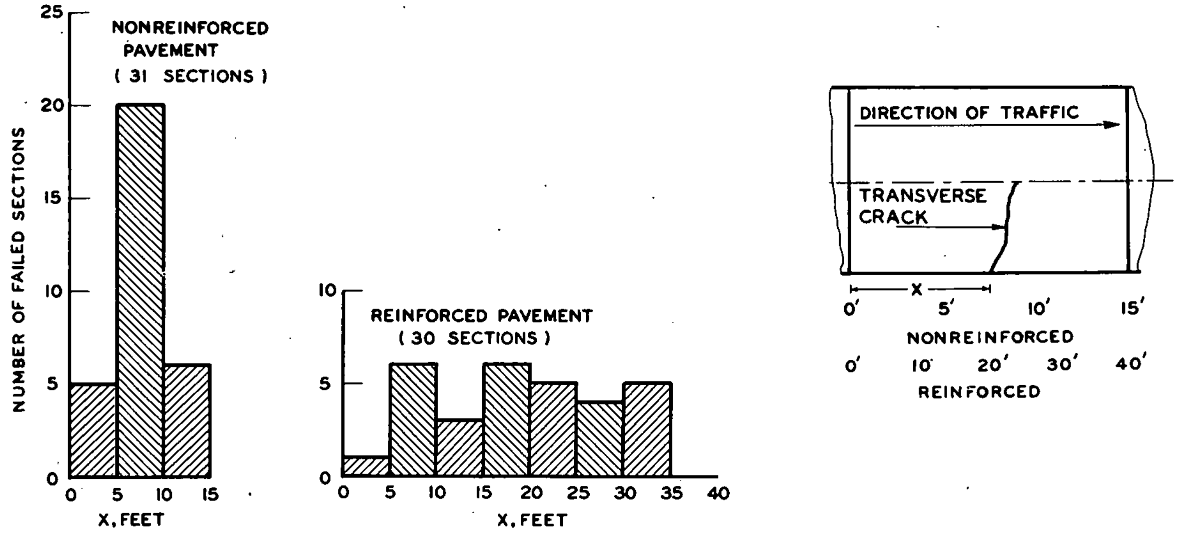

Figure 130. Summary of position of first crack in failed area of 61 failed sections where first crack was transverse, Experiment Designs 1 and 3.

Figure 132 shows that the panel first requiring maintenance usually had the highest cracking index of all panels in the section at the time the section was removed from test. This panel, in all probability, was chiefly responsible for the drop in serviceability level to 1.5. The point of origin of the first crack leading to such early failures (Figs. 129 and 130) therefore acquires additional significance.

*3.2.3.2 Pumping.*—The term "pumping," unless otherwise noted, refers to the ejection of material from beneath the pavement and its deposition along the pavement edge. Although fine material often was washed upward through joints and cracks, the amount of material transported in this manner at the Road Test was negligible when compared with the amount deposited along the edge.

In cases where pumping occurred in sections with subbase, the material ejected was the subbase material (usually including the coarse fractions) rather than the underlying soil. Thus, pumping of embankment soil was confined to those sections without subbase and to those sections with 3-in. subbase that pumped so severely that all granular material had been ejected prior to failure.

Severe pumping occurred in all loops, but was retricted to the first and second levels of slab thickness in each loop. Some pumping occurred in all sections except none of the pavements subjected to the 2-kip single axle load in Loop 2 showed any evidence of pumping.

Occasionally, a considerable volume of the subbase material was ejected along the edge of the pavement in a relatively short period of time. For example, Figure 133(a) shows a windrow containing approximately 3 cu yd of material which was pumped out over night and deposited adjacent to one 40-ft panel (Fig. 133 (b-f) shows other examples of pumping).

Following each rain, all sections under traffic were inspected for signs of pumping, and a rough estimate was made of the volume of material deposited along the pavement edge. After the inspection, the pumped material was removed from the vicinity of the pavement edge.

From the results of these surveys, a "pumping index" was computed. This index approximated the accumulated volume of material ejected per unit length of pavement, averaged over the length of test section. The dimensions chosen for the index were cubic inches of material pumped per inch of pavement length. Thus, a pumping index of 100 cu in. per in. is equivalent to 2.6 cu yd of material pumped from beneath 100 ft of pavement. Pumping index data are available in DS 4243 for each section of Designs 1 and 3 for each survey date.

Table 54 gives data where the pumping index corresponding to a serviceability level of 1.5 is given for each Design 1 section that fell to that level, or at $W = 1{,}114{,}000$ unweighted axle applications if the section survived the traffic test. The average pumping index for failed sections at $p = 1.5$ was 134; the average for surviving sections at $W = 1{,}114{,}000$ was 34. There was not a clear-cut definition of the value of the pumping index associated with the serviceability level of 1.5. For example, one section failed with a pumping index of 5 while another survived with a pumping index of 209. Nevertheless, the fact that pumping was a very important factor in the performance of rigid pavement sections is demonstrated by the survival curve in Figure 134.

No consistent trend was found relating the pumping index to subbase thickness, and no significant difference was found between reinforced and nonreinforced sections. The pumping index at $W = 1{,}114{,}000$, however, did show a trend with slab thickness and load. The amount of material pumped from beneath the same thickness of slab usually increased as load increased and under the same load decreased as slab thickness increased (Table 55).

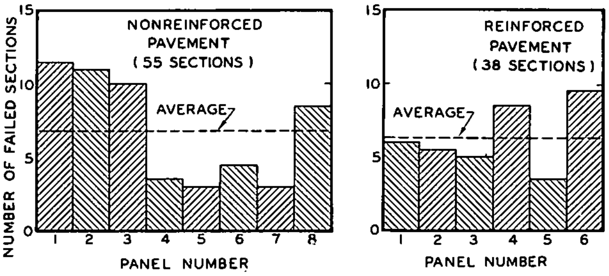

**Figure 131. Summary of failed sections by panel where first failure occurred, Experiment Designs 1 and 3. Panels numbered in direction of traffic.**

The permeability of the subbase material, according to tests made in the project laboratory on 24 specimens molded at a variety of moisture contents and densities, ranged from 6.9 x $10^{-6}$ to about 8.3 x $10^{-3}$ ft per min. These tests indicated that within the range of subbase densities determined in the course of the trench studies (Section 3.5.2.2) the permeability of the subbase probably did not exceed 3.5 x $10^{-3}$ ft per min and may have been lower. Thus, the estimated range of permeability of the subbase in place was, in round numbers, 7 x $10^{-6}$ to 4 x $10^{-3}$ ft per min. The grading of the material is given in Table 4.

Regardless of the permeability of the subbase, it was observed that free water collected under the slab during rains and did not drain laterally through the subbase material in the shoulder to the side ditches at a rate sufficient to prevent pumping. By removing the concrete from a few failed sections and sampling the underlying material, it was observed that subbase material had apparently been removed by erosive action of water moving across the top of the subbase, and that the remaining subbase material was relatively undisturbed. There was no evidence, either from gradation tests or from visual inspection, that fines from the embankment had entered the voids in the subbase layer.

Inasmuch as the great majority of the sections which failed pumped severely prior to failure, many of these sections would have survived the two years of traffic had the subbase material been stabilized effectively to resist erosion by water.

*3.2.3.3 Seasonal Changes in Transverse Profile.*—The transverse profile of the rigid pavement sections relative to the centerline elevation was determined at four locations in each nonreinforced and at six locations in each reinforced section, Designs 1 and 3 (Fig. 135), in October 1958, February 1959, June 1959, October 1959, February 1960, May 1960, August 1960, and November 1960. The instrument used was the transverse profilometer (Figs. 38 and 39). Elevations relative to the centerline were obtained at nine equally spaced points on the pavement at each cross-section location.

Figure 136 compares the average October 1958 transverse profile of sections with slab thicknesses at the two highest levels in each loop with the average profile of these sections in October 1959 and November 1960. The edges of the pavement, as well as intermediate points, apparently moved downward slightly relative to the centerline during this period with an accompanying deformation of the pavement. However, the data for these sections taken in October and February revealed a reversal of this movement in the winters of 1958-59 and 1959-60, apparently due to freezing of the subsurface materials (Fig. 137). It is presumed that the longitudinal center joint relieved any stresses which might have developed in the pavement as a result of these deformations.

The winter heave of the pavement, measured at the edges using deflection rods installed ad-

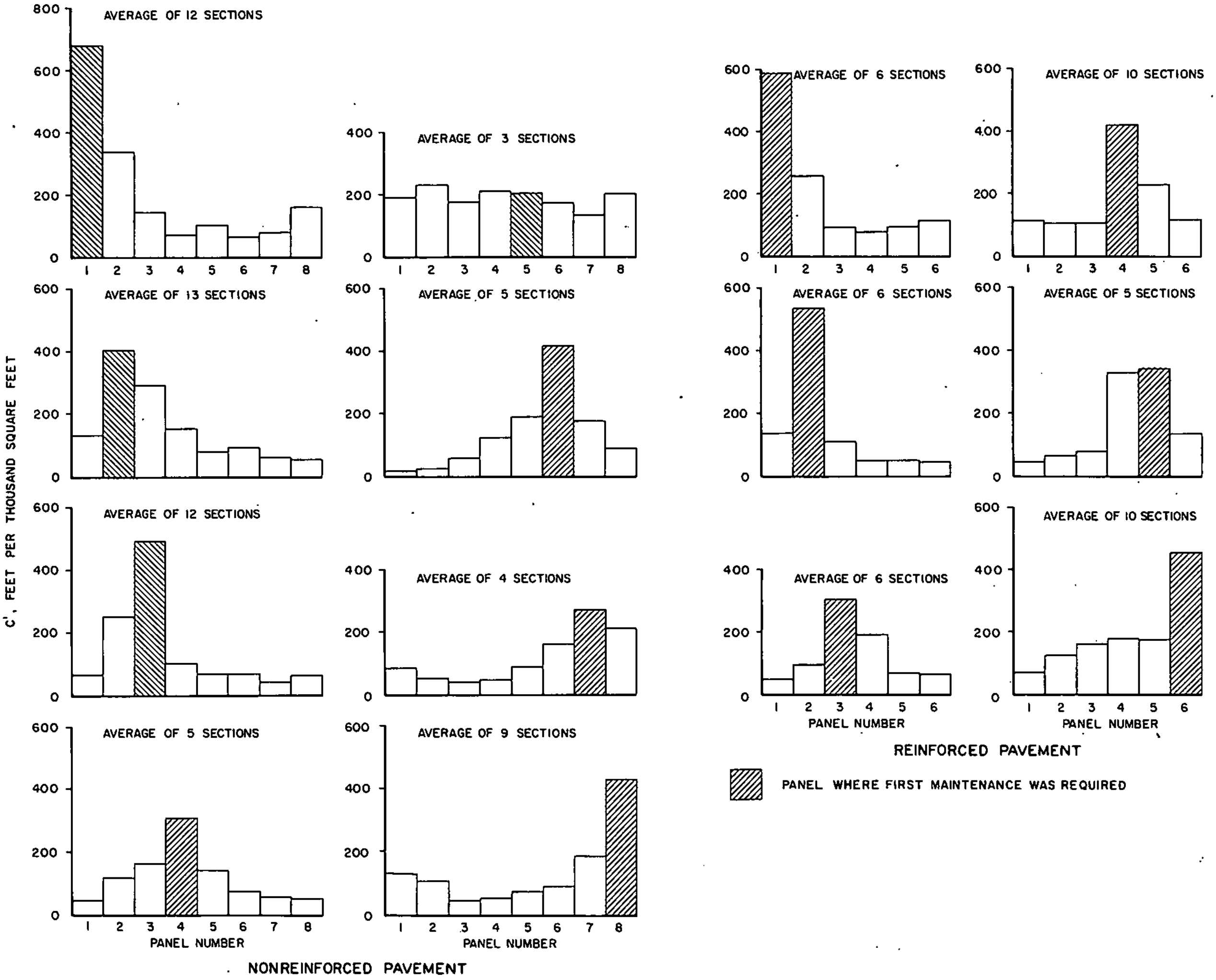

**Figure 132. Distribution of cracking by panels in failed sections, Experiment Designs 1 and 3.**

Void in shoulder through which subbase material was ejected from beneath pumping slab.

Subbase material ejected from beneath pavement overnight and deposited along edge.

Typical pile of subbase material pumped from beneath pavement, showing change in gradation of material from fine to coarse in direction of traffic, toward reader.

Embankment material pumped from beneath a pavement constructed without a subbase.

This void beneath pavement extended more than 5 ft from edge.

Transverse cross-section of a pumping slab showing void beneath pavement.

Figure 133. Examples of pumping.

## TABLE 54

### Pumping Index at $p = 1.5$[1] or $W = 1{,}114{,}000$, Experiment Design 1[2]

| Loop | Axle Load (kips) | Subbase Thickness (in.) | Pumping Index | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2.5-In. Surface | | 3.5-In. Surface | | 5.0-In. Surface | | 6.5-In. Surface | | 8.0-In. Surface | | 9.5-In. Surface | | 11.0-In. Surface | | 12.5-In. Surface | |
| | | | R | N | R | N | R | N | R | N | R | N | R | N | R | N | R | N |
| 2 | 2S | 0 | | | | | | | | | | | | | | | | |
| | | 3 | | | | | | | | | | | | | | | | |
| | | 6 | | | | | | | | | | | | | | | | |
| | 6S | 0 | 25* | 11* | 8 | 20 | 4 | 4 | | | | | | | | | | |
| | | 3 | 5* | 17 | 10<br>12 | 7 | 5 | 6<br>6 | | | | | | | | | | |
| | | 6 | 11 | 34 | 7 | 13 | 2 | 2 | | | | | | | | | | |
| 3 | 12S | 3 | | | 315* | 62* | 109<br>90 | 53 | 17 | 22<br>19 | 7 | 18 | | | | | | |
| | | 6 | | | 214* | 102* | 211* | 83<br>63 | 18<br>24 | 17 | 15 | 18 | | | | | | |
| | | 9 | | | 204* | 149* | 69 | 88 | 12 | 17 | 18 | 18 | | | | | | |
| | 24T | 3 | | | 92* | 37* | 86*<br>118* | 73* | 52 | 37<br>22 | 18 | 24 | | | | | | |
| | | 6 | | | 69* | 76* | 82* | 65<br>106* | 51<br>87 | 24 | 23 | 31 | | | | | | |
| | | 9 | | | 88* | 103* | 101* | 146* | 45 | 21 | 30 | 27 | | | | | | |
| 4 | 18S | 3 | | | | | 189* | 191* | 47<br>72 | 48 | 19 | 24<br>20 | 13 | 16 | | | | |
| | | 6 | | | | | 116* | 91* | 92 | 29<br>57 | 19<br>22 | 24 | 5 | 20 | | | | |
| | | 9 | | | | | 98* | 147* | 117 | 209 | 18 | 21 | 6 | 16 | | | | |
| | 32T | 3 | | | | | 216* | 202* | 89<br>152* | 50* | 26 | 35<br>29 | 34 | 53 | | | | |
| | | 6 | | | | | 202* | 101* | 210* | 112<br>86* | 41<br>39 | 39 | 12 | 28 | | | | |
| | | 9 | | | | | 75* | 118* | 116* | 178* | 32 | 30 | 11 | 27 | | | | |
| 5 | 22.4S | 3 | | | | | | | 207* | 133* | 146*<br>32 | 33 | 27 | 22<br>27 | 11 | 23 | | |
| | | 6 | | | | | | | 104* | 301* | 63 | 47<br>97 | 20<br>31 | 52 | 18 | 2 | | |
| | | 9 | | | | | | | 193* | 203* | 79 | 122* | 16 | 28 | 4 | 3 | | |
| | 40T | 3 | | | | | | | 91* | 108* | 127*<br>35 | 37 | 38 | 29<br>31 | 17 | 35 | | |
| | | 6 | | | | | | | 123* | 111* | 210* | 67<br>47 | 61<br>66 | 113 | 22 | 0 | | |
| | | 9 | | | | | | | 77* | 114* | 142 | 98* | 27 | 84 | 12 | 12 | | |
| 6 | 30S | 3 | | | | | | | | | 122* | 150* | 18<br>83 | 32 | 19 | 15<br>19 | 4 | 22 |
| | | 6 | | | | | | | | | 237* | 159 | 45 | 29<br>52 | 27<br>31 | 20 | 6 | 20 |
| | | 9 | | | | | | | | | 237* | 168 | 120 | 59 | 22 | 12 | 1 | 3 |
| | 48T | 3 | | | | | | | | | 95* | 164 | 52<br>44 | 185 | 26 | 25<br>22 | 6 | 53 |
| | | 6 | | | | | | | | | 208* | 133 | 41 | 36<br>83 | 60<br>26 | 21 | 20 | 46 |
| | | 9 | | | | | | | | | 123* | 105* | 228* | 40 | 86 | 24 | 3 | 22 |

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[1] Values with asterisk are for $p = 1.5$.

[2] R = reinforced; N = nonreinforced.

TABLE 55

PUMPING INDEX[1] FOR SURVIVING SECTIONS, EXPERIMENT DESIGN 1, $W$ = 1,114,000

| Axle Type | Axle Load (kips) | Pumping Index | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2.5-In. Slab | 3.5-In. Slab | 5.0-In. Slab | 6.5-In. Slab | 8.0-In. Slab | 9.5-In. Slab | 11.0-In. Slab | 12.5-In. Slab |
| Single | 2 | | | | | | | | |
| | 6 | 21 | 11 | 4 | | | | | |
| | 12 | | — | 79 | 18 | 16 | | | |
| | 18 | | | — | 84 | 21 | 13 | | |
| | 22.4 | | | | — | 59 | 28 | 10 | |
| | 30 | | | | | 164 | 55 | 21 | 9 |
| Tandem | 24 | | — | 65 | 42 | 26 | | | |
| | 32 | | | — | 101 | 34 | 28 | | |
| | 40 | | | | — | 66 | 56 | 16 | |
| | 48 | | | | | 149 | 69 | 36 | 25 |

[1] Each value is average for one to eight sections; replicate sections included in averages.

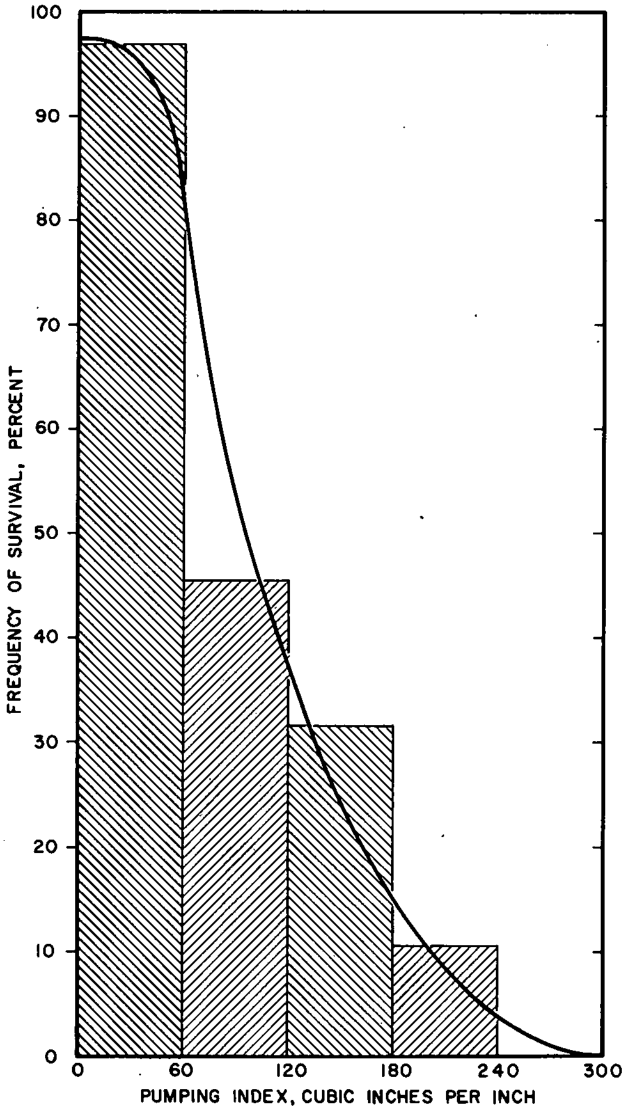

**Figure 134. Estimated probability that a test section with the indicating pumping index will survive 1,114,000 axle load applications.**

jacent to the pavement as references, averaged about 0.33 in. between October 1958 and March 1959. Measurements were not made for the succeeding winter period.

## 3.3 STRAIN AND DEFLECTION AS FUNCTIONS OF DESIGN, LOAD, TEMPERATURE AND SPEED

This section describes the instrumentation and procedures for the measurement of strains and deflections caused by the test traffic, and presents the results of the routine measurements programs in the form of equations. These are expressed in terms of design, load, and the distribution of temperature in a standard slab determined when the strain or deflection was measured.* Graphs of each equation are included from which strains and deflections may be estimated for the range of loads, designs and pavement temperatures observed at the Road Test (see Figs. 68 to 71).

Also described is a series of special studies, each designed to isolate the effect on strain and deflection of one of the following factors: axle load, pavement temperature distribution and vehicular speed.

The general level of deflection measured at approximately the same time of day over a period of several months did not change appreciably with increasing number of load applications (Sections 3.3 and 3.3.9).

Other factors being equal, strains and deflections were directly proportional to load (Section 3.3.2).

Twenty-four hour studies of the effect of fluctuating air temperatures showed that the deflection of panel corners, under vehicles traveling near the pavement edge, at times in-

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* This temperature distribution, or differential, is defined in Section 3.3.3 and is referred to as the standard differential, $T$.

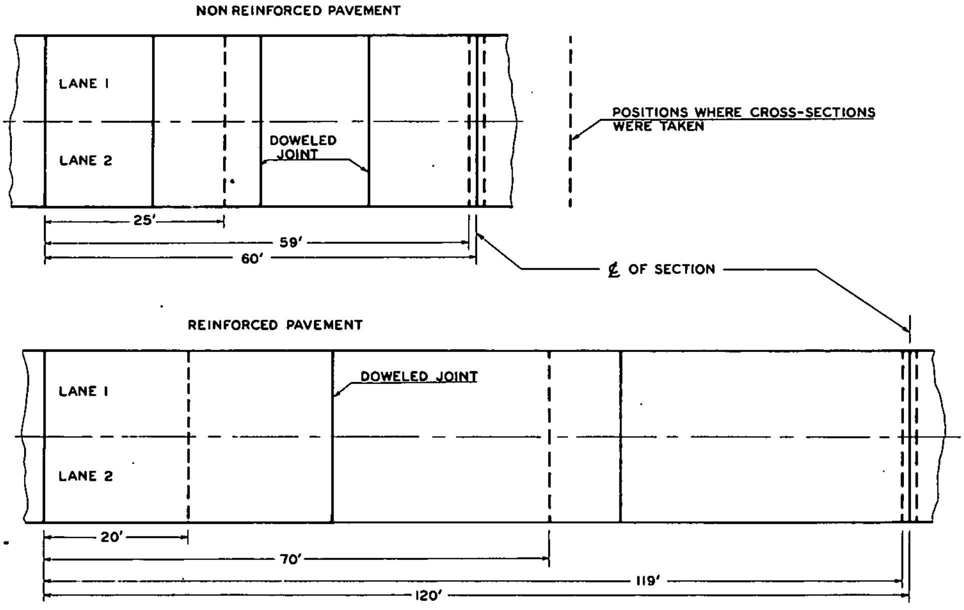

Figure 135. Transverse profiles locations.

creased several fold from afternoon to early morning. Strain and deflection, measured at a point on the edge at least 7.5 ft distant from the nearest transverse joint, were also affected but to a lesser extent (Sections 3.3.3, 3.3.4, 3.3.6 and 3.3.7).

The deflection of a corner of a 40-ft reinforced panel usually exceeded the deflection of a 15-ft nonreinforced panel, if load, slab thickness and temperature conditions were the same in both cases (Sections 3.3.5 and 3.3.7). On the other hand, deflections and strains measured at a point on the edge 7.5 ft distant from the nearest joint were not affected significantly by panel length (Sections 3.3.4 and 3.3.6).

Edge strains and corner deflections were found to decrease in approximately equal proportions with increase in vehicular speed. An increase in speed from 2 to 60 mph resulted in a decrease in strain or deflection of about 29 percent. Though there was considerable variation in the data, no consistent effect of pavement design or load on the percentage rate of reduction was found (Section 3.3.8).

Minor (but statistically significant) differences in the deflection under a 12-kip axle load were found from tests made in the various loops and lanes on sections having the same slab thickness. The differences were considered to be of no practical significance (Section 3.3.9).

Transient effects of the test vehicles which were measured in the pavements included dynamic edge strain, dynamic corner deflection, static edge rebound deflection and static corner rebound deflection. The instrumentation and procedures are described in Section 3.3.1.

Tables 56 and 57 summarize the schedule of routine static and dynamic testing in the traffic loops. Data were gathered by rounds; that is, a measurement crew collecting either static or dynamic data visited each test section of the selected factorial experiment only once until all sections in the experiment had been tested. The data so collected were lumped together into one round of data. Successive rounds of data from the same kind of measurements (dynamic or static) were numbered consecutively for identification (breaks in the sequences occurred when rounds were not completed due to equipment failure or other reasons).

As a rule, routine static measurements were made during the daily 5-hr and 20-min break in traffic, and routine dynamic measurements were made during an 8-hr work shift occurring during the regular 18-hr and 40-min daily traffic period. In both cases, the test vehicles regularly assigned to a lane were used for the tests in that lane. One round of static measurements usually required about 1 week. One round of dynamic measurements usually required from 3 to 4 weeks.

It had been anticipated that some consistent trend of strain and deflection with rounds (that is, with accumulated axle applications) would be observed. However, such was not the case, and any regular trends which might have been present apparently were masked by the overriding effect of daily fluctuations in temperature and possibly by other unknown variables.

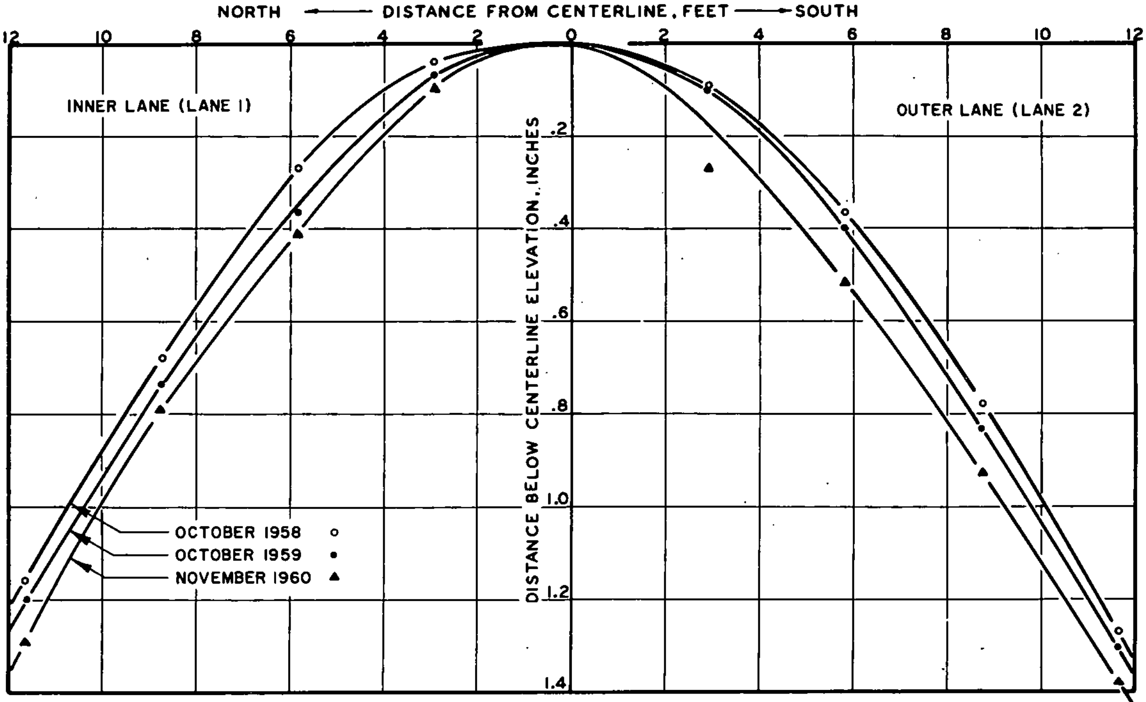

Figure 136. Transverse profile of pavement surface relative to centerline elevation before, during, and after the two years of test traffic. Data from test sections with slab thickness at the two highest levels in Loops 2 through 6, Experiment Design 1, including replicate sections.

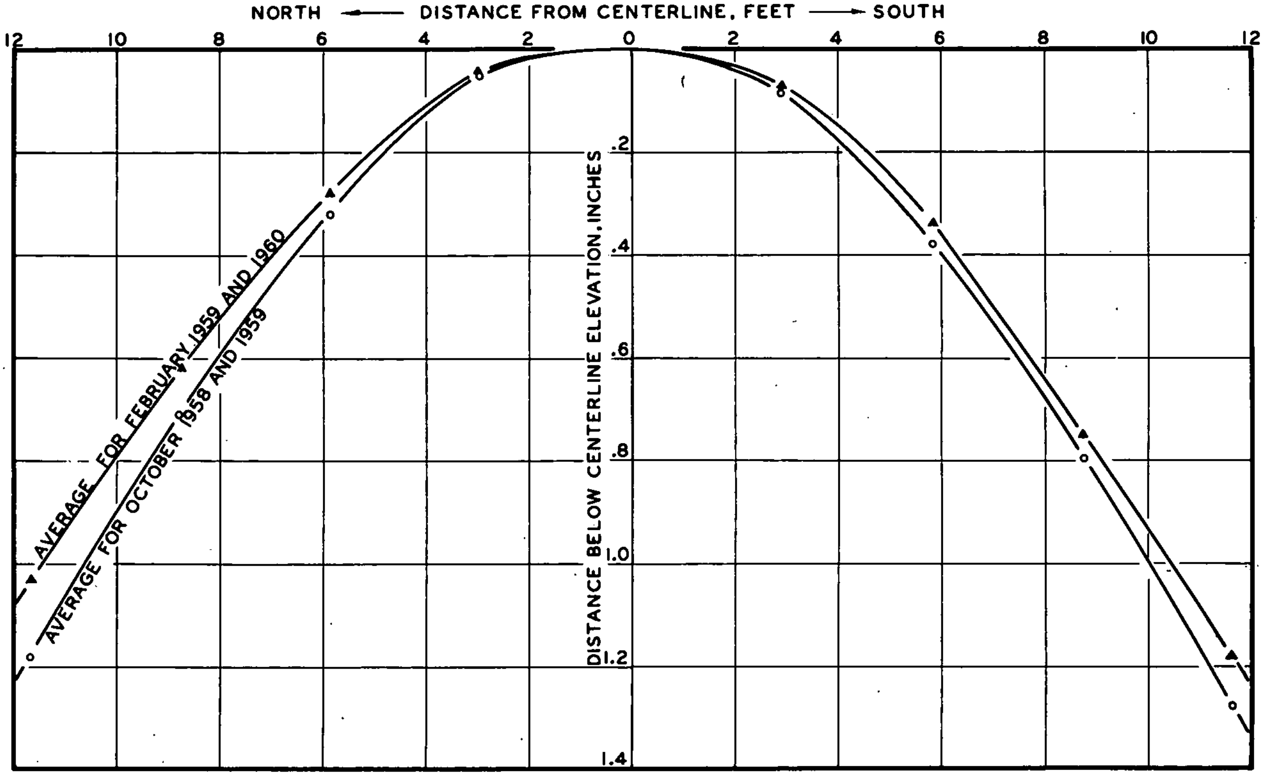

Figure 137. Effect of frost on shape of transverse cross-section of pavement surface. Data from same test sections used in Figure 136.

## TABLE 56

### SCHEDULE OF ROUTINE DYNAMIC EDGE STRAIN AND DYNAMIC CORNER DEFLECTION MEASUREMENTS IN LOOPS 2 THROUGH 6

### EXPERIMENT DESIGN 1

(Data available in DS 5250)

| Measurement | Round Number | Mid-Date of Observation Period | Hours | | Loops |
|---|---|---|---|---|---|
| | | | From | To | |
| Strain and deflection | 1 | Oct. 25, 1958 | 1000 | 2400 | 2, 3, 4, 5, 6 |
| Strain, ground frozen | 2 | Jan. 6, 1959 | 0700 | 2300 | 2, 3, 4, 5, 6 |
| Strain | 4 | Apr. 14, 1959 | 0900 | 2300 | 2, 3, 4, 5, 6 |
| Strain | 5 | May 16, 1959 | 1100 | 2300 | 2, 3, 4, 5, 6 |
| Strain and deflection | 6 | June 6, 1959 | 2300 | 0600 | 2[1], 3[1], 4[1], 5[1], 6[1] |
| Strain and deflection | 7 | June 23, 1959 | 2300 | 0500 | 2[1], 3[1], 4[1], 5[1], 6[1] |
| Strain | 8 | July 13, 1959 | 1100 | 2000 | 2, 3, 4, 5, 6 |
| Strain and deflection | 9 | Aug. 2, 1959 | 2300 | 0600 | 2, 3[2], 4, 5, 6 |
| Strain | 10 | Sept. 9, 1959 | 2300 | 0600 | 2, 3[2], 4, 5, 6 |
| Strain | 11 | Oct. 13, 1959 | 2200 | 0600 | 2, 3[2], 4[2], 5, 6 |
| Strain | 12 | Nov. 18, 1959 | 2200 | 0500 | 3[1,2], 4[1,2], 6[1] |
| Strain | 13 | Dec. 4, 1959 | 2300 | 0400 | 3[1,2], 4[1,2], 5[1] |
| Strain | 14 | Dec. 14, 1959 | 2300 | 0500 | 5[2], 6[2] |
| Strain and deflection | 17 | Apr. 21, 1960 | 0800 | 1500 | 6 |
| Strain and deflection | 18 | Apr. 27, 1960 | 2300 | 0500 | 6 |
| Strain and deflection | 19 | May 3, 1960 | 2300 | 0600 | 6 |
| Strain and deflection | 20 | May 18, 1960 | 0800 | 1600 | 6 |
| Strain and deflection | 21 | May 25, 1960 | 1000 | 1700 | 6 |
| Strain and deflection | 23 | June 10, 1960 | 2300 | 0600 | 6 |
| Strain and deflection | 24 | June 17, 1960 | 2300 | 0700 | 6 |
| Strain and deflection | 25 | June 29, 1960 | 0800 | 1600 | 6 |
| Strain and deflection | 26 | July 26, 1960 | 2400 | 0600 | 6 |
| Strain and deflection | 27 | Aug. 3, 1960 | 0800 | 1500 | 6[2] |

[1] Only sections on 6-in. subbase were tested.
[2] Thinnest level not tested.

## TABLE 57

### SCHEDULE OF ROUTINE EDGE AND CORNER STATIC REBOUND DEFLECTION MEASUREMENTS IN LOOPS 2 THROUGH 6, EXPERIMENT DESIGNS 1 AND 3

(Data available in DS 5280)

| Round Number | Mid-Date of Observation Period | Hours | | Loops |
|---|---|---|---|---|
| | | From | To | |
| 1 | Apr. 5, 1959 | 1000 | 1700 | 2, 3, 4, 5, 6 |
| 2 | May 1, 1959 | 0400 | 1000 | 2, 3, 4, 5, 6 |
| 3 | May 26, 1959 | 0600 | 1700 | 2, 3, 4, 5, 6 |
| 4A | June 16, 1959 | 1600 | 1800 | 3[1], 4[1], 5[1], 6[1] |
| 4B | June 16, 1959 | 1900 | 2100 | 3[1], 4[1], 5[1], 6[1] |
| 5 | July 11, 1959 | 0500 | 1000 | 2, 3[2], 4, 5, 6 |
| 6 | July 22, 1959 | 1100 | 1600 | 2, 3[2], 4, 5, 6 |
| 7 | Aug. 4, 1959 | 1700 | 2100 | 2, 3[2], 4, 5, 6 |
| 8 | Aug. 19, 1959 | 0500 | 1000 | 2, 3[2], 4, 5, 6 |
| 9 | Sept. 2, 1959 | 1000 | 1500 | 2, 3[2], 4, 5, 6 |
| 10 | Sept. 22, 1959 | 1600 | 2100 | 3[2], 4, 5, 6 |
| 11 | Oct. 28, 1959 | 1600 | 2000 | 3[2], 4[2], 6 |
| 12 | Nov. 4, 1959 | 0500 | 1100 | 2, 3[2], 4[2], 5, 6 |
| 13 | Nov. 25, 1959 | 0900 | 1700 | 2, 3[2], 4[2], 5[2], 6 |
| 14 | Dec. 16, 1959 | 1600 | 2100 | 2, 3[2], 4[2], 5[2], 6 |
| 15 | Feb. 14, 1960 | 0700 | 1100 | 3[2], 4[2], 5[2], 6 |
| 16 | Mar. 4, 1960 | 1200 | 1500 | 2, 3[2], 4[2], 5[2], 6 |
| 17 | Mar. 17, 1960 | 1300 | 1600 | 2, 3[2], 4[2], 5[2], 6 |
| 18 | Mar. 30, 1960 | 0600 | 1000 | 2, 3[2], 4[2], 5[2], 6 |
| 19 | Apr. 13, 1960 | 1800 | 2000 | 3[2], 4[2], 5[2], 6 |
| 20 | Apr. 27, 1960 | 1200 | 1500 | 2[2], 3[2], 4[2], 5[2], 6 |
| 21 | May 25, 1960 | 0500 | 1000 | 2[2], 3[2], 4[2], 5[2], 6 |
| 22 | June 15, 1960 | 1200 | 1500 | 2[2], 3[2], 4[2], 5[2], 6 |
| 23 | June 29, 1960 | 1700 | 2100 | 2[2], 3[3], 4[2], 5[2], 6 |
| 24 | July 7, 1960 | 0700 | 1000 | 2[2], 3[3], 4[2], 5[2], 6 |
| 25 | July 20, 1960 | 1100 | 1500 | 2[2], 3[3], 4[2], 5[2], 6 |
| 26 | Aug. 2, 1960 | 1700 | 2000 | 2[2], 3[3], 4[2], 5[2], 6 |
| 27 | Aug. 17, 1960 | 0700 | 1000 | 2[2], 3[3], 4[2], 5[2], 6 |
| 28 | Aug. 30, 1960 | 1200 | 1500 | 2[2], 3[3], 4[2], 5[2], 6 |
| 29 | Sept. 14, 1960 | 1800 | 2100 | 2[2], 3[3], 4[2], 5[2], 6 |
| 30 | Sept. 28, 1960 | 0700 | 0900 | 2[2], 3[3], 4[3], 5[2], 6[2] |
| 31 | Oct. 11, 1960 | 1100 | 1400 | 2[2], 3[3], 4[3], 5[2], 6[2] |
| 32 | Oct. 26, 1960 | 1800 | 2100 | 2[2], 3[3], 4[3], 5[2], 6[2] |
| 33 | Nov. 9, 1960 | 0600 | 1000 | 2[2], 3[3], 4[3], 5[2], 6[2] |
| 34 | Nov. 23, 1960 | 1200 | 1500 | 2[2], 3[3], 4[3], 5[2], 6[2] |

[1] Only sections on 6-in. subbase were tested.
[2] Thinnest level, Experiment Designs 1 and 3, not tested.
[3] Two thinnest levels, Design 1, and thinnest level, Design 3, not tested.

TABLE 58

Summary of Early Morning Rounds, Static Measurements[1], Design 1, Loops 3–6
(Data available in DS 5280)

| Round Number | Mid-Date of Observation Period | Mid-Hour of Observation Period | Average Static Rebound Deflection (in.) | |
|---|---|---|---|---|
| | | | Edge | Corner |
| 2 | May 1, 1959 | 0700 | 0.021 | 0.028 |
| 5 | July 11, 1959 | 0730 | 0.020 | 0.025 |
| 8 | Aug. 19, 1959 | 0730 | 0.018 | 0.023 |
| 12 | Nov. 4, 1959 | 0800 | 0.019 | 0.027 |
| 15[2] | Feb. 14, 1960 | 0900 | 0.010[2] | 0.012[2] |
| 18 | Mar. 30, 1960 | 0800 | 0.021 | 0.025 |
| 21 | May 25, 1960 | 0730 | 0.021 | 0.027 |
| Average, excluding winter round | | | 0.020 | 0.026 |
| Average, winter round | | | 0.010 | 0.012 |

[1] Data for thinnest pavement in each loop excluded.
[2] Subgrade frozen.

TABLE 59

Summary of Midday Rounds, Static Measurements[1], Design 1, Loops 3–6
(Data available in DS 5280)

| Round Number | Mid-Date of Observation Period | Mid-Hour of Observation Period | Average Static Rebound Deflection (in.) | |
|---|---|---|---|---|
| | | | Edge | Corner |
| 1 | April 5, 1959 | 1300 | 0.015 | 0.018 |
| 3 | May 26, 1959 | 1130 | 0.017 | 0.022 |
| 6 | July 22, 1959 | 1330 | 0.014 | 0.015 |
| 9 | Sept. 2, 1959 | 1230 | 0.015 | 0.019 |
| 13 | Nov. 25, 1959 | 1300 | 0.015 | 0.021 |
| 16[2] | Mar. 4, 1960 | 1330 | 0.005[2] | 0.007[2] |
| 17[2] | Mar. 17, 1960 | 1430 | 0.006[2] | 0.007[2] |
| 20 | Apr. 27, 1960 | 1330 | 0.017 | 0.019 |
| 22 | June 15, 1960 | 1330 | 0.018 | 0.021 |
| Average, excluding winter rounds | | | 0.016 | 0.019 |
| Average, winter rounds | | | 0.006 | 0.007 |

[1] Data for thinnest pavement in each loop excluded.
[2] Subgrade frozen.

TABLE 60

Summary of Late Afternoon Rounds, Static Measurements[1], Design 1, Loops 3–6
(Data available in DS 5280)

| Round Number | Mid-Date of Observation Period | Mid-Hour of Observation Period | Average Static Rebound Deflection (in.) | |
|---|---|---|---|---|
| | | | Edge | Corner |
| 7 | Aug. 4, 1959 | 1900 | 0.015 | 0.017 |
| 10 | Sept. 10, 1959 | 1830 | 0.013 | 0.016 |
| 14 | Dec. 12, 1959 | 1830 | 0.017 | 0.023 |
| 19 | Apr. 13, 1960 | 1900 | 0.022 | 0.025 |
| Average | | | 0.017 | 0.020 |

[1] Data for thinnest pavement in each loop excluded.

Tables 58, 59 and 60 give averaged static rebound deflection data measured at panel edges and corners for 7 rounds taken in the early morning hours between May 1959 and May 1960; for 9 rounds taken at midday between April 1959 and June 1960; and for 4 rounds taken in the late afternoon in the latter part of 1959 and the spring of 1960. Tables 58 and 59 indicate little or no change in the early morning and midday deflection levels during the year represented. Table 60 gives an apparent increase over earlier observations in the late afternoon deflection level occurring in December 1959 and April 1960. Whether this should be considered a real increase, or simply the result of rapidly changing temperature occurring during the periods of observation, cannot be demonstrated from available data. More detailed studies of temperature effects are described in Section 3.3.3.

It was observed that once a panel had cracked near the point of measurement, the values of strain and deflection usually were much greater or much less than previously observed. In such cases, the data were rejected, and the point of measurement was changed, if possible. If this was not possible, the section was dropped from the measurements program. Thus, in the following discussion, strain and deflection measurements may be assumed to apply to panels in good condition as determined by visual inspection.

### *3.3.1 Measurement Methods*

Static rebound deflections at edge and corner were measured by means of a Benkelman beam similar to that shown in Appendix D except that the length of the probe from pivot to tip was 10 ft. Electrical resistance strain gages and linear variable differential transformers were used for dynamic measurements of edge strain and corner deflection, respectively.

*3.3.1.1 Dynamic Measurements — Edge Strain, Corner Deflection.* — An electrical resistance strain gage was cemented to the pavement surface adjacent to the free edge on either side of the central transverse joint of each test section in Design 1 in Loops 3, 4, 5 and 6 (Fig. 138). In Loop 2 only the 2½-in. thick sections were instrumented.

The strain gage, as received from the manufacturer, consisted of a thin plastic strip, 1 in. by 6.5 in., on which was etched a foil resistance element (Fig. 139 a). The effective gage length

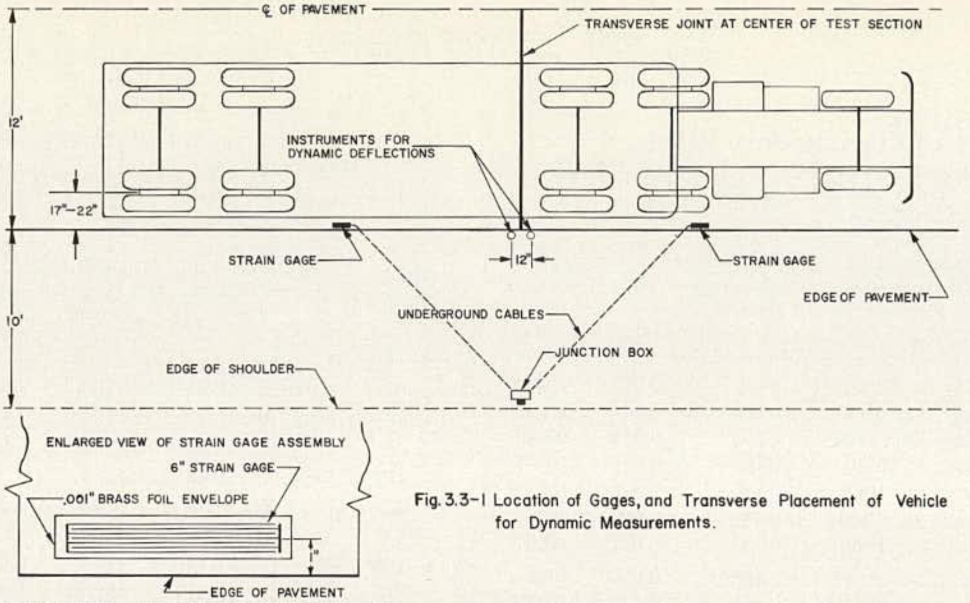

**Figure 138. Location of gages and transverse placement of vehicle for dynamic measurements.**

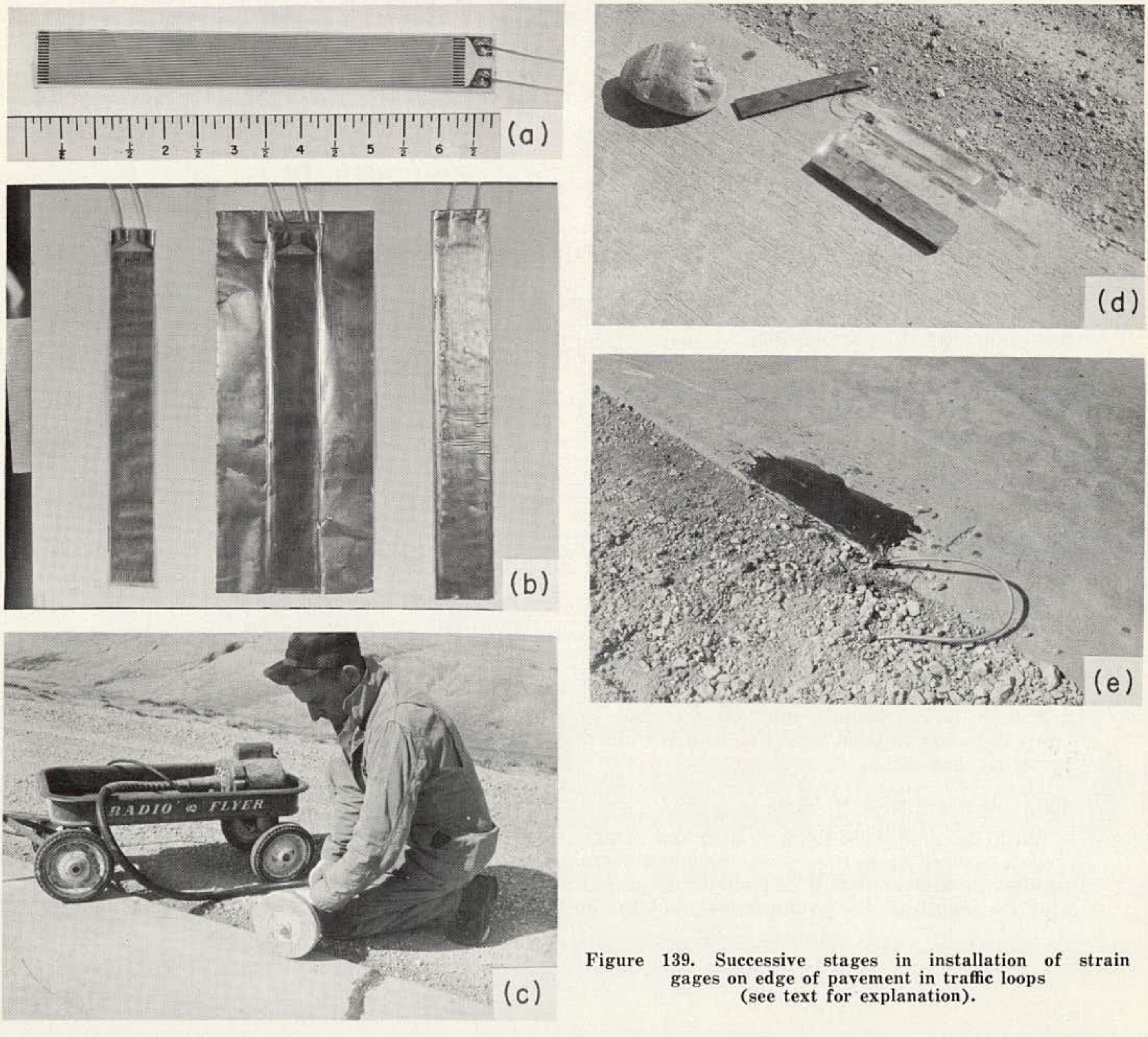

**Figure 139. Successive stages in installation of strain gages on edge of pavement in traffic loops (see text for explanation).**

was 6 in. and the nominal resistance 750 ohms. When used in conjunction with the project's specially developed equipment, the sensitivity of the gages was about ± 1 $\mu$in. per in. of strain.

Prior to installation, a thin coat of epoxy resin was applied to the gage. It was then wrapped in 1-mil brass shim stock (Fig. 139 b) for protection against weather and traffic. The assembly was cemented to the pavement which had previously been ground smooth at the point of installation (Fig. 139 c) and covered with a coat of epoxy resin (Fig. 139 d) followed by a layer of water-resistant waxy material (Fig. 139 e). A shielded underground cable connected the gage to a junction box at the outer edge of the shoulder.

The reference for dynamic deflection measurements was a ¼-in. diameter steel rod incased in an iron pipe (⅜-in. internal diameter) and anchored at a depth of approximately 8.5 ft below the pavement surface. Free water at a depth of about 10 ft prevented the use of a longer reference rod.

A reference rod was installed adjacent to the pavement at a distance of 6 in. on both sides of the central joint of each section instrumented for strain measurements.

The top of each reference rod was incased in a 2¼-in. (inside diameter) by 3¾-in. cylindrical metal housing which was bolted to the pavement edge. The housing provided a means for temporarily attaching a linear variable differential transformer (Fig. 140) to the pavement when deflections were to be measured. A rubber cork, with a central hole to accommodate the rod, closed the bottom of the housing and held the reference rod in position. When in use the housing was freed of forces tending to prevent free movement by removing the crushed stone shoulder material from around it.

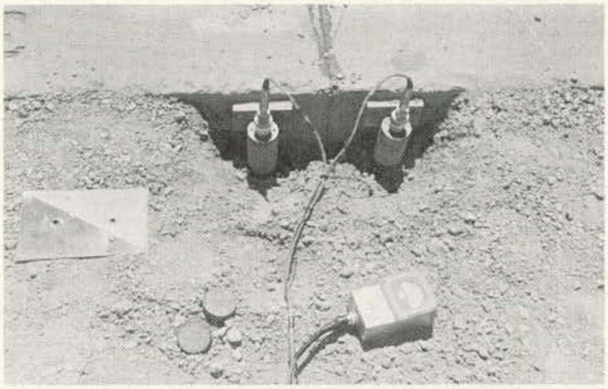

Figure 140. Instrumentation used in measurement of dynamic deflection at panel corners.

A special trailer van (Fig. 141), pulled by a panel-bodied truck and trailing a gasoline-powered generator, carried the electronic equipment necessary to energize the four dynamic gages and to record their output continuously on paper tape as the test vehicle passed by. The trailer also carried special devices for maintaining the calibration of the equipment (Figs. 142 and 143) as well as an indicator for measuring the transverse placement of the test vehicle (Fig. 144).

Dynamic measurements were accepted or rejected by the measurement crew on the basis of the transverse position of the outer dual wheel of the rear axle as it passed over the

Figure 141. Instrument van taking dynamic measurements. Device on pavement just ahead of truck measures transverse placement.

transverse joints separating the instrumented panels. If the centroid of this wheel was 20 in. (—3 in. to +2 in.)* from the pavement edge, the measurements were accepted; otherwise, they were rejected. The crew remained at each test section until at least three vehicles had succeeded in passing at the specified distance. At least 3 measurements on each of 2 strain gages (a total of six values) were averaged to obtain the section strain to be used in the analysis. Similarly, at least six measurements of corner deflection were averaged to obtain a representative value of deflection for the section.

*3.3.1.2 Static Measurements—Edge and Corner Deflection.*—An exploratory study in early 1959 indicated that the Benkelman beam could be used successfully for measuring the deflection of the free edge of a rigid pavement test section, provided the supports of the beam device were placed on the shoulder in the position shown in Figures 145 and 146. On the other hand, when the beam was placed on the pavement in the position normally used in the flexible pavement program, measurements indicated that the pavement beneath the supports of the device sometimes deflected slightly as the truck moved ahead, causing an error in the measured deflection. Thus, the measurement of interior deflections at creep speed was excluded from the rigid pavement program.

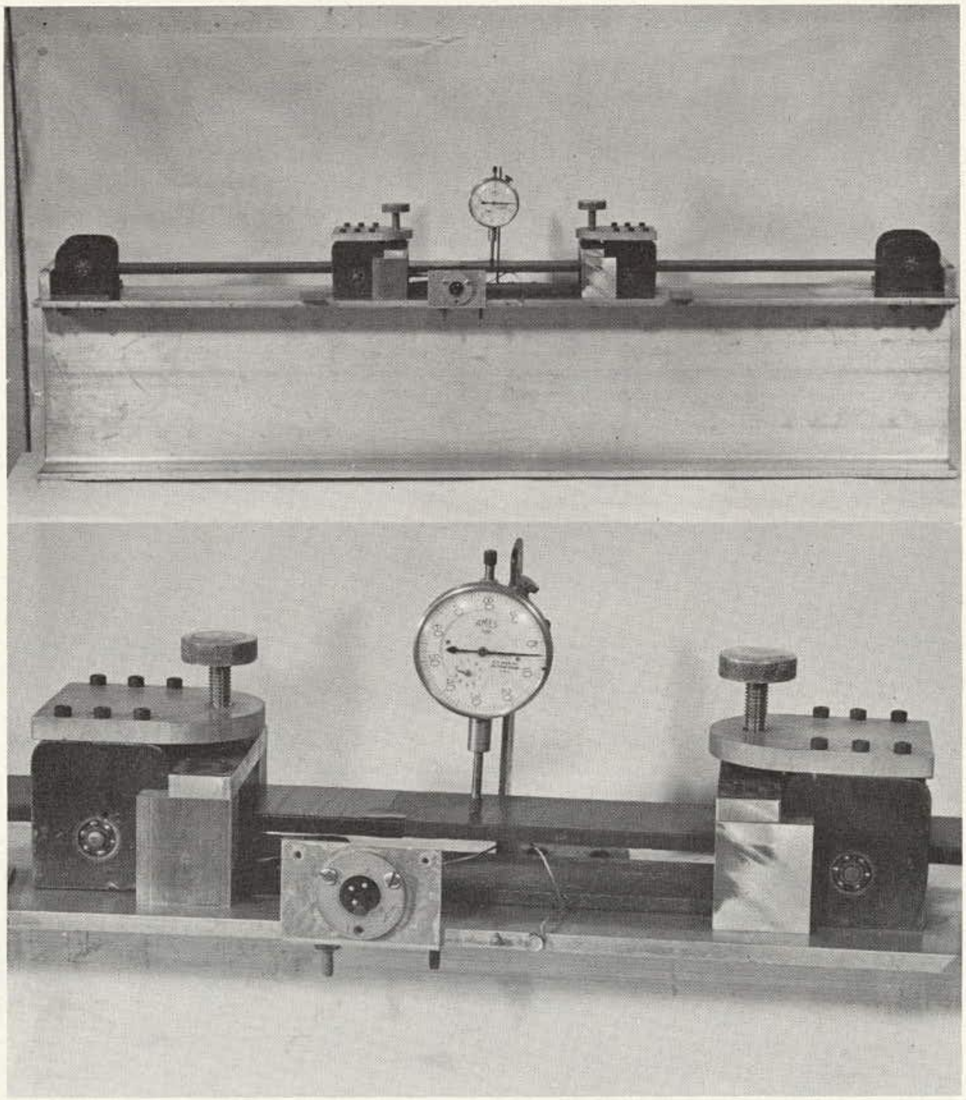

**Figure 142. Device for calibrating strain recording equipment.**

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* This biased tolerance was selected as the result of special studies of the distribution of the placement of vehicles whose operators were attempting to drive at the specified distance of 20 in. from the edge.

Placement studies showed that edge and corner deflections were strongly influenced by the transverse position of the test vehicle and that accurate control of the transverse placement of a moving vehicle was difficult and time consuming. As a result, a decision was made to place the vehicle in position before making a measurement and to measure the rebound deflection as the truck moved ahead at slow speed. Placement of the vehicle for edge and corner rebound deflection measurements is shown in Figure 145.

On each nonreinforced section, static rebound corner deflections were measured in panels 5 and 7 (panels were numbered consecutively in the direction of traffic) while the static rebound edge deflection was measured near the strain gage on panel 5 (Fig. 147). On reinforced sections, corner deflections were taken in panels 4 and 6, and edge deflections near the strain gage on panel 4. Thus, one edge deflection and the average of two corner deflections were available to represent the section for each round of data.

### *3.3.2 Strain and Deflection as Linear Functions of Load*

To determine the effect on strain and deflection of varying the axle load, other factors remaining constant, a series of load studies was conducted in Loops 4 and 6 in May, June and September 1959 during breaks in the normal test traffic.* Tables 61 and 62 give the loads, vehicular speeds and test sections involved, as well as other detailed information.

The testing procedure was as follows: The trucks were assembled on the loop in random order of axle load and axle type (single or tandem). Measurement crews took their stations at one or more test sections. If dynamic measurements were taken, all trucks passed over the section or sections being tested at either 5 or 35 mph (the most frequently used speed was 5 mph), and dynamic measurements were taken in accordance with the procedures

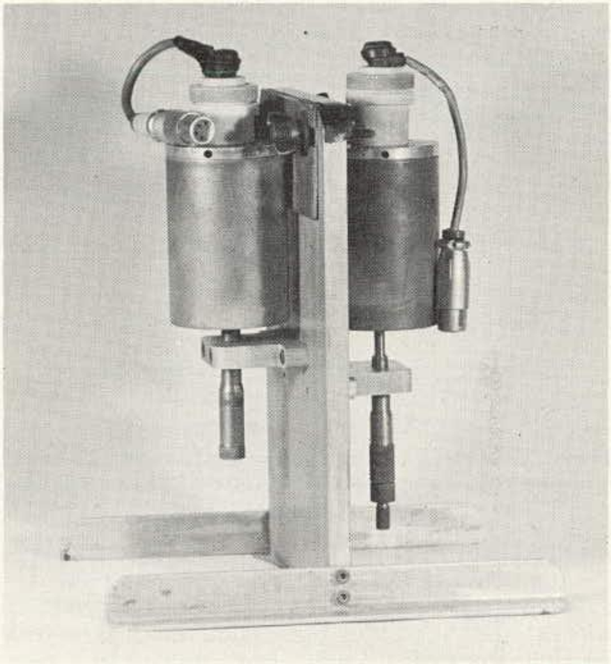

**Figure 143. Device for calibrating dynamic deflection recording equipment. Inverted depth gages used to move transformer cores through a known distance.**

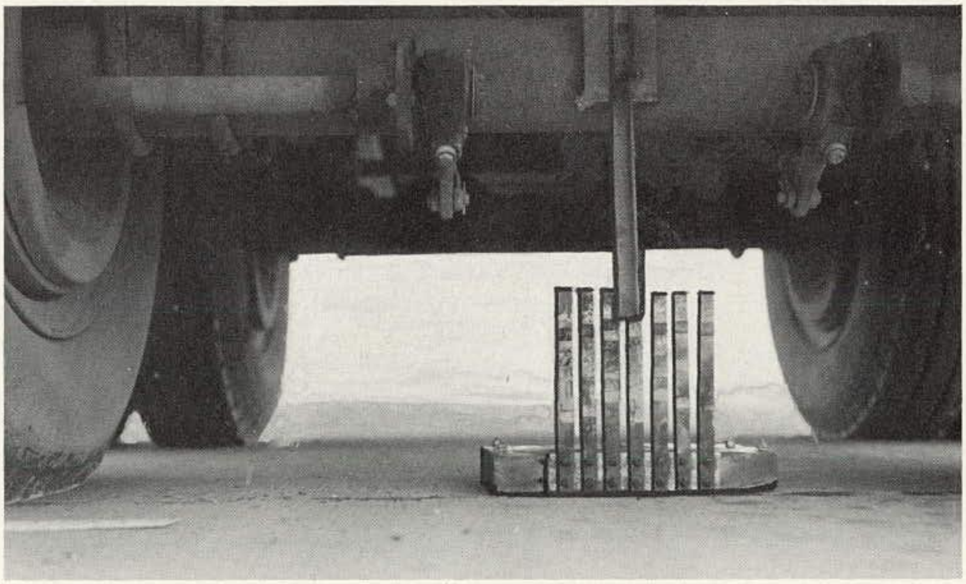

**Figure 144. Indicator for measuring transverse placement of moving vehicle.**

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* Simultaneously load studies were made on the flexible tangents as described in Section 2.3.5.

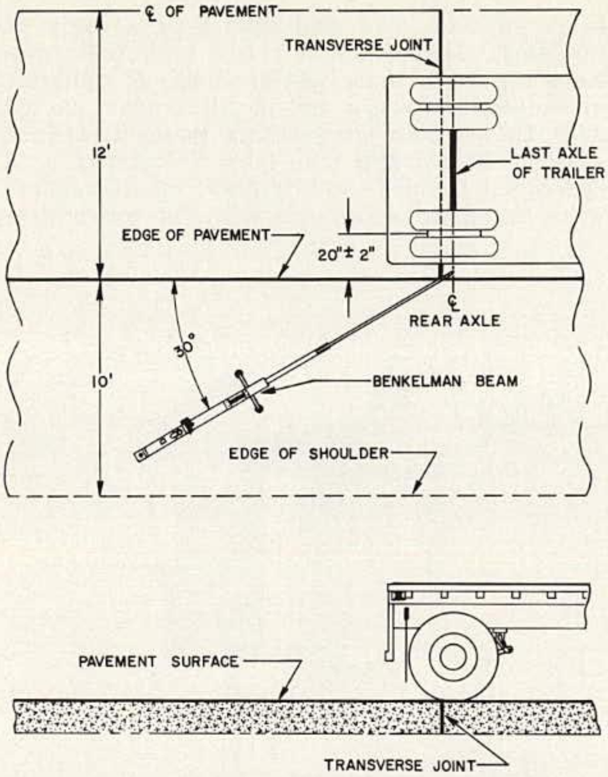


**Figure 145. Position of vehicle and Benkelman beam for making static rebound deflection measurements.**

described in Section 3.3.1.1. If static measurements were taken, the procedure was as described in Section 3.3.1.2. When measurements under all trucks had been completed at a test section, the measurement crew moved to a new section and the process was repeated.

The measurements made on each section subjected to a series of single (or tandem) axle loads on a given day were plotted against the axle loads. Typical graphs are shown in Figure 148 in which the symbols are defined as follows:

$\varepsilon$ = dynamic edge strain, in. × $10^{-6}$;

$d_c$ = dynamic corner deflection, in.;

$d_e'$ = static rebound edge deflection, in.; and

$d_c'$ = static rebound corner deflection, in.

Inspection of plots similar to those shown in Figure 148 suggested that a straight line passing through the origin would usually fit the data with errors little greater, if any, than the estimated errors associated with the measuring system used. Therefore, a linear model was fitted to the data for each test section-axle type combination given in Tables 61 and 62.

$$Y_i = a\ L_{1i} + e_i \tag{73}$$

in which

$Y_i$ = dynamic edge strain, dynamic corner deflection, static rebound edge deflection, or static rebound corner deflection, measured under the $i^{th}$ load;

$L_{1i}$ = the $i^{th}$ axle load, kips;

$a$ = a coefficient assumed to reflect the conditions of design, temperature and speed; and

$e_i$ = the $i^{th}$ residual.

The root mean square residuals were computed separately from the data corresponding to each line in Tables 61 and 62 and appear in the last column. The residuals were averaged

**Figure 146. Measuring static rebound deflection with the Benkelman beam.**

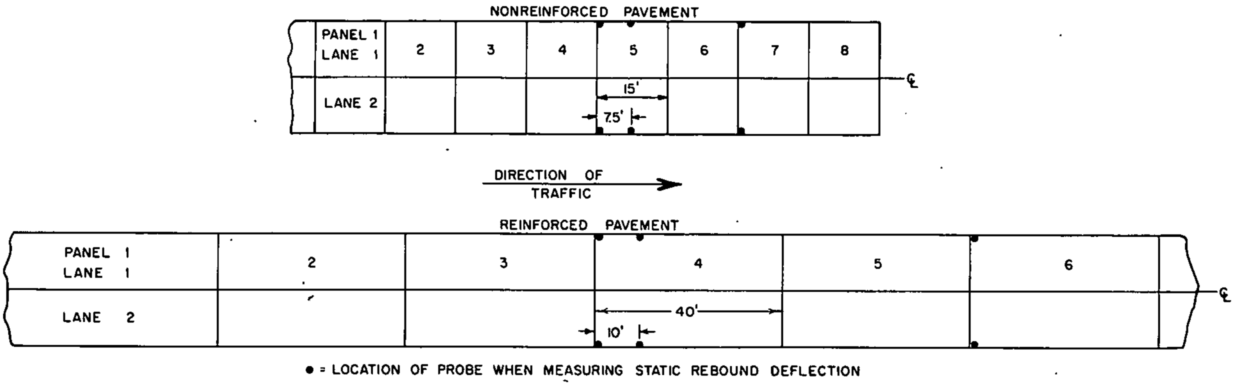


**Figure 147. Plan of test sections showing normal locations for measuring static rebound deflection.**

to obtain a value associated with each of the four measurement systems used in the load studies. These average values (Table 63) were of the same order of magnitude as estimated errors of the system which exceeded $\pm 2 \times 10^{-6}$ in. per in. for strain and ± 0.002 in. for deflection. Therefore, it was concluded that in any analysis of strain and deflection, these quantities could be considered to vary linearly with load (other factors remaining constant) without the introduction of appreciable error into the analysis. As a result of the load studies, the general mathematical model adopted for strains and deflection was

$$\frac{\text{Strain (or deflection)}}{\text{Axle load}} = f\text{ (design and other variables)} \qquad (74)$$

The data from experiments yet to be described furnished the form of the function, $f$, on the right. (See Sections 3.3.3 through 3.3.8.)

### *3.3.3 Strain and Deflection as Functions of Temperature*

Inasmuch as it had been observed that the results of deflection and strain measurements were markedly affected by daily temperature changes, a series of studies was made in an

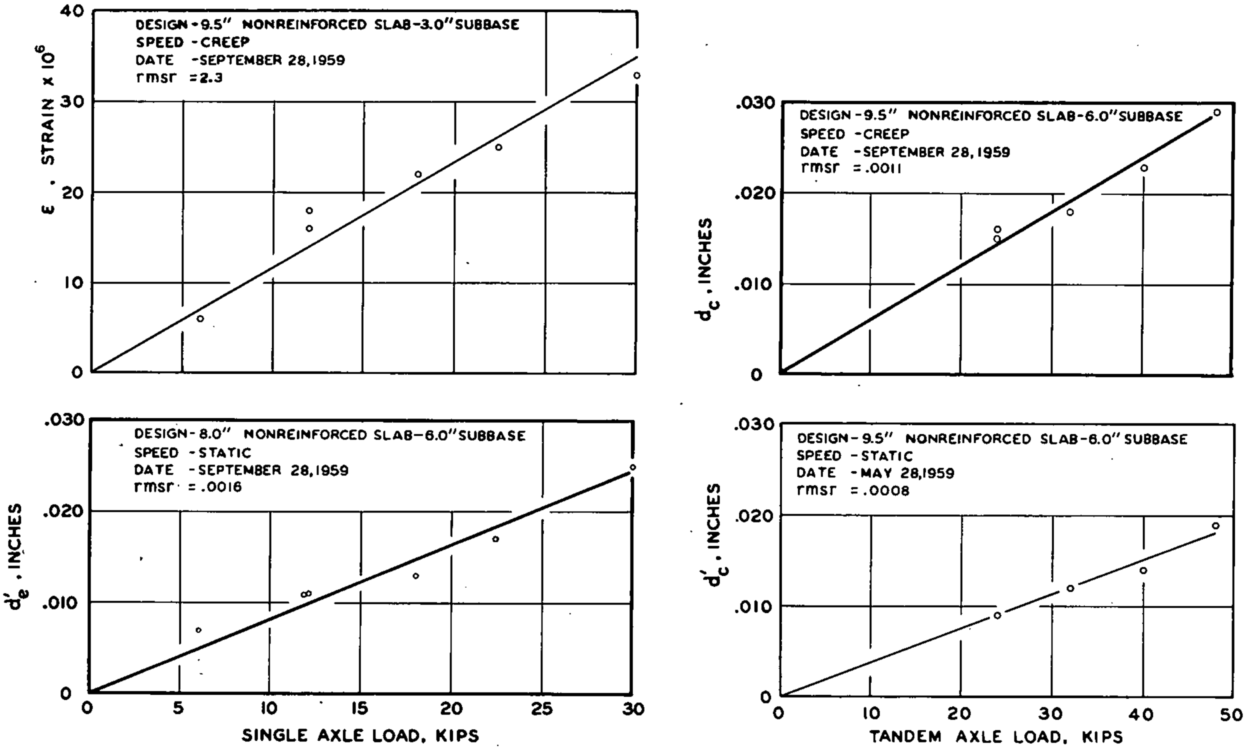


**Figure 148. Typical results from load studies.**

attempt to isolate these effects from those of load and design. Tables 64 and 65 give the dates, loads, and slab thicknesses tested in seven special experiments. In each experiment from four to nine sections were tested at frequent intervals during a 24-hr period.

The principal objective of these experiments was to investigate the correlation between the temperature differential existing between the top and bottom surfaces of a 6.5-in. slab selected as a standard and the changes in strain or deflection in pavements of various thicknesses, when load and design were held constant. Temperature data from the standard slab were recorded at hourly intervals during the two years of traffic testing. If suitable correlation existed, it would be possible to represent by a single equation data collected under widely varying temperature conditions.

Measurements taken during the 24-hr studies were plotted against the temperature differential existing in the standard slab (Fig. 149). The plots suggested the following mathematical model for representing the effect of temperature with design and load held constant:

$$\frac{Y}{L_1} = 10^{a_0 + a_1 T} \tag{75}$$

in which

$Y$ = dynamic edge strain, dynamic corner deflection, static rebound edge deflection or static rebound corner deflection;

$L_1$ = axle load, kips;

$T$ = temperature (°F) at a point $\frac{1}{4}$ in. below the top surface of the 6.5-in. slab minus the temperature at a point $\frac{1}{2}$ in. above the bottom surface, determined at the time the strain or deflection was measured ($T$ is referred to occasionally in the following sections as the standard differential);

$a_0$ = a coefficient, presumably dependent upon the conditions of load and design under which the strain or deflection data were obtained; and

$a_1$ = a constant presumably, representing the effect of temperature on $Y$.

The model was fitted separately to each series of observations made over the 24-hr test period on each section given in Tables 64 and 65, and the corresponding values of $a_0$, $a_1$ and the squared correlation coefficient, $r^2$, were com-

TABLE 61

LOAD STUDIES, DYNAMIC STRAIN AND DEFLECTION

| Axle Type | Axle Loads (kips) | Loop | Section Number | Slab Thickness (in.) | Date Tested | Speed (mph) | Root Mean Square Residual | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | For Edge Strain ($10^{-6}$ in./in.) | For Corner Deflection (in.) |
| Single | 6, 12, 18 | 4 | 705 | 6.5 | Sept. 29, 1959 | 5 | 1.0 | 0.0008 |
| | | | 671 | 8.0 | Sept. 29, 1959 | 5 | 2.1 | 0.0008 |
| | | | 691 | 8.0 | Sept. 29, 1959 | 5 | 2.1 | 0.0016 |
| | | | 691 | 8.0 | Sept. 29, 1959 | 35 | 1.8 | 0.0016 |
| | 6, 12, 18, 22.4, 30 | 6 | 393 | 8.0 | May 28, 1959 | 5 | 1.5 | 0.0007 |
| | | | 385 | 8.0 | May 28, 1959 | 5 | 1.4 | 0.0009 |
| | | | 353 | 8.0 | June 11, 1959 | 5 | 3.0 | 0.0003 |
| | | | 341 | 8.0 | June 11, 1959 | 5 | 1.6 | 0.0015 |
| | | | 381 | 9.5 | June 11, 1959 | 5 | 0.8 | 0.0008 |
| | | | 381 | 9.5 | Sept. 28, 1959 | 35 | 3.2 | 0.0007 |
| | | | 381 | 9.5 | Sept. 28, 1959 | 5 | 3.2 | 0.0008 |
| | | | 371 | 9.5 | Sept. 28, 1959 | 5 | 3.2 | 0.0036 |
| | | | 351 | 9.5 | Sept. 28, 1959 | 5 | 2.3 | 0.0011 |
| Tandem | 24, 32 | 4 | 705 | 6.5 | Sept. 29, 1959 | 5 | 2.1 | 0.0003 |
| | | | 691 | 8.0 | Sept. 29, 1959 | 5 | 2.4 | 0.0019 |
| | | | 671 | 8.0 | Sept. 29, 1959 | 5 | 0.9 | 0.0006 |
| | | | 691 | 8.0 | Sept. 29, 1959 | 35 | 2.3 | 0.0018 |
| | 24, 32, 40, 48 | 6 | 393 | 8.0 | May 28, 1959 | 5 | 3.0 | 0.0016 |
| | | | 385 | 8.0 | May 28, 1959 | 5 | 3.0 | 0.0015 |
| | | | 353 | 8.0 | June 11, 1959 | 5 | 6.4 | 0.0042 |
| | | | 341 | 8.0 | June 11, 1959 | 5 | 3.8 | 0.0013 |
| | | | 381 | 9.5 | June 11, 1959 | 5 | 3.3 | 0.0008 |
| | | | 381 | 9.5 | Sept. 28, 1959 | 5 | 1.6 | 0.0004 |
| | | | 371 | 9.5 | Sept. 28, 1959 | 5 | 3.3 | 0.0037 |
| | | | 351 | 9.5 | Sept. 28, 1959 | 5 | 2.9 | 0.0011 |
| | | | 381 | 9.5 | Sept. 28, 1959 | 35 | 2.6 | 0.0009 |

TABLE 62

LOAD STUDIES, STATIC DEFLECTION

| Axle Type | Axle Load (kips) | Loop | Section Number | Slab Thickness (in.) | Date Tested | Root Mean Square Residual (in.) | |
|---|---|---|---|---|---|---|---|
| | | | | | | At Corner | At Edge |
| Single | 6, 12, 18 | 4 | 705 | 6.5 | Sept. 29, 1959 | 0.0035 | 0.0025 |
| | | | 649 | 6.5 | Sept. 29, 1959 | 0.0025 | 0.0019 |
| | | | 649 | 6.5 | Sept. 29, 1959 | 0.0017 | 0.0026 |
| | | | 641 | 6.5 | Sept. 29, 1959 | 0.0035 | 0.0021 |
| | | | 671 | 8.0 | Sept. 29, 1959 | 0.0007 | 0.0013 |
| | | | 691 | 8.0 | Sept. 29, 1959 | 0.0029 | 0.0015 |
| | 6, 12, 18, 22.4, 30 | 6 | 393 | 8.0 | May 28, 1959 | 0.0009 | 0.0011 |
| | | | 385 | 8.0 | May 28, 1959 | 0.0020 | 0.0006 |
| | | | 353 | 8.0 | June 11, 1959 | 0.0015 | 0.0014 |
| | | | 341 | 8.0 | June 11, 1959 | 0.0011 | 0.0009 |
| | | | 393 | 8.0 | Sept. 28, 1959 | 0.0000 | 0.0016 |
| | | | 353 | 8.0 | Sept. 28, 1959 | 0.0021 | 0.0027 |
| | | | 341 | 8.0 | Sept. 28, 1959 | 0.0018 | 0.0014 |
| | | | 367 | 9.5 | May 28, 1959 | 0.0016 | 0.0018 |
| | | | 389 | 9.5 | May 28, 1959 | 0.0007 | 0.0009 |
| | | | 403 | 9.5 | May 28, 1959 | 0.0017 | 0.0025 |
| | | | 381 | 9.5 | June 11, 1959 | 0.0014 | 0.0013 |
| | | | 371 | 9.5 | June 11, 1959 | 0.0013 | 0.0016 |
| | | | 351 | 9.5 | June 11, 1959 | 0.0007 | 0.0017 |
| | | | 381 | 9.5 | Sept. 28, 1959 | 0.0021 | 0.0024 |
| | | | 371 | 9.5 | Sept. 28, 1959 | 0.0021 | 0.0030 |
| | | | 351 | 9.5 | Sept. 28, 1959 | 0.0031 | 0.0018 |
| Tandem | 24, 32 | 4 | 705 | 6.5 | Sept. 29, 1959 | 0.0010 | 0.0018 |
| | | | 649 | 6.5 | Sept. 29, 1959 | 0.0025 | 0.0010 |
| | | | 641 | 6.5 | Sept. 29, 1959 | 0.0007 | 0.0051 |
| | | | 691 | 8.0 | Sept. 29, 1959 | 0.0014 | 0.0025 |
| | | | 671 | 8.0 | Sept. 29, 1959 | 0.0019 | 0.0045 |
| | | | 687 | 8.0 | Sept. 29, 1959 | 0.0015 | 0.0023 |
| | 24, 32, 40, 48 | 6 | 393 | 8.0 | May 28, 1959 | 0.0024 | 0.0028 |
| | | | 385 | 8.0 | May 28, 1959 | 0.0014 | 0.0008 |
| | | | 353 | 8.0 | June 11, 1959 | 0.0019 | 0.0020 |
| | | | 341 | 8.0 | June 11, 1959 | 0.0019 | 0.0013 |
| | | | 393 | 8.0 | Sept. 28, 1959 | 0.0010 | 0.0011 |
| | | | 353 | 8.0 | Sept. 28, 1959 | 0.0019 | 0.0011 |
| | | | 341 | 8.0 | Sept. 28, 1959 | 0.0026 | 0.0034 |
| | | | 367 | 9.5 | May 28, 1959 | 0.0018 | 0.0030 |
| | | | 389 | 9.5 | May 28, 1959 | 0.0008 | 0.0009 |
| | | | 403 | 9.5 | May 28, 1959 | 0.0018 | 0.0036 |
| | | | 381 | 9.5 | June 11, 1959 | 0.0007 | 0.0012 |
| | | | 371 | 9.5 | June 11, 1959 | 0.0015 | 0.0012 |
| | | | 351 | 9 5 | June 11, 1959 | 0.0019 | 0.0016 |
| | | | 381 | 9.5 | Sept. 28, 1959 | 0.0011 | 0.0013 |
| | | | 371 | 9.5 | Sept. 28, 1959 | 0.0014 | 0.0016 |
| | | | 351 | 9.5 | Sept. 28, 1959 | 0.0022 | 0.0039 |

puted. As expected, $a_0$ was found to be related to design and load and is not considered further in this section. Tabulated average values of $a_1$ and $r^2$ from the different analyses are given in Tables 66, 67, 68 and 69.

Although $a_1$ varied considerably from section to section, and from one pavement thickness-axle load combination to another, there appeared to be no consistent trend of this coefficient with load and pavement thickness, as given by the weighted average values (Tables 66-69). In addition, inspection of the dynamic data gathered on May 12 and 13, 1960, for three different levels of vehicular speed (Table 64) failed to reveal any consistent trend of $a_1$ with speed.

From the data summarized in Table 70, it was concluded that usually a substantial amount (from 72 to 88 percent) of the variation in corner deflection observed during the 24-hr studies could be explained by the temperature statistic $T$, while from 34 to 42 percent of the variation in edge strain and deflection could be accounted for in the same way. As a result, the decision was made to combine Eqs. 74 and 75 into the following general model for use in the analysis of strain and deflection:

$$\frac{\text{Strain (or deflection)}}{\text{Axle load}} = f\text{ (design and random variables) x }10^{a_1 T} \qquad (76)$$

From the definition previously given, $T$, the standard differential, was positive when the top surface of the standard 6.5-in. slab was warmer than the bottom. Inspection of nearly 4,400 hourly observations of $T$ made from April 1 through September 30, 1959, revealed that 98 percent of the values were within the range, —10 F to +20 F. This range was therefore judged to be representative of the Ottawa area and was chosen for use in the graphs of the equations for strains and deflections given in the following subsections.

TABLE 63

AVERAGE ROOT MEAN SQUARE RESIDUAL FOR EACH TYPE OF MEASUREMENT INVESTIGATED IN SPECIAL LOAD STUDIES

| Measurement System | Unit of Measure | Average Root Mean Square Residual |
|---|---|---|
| Dynamic edge strain | $10^{-6}$ in./in. | 2.5 |
| Dynamic corner deflection | Inch | 0.0014 |
| Static corner deflection | Inch | 0.0017 |
| Static edge deflection | Inch | 0.0020 |

### *3.3.4 Dynamic Edge Strain as a Function of Design, Load and Temperature*

Dynamic edge strain data from rounds 4, 5, 8 and 9 (see Table 56) gathered between April and August 1959 were selected for use in determining an empirical relationship between edge strain, design, load and temperature. These rounds covered a representative range of spring, summer and fall temperatures and a great majority of the test sections were still in good condition, as determined by visual inspection, at the time and point of testing. Data from Loop 2 were excluded from the analysis after it was found that strain measurements on the 2.5-in. slabs (the only thickness instrumented in that loop) appeared to be inconsis-

TABLE 64

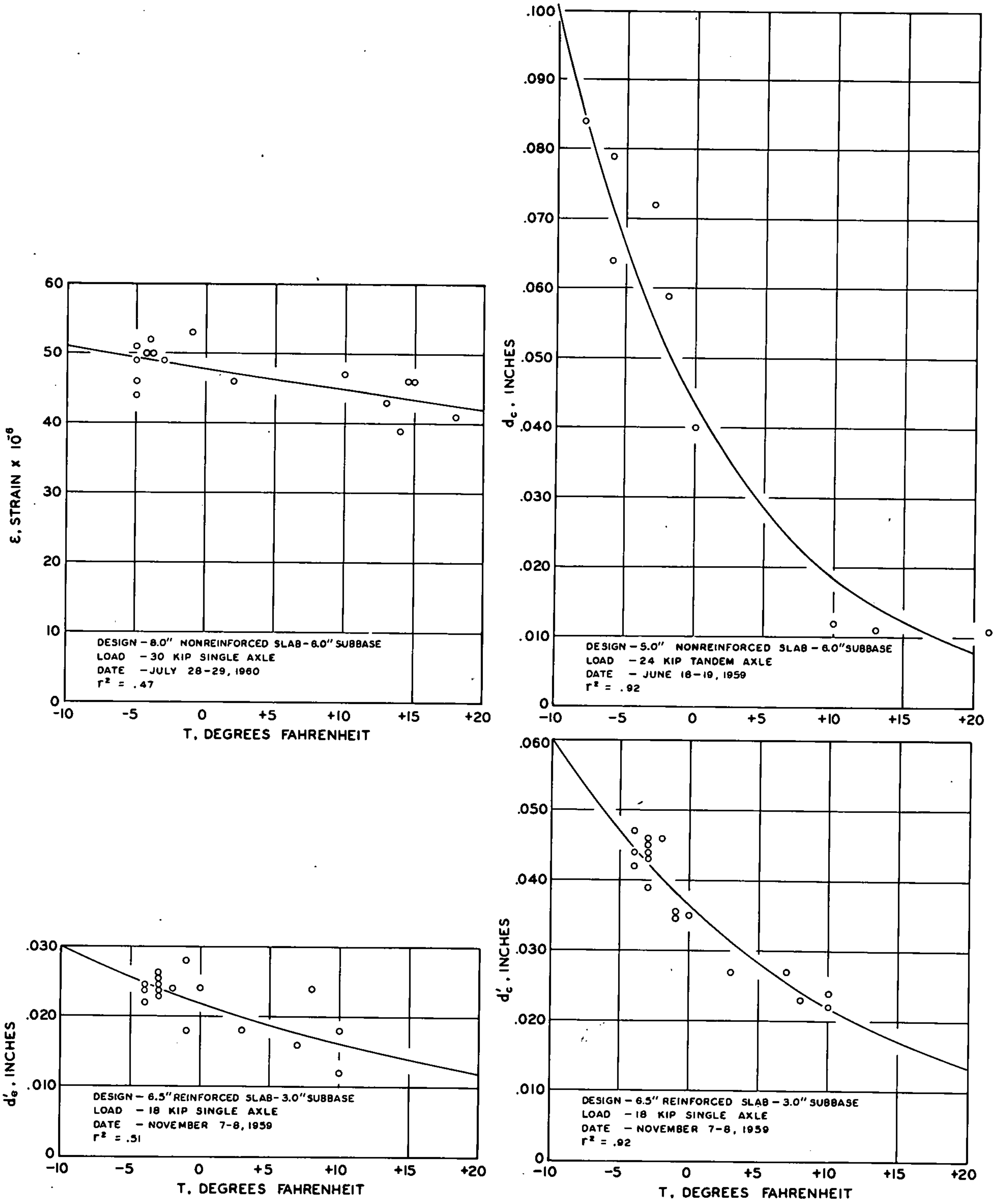
SCHEDULE OF SPECIAL 24-HOUR STUDIES OF DYNAMIC MEASUREMENTS VERSUS TEMPERATURE

| Date | Loop | Axle Type | Axle Load (kips) | Speed (mph) | Slab Thick. (in.) | No. Sections Tested |
|---|---|---|---|---|---|---|
| June 18-19, 1959 | 3 | Tandem | 24 | 35 | 5.0 | 1 |
| | | | | | 6.5 | 3 |
| Nov. 9-10, 1959 | 3 | Single | 12 | 35 | 5.0 | 3 |
| | | | | | 8.0 | 2 |
| May 12-13, 1960 | 6 | Single | 6, 12, 18, 22.4, 30 | 5, 20, 35 | 8.0 | 1 |
| | | | | | 9.5 | 1 |
| | | | | | 11.0 | 2 |
| | | | | | 12.5 | 1 |
| July 28-29, 1960 | 6 | Single | 30 | 35 | 8.0 | 1 |
| | | | | | 9.5 | 2 |
| | | | | | 11.0 | 1 |
| | | | | | 12.5 | 1 |

TABLE 65

SCHEDULE OF SPECIAL 24-HOUR STUDIES OF STATIC MEASUREMENTS VERSUS TEMPERATURE

| Date | Loop | Axle Type | Axle Load (kips) | Slab Thick. (in.) | No. Sections Tested |
|---|---|---|---|---|---|
| Nov. 7-8, 1959 | 4 | Single | 18 | 6.5 | 5 |
| | | | | 9.5 | 4 |
| Aug. 22-23, 1960 | 6 | Single | 30 | 8.0 | 2 |
| | | | | 9.5 | 3 |
| | | | | 11.0 | 2 |
| | | | | 12.5 | 2 |
| Oct. 1-2, 1960 | 6 | Single | 30 | 8.0 | 3 |
| | | | | 9.5 | 3 |
| | | | | 11.0 | 1 |
| | | | | 12.5 | 2 |



EDGE MEASUREMENTS

CORNER MEASUREMENTS

Figure 149. Typical results from temperature studies.

## TABLE 66

### AVERAGE VALUES OF $a_1$ AND $r^2$ FROM DYNAMIC EDGE STRAIN DATA FOR PAVEMENT THICKNESS-AXLE LOAD COMBINATIONS OCCURRING IN THE 24-HOUR TEMPERATURE STUDIES[1]

| Statistic | Axle | | Average Value | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Type | Load (kips) | 5.0-In. Slab | 6.5-In. Slab | 8.0-In. Slab | 9.5-In. Slab | 11.0-In. Slab | 12.5-In. Slab | Wtd. Avg. |
| $a_1$ | Single | 12 | −0.0030 (3) | | −0.0029 (2) | | | | −0.0030 (5) |
| | Single | 30 | | | −0.0028 (1) | −0.0009 (2) | +0.0002 (1) | +0.0009 (1) | −0.0007 (5) |
| | Single | Mixed[2] | | | −0.0014 (3) | −0.0004 (3) | −0.0017 (6) | −0.0020 (3) | −0.0014 (15) |
| | Tandem | 24 | −0.0038 (1) | −0.0052 (3) | | | | | −0.0049 (4) |
| | Wtd. avg. | | −0.0032 (4) | −0.0052 (3) | −0.0021 (6) | −0.0011 (5) | −0.0014 (7) | −0.0013 (4) | −0.0021 (29) |
| $r^2$ | | | | | | | | | 0.34 |

[1] Values in parentheses are number of sections observed.

[2] 6-, 12-, 18-, 22.4- and 30-kip single axle loads.

## TABLE 67

### AVERAGE VALUES OF $a_1$ AND $r^2$ FROM DYNAMIC CORNER DEFLECTION DATA FOR PAVEMENT THICKNESS-AXLE LOAD COMBINATIONS OCCURRING IN THE 24-HOUR TEMPERATURE STUDIES[1]

| Statistic | Axle | | Average Value | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Type | Load (kips) | 5.0-In. Slab | 6.5-In. Slab | 8.0-In. Slab | 9.5-In. Slab | 11.0-In. Slab | 12.5-In. Slab | Wtd. Avg. |
| $a_1$ | Single | 12 | −0.051 (3) | | −0.030 (2) | | | | −0.043 (5) |
| | Single | 30 | | | −0.012 (1) | −0.014 (2) | −0.017 (1) | 0.010 (1) | −0.013 (5) |
| | Single | Mixed[2] | | | −0.027 (3) | −0.022 (3) | −0.019 (6) | −0.020 (3) | −0.021 (15) |
| | Tandem | 24 | −0.037 (1) | −0.037 (3) | | | | | −0.037 (4) |
| | Wtd. avg. | | −0.048 (4) | −0.037 (3) | −0.026 (6) | −0.019 (5) | −0.019 (7) | −0.018 (4) | −0.026 (29) |
| $r^2$ | | | | | | | | | 0.88 |

[1] Values in parentheses are number of sections observed.

[2] 6-, 12-, 18-, 22.4- and 30-kip single axle loads.

## TABLE 68

## Average Values of $a_1$ and $r^2$ from Static Rebound Edge Deflection Data for Pavement Thickness-Axle Load Combinations Occurring in the 24-Hour Temperature Studies[1]

| Statistic | Axle | | Average Value | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Type | Load (kips) | 6.5-In. Slab | 8.0-In. Slab | 9.5-In. Slab | 11.0-In. Slab | 12.5-In. Slab | Wtd. Avg. |
| $a_1$ | Single | 18 | −0.012 (5) | | −0.012 (4) | | | −0.012 (9) |
| | Single | 30 | | −0.005 (5) | −0.010 (6) | −0.011 (3) | −0.002 (4) | −0.007 (18) |
| | Wtd. Avg. | | −0.012 (5) | −0.005 (5) | −0.011 (10) | −0.011 (3) | −0.002 (4) | −0.009 (27) |
| $r^2$ | | | | | | | | 0.42 |

[1] Values in parentheses are number of sections observed.

## TABLE 69

## Average Values of $a_1$ and $r^2$ from Static Rebound Corner Deflection Data for Pavement Thickness-Axle Load Combinations Occurring in the 24-Hour Temperature Studies[1]

| Statistic | Axle | | Average Value | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Type | Load (kips) | 6.5-In. Slab | 8.0-In. Slab | 9.5-In. Slab | 11.0-In. Slab | 12.5-In. Slab | Wtd. Avg. |
| $a_1$ | Single | 18 | −0.021 (5) | | −0.014 (4) | | | −0.018 (9) |
| | Single | 30 | | −0.009 (5) | −0.014 (6) | −0.014 (3) | −0.008 (4) | −0.011 (18) |
| | Wtd. Avg. | | −0.021 (5) | −0.009 (5) | −0.014 (10) | −0.014 (3) | −0.008 (4) | −0.013 (27) |
| $r^2$ | | | | | | | | 0.72 |

[1] Values in parentheses are number of sections observed.

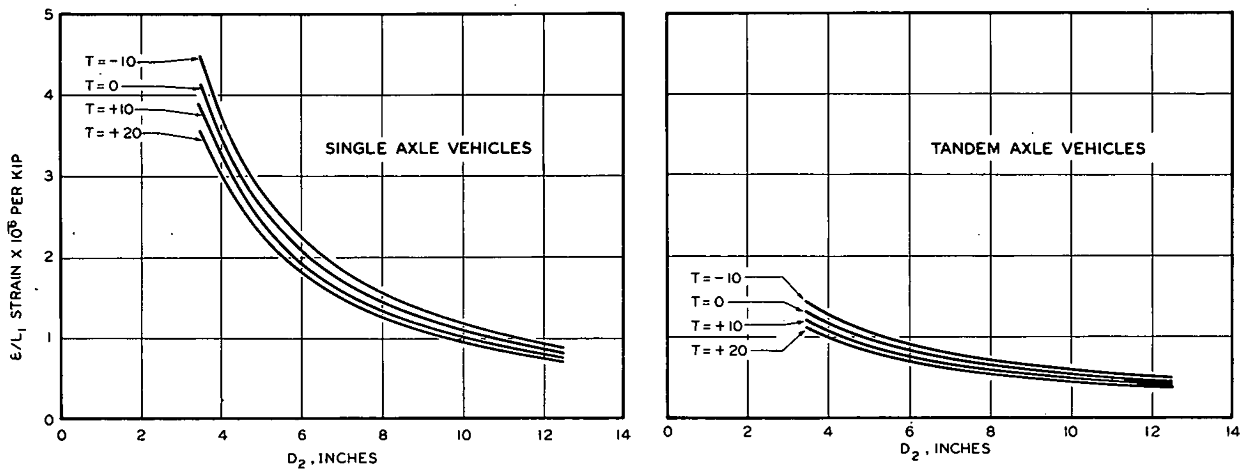


Figure 150. Dynamic edge strains, showing effect of temperature and pavement thickness.

tent with the data from the other loops. (Two-thirds of the observations made in Loop 2 were less than two-thirds, on the average, of the corresponding values predicted by Eq. 78.)

Plots of the data, together with information furnished by the special load studies (Section 3.3.2) and the 24-hr temperature studies (Section 3.3.3), led to the selection of the following model for use in the analysis:

$$\frac{\varepsilon}{L_1} = \frac{A_0}{10^{A_1 T} D_2^{A_2}} \tag{77}$$

in which $\varepsilon$ is dynamic edge strain x $10^{-6}$ in. per in.; $A_0$, $A_1$ and $A_2$ are positive constants to be determined from the analysis; and the other symbols are as previously defined.

The analysis indicated that the design variable, reinforcing (or slab length), was not significant. The following equations resulted:

*For single axle vehicles:*

$$\frac{\varepsilon}{L_1} = \frac{20.54}{10^{0.0031T} D_2^{1.278}} \tag{78}$$

TABLE 70

SUMMARY OF AVERAGES OF $a_1$ AND $r^2$ FOR 24-HOUR TEMPERATURE STUDIES

| Measurement | | Average for All Thicknesses and Speeds | |
|---|---|---|---|
| Point | Type | $a_1$ | $r^2$ |
| Edge | Dynamic strain | −0.002 | 0.34 |
| | Static deflection | −0.009 | 0.42 |
| Corner | Dynamic deflection | −0.026 | 0.88 |
| | Static deflection | −0.013 | 0.72 |

*For tandem axle vehicles:*

$$\frac{\varepsilon}{L_1} = \frac{3.814}{10^{0.0035T} D_2^{0.8523}} \tag{79}$$

Graphs of Eqs. 78 and 79 are shown in Figure 150. Residuals that are less than the average root mean square residual determined in the two analyses correspond to observations that range from 83 to 120 percent of the predicted values. The coefficients of $T$ were found to be 0.0031 and 0.0035, as compared to a value of 0.002 determined from the special 24-hr temperature studies (Table 70).

### *3.3.5 Dynamic Corner Deflection as a Function of Design and Load*

Of the four kinds of measurements discussed in Section 3.3.3 the least satisfactory (both from the standpoint of the time involved in making the measurements and certain unexplained reversals of trend in the data from section to section and from round to round) was the measurement of dynamic deflection. Since the same instrument van and crew were used for measuring both dynamic deflection and strain, it was decided early in the program that dynamic deflection would be measured only occasionally, and that the men and equipment available would be used primarily in making strain measurements that could be accumulated at a relatively rapid rate. Meanwhile, ample deflection data were gathered by a different crew making static rebound measurements with the Benkelman beam (see Table 57 and Sections 3.3.6 and 3.3.7).

Of the dynamic deflection data available, those from round 9 (gathered in July and August 1959 between 7:00 p.m. and 6:00 a.m.) were selected for analysis. Data from the 3.5-in. and 5.0-in. pavements were excluded from the analysis because they were inconsistent with data from the remaining six thickness levels tested. However, they were included in the error computations. Following is the general model chosen to represent the data:

$$\frac{d_c}{L_1} = A_0 D_2^{A_1} \tag{80}$$

in which $d_c$ is dynamic corner deflection in inches; $A_0$ and $A_1$ are constants to be determined from the analysis; and the other symbols are as previously defined.

Four separate equations resulted from the analyses as follows:

*For single axle vehicles on nonreinforced pavement:*

$$\frac{d_c}{L_1} = \frac{0.0214}{D_2^{1.374}} \tag{81}$$

*For single axle vehicles on reinforced pavement:*

$$\frac{d_c}{L_1} = \frac{0.0256}{D_2^{1.374}} \tag{82}$$

*For tandem axle vehicles° on nonreinforced pavement:*

$$\frac{d_c}{L_1} = \frac{0.00521}{D_2^{0.870}} \tag{83}$$

*For tandem axle vehicles on reinforced pavement:*

$$\frac{d_c}{L_1} = \frac{0.00623}{D_2^{0.870}} \tag{84}$$

The average absolute error, expressed as a percentage of the predicted deflections, ranged from 25 to 35 percent for the four equations, the average for all four being 29 percent.

An effort was made to include in these equations a term for the standard differential $T$, described in Section 3.3.3, but without success probably because not much variation in $T$ was observed during the period of testing.

Graphs of the Eqs. 81 through 84 for dynamic corner deflection are shown in Figure 151. The graphs show that the dynamic deflection measured under a given axle load at the corner of a 40-ft reinforced panel usually was greater than the corresponding deflection of a 15-ft nonreinforced panel of the same thickness and under the same load. A similar difference in static rebound deflections at the corner of 40- and 15-ft panels was also observed (see Section 3.3.7).

### *3.3.6 Static Edge Deflection as a Function of Design, Load and Temperature*

Static rebound edge deflection data from rounds 1 through 3 and 5 through 9, gathered from April to September 1959, were selected for analysis.* The dates of individual rounds and the hours during which the measurements were made in each round are given in Table 57. Measurement methods and procedures are described in Section 3.3.1.2.

The model selected for use in the analysis, based on Eq. 76 and plots of the deflection data, is

$$\frac{d'_e}{L_1} = \frac{A_0}{10^{A_1 T} D_2^{A_2}} \tag{85}$$

in which $d'_e$ is static rebound edge deflection, in in.; $L_1$, $T$, and $D_2$ are as previously defined; and $A_0$, $A_1$ and $A_2$ are constants to be determined from the analysis of the data.

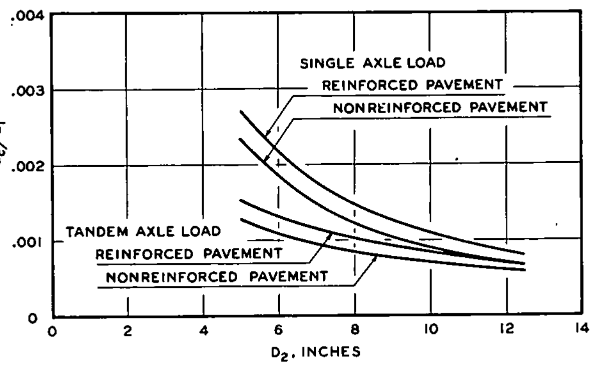


**Figure 151. Dynamic corner deflection, showing effect of reinforcing (or panel length) and pavement thickness.**

As in the case of edge strains the design variable, reinforcing (or slab length) was not significant. The resulting equations are as follows:

*For single axle vehicles:*

$$\frac{d'_e}{L_1} = \frac{0.00883}{10^{0.0075T} D_2^{1.178}} \tag{86}$$

*For tandem axle vehicles:*

$$\frac{d'_e}{L_1} = \frac{0.00279}{10^{0.010T} D_2^{0.711}} \tag{87}$$

Residuals that are less than the average root mean square residual determined in the two analyses correspond to observations that range from 74 to 135 percent of the predicted values.

This analysis, as in the case of the analysis made of dynamic edge strain, indicated that the design factor of reinforcing was not significant.

Figure 152 shows graphs of Eqs. 86 and 87

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* Data from Loop 2 were excluded from the analysis because the data were not consistent with those from the other loops.

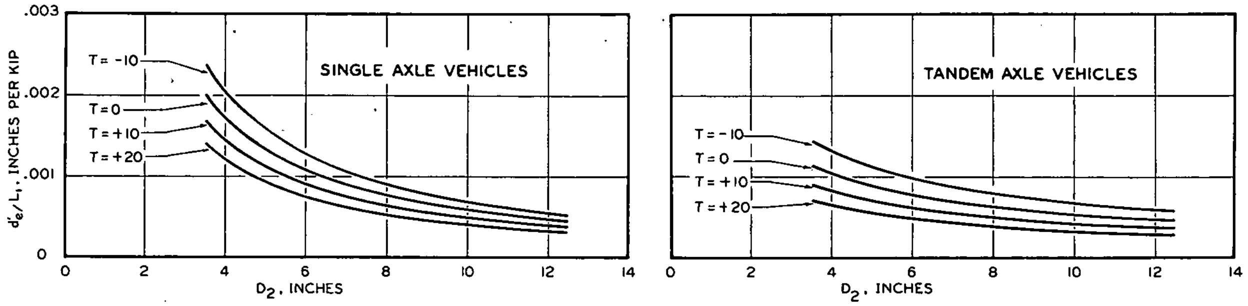

**Figure 152. Static rebound edge deflection, showing effect of temperature and pavement thickness.**

for several values of the temperature statistic *T*. The values of the coefficient of *T*, 0.0075 and 0.0100, found in the analyses compare favorably with the value 0.009 determined in the special 24-hr temperature studies (Table 70).

### *3.3.7 Static Corner Deflection as a Function of Design, Load and Temperature*

Static rebound corner deflection data selected for analysis were taken from the same rounds as the static rebound edge deflections (see Section 3.3.6). The same general model was also used. As in the case of dynamic corner deflections (see Section 3.3.5) the design factor, reinforcing and/or panel length, was found to have a significant effect with the result that four equations were developed as follows:

*For single axle vehicles on nonreinforced pavement:*

$$\frac{d'_c}{L_1} = \frac{0.013}{10^{0.011T} D_2^{1.25}} \qquad (88)$$

*For single axle vehicles on reinforced pavement:*

$$\frac{d'_c}{L_1} = \frac{0.013}{10^{0.015T} D_2^{1.18}} \qquad (89)$$

*For tandem axle vehicles on nonreinforced pavement:*

$$\frac{d'_c}{L_1} = \frac{0.00443}{10^{0.011T} D_2^{0.900}} \qquad (90)$$

*For tandem axle vehicles on reinforced pavement:*

$$\frac{d'_c}{L_1} = \frac{0.00443}{10^{0.015T} D_2^{0.767}} \qquad (91)$$

In these equations the symbol $d'_c$ represents static rebound corner deflection in inches, and the other symbols are as previously defined.

Residuals that are less than the average root mean square residual determined in the four analyses correspond to observations that range from 73 to 137 percent of the predicted values.

The values, 0.011 and 0.015, of the coefficient of *T* in Eqs. 88-91 may be compared with the value, 0.013, found from the special 24-hr temperature studies (Table 70).

Figure 153 shows graphs of the four equations for a range of values of the standard differential, *T*. The deflection at the corner of 40-ft panels usually exceeded the deflection at the corner of 15-ft panels other factors remaining constant, as was the case also for dynamic corner deflections (Section 3.3.5). On the other hand, static edge deflection, measured at a point at least 7.5 ft from the nearest joint, was found not to be significantly affected by panel length (see Section 3.3.6). It is concluded that for pavements constructed with different spacings of transverse joints, comparisons of deflections can better be made at a point at some distance from a joint than at a panel corner, unless the object of the comparison is to differentiate between joint designs or spacings.

### *3.3.8 Strain and Deflection as Functions of Speed*

Studies of the effect of speed on dynamic edge strain and dynamic corner deflection were conducted in Loops 4 and 6 in August, September and December 1959.* Table 71 gives the loads, nominal speeds and the number of sections of each thickness tested on the six study days.

Strains and deflections were measured with the equipment and in accordance with the procedure described in Section 3.3.1.1. In addition, the following special procedures were followed:

Several single axle vehicles of the specified loadings were assembled on Loop 4 or 6 and arranged in random order of load. The vehicles then proceeded around the loop at one of the selected speeds, measurements meanwhile being taken at one of the test sections. The vehicles continued to circle the loop until at least three readings of the section gages had been obtained for each axle load with the vehicles at

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* Simultaneously, speed studies were made on the flexible tangents as described in Section 2.3.6.

the proper transverse placement (see Figure 138). Then a new speed, selected at random, was assigned the vehicles, and the process repeated until the section had been tested under all combinations of nominal speed and axle load. Actual speeds were calculated from the recorded traces of the output of the gages and averaged over the three or more readings taken for each nominal speed-axle load combination. This procedure was repeated for each test section; the over-all time required was about 6 hr per loop.

For each axle load-test section combination occurring on a given day in Table 71, a table was prepared listing simultaneous values of the observed data (strain or deflection) and speed (typical graphs of the data are given in Fig. 154). To smooth the data (as well as to separate the speed effect from that of load, design, and temperature differential) a two-parameter model was fitted to the data from each of the 124 tables representing the results of the studies. The model, suggested by plots of the kind shown in Figure 154, was as follows:

$$Y = 10^{a_0+a_1 v} \tag{92}$$

in which

$Y$ = strain, in $10^{-6}$ in. per in., or deflection, in in.;

$v$ = speed, mph, within the observed range of 2 to 60;

$a_0$ = a coefficient presumed to depend upon the conditions of design, load and temperature under which the data were collected; and

$a_1$ = a constant presumed to represent the speed effect.

For each of the 124 sets of data a value of $a_0$, $a_1$ and $r^2$ was computed. The coefficient, $a_0$, as expected, was obviously related to design and load; $a_1$ exhibited no consistent trends with any known variables. The squared corrélation coefficient $r^2$ averaged 0.74 for the strain data and 0.71 for the deflection data. Table 72 gives average values of $a_1$ for strain and deflection data corresponding to each load-pavement thickness combination. The mean of all values of $a_1$ computed from strain data differed from the mean value computed from corner deflection data by only 0.0004. In view of the variability of the data, this difference was not considered significant and an average value of $a_1$ of 0.0026 was taken to represent the effect of speed on either dynamic edge strain or dynamic corner deflection.

The effect of speed on strain or deflection can be demonstrated as follows:

With $a_1$ = —0.0026, Eq. 92 becomes

$$Y = 10^{(a_0\ -0.0026v)} \tag{93}$$

$R$ is chosen to represent the estimated percentage reduction in edge strain or corner de-

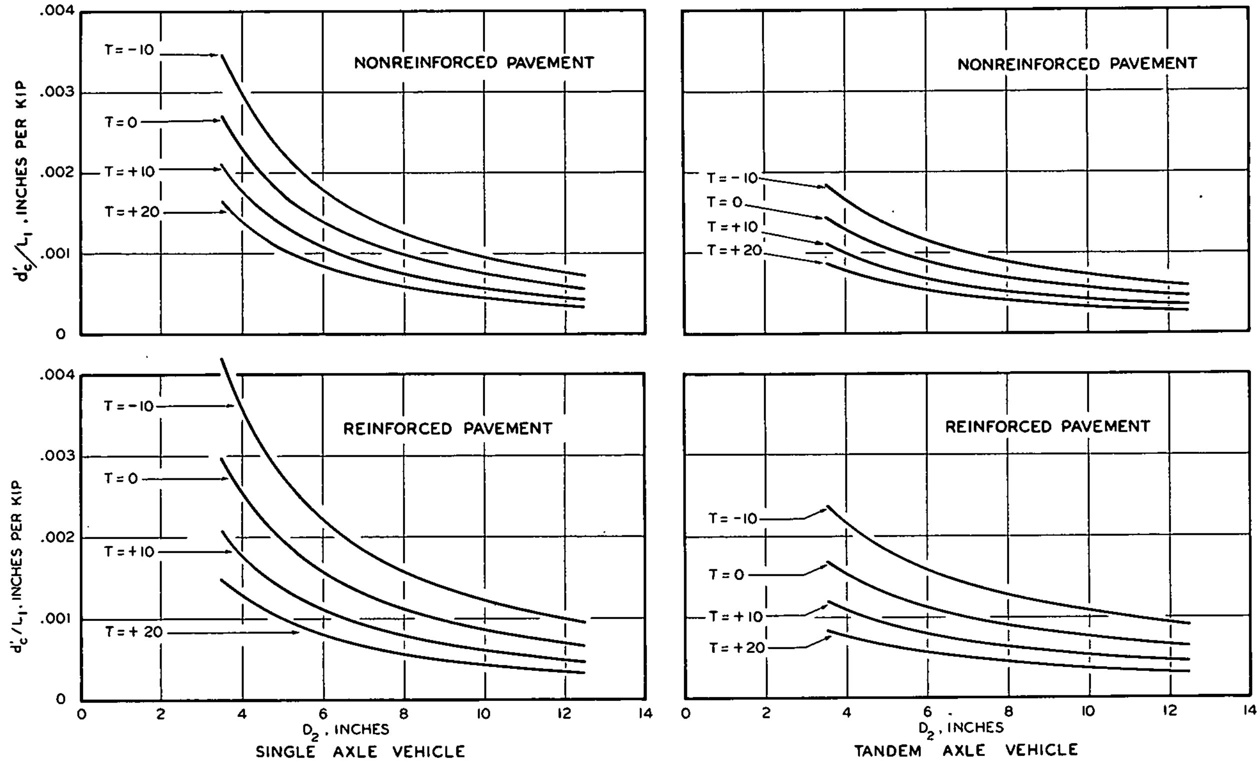

Figure 153. Static rebound corner deflection, showing effect of reinforcing (or panel length), temperature, and pavement thickness.

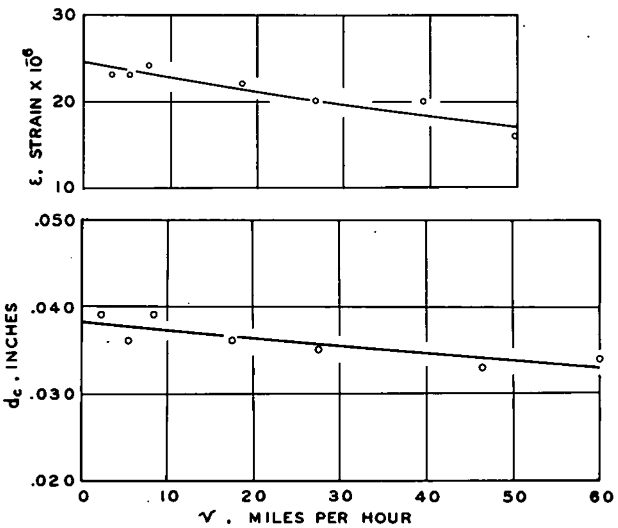

Figure 154. Typical results from speed studies.

flection for a rigid pavement test section of any design, as a single axle load increases in speed from 2 mph to the speed $v$ where $v \leq 60$ and the temperature differential $T$ remains fixed during the period of acceleration. Under these conditions $a_0$ is fixed and

$$R = 100 \, (1 - 1.012 \times 10^{-0.0026v}) \qquad (94)$$

Figure 155 plots $R$ against $v$ showing that an increase in speed from 2 to 60 mph resulted in a decrease in strain or deflection of about 29 percent.

### *3.3.9 Variation of Deflection Across Loops*

At intervals between April 1959 and June 1960, static rebound edge and corner deflections were measured under a 12-kip single axle load on all test sections in Design 1, Loops 3 through 6, for the purpose of determining whether a difference in deflection level existed between pavements of the same design but located in different lanes or loops. (Direct comparisons between sections in different lanes could not be made on the basis of routine deflection data since loop loads were used and these were different in every lane.) Eight rounds of data were gathered as given in Table 73 in which round averages for sections are grouped according to the time of day the deflections were measured to facilitate comparisons between rounds. To permit comparisons somewhat beyond the time when the weaker sections began to fail, data from all sections of the thinnest level of pavement thickness in each loop have been excluded from the averages. No consistent long-time trends in deflection level are apparent, as was also the case for the average deflection data in Tables 58, 59 and 60.

A portion of the data from round 1 (April 1959) was selected to represent the deflection level of the pavements prior to the development of excessive pumping. To permit sound comparisons across two or more loops it was necessary to limit the study to designs which were common to those loops. A choice was made of the 6.5- and 8.0-in. sections common to Loops 3, 4 and 5, and of the 8.0- and 9.5-in. sections

TABLE 71

SCHEDULE OF SPEED STUDIES

| Loop | Single Axle Load (kips) | Date | Nominal Speed (mph) | Slab Thickness (in.) | No. Sections Tested |
|---|---|---|---|---|---|
| 4 | 12, 18 | 8/27/59 | Creep, 5, 10, 20, 30, 40, 50 | 5 | 2 |
| | | | | 8 | 2 |
| | | 10/ 1/59 | Creep, 5, 10, 20, 30, 40, 50 | 6.5 | 3 |
| | | | | 8 | 3 |
| | | | | 9.5 | 2[1] |
| | | 12/ 2/59[2] | Creep, 5, 10, 20, 30, 40, 50 | 6.5 | 3 |
| | | | | 8 | 3 |
| | | | | 9.5 | 1 |
| 6 | 12, 30 | 8/26/59 | Creep, 5, 10, 20, 30, 40, 50 | 8 | 2 |
| | | | | 11 | 2 |
| | | 9/30/59 | Creep, 5, 10, 20, 30, 40 | 8 | 2 |
| | | | | 9.5 | 3 |
| | | | | 11 | 3 |
| | | 12/ 1/59[2] | Creep, 5, 10, 20, 30, 40 | 8 | 2 |
| | | | | 9.5 | 3 |
| | | | | 11 | 3 |

[1] Only one 9.5-in. section deflection tested.

[2] Deflection not measured on this date.

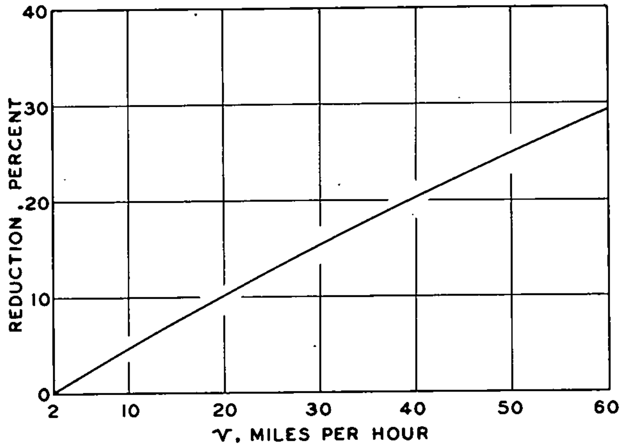

**Figure 155. Percentage reduction in edge strain or corner deflection with increase in vehicular speed.**

common to Loops 4, 5 and 6. These two groups, designated designs A and B, respectively, are shown in Table 74. There were 16 pairs of replicates in each design; therefore, differences between replicate sections could be used to test the statistical significance of any differences observed between loops or between lanes. In this section all significance tests were made at the 5 percent level.

Table 75 gives mean values of the deflections, first by loops and then by lanes. The aim of the analysis of variance was to test the statistical significance of the differences between the two or three mean deflections within each group. The findings were as follows:

1. In design A, the mean corner deflection for Loop 3 was significantly lower than that for Loops 4 and 5. The edge deflection for Loop 3 was also lower than that for Loops 4 and 5, but was not significant.
2. In design A, the mean corner deflection for lane 2 was significantly lower than that for lane 1. The mean edge deflection for lane 2 was also lower than for lane 1, but was not significant.
3. In design B, the mean corner deflection for Loop 6 was significantly lower than for Loop 4.
4. In design B, the mean edge deflection for lane 2 was significantly lower than that for lane 1. The mean corner deflection was also lower for lane 2 than for lane 1, but was not significant.

The reasons for the lower deflection in Loop 3, design A, and Loop 6, design B, are unknown, as are the reasons for consistently lower deflections in Lane 2. Although certain differences were shown to be statistically significant by the analysis, the maximum difference occurring in either experiment design (Table 75) was only 0.0015 in., a value which

TABLE 72

AVERAGE VALUES OF $a_1$ AND $r^2$ FOR PAVEMENT THICKNESS-LOAD COMBINATIONS OCCURRING IN SPEED STUDIES[1]

| Type of Measurement | Single Axle Load (kips) | $a_1$ | | | | | | $r^2$ |
|---|---|---|---|---|---|---|---|---|
| | | 5.0-In. Pvt. | 6.5-In. Pvt. | 8.0-In. Pvt. | 9.5-In. Pvt. | 11.0-In. Pvt. | Avg. | |
| Dynamic edge strain | 12 | −0.0019 (2) | −0.0038 (6) | −0.0025 (14) | −0.0028 (9) | −0.0023 (8) | | |
| | 18 | −0.0020 (2) | −0.0035 (6) | −0.0032 (8) | −0.0031 (3) | | | |
| | 30 | | | −0.0024 (6) | −0.0036 (6) | −0.0024 (8) | | |
| | Avg. | | | | | | −0.0028 | 0.74 |
| Dynamic corner defl. | 12 | −0.0014 (2) | −0.0020 (3) | −0.0023 (9) | −0.0037 (4) | −0.0030 (5) | | |
| | 18 | −0.0023 (2) | −0.0021 (3) | −0.0021 (5) | −0.0024 (1) | | | |
| | 30 | | | −0.0020 (4) | −0.0020 (3) | −0.0029 (5) | | |
| | Avg. | | | | | | −0.0024 | 0.71 |

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[1] Number of occurrences of each design-load combination shown in parentheses.

TABLE 73

SCHEDULE OF SPECIAL STATIC REBOUND DEFLECTION STUDIES WITH 12-KIP SINGLE AXLE LOAD, EXPERIMENT DESIGN 1
(Data available in DS 5283)

| Grouping by Time of Day | Hours | | Round Number | Mid-Date of Observation Period | Average Deflection, Loops 3, 4, 5, 6 (in.)[1] | |
|---|---|---|---|---|---|---|
| | From | To | | | At Edge | At Corner |
| Early morning | 0500 | 1000 | 2 | May 8, 1959 | 0.014 | 0.020 |
| | 0700 | 1000 | 6 | April 7, 1960 | 0.013 | 0.019 |
| Midday | 1000 | 1700 | 1 | April 18, 1959 | 0.007 | 0.010 |
| | 1100 | 1530 | 3 | July 29, 1959 | 0.008 | 0.008 |
| | 1100 | 1500 | 4 | September 9, 1959 | 0.008 | 0.010 |
| | 1100 | 1600 | 5 | December 9, 1959 | 0.009 | 0.012 |
| Late afternoon | 1800 | 2100 | 7 | April 20, 1960 | 0.015 | 0.019 |
| | 1700 | 2000 | 8 | June 23, 1960 | 0.010 | 0.012 |

[1] Thinnest level in each loop excluded.

could hardly be considered of practical significance. (For example, see Fig. 160 where the effect on pavement life of a difference of 0.0015 in. in corner deflection may be estimated.)

TABLE 74

TEST SECTIONS SELECTED FOR DETERMINATION OF VARIABILITY OF DEFLECTION ACROSS LOOPS AND LANES

| | | | SLAB THICKNESS INCHES | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 6.5 | | 8.0 | | 9.5 | |
| | | SUB. THICK. IN. | REINFORCING | | | | | |
| LOOP | LANE | | R | N | R | N | R | N |
| 3 | 1 | 3 | 1 | 2 | 1 | 1 | SECTIONS IN DESIGN A | |
| | | 6 | 2 | 1 | 1 | 1 | | |
| | | 9 | 1 | 1 | 1 | 1 | | |
| | 2 | 3 | 1 | 2 | 1 | 1 | | |
| | | 6 | 2 | 1 | 1 | 1 | | |
| | | 9 | 1 | 1 | 1 | 1 | | |
| 4 | 1 | 3 | 2 | 1 | 1 | 2 | 1 | 1 |
| | | 6 | 1 | 2 | 2 | 1 | 1 | 1 |
| | | 9 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 2 | 3 | 2 | 1 | 1 | 2 | 1 | 1 |
| | | 6 | 1 | 2 | 2 | 1 | 1 | 1 |
| | | 9 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | 1 | 3 | 1 | 1 | 2 | 1 | 1 | 2 |
| | | 6 | 1 | 1 | 1 | 2 | 2 | 1 |
| | | 9 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 2 | 3 | 1 | 1 | 2 | 1 | 1 | 2 |
| | | 6 | 1 | 1 | 1 | 2 | 2 | 1 |
| | | 9 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 3 | SECTIONS IN DESIGN B | | 1 | 1 | 2 | 1 |
| | | 6 | | | 1 | 1 | 1 | 2 |
| | | 9 | | | 1 | 1 | 1 | 1 |
| | 2 | 3 | | | 1 | 1 | 2 | 1 |
| | | 6 | | | 1 | 1 | 1 | 2 |
| | | 9 | | | 1 | 1 | 1 | 1 |

## 3.4 PREDICTION OF PERFORMANCE FROM STRAIN OR DEFLECTION

This section shows, by means of equations and graphs, the relationship between the number of axle load applications sustained by a test section before its serviceability index fell to 2.5, and the strain or deflection observed early in the life of the section. Graphs are presented from which the probability that a section will survive 1,114,000 applications of load may be estimated if the strain or deflection produced by that load is known.

The average life of a section to $p = 2.5$ for sections with the same thickness could be predicted with satisfactory accuracy from the average of 24 dynamic edge strains measured under the single axle load regularly assigned to that section (Fig. 156). Similar predictions could be made from static edge and corner deflections, but with somewhat less accuracy (Figs. 158 and 160).

One of the objectives of the Road Test was the investigation of the assumption that the life of a rigid pavement subjected to repeated applications of the same load can be satisfactorily predicted if the strain or deflection of the pavement, before visible deterioration of the pavement takes place, is known.

To test this assumption, performance data, in the form of log $W$ to a serviceability level of 2.5, were compared with data from early rounds of dynamic edge strain, static rebound edge deflection, and static rebound corner deflection.

The rounds selected for the analyses of performance as a function of strain or deflection were the same as those used in the analyses of strain and deflection as function of design and load. They are given in Sections 3.3.4, 3.3.6 and 3.3.7.

TABLE 75

MEAN DEFLECTIONS FROM SPECIAL STUDY WITH 12-KIP SINGLE AXLE LOAD

(Data from Round 1)

| Experiment Design | Slab Thickness (in.) | Loop | Mean Deflection, by Loop (in.) | | Lane | Mean Deflection, by Lane (in.) | |
|---|---|---|---|---|---|---|---|
| | | | Edge | Corner | | Edge | Corner |
| A | 6.5, 8.0 | 3 | 0.0073 | 0.0088 | 1 | 0.0082 | 0.0105 |
| | | 4 | 0.0080 | 0.0103 | 2 | 0.0075 | 0.0091 |
| | | 5 | 0.0082 | 0.0103 | | | |
| B | 8.0, 9.5 | 4 | 0.0063 | 0.0092 | 1 | 0.0069 | 0.0088 |
| | | 5 | 0.0068 | 0.0086 | 2 | 0.0059 | 0.0082 |
| | | 6 | 0.0061 | 0.0077 | | | |

Inasmuch as the performance analysis of Design 1 sections had shown that the effects of the design variables $D_1$ (reinforcing) and $D_3$ (subbase thickness) were not statistically significant (see Section 3.2.2.1), these variables were ignored in this analysis. As a consequence of experience gained in the performance analysis, data from the highest level of slab thickness in each loop were also excluded. Furthermore, a preliminary analysis having shown that the relationship between strain or deflection and the performance of test sections subjected to tandem axle vehicles was not well defined, data from the tandem axle lanes were omitted. Finally, Loop 2 data were excluded because of the small volume of data from failed sections. The resulting reduced experiment design is given in Table 76. Data representing 12 design-load combinations involving a total of 72 test sections went into each of the three analyses.

The general model chosen for the analyses was the following:

$$\overline{\log W_{2.5}} = A_0 + A_1 \overline{\log Y} \qquad (95)$$

in which

$\overline{\log W_{2.5}}$ = the logarithm of the number of unweighted axle applications at which $p = 2.5$, averaged over the six sections occurring in a design-load combination in Table 76; and

$\overline{\log Y}$ = the logarithm of dynamic edge strain (in $10^{-6}$ in. per in.), or static rebound edge deflection (in in.), or static rebound corner deflection (in in.), averaged over the six sections occurring in the design-load combination, and again averaged over the several rounds of data used in the analyses.

Three sets of values of $A_0$ and $A_1$ were obtained corresponding to the three kinds of measurements analyzed. The resulting equations are given in the three subsections immediately following.

### *3.4.1 Performance from Dynamic Edge Strain*

Dynamic edge strain data from each group of six sections (Table 76) were averaged without regard to the temperature conditions at the time the individual measurements were made. The resulting value was paired with the value of $\overline{\log W_{2.5}}$ for the same sections, if all six sections in the group fell to that serviceability level during the traffic test, and plotted in Figure 156 as a solid disc. If the serviceability level of some of the group of six sections was above 2.5 at the end of the traffic test, then Eq. 62 was used to estimate log $W$ at $p = 2.5$ for each section, these values were added to the observed values to arrive at an average for the six section group, and the result plotted as a triangle. In each case where all six sections ended the traffic test with serviceability levels greater than 2.5, the value of $\overline{\log W_{2.5}}$ was estimated for the corresponding load-slab thickness combination from Eq. 62 and plotted as an open circle.

TABLE 76

EXPERIMENT DESIGN FOR ANALYSIS OF PERFORMANCE AS A FUNCTION OF STRAIN AND DEFLECTION

| Single Axle Load (kips) | Number of Sections per Design-Load Combination | | | | | |
|---|---|---|---|---|---|---|
| | 3.5-In. Slab | 5.0-In. Slab | 6.5-In. Slab | 8.0-In. Slab | 9.5-In. Slab | 11.0-In. Slab |
| 12 | 6 | 6 | 6 | | | |
| 18 | | 6 | 6 | 6 | | |
| 22.4 | | | 6 | 6 | 6 | |
| 30 | | | | 6 | 6 | 6 |

When Eq. 95 was fitted to the strain data the following relationship resulted:

$$\overline{\log W_{2.5}} = 13.35 - 4.66 \overline{\log \varepsilon} \qquad (96)$$

in which $\overline{\log \varepsilon}$ is the logarithm of dynamic edge strain (in $10^{-6}$ in. per in.) averaged over the six sections occurring within a load-slab thickness combination, and again averaged over the four rounds of data analyzed; and $\overline{\log W_{2.5}}$ is as defined in Section 3.4.

The straight line (Fig. 156) is a plot of Eq. 96. It was concluded that the average of a large number of measured strains could be satisfactorily used to predict the average life of test sections of a given thickness subjected to repeated applications of a single axle load of constant weight.

Histograms (Fig. 157) were plotted from strain and performance data for all sections involved in Design 1, Loops 3 through 6. The graph on the left shows the percentage of all sections having an initial dynamic edge strain falling within a specified interval that ended the traffic test at a serviceability level greater than 1.5. The strain values were the individual round data for individual sections; therefore, each section is represented by four values not necessarily all the same. Thus, the curve drawn through the tops of the bars can be regarded as the estimated probability (given a single edge strain determination) that a section will survive 1,114,000 applications of a single axle load equal to that which caused the strain, and within the range of 12,000 to 30,000 lb. A similar interpretation can be made of the curve on the right, except that the load involved is a tandem axle within the range, 24,000 to 48,000 lb.

### 3.4.2 Performance from Static Edge Deflection

Because the effect of temperature on dy-

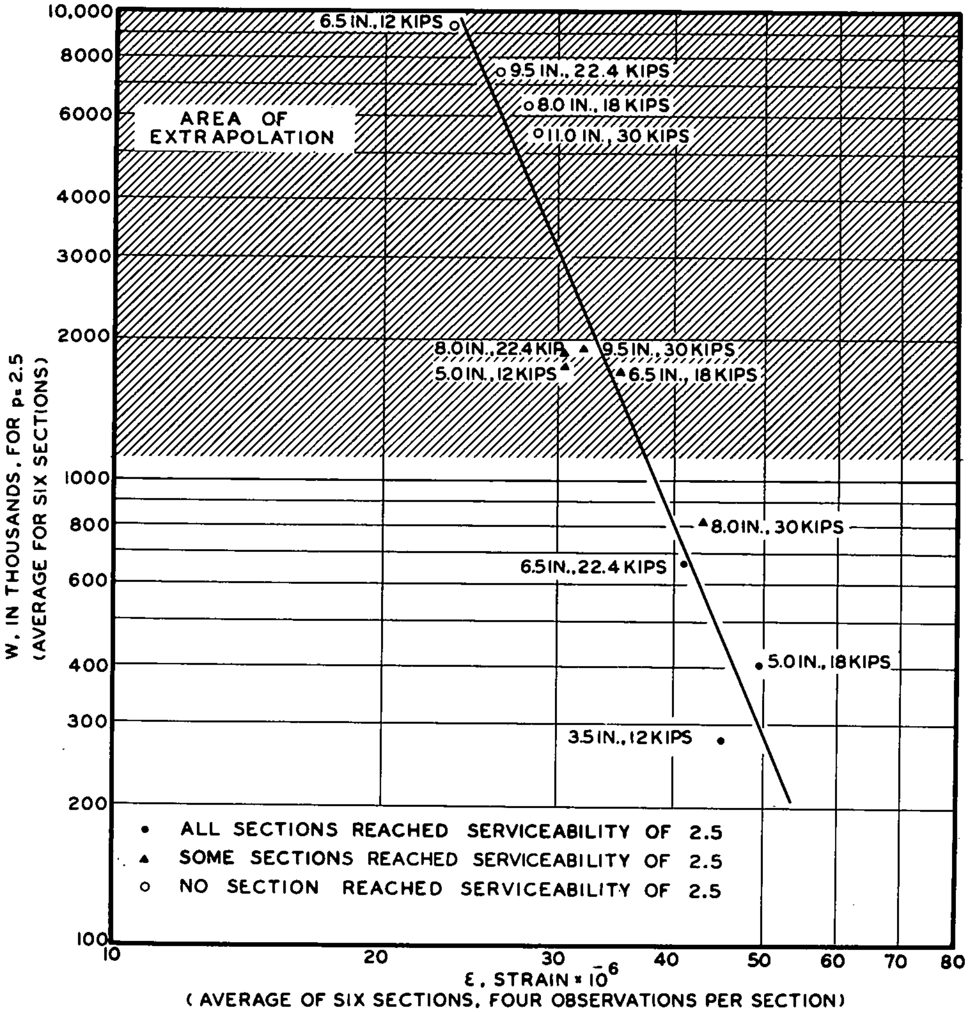

Figure 156. Performance as a function of dynamic edge strain data from Design 1, Loops 3 through 6.

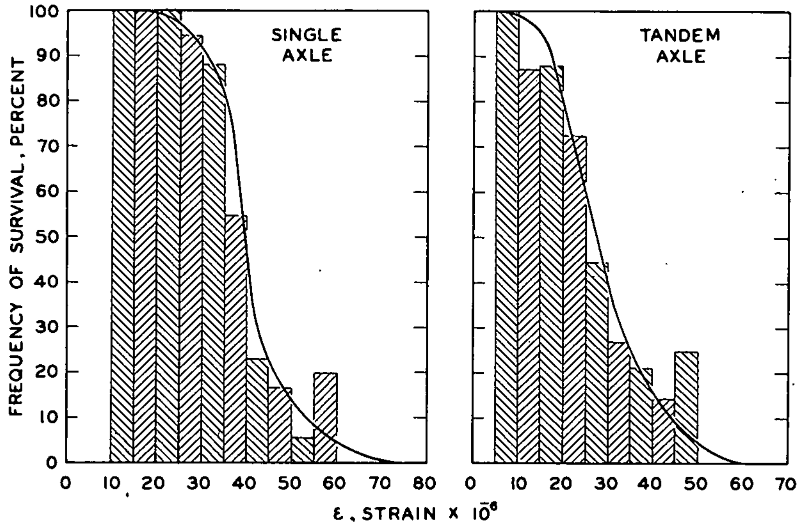

**Figure 157. Estimated probability that a test section will survive 1,114,000 axle load applications, based on measurements of dynamic edge strain. Bars plotted from strain and performance data, Experiment Design 1, Loops 3 through 6.**

namic edge strain was found to be relatively small (see Fig. 150) and thus could probably be neglected without large error, it was considered desirable to adjust all deflections to a common temperature condition prior to determining the relationship existing between deflection and performance (see Figs. 152 and 153). The adjustment of edge deflections was made on the basis of the coefficient of the temperature statistic, $T$, determined in the analysis described in Sections 3.3.3 and 3.3.6.

If $\tilde{d'}_e$ is an estimate of the deflection which would have been observed had $T$ been equal to zero (all other factors remaining the same), it can be shown that, according to Eq. 86,

$$\tilde{d'}_e = d'_e \text{ x } 10^{0.0075T} \tag{97}$$

Eq. 97 was used to adjust all deflections in the analysis to a common temperature condition, $T = 0$. The adjusted values were then treated in the same way as were the strain values (Section 3.4.1), and the resulting equation was as follows:

$$\overline{\log W_{2.5}} = 0.74 - 3.15\,\overline{\log \tilde{d'}_e} \tag{98}$$

in which $\overline{\log \tilde{d'}_e}$ is $\log \tilde{d'}_e$ averaged over the six test sections occurring within a design-load combination and again over the eight rounds of data being analyzed, and $\overline{\log W_{2.5}}$ is as defined in Section 3.4.

Figure 158 shows the graph of Eq. 98 as well as plotted values of the averaged data. The three symbols (a solid disc, a triangle and an open circle) are as defined in Section 3.4.1.

Comparing Figure 158 with Figure 156 indicates that generally a greater error would result in predicting the average life of sections from static rebound edge deflection than from dynamic edge strain.

Figure 159 was plotted from edge deflection data, but is otherwise identical to Figure 157. Therefore, the curves may be used to estimate the probability (given a single edge deflection) that a section will survive 1,114,000 applications of either a single or a tandem axle load equal to that which caused the deflection, and within the range covered by the data.

### *3.4.3 Performance from Static Corner Deflection*

By procedures paralleling those described in Section 3.4.2, the following equation connecting performance with static rebound corner deflection was derived:

$$\overline{\log W_{2.5}} = 0.95 - 3.29\,\overline{\log \tilde{d'}_c} \tag{99}$$

where

$\overline{\log \tilde{d'}_c}$ = $\log \tilde{d'}_c$ averaged over the six sections occurring within one load-slab thickness combination, and again over the eight rounds of data being analyzed; and

$\tilde{d'}_c$ = $d'_c$ adjusted to the temperature condition, $T = 0$.

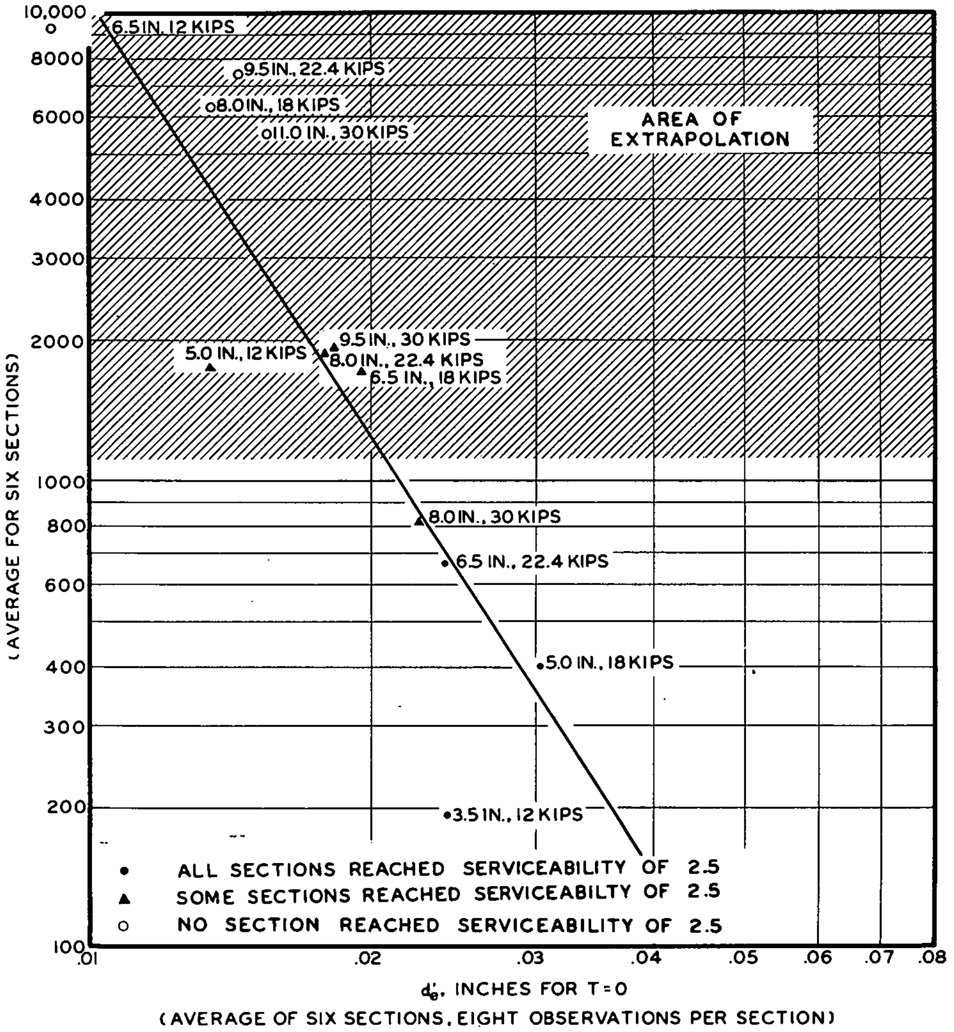

Figure 158. Performance as a function of static rebound edge deflection data from Design 1, Loops 3 through 6.

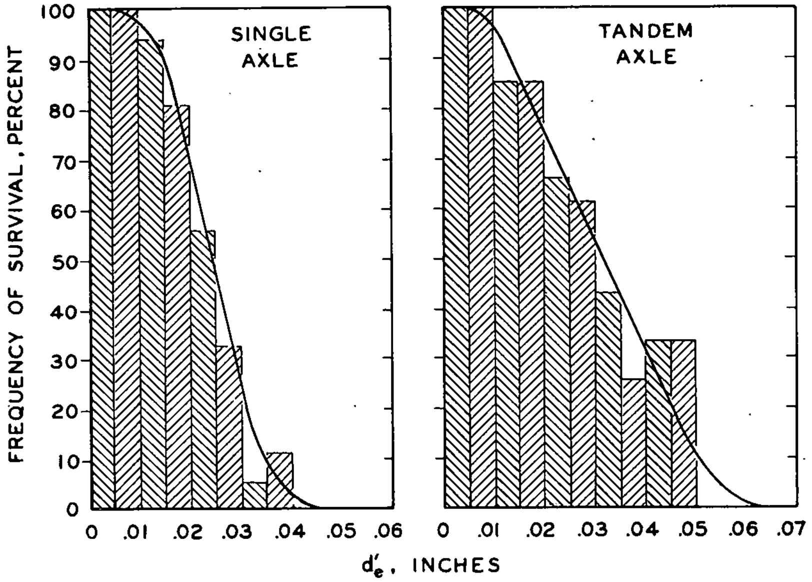

Figure 159. Estimated probability that a test section will survive 1,114,000 axle load applications, based on static rebound edge deflection. Bars plotted from edge deflection and performance data, Experiment Design 1, Loops 3 through 6.

Equations for adjusting static rebound corner deflections to the temperature condition, $T = 0$, based on Eqs. 88 and 89 are as follows:

*For nonreinforced sections:*

$$\tilde{d}'_c = d'_c\, 10^{0.011T} \qquad (100)$$

*For reinforced sections:*

$$\tilde{d}'_c = d'_c\, 10^{0.015T} \qquad (101)$$

Figure 160 shows a graph of Eq. 99 and plots of the data. Comparing Figure 160 with Figure 156 indicates that errors in prediction of performance based on static rebound corner deflections would generally exceed errors in predictions based on edge strains.

Figure 161 shows the estimated probability (given a single determination of static rebound corner deflection) that a section will survive 1,114,000 applications of a single or tandem axle load equal to that which caused the deflection, and within the range covered by the data.

## 3.5 AUXILIARY STUDIES

### *3.5.1 Overlays*

This subsection presents tabulated data from a special study of 18 test sections overlaid with asphaltic concrete at the time their serviceability level had declined to 1.5. Less than one-third of these overlays survived the traffic testing without further major maintenance. The volume of data was insufficient to permit derivation of performance equations.

When the serviceability level of rigid pavement test sections fell to 1.5, the pavement was either removed and the section rebuilt with flexible pavement materials, or it was overlaid with asphaltic concrete. The latter procedure was followed in a majority of the cases.

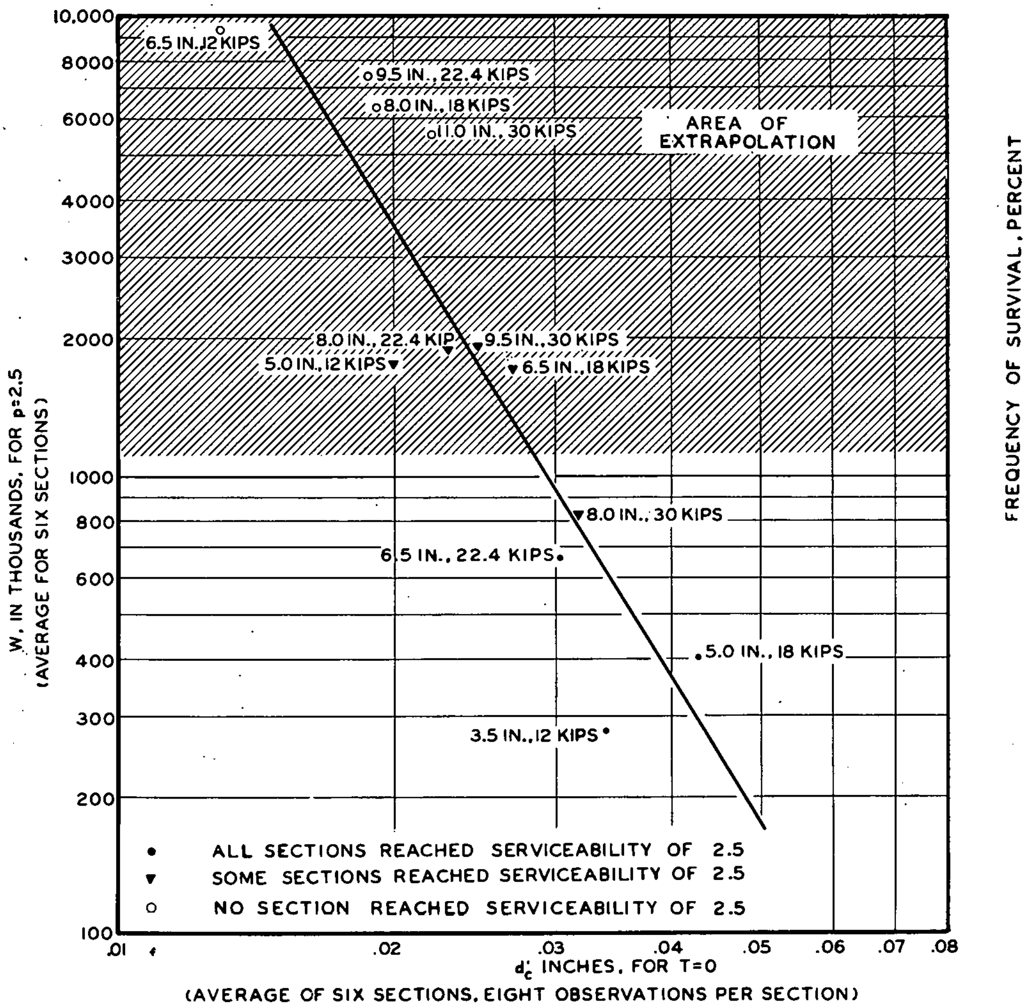

**Figure 160. Performance as a function of static rebound corner deflection data from Design 1, Loops 3 through 6.**

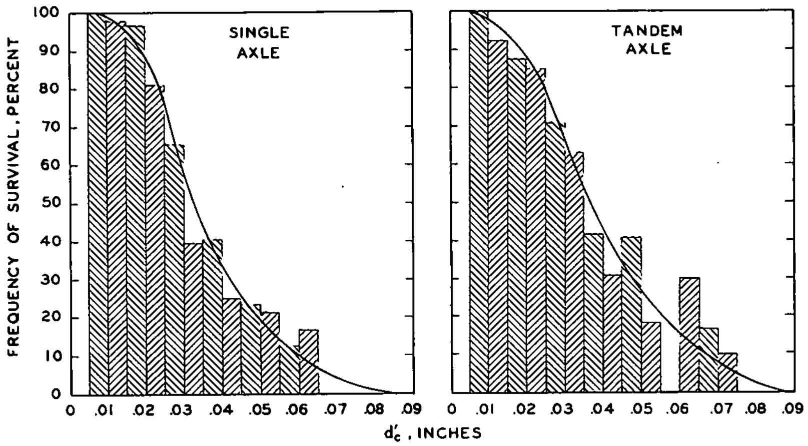

**Figure 161. Estimated probability that a test section will survive 1,114,000 axle load applications, based on static rebound corner deflection. Bars plotted from corner deflection and performance data, Experiment Design 1, Loops 3 through 6.**

Among the overlaid sections, 18 were selected for special study involving the measurement of areas of cracking and patching, rut depths and slope variance. These data were used in determining the serviceability index for each index day in accordance with the formula applying to flexible pavements (Section 2.2.1).

Table 77 gives design information pertaining to each of the selected sections and overlays, as well as basic performance data. Table 78 groups data for sections of the same slab thickness subjected to the same load, and averages essential performance data.

The date shown in the last column of Table 77 is when the study of an overlay was terminated because of the necessity for extensive patching or the placement of an additional overlay. Only 5 of the 18 overlays, or 28 percent, survived the period of traffic testing. However, sections of the Road Test were not overlaid until the serviceability level had fallen to 1.5. This level is lower than the serviceability at which most pavements in actual service are overlaid.

An analysis of overlay performance data leading to the development of performance equations similar to those pertaining to rigid pavement test sections (Section 3.2.2) was attempted but the results were not considered reliable because of insufficient data.

### *3.5.2 Subsurface*

This subsection presents in graphical or tabular form the results of CBR, density, moisture and plate bearing tests conducted on the subbase and embankment materials beneath selected pavements in the four main loops as well as in the non-traffic loop.

In the non-traffic loop the CBR and elastic modulus of both materials tended to be somewhat greater in summer than in spring periods, though the moisture content and density were practically unchanged.

In the traffic loops, tests made in spring 1960 yielded results not appreciably different from those obtained in the non-traffic loop for the same period, except that the average elastic modulus of both subbase and embankment was slightly greater in the traffic loops.

*3.5.2.1 Strength and Condition Data, Loop 1.*—A special study of the variation of subsurface strength and condition with time in the absence of traffic was conducted in the four sections of Design 5 in lane 2 of Loop 1. All four sections were nonreinforced, with a common slab thickness of 5 in. Two sections had a 6-in. subbase; the others, none.

The sections were 120 ft in length and were divided into 5- by 12-ft subpanels. Subpanels were selected in random order for trenches that were cut at periodic intervals (except in winter) beginning in spring 1959. Plate load, CBR, moisture content, and density tests were made on the subbase and the embankment. In each subpanel two CBR, moisture content, and density tests were made in each wheelpath (3 and 9 ft from pavement edge) on the subbase and embankment. The moisture contents and densities were determined at a depth of 0 to 4

## TABLE 77

### BASIC DATA, OVERLAY STUDY, RIGID PAVEMENT

| Loop | Axle Load (kips) | Original Design (in.) | Overlay | | | Marshall Data | | | | Axle Application (1,000's) | | Rut Depth at End of Study (in.) | Cracking and Patching at End of Study (sq ft/ 1,000 sq ft) | Serviceability | | | Date at End of Study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Voids | | | | | | | | | |
| | | | Thickness (in.) | Date | Asphalt Content (%) | Stability | Flow | Total (%) | Filled (%) | To $p=1.5$[1] | After Overlay | | | Before Overlay | After Overlay | End of Study | |
| 2 | 6S | 2.5–0–1 | 2 | 2/16/60 | 4.6 | 2554 | 14 | 3.76 | 74.80 | 485 | 249 | 0.05 | 67 | 1.3 | 2.4 | 1.5 | 6/15/60 |
| | 6S | 2.5–0–0 | 2 | 3/23/60 | 4.4 | 2357 | 13 | 6.04 | 63.65 | 568 | 166 | 0.05 | 133 | 1.1 | 1.4 | 2.9 | 6/15/60 |
| 3 | 12S | 5.0–6–1 | 3 | 6/ 1/60 | 4.5 | 2433 | 10 | 7.44 | 58.62 | 734 | 379 | 0.05 | 197 | 1.3 | 3.2 | 3.2 | 12/ 1/60 |
| 4 | 18S | 5.0–6–0 | 3 | 12/ 3/59 | 4.4 | 2199 | 11 | 4.72 | 69.40 | 354 | 420 | 0 | 144 | 1.4 | 3.2 | 1.8 | 6/15/60 |
| | 32T | 5.0–9–1 | 3 | 1/16/60 | 4.6 | 2052 | 11 | 5.90 | 64.91 | 413 | 700 | 0.15 | 82 | 1.5 | 3.3 | 1.8 | 12/ 1/60 |
| | 18S | 5.0–3–1 | 3 | 1/16/60 | 4.6 | 2052 | 11 | 5.90 | 64.91 | 413 | 361 | 0.15 | 173 | 1.1 | 3.4 | 3.1 | 6/15/60 |
| | 32T | 6.5–6–1 | 3 | 6/27/60 | 4.4 | 2081 | 10 | 5.01 | 66.92 | 803 | 310 | 0.10 | 133 | 1.4 | 3.0 | 1.9 | 12/ 1/60 |
| | 18S | 5.0–0–0 | 3 | 12/ 3/59 | 4.4 | 2199 | 11 | 4.72 | 69.40 | 354 | 282 | 0 | 145 | 1.4 | 3.0 | 1.2 | 4/20/60 |
| | 32T | 6.5–9–0 | 3 | 6/ 2/60 | 4.4 | 2846 | 10 | 7 48 | 58.11 | 735 | 378 | 0.05 | 167 | 1.0 | 3.1 | 2.8 | 12/ 1/60 |
| | 32T | 6.5–3–1 | 3 | 6/27/60 | 4.4 | 2081 | 10 | 5.01 | 66.92 | 803 | 310 | 0.10 | 125 | 1.3 | 3.3 | 2.9 | 12/ 1/60 |
| 5 | 22.4S | 6.5–6–1 | 3 | 12/14/59 | 4.4 | 2358 | 11 | 5.56 | 65.20 | 370 | 562 | 0.10 | 164 | 1.5 | 3.0 | 1.9 | 8/24/60 |
| | 40T | 6.5–3–0 | 3 | 12/ 1/59 | | | | | | 349 | 321 | 0.05 | 139 | 0.8 | 3.4 | 1.6 | 5/ 4/60 |
| | 40T | 6.5–6–0 | 3 | 12/16/59 | | | | | | 370 | 264 | 0.15 | 109 | 0.6 | 0.9 | 1.5 | 4/20/60 |
| | 40T | 6.5–9–1 | 3 | 4/15/60 | 4.5 | 1943 | 10 | 6.38 | 62.77 | 622 | 48 | 0.10 | 209 | 1.5 | 3.4 | 2.4 | 6/15/60 |
| 6 | 48T | 8.0–3–1 | 3 | 4/18/60 | 4.6 | 1955 | 11 | 5.98 | 64.65 | 615 | 143 | 0.10 | 152 | 1.3 | 3.4 | 2.7 | 6/15/60 |
| | 48T | 8.0–9–1 | 3 | 4/16/60 | 4.6 | 1890 | 10 | 7.44 | 59.28 | 615 | 68 | 0 | 98 | 1.7 | 2.7 | 2.2 | 6/15/60 |
| | 30S | 8.0–0–0 | 3 | 6/ 1/60 | 4.5 | 2433 | 10 | 7.44 | 58.62 | 735 | 39 | 0.20 | 113 | 1.4 | 2.9 | 2.7 | 6/15/60 |
| | 48T | 8.0–6–1 | 3½ | 1/20/60 | 4.4 | 2357 | 11 | 5.92 | 64.14 | 416 | 342 | 0.10 | 71 | 1.6 | 3.0 | 2.1 | 6/15/60 |

[1] Before overlay.

TABLE 78

PERFORMANCE DATA SUMMARY OF OVERLAID SECTIONS

| Loop | Lane | Slab Thickness (in.) | Overlays |  | Original Sections |  | Overlaid Sections |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Number | Thickness (in.) | Axle[1] Applications to $p = 1.5$ (1,000's) | Corresponding Serviceability Loss | Axle[1] Applications (1,000's) | Serviceability |  | Overlay Rut Depth at End of Study (in.) |
|  |  |  |  |  |  |  |  | Initial | Loss |  |
| 2 | 2 | 2.5 | 2 | 2 | 527 | 3.3 | 208 | 1.9 | −0.3[2] | 0.05 |
| 3 | 1 | 5.0 | 1 | 3 | 734 | 3.2 | 379 | 3.2 | 0 | 0.05 |
| 4 | 1 | 5.0 | 3 | 3 | 374 | 3.2 | 354 | 3.2 | 0.7 | 0.05 |
|  | 2 | 5.0 | 1 | 3 | 413 | 3.0 | 700 | 3.3 | 1.5 | 0.15 |
|  | 2 | 6.5 | 3 | 3 | 780 | 3.3 | 333 | 3.1 | 0.6 | 0.08 |
| 5 | 1 | 6.5 | 1 | 3 | 370 | 3.0 | 562 | 3.0 | 1.1 | 0.10 |
|  | 2 | 6.5 | 3 | 3 | 447 | 3.5 | 211 | 2.6 | 0.8 | 0.10 |
| 6 | 1 | 8.0 | 1 | 3 | 735 | 3.1 | 39 | 2.9 | 0.2 | 0.20 |
|  | 2 | 8.0 | 3 | 3 | 549 | 3.0 | 184 | 3.0 | 0.9 | 0.07 |
|  | All |  | 18 | 2.9 | 548 | 3.2 | 330 | 2.9 | 0.6 | 0.09 |

[1] Unweighted.

[2] Increase in serviceability.

in. in each material. One plate load test* was made in the outer wheelpath on the embankment in each subpanel. One plate load test was also made between wheelpaths (6 ft from pavement edge) on the subbase.

Details of testing procedures and data reduction are described in Appendix D. Figures 162 and 163 show the trends in condition (moisture content and density) and indicated strength (CBR and plate load tests) of the subbase and embankment soil with time. Figure 164 shows the observed differences in these two characteristics for the spring and summer periods.

The data indicated that the moisture content and density of the subbase and the embankment soil were practically the same in the spring and summer periods. However, increases in CBR and elastic modulus occurred from spring to summer.

Because in rigid pavement design the modulus $k_G$ is more commonly used than the elastic modulus $k_E$, data obtained from the trench studies in Loop 1 (in both flexible and rigid pavement sections) were used to develop a correlation between $k_E$ and $k_G$ (Fig. 165).

*3.5.2.2 Trenching Program, Loops 3–6.*—In April and May 1960, 5- by 12-ft sections of pavement were removed at transverse joints, or at various locations between joints, from seven test sections in Design 1, Loops 3 through 6, for the purpose of testing the subsurface materials. Each section had dropped to a serviceability level of 1.5 and its performance was no longer under observation at the time of the subsurface testing program.

The program included the determination of moisture content and density of the subbase and embankment materials at a depth of 0 to 4 in.. as well as CBR and plate bearing values. These data are given in Table 79 for the subbase and Table 80 for the embankment.

The moisture content, density and strength measured in three locations (outer wheelpath, between wheelpaths, and inner wheelpath) did not differ appreciably from one location to the next, nor were they appreciably different from corresponding values determined in Loop 1 at about the same time, with the exception of the elastic modulus $k_E$, which was somewhat greater for both subbase and embankment in Loops 3–6 than in the non-traffic loop (see Fig. 164 for spring 1960) according to the over-all means given in Tables 79 and 80.

### *3.5.3 Curling of Concrete Slabs*

This subsection deals with the vertical displacement, in the absence of loads other than gravity, observed at selected points on the surface of concrete slabs. It treats only the maximum displacement of these points, occurring as the temperature of the air changes from a

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* 30-in. diameter plate.

maximum to the next minimum, or from a minimum to the next maximum.

As background information, graphs are presented showing changes with time of the temperature distribution in plastic and hardened concrete slabs (Figs. 167, 168 and 169).

Changes in the standard temperature differential (see Section 3.3.3 for definition) are correlated with corresponding displacements observed at the corners of panels embracing a wide range of designs (Fig. 173). Changes in the standard differential are also related, by means of an equation, to corresponding changes in air temperature (Fig. 174).

Additional equations are given relating the displacement of a point on the pavement surface to the coordinates of the point and the thickness of the slab. From these equations, or from their graphs (Figs. 177 and 179), estimates of corner displacements approaching the greatest observed at the Road Test may be made.

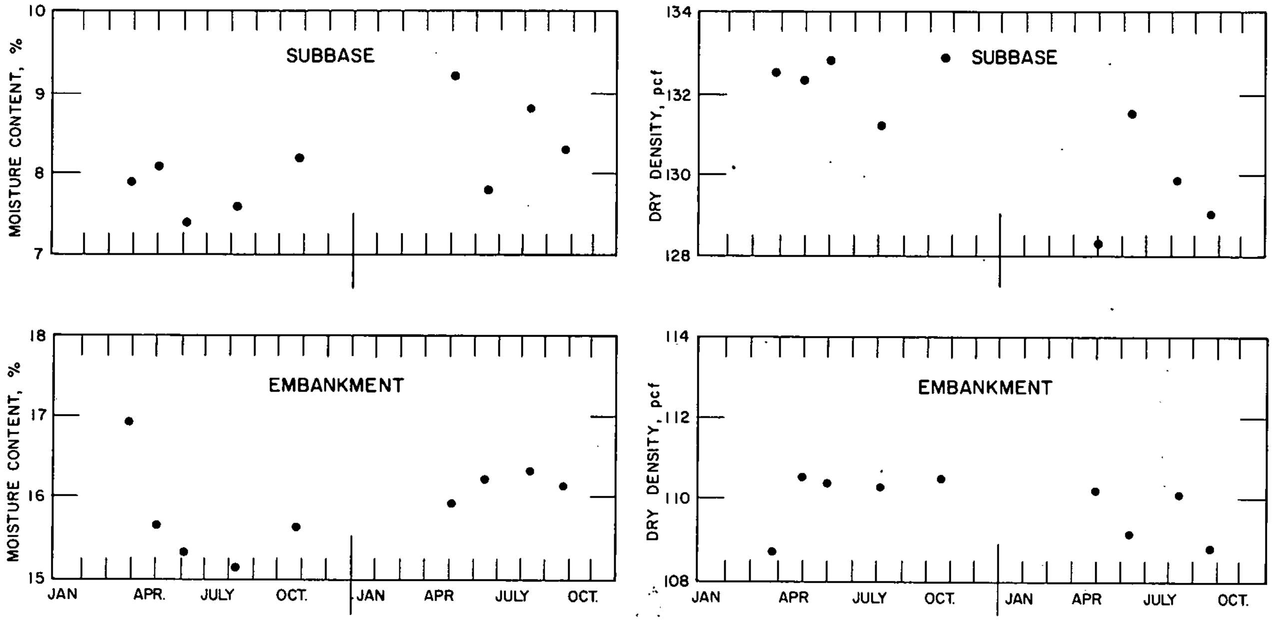

Figure 162. Seasonal subsurface conditions, Experiment Design 5, Loop 1, lane 2.

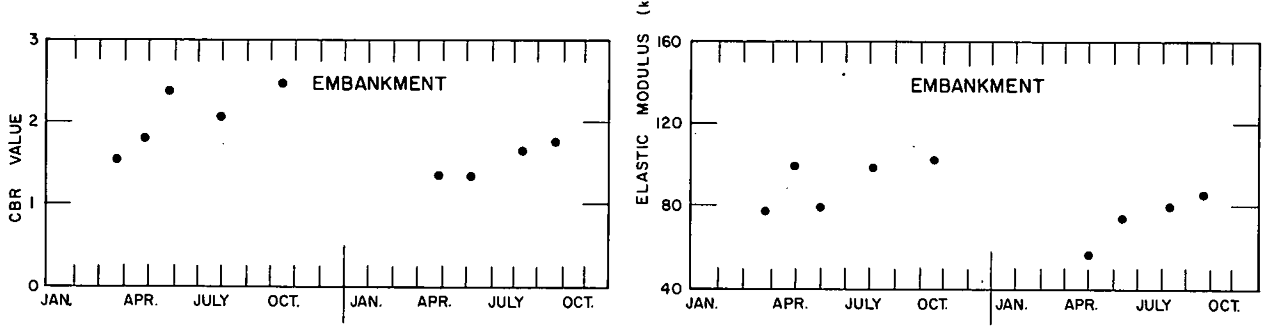

Figure 163. Seasonal strength tests, Experiment Design 5, Loop 1, lane 2.

## TABLE 79

### CONDITION DATA FOR SUBBASE, RIGID PAVEMENT TANGENTS
(from Spring Trench Program[1], 1960)

| Loop | Sect. No. | Design Code[2] | Outer Wheelpath | | | | Inner Wheelpath | | | | Between Wheelpaths | | Test Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Moisture Content (%) | Dry Density (pcf) | CBR[3] | $k_E$[4] | Moisture Content (%) | Dry Density (pcf) | CBR[3] | $k_E$[4] | Moisture Content (%) | Dry Density (pcf) | |
| 3 | 192 | 5R–6 | 7.0 | 135.7 | — | 94 | 7.3 | 134.9 | — | 101 | 7.1 | 139.8 | Joint |
| | 226 | 5N–3 | 7.7 | 133.7 | 2.8 | 107 | 7.8 | 135.2 | 3.0 | 103 | 6.8 | 139.4 | Joint |
| *Mean* | | | *7.4* | *134.7* | *2.8* | *101* | *7.6* | *135.1* | *3.0* | *102* | *7.0* | *139.6* | |
| 4 | 643 | 5N–3 | 7.1 | 134.2 | 6.7 | 85 | 7.2 | 132.5 | 4.4 | 85 | 7.2 | 132.6 | Joint |
| | 673 | 5R–9 | 6.8 | 137.0 | — | 124 | 7.8 | 137.2 | — | 117 | 7.3 | 133.9 | Joint |
| | 673 | 5R–9 | 6.5 | 140.9 | — | 113 | 8.6 | 131.7 | — | 135 | 7.2 | 135.8 | Panel |
| *Mean* | | | *6.8* | *137.4* | *6.7* | *107* | *7.9* | *133.8* | *4.4* | *112* | *7.2* | *134.1* | |
| 5 | 490 | 6.5N–6 | 7.9 | 131.8 | — | 78 | 7.2 | 142.4 | — | 97 | 7.9 | 134.4 | Joint |
| | 550 | 6.5R–9 | 5.6 | 141.1 | — | 107 | 5.3 | 138.6 | 8.8 | — | 5.5 | 138.2 | Joint |
| | 550 | 6.5R–9 | 7.9 | 135.1 | — | 105 | 6.9 | 137.0 | — | 123 | 7.5 | 130.0 | Panel |
| *Mean* | | | *7.1* | *136.0* | — | *97* | *6.5* | *139.3* | *8.8* | *110* | *7.0* | *134.2* | |
| 6 | 348 | 8R–9 | 10.2 | 133.1 | — | 122 | 10.8 | — | — | 113 | 9.0 | 135.8 | Panel |
| *Mean* | | | *10.2* | *133.1* | — | *122* | *10.8* | — | — | *113* | *9.0* | *135.8* | |
| *Over-all mean* | | | *7.9* | *135.3* | *4.8* | *107* | *8.2* | *136.1* | *5.4* | *109* | *7.6* | *135.9* | |

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[1] Tests made from April 23 to May 25, 1960.

[2] First figure is slab thickness, in inches; letter designates reinforcement; last number is subbase thickness, in inches.

[3] Penetration at 0.1 in.

[4] 30-in. plate.

## TABLE 80

### CONDITION DATA FOR EMBANKMENT, RIGID PAVEMENT TANGENTS
(from Spring Trench Program[1], 1960)

| Loop | Sect. No. | Design Code[2] | Outer Wheelpath | | | | Inner Wheelpath | | | | Between Wheelpaths | | Test Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Moisture Content (%) | Dry Density (pcf) | CBR[3] | $k_E$[4] | Moisture Content (%) | Dry Density (pcf) | CBR[3] | $k_E$[4] | Moisture Content (%) | Dry Density (pcf) | |
| 3 | 192 | 5R–6 | 14.0 | 112.0 | 1.3 | 76 | 15.1 | 111.5 | 1.3 | 82 | 16.0 | 109.2 | Joint |
| | 226 | 5N–3 | 15.6 | 111.4 | 2.2 | 90 | 15.0 | 108.8 | 1.9 | 98 | 15.3 | 110.6 | Joint |
| *Mean* | | | *14.8* | *111.7* | *1.8* | *83* | *15.1* | *110.2* | *1.6* | *90* | *15.7* | *109.9* | |
| 4 | 643 | 5N–3 | 17.9 | 104.6 | 1.2 | 70 | 18.3 | 104.7 | 1.5 | 63 | 17.5 | 104.8 | Joint |
| | 673 | 5R–9 | 14.6 | 111.0 | 1.9 | 81 | 16.6 | 109.9 | 1.0 | 77 | 13.9 | 112.6 | Joint |
| | 673 | 5R–9 | 16.8 | 109.8 | 0.7 | 68 | 14.4 | 109.2 | 2.2 | 90 | 14.4 | 109.8 | Panel |
| *Mean* | | | *16.4* | *108.5* | *1.3* | *73* | *16.4* | *107.9* | *1.6* | *77* | *15.3* | *109.1* | |
| 5 | 490 | 6.5N–6 | 19.4 | 105.2 | 1.1 | 64 | 17.0 | 108.0 | 1.0 | 69 | 17.9 | 105.5 | Joint |
| | 550 | 6.5R–9 | 15.0 | 111.8 | 2.0 | 84 | 15.5 | 112.3 | — | — | 15.8 | 111.9 | Joint |
| | 550 | 6.5R–9 | 15.9 | 108.6 | 1.6 | 84 | 15.5 | 110.4 | 2.5 | 96 | 15.8 | 111.8 | Panel |
| *Mean* | | | *16.8* | *108.5* | *1.6* | *77* | *16.0* | *110.2* | *1.8* | *83* | *16.5* | *109.7* | |
| 6 | 348 | 8R–9 | 13.4 | 114.4 | 2.4 | 105 | 12.4 | 114.7 | 2.3 | 97 | 13.0 | 114.8 | Panel |
| *Mean* | | | *13.4* | *114.4* | *2.4* | *105* | *12.4* | *114.7* | *2.3* | *97* | *13.0* | *114.8* | |
| *Over-all mean* | | | *15.4* | *110.8* | *1.8* | *85* | *15.0* | *110.8* | *1.8* | *87* | *15.1* | *110.9* | |

[1] Tests made from April 23 to May 25, 1960.

[2] First figure in slab thickness, in inches; letter designates reinforcement; last number is subbase thickness, in inches.

[3] Penetration at 0.1 in.

[4] 30-in. plate.

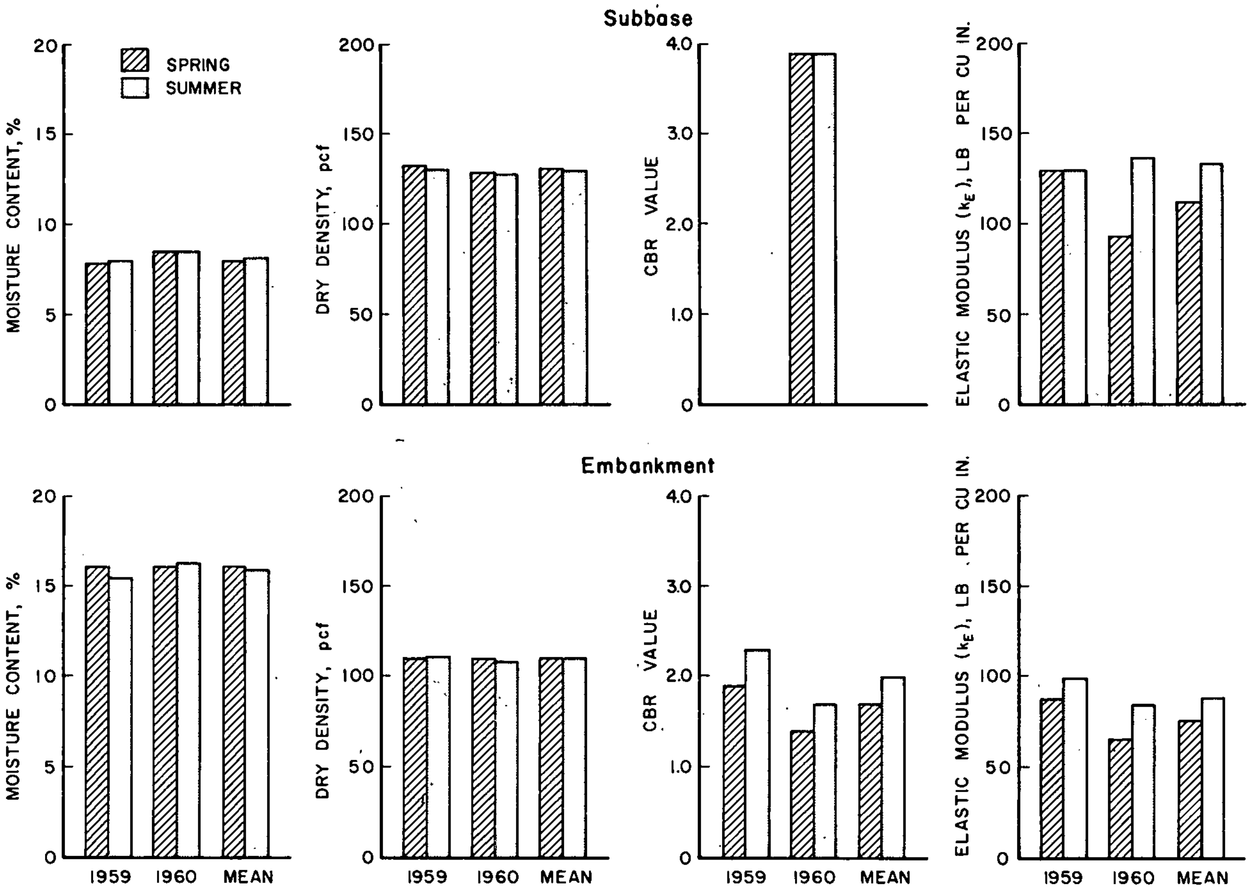

Figure 164. Spring and summer subsurface conditions, Experiment Design 5, Loop 1, lane 2.

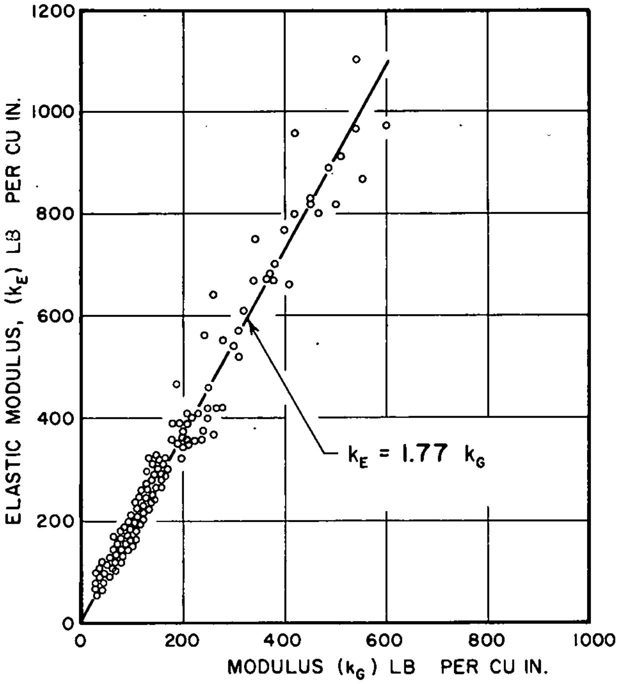

Figure 165. Relationship between elastic modulus and modulus of base, subbase and embankment soil.

During periods of continuously changing air temperature, points on the surface of the concrete slabs were in continuous vertical motion (Fig. 172).

The net change (in absolute value) of the standard differential associated with a change in air temperature from a maximum to the next minimum (or from a minimum to the next maximum) is represented by $|\Delta T|$. The corresponding change in elevation of a panel corner varied from about 0.003 x $|\Delta T|$ to about 0.005 x $|\Delta T|$ in. for slabs ranging in thickness from 2.5 to 12.5 in. (Table 85). Values of $|\Delta T|$ as high as 30 F were occasionally observed at the Road Test (Fig. 174); the corresponding estimated range of corner displacements is from 0.09 to 0.15 in.

The rate at which corner displacement changed with increase in slab thickness varied considerably (even changing signs) within the range of thicknesses investigated (Fig. 181).

Corner displacements measured over the same periods of time and averaged across subbase and slab thickness were practically the same for 15-ft nonreinforced and 40-ft reinforced panels (Table 85). However, the curvature of the surface of 15-ft panels in the region of the corner differed somewhat from that of

40-ft panels (Eqs. 103 and 104 and Figs. 177 and 179).

The results of observations of the vertical motion, in the absence of loads other than gravity, of points on the surface of the 24 test sections comprising Design 1, Loop 1, lane 2, are described in this section.

The symbol $m$ is used to denote the maximum vertical displacement, in inches, of a general point on the surface of a panel, occurring over a stated period of time. Positive values of $m$ indicate upward movement. If the observed point is located at the corner of a panel, its maximum vertical displacement is denoted by $m_c$.

The symbol, $\Delta T$, in degrees Fahrenheit, denotes the net change in the standard temperature differential $T$ (Section 3.3.3) occurring over a specified period of time. A positive value of $\Delta T$ signifies a net increase in $T$ over the period specified.

Two classes of experiments are described. In the first class (special studies of corner movements), the vertical displacement at the corner of a panel was determined once every 50 min over periods of time varying from about 12 to 36 hr. Table 81 gives the periods over which these observations were made. Table 82 gives the experiment design and observed values of $m_c$ for these experiments.

In the second class of experiments (special studies of the curling of concrete slabs), vertical displacements at 16 points on the surface of a panel were measured within a 10- to 20-min interval, and remeasured once every 2 hr over a period of about 30 hr. Table 83 shows the times at which the curling experiments were conducted, the design for each experiment, and observed values of $m_c$.

Table 83 indicates that each curling experiment involved only five test sections and that the only design variable within each experiment was slab thickness. The choice of a small factorial was dictated by the time required to make the measurements and the desirability of repeating them after time intervals not longer than about 2 hr, in order that plots of the data would furnish a reliable estimate of $m$. The choice of the design variable, slab thickness, was arbitrary. Values of $m$, taken from smoothed curves of displacement plotted against time, for the 16 points observed on each section (Table 83) are available in DS 5223.

*3.5.3.1 Changes in Internal Temperature Distribution with Time.*—To provide background information on corner movement and curling of concrete slabs, copper-constantine thermocouples were placed in all Design 1, Loop 1, lane 2 test sections (24 sections) and in four sections in lane 1. Thermocouples, attached to lucite spacer rods installed vertically, were placed in each section at a point 6 in. from the free edge and 14 in. from a transverse

TABLE 81

SCHEDULE OF SPECIAL STUDIES OF VERTICAL MOVEMENT AT PANEL CORNERS

DESIGN 1, LOOP 1, LANE 2

| Round Number | Up Movement, $m_c > 0$ | | | | | | | Down Movement, $m_c < 0$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | From | | | To | | | $\Delta T$ (°F) | From | | | To | | | $\Delta T$ (°F) |
| | Hour[1] | Date | $T$ (°F) | Hour[2] | Date | $T$ (°F) | | Hour[3] | Date | $T$ (°F) | Hour[4] | Date | $T$ (°F) | |
| 1 | 1328 | 5/31/60 | +20 | 0614 | 6/ 1/60 | −4 | −24 | 0505 | 6/ 1/60 | −4 | 1514 | 6/ 1/60 | +18 | +22 |
| 2 | 1250 | 6/29/60 | +17 | 0645 | 6/30/60 | −3 | −20 | 2057 | 6/29/60 | −1 | 1510 | 6/30/60 | +12 | +13 |
| 3a | 1237 | 7/21/60 | +18 | 0615 | 7/22/60 | −6 | −24 | 2358 | 7/21/60 | −6 | 1515 | 7/22/60 | +19 | +25 |
| 3b | 1054 | 7/22/60 | +14 | 0210 | 7/23/60 | −4 | −18 | | | | | | | |
| 4 | 1336 | 9/14/60 | —[5] | 0544 | 9/15/60 | —[5] | —[5] | | | | | | | |
| 5 | 1208 | 9/28/60 | +12 | 0604 | 9/29/60 | −7 | −19 | | | | | | | |
| 6 | 1135 | 10/ 5/60 | +14 | 0730 | 10/ 6/60 | −8 | −22 | 0006 | 10/ 5/60 | −4 | 1544 | 10/ 5/60 | +14 | +18 |

[1] Earliest time at which a panel corner, among the 24 observed, reversed direction of motion from downward to upward.
[2] Latest time at which a panel corner reversed direction of motion from upward to downward.
[3] Earliest time at which a panel corner reversed direction of motion from upward to downward.
[4] Latest time at which a panel corner reversed direction of motion from downward to upward.
[5] Not observed due to equipment failure.

# TABLE 82

## MAXIMUM VERTICAL MOVEMENT AT PANEL CORNERS, DESIGN 1, LOOP 1

| Slab Thickness (in.) | Sect. No. | Reinf. | Sub-base Thickness (in.) | Up Movement (in.) | | | | | | | | | Down Movement (in.) | | | | | | Over-All Average Movement (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Round 1 | Round 2 | Round 3a | Round 3b | Round 4 | Round 5 | Round 6 | Average per | | Round 1 | Round 2 | Round 3a | Round 6 | Average per | | |
| | | | | | | | | | | | Sect. | Thickness | | | | | Sect. | Thickness | |
| 2.5 | 936 | N | 0 | —[1] | 0.034 | 0.076 | 0.072 | 0.039 | 0.018 | 0.023 | 0.044 | | —[1] | 0.050 | 0.086 | 0.025 | 0.054 | | |
| | 934 | N | 6 | 0.066 | 0.055 | 0.117 | 0.110 | 0.084 | 0.042 | 0.027 | 0.072 | | 0.059 | 0.094 | 0.125 | 0.031 | 0.077 | | |
| | 896 | R | 0 | 0.052 | 0.043 | 0.114 | 0.095 | 0.122 | 0.045 | 0.043 | 0.073 | | 0.033 | 0.045 | 0.113 | 0.041 | 0.058 | | |
| | 898 | R | 0 | 0.059 | 0.067 | 0.126 | 0.085 | 0.164 | 0.076 | 0.067 | 0.092 | | 0.065 | 0.061 | 0.131 | 0.060 | 0.079 | | |
| | 932 | R | 6 | —[1] | 0.066 | 0.124 | 0.114 | 0.090 | 0.054 | 0.036 | 0.081 | | —[1] | 0.093 | 0.133 | 0.033 | 0.086 | | |
| | 900 | R | 6 | 0.086 | 0.065 | 0.104 | 0.075 | 0.095 | 0.051 | 0.043 | 0.074 | 0.073 | 0.056 | 0.065 | 0.123 | 0.040 | 0.071 | 0.071 | 0.072 |
| Round average | | | | 0.066 | 0.055 | 0.110 | 0.092 | 0.099 | 0.048 | 0.040 | | | 0.053 | 0.068 | 0.119 | 0.038 | | | |
| 5.0 | 890 | N | 0 | 0.095 | 0.081 | 0.134 | 0.104 | 0.143 | 0.080 | 0.080 | 0.102 | | 0.090 | 0.074 | 0.142 | 0.076 | 0.096 | | |
| | 924 | N | 0 | 0.060 | 0.033 | 0.101 | 0.084 | 0.075 | 0.070 | 0.066 | 0.070 | | 0.048 | 0.056 | 0.103 | 0.057 | 0.066 | | |
| | 926 | N | 6 | 0.072 | 0.039 | 0.109 | 0.091 | 0.123 | 0.071 | 0.064 | 0.081 | | 0.062 | 0.065 | 0.109 | 0.057 | 0.073 | | |
| | 892 | N | 6 | 0.099 | 0.071 | 0.120 | 0.105 | 0.127 | 0.068 | 0.068 | 0.094 | | 0.077 | 0.074 | 0.126 | 0.061 | 0.085 | | |
| | 906 | R | 0 | 0.101 | 0.091 | 0.145 | 0.111 | 0.124 | 0.076 | 0.082 | 0.104 | | 0.092 | 0.074 | 0.146 | 0.071 | 0.096 | | |
| | 928 | R | 6 | 0.050 | 0.028 | 0.078 | 0.069 | 0.079 | 0.048 | 0.043 | 0.056 | 0.085 | 0.041 | 0.049 | 0.073 | 0.038 | 0.053 | 0.078 | 0.082 |
| Round average | | | | 0.080 | 0.057 | 0.115 | 0.094 | 0.112 | 0.069 | 0.067 | | | 0.068 | 0.067 | 0.117 | 0.060 | | | |
| 9.5 | 920 | N | 0 | 0.095 | 0.044 | 0.085 | 0.136 | 0.046 | 0.083 | 0.085 | 0.082 | | 0.092 | 0.065 | 0.086 | 0.073 | 0.079 | | |
| | 918 | N | 6 | 0.101 | 0.062 | 0.125 | 0.104 | 0.098 | 0.101 | 0.100 | 0.099 | | 0.097 | 0.084 | 0.127 | 0.086 | 0.099 | | |
| | 908 | R | 0 | 0.079 | 0.063 | 0.089 | 0.078 | 0.083 | 0.074 | 0.083 | 0.078 | | 0.067 | 0.054 | 0.088 | 0.072 | 0.070 | | |
| | 922 | R | 0 | 0.065 | 0.032 | 0.075 | 0.061 | 0.071 | 0.084 | 0.069 | 0.065 | | 0.055 | 0.056 | 0.076 | 0.061 | 0.062 | | |
| | 916 | R | 6 | 0.058 | 0.031 | 0.067 | 0.062 | 0.067 | 0.076 | 0.070 | 0.062 | | 0.052 | 0.056 | 0.066 | 0.062 | 0.059 | | |
| | 888 | R | 6 | 0.085 | 0.069 | 0.093 | 0.070 | 0.099 | 0.074 | 0.076 | 0.081 | 0.078 | 0.071 | 0.058 | 0.096 | 0.071 | 0.074 | 0.074 | 0.076 |
| Round average | | | | 0.081 | 0.050 | 0.089 | 0.085 | 0.077 | 0.082 | 0.081 | | | 0.072 | 0.062 | 0.090 | 0.071 | | | |
| 12.5 | 886 | N | 0 | 0.109 | 0.080 | 0.092 | 0.076 | 0.112 | 0.091 | 0.100 | 0.094 | | 0.083 | 0.064 | 0.097 | 0.091 | 0.084 | | |
| | 882 | N | 0 | 0.120 | 0.082 | 0.102 | 0.107 | 0.095 | 0.089 | 0.098 | 0.099 | | 0.092 | 0.064 | 0.111 | 0.088 | 0.089 | | |
| | 910 | N | 6 | 0.092 | 0.063 | 0.090 | 0.070 | 0.096 | 0.085 | 0.092 | 0.084 | | 0.080 | 0.052 | 0.094 | 0.080 | 0.077 | | |
| | 914 | N | 6 | 0.074 | 0.043 | 0.080 | 0.081 | 0.086 | 0.092 | 0.089 | 0.078 | | 0.075 | 0.059 | 0.078 | 0.080 | 0.073 | | |
| | 884 | R | 0 | 0.140 | 0.090 | 0.107 | 0.074 | — | 0.093 | 0.100 | 0.101 | | 0.113 | 0.071 | 0.107 | 0.086 | 0.094 | | |
| | 912 | R | 6 | 0.120 | 0.067 | 0.123 | 0.090 | 0.102 | 0.095 | 0.102 | 0.100 | 0.092 | 0.114 | 0.072 | 0.129 | 0.088 | 0.101 | 0.086 | 0.089 |
| Round average | | | | 0.109 | 0.071 | 0.099 | 0.083 | 0.098 | 0.091 | 0.097 | | | 0.093 | 0.064 | 0.103 | 0.086 | | | |
| Round avg., all thicknesses | | | | 0.085 | 0.058 | 0.103 | 0.089 | 0.097 | 0.072 | 0.071 | | | 0.073 | 0.065 | 0.107 | 0.064 | | | |
| $\Delta T$ (°F) | | | | −24 | −20 | −24 | −18 | [1] | −19 | −22 | | | +22 | +13 | +25 | +18 | | | |

[1] Not observed due to equipment failure.

## TABLE 83

### SCHEDULE OF SLAB CURLING MEASUREMENTS MADE IN LOOP 1
(Data available in DS 5223)

| Number | | | Code | | Upward Movement at Corner | | | | Downward Movement at Corner | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Round | Sub-round | Section | Design[1] | Rep. | Dates | Hours | $M_c$ (in.) | Rep. 1 Avg. (in.) | Dates | Hours | $-M_c$ (in.) | Rep. 1 Avg. (in.) |
| 1 | 1 | 900 | 1R6 | 1 | June 23-24, 1959[2] | 1430–0330 | 0.143 | | June 24, 1959[1] | 0330–1500 | 0.085 | |
| | | 932 | 1R6 | 2 | | 1330–0145 | 0.128 | | | 0145–1500 | 0.106 | |
| | | 928 | 2R6 | 1 | | 1515–0400 | 0.120 | | | 0400–1515 | 0.113 | |
| | | 916 | 3R6 | 1 | | 1600–0445 | 0.090 | | | 0445–1615 | 0.097 | |
| | | 912 | 4R6 | 1 | | 1600–0545 | 0.144 | 0.124 | | 0545–1630 | 0.145 | 0.110 |
| | 2 | 934 | 1N6 | 1 | June 25-26, 1959 | 1545–0400 | 0.029 | | June 24-25, 1959 | 2330–1545 | 0.091 | |
| | | 926 | 2N6 | 1 | | 1600–0400 | 0.038 | | June 25, 1959 | 0430–1600 | 0.084 | |
| | | 918 | 3N6 | 1 | | 1600–0345 | 0.059 | | | 0515–1600 | 0.099 | |
| | | 910 | 4N6 | 1 | | 1700–0315 | 0.048 | | | 0545–1700 | 0.074 | |
| | | 914 | 4N6 | 2 | | 1600–0215 | 0.043 | 0.044 | | 0545–1600 | 0.077 | 0.087 |
| | 3 | 896 | 1R0 | 1 | July 14-15, 1959[2] | 1445–0345 | 0.145 | | July 15, 1959[3] | 0345–1445 | 0.118 | |
| | | 906 | 2R0 | 1 | | 1500–0530 | 0.135 | | | 0530–1515 | 0.127 | |
| | | 922 | 3R0 | 1 | | 1530–0515 | 0.070 | | | 0500–1515 | 0.088 | |
| | | 908 | 3R0 | 2 | | 1545–0500 | 0.082 | | | 0500–1515 | 0.088 | |
| | | 884 | 4R0 | 1 | | 1515–0530 | 0.106 | 0.114 | | 0530–1545 | 0.106 | 0.110 |
| | 4 | 936 | 1N0 | 1 | July 16-17, 1959[3] | 1500–0245 | 0.088 | | July 17, 1959[3] | 0245–1515 | 0.087 | |
| | | 924 | 2N0 | 1 | | 1615–0545 | 0.100 | | | 0545–1530 | 0.092 | |
| | | 890 | 2N0 | 2 | | 1545–0515 | 0.127 | | | 0515–1515 | 0.122 | |
| | | 920 | 3N0 | 1 | | 1600–0545 | 0.118 | | | 0545–1545 | 0.115 | |
| | | 886 | 4N0 | 1 | | 1545–0530 | 0.092 | 0.100 | | 0530–1545 | 0.091 | 0.096 |
| 3 | 1 | 936 | 1N0 | 1 | Oct. 14-15, 1959 | 1530–0315 | 0.024 | | Oct. 15, 1959 | 0315–1430 | 0.017 | |
| | | 924 | 2N0 | 1 | | 1415–0300 | 0.018 | | | 0300–1400 | 0.031 | |
| | | 890 | 2N0 | 2 | | 1445–0445 | 0.032 | | | 0445–1415 | 0.038 | |
| | | 920 | 3N0 | 1 | | 1345–0430 | 0.054 | | | 0430–1445 | 0.073 | |
| | | 886 | 4N0 | 1 | | 1500–0500 | 0.032 | 0.032 | | 0500–1500 | 0.058 | 0.045 |
| | 2 | 896 | 1R0 | 1 | Oct. 16-17, 1959 | 1200–0200 | 0.040 | | Oct. 17, 1959 | 0200–1345 | 0.022 | |
| | | 906 | 2R0 | 1 | | 1300–0300 | 0.042 | | | 0300–1415 | 0.029 | |
| | | 922 | 3R0 | 1 | | 1330–0315 | 0.032 | | | 0315–1445 | 0.035 | |
| | | 908 | 3R0 | 2 | | 1330–0345 | 0.031 | | | 0345–1430 | 0.040 | |
| | | 884 | 4R0 | 1 | | 1430–0500 | 0.055 | 0.042 | | 0500–1500 | 0.026 | 0.028 |
| | 3 | 900 | 1R6 | 1 | Oct. 19-20, 1959 | 1330–0200 | 0.035 | | Oct. 20, 1959 | 0200–1245 | 0.028 | |
| | | 932 | 1R6 | 2 | | 1300–0245 | 0.046 | | | 0245–1300 | 0.044 | |
| | | 928 | 2R6 | 1 | | 1315–0345 | 0.043 | | | 0345–1315 | 0.040 | |
| | | 916 | 3R6 | 1 | | 1430–0345 | 0.056 | | | 0345–1345 | 0.054 | |
| | | 912 | 4R6 | 1 | | 1500–0430 | 0.079 | 0.053 | | 0430–1415 | 0.076 | 0.050 |
| | 4 | 934 | 1N6 | 1 | Oct. 21-22, 1959 | 1415–0015 | 0.046 | | Oct. 22, 1959 | 0015–1345 | 0.060 | |
| | | 892 | 2N6 | 1 | | 1415–0045 | 0.027 | | | 0045–1400 | 0.053 | |
| | | 918 | 3N6 | 1 | | 1430–0130 | 0.062 | | | 0130–1415 | 0.079 | |
| | | 910 | 4N6 | 1 | | 1430–0315 | 0.050 | | | 0315–1430 | 0.052 | |
| | | 914 | 4N6 | 2 | | 1445–0300 | 0.041 | 0.046 | | 0300–1430 | 0.056 | 0.061 |
| 4 | 1 | 936 | 1N0 | 1 | June 2-3, 1960 | 1515–0130 | 0.026 | | June 3, 1960 | 0130–1330 | 0.030 | |
| | | 924 | 2N0 | 1 | | 1600–0430 | 0.073 | | | 0430–1530 | 0.077 | |
| | | 890 | 2N0 | 2 | | 1500–0515 | 0.083 | | | 0515–1430 | 0.081 | |
| | | 920 | 3N0 | 1 | | 1530–0500 | 0.084 | | | 0500–1530 | 0.089 | |
| | | 886 | 4N0 | 1 | | 1545–0445 | 0.095 | 0.070 | | 0445–1345 | 0.080 | 0.069 |
| | 2 | 934 | 1N6 | 1 | | | | | June 7, 1960[3] | 0215–1430 | 0.059 | |
| | | 892 | 2N6 | 1 | | | | | | 0430–1500 | 0.097 | |
| | | 918 | 3N6 | 1 | | | | | | 0545–1515 | 0.128 | |
| | | 910 | 4N6 | 1 | | | | | | 0600–1530 | 0.094 | |
| | | 914 | 4N6 | 2 | | | | | | 0600–1545 | 0.090 | 0.095 |
| | 3 | 896 | 1R0 | 1 | June 9-10, 1960[2] | 1545–0315 | 0.104 | | June 9, 1960[2] | 0300–1545 | 0.092 | |
| | | 906 | 2R0 | 1 | | 1630–0430 | 0.118 | | | 0530–1630 | 0.130 | |
| | | 922 | 3R0 | 1 | | 1530–0500 | 0.072 | | | 0500–1530 | 0.088 | |
| | | 908 | 3R0 | 2 | | 1530–0445 | 0.082 | | | 0515–1530 | 0.088 | |
| | | 884 | 4R0 | 1 | | 1600–0415 | 0.127 | 0.105 | | 0445–1600 | 0.123 | 0.111 |
| | 4 | 900 | 1R6 | 1 | | | | | June 11, 1960 | 0300–1315 | 0.078 | |
| | | 932 | 1R6 | 2 | | | | | June 10, 1960 | 2245–1245 | 0.075 | |
| | | 928 | 2R6 | 1 | | | | | June 11, 1960 | 0300–1330 | 0.041 | |
| | | 916 | 3R6 | 1 | | | | | | 0430–1330 | 0.048 | |
| | | 912 | 4R6 | 1 | | | | | | 0430–1545 | 0.099 | 0.067 |
| 5 | 1 | 900 | 1R6 | 1 | July 11-12, 1960 | 1530–0330 | 0.025 | | July 12, 1960 | 0330–1345 | 0.025 | |
| | | 932 | 1R6 | 2 | | 1500–0215 | 0.026 | | | 0215–1345 | 0.023 | |
| | | 928 | 2R6 | 1 | | 1545–0330 | 0.033 | | | 0330–1415 | 0.035 | |
| | | 916 | 3R6 | 1 | | 1600–0415 | 0.041 | | | 0415–1500 | 0.043 | |
| | | 912 | 4R6 | 1 | | 1630–0500 | 0.087 | 0.047 | | 0500–1500 | 0.104 | 0.052 |
| | 2 | 936 | 1N0 | 1 | July 13-14, 1960 | 1515–0430 | 0.017 | | July 14, 1960 | 0430–1315 | 0.017 | |
| | | 924 | 2N0 | 1 | | 1530–0515 | 0.075 | | | 0515–1615 | 0.070 | |
| | | 890 | 2N0 | 2 | | 1515–0500 | 0.103 | | | 0500–1530 | 0.091 | |
| | | 920 | 3N0 | 1 | | 1500–0530 | 0.087 | | | 0530–1500 | 0.082 | |
| | | 886 | 4N0 | 1 | | 1615–0515 | 0.110 | 0.072 | | 0515–1615 | 0.099 | 0.067 |
| | 3 | 934 | 1N6 | 1 | July 15-16, 1960[3] | 1445–0215 | 0.069 | | July 14, 1960 | 0430–1445 | 0.046 | |
| | | 892 | 2N6 | 1 | | 1515–0330 | 0.088 | | | 0430–1515 | 0.083 | |
| | | 918 | 3N6 | 1 | | 1615–0545 | 0.108 | | | 0600–1615 | 0.113 | |
| | | 910 | 4N6 | 1 | | 1615–0445 | 0.089 | | | 0545–1615 | 0.098 | |
| | | 914 | 4N6 | 2 | | 1615–0445 | 0.084 | 0.089 | | 0600–1615 | 0.094 | 0.085 |
| | 4 | 896 | 1R0 | 1 | July 19-20, 1960[2] | 1500–0600 | 0.146 | | July 19, 1960[2] | 0515–1500 | 0.123 | |
| | | 906 | 2R0 | 1 | | 1545–0615 | 0.156 | | | 0545–1545 | 0.150 | |
| | | 922 | 3R0 | 1 | | 1530–0530 | 0.088 | | | 0600–1530 | 0.088 | |
| | | 908 | 3R0 | 2 | | 1615–0615 | 0.091 | | | 0600–1615 | 0.096 | |
| | | 884 | 4R0 | 1 | | 1615–0600 | 0.126 | 0.129 | | 0600–1615 | 0.130 | 0.123 |

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[1] First figure is slab thickness, in inches; letter designates reinforcing; last figure is subbase thickness, in inches.

[2] Data taken this date were included in analysis of curling of 40-ft (reinforced) panels.

[3] Data taken this date were included in analysis of curling of 15-ft (nonreinforced) panels.

joint, at a second point 6 in. from the edge and midway between transverse joints, and at a third point 1-ft from the centerline and midway between transverse joints. Table 84 gives the depths at which the thermocouples were installed for each of the four slab thicknesses occurring in Loop 1.

The thermocouples in three 2.5- and three 5.0-in. panels were connected to a common junction box so that the temperatures in these six sections could be observed at frequent intervals over any desired period of time. Similarly, thermocouples in three 9.5- and three 12.5-in. panels were connected to a common junction box. Thermocouples in the remaining 22 sections were connected to individual junction boxes adjacent to the sections.

Automatic equipment (Fig. 166) made it possible to record on punched paper tape, at the end of intervals as short as 5 min, the output of as many as 225 thermocouples at a rate of about one thermocouple per second.

Figure 167, an example of the kind of information furnished by the thermocouple installation, illustrates changes in temperature distribution with time occurring in plastic concrete. Figure 168 shows simultaneous values of air temperatures. Apparently the concrete in this 12.5-in. panel took its initial set with a parabolic distribution of internal temperature similar to one of the curves shown. Neglecting the effects of future changes in moisture distribution, one would expect that the hardened slab would resume its initial shape only when this particular temperature distribution occurred again. Figure 169, which shows typical temperature distributions in hardened concrete, indicates that any particular distribution usually occurs only momentarily, so that any point on the surface of a concrete slab can be expected to be in continuous motion. This was found to be the case in the studies of corner movement and the curl of concrete slabs.

TABLE 84

DEPTHS AT WHICH THERMOCOUPLES WERE INSTALLED,[1] DESIGN 1, LOOP 1, LANE 2

| Thermocouple Number | Depth Below Surface of Pavement (in.) | | | |
|---|---|---|---|---|
| | 2.5-In. Slab | 5.0-In. Slab | 9.5-In. Slab | 12.5-In. Slab |
| 1 | .25 | .25 | .25 | .25 |
| 2 | 2.0 | 1.5 | 2.0 | 2.0 |
| 3 | 4.5 | 2.5 | 4.0 | 5.0 |
| 4 | 6.5 | 3.5 | 6.0 | 8.0 |
| 5 | 8.5 | 4.5 | 8.0 | 11.0 |
| 6 | 10.5 | 7.0 | 9.0 | 12.0 |
| 7 | | 9.0 | 11.5 | 14.5 |
| 8 | | 11.0 | 13.5 | 16.5 |
| 9 | | 13.0 | 15.5 | 18.5 |
| 10 | | | 17.5 | 20.5 |

[1] Thermocouples below horizontal line in each column were installed in subbase or embankment.

*3.3.5.2 Instrumentation of Corner Movement and Curling of Concrete Slabs.*—As shown in Figure 170, sixteen small brass plugs were installed in the pavement surface in a 6- x 6-ft square area in the corner region of all sections in Design 1, Loop 1, Lane 2, or a total of 24 sections. These plugs provided reference points in the pavement surface for use in the study of curling. Table 82 gives details of the designs of the 24 sections, each of which consisted of but one panel either 15 or 40 ft in length.

A reference rod and instrument housing, similar to those used in the traffic loops, were installed near the corner of each panel (Section 3.3.1.1). A dial gage with 2-in. travel graduated in thousandths of an inch (Fig. 171) was used for measuring movements of the corner relative to the top of the reference rod.

Displacements of the 16 brass plugs on the slab surface were measured by means of an aluminum beam (Fig. 171) equipped with a machinist's level, three movable probes, a fixed probe at one end, and an adjustable support at the other end. The probes were placed on 2-ft centers to coincide with the reference plugs in the pavement. The movable probes actuated dials similar to the one previously described.

The procedure followed in taking one set of measurements on the reference plugs in any panel was as follows.

The beam was first placed in the position shown in Figure 171 (designated Position No. 1) with the fixed probe resting on the plug nearest the panel corner, and the movable probes resting on the other three plugs in a line parallel to the transverse joint. The beam was leveled in this position and the readings of the dials were recorded. The beam was then rotated through 90 deg about the corner reference plug, and placed parallel to the pavement edge with the movable probes resting on the three plugs in a line parallel to the edge (Position No. 2). The beam was again leveled and the dial readings recorded.

The instrument was then moved inward over the second line of plugs parallel to the edge (Position No. 3), leveled, and the readings recorded. In the same manner measurements were made on the third (Position No. 4) and fourth (Position No. 5) lines of plugs parallel to the edge. Finally, the beam was returned to a position perpendicular to the edge (Position No. 6), and readings taken on the line of plugs farthest from the tranverse joint.

These measurements, combined with a measurment made of the distance between a point on the instrument housing (which was attached

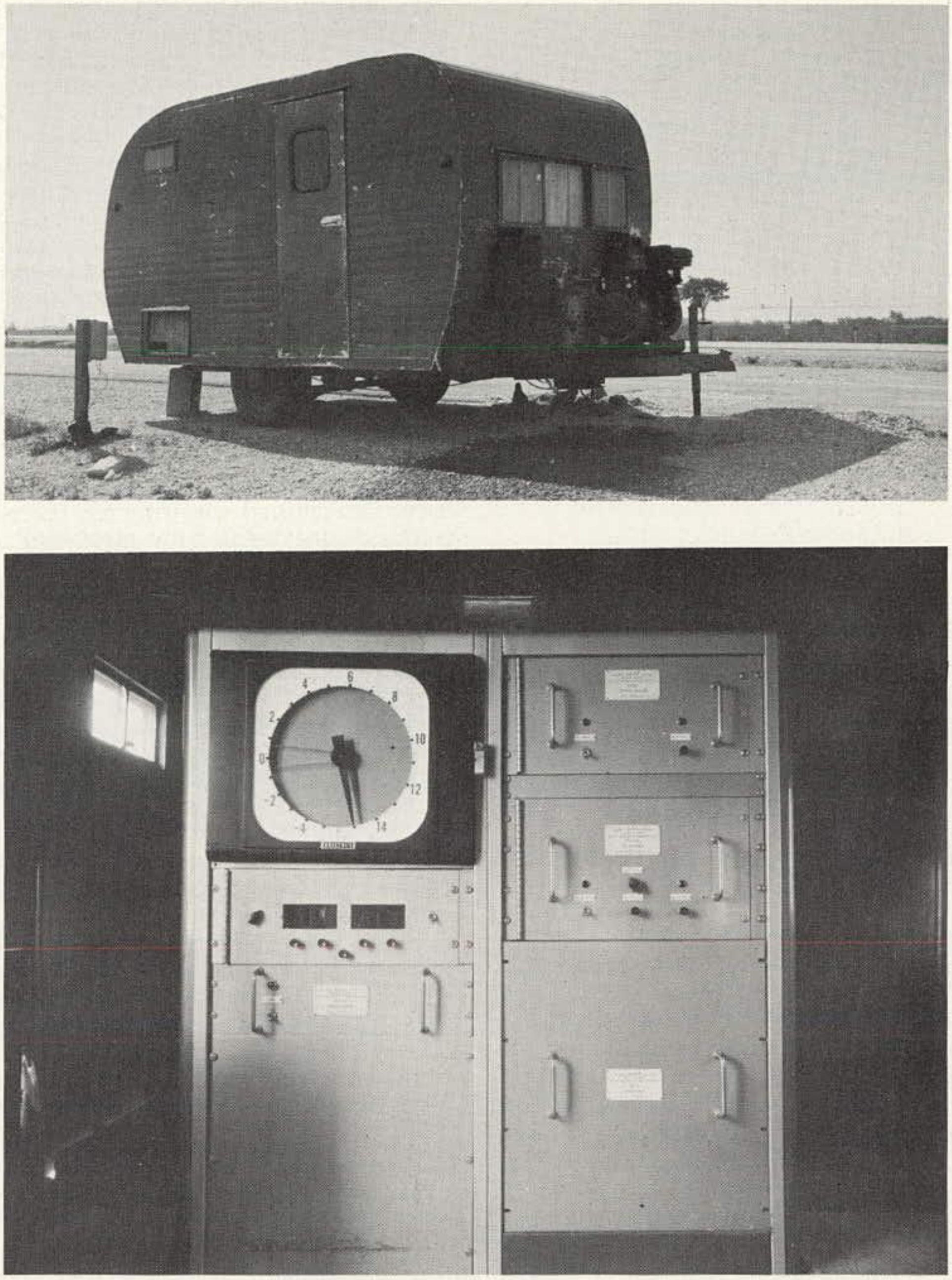

Figure 166. Van with equipment for recording internal pavement temperature.

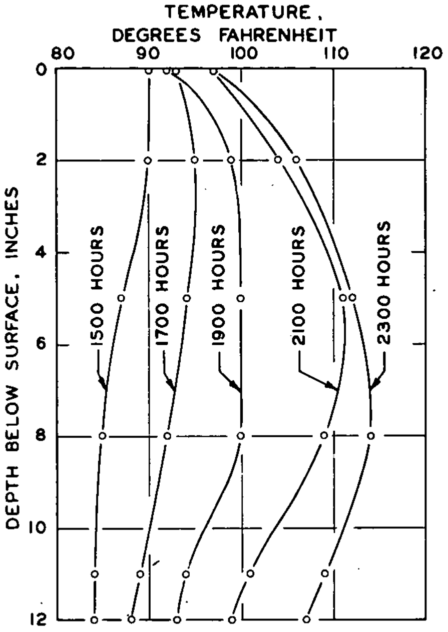

Figure 167. Changes in internal temperature distribution with time during early curing stages of a 12.5-in. slab in July 1958 (placing began about 1400 hours).

to the slab) and the top of the reference rod (which was anchored in the ground about 8.5 ft below the pavement surface) formed one complete set of readings. The measurements crew then proceeded to the next panel in the experiment.

When some time later (usually about 2 hours) a second set of measurements had been taken on a panel, the two sets together formed the basic data for which could be calculated for each reference plug the magnitude and direction of the vertical displacement (with reference to the earth*) occurring during the interval between the two sets of readings. In addition, in each set of readings the last three, taken with the beam in Position No. 6, were not necessary to the 16 calculations, and were used to compute an additional set of three displacements. The additional displacements, when compared with the corresponding displacements calculated from the first five beam positions, helped to establish the order of magnitude of the experimental error associated with the measuring system. These errors, though not used in the analysis (differences between replicate sections were available for the purpose) nevertheless provided a means for controlling the field work and led to improvements in the procedures and instrumentation.

As a rule, just before beginning and again just after finishing a set of measurements on the brass plugs in the slab surface, the field crew determined the internal temperature distribution in the slab by means of the thermocouples previously described.

*3.5.3.3 Movement at Corner with Changing Temperature Conditions.*—The procedure followed in determining $m_c$ and $\Delta T$ from data gathered during the special studies of corner movements is shown in Figure 172, which presents a part of the data from Round 1 (see Tables 81 and 82). The bottom curve shows vertical displacements, measured periodically at a panel corner over a 28-hr period, plotted against time, and plotted relative to the position of the corner at the first observation. Also shown are two values of $m_c$, +0.140 in. and —0.113 in., which were, respectively, the maximum upward and the maximum downward displacements observed. These values are given in Table 82, for section 884; the other values of $m_c$ were obtained in a similar manner.

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* In calculating displacements relative to the earth, it was necessary to assume that the displacement of the instrument housing with respect to the top of the reference rod was equal to the displacement of the reference plug nearest the slab corner with respect to the earth.

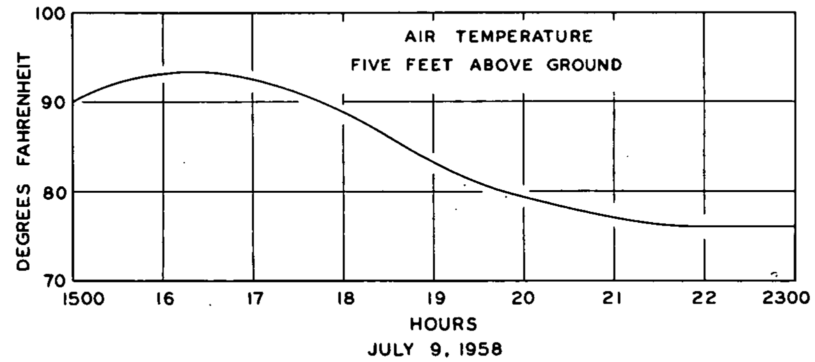

Figure 168. Air temperature corresponding to data shown in Figure 167.

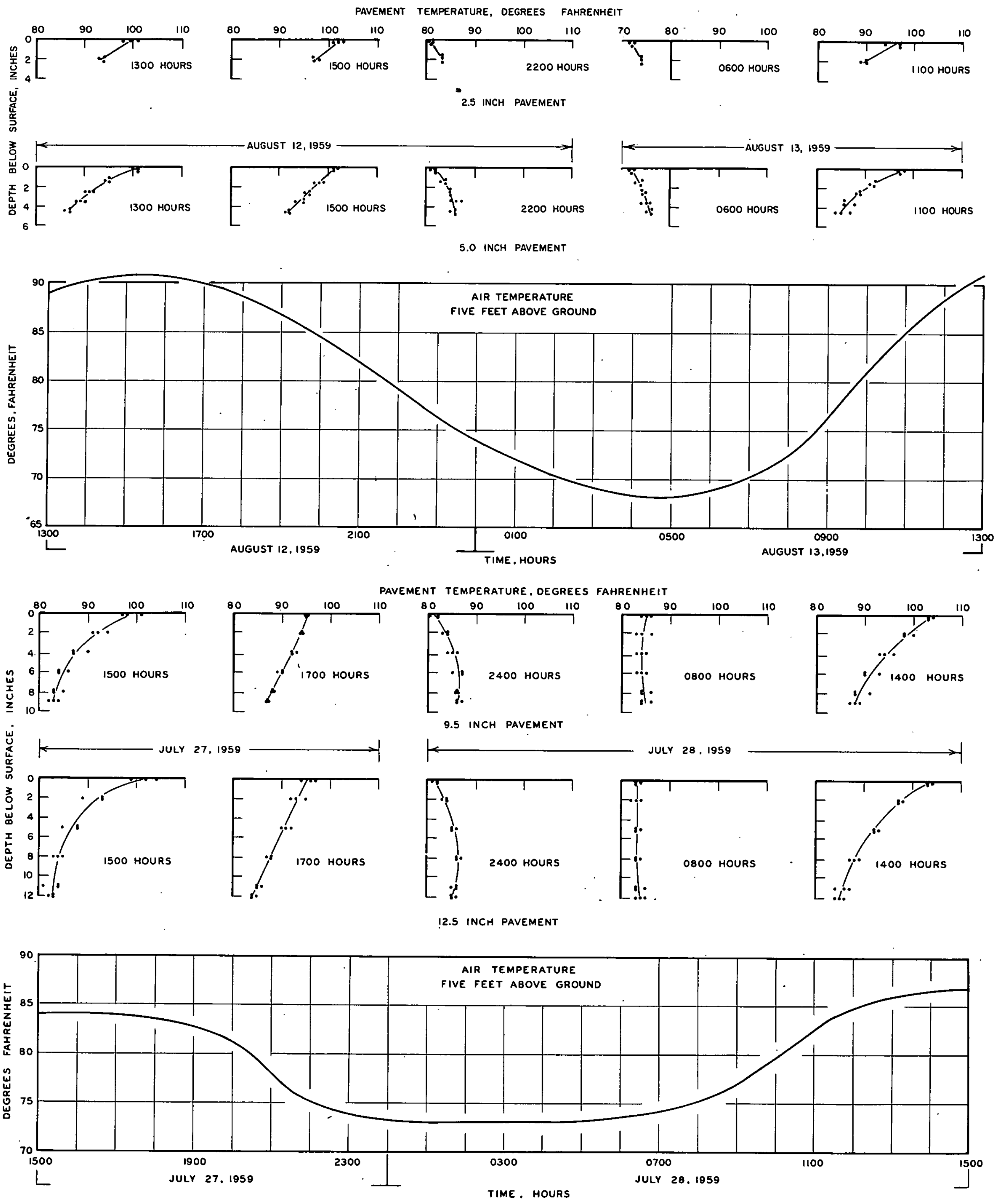

Figure 169. Typical changes in temperature distribution in summer for four thicknesses of pavements. Curves represent average of observations on three test sections.

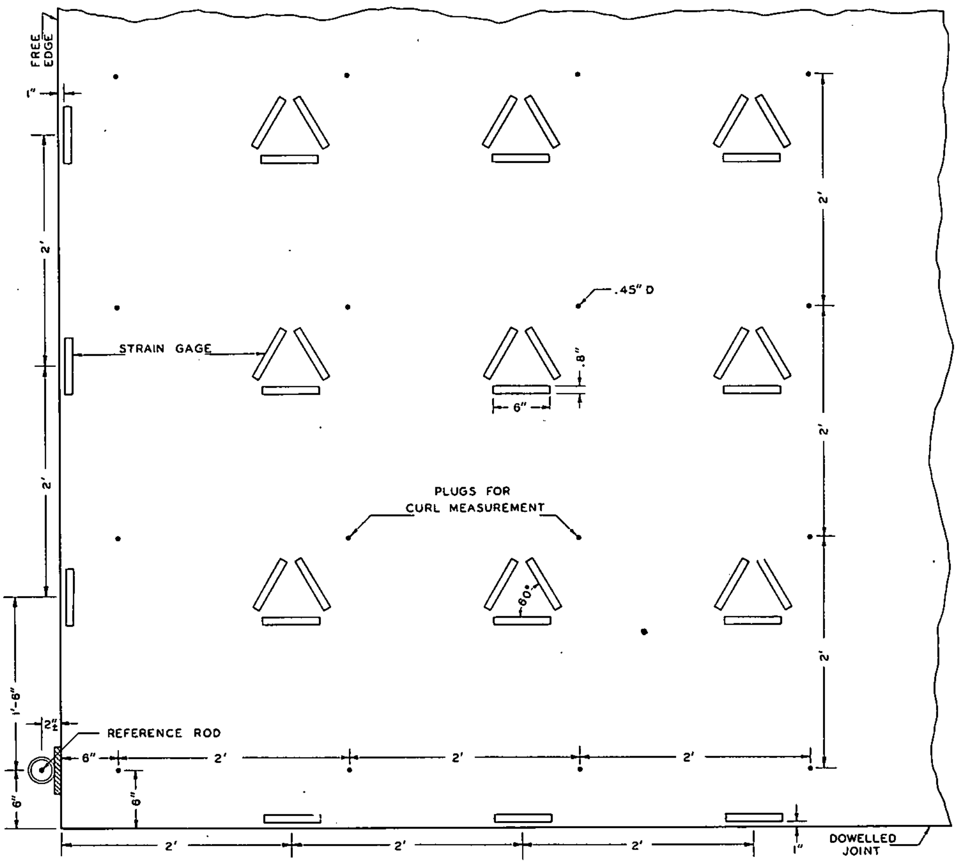

Figure 170. Layout of gages, plugs and reference rod for strain and curl measurement in Loop 1.

A comparison of the three curves (Fig. 172)—air temperature vs time, the temperature differential in a 6.5-in. slab vs time, and the corner displacement of a 12.5-in. slab vs time—indicates that the motion observed at the panel corner was closely related to the other two variables. Inasmuch as the temperature statistic $T$ had proved to be useful in explaining variation in load deflections with time (Section 3.3.3), this variable was chosen for an investigation of the correlation of corner movements with changes in temperature conditions.

The particular value of $\Delta T$ to be associated with each observed positive value of $m_c$ was selected in the following manner.

Within each round the beginning and ending times of the period during which each panel corner under observation was moving upward were determined. From these data, the earliest time (for example, $t_1$) at which any of the panel corners started its upward movement, and the latest time ($t_2$) at which any panel ended its upward movement, were found (see center curve, Fig. 172, for an example). The statistics, $\Delta T$, was defined as the net change in $T$ occurring over a period beginning at the time that $T$ was last at a maximum before time $t_1$, and ending at the time when $\Delta T$ was last at a minimum before $t_2$. By this method the values of $\Delta T$ shown at the bottom of Table 82, under "Up Movement" were obtained.

For each observed negative value of $m_c$, $\Delta T$ was selected in a manner analogous to that just described, as follows:

Within each round the beginning and ending times of the period during which each panel corner was moving downward were determined. From these data the earliest time ($t_3$) at which any panel corner started its downward movement, and the latest time ($t_4$) at which any panel corner ended its downward movement, were found. $\Delta T$ was defined as the net change in $T$ occurring over a period beginning at the time that $T$ was last at a minimum before time $t_3$ and ending at the time when $\Delta T$ was last at a maximum before $t_4$. Values of $\Delta T$ obtained by this procedure are given at the bottom of Table 82 under "Down Movement."

These definitions of $\Delta T$ insured that at least a portion of the temperature history prior to the time of observation would be included in the temperature statistic and that none of the temperature history occurring after the period of observation would be included.

The results of investigation of correlation between $\Delta T$ and $m_c$ are shown in Figure 173, in which $m_c$ was plotted against $\Delta T$ for eight combinations of slab thickness and panel length. The movement data are averages across subbase thickness of the values given in Table 82. The straight lines were fitted to the data by the method of least squares; the root mean square residual for each case is shown. Table 85 gives the slopes of these lines.

According to Figure 173 some degree of correlation exists between maximum movement at panel corners and the temperature statistic, $\Delta T$, within the observed range of $\Delta T$, except in the case of the 2.5-in. slabs, where the correlation appears to be poor or absent. Inasmuch as in all eight graphs the lines passed close to the origin, values of $\Delta T$ equal but opposite in sign are apparently associated with maximum corner displacements that are approximately equal but opposite in direction, at least within the range of values observed.

In the study of corner movements, an effort was made to restrict the observation periods to days during which large fluctuations in temperature were likely to occur, since large displacements were judged to be of greater practical interest than small ones. For this reason, the relationship of $m_c$ to $\Delta T$ is not well defined by the data for small values of $\Delta T$.

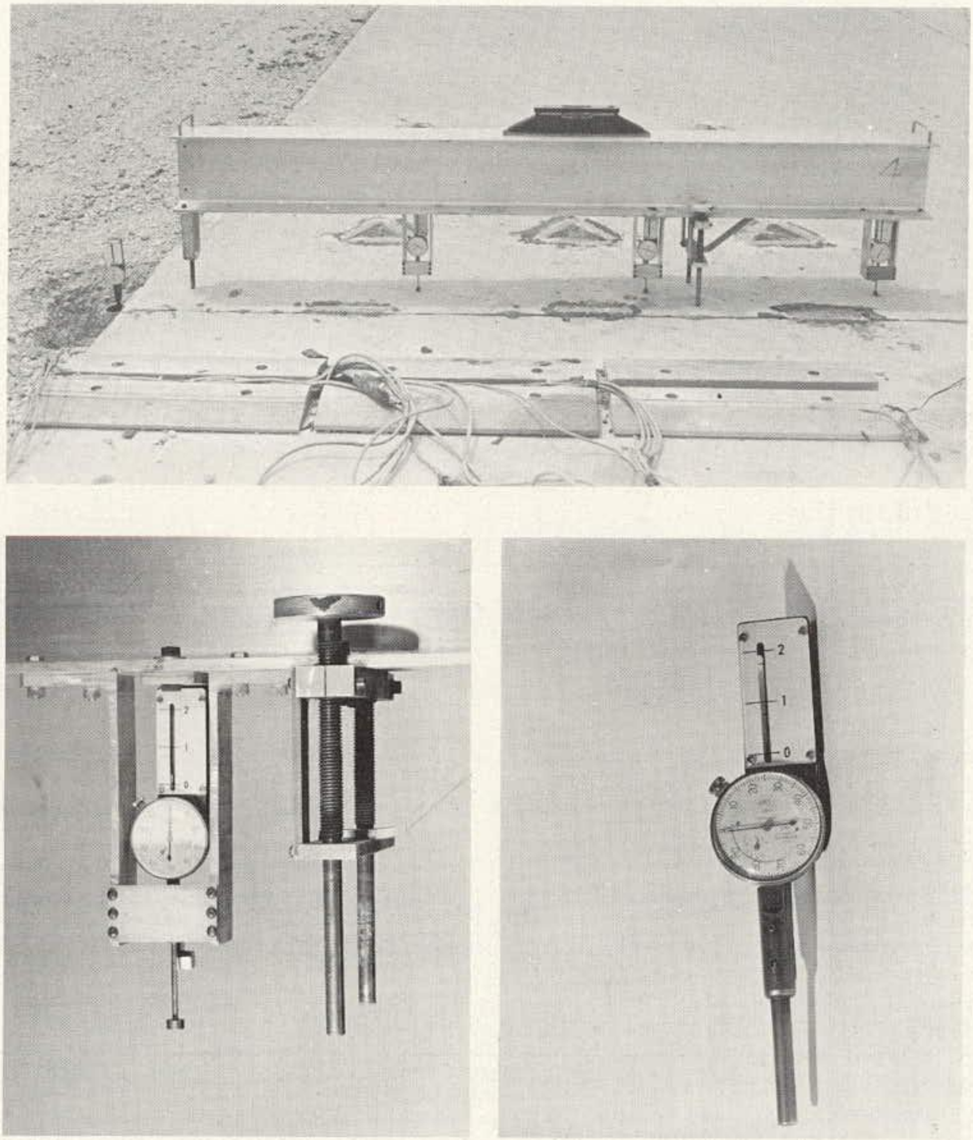

Figure 171. Curl beam in position 1 for measurement of vertical movement, with (upper left) close-up of probe near adjustable support and (upper right) instrument for measuring vertical movement at panel corners.

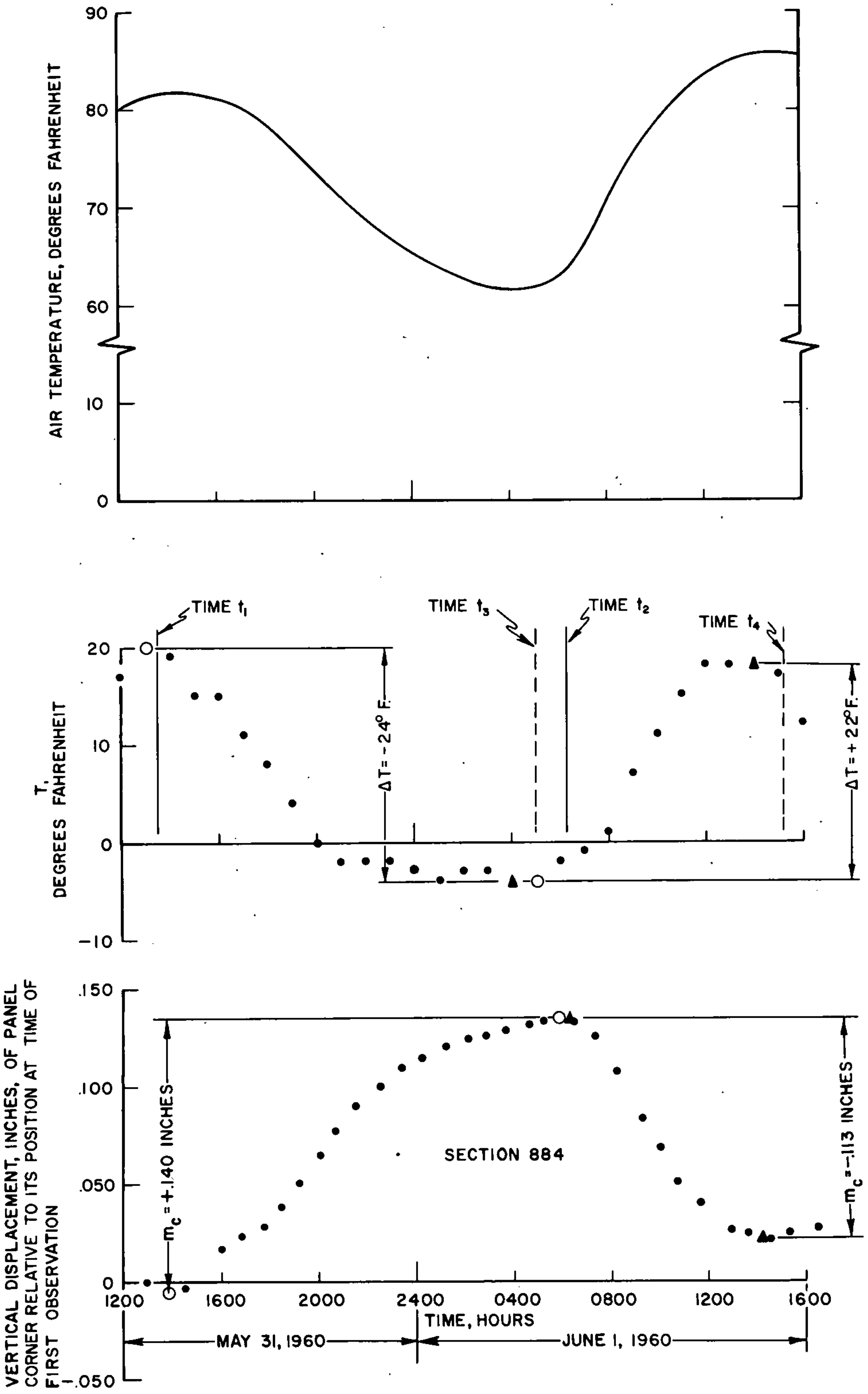

Figure 172. Time, temperature and displacement data from corner movement study of May 31-June 1, 1960.

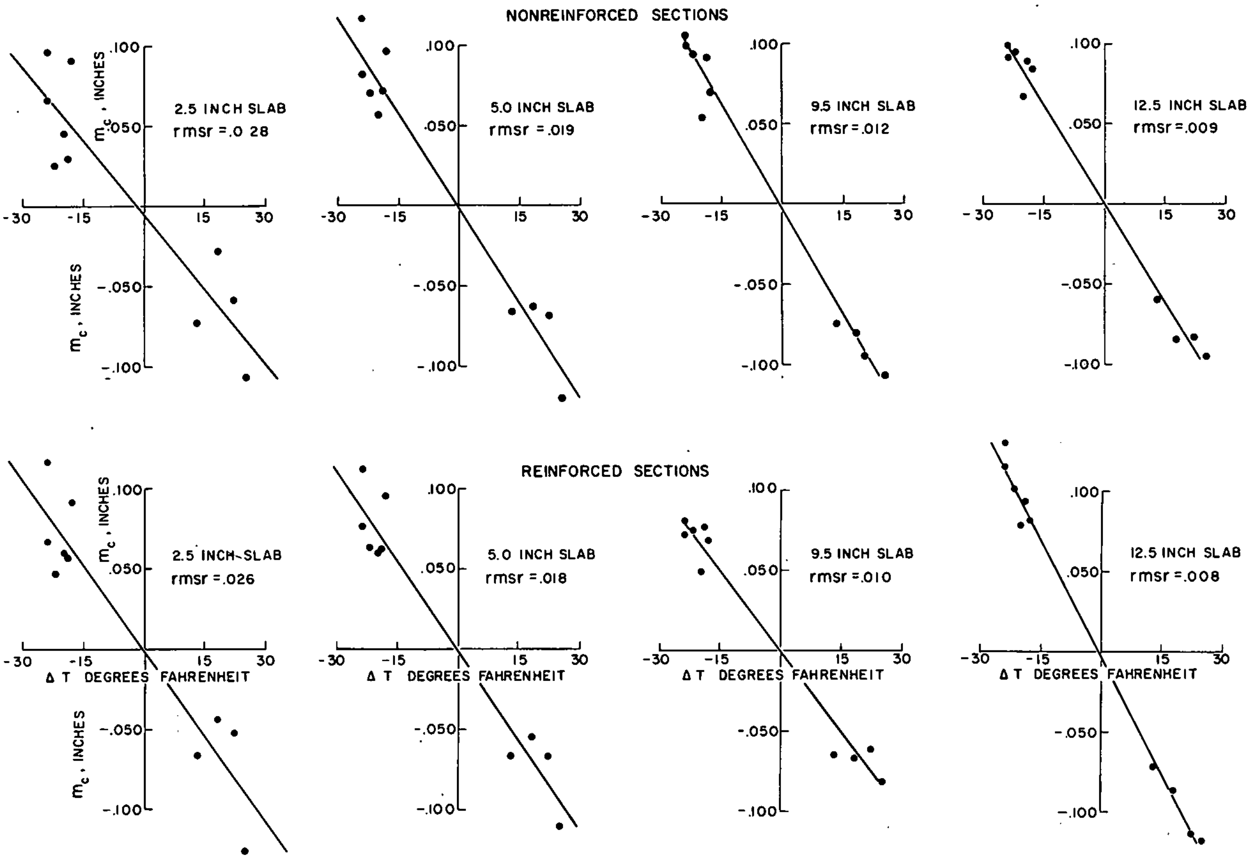

Figure 173. Maximum movement at panel corner vs corresponding change in *T*, Experiment Design 1, Loop 1, data from special studies of corner movements averaged across subbase thickness, replicate sections included. Round 4 excluded because of absence of temperature data.

The two top curves (Fig. 172), as well as theory*, indicate that successive amplitudes of the $T$ vs time curve are related to the corresponding amplitudes of the air temperature vs time curve. Pairs of corresponding amplitudes ($\Delta T$ for amplitudes of the $T$-time curve and $\Delta U$ for amplitudes of the air temperature-time curve) for a six-month period in 1959 were plotted as shown in Figure 174.

The convention adopted for determining the signs of $\Delta U$ and $\Delta T$ was as follows: An amplitude $\Delta U$ corresponding to a period during which the air temperature $U$ was increasing was given a positive sign. During the same (or approximately the same) period, $T$ was decreasing, and the amplitude $\Delta T$ was given a negative sign.

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* See, for example, Thomlinson, J., "Temperature Variations and Consequent Stresses Produced by Daily and Seasonal Temperature Cycles in Concrete Slabs." *Concrete and Constructional Engineering*, Concrete Publications, Ltd., London, England.

TABLE 85

SLOPES OF LINES IN FIGURE 173, DATA FROM SPECIAL STUDIES OF CORNER MOVEMENTS

| Panel Length (ft) | Slope (in./°F) | | | | |
|---|---|---|---|---|---|
| | 2.5-In. Slab | 5.0-In. Slab | 9.5-In. Slab | 12.5-In. Slab | Avg. |
| 15 | −0.0031 | −0.0040 | −0.0043 | −0.0041 | −0.0039 |
| 40 | −0.0036 | −0.0037 | −0.0033 | −0.0049 | −0.0039 |
| Avg. | −0.0033 | −0.0038 | −0.0038 | −0.0045 | |

Figure 174 suggested the following model for representing $\Delta T$ as a function of $\Delta U$:

$$|\Delta T| = A\,\sqrt[3]{(\Delta U)^2} \qquad (102)$$

in which $|\Delta T|$ is the absolute value of $\Delta T$; $A$ is a constant to be determined from the analysis; and $\Delta U$ is as previously defined.

The analysis, which minimized the sum of the squared deviations of the observations from the values predicted by the model, resulted in a value of $A = 3.10$. The graph of the model with this value of $A$ is shown in Figure 174. The values of $\Delta U$ and $\Delta T$ in dashed-line boxes were not used in the regression analysis.

*3.5.3.4 Typical Curling of Slabs in Corner Region.*—In the course of the special studies of curling (Table 83), there were 14 instances in which maximum upward displacements were determined at panel corners and 16 in which maximum downward displacements were measured. In each instance (hereafter referred to as an experiment) Table 83 gives the average value of $m_c$ for the four first-replicate sections involved, and Table 86 summarizes these averages.

As a preliminary step in the investigation of curling, each of the 30 experiments was analyzed separately (results are in DS 5226). However, because $m_c$ varied over a wide range (Table 86) and the larger movements were of the greater practical interest, it was decided to summarize the results of the study of curling by an analysis of data averaged over experiments yielding relatively high value of $m_c$.

Furthermore, the results of the analyses of load deflections at panel corners (Sections 3.3.5 and 3.3.7) suggested that there might be a difference between the shape assumed by a 15-ft nonreinforced panel at a given value of $T$ and that taken by a 40-ft reinforced panel at the same value of $T$, with corresponding differences to be expected in the motion of points on the slab surfaces. It was decided, therefore, that the summary analysis would be made in two parts—one of selected experiments made on nonreinforced sections and the other of selected experiments made on reinforced sections. The experiments chosen for analysis are given in Table 86. Further details of these experiments, including the value of $\Delta T$ associated with each, are given in Table 87.

Figure 175 plots the average values of $m_c$ (Table 86) against the corresponding values of $\Delta T$. The solid lines were fitted to the data by the method of least squares. For comparison

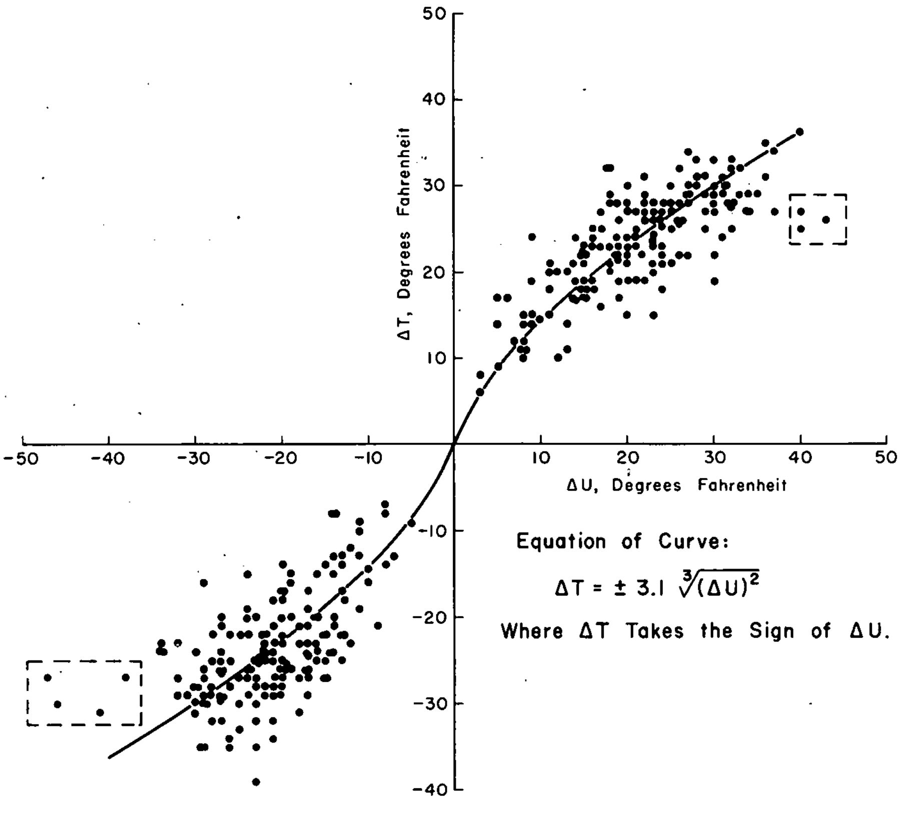


**Figure 174.** Relationship between amplitude of air temperature-time curve and corresponding amplitude of $T$-time curve, April 1-Sept. 30, 1959.

with the results of the study of corner movements (Section 3.5.3.3) dashed lines, with slopes equal to the average given in the last column of Table 85 have also been drawn. The differences between the slopes of the dashed and solid lines appeared to be of little practical significance, and it was concluded that the experiments selected for analysis were not abnormal, at least with respect to the maximum displacements observed at the corners of the panels.

Processing the Data.—In the procedure for making the measurements described in Section 3.5.3.2, successive measurements on any one of the reference points on the pavement were always made with the beam in the same position. The differences between successive readings of the dial gage actuated by the probe resting on the point represented successive displacements of that point relative to the point supporting the fixed probe at the end of the beam. Thus, within an experiment, there was associated with each of the points on a panel (including the corner point) a series of readings of the same dial that represented the data gathered at that point. This series of dial readings is referred to hereafter as the basic data for the point. The basic data for the corner point was the series of successive readings taken on the reference rod at the corner.

The data were smoothed and values of *m* were determined as follows: The basic data for

TABLE 86

AVERAGE MOVEMENT AT PANEL CORNER FOR FIRST REPLICATE SECTIONS LISTED IN TABLE 79

| Rnd. | Sub Rnd. | Movement (in.) | | | |
|---|---|---|---|---|---|
| | | Reinforced | | Nonreinforced | |
| | | Up | Down | Up | Down |
| 1 | 1 | 0.124[1] | 0.110[1] | | |
| | 2 | | | 0.044 | 0.087 |
| | 3 | 0.114[1] | 0.110[1] | | |
| | 4 | | | 0.100[2] | 0.096[2] |
| 3 | 1 | | | 0.032 | 0.045 |
| | 2 | 0.042 | 0.028 | | |
| | 3 | 0.053 | 0.050 | | |
| | 4 | | | 0.046 | 0.061 |
| 4 | 1 | | | 0.070 | 0.069 |
| | 2 | | | | 0.095[2] |
| | 3 | 0.105[1] | 0.111[1] | | |
| | 4 | | 0.067 | | |
| 5 | 1 | 0.047 | 0.052 | | |
| | 2 | | | 0.072 | 0.067 |
| | 3 | | | 0.089[2] | 0.085 |
| | 4 | 0.129[1] | 0.123[1] | | |

[1] Data from sections represented by this average were used in analysis of curling of 40-ft (reinforced) panels.

[2] Data from sections represented by this average were used in analysis of curling of 15-ft (nonreinforced) panels.

TABLE 87

SCHEDULE OF SPECIAL STUDIES OF CURLING OF CONCRETE SLABS FROM WHICH EQUATIONS WERE DERIVED

DESIGN 1, LOOP 1, LANE 2

| Panel | | | | Up Movement | | | | | | | Down Movement | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | From | | | To | | | | From | | | To | | | |
| Rnd. | Sub Rnd. | Lgth. (ft) | Type[1] | Hr[2] | Date | $T$ (°F) | Hr[3] | Date | $T$ (°F) | $\Delta T$ (°F) | Hr[4] | Date | $T$ (°F) | Hr[5] | Date | $T$ (°F) | $\Delta T$ (°F) |
| 1 | 4 | 15 | N | 1430 | 7/16/59 | +20 | 0445 | 7/17/59 | − 8 | −28 | 0245 | 7/17/59 | − 8 | 1545 | 7/17/59 | +20 | +28 |
| 4 | 2 | 15 | N | | | | | | | | 0100 | 6/ 7/60 | −10 | 1500 | 6/ 7/60 | +18 | +28 |
| 5 | 3 | 15 | N | 1315 | 7/14/60 | +13 | 0500 | 7/15/60 | − 8 | −21 | 0400 | 7/14/60 | −10 | 1600 | 7/14/60 | +22 | +32 |
| 1 | 1 | 40 | R | 1230 | 6/23/59 | +16 | 0530 | 6/24/59 | −10 | −26 | 0215 | 6/24/59 | −10 | 1615 | 6/24/59 | +19 | +29 |
| 1 | 3 | 40 | R | 1430 | 7/14/59 | +24 | 0500 | 7/15/59 | −11 | −35 | 0215 | 7/15/59 | −11 | 1600 | 7/15/59 | +19 | +30 |
| 4 | 3 | 40 | R | 1345 | 6/ 9/60 | +18 | 0430 | 6/10/60 | − 7 | −25 | 0315 | 6/ 9/60 | − 8 | 1530 | 6/ 9/60 | +18 | +26 |
| 5 | 4 | 40 | R | 1345 | 7/19/60 | +17 | 0600 | 7/20/60 | − 8 | −25 | 0430 | 7/19/60 | − 6 | 1600 | 7/19/60 | +17 | +23 |

[1] N = nonreinforced; R = reinforced.

[2] Earliest time at which a panel corner, among the five observed, reversed direction of motion from downward to upward.

[3] Latest time at which a panel corner reversed direction of motion from upward to downward.

[4] Earliest time at which a panel corner reversed direction of motion from upward to downward.

[5] Latest time at which a panel corner reversed direction of motion from downward to upward.

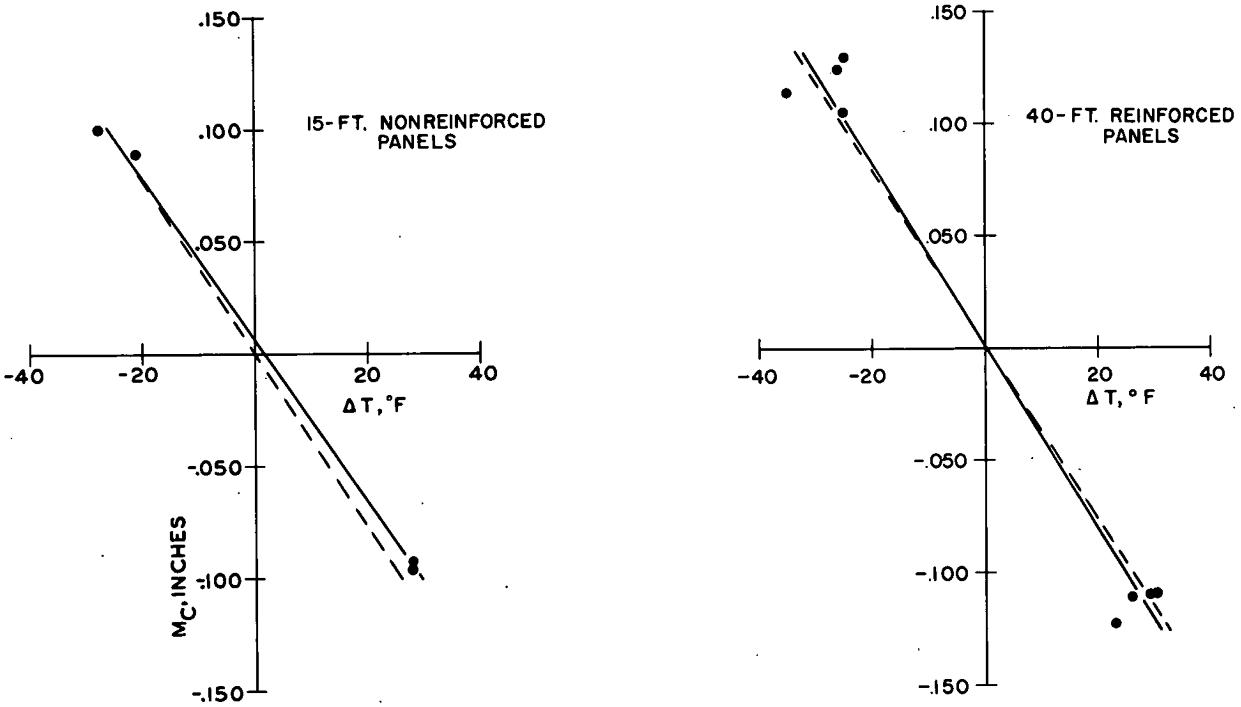


Figure 175. Analysis of curling of concrete slabs, average (solid lines) over slab and subbase thickness (Sec. 3.5.3.4). Dashed lines from special studies of panel corners (Sec. 3.5.3.3).

each of the 80 reference points within an experiment were plotted against time and curves drawn through the points. Next, the times at which these curves were at maxima and minima were determined. If the times of maxima and minima for the 16 points within a panel differed, the average times were used to define maxima and minima for the panel. Smoothed readings of the dial gages at the time established for panel maxima and minima were taken from the curve for each point. From linear combinations of the smoothed readings for all 16 points on a panel, values for $m$ were calculated for each point. The value of $\Delta T$ for each experiment was determined in accordance with the procedure described previously.

The conclusion was stated in Section 3.5.3.3 that equal values of $\Delta T$ opposite in sign resulted in movements at panel corners that were equal in magnitude but opposite in direction. In the processing of data from the selected experiments (Table 87), it was assumed that the same rule applied to other points on the surface of a panel. In accordance with this assumption and with the decision stated earlier to combine the data from certain experiments yielding high values of $m_c$, the data were processed prior to analysis as follows:

1. In experiments involving downward motion at panel corners, the sign of each value of $m$ was reversed, so that the signs of $m$ would be consistent in all experiments.

2. In experiments involving one level of reinforcing, all values of $m$ associated with one level of slab thickness and with one location on the panel were averaged.

These processes resulted in two sets of data, one for nonreinforced and one for reinforced panels, with each set consisting of four sub-sets corresponding to the four levels of slap thickness (2.5, 5.0, 9.5 and 12.5 in.). Each sub-set in turn, was made up of 16 averaged values of $m$ corresponding to the 16 reference points on a panel.

Analysis.—A linear model, whose terms were mutually orthogonal polynomials in the coordinates $x$ and $y$ of the reference points (Fig. 176) and the slab thickness $D_2$, was used to represent each set of data. The model consisted of a total of 64 terms (16 reference points times four thickness levels) with coefficients determined by the data. Data from replicate sections were used to determine experimental error, and only coefficients that were found to be significant at the 1 percent level were retained in the equations resulting from the two analyses.

*For nonreinforced sections:*

$$m \times 10^3 = 24.9 - 0.729x - 0.652y + 0.00635x^2 + 0.00743y^2 + H_1 \ (0.2945 - 0.00544x + 0.00108y - 0.0000979y^2) - H_2 \ (0.00599$$

$$- 0.000112x - 0.000226y) - H_3 (0.000461 - 0.00000248x + 0.00000516y) \quad (103)$$

*For reinforced sections:*

$$m \times 10^3 = 24.7x - 0.858x - 0.900y + 0.00760x^2 + 0.0120y^2 + H_1 (0.1724 - 0.00312x + 0.00279y - 0.000188y^2) - H_2 (0.000451 + 0.000102x + 0.000208y) + H_3 (0.000499 - 0.00000393x - 0.0000108y) \quad (104)$$

in which

$m$ = maximum displacement, in in., at a point within the area of observation;

$x, y$ = coordinates, in., of the point, $(-3 \leq x,y, \leq +3)$.

$H_1, H_2, H_3$ = functions of slab thickness defined as follows:

$$H_1 = 8D_2 - 59$$
$$H_2 = H_1^2 - 1.9875H_1 - 963$$
$$H_3 = H_1^3 - 4.0309H_1^2 - 1381.7H_1 + 1967.7$$

$D_2$ = slab thickness, in. $(2.5 \leq D_2 \leq 12.5)$.

The average absolute residual per observation was 0.004 in. and 0.010 in., respectively, for Eqs. 103 and 104. In computing these errors, predictions from the equations were compared with original observations, rather than with the average data analyzed.

The locations of contours of $m$ (Fig. 177) were determined from Eq. 103. Predictions from this equation at the four corners of the area observed on the panels are plotted against slab thickness in Figure 178, which also shows plots of the observed data prior to averaging. Similar contours representing Eq. 104 and a comparison between observed and predicted values are shown in Figures 179 and 180. Negative numbers (Figs. 177 and 179) adjacent to contour lines indicate displacements in the direction opposite to that observed at the panel corner.

Figure 181 shows a comparison between the displacements at panel corners predicted from Eqs. 103 and 104 and averaged values of the data from the study of corner movements. The generally higher predicted levels of displacement may be explained in part by difference in temperature. The average absolute value of $\Delta T$ for the data was 27 F, whereas the average absolute value existing during the studies of corner movements was 21 F. No explanation has been found for the particular trends of displacement with pavement thickness (Fig. 181).

The load-deflection data (Section 3.3.5 and 3.3.7) resulted in equations indicating that higher deflections usually occurred at the corners of the longer (reinforced) panels.

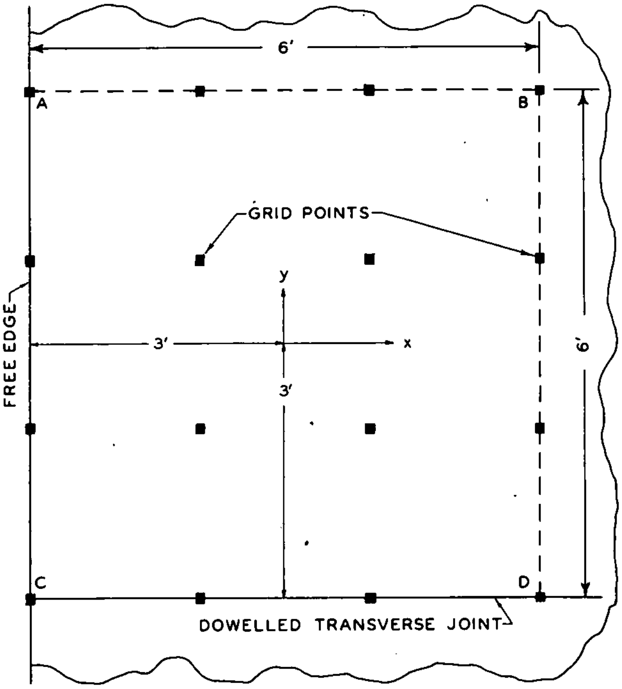


**Figure 176. In analyses of Loop 1 strain and curl data, measurements taken at gages shown in Figure 170 were assumed to apply to points shown here.**

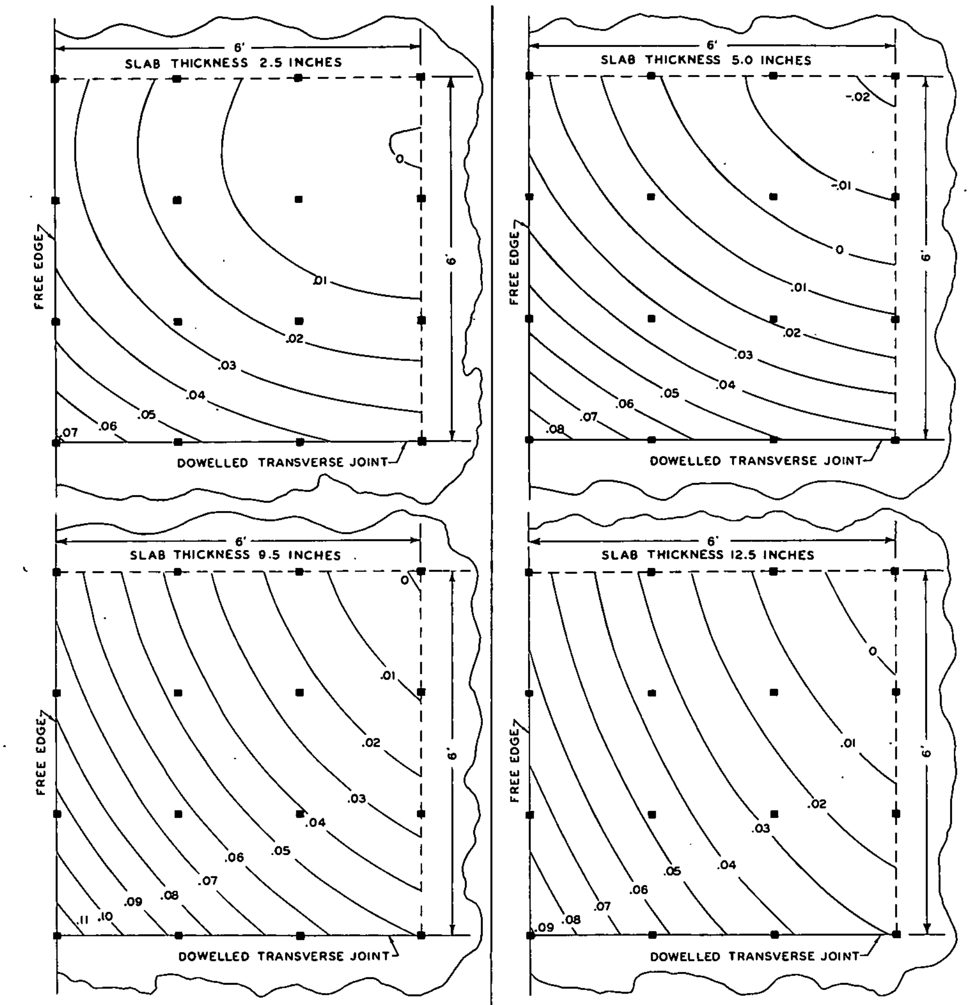


Figure 177. Typical contours of vertical movement (inches), nonreinforced sections, Loop 1, Design 1.

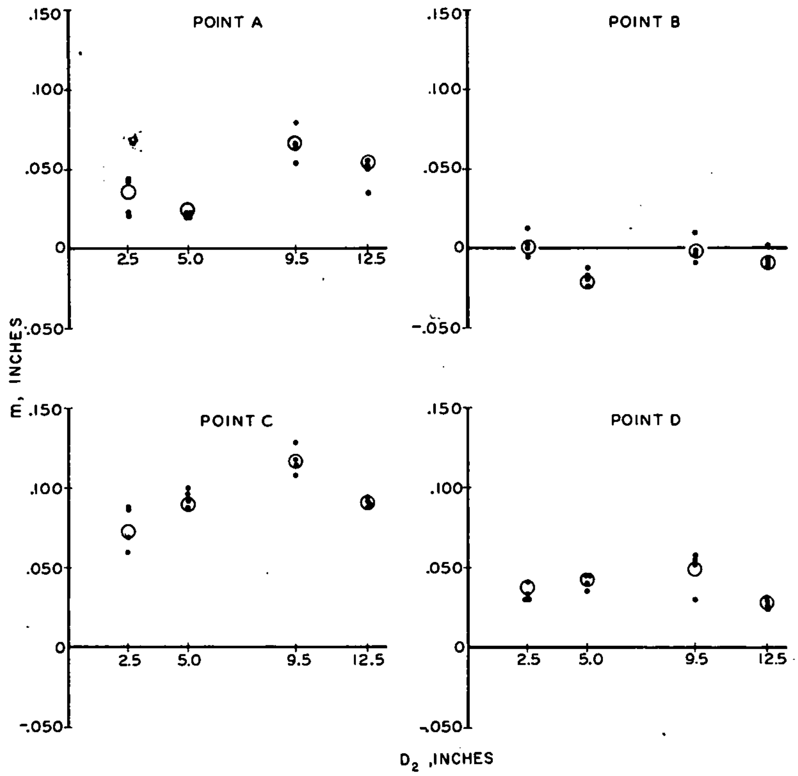


Figure 178. Location of points A, B, C and D is shown in Figure 176. Open circles represent points computed from mathematical model for nonreinforced pavement; others represent observed data for which average absolute value of $\Delta T$ was 18 F.

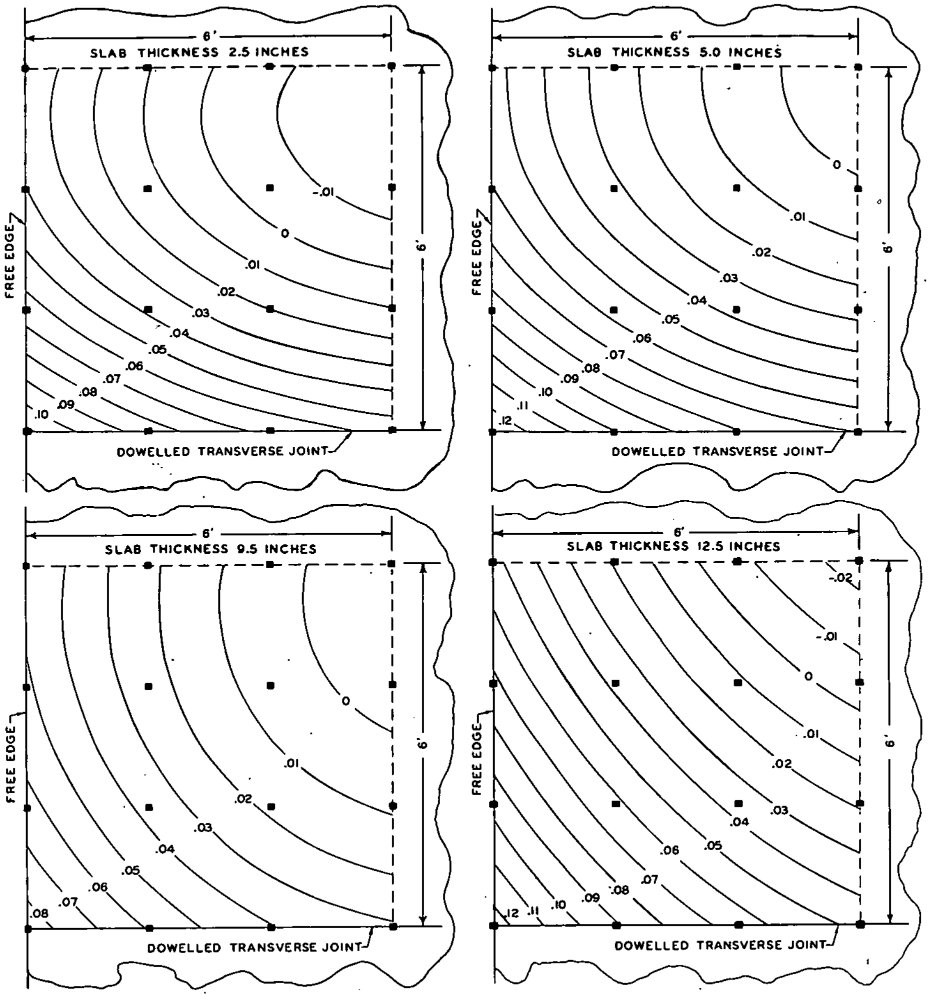


Figure 179. Typical contours of vertical movement (inches), reinforced sections, Loop 1, Design 1.

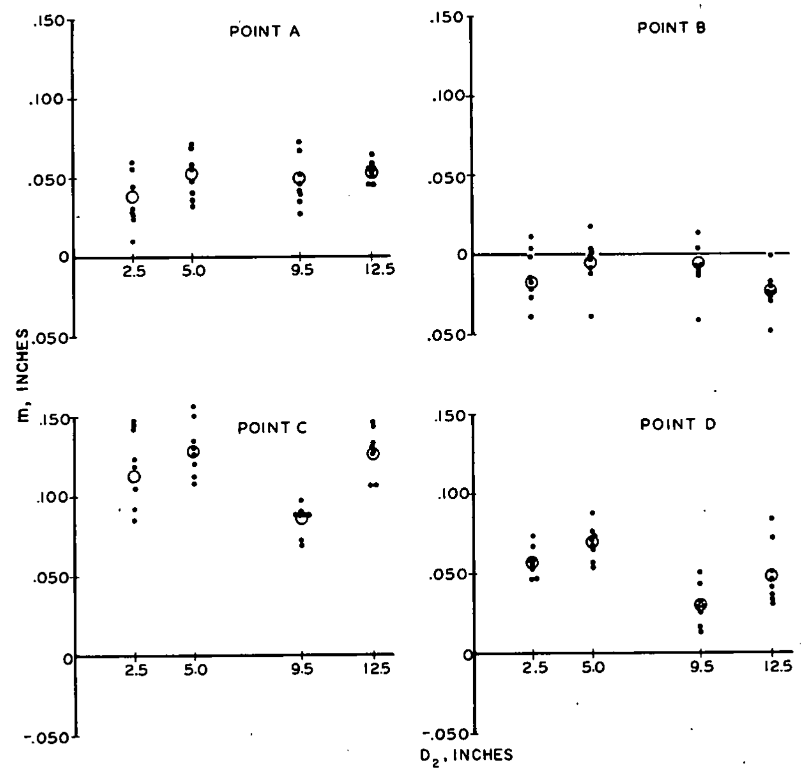


Figure 180. Location of Points A, B, C and D is shown in Figure 176. Open circles represent points computed from mathematical model for reinforced pavement; others represent observed data for which average absolute value of $\Delta T$ was 20 F.

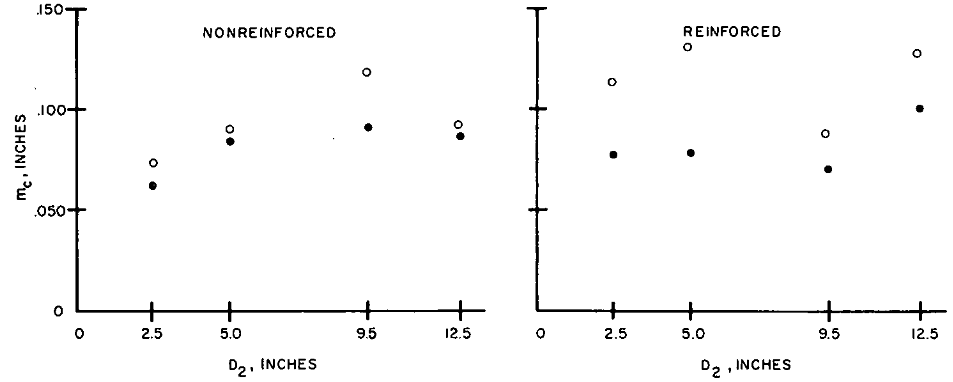


**Figure 181.** **Comparison of results of corner movement study (solid circles) with predictions from equations for curling of concrete slabs (open circles).**

There was little evidence, however, from the studies of corner movements and the curling of concrete slabs that the displacements at panel corners relative to the earth were substantially and consistently greater in the case of the reinforced than in the nonreinforced panels (see Tables 82 and 86).

### *3.5.4 Load Stresses in Surface of Concrete Slabs*

Surface strains resulting from the application of a rapidly oscillating load (6 cps) were measured in a series of experiments in the non-traffic loop. These measurements served as a means for estimating the stress in the upper surface of concrete slabs caused solely by load (as distinguished from stress resulting from environmental changes). The pavement design variables were reinforcing (and/or panel length), subbase thickness and slab thickness.

Four positions of the load (which simulated that of a single axle load in the traffic loops) were investigated. These were chosen to represent four successive positions (relative to a transverse joint) of a vehicle traveling with its outer dual wheel centered on a line parallel to and 1 ft distant from the pavement edge.

This subsection describes the instrumentation, field procedures and analytical methods followed in the experiments. Results are presented in graphs of the major and minor principal stresses in a 36-sq ft region bounded by the pavement edge and a transverse joint (Figs. 187 through 190).

An equation is given from which may be estimated the critical stress, in terms of slab thickness and axle load, caused by a single-axle vehicle traveling near the edge of the pavement.

Of the three pavement design variables, only slab thickness had an appreciable effect on measured strains. For a constant axle load the greatest tensile stress occurred when the two loaded areas, each of which simulated the contact area of a dual tire, were nearest the transverse joint, for all slab thicknesses. The greatest compressive stress occurred at a point on the pavement edge with the loaded areas 4 to 6 ft distant from the joint (Figs. 187 through 190, Table 90).

For a constant axle weight and slab thickness, it was estimated that the maximum compressive stress at the edge due to edge loading exceeded, in absolute value, the maximum tensile stress due to corner loading by 51 to 112 percent. The exact percentage depended upon the thickness of the slab (Table 90).

Between October 9, 1959, and November 2, 1960, a series of eight experiments, designed to furnish information regarding the distribution of load stress in the surface of concrete slabs, was conducted on the sections comprising Design 1, Loop 1, lane 2, with the exception of the 2.5-in. pavements. The latter were excluded because the equipment used for applying load was too heavy to be placed on pavements of that thickness. Table 88 gives the designs of the 18 test sections involved in each experiment.

A rapidly oscillating load was applied to the pavement through two wooden pads on 6-ft centers, each approximating the contact area of a typical dual tire assembly used in Loop 4 (Fig. 182). Each load cycle was intended to

TABLE 88

EXPERIMENT DESIGN FOR SPECIAL STUDIES OF LOAD STRESSES IN SURFACE OF CONCRETE SLABS

| Subbase Thickness (in.) | Number of Sections | | | | | |
|---|---|---|---|---|---|---|
| | 5.0-In. Slab[1] | | 9.5-In. Slab[1] | | 12.5-In. Slab[1] | |
| | N | R | N | R | N | R |
| 0 | 2 | 1 | 1 | 2 | 2 | 1 |
| 6 | 2 | 1 | 1 | 2 | 2 | 1 |

[1] N = nonreinforced; R = reinforced.

simulate the dynamic load applied by a typical single axle vehicle as used in the main loops.

Strain was measured by 33 electrical resistance strain gages of the type used in the traffic loops (Section 3.3.1.1) distributed over the same area as that within which displacements were measured in the study of curling (Fig. 170). Dynamic rather than static loading was used because of the tendency of the strain gages to drift from their initial readings during the period of time that would have been required to apply a static load and read the 33 gages.

During each of the eight experiments (rounds), the simulated single axle load was applied at three or more of the positions indicated in Figure 182. Table 89 gives dates, hours, load positions and other general information pertaining to the experiments. Data from Round 7, taken during the early morning hours when panel corners were curled upward and the strains were among the highest observed, were selected for analysis. Data from all rounds, in the form of the magnitude and direction of the major and minor principal strains observed at 15 points on a panel, are available in DS 5205 for all section-load-position combinations occurring in Table 89.

*3.5.4.1 Instrumentation.*—Strain gages, prepared as described in Section 3.3.1.1, were cemented to the surface of each panel at the locations shown in Figure 170. The use of delta rosettes at the nine interior points permitted the computation of the magnitude and direction of the principal strains at those points. Only single gages were required along the edge and transverse joint, as it was assumed that the strain perpendicular to the edge or joint could be calculated by use of Poisson's ratio

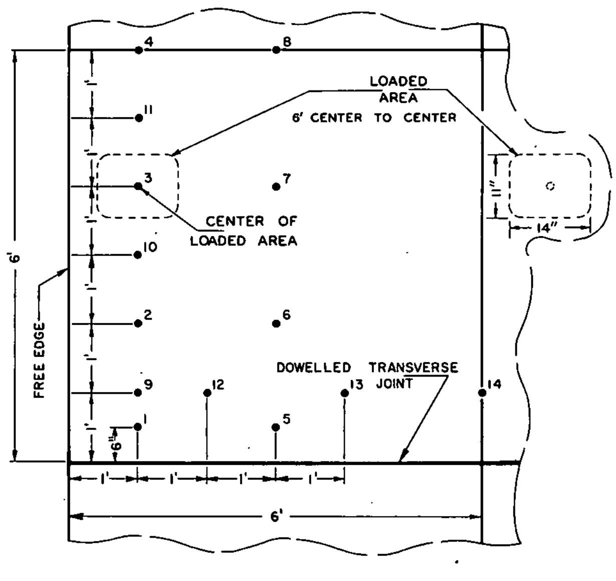


**Figure 182. Numbered points show the several load positions used in special strain studies.**

TABLE 89

SCHEDULE OF STRAIN EXPERIMENTS CONDUCTED IN LOOP 1

| Round No. | Dates | Hours | 5.0-In. Slab | | 9.5-In. Slab | | 12.5-In. Slab | |
|---|---|---|---|---|---|---|---|---|
| | | | No. of Sect. Tested | Load Positions | No. of Sect. Tested | Load Positions | No. of Sect. Tested | Load Positions |
| 1 | 10/9–22/59 | 1030–1630 | 6 | 9, 10,11 | 6 | 9, 10, 11 | 6 | 9, 10, 11 |
| 2 | 10/29–11/12/59 | 0130–0530 | 6 | 9, 10, 11 | 6 | 9, 10, 11 | 2 | 9, 10, 11 |
| 3 | 6/14–7/11/60 | 0030–0500 | 6 | 2, 3, 4 | 6 | 2, 3, 4, 12, 13, 14 | 6 | 2, 3, 4 |
| 4 | 7/5–8/5/60 | 1030–1600 | 6 | 2, 3, 4, 12, 13, 14 | 2<br>4 | 2, 3, 4, 12, 13, 14<br>2, 3, 4 | 6 | 2, 3, 4 |
| 5 | 8/8–24/60 | 0100–0530 | 6 | 1, 2, 3, 4 | 6 | 1, 2, 3, 4 | 6 | 1, 2, 3, 4 |
| 6 | 8/25–9/3/60 | 1100–1800 | 6 | 1, 2, 3, 4 | 6 | 1, 2, 3, 4 | 6 | 1, 2, 3, 4 |
| 7* | 9/6–22/60 | 2400–0500 | 6 | 1, 2, 3, 4 | 6 | 1, 2, 3, 4 | 6 | 1, 2, 3, 4 |
| 8 | 10/14–11/2/60 | 1130–1630 | 6 | 5, 6, 7, 8 | 6 | 5, 6, 7, 8 | 6 | 5, 6, 7, 8 |

* Analysis of this round reported herein.

for the concrete. No gages were required at the intersection of joint and edge as the strain there was assumed to be zero. Figure 183 shows gages being installed; Figure 184 shows a finished installation. As in the case of the traffic loop installations, cables placed underground connected gages to a junction box adjacent to the panel.

The vibrating loader was mounted on a truck (Fig. 185). The essential parts were two adjustable weights rotating in opposite directions in a vertical plane in such a manner that all dynamic force components except those in a vertical direction were balanced by equal and opposite components. The dead weight necessary to prevent the upward components from lifting the truck from the pavement was provided in the form of concrete blocks resting on a platform located directly above the rotating weights. The load was transmitted through inverted A-frames which could be folded upward against the side of the vehicle when not in use. Contact with the pavement was made through wooden pads (Section 3.5.4). Strain gages mounted on each member of the two A-frames (Fig. 186) provided a means for calibrating the device on the project's electronic scales and for obtaining a continuous

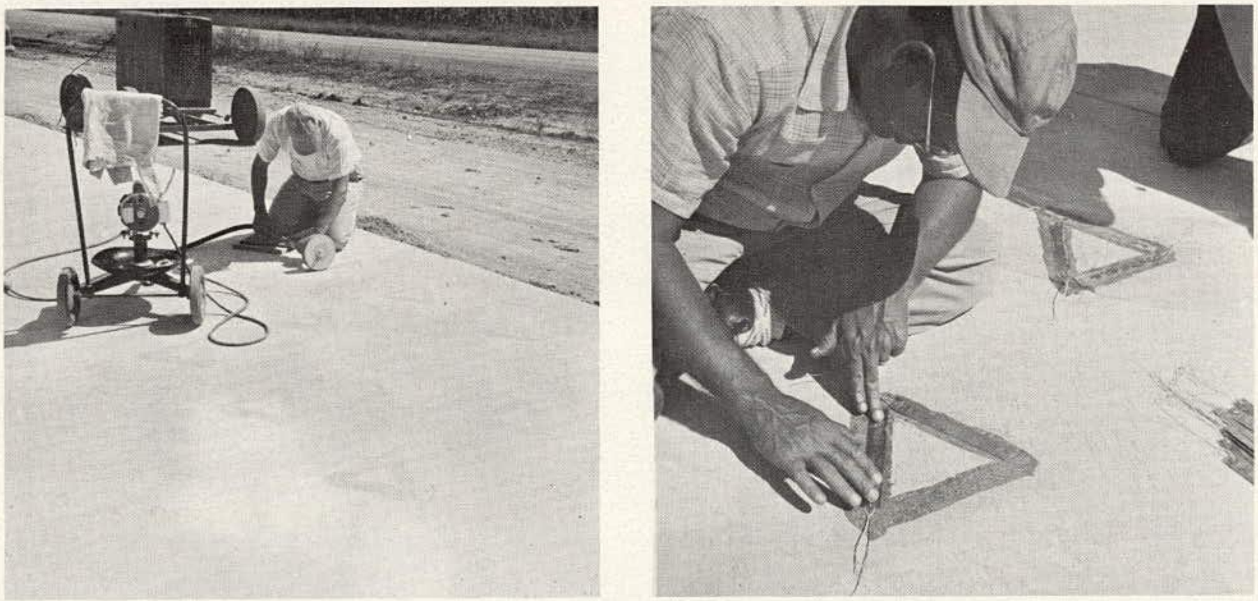


**Figure 183. Two of the several steps in installation of strain gages in Loop 1.**

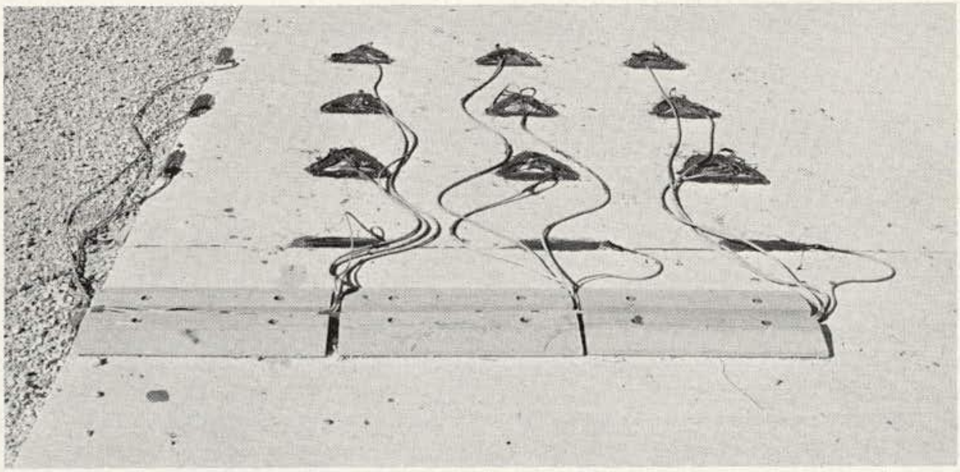


**Figure 184. A finished installation of strain gages in Loop 1. There were 18 installations of this type. Ramp protected cables from truck-mounted vibrating loader.**

Figure 185. Truck-mounted vibrating loader. Load was transmitted to pavement through inverted A-frames and wooden pads. Front tires were lifted from pavement to minimize vibration at front axle.

record of loading while a pavement gage output was being recorded. Drawings of the vibrating loader are available upon request (DS 5200).

In normal operation the load was varied sinusoidally with time, at a frequency of 6 cps, from a minimum value of about 500 lb on each contact area to a maximum value which depended upon the thickness of the pavement being tested. The measured strain also varied sinusoidally with time, very nearly in phase with the load, and of course at the same frequency. From examination of simultaneous traces of the load wave and strain wave it was possible to determine the amplitude of each, as well as the nature (tension or compression) of the strain. The nominal amplitude of the load applied to 5-in. pavements was 12,000 lb. For the 9.5-in. pavements it was 22,400 lb and for the 12.5-in. pavements 30,000 lb. These loads corresponded to the single axle loads in Loops 3, 5 and 6.

*3.5.4.2 Field Procedures and Data Processing.*—Field Procedures.—The normal procedure in taking the data was to begin at the westernmost factorial section on Loop 1 and proceed eastward. Usually all load positions

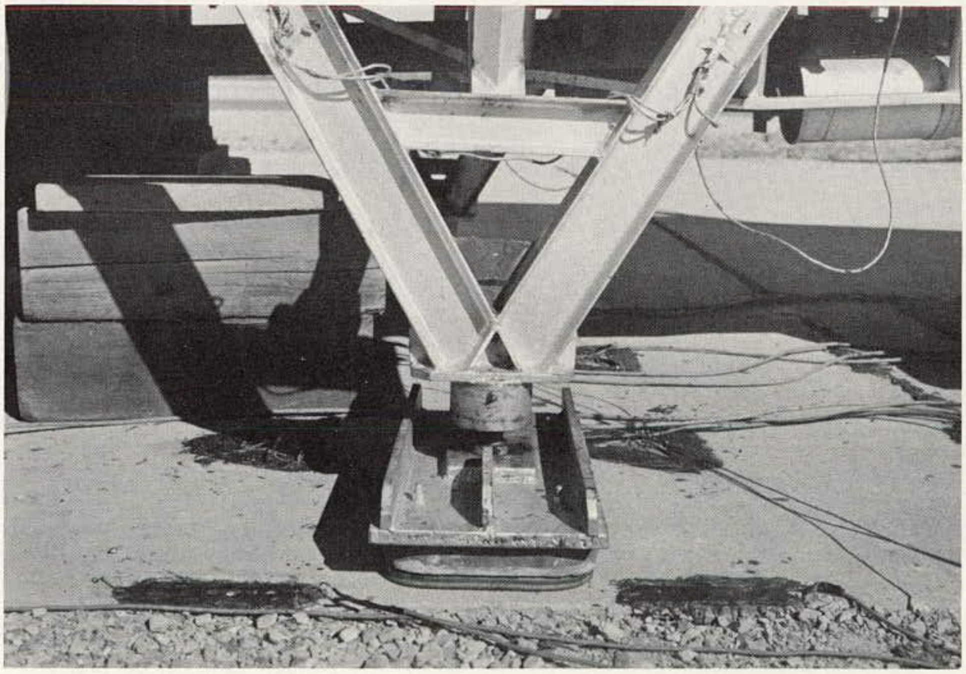


Figure 186. Close-up of strut on vibrating loader, showing location of strain gages that provided continuous record of loading.

selected for a particular round were completed on a section before measurements were made on the next section.

With the load in one of the selected positions, the recording equipment mounted in a van (similar to that shown in Fig. 141) was switched to each of of the 33 pavement gages in succession. The output of each pavement gage was recorded as an oscillating line on paper tape, adjacent to the record from the load gages. The over-all time required to complete the measurements associated with one load position on one panel, including the time required to set up the vibrating loader, was about 30 min, of which about 5 min were spent in recording the strains.

Data Processing.—The first objective of each experiment was to derive by statistical techniques a pair of empirical equations for each load position, of the following general forms:

Major principal strain = a function of pavement design, load, and the coordinates of the gage point. (105)

Minor principal strain = a function of pavement design, load, and the coordinates of the gage point. (106)

(The coordinate system used was that shown in Figure 176.)

The second objective was to compute from Eqs. 105 and 106 and the appropriate plane stress equations linking stress and strain the estimated value of major and minor principal stresses at closely spaced points in the pavement surface within the 36-sq ft area of observation.

Minor variations in load were observed during the 5 min spent in rèading the output of the 33 pavement gages. It was assumed (based on the special load tests conducted in the traffic loops, Section 3.3.2, and on several pilot experiments on these test sections) that strain was proportional to load. Therefore, as the first step in processing the data, the reading of each gage was adjusted to a value corresponding to the nominal load (12,000, 22,400 or 30,000 lb) assigned to the test section.

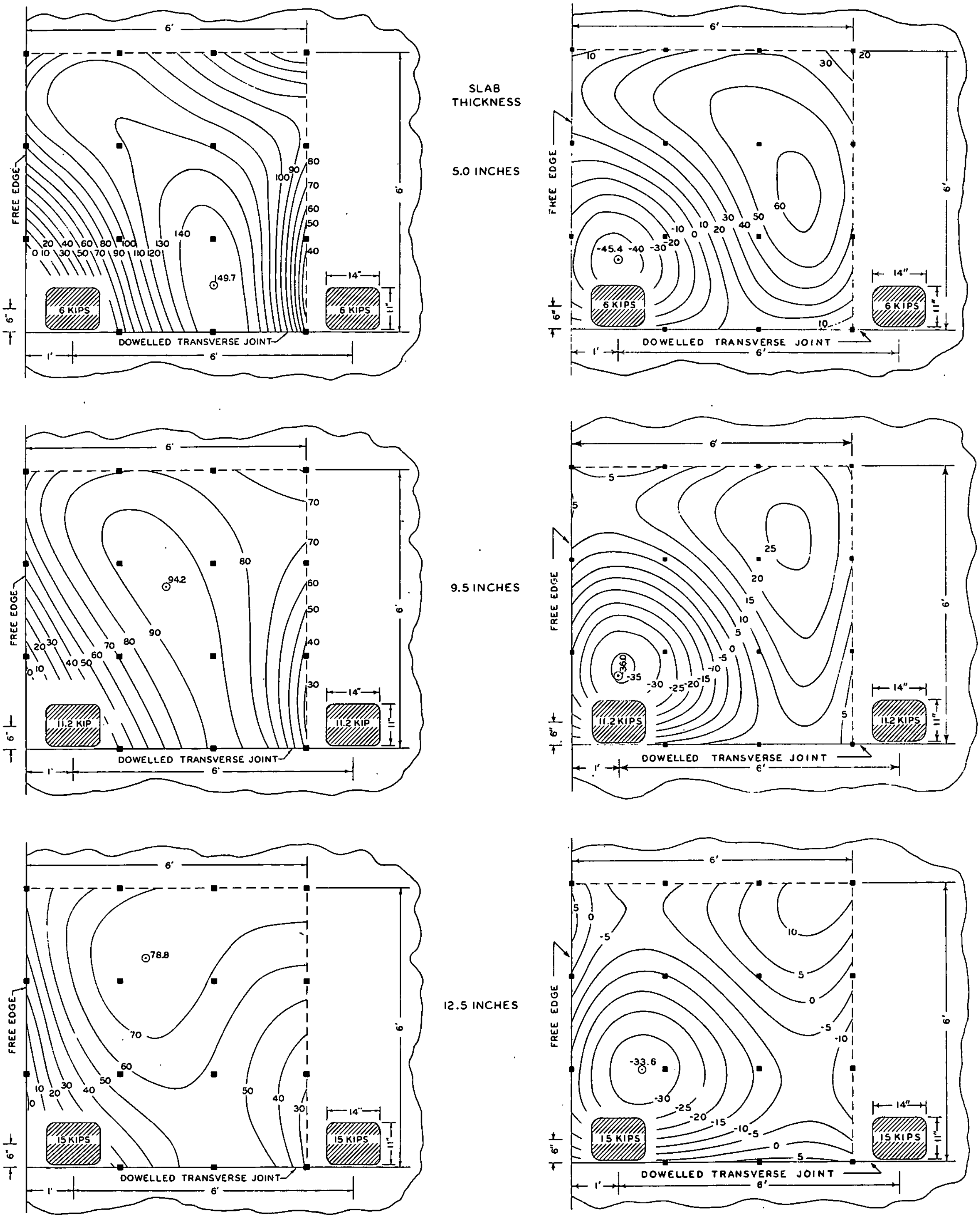
An examination of the adjusted values indicated that variations in the strain on panels at the same level of slab thickness but at different levels of reinforcing and/or subbase thickness were small and apparently random in nature. Therefore, within each round and for the same load position, the readings of gages with the same coordinates, $x$ and $y$, installed on panels of the same slab thickness (irrespective of subbase thickness and reinforcing) were averaged to obtain a set of data representing that round-load position-slab thickness combination.

Thus, for one load position within an experiment, the processing resulted in three sets of data corresponding to the three levels of slab thickness (5.0, 9.5 and 12.5 in.), with each set consisting of 33 averaged strain gage readings. As the third step in processing, each such set was converted from strain gage readings to magnitude and direction of major and minor principal strains at the 15 gage points on a panel, employing standard techniques based on elastic theory (see Appendix E). These data are available in DS 5205.

As the final step before analysis, each principal strain was divided by the corresponding load in accordance with the assumption that strain is directly proportional to load. Thus, as a result of the four-step processing of data, the only remaining independent variables to be considered in the analysis of strain were the coordinates $x$ and $y$ of a gage point and the thickness, $D_2$, of the slab.

*3.5.4.3 Typical Stress Distributions.*—Analysis of Strains.—The three sets of data corresponding to each round-load position combination given in Table 89 (except combinations involving Round 2, and load positions 12, 13 and 14 in Round 4) were analyzed using statistical procedures. The strain data were represented by a linear model whose 48 terms (3 slab thicknesses by 16 combinations of $x$ and $y$) were mutually orthogonal polynomials in $x$, $y$ and $D_2$. As a result of the elimination of reinforcing and subbase thickness as independent variables, there were six sections within each round-load position-slab thickness combination whose variation in strain furnished a measure of residual effects. The residual effects, in turn, were used to determine the statistical significance of each coefficient. (The coefficients from each analysis with significant terms indicated are available in DS 5211.) Of the 48 original coefficients the 16 terms of the highest order were discarded, and of the remaining 32 only those that were found to be significant at the 1 percent level were used in the calculations.

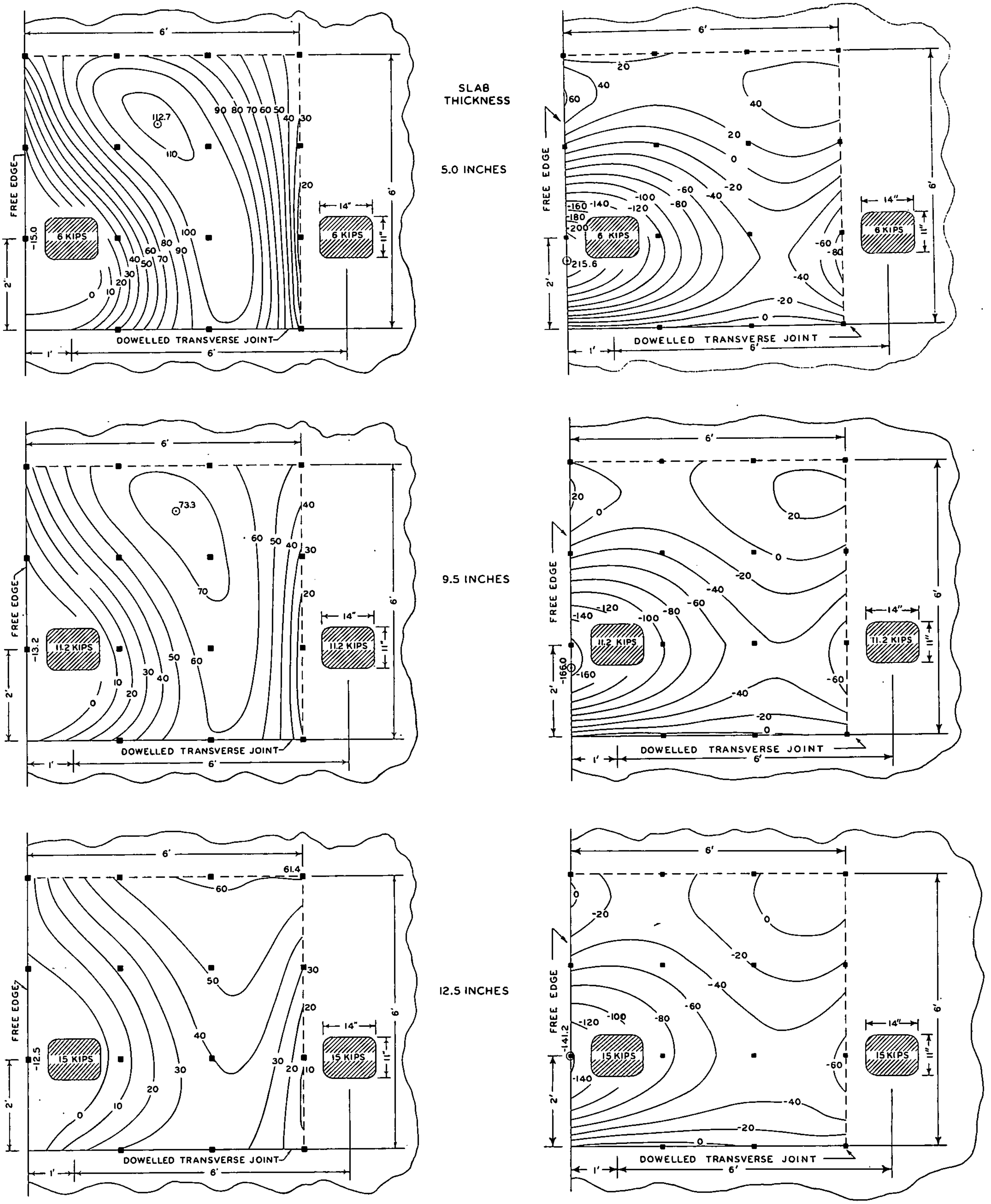
Distribution of Principal Stresses.—The analyses of data from load positions 1, 2, 3 and 4 of Round 7 resulted in four pairs of equations (one for each load position) like the pair given as Eqs. 105 and 106. Principal strains predicted from these equations were converted to principal stresses in accordance with the formulas from elastic theory given in Appendix E, using values of Young's modulus and Poisson's ratio for the pavement concrete determined in the Road Test laboratory. The stresses so determined were used in plotting contours of principal stress (Figs. 187, 188, 189, and 190). All stresses are recorded in pounds per square inch, with the usual sign convention—



MAJOR PRINCIPAL STRESS, psi

MINOR PRINCIPAL STRESS, psi

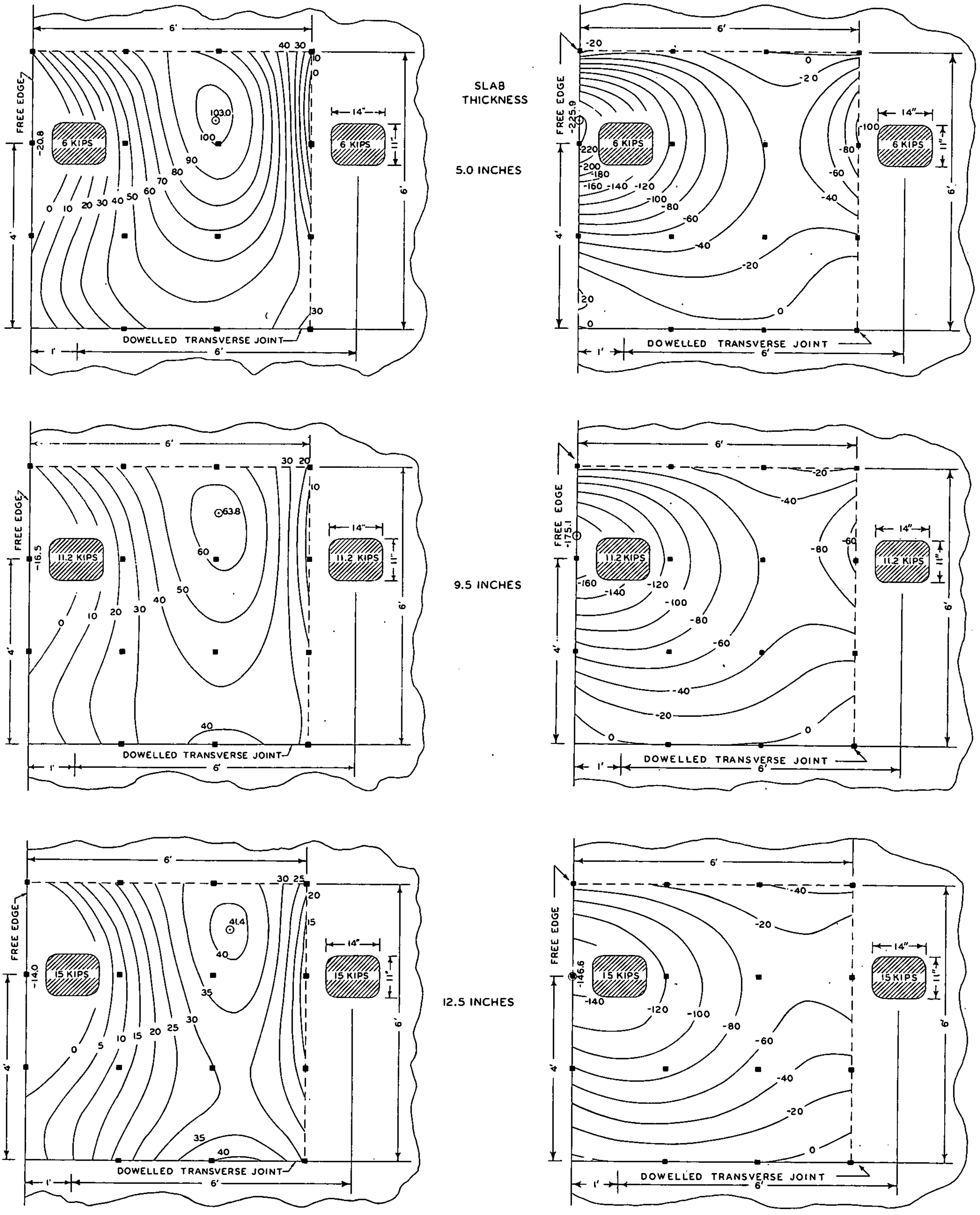
Figure 187. Contours of major and minor principal stresses for corner loading (load position 1).



MAJOR PRINCIPAL STRESS, psi

MINOR PRINCIPAL STRESS, psi

Figure 188. Contours of major and minor principal stresses for load position 2.



MAJOR PRINCIPAL STRESS, psi

MINOR PRINCIPAL STRESS, psi

Figure 189. Contours of major and minor principal stresses for load position 3.

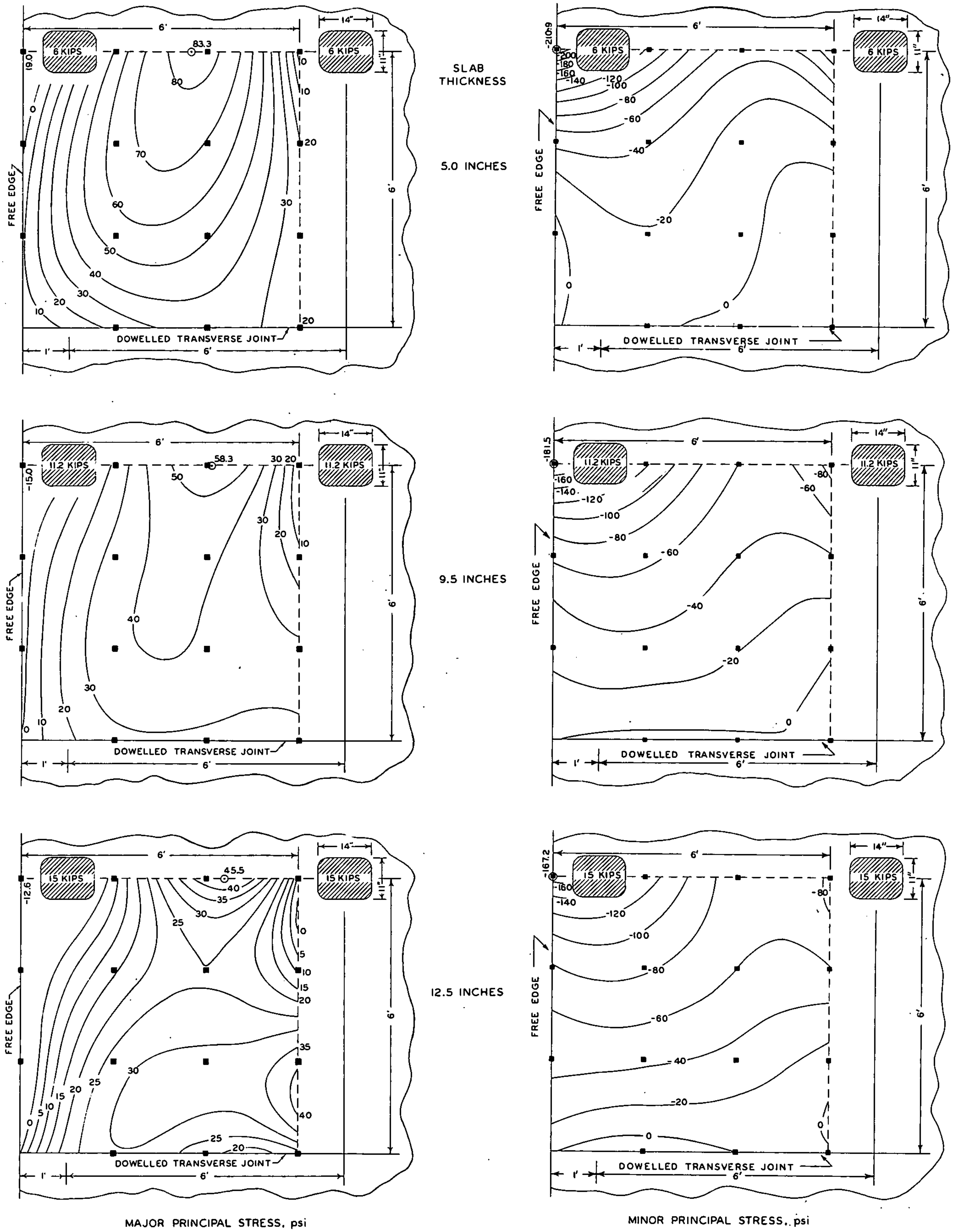


Figure 190. Contours of major and minor principal stresses for load position 4.

tensile stresses positive, compressive stresses negative.

Critical Stresses.—Maximum values of tensile stresses are shown at the points at which they occur in each of the 12 graphs representing major principal stresses (Figs. 187 through 190). Similarly, maximum values of compressive stresses are shown for minor principal stresses. If each such maximum is divided by the corresponding axle load, the result is the set of maximum stresses for a 1-kip axle load in Table 90.

According to a common assumption in the application of elastic theory to a slab resting on an elastic foundation, the stresses at points on a vertical line through the slab are equal but opposite in sign at the slab surfaces and exceed, in absolute value, the stress at any other point on the line. Therefore, each stress marked with an asterisk in Table 90 is equivalent, in absolute value, to the critical tensile stress for the indicated slab thickness and load position. These stresses occur along the pavement edge with the center of the outer loaded area at a distance of 1 ft from the edge and 4 to 6 ft from the nearest transverse joint.

An empirical equation fitted to the three pairs of values of $D_2$ and critical stress (Table 90) is as follows:

$$\sigma = \frac{160L_1}{D_2^{4/3}} \qquad (107)$$

in which

$\sigma$ = the critical stress, in lb per sq in.;
$L_1$ = a single axle load, in kips; and
$D_2$ = slab thickness, in in.

Eq. 107 predicts the three critical stresses denoted by asterisks in Table 90 with an error of less than 2 percent. Figure 191 is a graph of the equation, from which the critical load stress for any single axle load-pavement thickness combination, within the range observed, may be estimated by multiplying the value taken from the curve corresponding to the given slab thickness by the axle load in kips. Additional stresses which may be present as the result of temperature or moisture fluctuations are not included in the stress estimated from this curve or from the contours (Figs. 187 through 190). It is also probable that stresses arising from static loads would be greater than those estimated from the strains measured in this study.

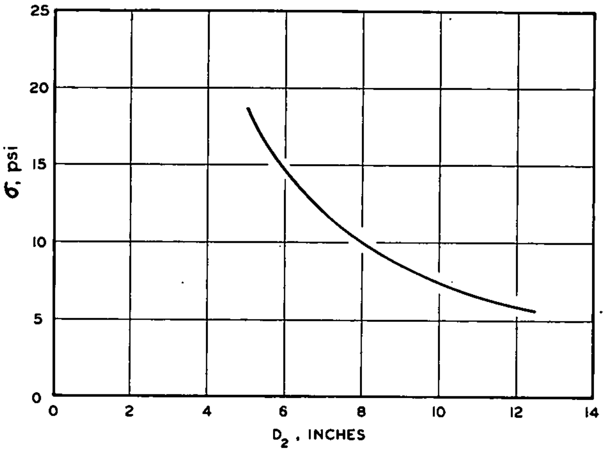


**Figure 191.** Maximum compressive stresses for a 1-kip single axle load, outer wheel near edge of pavement.

### 3.5.5 *Moisture and Temperature Coefficients of Expansion*

Linear coefficients of thermal expansion of the concrete used in rigid pavements were determined from beams sawed from sections in Loop 1. Values determined in the Road Test laboratory ranged from 4.6 x $10^{-6}$ to 5.1 x $10^{-6}$ per deg F. Values reported by the Skokie, Ill., laboratory of the Portland Cement Association varied from 4.6 x $10^{-6}$ to 5.6 x $10^{-6}$ per deg F.

TABLE 90

MAXIMUM TENSILE AND COMPRESSIVE STRESSES FOR A 1-KIP SINGLE AXLE LOAD
(Data from Design 1, Loop 1, Lane 2)

| Load Position | Maximum Stress (psi) | | | | | |
|---|---|---|---|---|---|---|
| | Tensile | | | Compressive | | |
| | 5.0-In. Slab | 9.5-In. Slab | 12.5-In. Slab | 5.0-In. Slab | 9.5-In. Slab | 12.5-In. Slab |
| 1 | 12.47 | 4.21 | 2.63 | 3.78 | 1.61 | 1.12 |
| 2 | 9.39 | 3.27 | 2.05 | 17.97 | 7.41 | 4.71 |
| 3 | 8.58 | 2.85 | 1.38 | 18.82* | 7.82 | 4.89 |
| 4 | 6.94 | 2.60 | 1.52 | 17.57 | 8.10* | 5.57* |

* Maximum for indicated slab thickness.

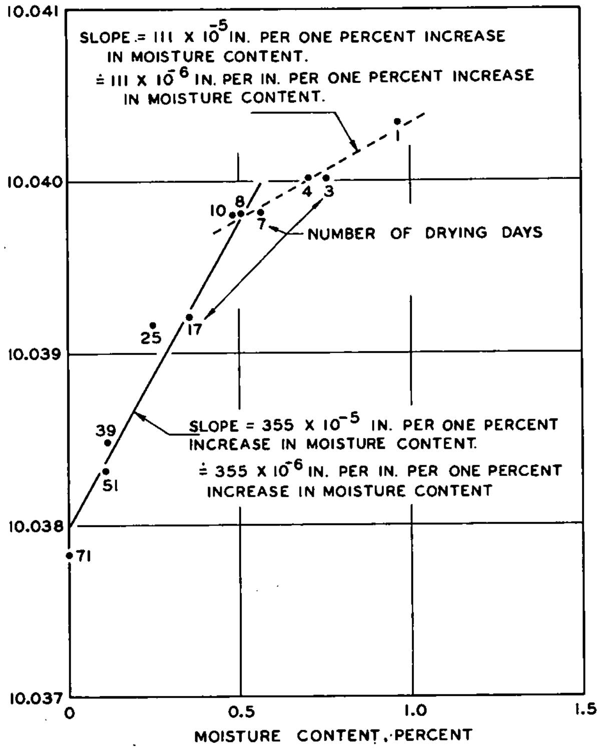


**Figure 192.** Effect of moisture content on length of concrete beam. Each point is average of measurements on six specimens.

The Road Test laboratory found that length decreased with moisture loss at a rate as high as 355 x $10^{-6}$ in. per in. per 1 percent decrease in moisture content. The Portland Cement Association reported a unit decrease in length of 229 x $10^{-6}$ associated with a decrease of 50 percent in the relative humidity of the air surrounding the specimens.

Three laboratory studies were made at the Road Test for the purpose of determining coefficients of expansion of samples of concrete sawed from nonreinforced sections in Design 5, Loop 1, lane 2. Six 5- by 5- by 14-in. beams (two from each of three 5-in. slab sections) were used. Two brass gage plugs were cemented into holes drilled on 10-in. centers on each face of each specimen. Periodically during the studies gage lengths were measured with a Whittemore strain gage, and the weight and the temperature of the specimens were determined.

In the first study, the specimens were soaked in water for 16 days, and then measurements were made periodically as they dried at a temperature of about 70 F. Plotted points in Figure 192 represent averages of measurements made on the six beams. The change in length with increase in moisture content is represented by two straight lines with different slopes.

In the second study, the temperature of the specimens was varied while the moisture content was held at a constant value near zero. Figure 193 shows averaged results; the arrows indicate the order in which the successive sets of measurements were made.

The third study was similar to the second, except that the beams were in a saturated condition (Fig. 194). A comparison of Figures 193 and 194 shows that the dry specimens usually increased their length by a slightly greater amount than the saturated specimens for the same increase in temperature.

A comparison of the estimated coefficients of expansion (Figs. 192 and 193) suggests that adding 0.5 percent moisture to dry specimens would produce the same unit increase in linear dimensions that occurred when the temperature was increased by about 35 F.

At the time beams were sawed from Loop 1 sections for testing at the Road Test laboratory, additional beams were forwarded to the Portland Cement Association Laboratory at Skokie, Ill. The laboratory measured changes in the length of these beams occurring (a) with a change of temperature, relative humidity held constant; and (b) with a change in relative humidity, temperature held practically constant. Results for temperature changes at constant humidity are given in Table 91; length changes associated with an increase in temperature differed from those resulting from a decrease in temperature.

In the test involving a change in humidity, the beams were first allowed to reach constant weight in a moist room adjusted to 100 percent relative humidity at 69 F. Relative

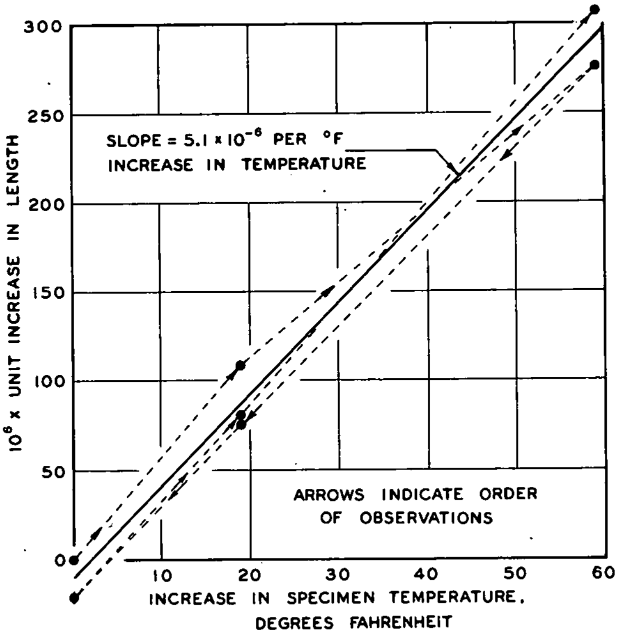


**Figure 193.** Effect of temperature changes on length of a 5 x 5 x 14-in. beam sawed from pavement (design 5, Loop 1, lane 2). Test made at average moisture content near zero.

humidity was then reduced to 50 percent at 73 F, and the beams were again allowed to reach constant weight. The resulting unit change in length was 229 x $10^{-6}$.

### *3.5.6 Serviceability Changes, Non-Traffic Loop*

Twenty-four test sections in the inner lane of the non-traffic loop were reserved for a study of changes in serviceability in the absence of traffic. No cracking occurred, and biweekly determinations of the serviceability index from slope variance revealed no significant changes in serviceability over the 2-yr test period.

The 24 sections making up Design 1, Loop 1, lane 1 were reserved for a special study of the changes in serviceability index which might occur in the absence of traffic. Only the longitudinal profilometer and its light towing vehicle, used in the determination of the serviceability index, were permitted to travel over these sections.

The sections were inspected weekly in connection with the routine condition surveys made on all test sections. No cracking or other visible defects (beyond a few square inches of spalling at some joints and occasional "pop-outs") developed during the 2-yr period of traffic testing, nor through October 26, 1961.

Values of the serviceability index for each section for index days 11, 22, 33, 44 and 55 are given in Appendix D. These data were determined on the same index days and in the same manner as were the levels of serviceability used in the analysis of performance of rigid pavement sections.

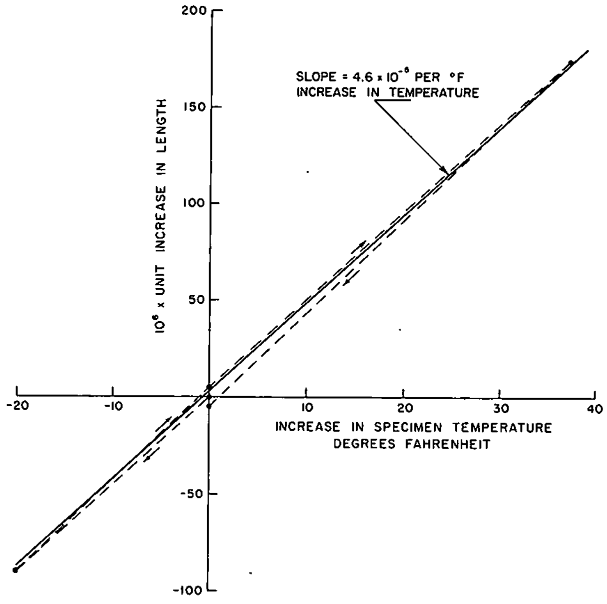


**Figure 194. Effect of temperature changes on length of a 5 x 5 x 14-in. beam sawed from pavement (Design 5, Loop 1, lane 2). Test made with specimens in saturated condition.**

TABLE 91

EFFECT OF TEMPERATURE AND MOISTURE CONTENT CHANGES ON LENGTH OF CONCRETE BEAMS

(Tests by Portland Cement Association)

| Temp. (°F) | Relative Humidity (%) | Coefficient of Expansion[1] ($10^{-6}$ in./in./°F) |
|---|---|---|
| 70 to 97 | 100 | 5.56 |
| 97 to 70 | 100 | 4.61 |
| 73 to 100 | 50 | 5.51 |
| 100 to 73 | 50 | 4.96 |

[1] Average of measurements made on two faces of each of the three beams.

The average serviceability level for the 24 sections on each of the index days was 4.5, 4.4, 4.4, 4.5 and 4.5, respectively. It is obvious that there was no consistent trend with time of the average serviceability level of these sections over the 2-yr period. Continuing observations of the serviceability level of these test sections will be made by the Illinois Division of Highways.

## 3.6 SUMMARY OF FINDINGS AND NEEDED RESEARCH

### *3.6.1 Summary of Findings*

Descriptions of the rigid pavement research and of the findings that resulted have been summarized at the beginning of the appropriate subsections and documented in the text. In this section the more important material contained in the summaries is repeated for ready reference. Section numbers of the source material in the body of the report are included.

Those objectives of the Road Test (Sec. 1.1.2) that are pertinent to rigid pavement[*] research are as follows:

1. To determine the significant relationships between the number of repetitions of specified axle loads of different magnitude and arrangement and the performance of different thicknesses of uniformly designed and constructed . . . plain portland cement concrete, and reinforced portland cement concrete surfaces on different thicknesses of . . . subbases when on a basement soil of known characteristics.
3. To make special studies dealing with such subjects as paved shoulders, . . . pavement fatigue, . . . and to correlate the findings of these special studies with the results of the basic research.
5. To develop instrumentation, test procedures, data, charts, graphs, and formulas, which will reflect the capabilities of the various test sections; and which will be helpful in future highway design, in the evaluation of the load-carrying capabilities of existing highways and in determining the most promising areas for further highway research.

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[*] Material applicable to flexible pavement research only, and to research described in Reports 3, 4, and 6, has been deleted.

The major effort of the staff was directed toward fulfillment of the first objective—to find the relationship between pavement performance on the one hand and pavement design, loading and number of load applications on the other.

*Pavement Performance (Section 3.2.2).*—An innovation at the Road Test that strongly influenced the direction taken by the research was the development of a definition of pavement performance in terms of the trend in *pavement serviceability* (momentary ability to serve traffic) with increasing number of load applications. The serviceability of each section at the Road Test was determined at regular intervals from the roughness, cracking and patching existing in the section (Section 3.2.1 and Appendix F).

Most of the major findings relative to the first objective were based on data from the 312-section main factorial experiment, and are embodied in equations defining the relationship between slab thickness, axle load, number of applications of the load, and the corresponding reduction in pavement serviceability (Eqs. 61, 62, 65 and 66). Given any three of these factors, the fourth may be found from the equations, or from graphs of the equations provided for that purpose (Figs. 116 and 117).

Because of random variations in the observed data, there were unavoidable differences between predictions from the equations and the actual performance of individual sections. Analysis of these differences shows that the scatter corresponds approximately to ± 12 percent of the slab thicknesses given by the performance curves. Figures 120 through 123 show comparisons of observed data with predictions from the equations. If comparisons are made with the observed performance of an actual highway in service, additional allowances should be made to account for differences between the highway and the Road Test in materials, environment and loading history.

The effect on performance of the pavement design variable, reinforcing (and/or panel length), was not significant; consequently, this variable was excluded from the performance equations (see Table 68 for differences in design between reinforced and nonreinforced sections). It should be noted that the transverse joints were dowelled in both the reinforced and nonreinforced slabs.

The effect on performance of varying the thickness of the subbase between 3 and 9 in. was not significant, and this variable also was excluded from the performance equations. However, in a separate experiment, the performance of sections on 6 in. of subbase was found to be superior to that of sections with no subbase.

*Subbase—Paved Shoulder Experiment (Section 3.2.2.2).*—Sixty-four nonreinforced test sections were provided to permit direct performance comparisons between sections with and without subbase, and between sections with and without shoulder paving. The subbase was 6 in. in thickness; shoulder paving was a 3-in. layer of asphaltic concrete 6 ft wide. No increase in life resulted from use of paved shoulders. However, the results may have been affected in some cases by damage to the shoulder by test traffic. Sections with subbase had an average life about one-third longer than those without subbase.

*Structural Deterioration (Section 3.2.3).*—Inspections of the pavements were made weekly and after each rain. Faulting occasionally occurred at cracks, never at transverse joints (all joints were doweled). Longitudinal cracks tended to originate at transverse joints near dowel bars in 2.5-, 3.5- and 5-in. slabs but not necessarily in thicker pavements. No part of the cracking of pavements in the traffic loops was attributed solely to environmental changes, since no cracks appeared in the non-traffic loop (Loop 1).

From cracking data, equations were derived from which the number of axle applications associated with any given level of cracking (per unit of surface area) can be computed for a given pavement design and load (Eqs. 69, 70, 71 and 72). Graphs of the equations for a selected level of cracking are shown in Figure 127.

Pumping of subbase material, including the coarser fractions, was a major factor in the majority of the failures of sections with subbase. Pumping of embankment material was confined to those sections constructed without subbase. The amount of either material pumped through joints and cracks was negligible when compared with the amount ejected along the edge (Fig. 133).

*Strain and Deflection as Functions of Design, Load, Temperature and Speed (Section 3.3).*—Strains were measured at a point on the edge of the pavement 7.5 ft from the nearest joint. Deflections were measured at the same point as well as at panel corners. All measurements were made with the center of the contact area of the outer dual wheels of the test vehicles approximately 20 in. from the pavement edge.

Both static (vehicle stationary) and dynamic (vehicle traveling at 35 mph) deflections were measured at panel corners. Edge deflections were of the static type. Edge strains were determined with the vehicle moving at 35 mph. Test vehicles were normally those regularly assigned to the section, but a series of special studies was conducted involving other loads, as well as different speeds.

The general level of deflection measured at approximately the same time of day over a period of several months did not change appreciably with increasing number of load applications (Sections 3.3 and 3.3.9). Other factors being equal, strains and deflections were directly proportional to load (Section 3.3.2).

Twenty-four hour studies of the effect of fluctuating air temperature showed that the deflection of panel corners, under vehicles traveling near the pavement edge, at times increased several fold from afternoon to early morning. Edge strains and deflections were affected to a lesser extent (Sections 3.3.3., 3.3.4, 3.3.6 and 3.3.7).

The deflection of a corner of a 40-ft reinforced panel usually exceeded that of a 15-ft nonreinforced panel, if load, slab thickness and temperature conditions were the same in both cases (Sections 3.3.5 and 3.3.7). Edge deflections and strains were not affected significantly by panel length and/or reinforcing (Sections 3.3.4 and 3.3.6).

An increase in vehicular speed from 2 to 60 mph resulted in a decrease in strain or deflection of about 29 percent. Design and load had no consistent effect on the percentage reduction (Section 3.3.8).

*Prediction of Performance from Strain or Deflection (Section 3.4).*—The average life to a serviceability level of 2.5 of sections of the same slab thickness could be predicted with satisfactory accuracy (Fig. 156) from the average of 24 dynamic edge strains measured under the single-axle load regularly assigned to that section. Similar predictions could be made from static edge and corner deflections, but with somewhat less accuracy (Figs. 158 and 160).

*Subsurface Studies (Section 3.5.2).*—In the non-traffic loop (Loop 1) CBR and plate bearing values for both the subbase and the embankment tended to be somewhat higher in the summer than in spring periods. Plate bearing values determined in spring 1960 in the traffic loops were slightly greater than those measured at the same time in the non-traffic loop.

*Curling of Concrete Slabs (Section 3.5.3).*—A study was made in the non-traffic loop (Loop 1) of the maximum displacements of points on concrete slabs occurring as the temperature of the air changed from a maximum to the next minimum, or from a minimum to the next maximum.

During periods of continuously changing air temperature, points on the surface of the concrete slabs were in continuous vertical motion (Fig. 172). Vertical displacements of panel corners exceeding 0.1 in. were frequently observed (Table 82).

Displacements of panel corners can be estimated from corresponding changes in ambient temperatures (Table 85 and Fig. 174). The rate at which corner displacement changed with increase in slab thickness varied considerably—even changing signs—within the range of thickness (2.5 to 12.5 in.) investigated (Figure 181).

*Load Stresses in the Surface of Concrete Slabs (Section 3.5.4).*—Surface strains resulting from the application of a rapidly oscillating load (6 cps) were measured in a series of experiments in the non-traffic loop. These measurements served as a means for estimating the stress in the upper surface of concrete slabs caused solely by load (as distinguished from stress resulting from environmental changes).

Equal loads were applied on two areas separated by a distance of 6 ft. Each area simulated the contact area of a dual tire of the type used in the traffic loops. Four positions of the load were investigated. These were chosen to represent four successive positions (relative to a transverse joint) of a vehicle traveling with its outer dual wheel centered on a line parallel to and 1 ft from the pavement edge. The pavement design variables were reinforcing (and/or panel length), subbase thickness, and slab thickness.

Of the three pavement design variables, only slab thickness had an appreciable effect on measured strains.

For a constant axle load, the greatest tensile stress occurred when the two loaded areas were nearest the transverse joint, for all slab thicknesses. The greatest compressive stress occurred at a point on the pavement edge with the loaded areas 4 to 6 ft from the joint (Figs. 187 through 190, Table 90).

For a constant axle weight and slab thickness, it was estimated that the maximum compressive stress at the edge due to edge loading exceeded, in absolute value, the maximum tensile stress due to corner loading by 51 to 112 percent. The exact percentage depended upon the thickness of the slab (Table 90).

An equation is given from which may be estimated the critical stress, in terms of slab thickness and axle load, caused by a single-axle vehicle traveling near the edge of the pavement (Eq. 107).

*Moisture and Temperature Coefficients of Expansion (Section 3.5.5).*—Linear coefficients of thermal expansion of the portland cement concrete, as determined in the Road Test laboratory and by the Portland Cement Association ranged from 4.6 x $10^{-6}$ to 5.6 x $10^{-6}$ per deg F. The Road Test laboratory reported decreases in length with moisture loss as high as 355 x $10^{-6}$ in. per in. per 1 percent decrease in moisture content. The Portland Cement Association reported an average unit decrease in length of 229 x $10^{-6}$ associated with a decrease of 50 percent in the relative humidity of the air surrounding the test specimens.

*Serviceability Changes, Non-Traffic Loop (Section 3.5.6).*—Twenty-four test sections in and biweekly determinations of the serviceability index from slope variance revealed no significant changes in serviceability over the 2-yr period of the test.

### *3.6.2 Needed Research*

In Section 1.4 there is a general discussion of research that would be desirable to improve and simplify the relationships found in the AASHO Road Test and to extend the findings of the Road Test to include other soils, materials, and environments. The more important areas of research suggested by observations of pavement performance at the Road Test are discussed in this subsection.

The constants appearing in the rigid pavement performance equations would possibly have taken on significantly different values had the Road Test embankment soil, subbase material or environment been substantially different. Therefore, if Road Test findings are to be applied in areas where such differences exist, additional experiments of the satellite type (Section 1.4) would be useful in assisting engineers to adjust these constants to correspond with local conditions.

At the Road Test failure was confined largely to sections which, according to normal highway engineering practices, were underdesigned for the assigned loading. The majority of these failures followed severe pumping involving the ejection of subbase material from beneath the slab. There was evidence that the material was removed from the upper surface of the subbase by the erosive action of water moving towards the pavement edge. These factors, taken together, suggest the desirability of additional experiments permitting direct comparisons of performance between relatively thin slabs constructed on typical granular subbases, and slabs of the same design built on subbase materials resistant to erosion by water.

Subbase thickness in the range from 3 to 9 in. did not significantly affect pavement performance at the Road Test. However, the question of the effect of thickness on performance in cases involving more stable subbase materials—particularly if such materials are resistant to erosion by water—probably can be answered with precision only through further research.

The failure of the subbase material to drain laterally at a rate sufficient to prevent pumping suggests the need for further research directed toward development of more positive criteria for selection of granular subbases.

# Appendix A

## Pavement Performance Data

This appendix includes the basic performance data for all test sections. At least five sets of coordinates on the serviceability-applications history curve are given for each section or subsection in the AASHO Road Test. For those sections that failed prior to the end of test traffic the logarithms of the number of applications at which the smoothed serviceability history curve crossed serviceability levels of 3.5, 3.0, 2.5, 2.0, and 1.5 are given in the columns in the left half of the table. For the sections whose serviceability level did not fall to $p = 1.5$, the columns on the right give the serviceability levels at 22-week (11-index day) intervals throughout the test traffic period.

For the main factorial sections only, coordinates for additional points are given where appropriate. For example, for a section that failed, the principal performance data would be the five points (applications at $p = 3.5, 2.5, \ldots 1.5$) on the left of the table. If this section survived, say 30 index days, the serviceabilities at 11 and 22 index days also are given in the right of the table. Conversely, where complete (5-point) data show on the right, additional points are given on the left where appropriate. In certain of these cases, apparent inconsistencies will be noted between information on the two sides of the table. These are due to the techniques used in smoothing and rounding off the data for the tables—in case of doubt the complete (5-point) set of data should be used. The tables are given in the following order:

# FACTORIAL EXPERIMENT—DESIGN 1
# FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS

| | | | | | | | | INDEX DAY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 75 | 290 | 401 | 944 | 1226 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | | | | |
| LOOP | LANE | SECTION | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | |
| 2 | 1 | 721 | 3732 | 4042 | 4086 | 4093 | 4117 | | | | | | 1 | 0 | 00 | 721 |
| 2 | 1 | 727 | 4075 | 4139 | 4691 | 4845 | 4890 | 16 | | | | | 1 | 0 | 04 | 727 |
| 2 | 1 | 743 | 5112 | 5618 | 5636 | 5641 | 5650 | 36 | 33 | 31 | | | 1 | 3 | 00 | 743 |
| 2 | 1 | 717 | 4033 | 4856 | | | | 30 | 29 | 30 | 26 | 25 | 1 | 3 | 04 | 717 |
| 2 | 1 | 755 | 4960 | 5678 | | | | 36 | 34 | 32 | 28 | 28 | 1 | 6 | 00 | 755 |
| 2 | 1 | 719 | 4823 | 5860 | | | | 35 | 31 | 32 | 30 | 32 | 1 | 6 | 04 | 719 |
| 2 | 1 | 771 | 4823 | 5794 | 5860 | 5865 | 5868 | 35 | 35 | 35 | | | 2 | 0 | 00 | 771 |
| 2 | 1 | 729 | 3732 | 5053 | 5756 | 6031 | | 33 | 28 | 28 | 21 | 17 | 2 | 0 | 04 | 729 |
| 2 | 1 | 759 | | | | | | 40 | 40 | 39 | 39 | 38 | 2 | 3 | 00 | 759 |
| 2 | 1 | 731 | 5009 | 5325 | 5972 | | | 36 | 30 | 31 | 25 | 24 | 2 | 3 | 00 | 731 |
| 2 | 1 | 741 | 5886 | | | | | 39 | 37 | 37 | 35 | 35 | 2 | 3 | 04 | 741 |
| 2 | 1 | 709 | 4051 | | | | | 34 | 34 | 33 | 33 | 33 | 2 | 3 | 04 | 709 |
| 2 | 1 | 775 | 3732 | | | | | 35 | 34 | 34 | 34 | 34 | 2 | 6 | 00 | 775 |
| 2 | 1 | 757 | | | | | | 38 | 38 | 37 | 37 | 37 | 2 | 6 | 00 | 757 |
| 2 | 1 | 737 | 5204 | | | | | 36 | 35 | 35 | 36 | 36 | 2 | 6 | 04 | 737 |
| 2 | 1 | 711 | 4813 | | | | | 34 | 33 | 34 | 33 | 33 | 2 | 6 | 04 | 711 |
| 2 | 1 | 769 | 5832 | 5915 | | | | 37 | 37 | 37 | 29 | 30 | 3 | 0 | 00 | 769 |
| 2 | 1 | 739 | 5200 | | | | | 37 | 33 | 34 | 33 | 33 | 3 | 0 | 04 | 739 |
| 2 | 1 | 773 | | | | | | 40 | 40 | 40 | 38 | 38 | 3 | 3 | 00 | 773 |
| 2 | 1 | 745 | | | | | | 40 | 37 | 38 | 38 | 38 | 3 | 3 | 04 | 745 |
| 2 | 1 | 749 | 5204 | | | | | 38 | 34 | 33 | 35 | 36 | 3 | 6 | 00 | 749 |
| 2 | 1 | 763 | | | | | | 40 | 40 | 40 | 39 | 39 | 3 | 6 | 04 | 763 |
| 2 | 2 | 722 | 2954 | 3130 | 3255 | 3255 | 3352 | | | | | | 1 | 0 | 00 | 722 |
| 2 | 2 | 728 | 3130 | 3130 | 3255 | 3352 | 3431 | | | | | | 1 | 0 | 04 | 728 |
| 2 | 2 | 744 | 3846 | 4089 | 4093 | 4322 | 4450 | | | | | | 1 | 3 | 00 | 734 |
| 2 | 2 | 718 | 4033 | 4291 | 4494 | 4570 | 4635 | | | | | | 1 | 3 | 04 | 718. |
| 2 | 2 | 756 | 4093 | 4691 | 4905 | 5063 | 5160 | 26 | | | | | 1 | 6 | 00 | 756 |
| 2 | 2 | 720 | 4093 | 5229 | 5592 | 5631 | 5678 | 33 | 28 | 24 | | | 1 | 6 | 04 | 720 |
| 2 | 2 | 772 | 4450 | 4534 | 4604 | 4635 | 4691 | | | | | | 2 | 0 | 00 | 772 |
| 2 | 2 | 730 | 4291 | 4777 | 4875 | 5008 | 5020 | 31 | | | | | 2 | 0 | 04 | 730 |
| 2 | 2 | 760 | 5170 | 5266 | 5338 | 5397 | 5486 | 37 | 16 | | | | 2 | 3 | 00 | 760 |
| 2 | 2 | 732 | 4985 | 5118 | 5170 | 5213 | 5213 | 37 | | | | | 2 | 3 | 00 | 732 |
| 2 | 2 | 742 | 5165 | 5678 | 5702 | 5713 | 5724 | 37 | 35 | 34 | | | 2 | 3 | 04 | 742 |
| 2 | 2 | 710 | 3431 | 5630 | 5846 | 5927 | | 32 | 33 | 32 | 19 | 18 | 2 | 3 | 04 | 710 |
| 2 | 2 | 776 | 5009 | | | | | 35 | 35 | 34 | 33 | 35 | 2 | 6 | 00 | 7.76 |
| 2 | 2 | 758 | 5636 | 5897 | | | | 40 | 39 | 40 | 27 | 25 | 2 | 6 | 00 | 758 |
| 2 | 2 | 738 | 5239 | | | | | 37 | 35 | 33 | 32 | 32 | 2 | 6 | 04 | 738 |
| 2 | 2 | 712 | 3653 | 5009 | | | | 31 | 31 | 30 | 25 | 26 | 2 | 6 | 04 | 712 |
| 2 | 2 | 770 | 4865 | 5118 | 5129 | 5140 | 5150 | 35 | | | | | 3 | 0 | 00 | 770 |
| 2 | 2 | 740 | 4764 | 5118 | 5134 | 5145 | 5160 | 34 | | | | | 3 | 0 | 04 | 740 |
| 2 | 2 | 774 | 5568 | 5786 | 5902 | 5902 | 5904 | 38 | 36 | 34 | | | 3 | 3 | 00 | 774 |
| 2 | 2 | 746 | 5009 | 6015 | | | | 35 | 36 | 36 | 31 | 27 | 3 | 3 | 04 | 746 |
| 2 | 2 | 750 | 4834 | | | | | 34 | 34 | 34 | 32 | 31 | 3 | 6 | 00 | 750 |
| 2 | 2 | 764 | | | | | | 38 | 39 | 38 | 36 | 36 | 3 | 6 | 04 | 764 |

*BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.
**BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

# FACTORIAL EXPERIMENT—DESIGN 1
# FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS
# (Continued)

| | | | SERVICEABILITY TREND LEVEL | | | | | INDEX DAY | | | | | STRUCTURE DESIGN | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 75 | 290 | 401 | 944 | 1226 | | | | |
| | | | | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | | | | |
| LOOP | LANE | SECTION | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | |
| 3 | 1 | 165 | | 4139 | 4222 | 4258 | 4322 | | | | | | 2 | 0 | 00 | 165 |
| 3 | 1 | 125 | | 3255 | 3431 | 3556 | 3653 | | | | | | 2 | 0 | 04 | 125 |
| 3 | 1 | 143 | 4494 | 4534 | 4570 | 4604 | 4635 | | | | | | 2 | 0 | 08 | 143 |
| 3 | 1 | 133 | 4351 | 4570 | 4717 | 4764 | 4777 | | | | | | 2 | 0 | 08 | 133 |
| 3 | 1 | 113 | 4183 | 4222 | 4291 | 4322 | 4351 | | | | | | 2 | 3 | 00 | 113 |
| 3 | 1 | 135 | 4450 | 4494 | 4534 | 4604 | 4635 | | | | | | 2 | 3 | 04 | 135 |
| 3 | 1 | 159 | | 4403 | 4823 | 4960 | 5031 | 23 | | | | | 2 | 3 | 08 | 159 |
| 3 | 1 | 127 | 4135 | 4534 | 4635 | 4717 | 4801 | | | | | | 2 | 6 | 00 | 127 |
| 3 | 1 | 157 | 4093 | 4947 | 5020 | 5031 | 5042 | 32 | | | | | 2 | 6 | 04 | 157 |
| 3 | 1 | 111 | 5628 | 5702 | 5832 | 5881 | 5910 | 39 | 37 | 37 | | | 2 | 6 | 08 | 111 |
| 3 | 1 | 137 | 4075 | 4717 | 4764 | 4777 | 4777 | | | | | | 3 | 0 | 00 | 137 |
| 3 | 1 | 163 | 4834 | 4933 | 4997 | 5008 | 5020 | 34 | | | | | 3 | 0 | 04 | 163 |
| 3 | 1 | 109 | 4890 | 5053 | 5112 | 5118 | 5123 | 35 | | | | | 3 | 0 | 08 | 109 |
| 3 | 1 | 147 | 4093 | 4403 | 4494 | 4570 | 4604 | | | | | | 3 | 3 | 00 | 147 |
| 3 | 1 | 107 | 4823 | 4960 | 5008 | 5020 | 5020 | 31 | | | | | 3 | 3 | 04 | 107 |
| 3 | 1 | 115 | | 4570 | 4865 | 4960 | 5020 | 25 | | | | | 3 | 3 | 04 | 115 |
| 3 | 1 | 129 | 5170 | 5301 | 5626 | 5650 | 5664 | 39 | 29 | 27 | | | 3 | 3 | 08 | 129 |
| 3 | 1 | 117 | 4717 | 4919 | 5008 | 5020 | 5020 | 31 | | | | | 3 | 6 | 00 | 117 |
| 3 | 1 | 131 | 5390 | 5612 | 5690 | 5713 | 5746 | 38 | 34 | 30 | | | 3 | 6 | 04 | 131 |
| 3 | 1 | 155 | 5558 | 5678 | 5863 | 5914 | | 38 | 36 | 34 | 19 | 16 | 3 | 6 | 08 | 155 |
| 3 | 1 | 119 | 4131 | 4717 | 4777 | 4801 | 4812 | | | | | | 4 | 0 | 00 | 119 |
| 3 | 1 | 141 | 4494 | 4777 | 4789 | 4812 | 4823 | | | | | | 4 | 0 | 04 | 141 |
| 3 | 1 | 153 | 4812 | 4997 | 5123 | 5155 | 5170 | 34 | | | | | 4 | 0 | 08 | 153 |
| 3 | 1 | 145 | 4875 | 4875 | 4890 | 4890 | 4890 | 35 | | | | | 4 | 3 | 00 | 145 |
| 3 | 1 | 151 | 4403 | 4960 | 5123 | 5165 | 5170 | 32 | | | | | 4 | 3 | 04 | 151 |
| 3 | 1 | 121 | 5190 | 5631 | 5724 | 5786 | 5809 | 36 | 34 | 33 | | | 4 | 3 | 08 | 121 |
| 3 | 1 | 161 | 4801 | 5112 | 5208 | 5286 | 5365 | 34 | | | | | 4 | 6 | 00 | 161 |
| 3 | 1 | 149 | 4691 | 5118 | 5165 | 5170 | 5170 | 33 | | | | | 4 | 6 | 00 | 149 |
| 3 | 1 | 123 | 5624 | 5871 | 5908 | | | 38 | 37 | 36 | 21 | 23 | 4 | 6 | 04 | 123 |
| 3 | 1 | 139 | | | | | | 40 | 39 | 38 | 38 | 36 | 4 | 6 | 08 | 139 |
| 3 | 2 | 166 | 3811 | 4183 | 4222 | 4291 | 4322 | | | | | | 2 | 0 | 00 | 166 |
| 3 | 2 | 126 | 3130 | 3255 | 3352 | 3498 | 3556 | | | | | | 2 | 0 | 04 | 126 |
| 3 | 2 | 144 | 4450 | 4534 | 4604 | 4635 | 4691 | | | | | | 2 | 0 | 08 | 144 |
| 3 | 2 | 134 | 4450 | 4534 | 4570 | 4635 | 4664 | | | | | | 2 | 0 | 08 | 134 |
| 3 | 2 | 114 | 4042 | 4093 | 4139 | 4450 | 4450 | | | | | | 2 | 3 | 00 | 114 |
| 3 | 2 | 136 | 4093 | 4183 | 4534 | 4664 | 4764 | | | | | | 2 | 3 | 04 | 136 |
| 3 | 2 | 160 | 4033 | 4494 | 4812 | 4875 | 4890 | 20 | | | | | 2 | 3 | 08 | 160 |
| 3 | 2 | 128 | 4450 | 4494 | 4534 | 4570 | 4604 | | | | | | 2 | 6 | 00 | 128 |
| 3 | 2 | 158 | 4033 | 4427 | 4789 | 4875 | 4905 | 20 | | | | | 2 | 6 | 04 | 158 |
| 3 | 2 | 112 | 4789 | 5564 | 5624 | 5641 | 5655 | 34 | 30 | 28 | | | 2 | 6 | 08 | 112 |
| 3 | 2 | 138 | 4033 | 4494 | 4534 | 4534 | 4570 | | | | | | 3 | 0 | 00 | 138 |
| 3 | 2 | 164 | 4604 | 4875 | 4875 | 4890 | 4890 | 28 | | | | | 3 | 0 | 04 | 164 |
| 3 | 2 | 110 | 4071 | 4890 | 4997 | 5031 | 5053 | 31 | | | | | 3 | 0 | 08 | 110 |
| 3 | 2 | 148 | 4494 | 4570 | 4635 | 4664 | 4717 | | | | | | 3 | 3 | 00 | 148 |
| 3 | 2 | 108 | 4033 | 4812 | 4947 | 5008 | 5008 | 28 | | | | | 3 | 3 | 04 | 108 |
| 3 | 2 | 116 | 4450 | 4875 | 4890 | 4905 | 4919 | 30 | | | | | 3 | 3 | 04 | 116 |
| 3 | 2 | 130 | 4855 | 4997 | 5093 | 5145 | 5180 | 34 | | | | | 3 | 3 | 08 | 130 |
| 3 | 2 | 118 | 4222 | 4875 | 4875 | 4890 | 4890 | 30 | | | | | 3 | 6 | 00 | 118 |
| 3 | 2 | 132 | 4351 | 4875 | 5084 | 5123 | 5140 | 30 | | | | | 3 | 6 | 04 | 132 |
| 3 | 2 | 156 | 4865 | 5233 | 5623 | 5702 | 5817 | 35 | 27 | 26 | | | 3 | 6 | 08 | 156 |
| 3 | 2 | 120 | 4042 | 4403 | 4494 | 4534 | 4570 | | | | | | 4 | 0 | 00 | 120 |
| 3 | 2 | 142 | 4291 | 4812 | 4875 | 4875 | 4875 | 25 | | | | | 4 | 0 | 04 | 142 |
| 3 | 2 | 154 | 4789 | 4947 | 5008 | 5020 | 5031 | 33 | | | | | 4 | 0 | 08 | 154 |
| 3 | 2 | 146 | 4717 | 4919 | 5008 | 5020 | 5031 | 32 | | | | | 4 | 3 | 00 | 146 |
| 3 | 2 | 152 | 4812 | 5008 | 5084 | 5118 | 5123 | 33 | | | | | 4 | 3 | 04 | 152 |
| 3 | 2 | 122 | 5367 | 5486 | 5625 | 5646 | 5660 | 39 | 31 | 30 | | | 4 | 3 | 08 | 122 |
| 3 | 2 | 162 | 4801 | 5084 | 5274 | 5343 | 5360 | 33 | | | | | 4 | 6 | 00 | 162 |
| 3 | 2 | 150 | 4801 | 5008 | 5042 | 5074 | 5093 | 33 | | | | | 4 | 6 | 00 | 150 |
| 3 | 2 | 124 | 5660 | 5801 | 5817 | 5832 | 5846 | 40 | 38 | 37 | | | 4 | 6 | 04 | 124 |
| 3 | 2 | 140 | 5802 | | | | | 38 | 37 | 37 | 31 | 33 | 4 | 6 | 08 | 140 |

# FACTORIAL EXPERIMENT—DESIGN 1
# FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS
# (Continued)

| | | | | | | | | INDEX DAY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 75 | 290 | 401 | 944 | 1226 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | | | | |
| LOOP | LANE | SECTION | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | |
| 4 | 1 | 633 | | | 3130 | 3130 | 3255 | | | | | | 3 | 0 | 04 | 633 |
| 4 | 1 | 607 | 4378 | 4494 | 4534 | 4570 | 4604 | | | | | | 3 | 0 | 08 | 607 |
| 4 | 1 | 571 | 4834 | 4890 | 4905 | 4919 | 4933 | 31 | | | | | 3 | 0 | 12 | 571 |
| 4 | 1 | 569 | 4812 | 4997 | 5103 | 5150 | 5195 | 33 | | | | | 3 | 0 | 12 | 569 |
| 4 | 1 | 599 | 4494 | 4570 | 4604 | 4664 | 4692 | | | | | | 3 | 3 | 04 | 599 |
| 4 | 1 | 573 | 4875 | 4890 | 4905 | 4919 | 4933 | 35 | | | | | 3 | 3 | 08 | 573 |
| 4 | 1 | 617 | 5063 | 5629 | 5678 | 5702 | 5724 | 37 | 35 | 33 | | | 3 | 3 | 12 | 617 |
| 4 | 1 | 585 | 4635 | 4823 | 4875 | 4875 | 4875 | 20 | | | | | 3 | 6 | 04 | 585 |
| 4 | 1 | 623 | 4764 | 4890 | 4947 | 5008 | 5063 | 30 | | | | | 3 | 6 | 08 | 623 |
| 4 | 1 | 601 | 5113 | 5626 | 5832 | 5951 | | 37 | 33 | 32 | 19 | 16 | 3 | 6 | 12 | 601 |
| 4 | 1 | 583 | 4777 | 4789 | 4801 | 4823 | 4834 | | | | | | 4 | 0 | 04 | 583 |
| 4 | 1 | 619 | 4997 | 5118 | 5145 | 5165 | 5165 | 38 | | | | | 4 | 0 | 08 | 619 |
| 4 | 1 | 603 | 4960 | 5160 | 5290 | 5588 | 5597 | 36 | 23 | | | | 4 | 0 | 12 | 603 |
| 4 | 1 | 627 | 4789 | 4973 | 5008 | 5020 | 5020 | 33 | | | | | 4 | 3 | 04 | 627 |
| 4 | 1 | 589 | 4972 | 5053 | 5112 | 5118 | 5123 | 37 | | | | | 4 | 3 | 08 | 589 |
| 4 | 1 | 597 | 4997 | 5123 | 5155 | 5170 | 5180 | 38 | | | | | 4 | 3 | 08 | 597 |
| 4 | 1 | 575 | 5603 | 5776 | 5878 | 5944 | 6087 | 41 | 37 | 35 | 20 | | 4 | 3 | 12 | 575 |
| 4 | 1 | 595 | 4812 | 4960 | 5008 | 5031 | 5042 | 33 | | | | | 4 | 6 | 04 | 595 |
| 4 | 1 | 577 | 5756 | 5886 | 5941 | 6071 | | 42 | 38 | 37 | 24 | 19 | 4 | 6 | 08 | 577 |
| 4 | 1 | 625 | 5589 | 5810 | 5891 | 5951 | | 40 | 38 | 34 | 19 | 19 | 4 | 6 | 12 | 625 |
| 4 | 1 | 605 | 4801 | 5008 | 5020 | 5020 | 5031 | 33 | | | | | 5 | 0 | 04 | 605 |
| 4 | 1 | 587 | 5112 | 5165 | 5180 | 5195 | 5209 | 39 | | | | | 5 | 0 | 08 | 587 |
| 4 | 1 | 621 | 5150 | 5282 | 5746 | 5865 | 5889 | 40 | 31 | 29 | | | 5 | 0 | 12 | 621 |
| 4 | 1 | 579 | 5063 | 5170 | 5208 | 5218 | 5228 | 38 | | | | | 5 | 3 | 04 | 579 |
| 4 | 1 | 631 | 4947 | 5258 | 5520 | 5608 | 5746 | 36 | 25 | 20 | | | 5 | 3 | 08 | 631 |
| 4 | 1 | 593 | 5084 | 5655 | 5702 | 5724 | 5756 | 37 | 34 | 33 | | | 5 | 3 | 12 | 593 |
| 4 | 1 | 629 | 5628 | 5678 | 5794 | 5846 | 5865 | 40 | 40 | 37 | | | 5 | 6 | 04 | 629 |
| 4 | 1 | 615 | 5084 | 5629 | 5724 | 5786 | 5809 | 37 | 33 | 32 | | | 5 | 6 | 04 | 615 |
| 4 | 1 | 591 | | | | | | 43 | 43 | 42 | 37 | 36 | 5 | 6 | 08 | 591 |
| 4 | 1 | 581 | 5135 | | | | | 39 | 35 | 34 | 32 | 33 | 5 | 6 | 12 | 581 |
| 4 | 2 | 634 | 3936 | 4033 | 4033 | 4037 | 4037 | | | | | | 3 | 0 | 04 | 634 |
| 4 | 2 | 608 | 4494 | 4534 | 4604 | 4635 | 4691 | | | | | | 3 | 0 | 08 | 608 |
| 4 | 2 | 572 | 4865 | 5042 | 5112 | 5134 | 5160 | 35 | | | | | 3 | 0 | 12 | 572 |
| 4 | 2 | 570 | 4890 | 5063 | 5134 | 5165 | 5194 | 35 | | | | | 3 | 0 | 12 | 570 |
| 4 | 2 | 600 | 4494 | 4570 | 4635 | 4691 | 4741 | | | | | | 3 | 3 | 04 | 600 |
| 4 | 2 | 574 | 4777 | 4947 | 5008 | 5008 | 5008 | 32 | | | | | 3 | 3 | 08 | 574 |
| 4 | 2 | 618 | 5213 | 5678 | 5724 | 5756 | 5786 | 37 | 34 | 33 | | | 3 | 3 | 12 | 618 |
| 4 | 2 | 586 | 4635 | 4845 | 4875 | 4890 | 4890 | 25 | | | | | 3 | 6 | 04 | 586 |
| 4 | 2 | 624 | 4378 | 5084 | 5270 | 5587 | 5678 | 32 | 22 | 19 | | | 3 | 6 | 08 | 624 |
| 4 | 2 | 602 | 5213 | 5628 | 5690 | 5756 | 5824 | 38 | 34 | 34 | | | 3 | 6 | 12 | 602 |
| 4 | 2 | 584 | 4875 | 4905 | 4919 | 4933 | 4960 | 35 | | | | | 4 | 0 | 04 | 584 |
| 4 | 2 | 620 | 4875 | 5112 | 5123 | 5129 | 5134 | 35 | | | | | 4 | 0 | 08 | 620 |
| 4 | 2 | 604 | 5417 | 5542 | 5678 | 5690 | 5702 | 39 | 32 | 28 | | | 4 | 0 | 12 | 604 |
| 4 | 2 | 628 | 4403 | 5020 | 5031 | 5053 | 5074 | 32 | | | | | 4 | 3 | 04 | 628 |
| 4 | 2 | 590 | 4997 | 5112 | 5170 | 5223 | 5301 | 38 | | | | | 4 | 3 | 08 | 590 |
| 4 | 2 | 598 | 5063 | 5155 | 5194 | 5243 | 5270 | 39 | | | | | 4 | 3 | 08 | 598 |
| 4 | 2 | 576 | 5615 | 5690 | 5839 | 5892 | 5967 | 39 | 37 | 35 | | | 4 | 3 | 12 | 576 |
| 4 | 2 | 596 | 4812 | 5053 | 5140 | 5190 | 5213 | 34 | | | | | 4 | 6 | 04 | 596 |
| 4 | 2 | 578 | 5474 | 5832 | 5908 | 5992 | | 40 | 35 | 32 | 21 | 20 | 4 | 6 | 08 | 578 |
| 4 | 2 | 626 | 5632 | 6058 | | | | 35 | 36 | 36 | 30 | 31 | 4 | 6 | 12 | 626 |
| 4 | 2 | 606 | 4960 | 5118 | 5123 | 5134 | 5140 | 36 | | | | | 5 | 0 | 04 | 606 |
| 4 | 2 | 588 | 5074 | 5190 | 5218 | 5223 | 5233 | 38 | | | | | 5 | 0 | 08 | 588 |
| 4 | 2 | 622 | 5204 | 5702 | 5853 | 5915 | 6005 | 37 | 34 | 33 | 18 | | 5 | 0 | 12 | 622 |
| 4 | 2 | 580 | 5145 | 5204 | 5258 | 5282 | 5301 | 38 | | | | | 5 | 3 | 04 | 580 |
| 4 | 2 | 632 | 5118 | 5440 | 5860 | 5901 | 5934 | 37 | 30 | 27 | | | 5 | 3 | 08 | 632 |
| 4 | 2 | 594 | 5282 | 5892 | 5981 | | | 39 | 34 | 32 | 26 | 22 | 5 | 3 | 12 | 594 |
| 4 | 2 | 630 | 5262 | 5786 | 5887 | 5904 | 5916 | 37 | 35 | 33 | | | 5 | 6 | 04 | 630 |
| 4 | 2 | 616 | 5461 | 5650 | 5756 | 5801 | 5832 | 39 | 35 | 33 | | | 5 | 6 | 04 | 616 |
| 4 | 2 | 592 | 5713 | 5968 | | | | 40 | 39 | 37 | 30 | 27 | 5 | 6 | 08 | 592 |
| 4 | 2 | 582 | 5316 | 5873 | | | | 39 | 34 | 33 | 29 | 27 | 5 | 6 | 12 | 582 |

## FACTORIAL EXPERIMENT—DESIGN 1
## FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS
## (Continued)

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | INDEX DAY | | | | | | | | |
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 75 | 290 | 401 | 944 | 1226 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | | | | |
| LOOP | LANE | SECTION | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | |
| 5 | 1 | 485 | 3732 | 4059 | 4322 | 4450 | 4494 | | | | | | 3 | 3 | 04 | 485 |
| 5 | 1 | 451 | 3811 | 4378 | 4494 | 4534 | 4604 | | | | | | 3 | 3 | 08 | 451 |
| 5 | 1 | 415 | 4865 | 4972 | 5008 | 5020 | 5020 | 34 | | | | | 3 | 3 | 12 | 415 |
| 5 | 1 | 429 | 4258 | 4570 | 4691 | 4764 | 4777 | | | | | | 3 | 3 | 12 | 429 |
| 5 | 1 | 449 | 4450 | 4494 | 4534 | 4570 | 4604 | | | | | | 3 | 6 | 04 | 449 |
| 5 | 1 | 419 | 4534 | 4570 | 4635 | 4691 | 4741 | | | | | | 3 | 6 | 08 | 419 |
| 5 | 1 | 487 | 4112 | 4494 | 4812 | 5520 | 5592 | 23 | 21 | | | | 3 | 6 | 12 | 487 |
| 5 | 1 | 413 | 4664 | 4834 | 4875 | 4890 | 4905 | 25 | | | | | 3 | 9 | 04 | 413 |
| 5 | 1 | 471 | 4494 | 4777 | 4855 | 4947 | 5020 | 23 | | | | | 3 | 9 | 08 | 471 |
| 5 | 1 | 441 | 5053 | 5558 | | | | 37 | 31 | 28 | 29 | 29 | 3 | 9 | 12 | 441 |
| 5 | 1 | 411 | 3987 | 4093 | 4403 | 4494 | 4534 | | | | | | 4 | 3 | 04 | 411 |
| 5 | 1 | 481 | 4812 | 4875 | 4890 | 4919 | 4933 | 28 | | | | | 4 | 3 | 08 | 481 |
| 5 | 1 | 443 | 4604 | 4875 | 5042 | 5118 | 5150 | 30 | | | | | 4 | 3 | 12 | 443 |
| 5 | 1 | 473 | 4494 | 4801 | 4875 | 4875 | 4890 | 23 | | | | | 4 | 6 | 04 | 473 |
| 5 | 1 | 455 | 4834 | 4997 | 5103 | 5155 | 5170 | 34 | | | | | 4 | 6 | 08 | 455 |
| 5 | 1 | 453 | 4777 | 4933 | 5053 | 5118 | 5140 | 32 | | | | | 4 | 6 | 08 | 453 |
| 5 | 1 | 425 | 5063 | 5390 | 5626 | 5735 | 5794 | 37 | 29 | 27 | | | 4 | 6 | 12 | 425 |
| 5 | 1 | 437 | 4664 | 4834 | 4947 | 5118 | 5134 | 28 | | | | | 4 | 9 | 04 | 437 |
| 5 | 1 | 417 | 4890 | 5123 | 5347 | 5585 | 5622 | 35 | 23 | 16 | | | 4 | 9 | 08 | 417 |
| 5 | 1 | 477 | 5166 | 5901 | 6086 | | | 38 | 36 | 33 | 29 | 24 | 4 | 9 | 12 | 477 |
| 5 | 1 | 439 | 4691 | 4777 | 4789 | 4812 | 4823 | | | | | | 5 | 3 | 04 | 439 |
| 5 | 1 | 421 | 5042 | 5118 | 5129 | 5134 | 5145 | 38 | | | | | 5 | 3 | 08 | 421 |
| 5 | 1 | 479 | 5160 | 5577 | 5809 | 5890 | 5937 | 41 | 31 | 29 | | | 5 | 3 | 12 | 479 |
| 5 | 1 | 423 | 4960 | 5074 | 5112 | 5123 | 5129 | 37 | | | | | 5 | 6 | 04 | 423 |
| 5 | 1 | 469 | 4905 | 5238 | 5664 | 5824 | 5873 | 36 | 28 | 26 | | | 5 | 6 | 08 | 469 |
| 5 | 1 | 445 | 5204 | 5776 | 5900 | 6086 | | 39 | 34 | 33 | 22 | 20 | 5 | 6 | 12 | 445 |
| 5 | 1 | 475 | 5603 | 5735 | 5801 | 5817 | 5839 | 40 | 37 | 35 | | | 5 | 9 | 04 | 475 |
| 5 | 1 | 483 | 5461 | 5590 | 5621 | 5626 | 5746 | 36 | 35 | 26 | | | 5 | 9 | 04 | 483 |
| 5 | 1 | 447 | 5735 | 5927 | | | | 40 | 39 | 37 | 29 | 27 | 5 | 9 | 08 | 447 |
| 5 | 1 | 427 | 5874 | | | | | 40 | 39 | 37 | 35 | 35 | 5 | 9 | 12 | 427 |
| 5 | 2 | 486 | 3255 | 3352 | 3431 | 3556 | 3607 | | | | | | 3 | 3 | 04 | 486 |
| 5 | 2 | 452 | 4351 | 4494 | 4570 | 4604 | 4664 | | | | | | 3 | 3 | 08 | 452 |
| 5 | 2 | 416 | 4604 | 4834 | 4985 | 5118 | 5190 | 28 | | | | | 3 | 3 | 12 | 416 |
| 5 | 2 | 430 | 4534 | 4812 | 4875 | 4905 | 4919 | 25 | | | | | 3 | 3 | 12 | 430 |
| 5 | 2 | 450 | 4494 | 4570 | 4604 | 4664 | 4717 | | | | | | 3 | 6 | 04 | 450 |
| 5 | 2 | 420 | 4403 | 4635 | 4764 | 4777 | 4777 | | | | | | 3 | 6 | 08 | 420 |
| 5 | 2 | 488 | 4789 | 5585 | 5610 | 5627 | 5655 | 34 | 31 | 26 | | | 3 | 6 | 12 | 488 |
| 5 | 2 | 414 | 4570 | 4834 | 4890 | 4905 | 4919 | 26 | | | | | 3 | 9 | 04 | 414 |
| 5 | 2 | 472 | 4534 | 4845 | 4997 | 5112 | 5160 | 29 | | | | | 3 | 9 | 08 | 472 |
| 5 | 2 | 442 | 4717 | 5074 | 5306 | 5735 | 5876 | 32 | 23 | 21 | | | 3 | 9 | 12 | 442 |
| 5 | 2 | 412 | 4093 | 4139 | 4258 | 4322 | 4378 | | | | | | 4 | 3 | 04 | 412 |
| 5 | 2 | 482 | 4635 | 4855 | 4890 | 4919 | 4933 | 26 | | | | | 4 | 3 | 08 | 482 |
| 5 | 2 | 444 | 4855 | 5031 | 5112 | 5129 | 5140 | 34 | | | | | 4 | 3 | 12 | 444 |
| 5 | 2 | 474 | 4845 | 4890 | 4905 | 4919 | 4933 | 30 | | | | | 4 | 6 | 04 | 474 |
| 5 | 2 | 456 | 4604 | 4875 | 5074 | 5190 | 5546 | 30 | 16 | | | | 4 | 6 | 08 | 456 |
| 5 | 2 | 454 | 4570 | 5103 | 5301 | 5372 | 5631 | 33 | 17 | 19 | | | 4 | 6 | 08 | 454 |
| 5 | 2 | 426 | 4789 | 5042 | 5372 | 5590 | 5646 | 33 | 24 | 19 | | | 4 | 6 | 12 | 426 |
| 5 | 2 | 438 | 4801 | 4985 | 5118 | 5160 | 5180 | 33 | | | | | 4 | 9 | 04 | 438 |
| 5 | 2 | 418 | 4865 | 5112 | 5223 | 5342 | 5590 | 35 | 19 | | | | 4 | 9 | 08 | 418 |
| 5 | 2 | 478 | 5166 | 5866 | | | | 38 | 36 | 33 | 26 | 30 | 4 | 9 | 12 | 478 |
| 5 | 2 | 440 | 4947 | 5020 | 5020 | 5031 | 5042 | 36 | | | | | 5 | 3 | 04 | 440 |
| 5 | 2 | 422 | 4960 | 5103 | 5165 | 5204 | 5243 | 37 | | | | | 5 | 3 | 08 | 422 |
| 5 | 2 | 480 | 5084 | 5440 | 5810 | 5900 | | 39 | 30 | 25 | 17 | 19 | 5 | 3 | 12 | 480 |
| 5 | 2 | 424 | 4933 | 5093 | 5140 | 5165 | 5185 | 37 | | | | | 5 | 6 | 04 | 424 |
| 5 | 2 | 470 | 4920 | 5200 | 5585 | 5903 | | 35 | 26 | 25 | 17 | 19 | 5 | 6 | 08 | 470 |
| 5 | 2 | 446 | 5545 | 5832 | 5944 | | | 39 | 35 | 34 | 24 | 24 | 5 | 6 | 12 | 446 |
| 5 | 2 | 476 | 5180 | 5404 | 5474 | 5589 | 5846 | 38 | 26 | 20 | | | 5 | 9 | 04 | 476 |
| 5 | 2 | 484 | 4875 | 5579 | 5612 | 5650 | 5786 | 35 | 32 | 26 | | | 5 | 9 | 04 | 484 |
| 5 | 2 | 448 | 5604 | 5868 | 5991 | | | 39 | 37 | 35 | 25 | 26 | 5 | 9 | 08 | 448 |
| 5 | 2 | 428 | 5665 | 5876 | | | | 40 | 37 | 37 | 31 | 32 | 5 | 9 | 12 | 428 |

## FACTORIAL EXPERIMENT—DESIGN 1
## FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS
## (Continued)

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | INDEX DAY | | | | | | | |
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | |
| | | | | | | | | 75 | 290 | 401 | 944 | 1226 | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | | | |
| LOOP | LANE | SECTION | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | D1 | D2 | D3 | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | |
| 6 | 1 | 269 | 3846 | 4450 | 4494 | 4534 | 4570 | | | | | | 4 | 3 | .08 | 269 |
| 6 | 1 | 299 | 5008 | 5165 | 5258 | 5386 | 5585 | 37 | 18 | | | | 4 | 3 | 12 | 299 |
| 6 | 1 | 317 | 4875 | 5008 | 5112 | 5170 | 5262 | 35 | | | | | 4 | 3 | 16 | 317 |
| 6 | 1 | 329 | 4777 | 4905 | 4997 | 5031 | 5053 | 31 | | | | | 4 | 3 | 16 | 329 |
| 6 | 1 | 303 | 4604 | 4823 | 4890 | 4905 | 4933 | 26 | | | | | 4 | 6 | 08 | 303 |
| 6 | 1 | 323 | 4764 | 4845 | 4890 | 4919 | 4947 | 26 | | | | | 4 | 6 | 12 | 323 |
| 6 | 1 | 253 | 5134 | 5372 | 5606 | 5641 | 5650 | 38 | 31 | 25 | | | 4 | 6 | 16 | 253 |
| 6 | 1 | 321 | 4427 | 4812 | 4875 | 4905 | 4919 | 25 | | | | | 4 | 9 | 08 | 321 |
| 6 | 1 | 267 | 4933 | 5084 | 5170 | 5238 | 5564 | 36 | 16 | | | | 4 | 9 | 12 | 267 |
| 6 | 1 | 309 | 5669 | 5886 | 6072 | 6089 | | 40 | 37 | 36 | 26 | 20 | 4 | 9 | 16 | 309 |
| 6 | 1 | 319 | 4777 | 4789 | 4812 | 4823 | 4834 | | | | | | 5 | 3 | 08 | 319 |
| 6 | 1 | 261 | 4834 | 4985 | 5063 | 5112 | 5129 | 33 | | | | | 5 | 3 | 12 | 261 |
| 6 | 1 | 315 | 5140 | 5507 | 5624 | 5650 | 5690 | 39 | 31 | 28 | | | 5 | 3 | 16 | 315 |
| 6 | 1 | 259 | 4834 | 4985 | 5053 | 5112 | 5123 | 33 | | | | | 5 | 6 | 08 | 259 |
| 6 | 1 | 307 | 5150 | 5673 | 5735 | 5786 | 5860 | 40 | 36 | 35 | | | 5 | 6 | 12 | 307 |
| 6 | 1 | 305 | 4997 | 5145 | 5233 | 5383 | 5593 | 37 | 18 | | | | 5 | 6 | 12 | 305 |
| 6 | 1 | 327 | 5564 | 5746 | 5889 | 6084 | | 41 | 35 | 34 | 20 | 18 | 5 | 6 | 16 | 327 |
| 6 | 1 | 313 | 5042 | 5372 | 5602 | 5631 | 5766 | 37 | 28 | 25 | | | 5 | 9 | 08 | 313 |
| 6 | 1 | 331 | 5084 | 5347 | 5660 | 5873 | 5909 | 37 | 28 | 28 | | | 5 | 9 | 12 | 331 |
| 6 | 1 | 265 | 5886 | | | | | 41 | 40 | 39 | 35 | 33 | 5 | 9 | 16 | 265 |
| 6 | 1 | 297 | 4947 | 5118 | 5180 | 5243 | 5278 | 36 | | | | | 6 | 3 | 08 | 297 |
| 6 | 1 | 335 | 4777 | 4972 | 5093 | 5140 | 5185 | 33 | | | | | 6 | 3 | 12 | 335 |
| 6 | 1 | 255 | 5199 | 5600 | 5650 | 5766 | 5846 | 41 | 31 | 30 | | | 6 | 3 | 16 | 255 |
| 6 | 1 | 325 | 5112 | 5129 | 5140 | 5150 | 5160 | 40 | | | | | 6 | 6 | 08 | 325 |
| 6 | 1 | 257 | 5140 | 5258 | 5906 | 6015 | | 42 | 32 | 32 | 22 | 16 | 6 | 6 | 12 | 257 |
| 6 | 1 | 301 | 5713 | 5914 | | | | 41 | 36 | 37 | 29 | 32 | 6 | 6 | 16 | 301 |
| 6 | 1 | 263 | 5118 | 5243 | 5627 | 5794 | 5839 | 39 | 28 | 26 | | | 6 | 9 | 08 | 263 |
| 6 | 1 | 271 | 5451 | 5713 | 5901 | | | 42 | 35 | 33 | 23 | 21 | 6 | 9 | 08 | 271 |
| 6 | 1 | 311 | 5343 | 5641 | 5886 | | | 41 | 33 | 34 | 26 | 28 | 6 | 9 | 12 | 311 |
| 6 | 1 | 333 | 5440 | 5626 | | | | 40 | 34 | 31 | 26 | 27 | 6 | 9 | 16 | 333 |
| 6 | 2 | 270 | 4351 | 4691 | 4801 | 4834 | 4875 | 15 | | | | | 4 | 3 | 08 | 270 |
| 6 | 2 | 300 | 5165 | 5590 | 5616 | 5628 | 5690 | 39 | 33 | 27 | | | 4 | 3 | 12 | 300 |
| 6 | 2 | 318 | 5253 | 5631 | 5702 | 5766 | 5832 | 40 | 34 | 34 | | | 4 | 3 | 16 | 318 |
| 6 | 2 | 330 | 5074 | 5118 | 5129 | 5140 | 5150 | 39 | | | | | 4 | 3 | 16 | 330 |
| 6 | 2 | 304 | 5031 | 5134 | 5190 | 5238 | 5585 | 39 | 15 | | | | 4 | 6 | 08 | 304 |
| 6 | 2 | 324 | 4812 | 4933 | 5031 | 5093 | 5123 | 32 | | | | | 4 | 6 | 12 | 324 |
| 6 | 2 | 254 | 4972 | 5150 | 5440 | 5786 | 5832 | 37 | 24 | 24 | | | 4 | 6 | 16 | 254 |
| 6 | 2 | 322 | 4905 | 5129 | 5208 | 5347 | 5474 | 35 | 20 | | | | 4 | 9 | 08 | 322 |
| 6 | 2 | 268 | 4985 | 5175 | 5461 | 5824 | 5920 | 37 | 25 | 25 | | | 4 | 9 | 12 | 268 |
| 6 | 2 | 310 | 5860 | 5927 | | | | 41 | 39 | 39 | 29 | 32 | 4 | 9 | 16 | 310 |
| 6 | 2 | 320 | 5112 | 5123 | 5129 | 5140 | 5145 | 38 | | | | | 5 | 3 | 08 | 320 |
| 6 | 2 | 262 | 4972 | 5123 | 5194 | 5262 | 5595 | 37 | 16 | | | | 5 | 3 | 12 | 262 |
| 6 | 2 | 316 | 5112 | 5636 | 5756 | 5832 | 5873 | 38 | 33 | 32 | | | 5 | 3 | 16 | 316 |
| 6 | 2 | 260 | 4855 | 5112 | 5129 | 5140 | 5155 | 35 | | | | | 5 | 6 | 08 | 260 |
| 6 | 2 | 308 | 5118 | 5301 | 5626 | 5724 | 5766 | 39 | 29 | 27 | | | 5 | 6 | 12 | 308 |
| 6 | 2 | 306 | 5145 | 5588 | 5786 | 5809 | 5824 | 40 | 31 | 29 | | | 5 | 6 | 12 | 306 |
| 6 | 2 | 328 | 5160 | 5461 | 5702 | 5904 | 5976 | 40 | 30 | 29 | 15 | | 5 | 6 | 16 | 328 |
| 6 | 2 | 314 | 5243 | 5669 | 5766 | 5809 | 5839 | 39 | 35 | 34 | | | 5 | 9 | 08 | 314 |
| 6 | 2 | 332 | 5145 | 5360 | 5502 | 5846 | 5910 | 39 | 28 | 26 | | | 5 | 9 | 12 | 332 |
| 6 | 2 | 266 | 5678 | | | | | 39 | 38 | 37 | 34 | 35 | 5 | 9 | 16 | 266 |
| 6 | 2 | 298 | 5129 | 5233 | 5690 | 5702 | 5713 | 41 | 29 | 29 | | | 6 | 3 | 08 | 298 |
| 6 | 2 | 336 | 4450 | 5031 | 5180 | 5494 | 5621 | 33 | 21 | 18 | | | 6 | 3 | 12 | 336 |
| 6 | 2 | 256 | 5185 | 5904 | 6086 | | | 40 | 36 | 34 | 26 | 24 | 6 | 3 | 16 | 256 |
| 6 | 2 | 326 | 5074 | 5160 | 5213 | 5293 | 5486 | 42 | 15 | | | | 6 | 6 | 08 | 326 |
| 6 | 2 | 258 | 5180 | 5976 | | | | 40 | 36 | 34 | 30 | 30 | 6 | 6 | 12 | 258 |
| 6 | 2 | 302 | | | | | | 40 | 40 | 39 | 38 | 39 | 6 | 6 | 16 | 302 |
| 6 | 2 | 264 | 5234 | 5767 | | | | 39 | 34 | 35 | 26 | 26 | 6 | 9 | 08 | 264 |
| 6 | 2 | 272 | 5373 | 5636 | 5825 | 6042 | | 40 | 34 | 34 | 21 | 17 | 6 | 9 | 08 | 272 |
| 6 | 2 | 312 | 5846 | 5937 | | | | 40 | 38 | 38 | 29 | 26 | 6 | 9 | 12 | 312 |
| 6 | 2 | 334 | 5917 | | | | | 40 | 38 | 37 | 35 | 36 | 6 | 9 | 16 | 334 |

# FACTORIAL EXPERIMENT—DESIGN 1
# FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | INDEX DAY | | | | | | | | |
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* (x.xxx) | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** (x.x) | | | | | D<sub>1</sub> | D<sub>2</sub> (in.) | D<sub>3</sub> | SECTION |
| 2 | 1 | 721 | 3716 | 4129 | 4413 | 4542 | 4716 | | | | | | 1 | 0 | 00 | 721 |
| 2 | 1 | 727 | 4336 | 4766 | 4870 | 4895 | 4904 | 16 | | | | | 1 | 0 | 04 | 727 |
| 2 | 1 | 743 | 4990 | 5678 | 5734 | 5736 | 5741 | 36 | 33 | 31 | | | 1 | 3 | 00 | 743 |
| 2 | 1 | 717 | 4057 | 4898 | | | | 30 | 29 | 30 | 26 | 25 | 1 | 3 | 04 | 717 |
| 2 | 1 | 755 | 4922 | 5756 | | | | 36 | 34 | 32 | 28 | 28 | 1 | 6 | 00 | 755 |
| 2 | 1 | 719 | 4892 | 5802 | | | | 35 | 31 | 32 | 30 | 32 | 1 | 6 | 04 | 719 |
| 2 | 1 | 771 | 4891 | 5781 | 5802 | 5806 | 5809 | 35 | 35 | 35 | | | 2 | 0 | 00 | 771 |
| 2 | 1 | 729 | 3716 | 4958 | 5772 | 5955 | | 33 | 28 | 28 | 21 | 17 | 2 | 0 | 04 | 729 |
| 2 | 1 | 759 | | | | | | 40 | 40 | 39 | 39 | 38 | 2 | 3 | 00 | 759 |
| 2 | 1 | 731 | 4934 | 5204 | 5905 | | | 36 | 30 | 31 | 25 | 24 | 2 | 3 | 00 | 731 |
| 2 | 1 | 741 | 5826 | | | | | 39 | 37 | 37 | 35 | 35 | 2 | 3 | 04 | 741 |
| 2 | 1 | 709 | 4190 | | | | | 34 | 34 | 33 | 33 | 33 | 2 | 3 | 04 | 709 |
| 2 | 1 | 775 | 3716 | | | | | 35 | 34 | 34 | 34 | 34 | 2 | 6 | 00 | 775 |
| 2 | 1 | 757 | | | | | | 38 | 38 | 37 | 37 | 37 | 2 | 6 | 00 | 757 |
| 2 | 1 | 737 | 5071 | | | | | 36 | 35 | 35 | 36 | 36 | 2 | 6 | 04 | 737 |
| 2 | 1 | 711 | 4890 | | | | | 34 | 33 | 34 | 33 | 33 | 2 | 6 | 04 | 711 |
| 2 | 1 | 769 | 5793 | 5864 | | | | 37 | 37 | 37 | 29 | 30 | 3 | 0 | 00 | 769 |
| 2 | 1 | 739 | 5066 | | | | | 37 | 33 | 34 | 33 | 33 | 3 | 0 | 04 | 739 |
| 2 | 1 | 773 | | | | | | 40 | 40 | 40 | 38 | 38 | 3 | 3 | 00 | 773 |
| 2 | 1 | 745 | | | | | | 40 | 37 | 38 | 38 | 38 | 3 | 3 | 04 | 745 |
| 2 | 1 | 749 | 5071 | | | | | 38 | 34 | 33 | 35 | 36 | 3 | 6 | 00 | 749 |
| 2 | 1 | 763 | | | | | | 40 | 40 | 40 | 39 | 39 | 3 | 6 | 04 | 763 |
| 2 | 2 | 722 | 2845 | 3060 | 3204 | 3204 | 3311 | | | | | | 1 | 0 | 00 | 722 |
| 2 | 2 | 728 | 3060 | 3060 | 3204 | 3311 | 3397 | | | | | | 1 | 0 | 04 | 728 |
| 2 | 2 | 744 | 3848 | 4436 | 4650 | 4806 | 4842 | | | | | | 1 | 3 | 00 | 744 |
| 2 | 2 | 718 | 4056 | 4798 | 4846 | 4854 | 4862 | | | | | | 1 | 3 | 04 | 718 |
| 2 | 2 | 756 | 4507 | 4870 | 4908 | 4963 | 5026 | 26 | | | | | 1 | 6 | 00 | 756 |
| 2 | 2 | 720 | 4516 | 5096 | 5610 | 5732 | 5756 | 33 | 28 | 24 | | | 1 | 6 | 04 | 720 |
| 2 | 2 | 772 | 4842 | 4850 | 4858 | 4862 | 4870 | | | | | | 2 | 0 | 00 | 772 |
| 2 | 2 | 730 | 4798 | 4883 | 4901 | 4934 | 4940 | 31 | | | | | 2 | 0 | 04 | 730 |
| 2 | 2 | 760 | 5035 | 5132 | 5217 | 5287 | 5397 | 37 | 16 | | | | 2 | 3 | 00 | 760 |
| 2 | 2 | 732 | 4928 | 4994 | 5035 | 5080 | 5080 | 37 | | | | | 2 | 3 | 00 | 732 |
| 2 | 2 | 742 | 5030 | 5755 | 5760 | 5762 | 5765 | 37 | 35 | 34 | | | 2 | 3 | 04 | 742 |
| 2 | 2 | 710 | 3398 | 5724 | 5798 | 5872 | | 32 | 33 | 32 | 19 | 18 | 2 | 3 | 04 | 710 |
| 2 | 2 | 776 | 4934 | | | | | 35 | 35 | 34 | 33 | 35 | 2 | 6 | 00 | 776 |
| 2 | 2 | 758 | 5735 | 5841 | | | | 40 | 39 | 40 | 27 | 25 | 2 | 6 | 00 | 758 |
| 2 | 2 | 738 | 5105 | | | | | 37 | 35 | 33 | 32 | 32 | 2 | 6 | 04 | 738 |
| 2 | 2 | 712 | 3633 | 4934 | | | | 31 | 31 | 30 | 25 | 26 | 2 | 6 | 04 | 712 |
| 2 | 2 | 770 | 4899 | 4994 | 5002 | 5010 | 5018 | 35 | | | | | 3 | 0 | 00 | 770 |
| 2 | 2 | 740 | 4881 | 4994 | 5006 | 5014 | 5026 | 34 | | | | | 3 | 0 | 04 | 740 |
| 2 | 2 | 774 | 5552 | 5779 | 5849 | 5849 | 5851 | 38 | 36 | 34 | | | 3 | 3 | 00 | 774 |
| 2 | 2 | 746 | 4934 | 5938 | | | | 35 | 36 | 36 | 31 | 27 | 3 | 3 | 04 | 746 |
| 2 | 2 | 750 | 4894 | | | | | 34 | 34 | 34 | 32 | 31 | 3 | 6 | 00 | 750 |
| 2 | 2 | 764 | | | | | | 38 | 39 | 38 | 36 | 36 | 3 | 6 | 04 | 764 |

*BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

**BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

# FACTORIAL EXPERIMENT—DESIGN 1
# FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS
(Continued)

| | | | | | | | | INDEX DAY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | |
| 3 | 1 | 165 | | 4766 | 4782 | 4790 | 4806 | | | | | | 2 | 0 | 00 | 165 |
| 3 | 1 | 125 | | 3204 | 3397 | 3531 | 3633 | | | | | | 2 | 0 | 04 | 125 |
| 3 | 1 | 143 | 4846 | 4850 | 4854 | 4858 | 4862 | | | | | | 2 | 0 | 08 | 143 |
| 3 | 1 | 133 | 4813 | 4854 | 4874 | 4881 | 4883 | | | | | | 2 | 0 | 08 | 133 |
| 3 | 1 | 113 | 4774 | 4783 | 4798 | 4806 | 4813 | | | | | | 2 | 3 | 00 | 113 |
| 3 | 1 | 135 | 4842 | 4846 | 4850 | 4858 | 4862 | | | | | | 2 | 3 | 04 | 135 |
| 3 | 1 | 159 | | 4828 | 4891 | 4921 | 4946 | 23 | | | | | 2 | 3 | 08 | 159 |
| 3 | 1 | 127 | 4756 | 4850 | 4862 | 4874 | 4887 | | | | | | 2 | 6 | 00 | 127 |
| 3 | 1 | 157 | 4457 | 4918 | 4940 | 4946 | 4952 | 32 | | | | | 2 | 6 | 04 | 157 |
| 3 | 1 | 111 | 5715 | 5760 | 5793 | 5820 | 5858 | 39 | 37 | 37 | | | 2 | 6 | 08 | 111 |
| 3 | 1 | 137 | 4336 | 4874 | 4881 | 4883 | 4883 | | | | | | 3 | 0 | 00 | 137 |
| 3 | 1 | 163 | 4893 | 4914 | 4931 | 4934 | 4940 | 34 | | | | | 3 | 0 | 04 | 163 |
| 3 | 1 | 109 | 4904 | 4957 | 4990 | 4994 | 4998 | 35 | | | | | 3 | 0 | 08 | 109 |
| 3 | 1 | 147 | 4457 | 4828 | 4846 | 4854 | 4858 | | | | | | 3 | 3 | 00 | 147 |
| 3 | 1 | 107 | 4891 | 4921 | 4934 | 4940 | 4940 | 31 | | | | | 3 | 3 | 04 | 107 |
| 3 | 1 | 115 | | 4854 | 4899 | 4921 | 4940 | 25 | | | | | 3 | 3 | 04 | 115 |
| 3 | 1 | 129 | 5035 | 5179 | 5703 | 5741 | 5748 | 39 | 29 | 27 | | | 3 | 3 | 08 | 129 |
| 3 | 1 | 117 | 4874 | 4911 | 4934 | 4940 | 4940 | 31 | | | | | 3 | 6 | 00 | 117 |
| 3 | 1 | 131 | 5280 | 5664 | 5758 | 5762 | 5769 | 38 | 34 | 30 | | | 3 | 6 | 04 | 131 |
| 3 | 1 | 155 | 5538 | 5756 | 5804 | 5862 | | 38 | 36 | 34 | 19 | 16 | 3 | 6 | 08 | 155 |
| 3 | 1 | 119 | 4747 | 4874 | 4883 | 4887 | 4889 | | | | | | 4 | 0 | 00 | 119 |
| 3 | 1 | 141 | 4846 | 4883 | 4885 | 4889 | 4891 | | | | | | 4 | 0 | 04 | 141 |
| 3 | 1 | 153 | 4889 | 4931 | 4998 | 5022 | 5036 | 34 | | | | | 4 | 0 | 08 | 153 |
| 3 | 1 | 145 | 4901 | 4901 | 4904 | 4904 | 4904 | 35 | | | | | 4 | 3 | 00 | 145 |
| 3 | 1 | 151 | 4828 | 4921 | 4998 | 5030 | 5036 | 32 | | | | | 4 | 3 | 04 | 141 |
| 3 | 1 | 121 | 5056 | 5732 | 5765 | 5779 | 5786 | 36 | 34 | 33 | | | 4 | 3 | 08 | 121 |
| 3 | 1 | 161 | 4887 | 4990 | 5076 | 5159 | 5250 | 34 | | | | | 4 | 6 | 00 | 161 |
| 3 | 1 | 149 | 4870 | 4994 | 5030 | 5035 | 5035 | 33 | | | | | 4 | 6 | 00 | 149 |
| 3 | 1 | 123 | 5697 | 5812 | 5855 | | | 38 | 37 | 36 | 21 | 23 | 4 | 6 | 04 | 123 |
| 3 | 1 | 139 | | | | | | 40 | 39 | 38 | 38 | 36 | 4 | 6 | 08 | 139 |
| 3 | 2 | 166 | 3808 | 4774 | 4782 | 4798 | 4806 | | | | | | 2 | 0 | 00 | 166 |
| 3 | 2 | 126 | 3060 | 3204 | 3311 | 3469 | 3531 | | | | | | 2 | 0 | 04 | 126 |
| 3 | 2 | 144 | 4842 | 4850 | 4858 | 4862 | 4870 | | | | | | 2 | 0 | 08 | 144 |
| 3 | 2 | 134 | 4842 | 4850 | 4854 | 4862 | 4866 | | | | | | 2 | 0 | 08 | 134 |
| 3 | 2 | 114 | 4129 | 4478 | 4766 | 4842 | 4842 | | | | | | 2 | 3 | 00 | 114 |
| 3 | 2 | 136 | 4507 | 4774 | 4850 | 4866 | 4881 | | | | | | 2 | 3 | 04 | 136 |
| 3 | 2 | 160 | 4056 | 4846 | 4889 | 4901 | 4904 | 20 | | | | | 2 | 3 | 08 | 160 |
| 3 | 2 | 128 | 4842 | 4846 | 4850 | 4854 | 4858 | | | | | | 2 | 6 | 00 | 128 |
| 3 | 2 | 158 | 4056 | 4835 | 4885 | 4901 | 4908 | 20 | | | | | 2 | 6 | 04 | 158 |
| 3 | 2 | 112 | 4885 | 5547 | 5699 | 5736 | 5744 | 34 | 30 | 28 | | | 2 | 6 | 08 | 112 |
| 3 | 2 | 138 | 4056 | 4846 | 4851 | 4851 | 4854 | | | | | | 3 | 0 | 00 | 138 |
| 3 | 2 | 164 | 4858 | 4901 | 4901 | 4904 | 4904 | 28 | | | | | 3 | 0 | 04 | 164 |
| 3 | 2 | 110 | 4315 | 4904 | 4931 | 4946 | 4957 | 31 | | | | | 3 | 0 | 08 | 110 |
| 3 | 2 | 148 | 4846 | 4854 | 4862 | 4866 | 4874 | | | | | | 3 | 3 | 00 | 148 |
| 3 | 2 | 108 | 4056 | 4889 | 4918 | 4934 | 4934 | 28 | | | | | 3 | 3 | 04 | 108 |
| 3 | 2 | 116 | 4842 | 4901 | 4904 | 4908 | 4911 | 30 | | | | | 3 | 3 | 04 | 116 |
| 3 | 2 | 130 | 4897 | 4931 | 4979 | 5014 | 5046 | 34 | | | | | 3 | 3 | 08 | 130 |
| 3 | 2 | 118 | 4782 | 4901 | 4901 | 4904 | 4904 | 30 | | | | | 3 | 6 | 00 | 118 |
| 3 | 2 | 132 | 4813 | 4901 | 4974 | 4998 | 5010 | 30 | | | | | 3 | 6 | 04 | 132 |
| 3 | 2 | 156 | 4899 | 5100 | 5692 | 5760 | 5788 | 35 | 27 | 26 | | | 3 | 6 | 08 | 156 |
| 3 | 2 | 120 | 4129 | 4828 | 4846 | 4850 | 4854 | | | | | | 4 | 0 | 00 | 120 |
| 3 | 2 | 142 | 4798 | 4889 | 4901 | 4901 | 4901 | 25 | | | | | 4 | 0 | 04 | 142 |
| 3 | 2 | 154 | 4885 | 4918 | 4934 | 4940 | 4946 | 33 | | | | | 4 | 0 | 08 | 154 |
| 3 | 2 | 146 | 4874 | 4911 | 4934 | 4940 | 4946 | 32 | | | | | 4 | 3 | 00 | 146 |
| 3 | 2 | 152 | 4889 | 4934 | 4974 | 4994 | 4998 | 33 | | | | | 4 | 3 | 04 | 152 |
| 3 | 2 | 122 | 5253 | 5397 | 5701 | 5739 | 5746 | 39 | 31 | 30 | | | 4 | 3 | 08 | 122 |
| 3 | 2 | 162 | 4887 | 4974 | 5143 | 5220 | 5244 | 33 | | | | | 4 | 6 | 00 | 162 |
| 3 | 2 | 150 | 4887 | 4934 | 4952 | 4968 | 4979 | 33 | | | | | 4 | 6 | 00 | 150 |
| 3 | 2 | 124 | 5746 | 5783 | 5788 | 5793 | 5797 | 40 | 38 | 37 | | | 4 | 6 | 04 | 124 |
| 3 | 2 | 140 | 5784 | | | | | 38 | 37 | 37 | 31 | 33 | 4 | 6 | 08 | 140 |

# FACTORIAL EXPERIMENT—DESIGN 1
# FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS
# (Continued)

| | | | | | | | | INDEX DAY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | D1 | D2 | D3 | SECTION |
| | | | | | (x.xxx) | | | | | (x.x) | | | | (in.) | | |
| 4 | 1 | 633 | | | 3060 | 3060 | 3204 | | | | | | 3 | 0 | 04 | 633 |
| 4 | 1 | 607 | 4821 | 4846 | 4850 | 4854 | 4858 | | | | | | 3 | 0 | 08 | 607 |
| 4 | 1 | 571 | 4893 | 4904 | 4908 | 4911 | 4914 | 31 | | | | | 3 | 0 | 12 | 571 |
| 4 | 1 | 569 | 4889 | 4931 | 4985 | 5018 | 5061 | 33 | | | | | 3 | 0 | 12 | 569 |
| 4 | 1 | 599 | 4846 | 4854 | 4859 | 4866 | 4871 | | | | | | 3 | 3 | 04 | 599 |
| 4 | 1 | 573 | 4901 | 4904 | 4908 | 4911 | 4914 | 35 | | | | | 3 | 3 | 08 | 573 |
| 4 | 1 | 617 | 4963 | 5723 | 5755 | 5760 | 5765 | 37 | 35 | 33 | | | 3 | 3 | 12 | 617 |
| 4 | 1 | 585 | 4862 | 4891 | 4901 | 4901 | 4901 | 20 | | | | | 3 | 6 | 04 | 585 |
| 4 | 1 | 623 | 4881 | 4904 | 4918 | 4934 | 4963 | 30 | | | | | 3 | 6 | 08 | 623 |
| 4 | 1 | 601 | 4990 | 5704 | 5793 | 5887 | | 37 | 33 | 32 | 19 | 16 | 3 | 6 | 12 | 601 |
| 4 | 1 | 583 | 4883 | 4885 | 4887 | 4891 | 4893 | | | | | | 4 | 0 | 04 | 583 |
| 4 | 1 | 619 | 4931 | 4994 | 5014 | 5030 | 5030 | 38 | | | | | 4 | 0 | 08 | 619 |
| 4 | 1 | 603 | 4921 | 5026 | 5164 | 5585 | 5629 | 36 | 23 | | | | 4 | 0 | 12 | 603 |
| 4 | 1 | 627 | 4885 | 4925 | 4934 | 4940 | 4940 | 33 | | | | | 4 | 3 | 04 | 627 |
| 4 | 1 | 589 | 4924 | 4957 | 4990 | 4994 | 4998 | 37 | | | | | 4 | 3 | 08 | 589 |
| 4 | 1 | 597 | 4931 | 4998 | 5022 | 5035 | 5046 | 38 | | | | | 4 | 3 | 08 | 597 |
| 4 | 1 | 575 | 5647 | 5776 | 5818 | 5882 | 6045 | 41 | 37 | 35 | 20 | | 4 | 3 | 12 | 575 |
| 4 | 1 | 595 | 4889 | 4921 | 4934 | 4946 | 4952 | 33 | | | | | 4 | 6 | 04 | 595 |
| 4 | 1 | 577 | 5772 | 5826 | 5881 | 6007 | | 42 | 38 | 37 | 24 | 19 | 4 | 6 | 08 | 577 |
| 4 | 1 | 625 | 5593 | 5786 | 5832 | 5887 | | 40 | 38 | 34 | 19 | 19 | 4 | 6 | 12 | 625 |
| 4 | 1 | 605 | 4887 | 4934 | 4940 | 4940 | 4946 | 33 | | | | | 5 | 0 | 04 | 605 |
| 4 | 1 | 587 | 4990 | 5030 | 5046 | 5061 | 5076 | 39 | | | | | 5 | 0 | 08 | 587 |
| 4 | 1 | 621 | 5018 | 5154 | 5769 | 5806 | 5830 | 40 | 31 | 29 | | | 5 | 0 | 12 | 621 |
| 4 | 1 | 579 | 4963 | 5035 | 5076 | 5085 | 5095 | 38 | | | | | 5 | 3 | 04 | 579 |
| 4 | 1 | 631 | 4918 | 5123 | 5461 | 5658 | 5769 | 36 | 25 | 20 | | | 5 | 3 | 08 | 631 |
| 4 | 1 | 593 | 4974 | 5744 | 5760 | 5765 | 5772 | 37 | 34 | 33 | | | 5 | 3 | 12 | 593 |
| 4 | 1 | 629 | 5715 | 5755 | 5781 | 5797 | 5806 | 40 | 40 | 37 | | | 5 | 6 | 04 | 629 |
| 4 | 1 | 615 | 4974 | 5723 | 5765 | 5779 | 5786 | 37 | 33 | 32 | | | 5 | 6 | 04 | 615 |
| 4 | 1 | 591 | | | | | | 43 | 43 | 42 | 37 | 36 | 5 | 6 | 08 | 591 |
| 4 | 1 | 581 | 5007 | | | | | 39 | 35 | 34 | 32 | 33 | 5 | 6 | 12 | 581 |
| 4 | 2 | 634 | 3950 | 4056 | 4056 | 4094 | 4094 | | | | | | 3 | 0 | 04 | 634 |
| 4 | 2 | 608 | 4846 | 4850 | 4858 | 4862 | 4870 | | | | | | 3 | 0 | 08 | 608 |
| 4 | 2 | 572 | 4899 | 4952 | 4990 | 5006 | 5026 | 35 | | | | | 3 | 0 | 12 | 572 |
| 4 | 2 | 570 | 4904 | 4963 | 5006 | 5030 | 5061 | 35 | | | | | 3 | 0 | 12 | 570 |
| 4 | 2 | 600 | 4846 | 4854 | 4862 | 4870 | 4878 | | | | | | 3 | 3 | 04 | 600 |
| 4 | 2 | 574 | 4883 | 4918 | 4934 | 4934 | 4934 | 32 | | | | | 3 | 3 | 08 | 574 |
| 4 | 2 | 618 | 5080 | 5755 | 5765 | 5772 | 5779 | 37 | 34 | 33 | | | 3 | 3 | 12 | 618 |
| 4 | 2 | 586 | 4862 | 4895 | 4901 | 4904 | 4904 | 25 | | | | | 3 | 6 | 04 | 586 |
| 4 | 2 | 624 | 4821 | 4974 | 5138 | 5581 | 5755 | 32 | 22 | 19 | | | 3 | 6 | 08 | 624 |
| 4 | 2 | 602 | 5080 | 5718 | 5758 | 5772 | 5790 | 38 | 34 | 34 | | | 3 | 6 | 12 | 602 |
| 4 | 2 | 584 | 4901 | 4908 | 4911 | 4914 | 4921 | 35 | | | | | 4 | 0 | 04 | 584 |
| 4 | 2 | 620 | 4901 | 4990 | 4998 | 5002 | 5006 | 35 | | | | | 4 | 0 | 08 | 620 |
| 4 | 2 | 604 | 5310 | 5510 | 5755 | 5758 | 5760 | 39 | 32 | 28 | | | 4 | 0 | 12 | 604 |
| 4 | 2 | 628 | 4828 | 4940 | 4946 | 4957 | 4968 | 32 | | | | | 4 | 3 | 04 | 628 |
| 4 | 2 | 590 | 4931 | 4990 | 5035 | 5090 | 5179 | 38 | | | | | 4 | 3 | 08 | 590 |
| 4 | 2 | 598 | 4963 | 5022 | 5061 | 5109 | 5138 | 39 | | | | | 4 | 3 | 08 | 598 |
| 4 | 2 | 576 | 5671 | 5758 | 5795 | 5834 | 5901 | 39 | 37 | 35 | | | 4 | 3 | 12 | 576 |
| 4 | 2 | 596 | 4889 | 4957 | 5010 | 5056 | 5080 | 34 | | | | | 4 | 6 | 04 | 596 |
| 4 | 2 | 578 | 5383 | 5793 | 5855 | 5918 | | 40 | 35 | 32 | 21 | 20 | 4 | 6 | 08 | 578 |
| 4 | 2 | 626 | 5732 | 5989 | | | | 35 | 36 | 36 | 30 | 31 | 4 | 6 | 12 | 626 |
| 4 | 2 | 606 | 4921 | 4994 | 4998 | 5006 | 5010 | 36 | | | | | 5 | 0 | 04 | 606 |
| 4 | 2 | 588 | 4968 | 5056 | 5085 | 5090 | 5100 | 38 | | | | | 5 | 0 | 08 | 588 |
| 4 | 2 | 622 | 5071 | 5760 | 5799 | 5863 | 5929 | 37 | 34 | 33 | 18 | | 5 | 0 | 12 | 622 |
| 4 | 2 | 580 | 5014 | 5071 | 5123 | 5154 | 5179 | 38 | | | | | 5 | 3 | 04 | 580 |
| 4 | 2 | 632 | 4994 | 5336 | 5802 | 5848 | 5876 | 37 | 30 | 27 | | | 5 | 3 | 08 | 632 |
| 4 | 2 | 594 | 5154 | 5835 | 5911 | | | 39 | 34 | 32 | 26 | 22 | 5 | 3 | 12 | 594 |
| 4 | 2 | 630 | 5127 | 5779 | 5827 | 5851 | 5865 | 37 | 35 | 33 | | | 5 | 6 | 04 | 630 |
| 4 | 2 | 616 | 5367 | 5741 | 5772 | 5783 | 5793 | 38 | 35 | 33 | | | 5 | 6 | 04 | 616 |
| 4 | 2 | 592 | 5763 | 5901 | | | | 40 | 39 | 37 | 30 | 27 | 5 | 6 | 08 | 592 |
| 4 | 2 | 582 | 5194 | 5814 | | | | 39 | 34 | 33 | 29 | 27 | 5 | 6 | 12 | 582 |

## FACTORIAL EXPERIMENT—DESIGN 1
## FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS
## (Continued)

| | | | | | | | | INDEX DAY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | |
| 5 | 1 | 485 | 3716 | 4245 | 4806 | 4842 | 4846 | | | | | | 3 | 3 | 04 | 485 |
| 5 | 1 | 451 | 3808 | 4821 | 4846 | 4850 | 4858 | | | | | | 3 | 3 | 08 | 451 |
| 5 | 1 | 415 | 4899 | 4924 | 4934 | 4940 | 4940 | 34 | | | | | 3 | 3 | 12 | 415 |
| 5 | 1 | 429 | 4790 | 4854 | 4870 | 4881 | 4883 | | | | | | 3 | 3 | 12 | 429 |
| 5 | 1 | 449 | 4842 | 4846 | 4850 | 4854 | 4858 | | | | | | 3 | 6 | 04 | 449 |
| 5 | 1 | 419 | 4850 | 4854 | 4862 | 4870 | 4878 | | | | | | 3 | 6 | 08 | 419 |
| 5 | 1 | 487 | 4705 | 4846 | 4889 | 5461 | 5610 | 23 | 21 | | | | 3 | 6 | 12 | 487 |
| 5 | 1 | 413 | 4866 | 4893 | 4901 | 4904 | 4908 | 25 | | | | | 3 | 9 | 04 | 413 |
| 5 | 1 | 471 | 4846 | 4883 | 4897 | 4918 | 4940 | 23 | | | | | 3 | 9 | 08 | 471 |
| 5 | 1 | 441 | 4958 | 5538 | | | | 37 | 31 | 28 | 29 | 29 | 3 | 9 | 12 | 441 |
| 5 | 1 | 411 | 4006 | 4457 | 4828 | 4846 | 4850 | | | | | | 4 | 3 | 04 | 411 |
| 5 | 1 | 481 | 4889 | 4901 | 4904 | 4911 | 4914 | 28 | | | | | 4 | 3 | 08 | 481 |
| 5 | 1 | 443 | 4858 | 4901 | 4952 | 4994 | 5018 | 30 | | | | | 4 | 3 | 12 | 443 |
| 5 | 1 | 473 | 4846 | 4887 | 4901 | 4901 | 4904 | 23 | | | | | 4 | 6 | 04 | 473 |
| 5 | 1 | 455 | 4893 | 4931 | 4985 | 5022 | 5035 | 34 | | | | | 4 | 6 | 08 | 455 |
| 5 | 1 | 453 | 4883 | 4914 | 4957 | 4994 | 5010 | 32 | | | | | 4 | 6 | 08 | 453 |
| 5 | 1 | 425 | 4963 | 5280 | 5703 | 5767 | 5781 | 37 | 29 | 27 | | | 4 | 6 | 12 | 425 |
| 5 | 1 | 437 | 4866 | 4893 | 4918 | 4994 | 5006 | 28 | | | | | 4 | 9 | 04 | 437 |
| 5 | 1 | 417 | 4904 | 4998 | 5226 | 5571 | 5690 | 35 | 23 | 16 | | | 4 | 9 | 08 | 417 |
| 5 | 1 | 477 | 5030 | 5848 | 6041 | | | 38 | 36 | 33 | 29 | 24 | 4 | 9 | 12 | 477 |
| 5 | 1 | 439 | 4870 | 4883 | 4885 | 4889 | 4891 | | | | | | 5 | 3 | 04 | 439 |
| 5 | 1 | 421 | 4952 | 4994 | 5002 | 5006 | 5014 | 38 | | | | | 5 | 3 | 08 | 421 |
| 5 | 1 | 479 | 5026 | 5562 | 5786 | 5832 | 5878 | 41 | 31 | 29 | | | 5 | 3 | 12 | 479 |
| 5 | 1 | 423 | 4921 | 4968 | 4990 | 4998 | 5002 | 37 | | | | | 5 | 6 | 04 | 423 |
| 5 | 1 | 469 | 4908 | 5104 | 5748 | 5790 | 5813 | 36 | 28 | 26 | | | 5 | 6 | 08 | 469 |
| 5 | 1 | 445 | 5071 | 5777 | 5846 | 6041 | | 39 | 34 | 33 | 22 | 20 | 5 | 6 | 12 | 445 |
| 5 | 1 | 475 | 5647 | 5767 | 5783 | 5788 | 5795 | 40 | 37 | 35 | | | 5 | 9 | 04 | 475 |
| 5 | 1 | 483 | 5367 | 5603 | 5685 | 5703 | 5769 | 36 | 35 | 26 | | | 5 | 9 | 04 | 483 |
| 5 | 1 | 447 | 5768 | 5872 | | | | 40 | 39 | 37 | 29 | 27 | 5 | 9 | 08 | 447 |
| 5 | 1 | 427 | 5814 | | | | | 40 | 39 | 37 | 35 | 35 | 5 | 9 | 12 | 427 |
| 5 | 2 | 486 | 3204 | 3311 | 3397 | 3531 | 3585 | | | | | | 3 | 3 | 04 | 486 |
| 5 | 2 | 452 | 4813 | 4846 | 4854 | 4858 | 4866 | | | | | | 3 | 3 | 08 | 452 |
| 5 | 2 | 416 | 4858 | 4893 | 4928 | 4994 | 5056 | 28 | | | | | 3 | 3 | 12 | 416 |
| 5 | 2 | 430 | 4850 | 4889 | 4901 | 4908 | 4911 | 25 | | | | | 3 | 3 | 12 | 430 |
| 5 | 2 | 450 | 4846 | 4854 | 4858 | 4866 | 4874 | | | | | | 3 | 6 | 04 | 450 |
| 5 | 2 | 420 | 4828 | 4862 | 4881 | 4883 | 4883 | | | | | | 3 | 6 | 08 | 420 |
| 5 | 2 | 488 | 4885 | 5571 | 5661 | 5709 | 5744 | 34 | 31 | 26 | | | 3 | 6 | 12 | 488 |
| 5 | 2 | 414 | 4854 | 4893 | 4904 | 4908 | 4911 | 26 | | | | | 3 | 9 | 04 | 414 |
| 5 | 2 | 472 | 4850 | 4895 | 4931 | 4990 | 5026 | 29 | | | | | 3 | 9 | 08 | 472 |
| 5 | 2 | 442 | 4874 | 4968 | 5184 | 5767 | 5816 | 32 | 23 | 21 | | | 3 | 9 | 12 | 442 |
| 5 | 2 | 412 | 4478 | 4766 | 4790 | 4806 | 4821 | | | | | | 4 | 3 | 04 | 412 |
| 5 | 2 | 482 | 4862 | 4897 | 4904 | 4911 | 4914 | 26 | | | | | 4 | 3 | 08 | 482 |
| 5 | 2 | 444 | 4897 | 4946 | 4990 | 5002 | 5010 | 34 | | | | | 4 | 3 | 12 | 444 |
| 5 | 2 | 474 | 4895 | 4904 | 4908 | 4911 | 4914 | 30 | | | | | 4 | 6 | 04 | 474 |
| 5 | 2 | 456 | 4858 | 4901 | 4968 | 5056 | 5518 | 30 | 16 | | | | 4 | 6 | 08 | 456 |
| 5 | 2 | 454 | 4854 | 4985 | 5179 | 5260 | 5732 | 33 | 17 | 19 | | | 4 | 6 | 08 | 454 |
| 5 | 2 | 426 | 4885 | 4952 | 5260 | 5600 | 5739 | 33 | 24 | 19 | | | 4 | 6 | 12 | 426 |
| 5 | 2 | 438 | 4887 | 4928 | 4994 | 5026 | 5046 | 33 | | | | | 4 | 9 | 04 | 438 |
| 5 | 2 | 418 | 4899 | 4990 | 5090 | 5222 | 5603 | 35 | 19 | | | | 4 | 9 | 08 | 418 |
| 5 | 2 | 478 | 5030 | 5807 | | | | 38 | 36 | 33 | 26 | 30 | 4 | 9 | 12 | 478 |
| 5 | 2 | 440 | 4918 | 4940 | 4940 | 4946 | 4952 | 36 | | | | | 5 | 3 | 04 | 440 |
| 5 | 2 | 422 | 4921 | 4985 | 5030 | 5071 | 5110 | 37 | | | | | 5 | 3 | 08 | 422 |
| 5 | 2 | 480 | 4975 | 5336 | 5786 | 5846 | | 39 | 30 | 25 | 17 | 19 | 5 | 3 | 12 | 480 |
| 5 | 2 | 424 | 4914 | 4979 | 5010 | 5030 | 5051 | 37 | | | | | 5 | 6 | 04 | 424 |
| 5 | 2 | 470 | 4912 | 5066 | 5572 | 5850 | | 35 | 26 | 25 | 17 | 19 | 5 | 6 | 08 | 470 |
| 5 | 2 | 446 | 5516 | 5793 | 5883 | | | 39 | 35 | 34 | 24 | 24 | 5 | 6 | 12 | 446 |
| 5 | 2 | 476 | 5046 | 5295 | 5382 | 5593 | 5797 | 38 | 26 | 20 | | | 5 | 9 | 04 | 476 |
| 5 | 2 | 484 | 4901 | 5564 | 5664 | 5741 | 5779 | 35 | 32 | 26 | | | 5 | 9 | 04 | 484 |
| 5 | 2 | 448 | 5648 | 5809 | 5903 | | | 39 | 37 | 35 | 25 | 26 | 5 | 9 | 08 | 448 |
| 5 | 2 | 428 | 5749 | 5816 | | | | 40 | 37 | 37 | 31 | 32 | 5 | 9 | 12 | 428 |

# FACTORIAL EXPERIMENT—DESIGN 1
# FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS
# (Continued)

| | | | | | | | | INDEX DAY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | |
| 6 | 1 | 269 | 3848 | 4842 | 4846 | 4850 | 4854 | | | | | | 4 | 3 | 08 | 269 |
| 6 | 1 | 299 | 4934 | 5030 | 5123 | 5276 | 5571 | 37 | 18 | | | | 4 | 3 | 12 | 299 |
| 6 | 1 | 317 | 4901 | 4934 | 4990 | 5035 | 5127 | 35 | | | | | 4 | 3 | 16 | 317 |
| 6 | 1 | 329 | 4883 | 4908 | 4931 | 4946 | 4957 | 31 | | | | | 4 | 3 | 16 | 329 |
| 6 | 1 | 303 | 4858 | 4891 | 4904 | 4908 | 4914 | 26 | | | | | 4 | 6 | 08 | 303 |
| 6 | 1 | 323 | 4881 | 4895 | 4904 | 4911 | 4918 | 26 | | | | | 4 | 6 | 12 | 323 |
| 6 | 1 | 253 | 5006 | 5260 | 5654 | 5736 | 5741 | 38 | 31 | 25 | | | 4 | 6 | 16 | 253 |
| 6 | 1 | 321 | 4835 | 4889 | 4901 | 4908 | 4911 | 25 | | | | | 4 | 9 | 08 | 321 |
| 6 | 1 | 267 | 4914 | 4974 | 5035 | 5104 | 5547 | 36 | 16 | | | | 4 | 9 | 12 | 267 |
| 6 | 1 | 309 | 5751 | 5826 | 6010 | 6047 | | 40 | 37 | 36 | 26 | 20 | 4 | 9 | 16 | 309 |
| 6 | 1 | 319 | 4883 | 4885 | 4889 | 4891 | 4893 | | | | | | 5 | 3 | 08 | 319 |
| 6 | 1 | 261 | 4893 | 4928 | 4963 | 4990 | 5002 | 33 | | | | | 5 | 3 | 12 | 261 |
| 6 | 1 | 315 | 5010 | 5441 | 5697 | 5741 | 5758 | 39 | 31 | 28 | | | 5 | 3 | 16 | 315 |
| 6 | 1 | 259 | 4893 | 4928 | 4957 | 4990 | 4998 | 33 | | | | | 5 | 6 | 08 | 259 |
| 6 | 1 | 307 | 5018 | 5753 | 5767 | 5779 | 5802 | 40 | 36 | 35 | | | 5 | 6 | 12 | 307 |
| 6 | 1 | 305 | 4931 | 5014 | 5100 | 5272 | 5614 | 37 | 18 | | | | 5 | 6 | 12 | 305 |
| 6 | 1 | 327 | 5547 | 5769 | 5830 | 6035 | | 41 | 35 | 34 | 20 | 18 | 5 | 6 | 16 | 327 |
| 6 | 1 | 313 | 4952 | 5260 | 5644 | 5729 | 5774 | 37 | 28 | 25 | | | 5 | 9 | 08 | 313 |
| 6 | 1 | 331 | 4974 | 5226 | 5746 | 5813 | 5856 | 37 | 28 | 28 | | | 5 | 9 | 12 | 331 |
| 6 | 1 | 265 | 5826 | | | | | 41 | 40 | 39 | 35 | 33 | 5 | 9 | 16 | 265 |
| 6 | 1 | 297 | 4918 | 4994 | 5046 | 5109 | 5149 | 36 | | | | | 6 | 3 | 08 | 297 |
| 6 | 1 | 335 | 4883 | 4924 | 4979 | 5010 | 5051 | 33 | | | | | 6 | 3 | 12 | 335 |
| 6 | 1 | 255 | 5066 | 5637 | 5741 | 5774 | 5797 | 41 | 31 | 30 | | | 6 | 3 | 16 | 255 |
| 6 | 1 | 325 | 4990 | 5002 | 5010 | 5018 | 5026 | 40 | | | | | 6 | 6 | 08 | 325 |
| 6 | 1 | 257 | 5011 | 5123 | 5853 | 5938 | | 42 | 32 | 32 | 22 | 16 | 6 | 6 | 12 | 257 |
| 6 | 1 | 301 | 5763 | 5862 | | | | 41 | 36 | 37 | 29 | 32 | 6 | 6 | 16 | 301 |
| 6 | 1 | 263 | 4994 | 5109 | 5709 | 5781 | 5795 | 39 | 28 | 26 | | | 6 | 9 | 08 | 263 |
| 6 | 1 | 271 | 5352 | 5763 | 5848 | | | 42 | 35 | 33 | 23 | 21 | 6 | 9 | 08 | 271 |
| 6 | 1 | 311 | 5222 | 5737 | 5826 | | | 41 | 33 | 34 | 26 | 28 | 6 | 9 | 12 | 311 |
| 6 | 1 | 333 | 5336 | 5704 | | | | 40 | 34 | 31 | 26 | 27 | 6 | 9 | 16 | 333 |
| 6 | 2 | 270 | 4813 | 4870 | 4887 | 4893 | 4901 | 15 | | | | | 4 | 3 | 08 | 270 |
| 6 | 2 | 300 | 5030 | 5600 | 5674 | 5718 | 5758 | 39 | 33 | 27 | | | 4 | 3 | 12 | 300 |
| 6 | 2 | 318 | 5118 | 5729 | 5760 | 5774 | 5793 | 40 | 34 | 34 | | | 4 | 3 | 16 | 318 |
| 6 | 2 | 330 | 4968 | 4994 | 5002 | 5010 | 5018 | 39 | | | | | 4 | 3 | 16 | 330 |
| 6 | 2 | 304 | 4946 | 5006 | 5056 | 5104 | 5571 | 39 | 15 | | | | 4 | 6 | 08 | 304 |
| 6 | 2 | 324 | 4889 | 4914 | 4946 | 4979 | 4998 | 32 | | | | | 4 | 6 | 12 | 324 |
| 6 | 2 | 254 | 4924 | 5018 | 5336 | 5779 | 5793 | 37 | 24 | 24 | | | 4 | 6 | 16 | 254 |
| 6 | 2 | 322 | 4908 | 5002 | 5076 | 5226 | 5383 | 35 | 20 | | | | 4 | 9 | 08 | 322 |
| 6 | 2 | 268 | 4928 | 5040 | 5367 | 5790 | 5867 | 37 | 25 | 25 | | | 4 | 9 | 12 | 268 |
| 6 | 2 | 310 | 5802 | 5872 | | | | 41 | 39 | 39 | 29 | 32 | 4 | 9 | 16 | 310 |
| 6 | 2 | 320 | 4990 | 4998 | 5002 | 5010 | 5014 | 38 | | | | | 5 | 3 | 08 | 320 |
| 6 | 2 | 262 | 4924 | 4998 | 5061 | 5127 | 5622 | 37 | 16 | | | | 5 | 3 | 12 | 262 |
| 6 | 2 | 316 | 4990 | 5734 | 5772 | 5793 | 5813 | 38 | 33 | 32 | | | 5 | 3 | 16 | 316 |
| 6 | 2 | 260 | 4897 | 4990 | 5002 | 5010 | 5022 | 35 | | | | | 5 | 6 | 08 | 260 |
| 6 | 2 | 308 | 4994 | 5179 | 5703 | 5765 | 5774 | 39 | 29 | 27 | | | 5 | 6 | 12 | 308 |
| 6 | 2 | 306 | 5014 | 5585 | 5779 | 5786 | 5790 | 40 | 31 | 29 | | | 5 | 6 | 12 | 306 |
| 6 | 2 | 328 | 5026 | 5367 | 5760 | 5851 | 5908 | 40 | 30 | 29 | 15 | | 5 | 6 | 16 | 328 |
| 6 | 2 | 314 | 5109 | 5751 | 5774 | 5786 | 5795 | 39 | 35 | 34 | | | 5 | 9 | 08 | 314 |
| 6 | 2 | 332 | 5014 | 5244 | 5432 | 5797 | 5858 | 39 | 28 | 26 | | | 5 | 9 | 12 | 332 |
| 6 | 2 | 266 | 5756 | | | | | 39 | 38 | 37 | 34 | 35 | 5 | 9 | 16 | 266 |
| 6 | 2 | 298 | 5002 | 5100 | 5758 | 5760 | 5762 | 41 | 29 | 29 | | | 6 | 3 | 08 | 298 |
| 6 | 2 | 336 | 4842 | 4946 | 5046 | 5415 | 5685 | 33 | 21 | 18 | | | 6 | 3 | 12 | 336 |
| 6 | 2 | 256 | 5051 | 5852 | 6041 | | | 40 | 36 | 34 | 26 | 24 | 6 | 3 | 16 | 256 |
| 6 | 2 | 326 | 4968 | 5026 | 5080 | 5169 | 5397 | 42 | 15 | | | | 6 | 6 | 08 | 326 |
| 6 | 2 | 258 | 5046 | 5910 | | | | 40 | 36 | 34 | 30 | 30 | 6 | 6 | 12 | 258 |
| 6 | 2 | 302 | | | | | | 40 | 40 | 39 | 38 | 39 | 6 | 6 | 16 | 302 |
| 6 | 2 | 264 | 5100 | 5775 | | | | 39 | 34 | 35 | 26 | 26 | 6 | 9 | 08 | 264 |
| 6 | 2 | 272 | 5260 | 5735 | 5791 | 5968 | | 40 | 34 | 34 | 21 | 17 | 6 | 9 | 08 | 272 |
| 6 | 2 | 312 | 5798 | 5879 | | | | 40 | 38 | 38 | 29 | 26 | 6 | 9 | 12 | 312 |
| 6 | 2 | 334 | 5865 | | | | | 40 | 38 | 37 | 35 | 36 | 6 | 9 | 16 | 334 |

## PAVED SHOULDER EXPERIMENT—DESIGN 2
## FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS

| LOOP | LANE | SECTION | SUBSECTION* | SERVICEABILITY TREND LEVEL | | | | | INDEX DAY | | | | | STRUCTURE DESIGN | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | |
| | | | | | | | | | 75 | 290 | 401 | 944 | 1226 | | | |
| | | | | | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | | | |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | | | |
| | | | | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL** (x.xxx) | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** (x.x) | | | | | D1 | D2 (in.) | D3 |
| 3 | 1 | 177 | 1 | 4222 | 4403 | 4494 | 4570 | 4635 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 177 | 2 | 4126 | 4494 | 4717 | 4764 | 4777 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 177 | 3 | 4093 | 4121 | 4258 | 4450 | 4664 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 177 | 4 | 4139 | 4351 | 4494 | 4534 | 4664 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 179 | 1 | 4112 | 4322 | 4450 | 4494 | 4534 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 179 | 2 | 4126 | 4351 | 4494 | 4635 | 4691 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 179 | 3 | 4103 | 4351 | 4534 | 4741 | 4823 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 179 | 4 | | 4139 | 4450 | 4494 | 4570 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 175 | 1 | 4812 | 5042 | 5155 | 5213 | 5218 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 175 | 2 | 4865 | 5031 | 5123 | 5165 | 5175 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 175 | 3 | 4933 | 5112 | 5204 | 5420 | 5562 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 175 | 4 | 4933 | 5175 | 5455 | 5587 | 5610 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 183 | 1 | 3936 | 4960 | 5134 | 5233 | 5549 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 183 | 2 | 5150 | 5372 | 5599 | 5627 | 5636 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 183 | 3 | 5175 | 5262 | 5390 | 5624 | 5631 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 183 | 4 | 2954 | 4777 | 4960 | 5112 | 5219 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 173 | 1 | 4890 | 5053 | 5112 | 5123 | 5134 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 173 | 2 | 4905 | 5053 | 5112 | 5134 | 5155 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 173 | 3 | 4890 | 5053 | 5112 | 5129 | 5134 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 173 | 4 | 4865 | 5042 | 5112 | 5118 | 5134 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 181 | 1 | 5020 | 5093 | 5118 | 5123 | 5129 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 181 | 2 | 5118 | 5165 | 5170 | 5180 | 5185 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 181 | 3 | 5165 | 5170 | 5175 | 5180 | 5185 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 181 | 4 | 5020 | 5074 | 5118 | 5134 | 5145 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 178 | 1 | 3732 | 4033 | 4037 | 4037 | 4037 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 178 | 2 | 3846 | 4033 | 4063 | 4082 | 4093 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 178 | 3 | 3908 | 4042 | 4071 | 4079 | 4082 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 178 | 4 | 3255 | 3352 | 3431 | 3498 | 3607 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 180 | 1 | 3694 | 3987 | 4059 | 4077 | 4082 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 180 | 2 | 3694 | 4033 | 4033 | 4037 | 4037 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 180 | 3 | 3811 | 3987 | 4055 | 4079 | 4093 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 180 | 4 | 4077 | 4093 | 4258 | 4450 | 4494 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 176 | 1 | 3130 | 4081 | 4664 | 4764 | 4777 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 176 | 2 | 4075 | 4789 | 4875 | 4890 | 4890 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 176 | 3 | 4534 | 4834 | 4875 | 4890 | 4905 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 176 | 4 | 4403 | 4801 | 4875 | 4890 | 4890 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 184 | 1 | | 3732 | 4664 | 4875 | 4890 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 184 | 2 | 5008 | 5155 | 5213 | 5262 | 5286 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 184 | 3 | 4570 | 4890 | 4997 | 5042 | 5093 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 184 | 4 | 4084 | 4664 | 4845 | 4960 | 5020 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 174 | 1 | | 4764 | 4875 | 4890 | 4890 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 174 | 2 | 4604 | 4875 | 4985 | 5008 | 5020 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 174 | 3 | 4789 | 4933 | 5053 | 5112 | 5123 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 174 | 4 | 4789 | 4919 | 5008 | 5020 | 5042 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 182 | 1 | 4570 | 4875 | 4960 | 5020 | 5031 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 182 | 2 | 4905 | 5020 | 5042 | 5063 | 5074 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 182 | 3 | 4741 | 4960 | 5008 | 5020 | 5031 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 182 | 4 | 5008 | 5020 | 5031 | 5053 | 5074 | | | | | | 4 | 3 | 00 |

*AVERAGE WIDTH OF PAVED SHOULDER, SUBSECTION 1 - 1 FT; SUBSECTION 2 - 3 FT; SUBSECTION 3 - 5 FT; SUBSECTION 4 - 7 FT.

**BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

***BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

## PAVED SHOULDER EXPERIMENT—DESIGN 2
## FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS
## (Continued)

| | | | | | | | | | INDEX DAY | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | |
| | | | | | | | | | 75 | 290 | 401 | 944 | 1226 | | | |
| | | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | | | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** | | | | | $D_1$ | $D_2$ | $D_3$ |
| | | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | |
| 4 | 1 | 637 | 1 | 3987 | 4093 | 4139 | 4450 | 4450 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 637 | 2 | 4450 | 4450 | 4450 | 4450 | 4494 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 637 | 3 | 4067 | 4450 | 4450 | 4450 | 4494 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 637 | 4 | 4075 | 4256 | 4322 | 4403 | 4450 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 609 | 1 | 3130 | 3352 | 3431 | 3498 | 3555 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 609 | 2 | 4093 | 4322 | 4450 | 4450 | 4450 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 609 | 3 | 4037 | 4093 | 4112 | 4322 | 4450 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 609 | 4 | 3878 | 4082 | 4093 | 4351 | 4494 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 635 | 1 | 4875 | 5020 | 5093 | 5134 | 5134 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 635 | 2 | 4801 | 4960 | 5074 | 5112 | 5113 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 635 | 3 | 4855 | 5042 | 5103 | 5123 | 5134 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 635 | 4 | 4947 | 5053 | 5134 | 5145 | 5160 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 611 | 1 | 4777 | 4801 | 4823 | 4845 | 4855 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 611 | 2 | 4777 | 4919 | 5008 | 5008 | 5020 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 611 | 3 | 4741 | 4890 | 4985 | 5008 | 5008 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 611 | 4 | 4789 | 4845 | 4875 | 4875 | 4890 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 639 | 1 | 5112 | 5123 | 5129 | 5134 | 5140 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 639 | 2 | 5145 | 5160 | 5160 | 5160 | 5160 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 639 | 3 | 5123 | 5145 | 5185 | 5190 | 5190 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 639 | 4 | | 4789 | 5031 | 5112 | 5118 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 613 | 1 | 4997 | 5112 | 5118 | 5118 | 5123 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 613 | 2 | 5112 | 5123 | 5129 | 5140 | 5145 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 613 | 3 | 4947 | 5112 | 5118 | 5123 | 5129 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 613 | 4 | 4919 | 5020 | 5053 | 5074 | 5093 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 638 | 1 | 4183 | 4494 | 4717 | 4764 | 4764 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 638 | 2 | 4691 | 4691 | 4717 | 4717 | 4741 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 638 | 3 | 4604 | 4635 | 4635 | 4635 | 4664 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 638 | 4 | 4033 | 4494 | 4494 | 4534 | 4534 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 610 | 1 | 3255 | 3352 | 3431 | 3498 | 3556 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 610 | 2 | 3255 | 3352 | 3498 | 3556 | 3556 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 610 | 3 | 3556 | 3694 | 3773 | 3811 | 3811 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 610 | 4 | 3255 | 3352 | 3431 | 3498 | 3556 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 636 | 1 | 5008 | 5020 | 5031 | 5042 | 5053 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 636 | 2 | 5020 | 5053 | 5074 | 5084 | 5093 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 636 | 3 | 4985 | 5112 | 5145 | 5170 | 5185 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 636 | 4 | 4834 | 5020 | 5140 | 5170 | 5175 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 612 | 1 | 4947 | 5008 | 5020 | 5031 | 5031 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 612 | 2 | 5008 | 5020 | 5042 | 5053 | 5063 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 612 | 3 | 5020 | 5053 | 5074 | 5103 | 5118 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 612 | 4 | 5008 | 5042 | 5063 | 5084 | 5103 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 640 | 1 | 5093 | 5165 | 5175 | 5180 | 5185 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 640 | 2 | 5123 | 5134 | 5145 | 5155 | 5170 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 640 | 3 | 4919 | 5134 | 5155 | 5170 | 5170 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 640 | 4 | | 4985 | 5165 | 5170 | 5170 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 614 | 1 | 5042 | 5118 | 5123 | 5129 | 5140 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 614 | 2 | 4789 | 5123 | 5140 | 5155 | 5160 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 614 | 3 | 5118 | 5129 | 5145 | 5155 | 5160 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 614 | 4 | 4933 | 5118 | 5123 | 5129 | 5134 | | | | | | 5 | 0 | 04 |

# PAVED SHOULDER EXPERIMENT—DESIGN 2
# FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS
# (Continued)

| | | | | | | | | | INDEX DAY | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | |
| | | | | | | | | | 75 | 290 | 401 | 944 | 1226 | | | |
| | | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | | | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** | | | | | D1 | D2 | D3 |
| | | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | |
| 5 | 1 | 435 | 1 | 4139 | 4403 | 4494 | 4570 | 4604 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 435 | 2 | 4322 | 4494 | 4534 | 4570 | 4604 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 435 | 3 | 4131 | 4322 | 4450 | 4494 | 4494 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 435 | 4 | 3773 | 4093 | 4112 | 4258 | 4378 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 407 | 1 | 3811 | 4042 | 4086 | 4139 | 4258 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 407 | 2 | 4117 | 4322 | 4494 | 4635 | 4764 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 407 | 3 | 4079 | 4139 | 4403 | 4494 | 4494 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 407 | 4 | 4183 | 4378 | 4534 | 4635 | 4741 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 431 | 1 | 4351 | 4664 | 4801 | 4865 | 4890 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 431 | 2 | 4403 | 4741 | 4801 | 4855 | 4875 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 431 | 3 | 4427 | 4717 | 4801 | 4834 | 4865 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 431 | 4 | 4117 | 4322 | 4534 | 4717 | 4812 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 405 | 1 | 4093 | 4139 | 4494 | 4635 | 4717 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 405 | 2 | 4093 | 4139 | 4291 | 4427 | 4534 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 405 | 3 | 3607 | 4112 | 4494 | 4741 | 4777 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 405 | 4 | 4112 | 4291 | 4534 | 4664 | 4764 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 433 | 1 | 4865 | 5031 | 5103 | 5118 | 5123 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 433 | 2 | 5031 | 5084 | 5112 | 5118 | 5123 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 433 | 3 | 5093 | 5118 | 5123 | 5129 | 5134 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 433 | 4 | 4801 | 5008 | 5118 | 5123 | 5134 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 409 | 1 | 4905 | 5020 | 5053 | 5084 | 5103 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 409 | 2 | 5053 | 5118 | 5123 | 5129 | 5134 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 409 | 3 | 4604 | 4947 | 5074 | 5112 | 5118 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 409 | 4 | 4855 | 5063 | 5112 | 5118 | 5123 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 436 | 1 | 3130 | 3255 | 3431 | 3498 | 3556 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 436 | 2 | | 3130 | 3255 | 3431 | 3498 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 436 | 3 | | 3255 | 3498 | 3694 | 3773 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 436 | 4 | | | 3255 | 3431 | 3556 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 408 | 1 | 3255 | 3431 | 3498 | 3607 | 3694 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 408 | 2 | 3352 | 3498 | 3556 | 3653 | 3732 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 408 | 3 | 3352 | 3498 | 3556 | 3653 | 3732 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 408 | 4 | 3431 | 3556 | 3653 | 3773 | 3773 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 432 | 1 | 4351 | 4764 | 4855 | 4875 | 4890 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 432 | 2 | 4050 | 4494 | 4691 | 4789 | 4823 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 432 | 3 | 4131 | 4570 | 4717 | 4789 | 4823 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 432 | 4 | 4103 | 4322 | 4635 | 4764 | 4834 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 406 | 1 | 4183 | 4691 | 4834 | 4875 | 4890 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 406 | 2 | 4075 | 4107 | 4378 | 4741 | 4834 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 406 | 3 | 4183 | 4741 | 4823 | 4890 | 4890 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 406 | 4 | 4042 | 4093 | 4139 | 4534 | 4664 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 434 | 1 | 4855 | 5020 | 5031 | 5042 | 5053 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 434 | 2 | 4960 | 5020 | 5031 | 5042 | 5053 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 434 | 3 | 4823 | 5020 | 5042 | 5053 | 5074 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 434 | 4 | 4378 | 4865 | 5074 | 5118 | 5123 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 410 | 1 | 4947 | 5042 | 5084 | 5140 | 5145 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 410 | 2 | 5112 | 5118 | 5123 | 5129 | 5134 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 410 | 3 | 5020 | 5031 | 5053 | 5063 | 5084 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 410 | 4 | 5008 | 5031 | 5042 | 5063 | 5084 | | | | | | 5 | 3 | 04 |

# PAVED SHOULDER EXPERIMENT—DESIGN 2
# FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS
# (Continued)

| | | | | | | | | | INDEX DAY | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | |
| | | | | | | | | | 75 | 290 | 401 | 944 | 1226 | | | |
| | | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | | | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** | | | | | $D_1$ | $D_2$ | $D_3$ |
| | | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | |
| 6 | 1 | 291 | 1 | 4450 | 4494 | 4494 | 4534 | 4570 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 291 | 2 | 4450 | 4494 | 4534 | 4570 | 4570 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 291 | 3 | 4075 | 4494 | 4534 | 4570 | 4604 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 291 | 4 | 4494 | 4534 | 4570 | 4604 | 4635 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 275 | 1 | 4570 | 4664 | 4691 | 4691 | 4717 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 275 | 2 | 4691 | 4691 | 4717 | 4717 | 4741 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 275 | 3 | 4691 | 4691 | 4717 | 4717 | 4741 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 275 | 4 | 4450 | 4534 | 4604 | 4664 | 4691 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 293 | 1 | 5103 | 5204 | 5347 | 5507 | 5603 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 293 | 2 | 5223 | 5564 | 5620 | 5636 | 5646 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 293 | 3 | 5589 | 5650 | 5678 | 5801 | 5824 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 293 | 4 | 5123 | 5218 | 5311 | 5479 | 5626 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 273 | 1 | 4875 | 5008 | 5118 | 5123 | 5262 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 273 | 2 | 4960 | 5093 | 5150 | 5190 | 5248 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 273 | 3 | 4855 | 4960 | 5042 | 5112 | 5134 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 273 | 4 | 4855 | 4972 | 5074 | 5155 | 5233 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 295 | 1 | 4905 | 5020 | 5103 | 5140 | 5155 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 295 | 2 | 5118 | 5129 | 5134 | 5145 | 5150 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 295 | 3 | 4972 | 5084 | 5140 | 5155 | 5213 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 295 | 4 | 4947 | 5074 | 5134 | 5150 | 5160 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 277 | 1 | 4933 | 5063 | 5112 | 5123 | 5134 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 277 | 2 | 5042 | 5093 | 5118 | 5123 | 5134 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 277 | 3 | 4997 | 5093 | 5118 | 5134 | 5150 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 277 | 4 | 4947 | 5074 | 5118 | 5134 | 5145 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 292 | 1 | 4855 | 4875 | 4890 | 4905 | 4919 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 292 | 2 | 4741 | 4845 | 4875 | 4890 | 4890 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 292 | 3 | 4823 | 4855 | 4875 | 4890 | 4890 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 292 | 4 | 4717 | 4875 | 4890 | 4905 | 4919 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 276 | 1 | 4427 | 4764 | 4834 | 4875 | 4890 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 276 | 2 | 4635 | 4801 | 4865 | 4875 | 4890 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 276 | 3 | 4450 | 4664 | 4741 | 4789 | 4812 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 276 | 4 | 4450 | 4664 | 4764 | 4789 | 4812 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 294 | 1 | | | | | | 43 | 37 | 36 | 30 | 30 | 4 | 3 | 16 |
| 6 | 2 | 294 | 2 | | | | | | 43 | 39 | 40 | 37 | 37 | 4 | 3 | 16 |
| 6 | 2 | 294 | 3 | | | | | | 40 | 36 | 35 | 34 | 25 | 4 | 3 | 16 |
| 6 | 2 | 294 | 4 | 4823 | 5218 | 5631 | 5862 | 5902 | | | | | | 4 | 3 | 16 |
| 6 | 2 | 274 | 1 | 5008 | 5338 | 5746 | 5862 | 5878 | | | | | | 4 | 3 | 16 |
| 6 | 2 | 274 | 2 | 5008 | 5129 | 5204 | 5586 | 5631 | | | | | | 4 | 3 | 16 |
| 6 | 2 | 274 | 3 | 4997 | 5155 | 5592 | 5702 | 5746 | | | | | | 4 | 3 | 16 |
| 6 | 2 | 274 | 4 | 4845 | 5008 | 5118 | 5150 | 5165 | | | | | | 4 | 3 | 16 |
| 6 | 2 | 296 | 1 | 5008 | 5118 | 5129 | 5134 | 5145 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 296 | 2 | 5042 | 5145 | 5204 | 5274 | 5596 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 296 | 3 | 5093 | 5165 | 5228 | 5586 | 5621 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 296 | 4 | 4997 | 5145 | 5218 | 5306 | 5628 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 278 | 1 | 4960 | 5118 | 5175 | 5213 | 5218 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 278 | 2 | 5031 | 5123 | 5170 | 5190 | 5262 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 278 | 3 | 5103 | 5194 | 5248 | 5320 | 5338 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 278 | 4 | 5031 | 5155 | 5233 | 5630 | 5724 | | | | | | 6 | 3 | 08 |

# PAVED SHOULDER EXPERIMENT—DESIGN 2
# FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS

| | | | | SERVICEABILITY TREND LEVEL | | | | | INDEX DAY | | | | | STRUCTURE DESIGN | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 11 | 22 | 33 | 44 | 55 | | | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | |
| | | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | |
| | | | | | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | | | |
| | | | | | | | | | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** | | | | | $D_1$ | $D_2$ | $D_3$ |
| | | | | (x.xxx) | | | | | (x.x) | | | | | | (in.) | |
| 3 | 1 | 177 | 1 | 4782 | 4828 | 4846 | 4854 | 4862 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 177 | 2 | 4737 | 4846 | 4874 | 4881 | 4883 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 177 | 3 | 4609 | 4726 | 4790 | 4842 | 4866 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 177 | 4 | 4766 | 4813 | 4846 | 4850 | 4866 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 179 | 1 | 4705 | 4806 | 4842 | 4846 | 4850 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 179 | 2 | 4737 | 4813 | 4846 | 4862 | 4870 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 179 | 3 | 4683 | 4813 | 4850 | 4878 | 4891 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 179 | 4 | | 4766 | 4842 | 4846 | 4854 | | | | | | 2 | 3 | 00 |
| 3 | 1 | 175 | 1 | 4889 | 4952 | 5022 | 5080 | 5085 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 175 | 2 | 4899 | 4946 | 4998 | 5030 | 5040 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 175 | 3 | 4914 | 4990 | 5071 | 5314 | 5543 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 175 | 4 | 4914 | 5040 | 5358 | 5583 | 5661 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 183 | 1 | 3950 | 4921 | 5006 | 5100 | 5523 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 183 | 2 | 5018 | 5260 | 5633 | 5709 | 5734 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 183 | 3 | 5040 | 5127 | 5280 | 5697 | 5732 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 183 | 4 | 2845 | 4883 | 4921 | 4990 | 5085 | | | | | | 2 | 3 | 08 |
| 3 | 1 | 173 | 1 | 4904 | 4957 | 4990 | 4998 | 5006 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 173 | 2 | 4908 | 4957 | 4990 | 5006 | 5022 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 173 | 3 | 4904 | 4957 | 4990 | 5002 | 5006 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 173 | 4 | 4899 | 4952 | 4990 | 4994 | 5006 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 181 | 1 | 4940 | 4979 | 4994 | 4998 | 5002 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 181 | 2 | 4994 | 5030 | 5035 | 5046 | 5051 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 181 | 3 | 5030 | 5035 | 5040 | 5046 | 5051 | | | | | | 4 | 3 | 00 |
| 3 | 1 | 181 | 4 | 4940 | 4968 | 4994 | 5006 | 5014 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 178 | 1 | 3716 | 4056 | 4094 | 4094 | 4094 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 178 | 2 | 3848 | 4056 | 4269 | 4389 | 4457 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 178 | 3 | 3919 | 4129 | 4315 | 4363 | 4389 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 178 | 4 | 3204 | 3311 | 3397 | 3469 | 3585 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 180 | 1 | 3676 | 4006 | 4245 | 4350 | 4389 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 180 | 2 | 3676 | 4056 | 4056 | 4094 | 4094 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 180 | 3 | 3808 | 4006 | 4218 | 4363 | 4457 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 180 | 4 | 4350 | 4630 | 4790 | 4842 | 4846 | | | | | | 2 | 3 | 00 |
| 3 | 2 | 176 | 1 | 2845 | 4376 | 4866 | 4881 | 4883 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 176 | 2 | 4336 | 4885 | 4901 | 4904 | 4904 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 176 | 3 | 4850 | 4893 | 4901 | 4904 | 4908 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 176 | 4 | 4828 | 4887 | 4901 | 4904 | 4904 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 184 | 1 | | 3716 | 4866 | 4901 | 4904 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 184 | 2 | 4934 | 5022 | 5080 | 5127 | 5159 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 184 | 3 | 4854 | 4904 | 4931 | 4952 | 4979 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 184 | 4 | 4401 | 4866 | 4895 | 4921 | 4940 | | | | | | 2 | 3 | 08 |
| 3 | 2 | 174 | 1 | | 4881 | 4901 | 4904 | 4904 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 174 | 2 | 4858 | 4901 | 4928 | 4934 | 4940 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 174 | 3 | 4885 | 4914 | 4957 | 4990 | 4998 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 174 | 4 | 4885 | 4911 | 4934 | 4940 | 4952 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 182 | 1 | 4854 | 4901 | 4921 | 4940 | 4946 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 182 | 2 | 4908 | 4940 | 4952 | 4963 | 4968 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 182 | 3 | 4878 | 4921 | 4934 | 4940 | 4946 | | | | | | 4 | 3 | 00 |
| 3 | 2 | 182 | 4 | 4934 | 4940 | 4946 | 4957 | 4968 | | | | | | 4 | 3 | 00 |

*AVERAGE WIDTH OF PAVED SHOULDER, SUBSECTION 1 - 1 FT; SUBSECTION 2 - 3 FT; SUBSECTION 3 - 5 FT; SUBSECTION 4 - 7 FT.

**BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

***BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

# PAVED SHOULDER EXPERIMENT—DESIGN 2
# FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS
(Continued)

| | | | | | | | | | INDEX DAY<br>11 | 22 | 33 | 44 | 55 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS<br>80 | 233 | 445 | 807 | 1114 | | | |
| | | | | SERVICEABILITY TREND LEVEL<br>3.5 | 3.0 | 2.5 | 2.0 | 1.5 | LOG APPLICATIONS THROUGH INDEX DAY<br>4.901 | 5.368 | 5.648 | 5.907 | 6.047 | STRUCTURE DESIGN | | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** | | | | | $D_1$ | $D_2$ | $D_3$ |
| | | | | (x.xxx) | | | | | (x.x) | | | | | | (in.) | |
| 4 | 1 | 637 | 1 | 4006 | 4516 | 4766 | 4842 | 4842 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 637 | 2 | 4842 | 4842 | 4842 | 4842 | 4846 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 637 | 3 | 4293 | 4842 | 4842 | 4842 | 4846 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 637 | 4 | 4336 | 4790 | 4806 | 4828 | 4842 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 609 | 1 | 3060 | 3311 | 3397 | 3469 | 3531 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 609 | 2 | 4659 | 4806 | 4842 | 4842 | 4842 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 609 | 3 | 4094 | 4507 | 4705 | 4806 | 4842 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 609 | 4 | 3885 | 4389 | 4609 | 4813 | 4846 | | | | | | 3 | 0 | 04 |
| 4 | 1 | 635 | 1 | 4901 | 4940 | 4979 | 5006 | 5006 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 635 | 2 | 4887 | 4921 | 4968 | 4990 | 4994 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 635 | 3 | 4897 | 4952 | 4985 | 4998 | 5006 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 635 | 4 | 4918 | 4957 | 5006 | 5014 | 5026 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 611 | 1 | 4883 | 4887 | 4891 | 4895 | 4897 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 611 | 2 | 4883 | 4911 | 4934 | 4934 | 4940 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 611 | 3 | 4878 | 4904 | 4928 | 4934 | 4934 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 611 | 4 | 4885 | 4895 | 4901 | 4901 | 4904 | | | | | | 3 | 6 | 04 |
| 4 | 1 | 639 | 1 | 4990 | 4998 | 5002 | 5006 | 5010 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 639 | 2 | 5014 | 5026 | 5026 | 5026 | 5026 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 639 | 3 | 4998 | 5014 | 5051 | 5056 | 5056 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 639 | 4 | | 4885 | 4946 | 4990 | 4994 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 613 | 1 | 4931 | 4990 | 4994 | 4994 | 4998 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 613 | 2 | 4990 | 4998 | 5002 | 5010 | 5014 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 613 | 3 | 4918 | 4990 | 4994 | 4998 | 5002 | | | | | | 5 | 0 | 04 |
| 4 | 1 | 613 | 4 | 4911 | 4940 | 4957 | 4968 | 4979 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 638 | 1 | 4774 | 4846 | 4874 | 4881 | 4881 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 638 | 2 | 4870 | 4870 | 4874 | 4874 | 4878 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 638 | 3 | 4858 | 4862 | 4862 | 4862 | 4866 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 638 | 4 | 4056 | 4846 | 4846 | 4850 | 4850 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 610 | 1 | 3204 | 3311 | 3397 | 3469 | 3531 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 610 | 2 | 3204 | 3317 | 3469 | 3531 | 3531 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 610 | 3 | 3531 | 3676 | 3764 | 3808 | 3808 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 610 | 4 | 3204 | 3317 | 3397 | 3469 | 3531 | | | | | | 3 | 0 | 04 |
| 4 | 2 | 636 | 1 | 4934 | 4940 | 4946 | 4952 | 4957 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 636 | 2 | 4940 | 4957 | 4968 | 4974 | 4979 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 636 | 3 | 4928 | 4990 | 5014 | 5035 | 5051 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 636 | 4 | 4893 | 4940 | 5010 | 5035 | 5040 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 612 | 1 | 4918 | 4934 | 4940 | 4946 | 4946 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 612 | 2 | 4934 | 4940 | 4952 | 4957 | 4963 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 612 | 3 | 4940 | 4957 | 4968 | 4985 | 4994 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 612 | 4 | 4934 | 4952 | 4963 | 4974 | 4985 | | | | | | 3 | 6 | 04 |
| 4 | 2 | 640 | 1 | 4979 | 5030 | 5040 | 5046 | 5051 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 640 | 2 | 4998 | 5006 | 5014 | 5022 | 5035 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 640 | 3 | 4911 | 5006 | 5022 | 5035 | 5035 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 640 | 4 | | 4928 | 5030 | 5035 | 5035 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 614 | 1 | 4952 | 4994 | 4998 | 5002 | 5010 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 614 | 2 | 4885 | 4998 | 5010 | 5022 | 5026 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 614 | 3 | 4994 | 5002 | 5014 | 5022 | 5026 | | | | | | 5 | 0 | 04 |
| 4 | 2 | 614 | 4 | 4914 | 4994 | 4998 | 5002 | 5006 | | | | | | 5 | 0 | 04 |

# PAVED SHOULDER EXPERIMENT—DESIGN 2
# FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS
# (Continued)

| | | | | | | | | | INDEX DAY | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | |
| | | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | |
| | | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL** (x.xxx) | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** (x.x) | | | | | $D_1$ | $D_2$ (in.) | $D_3$ |
| 5 | 1 | 435 | 1 | 4766 | 4828 | 4846 | 4854 | 4858 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 435 | 2 | 4806 | 4846 | 4850 | 4854 | 4858 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 435 | 3 | 4747 | 4806 | 4842 | 4846 | 4846 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 435 | 4 | 3764 | 4551 | 4705 | 4790 | 4821 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 407 | 1 | 3808 | 4129 | 4413 | 4766 | 4790 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 407 | 2 | 4716 | 4806 | 4846 | 4862 | 4881 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 407 | 3 | 4363 | 4766 | 4828 | 4846 | 4846 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 407 | 4 | 4774 | 4821 | 4850 | 4862 | 4878 | | | | | | 3 | 3 | 04 |
| 5 | 1 | 431 | 1 | 4813 | 4860 | 4887 | 4899 | 4904 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 431 | 2 | 4828 | 4878 | 4887 | 4897 | 4901 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 431 | 3 | 4835 | 4874 | 4887 | 4893 | 4899 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 431 | 4 | 4716 | 4806 | 4850 | 4874 | 4889 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 405 | 1 | 4659 | 4766 | 4846 | 4862 | 4874 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 405 | 2 | 4586 | 4766 | 4798 | 4835 | 4850 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 405 | 3 | 3585 | 4705 | 4846 | 4878 | 4883 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 405 | 4 | 4705 | 4798 | 4850 | 4866 | 4881 | | | | | | 3 | 9 | 04 |
| 5 | 1 | 433 | 1 | 4899 | 4946 | 4985 | 4994 | 4998 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 433 | 2 | 4946 | 4974 | 4990 | 4994 | 4998 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 433 | 3 | 4979 | 4994 | 4998 | 5002 | 5006 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 433 | 4 | 4887 | 4934 | 4994 | 4998 | 5006 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 409 | 1 | 4908 | 4940 | 4957 | 4974 | 4985 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 409 | 2 | 4957 | 4994 | 4998 | 5002 | 5006 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 409 | 3 | 4858 | 4918 | 4968 | 4990 | 4994 | | | | | | 5 | 3 | 04 |
| 5 | 1 | 409 | 4 | 4897 | 4963 | 4990 | 4994 | 4998 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 436 | 1 | 3060 | 3204 | 3397 | 3469 | 3531 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 436 | 2 | | 3060 | 3204 | 3397 | 3469 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 436 | 3 | | 3204 | 3469 | 3676 | 3764 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 436 | 4 | | | 3204 | 3397 | 3531 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 408 | 1 | 3204 | 3397 | 3469 | 3585 | 3676 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 408 | 2 | 3311 | 3469 | 3531 | 3633 | 3716 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 408 | 3 | 3311 | 3469 | 3531 | 3633 | 3716 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 408 | 4 | 3397 | 3531 | 3633 | 3764 | 3764 | | | | | | 3 | 3 | 04 |
| 5 | 2 | 432 | 1 | 4813 | 4881 | 4897 | 4901 | 4904 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 432 | 2 | 4190 | 4846 | 4870 | 4885 | 4891 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 432 | 3 | 4747 | 4854 | 4874 | 4885 | 4891 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 432 | 4 | 4683 | 4806 | 4862 | 4881 | 4893 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 406 | 1 | 4774 | 4870 | 4893 | 4901 | 4904 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 406 | 2 | 4336 | 4694 | 4821 | 4878 | 4893 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 406 | 3 | 4774 | 4878 | 4891 | 4904 | 4904 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 406 | 4 | 4129 | 4488 | 4766 | 4850 | 4866 | | | | | | 3 | 9 | 04 |
| 5 | 2 | 434 | 1 | 4897 | 4940 | 4946 | 4952 | 4957 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 434 | 2 | 4921 | 4940 | 4946 | 4952 | 4957 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 434 | 3 | 4891 | 4940 | 4952 | 4957 | 4968 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 434 | 4 | 4821 | 4899 | 4968 | 4994 | 4998 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 410 | 1 | 4918 | 4952 | 4974 | 5010 | 5014 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 410 | 2 | 4990 | 4994 | 4998 | 5002 | 5006 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 410 | 3 | 4940 | 4946 | 4957 | 4963 | 4974 | | | | | | 5 | 3 | 04 |
| 5 | 2 | 410 | 4 | 4934 | 4946 | 4952 | 4963 | 4974 | | | | | | 5 | 3 | 04 |

## PAVED SHOULDER EXPERIMENT—DESIGN 2
## FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS
## (Continued)

| | | | | | | | | | INDEX DAY | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | |
| | | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | |
| | | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** | | | | | $D_1$ | $D_2$ | $D_3$ |
| | | | | (x.xxx) | | | | | (x.x) | | | | | | (in.) | |
| 6 | 1 | 291 | 1 | 4842 | 4846 | 4846 | 4850 | 4854 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 291 | 2 | 4842 | 4846 | 4850 | 4854 | 4854 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 291 | 3 | 4336 | 4846 | 4850 | 4854 | 4858 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 291 | 4 | 4846 | 4850 | 4854 | 4858 | 4862 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 275 | 1 | 4854 | 4866 | 4870 | 4870 | 4874 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 275 | 2 | 4870 | 4870 | 4874 | 4874 | 4878 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 275 | 3 | 4870 | 4870 | 4874 | 4874 | 4878 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 275 | 4 | 4842 | 4850 | 4858 | 4866 | 4870 | | | | | | 4 | 3 | 08 |
| 6 | 1 | 293 | 1 | 4985 | 5071 | 5226 | 5441 | 5647 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 293 | 2 | 5090 | 5547 | 5683 | 5734 | 5739 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 293 | 3 | 5593 | 5741 | 5755 | 5783 | 5790 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 293 | 4 | 4998 | 5085 | 5189 | 5388 | 5706 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 273 | 1 | 4901 | 4934 | 4994 | 5040 | 5127 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 273 | 2 | 4921 | 4979 | 5018 | 5056 | 5114 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 273 | 3 | 4897 | 4921 | 4952 | 4990 | 5006 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 273 | 4 | 4897 | 4924 | 4968 | 5022 | 5100 | | | | | | 4 | 3 | 16 |
| 6 | 1 | 295 | 1 | 4908 | 4940 | 4985 | 5010 | 5022 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 295 | 2 | 4994 | 5002 | 5006 | 5014 | 5018 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 295 | 3 | 4924 | 4974 | 5010 | 5022 | 5080 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 295 | 4 | 4918 | 4968 | 5006 | 5018 | 5026 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 277 | 1 | 4914 | 4963 | 4990 | 4998 | 5006 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 277 | 2 | 4952 | 4979 | 4994 | 4998 | 5006 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 277 | 3 | 4931 | 4979 | 4994 | 5006 | 5018 | | | | | | 6 | 3 | 08 |
| 6 | 1 | 277 | 4 | 4918 | 4968 | 4994 | 5006 | 5014 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 292 | 1 | 4897 | 4901 | 4904 | 4908 | 4911 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 292 | 2 | 4878 | 4895 | 4901 | 4904 | 4904 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 292 | 3 | 4891 | 4897 | 4901 | 4904 | 4904 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 292 | 4 | 4874 | 4901 | 4904 | 4908 | 4911 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 276 | 1 | 4835 | 4881 | 4893 | 4901 | 4904 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 276 | 2 | 4862 | 4887 | 4899 | 4901 | 4904 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 276 | 3 | 4842 | 4866 | 4878 | 4885 | 4889 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 276 | 4 | 4842 | 4866 | 4881 | 4885 | 4889 | | | | | | 4 | 3 | 08 |
| 6 | 2 | 294 | 1 | | | | | | 43 | 37 | 36 | 30 | 30 | 4 | 3 | 16 |
| 6 | 2 | 294 | 2 | | | | | | 43 | 39 | 40 | 37 | 37 | 4 | 3 | 16 |
| 6 | 2 | 294 | 3 | | | | | | 40 | 36 | 35 | 34 | 25 | 4 | 3 | 16 |
| 6 | 2 | 294 | 4 | 4891 | 5085 | 5732 | 5804 | 5849 | | | | | | 4 | 3 | 16 |
| 6 | 2 | 274 | 1 | 4934 | 5217 | 5769 | 5804 | 5818 | | | | | | 4 | 3 | 16 |
| 6 | 2 | 274 | 2 | 4934 | 5002 | 5071 | 5577 | 5732 | | | | | | 4 | 3 | 16 |
| 6 | 2 | 274 | 3 | 4931 | 5022 | 5610 | 5760 | 5769 | | | | | | 4 | 3 | 16 |
| 6 | 2 | 274 | 4 | 4895 | 4934 | 4994 | 5018 | 5030 | | | | | | 4 | 3 | 16 |
| 6 | 2 | 296 | 1 | 4934 | 4994 | 5002 | 5006 | 5014 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 296 | 2 | 4952 | 5014 | 5071 | 5143 | 5625 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 296 | 3 | 4979 | 5030 | 5095 | 5577 | 5688 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 296 | 4 | 4931 | 5014 | 5085 | 5184 | 5715 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 278 | 1 | 4921 | 4994 | 5040 | 5080 | 5085 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 278 | 2 | 4946 | 4998 | 5035 | 5056 | 5127 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 278 | 3 | 4985 | 5061 | 5114 | 5199 | 5217 | | | | | | 6 | 3 | 08 |
| 6 | 2 | 278 | 4 | 4946 | 5022 | 5100 | 5726 | 5765 | | | | | | 6 | 3 | 08 |

# SPECIAL BASES EXPERIMENT—DESIGN 4
# FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS

| | | | | | | | | | INDEX DAY | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | |
| | | | | | | | | | 75 | 290 | 401 | 944 | 1126 | |
| | | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | AVERAGE BASE THICKNESS OF EACH SUBSECTION |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** | | | | | |
| | | | | (x.xxx) | | | | | (x.x) | | | | | (x.xxx) |
| 3 | 1 | 169 | 1 | | | | | | 38 | 38 | 36 | 23 | 24 | 12500 |
| 3 | 1 | 169 | 2 | 5194 | 5301 | 5603 | 5650 | 5817 | | | | | | 9500 |
| 3 | 1 | 169 | 3 | 4812 | 4972 | 5042 | 5112 | 5140 | | | | | | 6500 |
| 3 | 1 | 169 | 4 | 4875 | 4905 | 4919 | 4947 | 4985 | | | | | | 3500 |
| 3 | 1 | 105 | 1 | | | | | | 37 | 34 | 33 | 19 | 19 | 12500 |
| 3 | 1 | 105 | 2 | 4845 | 5160 | 5620 | 5629 | 5660 | | | | | | 9500 |
| 3 | 1 | 105 | 3 | 4450 | 4717 | 4823 | 4905 | 4947 | | | | | | 6500 |
| 3 | 1 | 105 | 4 | 4450 | 4494 | 4494 | 4534 | 4570 | | | | | | 3500 |
| 3 | 1 | 171 | 1 | 5655 | 5669 | 5690 | 5702 | 5702 | | | | | | 12500 |
| 3 | 1 | 171 | 2 | 5140 | 5355 | 5628 | 5636 | 5650 | | | | | | 9500 |
| 3 | 1 | 171 | 3 | 4947 | 5103 | 5160 | 5204 | 5223 | | | | | | 6500 |
| 3 | 1 | 171 | 4 | 4450 | 4777 | 4789 | 4801 | 4823 | | | | | | 3500 |
| 3 | 1 | 103 | 1 | 5150 | 5301 | 5628 | 5630 | 5660 | | | | | | 12500 |
| 3 | 1 | 103 | 2 | 4801 | 4960 | 5140 | 5165 | 5170 | | | | | | 9500 |
| 3 | 1 | 103 | 3 | 4570 | 4717 | 4764 | 4777 | 4777 | | | | | | 6500 |
| 3 | 1 | 103 | 4 | 4494 | 4534 | 4604 | 4635 | 4664 | | | | | | 3500 |
| 3 | 1 | 167 | 1 | | | | | | 34 | 36 | 36 | 36 | 37 | 9875 |
| 3 | 1 | 167 | 2 | | | | | | 39 | 39 | 40 | 39 | 39 | 7625 |
| 3 | 1 | 167 | 3 | | | | | | 40 | 41 | 41 | 40 | 41 | 5375 |
| 3 | 1 | 167 | 4 | | | | | | 32 | 18 | 23 | 18 | 17 | 3125 |
| 3 | 1 | 101 | 1 | | | | | | 38 | 38 | 38 | 37 | 37 | 9875 |
| 3 | 1 | 101 | 2 | | | | | | 41 | 41 | 41 | 41 | 42 | 7625 |
| 3 | 1 | 101 | 3 | | | | | | 41 | 40 | 41 | 40 | 39 | 5375 |
| 3 | 1 | 101 | 4 | 4093 | 5204 | 5365 | 5532 | 5533 | | | | | | 3125 |
| 3 | 2 | 170 | 1 | 5620 | 5641 | 5735 | 5839 | 5893 | | | | | | 12500 |
| 3 | 2 | 170 | 2 | | 4919 | 5175 | 5243 | 5293 | | | | | | 9500 |
| 3 | 2 | 170 | 3 | | 4403 | 4855 | 5020 | 5118 | | | | | | 6500 |
| 3 | 2 | 170 | 4 | 4570 | 4741 | 4764 | 4764 | 4777 | | | | | | 3500 |
| 3 | 2 | 106 | 1 | 5213 | 5669 | 5839 | 5889 | 5920 | | | | | | 12500 |
| 3 | 2 | 106 | 2 | 4063 | 4960 | 5112 | 5175 | 5228 | | | | | | 9500 |
| 3 | 2 | 106 | 3 | 4112 | 4450 | 4777 | 4834 | 5008 | | | | | | 6500 |
| 3 | 2 | 106 | 4 | 4450 | 4494 | 4534 | 4570 | 4604 | | | | | | 3500 |
| 3 | 2 | 172 | 1 | 5588 | 5627 | 5702 | 5724 | 5746 | | | | | | 12500 |
| 3 | 2 | 172 | 2 | 4972 | 5112 | 5170 | 5213 | 5223 | | | | | | 9500 |
| 3 | 2 | 172 | 3 | 4403 | 4635 | 4777 | 4834 | 4890 | | | | | | 6500 |
| 3 | 2 | 172 | 4 | | 4494 | 4534 | 4570 | 4604 | | | | | | 3500 |
| 3 | 2 | 104 | 1 | 5238 | 5629 | 5631 | 5636 | 5650 | | | | | | 12500 |
| 3 | 2 | 104 | 2 | 4933 | 5063 | 5129 | 5165 | 5170 | | | | | | 9500 |
| 3 | 2 | 104 | 3 | 4093 | 4664 | 4777 | 4834 | 4875 | | | | | | 6500 |
| 3 | 2 | 104 | 4 | 4093 | 4322 | 4450 | 4450 | 4450 | | | | | | 3500 |
| 3 | 2 | 168 | 1 | | | | | | 37 | 39 | 39 | 39 | 39 | 9875 |
| 3 | 2 | 168 | 2 | | | | | | 37 | 38 | 40 | 38 | 40 | 7625 |
| 3 | 2 | 168 | 3 | | | | | | 43 | 41 | 40 | 39 | 38 | 5375 |
| 3 | 2 | 168 | 4 | 4033 | 4985 | 5190 | 5355 | 5944 | | | | | | 3125 |
| 3 | 2 | 102 | 1 | | | | | | 40 | 40 | 39 | 39 | 39 | 9875 |
| 3 | 2 | 102 | 2 | | | | | | 40 | 41 | 41 | 40 | 40 | 7625 |
| 3 | 2 | 102 | 3 | | | | | | 34 | 32 | 34 | 27 | 27 | 5375 |
| 3 | 2 | 102 | 4 | 3811 | 4635 | 5123 | 5213 | 5282 | | | | | | 3125 |

*BASIC DESIGN OF SECTIONS - 3-INCH SURFACE, VARIABLE THICKNESS BASE, 0-INCH SUBBASE.

**BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

***BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

# SPECIAL BASES EXPERIMENT—DESIGN 4
# FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS
# (Continued)

| | | | | | | | | | INDEX DAY | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | |
| | | | | | | | | | 75 | 290 | 401 | 944 | 1126 | |
| | | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | AVERAGE BASE THICKNESS OF EACH SUBSECTION |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** | | | | | |
| | | | | (x.xxx) | | | | | (x.x) | | | | | (x.xxx) |
| 4 | 1 | 567 | 1 | | | | | | 37 | 38 | 36 | 27 | 25 | 14250 |
| 4 | 1 | 567 | 2 | 4789 | 5020 | 5165 | 5315 | 5628 | | | | | | 10750 |
| 4 | 1 | 567 | 3 | 4664 | 4812 | 4875 | 4875 | 4890 | | | | | | 7250 |
| 4 | 1 | 567 | 4 | 4764 | 4764 | 4764 | 4764 | 4777 | | | | | | 3750 |
| 4 | 1 | 561 | 1 | | | | | | 39 | 41 | 38 | 38 | 39 | 14250 |
| 4 | 1 | 561 | 2 | 4865 | 5155 | 5620 | 5627 | 5650 | | | | | | 10750 |
| 4 | 1 | 561 | 3 | 4403 | 4717 | 4834 | 4947 | 5008 | | | | | | 7250 |
| 4 | 1 | 561 | 4 | | | 4093 | 4403 | 4534 | | | | | | 3750 |
| 4 | 1 | 565 | 1 | | | | | | | | | | | 14250 |
| 4 | 1 | 565 | 2 | 5074 | 5165 | 5180 | 5194 | 5208 | | | | | | 10750 |
| 4 | 1 | 565 | 3 | 4875 | 4890 | 4905 | 4919 | 4933 | | | | | | 7250 |
| 4 | 1 | 565 | 4 | 3130 | 3556 | 3732 | 3811 | 3846 | | | | | | 3750 |
| 4 | 1 | 559 | 1 | 5204 | 5453 | 5587 | 5603 | 5605 | | | | | | 14250 |
| 4 | 1 | 559 | 2 | 4378 | 4919 | 5084 | 5134 | 5155 | | | | | | 10750 |
| 4 | 1 | 559 | 3 | 4378 | 4777 | 4890 | 5008 | 5020 | | | | | | 7250 |
| 4 | 1 | 559 | 4 | 4033 | 4093 | 4222 | 4378 | 4534 | | | | | | 3750 |
| 4 | 1 | 563 | 1 | | | | | | 37 | 40 | 41 | 40 | 39 | 9000 |
| 4 | 1 | 563 | 2 | 5623 | 5702 | 5824 | 5890 | 5950 | | | | | | 7000 |
| 4 | 1 | 563 | 3 | 4789 | 5258 | 5329 | 5400 | 5502 | | | | | | 5000 |
| 4 | 1 | 563 | 4 | 3732 | 4139 | 4351 | 4635 | 4933 | | | | | | 3000 |
| 4 | 1 | 557 | 1 | | | | | | 38 | 35 | 35 | 28 | 27 | 9000 |
| 4 | 1 | 557 | 2 | 5355 | 5599 | 5623 | 5631 | 5660 | | | | | | 7000 |
| 4 | 1 | 557 | 3 | 4947 | 5008 | 5093 | 5118 | 5118 | | | | | | 5000 |
| 4 | 1 | 557 | 4 | | 4131 | 4534 | 4741 | 4855 | | | | | | 3000 |
| 4 | 2 | 568 | 1 | | | | | | 39 | 39 | 39 | 29 | 29 | 14250 |
| 4 | 2 | 568 | 2 | 4823 | 5093 | 5199 | 5278 | 5596 | | | | | | 10750 |
| 4 | 2 | 568 | 3 | 4427 | 4801 | 4855 | 4875 | 4890 | | | | | | 7250 |
| 4 | 2 | 568 | 4 | 4183 | 4604 | 4764 | 4764 | 4777 | | | | | | 3750 |
| 4 | 2 | 562 | 1 | | | | | | 39 | 42 | 40 | 29 | 30 | 14250 |
| 4 | 2 | 562 | 2 | 4823 | 5053 | 5262 | 5506 | 5551 | | | | | | 10750 |
| 4 | 2 | 562 | 3 | | 4378 | 4717 | 4845 | 4890 | | | | | | 7250 |
| 4 | 2 | 562 | 4 | 3352 | 3653 | 3987 | 4093 | 4351 | | | | | | 3750 |
| 4 | 2 | 566 | 1 | | | | | | | | | | | 14250 |
| 4 | 2 | 566 | 2 | 4855 | 5074 | 5170 | 5185 | 5199 | | | | | | 10750 |
| 4 | 2 | 566 | 3 | 4351 | 4717 | 4865 | 4985 | 5020 | | | | | | 7250 |
| 4 | 2 | 566 | 4 | 3352 | 3694 | 3878 | 4059 | 4183 | | | | | | 3750 |
| 4 | 2 | 560 | 1 | 4960 | 5160 | 5228 | 5262 | 5290 | | | | | | 14250 |
| 4 | 2 | 560 | 2 | 5063 | 5118 | 5129 | 5140 | 5145 | | | | | | 10750 |
| 4 | 2 | 560 | 3 | 4403 | 4664 | 4801 | 4865 | 4933 | | | | | | 7250 |
| 4 | 2 | 560 | 4 | 3352 | 4093 | 4183 | 4322 | 4403 | | | | | | 3750 |
| 4 | 2 | 564 | 1 | | | | | | 40 | 43 | 42 | 42 | 42 | 9000 |
| 4 | 2 | 564 | 2 | 5362 | 5603 | 5629 | 5629 | 5724 | | | | | | 7000 |
| 4 | 2 | 564 | 3 | 4919 | 5112 | 5180 | 5233 | 5286 | | | | | | 5000 |
| 4 | 2 | 564 | 4 | | 3130 | 3653 | 4011 | 4834 | | | | | | 3000 |
| 4 | 2 | 558 | 1 | | | | | | 39 | 36 | 36 | 25 | 25 | 9000 |
| 4 | 2 | 558 | 2 | 5063 | 5213 | 5334 | 5542 | 5559 | | | | | | 7000 |
| 4 | 2 | 558 | 3 | 4812 | 5031 | 5150 | 5199 | 5213 | | | | | | 5000 |
| 4 | 2 | 558 | 4 | 4222 | 4604 | 4801 | 4875 | 4875 | | | | | | 3000 |

*BASIC DESIGN OF SECTIONS - 3-INCH SURFACE, VARIABLE THICKNESS BASE, 4-INCH SUBBASE.

**BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

***BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

# SPECIAL BASES EXPERIMENT—DESIGN 4
# FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS
# (Continued)

| | | | | | | | | | INDEX DAY | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | |
| | | | | | | | | | 75 | 290 | 401 | 944 | 1126 | |
| | | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | AVERAGE BASE THICKNESS OF EACH SUBSECTION |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** | | | | | |
| | | | | (x.xxx) | | | | | (x.x) | | | | | (x.xxx) |
| 5 | 1 | 467 | 1 | 3846 | 4042 | 4081 | 4093 | 4351 | | | | | | 16125 |
| 5 | 1 | 467 | 2 | 4258 | 4322 | 4378 | 4427 | 4494 | | | | | | 12375 |
| 5 | 1 | 467 | 3 | 3732 | 4121 | 4183 | 4322 | 4427 | | | | | | 8625 |
| 5 | 1 | 467 | 4 | 3498 | 3908 | 4067 | 4093 | 4322 | | | | | | 4875 |
| 5 | 1 | 457 | 1 | 4635 | 4834 | 4890 | 4905 | 4919 | | | | | | 16125 |
| 5 | 1 | 457 | 2 | 4534 | 4789 | 4875 | 4919 | 4933 | | | | | | 12375 |
| 5 | 1 | 457 | 3 | 4427 | 4494 | 4570 | 4604 | 4664 | | | | | | 8625 |
| 5 | 1 | 457 | 4 | 4093 | 4107 | 4291 | 4351 | 4403 | | | | | | 4875 |
| 5 | 1 | 463 | 1 | | | | | | 39 | 42 | 41 | 40 | 39 | 14375 |
| 5 | 1 | 463 | 2 | | | | | | 42 | 44 | 43 | 43 | 44 | 11125 |
| 5 | 1 | 463 | 3 | | | | | | 40 | 42 | 39 | 37 | 34 | 7875 |
| 5 | 1 | 463 | 4 | 4534 | 4834 | 4985 | 5118 | 5213 | | | | | | 4625 |
| 5 | 1 | 459 | 1 | | | | | | 42 | 43 | 42 | 42 | 42 | 14375 |
| 5 | 1 | 459 | 2 | | | | | | 39 | 37 | 36 | 34 | 33 | 11125 |
| 5 | 1 | 459 | 3 | | | | | | 43 | 36 | 34 | 36 | 27 | 7875 |
| 5 | 1 | 459 | 4 | 5031 | 5150 | 5190 | 5213 | 5218 | | | | | | 4625 |
| 5 | 1 | 465 | 1 | | | | | | 39 | 41 | 40 | 37 | 37 | 10875 |
| 5 | 1 | 465 | 2 | 5564 | 5621 | 5628 | 5646 | 5669 | | | | | | 8625 |
| 5 | 1 | 465 | 3 | 4905 | 5008 | 5020 | 5020 | 5031 | | | | | | 6375 |
| 5 | 1 | 465 | 4 | 4093 | 4126 | 4183 | 4378 | 4534 | | | | | | 4125 |
| 5 | 1 | 461 | 1 | | | | | | 42 | 41 | 37 | 38 | 37 | 10875 |
| 5 | 1 | 461 | 2 | 5521 | 5626 | 5641 | 5724 | 5786 | | | | | | 8625 |
| 5 | 1 | 461 | 3 | 4875 | 5103 | 5424 | 5504 | 5506 | | | | | | 6375 |
| 5 | 1 | 461 | 4 | 4845 | 4875 | 4875 | 4875 | 4890 | | | | | | 4125 |
| 5 | 2 | 468 | 1 | 3811 | 4046 | 4082 | 4093 | 4183 | | | | | | 16125 |
| 5 | 2 | 468 | 2 | 4322 | 4403 | 4450 | 4494 | 4494 | | | | | | 12375 |
| 5 | 2 | 468 | 3 | 4322 | 4403 | 4450 | 4494 | 4494 | | | | | | 8625 |
| 5 | 2 | 468 | 4 | 3498 | 3653 | 3773 | 3811 | 3878 | | | | | | 4875 |
| 5 | 2 | 458 | 1 | | | | | | | | | | | 16125 |
| 5 | 2 | 458 | 2 | 4351 | 4450 | 4534 | 4604 | 4664 | | | | | | 12375 |
| 5 | 2 | 458 | 3 | 4534 | 4691 | 4777 | 4823 | 4865 | | | | | | 8625 |
| 5 | 2 | 458 | 4 | 4378 | 4494 | 4604 | 4635 | 4635 | | | | | | 4875 |
| 5 | 2 | 464 | 1 | | | | | | 42 | 44 | 42 | 41 | 42 | 14375 |
| 5 | 2 | 464 | 2 | | | | | | 39 | 44 | 43 | 42 | 44 | 11125 |
| 5 | 2 | 464 | 3 | | | | | | 41 | 42 | 40 | 40 | 39 | 7875 |
| 5 | 2 | 464 | 4 | 4741 | 4919 | 5053 | 5134 | 5155 | | | | | | 4625 |
| 5 | 2 | 460 | 1 | | | | | | 40 | 41 | 40 | 39 | 38 | 14375 |
| 5 | 2 | 460 | 2 | | | | | | 41 | 45 | 43 | 43 | 43 | 11125 |
| 5 | 2 | 460 | 3 | | | | | | 41 | 36 | 36 | 34 | 35 | 7875 |
| 5 | 2 | 460 | 4 | 4919 | 5123 | 5185 | 5223 | 5262 | | | | | | 4625 |
| 5 | 2 | 466 | 1 | | | | | | 41 | 42 | 42 | 38 | 40 | 10875 |
| 5 | 2 | 466 | 2 | 5282 | 5673 | 5817 | 5876 | 5901 | | | | | | 8625 |
| 5 | 2 | 466 | 3 | 4777 | 4997 | 5134 | 5165 | 5175 | | | | | | 6375 |
| 5 | 2 | 466 | 4 | | 4183 | 4322 | 4403 | 4534 | | | | | | 4125 |
| 5 | 2 | 462 | 1 | | | | | | 42 | 45 | 42 | 37 | 36 | 10875 |
| 5 | 2 | 462 | 2 | 5554 | 5589 | 5678 | 5702 | 5724 | | | | | | 8625 |
| 5 | 2 | 462 | 3 | 4534 | 4834 | 5042 | 5185 | 5286 | | | | | | 6375 |
| 5 | 2 | 462 | 4 | 4691 | 4777 | 4801 | 4812 | 4834 | | | | | | 4125 |

*BASIC DESIGN OF SECTIONS - 3-INCH SURFACE, VARIABLE THICKNESS BASE, 4-INCH SUBBASE.

**BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

***BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

# SPECIAL BASES EXPERIMENT—DESIGN 4
# FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS
# (Continued)

| | | | | | | | | | INDEX DAY | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | |
| | | | | | | | | | 75 | 290 | 401 | 944 | 1126 | |
| | | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | AVERAGE BASE THICKNESS OF EACH SUBSECTION |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** | | | | | |
| | | | | (x.xxx) | | | | | (x.x) | | | | | (x.xxx) |
| 6 | 1 | 287 | 1 | | | | | | 41 | 40 | 41 | 33 | 34 | 17000 |
| 6 | 1 | 287 | 2 | | | | | | 41 | 40 | 36 | 29 | 27 | 13000 |
| 6 | 1 | 287 | 3 | 4801 | 4875 | 4890 | 4890 | 4905 | | | | | | 9000 |
| 6 | 1 | 287 | 4 | 4126 | 4534 | 4801 | 4855 | 4875 | | | | | | 5000 |
| 6 | 1 | 279 | 1 | | | | | | 41 | 42 | 42 | 41 | 41 | 17000 |
| 6 | 1 | 279 | 2 | | | | | | 41 | 32 | 33 | 18 | 19 | 13000 |
| 6 | 1 | 279 | 3 | 4691 | 4890 | 5031 | 5134 | 5204 | | | | | | 9000 |
| 6 | 1 | 279 | 4 | 4764 | 4777 | 4801 | 4812 | 4823 | | | | | | 5000 |
| 6 | 1 | 285 | 1 | | | | | | 44 | 43 | 41 | 42 | 39 | 16125 |
| 6 | 1 | 285 | 2 | | | | | | 43 | 43 | 42 | 42 | 41 | 12375 |
| 6 | 1 | 285 | 3 | 5150 | 5253 | 5471 | 5591 | 5920 | | | | | | 8625 |
| 6 | 1 | 285 | 4 | 4855 | 5112 | 5140 | 5160 | 5160 | | | | | | 4875 |
| 6 | 1 | 283 | 1 | | | | | | 39 | 37 | 37 | 36 | 34 | 16125 |
| 6 | 1 | 283 | 2 | | | | | | 41 | 42 | 40 | 41 | 40 | 12375 |
| 6 | 1 | 283 | 3 | 5223 | 5461 | 5746 | 5896 | 6005 | | | | | | 8625 |
| 6 | 1 | 283 | 4 | 5084 | 5160 | 5199 | 5253 | 5286 | | | | | | 4875 |
| 6 | 1 | 289 | 1 | | | | | | 39 | 39 | 37 | 31 | 34 | 11750 |
| 6 | 1 | 289 | 2 | 5338 | 5444 | 5497 | 5547 | 5595 | | | | | | 9250 |
| 6 | 1 | 289 | 3 | 4635 | 4823 | 4919 | 5008 | 5042 | | | | | | 6750 |
| 6 | 1 | 289 | 4 | 4450 | 4494 | 4494 | 4534 | 4534 | | | | | | 4250 |
| 6 | 1 | 281 | 1 | | | | | | 39 | 39 | 40 | 32 | 33 | 11750 |
| 6 | 1 | 281 | 2 | 5502 | 5587 | 5625 | 5846 | 6085 | | | | | | 9250 |
| 6 | 1 | 281 | 3 | 5042 | 5134 | 5180 | 5213 | 5258 | | | | | | 6750 |
| 6 | 1 | 281 | 4 | 4322 | 4635 | 4801 | 4865 | 4875 | | | | | | 4250 |
| 6 | 2 | 288 | 1 | | | | | | 42 | 44 | 43 | 41 | 40 | 17000 |
| 6 | 2 | 288 | 2 | | | | | | 42 | 43 | 42 | 39 | 37 | 13000 |
| 6 | 2 | 288 | 3 | 4997 | 5129 | 5190 | 5311 | 5610 | | | | | | 9000 |
| 6 | 2 | 288 | 4 | | 4534 | 4834 | 4960 | 5074 | | | | | | 5000 |
| 6 | 2 | 280 | 1 | | | | | | 40 | 39 | 39 | 38 | 38 | 17000 |
| 6 | 2 | 280 | 2 | | | | | | 42 | 39 | 39 | 33 | 35 | 13000 |
| 6 | 2 | 280 | 3 | 4812 | 4947 | 5084 | 5160 | 5766 | | | | | | 9000 |
| 6 | 2 | 280 | 4 | 4534 | 4801 | 4855 | 4875 | 4890 | | | | | | 5000 |
| 6 | 2 | 286 | 1 | | | | | | 40 | 40 | 40 | 38 | 35 | 16125 |
| 6 | 2 | 286 | 2 | | | | | | 40 | 39 | 38 | 37 | 37 | 12375 |
| 6 | 2 | 286 | 3 | | | | | | 39 | 25 | 28 | 21 | 19 | 8625 |
| 6 | 2 | 286 | 4 | | 4845 | 5042 | 5140 | 5165 | | | | | | 4875 |
| 6 | 2 | 284 | 1 | | | | | | 41 | 38 | 38 | 39 | 35 | 16125 |
| 6 | 2 | 284 | 2 | | | | | | 41 | 43 | 43 | 41 | 41 | 12375 |
| 6 | 2 | 284 | 3 | | | | | | 42 | 36 | 37 | 31 | 30 | 8625 |
| 6 | 2 | 284 | 4 | 4985 | 5223 | 5325 | 5352 | 5370 | | | | | | 4875 |
| 6 | 2 | 290 | 1 | | | | | | 42 | 44 | 42 | 37 | 32 | 11750 |
| 6 | 2 | 290 | 2 | | | | | | 41 | 32 | 33 | 20 | 21 | 9250 |
| 6 | 2 | 290 | 3 | 4890 | 5053 | 5155 | 5213 | 5223 | | | | | | 6750 |
| 6 | 2 | 290 | 4 | 4764 | 4764 | 4777 | 4777 | 4777 | | | | | | 4250 |
| 6 | 2 | 282 | 1 | | | | | | 43 | 43 | 40 | 36 | 32 | 11750 |
| 6 | 2 | 282 | 2 | | | | | | 40 | 37 | 29 | 23 | 24 | 9250 |
| 6 | 2 | 282 | 3 | 5112 | 5185 | 5238 | 5286 | 5306 | | | | | | 6750 |
| 6 | 2 | 282 | 4 | 5008 | 5020 | 5020 | 5031 | 5031 | | | | | | 4250 |

*BASIC DESIGN OF SECTIONS - 4-INCH SURFACE, VARIABLE THICKNESS BASE, 4-INCH SUBBASE FOR BITUMINOUS AND CEMENT BASE AND 8-INCH STONE BASE.

**BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

***BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

# SPECIAL BASES EXPERIMENT—DESIGN 4
# FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS

| | | | | | | | | | INDEX DAY | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | |
| | | | | | | | | | 80 | 233 | 445 | 807 | 1114 | |
| | | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | AVERAGE BASE THICKNESS OF EACH SUBSECTION |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | |
| LOOP | LANE | SECTION | SUBSECTION* | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL** | | | | | SERVICEABILTY TREND VALUE ON INDEX DAY*** | | | | | |
| | | | | (x.xxx) | | | | | (x.x) | | | | | (x.xxx) |
| 3 | 1 | 169 | 1 | | | | | | 38 | 38 | 36 | 23 | 24 | 12500 |
| 3 | 1 | 169 | 2 | 5061 | 5179 | 5647 | 5741 | 5788 | | | | | | 9500 |
| 3 | 1 | 169 | 3 | 4889 | 4924 | 4952 | 4990 | 5010 | | | | | | 6500 |
| 3 | 1 | 169 | 4 | 4901 | 4908 | 4911 | 4918 | 4928 | | | | | | 3500 |
| 3 | 1 | 105 | 1 | | | | | | 37 | 34 | 33 | 19 | 19 | 12500 |
| 3 | 1 | 105 | 2 | 4895 | 5026 | 5683 | 5728 | 5746 | | | | | | 9500 |
| 3 | 1 | 105 | 3 | 4842 | 4874 | 4891 | 4908 | 4918 | | | | | | 6500 |
| 3 | 1 | 105 | 4 | 4842 | 4846 | 4846 | 4850 | 4854 | | | | | | 3500 |
| 3 | 1 | 171 | 1 | 5744 | 5751 | 5758 | 5760 | 5760 | | | | | | 12500 |
| 3 | 1 | 171 | 2 | 5010 | 5237 | 5718 | 5734 | 5741 | | | | | | 9500 |
| 3 | 1 | 171 | 3 | 4918 | 4985 | 5026 | 5071 | 5090 | | | | | | 6500 |
| 3 | 1 | 171 | 4 | 4842 | 4883 | 4885 | 4887 | 4891 | | | | | | 3500 |
| 3 | 1 | 103 | 1 | 5018 | 5179 | 5715 | 5726 | 5746 | | | | | | 12500 |
| 3 | 1 | 103 | 2 | 4887 | 4921 | 5010 | 5030 | 5035 | | | | | | 9500 |
| 3 | 1 | 103 | 3 | 4854 | 4874 | 4881 | 4883 | 4883 | | | | | | 6500 |
| 3 | 1 | 103 | 4 | 4846 | 4850 | 4858 | 4862 | 4866 | | | | | | 3500 |
| 3 | 1 | 167 | 1 | | | | | | 34 | 36 | 36 | 36 | 37 | 9875 |
| 3 | 1 | 167 | 2 | | | | | | 39 | 39 | 40 | 39 | 39 | 7625 |
| 3 | 1 | 167 | 3 | | | | | | 40 | 41 | 41 | 40 | 41 | 5375 |
| 3 | 1 | 167 | 4 | | | | | | 32 | 18 | 23 | 18 | 17 | 3125 |
| 3 | 1 | 101 | 1 | | | | | | 38 | 38 | 38 | 37 | 37 | 9875 |
| 3 | 1 | 101 | 2 | | | | | | 41 | 41 | 41 | 41 | 42 | 7625 |
| 3 | 1 | 101 | 3 | | | | | | 41 | 40 | 41 | 40 | 39 | 5375 |
| 3 | 1 | 101 | 4 | 4488 | 5071 | 5250 | 5487 | 5489 | | | | | | 3125 |
| 3 | 2 | 170 | 1 | 5683 | 5736 | 5767 | 5795 | 5836 | | | | | | 12500 |
| 3 | 2 | 170 | 2 | | 4911 | 5040 | 5109 | 5169 | | | | | | 9500 |
| 3 | 2 | 170 | 3 | | 4828 | 4897 | 4940 | 4994 | | | | | | 6500 |
| 3 | 2 | 170 | 4 | 4854 | 4878 | 4881 | 4881 | 4883 | | | | | | 3500 |
| 3 | 2 | 106 | 1 | 5080 | 5751 | 5795 | 5830 | 5865 | | | | | | 12500 |
| 3 | 2 | 106 | 2 | 4269 | 4921 | 4990 | 5040 | 5095 | | | | | | 9500 |
| 3 | 2 | 106 | 3 | 4705 | 4842 | 4883 | 4893 | 4934 | | | | | | 6500 |
| 3 | 2 | 106 | 4 | 4842 | 4846 | 4850 | 4854 | 4858 | | | | | | 3500 |
| 3 | 2 | 172 | 1 | 5585 | 5709 | 5760 | 5765 | 5769 | | | | | | 12500 |
| 3 | 2 | 172 | 2 | 4924 | 4990 | 5035 | 5080 | 5090 | | | | | | 9500 |
| 3 | 2 | 172 | 3 | 4828 | 4862 | 4883 | 4893 | 4904 | | | | | | 6500 |
| 3 | 2 | 172 | 4 | | 4846 | 4850 | 4854 | 4858 | | | | | | 3500 |
| 3 | 2 | 104 | 1 | 5104 | 5723 | 5732 | 5734 | 5741 | | | | | | 12500 |
| 3 | 2 | 104 | 2 | 4914 | 4963 | 5002 | 5030 | 5035 | | | | | | 9500 |
| 3 | 2 | 104 | 3 | 4457 | 4866 | 4883 | 4893 | 4901 | | | | | | 6500 |
| 3 | 2 | 104 | 4 | 4457 | 4806 | 4842 | 4842 | 4842 | | | | | | 3500 |
| 3 | 2 | 168 | 1 | | | | | | 37 | 39 | 39 | 39 | 39 | 9875 |
| 3 | 2 | 168 | 2 | | | | | | 37 | 38 | 40 | 38 | 40 | 7625 |
| 3 | 2 | 168 | 3 | | | | | | 43 | 41 | 40 | 39 | 38 | 5375 |
| 3 | 2 | 168 | 4 | 4056 | 4928 | 5056 | 5237 | 5882 | | | | | | 3125 |
| 3 | 2 | 102 | 1 | | | | | | 40 | 40 | 39 | 39 | 39 | 9875 |
| 3 | 2 | 102 | 2 | | | | | | 40 | 41 | 41 | 40 | 40 | 7625 |
| 3 | 2 | 102 | 3 | | | | | | 34 | 32 | 34 | 27 | 27 | 5375 |
| 3 | 2 | 102 | 4 | 3808 | 4862 | 4998 | 5080 | 5154 | | | | | | 3125 |

*BASIC DESIGN OF SECTIONS - 3-INCH SURFACE, VARIABLE THICKNESS BASE, 0-INCH SUBBASE.

**BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

***BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

## SPECIAL BASES EXPERIMENT—DESIGN 4
## FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS
## (Continued)

| | | | | | | | | | INDEX DAY<br>11 | 22 | 33 | 44 | 55 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS<br>80 | 233 | 445 | 807 | 1114 | |
| | | | | SERVICEABILITY TREND LEVEL<br>3.5 | 3.0 | 2.5 | 2.0 | 1.5 | LOG APPLICATIONS THROUGH INDEX DAY<br>4.901 | 5.368 | 5.648 | 5.907 | 6.047 | AVERAGE BASE THICKNESS OF EACH SUBSECTION |
| LOOP | LANE | SECTION | SUBSECTION* | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL** (x.xxx) | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** (x.x) | | | | | (x.xxx) |
| 4 | 1 | 567 | 1 | | | | | | 37 | 38 | 36 | 27 | 25 | 14250 |
| 4 | 1 | 567 | 2 | 4885 | 4940 | 5030 | 5194 | 5715 | | | | | | 10750 |
| 4 | 1 | 567 | 3 | 4866 | 4889 | 4901 | 4901 | 4904 | | | | | | 7250 |
| 4 | 1 | 567 | 4 | 4881 | 4881 | 4881 | 4881 | 4883 | | | | | | 3750 |
| 4 | 1 | 561 | 1 | | | | | | 39 | 41 | 38 | 38 | 39 | 14250 |
| 4 | 1 | 561 | 2 | 4899 | 5022 | 5683 | 5709 | 5741 | | | | | | 10750 |
| 4 | 1 | 561 | 3 | 4828 | 4874 | 4893 | 4918 | 4934 | | | | | | 7250 |
| 4 | 1 | 561 | 4 | | | 4609 | 4828 | 4850 | | | | | | 3750 |
| 4 | 1 | 565 | 1 | | | | | | | | | | | 14250 |
| 4 | 1 | 565 | 2 | 4968 | 5030 | 5046 | 5061 | 5076 | | | | | | 10750 |
| 4 | 1 | 565 | 3 | 4901 | 4904 | 4908 | 4911 | 4914 | | | | | | 7250 |
| 4 | 1 | 565 | 4 | 3061 | 3531 | 3716 | 3808 | 3848 | | | | | | 3750 |
| 4 | 1 | 559 | 1 | 5071 | 5355 | 5583 | 5647 | 5651 | | | | | | 14250 |
| 4 | 1 | 559 | 2 | 4821 | 4911 | 4974 | 5006 | 5022 | | | | | | 10750 |
| 4 | 1 | 559 | 3 | 4821 | 4883 | 4904 | 4934 | 4940 | | | | | | 7250 |
| 4 | 1 | 559 | 4 | 4056 | 4619 | 4782 | 4821 | 4850 | | | | | | 3750 |
| 4 | 1 | 563 | 1 | | | | | | 37 | 40 | 41 | 40 | 39 | 9000 |
| 4 | 1 | 563 | 2 | 5694 | 5760 | 5790 | 5832 | 5887 | | | | | | 7000 |
| 4 | 1 | 563 | 3 | 4885 | 5123 | 5208 | 5291 | 5432 | | | | | | 5000 |
| 4 | 1 | 563 | 4 | 3716 | 4766 | 4813 | 4862 | 4914 | | | | | | 3000 |
| 4 | 1 | 557 | 1 | | | | | | 38 | 35 | 35 | 28 | 27 | 9000 |
| 4 | 1 | 557 | 2 | 5237 | 5633 | 5692 | 5729 | 5746 | | | | | | 7000 |
| 4 | 1 | 557 | 3 | 4918 | 4934 | 4979 | 4994 | 4994 | | | | | | 5000 |
| 4 | 1 | 557 | 4 | | 4747 | 4850 | 4878 | 4897 | | | | | | 3000 |
| 4 | 2 | 568 | 1 | | | | | | 39 | 39 | 39 | 29 | 29 | 14250 |
| 4 | 2 | 568 | 2 | 4891 | 4979 | 5066 | 5149 | 5625 | | | | | | 10750 |
| 4 | 2 | 568 | 3 | 4835 | 4887 | 4897 | 4901 | 4904 | | | | | | 7250 |
| 4 | 2 | 568 | 4 | 4774 | 4858 | 4881 | 4881 | 4883 | | | | | | 3750 |
| 4 | 2 | 562 | 1 | | | | | | 39 | 42 | 40 | 29 | 30 | 14250 |
| 4 | 2 | 562 | 2 | 4891 | 4957 | 5127 | 5438 | 5529 | | | | | | 10750 |
| 4 | 2 | 562 | 3 | | 4821 | 4874 | 4895 | 4904 | | | | | | 7250 |
| 4 | 2 | 562 | 4 | 3311 | 3633 | 4006 | 4598 | 4813 | | | | | | 3750 |
| 4 | 2 | 566 | 1 | | | | | | | | | | | 14250 |
| 4 | 2 | 566 | 2 | 4897 | 4968 | 5035 | 5051 | 5066 | | | | | | 10750 |
| 4 | 2 | 566 | 3 | 4813 | 4874 | 4899 | 4928 | 4940 | | | | | | 7250 |
| 4 | 2 | 566 | 4 | 3311 | 3676 | 3885 | 4245 | 4774 | | | | | | 3750 |
| 4 | 2 | 560 | 1 | 4921 | 5026 | 5095 | 5127 | 5164 | | | | | | 14250 |
| 4 | 2 | 560 | 2 | 4963 | 4994 | 5002 | 5010 | 5014 | | | | | | 10750 |
| 4 | 2 | 560 | 3 | 4828 | 4866 | 4887 | 4899 | 4914 | | | | | | 7250 |
| 4 | 2 | 560 | 4 | 3311 | 4609 | 4774 | 4806 | 4828 | | | | | | 3750 |
| 4 | 2 | 564 | 1 | | | | | | 40 | 43 | 42 | 42 | 42 | 9000 |
| 4 | 2 | 564 | 2 | 5247 | 5647 | 5721 | 5748 | 5765 | | | | | | 7000 |
| 4 | 2 | 564 | 3 | 4911 | 4990 | 5046 | 5100 | 5159 | | | | | | 5000 |
| 4 | 2 | 564 | 4 | | 3060 | 3633 | 4032 | 4893 | | | | | | 3000 |
| 4 | 2 | 558 | 1 | | | | | | 39 | 36 | 36 | 25 | 25 | 9000 |
| 4 | 2 | 558 | 2 | 4963 | 5080 | 5213 | 5510 | 5540 | | | | | | 7000 |
| 4 | 2 | 558 | 3 | 4889 | 4946 | 5018 | 5066 | 5080 | | | | | | 5000 |
| 4 | 2 | 558 | 4 | 4782 | 4858 | 4887 | 4901 | 4901 | | | | | | 3000 |

*BASIC DESIGN OF SECTIONS - 3-INCH SURFACE, VARIABLE THICKNESS BASE, 4-INCH SUBBASE.

**BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

***BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

# SPECIAL BASES EXPERIMENT—DESIGN 4
# FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS
# (Continued)

|  |  |  |  |  |  |  |  |  | INDEX DAY |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  | 11 | 22 | 33 | 44 | 55 |  |
|  |  |  |  |  |  |  |  |  | APPLICATIONS THROUGH INDEX DAY - THOUSANDS |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 80 | 233 | 445 | 807 | 1114 |  |
|  |  |  |  | SERVICEABILITY TREND LEVEL |  |  |  |  | LOG APPLICATIONS THROUGH INDEX DAY |  |  |  |  | AVERAGE BASE THICKNESS OF EACH SUBSECTION |
|  |  |  |  | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 |  |
| LOOP | LANE | SECTION | SUBSECTION* | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL** |  |  |  |  | SERVICEABILITY TREND VALUE ON INDEX DAY*** |  |  |  |  |  |
|  |  |  |  | (x.xxx) |  |  |  |  | (x.x) |  |  |  |  | (x.xxx) |
| 5 | 1 | 467 | 1 | 3848 | 4129 | 4376 | 4619 | 4813 |  |  |  |  |  | 16125 |
| 5 | 1 | 467 | 2 | 4790 | 4806 | 4821 | 4835 | 4846 |  |  |  |  |  | 12375 |
| 5 | 1 | 467 | 3 | 3716 | 4726 | 4774 | 4806 | 4835 |  |  |  |  |  | 8625 |
| 5 | 1 | 467 | 4 | 3469 | 3919 | 4293 | 4659 | 4806 |  |  |  |  |  | 4875 |
| 5 | 1 | 457 | 1 | 4862 | 4893 | 4904 | 4908 | 4911 |  |  |  |  |  | 16125 |
| 5 | 1 | 457 | 2 | 4850 | 4885 | 4901 | 4911 | 4914 |  |  |  |  |  | 12375 |
| 5 | 1 | 457 | 3 | 4835 | 4846 | 4854 | 4858 | 4866 |  |  |  |  |  | 8625 |
| 5 | 1 | 457 | 4 | 4563 | 4694 | 4798 | 4813 | 4828 |  |  |  |  |  | 4875 |
| 5 | 1 | 463 | 1 |  |  |  |  |  | 39 | 42 | 41 | 40 | 39 | 14375 |
| 5 | 1 | 463 | 2 |  |  |  |  |  | 42 | 44 | 43 | 43 | 44 | 11125 |
| 5 | 1 | 463 | 3 |  |  |  |  |  | 40 | 42 | 39 | 37 | 34 | 7875 |
| 5 | 1 | 463 | 4 | 4850 | 4893 | 4928 | 4994 | 5080 |  |  |  |  |  | 4625 |
| 5 | 1 | 459 | 1 |  |  |  |  |  | 42 | 43 | 42 | 42 | 42 | 14375 |
| 5 | 1 | 459 | 2 |  |  |  |  |  | 39 | 37 | 36 | 34 | 33 | 11125 |
| 5 | 1 | 459 | 3 |  |  |  |  |  | 43 | 36 | 34 | 36 | 27 | 7875 |
| 5 | 1 | 459 | 4 | 4946 | 5018 | 5056 | 5080 | 5085 |  |  |  |  |  | 4625 |
| 5 | 1 | 465 | 1 |  |  |  |  |  | 39 | 41 | 40 | 37 | 37 | 10875 |
| 5 | 1 | 465 | 2 | 5547 | 5685 | 5718 | 5739 | 5751 |  |  |  |  |  | 8625 |
| 5 | 1 | 465 | 3 | 4908 | 4934 | 4940 | 4940 | 4946 |  |  |  |  |  | 6375 |
| 5 | 1 | 465 | 4 | 4516 | 4737 | 4774 | 4821 | 4850 |  |  |  |  |  | 4125 |
| 5 | 1 | 461 | 1 |  |  |  |  |  | 42 | 41 | 37 | 38 | 37 | 10875 |
| 5 | 1 | 461 | 2 | 5463 | 5703 | 5736 | 5765 | 5779 |  |  |  |  |  | 8625 |
| 5 | 1 | 461 | 3 | 4901 | 4985 | 5318 | 5435 | 5438 |  |  |  |  |  | 6375 |
| 5 | 1 | 461 | 4 | 4895 | 4901 | 4901 | 4901 | 4904 |  |  |  |  |  | 4125 |
| 5 | 2 | 468 | 1 | 3808 | 4161 | 4389 | 4542 | 4774 |  |  |  |  |  | 16125 |
| 5 | 2 | 468 | 2 | 4806 | 4828 | 4842 | 4846 | 4846 |  |  |  |  |  | 12375 |
| 5 | 2 | 468 | 3 | 4806 | 4828 | 4842 | 4846 | 4846 |  |  |  |  |  | 8625 |
| 5 | 2 | 468 | 4 | 3469 | 3633 | 3764 | 3808 | 3885 |  |  |  |  |  | 4875 |
| 5 | 2 | 458 | 1 |  |  |  |  |  |  |  |  |  |  | 16125 |
| 5 | 2 | 458 | 2 | 4813 | 4842 | 4850 | 4858 | 4866 |  |  |  |  |  | 12375 |
| 5 | 2 | 458 | 3 | 4850 | 4870 | 4883 | 4891 | 4899 |  |  |  |  |  | 8625 |
| 5 | 2 | 458 | 4 | 4821 | 4846 | 4858 | 4662 | 4862 |  |  |  |  |  | 4875 |
| 5 | 2 | 464 | 1 |  |  |  |  |  | 42 | 44 | 42 | 41 | 42 | 14375 |
| 5 | 2 | 464 | 2 |  |  |  |  |  | 39 | 44 | 43 | 42 | 44 | 11125 |
| 5 | 2 | 464 | 3 |  |  |  |  |  | 41 | 42 | 40 | 40 | 39 | 7875 |
| 5 | 2 | 464 | 4 | 4878 | 4911 | 4957 | 5006 | 5022 |  |  |  |  |  | 4625 |
| 5 | 2 | 460 | 1 |  |  |  |  |  | 40 | 41 | 40 | 39 | 38 | 14375 |
| 5 | 2 | 460 | 2 |  |  |  |  |  | 41 | 45 | 43 | 43 | 43 | 11125 |
| 5 | 2 | 460 | 3 |  |  |  |  |  | 41 | 36 | 36 | 34 | 35 | 7875 |
| 5 | 2 | 460 | 4 | 4911 | 4998 | 5051 | 5090 | 5127 |  |  |  |  |  | 4625 |
| 5 | 2 | 466 | 1 |  |  |  |  |  | 41 | 42 | 42 | 38 | 40 | 10875 |
| 5 | 2 | 466 | 2 | 5154 | 5753 | 5788 | 5816 | 5848 |  |  |  |  |  | 8625 |
| 5 | 2 | 466 | 3 | 4883 | 4931 | 5006 | 5030 | 5040 |  |  |  |  |  | 6375 |
| 5 | 2 | 466 | 4 |  | 4774 | 4806 | 4828 | 4850 |  |  |  |  |  | 4125 |
| 5 | 2 | 462 | 1 |  |  |  |  |  | 42 | 45 | 42 | 37 | 36 | 10875 |
| 5 | 2 | 462 | 2 | 5533 | 5595 | 5755 | 5760 | 5765 |  |  |  |  |  | 8625 |
| 5 | 2 | 462 | 3 | 4850 | 4893 | 4952 | 5051 | 5159 |  |  |  |  |  | 6375 |
| 5 | 2 | 462 | 4 | 4870 | 4883 | 4887 | 4889 | 4893 |  |  |  |  |  | 4125 |

*BASIC DESIGN OF SECTIONS - 3-INCH SURFACE, VARIABLE THICKNESS BASE, 4-INCH SUBBASE.

**BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

***BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

# SPECIAL BASES EXPERIMENT—DESIGN 4
# FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS
# (Continued)

| LOOP | LANE | SECTION | SUBSECTION* | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL** (x.xxx) | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY*** (x.x) | | | | | AVERAGE BASE THICKNESS OF EACH SUBSECTION (x.xxx) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | SERVICEABILITY TREND LEVEL | | | | | INDEX DAY | | | | | |
| | | | | | | | | | 11 | 22 | 33 | 44 | 55 | |
| | | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | |
| | | | | | | | | | 80 | 233 | 445 | 807 | 1114 | |
| | | | | | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | |
| | | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | |
| 6 | 1 | 287 | 1 | | | | | | 41 | 40 | 41 | 33 | 34 | 17000 |
| 6 | 1 | 287 | 2 | | | | | | 41 | 40 | 36 | 29 | 27 | 13000 |
| 6 | 1 | 287 | 3 | 4887 | 4901 | 4904 | 4904 | 4908 | | | | | | 9000 |
| 6 | 1 | 287 | 4 | 4737 | 4850 | 4887 | 4897 | 4901 | | | | | | 5000 |
| 6 | 1 | 279 | 1 | | | | | | 41 | 42 | 42 | 41 | 41 | 17000 |
| 6 | 1 | 279 | 2 | | | | | | 41 | 32 | 33 | 18 | 19 | 13000 |
| 6 | 1 | 279 | 3 | 4870 | 4904 | 4946 | 5006 | 5071 | | | | | | 9000 |
| 6 | 1 | 279 | 4 | 4881 | 4883 | 4887 | 4889 | 4891 | | | | | | 5000 |
| 6 | 1 | 285 | 1 | | | | | | 44 | 43 | 41 | 42 | 39 | 16125 |
| 6 | 1 | 285 | 2 | | | | | | 43 | 43 | 42 | 42 | 41 | 12375 |
| 6 | 1 | 285 | 3 | 5018 | 5118 | 5379 | 5605 | 5867 | | | | | | 8625 |
| 6 | 1 | 285 | 4 | 4897 | 4990 | 5010 | 5026 | 5026 | | | | | | 4875 |
| 6 | 1 | 283 | 1 | | | | | | 39 | 37 | 37 | 36 | 34 | 16125 |
| 6 | 1 | 283 | 2 | | | | | | 41 | 42 | 40 | 41 | 40 | 12375 |
| 6 | 1 | 283 | 3 | 5090 | 5367 | 5769 | 5841 | 5929 | | | | | | 8625 |
| 6 | 1 | 283 | 4 | 4974 | 5026 | 5066 | 5118 | 5159 | | | | | | 4875 |
| 6 | 1 | 289 | 1 | | | | | | 39 | 39 | 37 | 31 | 34 | 11750 |
| 6 | 1 | 289 | 2 | 5217 | 5342 | 5422 | 5521 | 5622 | | | | | | 9250 |
| 6 | 1 | 289 | 3 | 4862 | 4891 | 4911 | 4934 | 4952 | | | | | | 6750 |
| 6 | 1 | 289 | 4 | 4842 | 4846 | 4846 | 4850 | 4850 | | | | | | 4250 |
| 6 | 1 | 281 | 1 | | | | | | 39 | 39 | 40 | 32 | 33 | 11750 |
| 6 | 1 | 281 | 2 | 5432 | 5584 | 5701 | 5797 | 6038 | | | | | | 9250 |
| 6 | 1 | 281 | 3 | 4952 | 5006 | 5046 | 5080 | 5123 | | | | | | 6750 |
| 6 | 1 | 281 | 4 | 4806 | 4862 | 4887 | 4899 | 4901 | | | | | | 4250 |
| 6 | 2 | 288 | 1 | | | | | | 42 | 44 | 43 | 41 | 40 | 17000 |
| 6 | 2 | 288 | 2 | | | | | | 42 | 43 | 42 | 39 | 37 | 13000 |
| 6 | 2 | 288 | 3 | 4931 | 5002 | 5056 | 5189 | 5661 | | | | | | 9000 |
| 6 | 2 | 288 | 4 | | 4850 | 4893 | 4921 | 4968 | | | | | | 5000 |
| 6 | 2 | 280 | 1 | | | | | | 40 | 39 | 39 | 38 | 38 | 17000 |
| 6 | 2 | 280 | 2 | | | | | | 42 | 39 | 39 | 33 | 35 | 13000 |
| 6 | 2 | 280 | 3 | 4889 | 4918 | 4974 | 5026 | 5774 | | | | | | 9000 |
| 6 | 2 | 280 | 4 | 4850 | 4887 | 4897 | 4901 | 4904 | | | | | | 5000 |
| 6 | 2 | 286 | 1 | | | | | | 40 | 40 | 40 | 38 | 35 | 16125 |
| 6 | 2 | 286 | 2 | | | | | | 40 | 39 | 38 | 37 | 37 | 12375 |
| 6 | 2 | 286 | 3 | | | | | | 39 | 25 | 28 | 21 | 19 | 8625 |
| 6 | 2 | 286 | 4 | | 4895 | 4952 | 5010 | 5030 | | | | | | 4875 |
| 6 | 2 | 284 | 1 | | | | | | 41 | 38 | 38 | 39 | 35 | 16125 |
| 6 | 2 | 284 | 2 | | | | | | 41 | 43 | 43 | 41 | 41 | 12375 |
| 6 | 2 | 284 | 3 | | | | | | 42 | 36 | 37 | 31 | 30 | 8625 |
| 6 | 2 | 284 | 4 | 4928 | 5090 | 5203 | 5233 | 5256 | | | | | | 4875 |
| 6 | 2 | 290 | 1 | | | | | | 42 | 44 | 42 | 37 | 32 | 11750 |
| 6 | 2 | 290 | 2 | | | | | | 41 | 32 | 33 | 20 | 21 | 9250 |
| 6 | 2 | 290 | 3 | 4904 | 4957 | 5022 | 5080 | 5090 | | | | | | 6750 |
| 6 | 2 | 290 | 4 | 4881 | 4881 | 4883 | 4883 | 4883 | | | | | | 4250 |
| 6 | 2 | 282 | 1 | | | | | | 43 | 43 | 40 | 36 | 32 | 11750 |
| 6 | 2 | 282 | 2 | | | | | | 40 | 37 | 29 | 23 | 24 | 9250 |
| 6 | 2 | 282 | 3 | 4990 | 5051 | 5104 | 5159 | 5184 | | | | | | 6750 |
| 6 | 2 | 282 | 4 | 4934 | 4940 | 4940 | 4946 | 4946 | | | | | | 4250 |

*BASIC DESIGN OF SECTIONS - 4-INCH SURFACE, VARIABLE THICKNESS BASE, 4-INCH SUBBASE FOR BITUMINOUS AND CEMENT BASE AND 8-INCH STONE BASE.

# SURFACE TREATMENT EXPERIMENT—DESIGN 6
# FLEXIBLE PAVEMENT, WEIGHTED APPLICATIONS

| | | | | | | | | INDEX DAY | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | | |
| | | | | | | | | 75 | 290 | 401 | 944 | 1226 | | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.876 | 5.462 | 5.604 | 5.975 | 6.089 | | | | | |
| LOOP | LANE | SECTION | LOG WEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | D1 | D2 | D3 | | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | | |
| 2 | 1 | 733 | | | | 3498 | 3695 | | | | | | 0 | 0 | 00 | | 733 |
| 2 | 1 | 751 | | | 3812 | 4093 | 4093 | | | | | | 0 | 0 | 00 | | 751 |
| 2 | 1 | 753 | | | 2954 | 4072 | 4428 | | | | | | 0 | 0 | 04 | | 753 |
| 2 | 1 | 723 | | | | 3255 | 3431 | | | | | | 0 | 0 | 04 | | 723 |
| 2 | 1 | 725 | | | 3431 | 4183 | 4570 | | | | | | 0 | 3 | 00 | | 725 |
| 2 | 1 | 767 | | | 4063 | 4140 | 4876 | | | | | | 0 | 3 | 00 | | 767 |
| 2 | 1 | 765 | | | 4093 | 4113 | | 11 | 17 | 16 | 12 | 12 | 0 | 3 | 04 | | 765 |
| 2 | 1 | 715 | | | 3908 | 4093 | | 13 | 18 | 17 | 11 | 11 | 0 | 3 | 04 | | 715 |
| 2 | 1 | 747 | | | 4078 | | | 17 | 19 | 19 | 17 | 17 | 0 | 6 | 00 | | 747 |
| 2 | 1 | 735 | | | 2954 | 4636 | | 12 | 14 | 15 | 14 | 14 | 0 | 6 | 00 | | 735 |
| 2 | 1 | 761 | | | 4063 | | | 19 | 18 | 18 | 20 | 19 | 0 | 6 | 04 | | 761 |
| 2 | 1 | 713 | | | 4055 | 4570 | | 14 | 16 | 17 | 17 | 19 | 0 | 6 | 04 | | 713 |
| 2 | 2 | 734 | | | 3130 | 3352 | 3498 | | | | | | 0 | 0 | 00 | | 734 |
| 2 | 2 | 752 | | | 3130 | 3255 | 3352 | | | | | | 0 | 0 | 00 | | 752 |
| 2 | 2 | 754 | | | | 3130 | 3352 | | | | | | 0 | 0 | 04 | | 754 |
| 2 | 2 | 724 | | | | | 2732 | | | | | | 0 | 0 | 04 | | 724 |
| 2 | 2 | 726 | 2954 | 3255 | 3352 | 3431 | 3498 | | | | | | 0 | 3 | 00 | | 726 |
| 2 | 2 | 768 | | | 3732 | 3846 | 3963 | | | | | | 0 | 3 | 00 | | 768 |
| 2 | 2 | 766 | | | 4450 | 4534 | 4604 | | | | | | 0 | 3 | 04 | | 766 |
| 2 | 2 | 716 | | | 3255 | 3431 | 3556 | | | | | | 0 | 3 | 04 | | 716 |
| 2 | 2 | 748 | | | 4534 | 4570 | 4604 | | | | | | 0 | 6 | 00 | | 748 |
| 2 | 2 | 736 | | | 4093 | 4450 | 4718 | | | | | | 0 | 6 | 00 | | 736 |
| 2 | 2 | 762 | | | 4636 | 5713 | | 19 | 19 | 21 | 11 | 13 | 0 | 6 | 04 | | 762 |
| 2 | 2 | 714 | | | 4055 | 4093 | 4742 | 9 | 13 | 11 | | | 0 | 6 | 04 | | 714 |

*BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.

** BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

## SURFACE TREATMENT EXPERIMENT—DESIGN 6
## FLEXIBLE PAVEMENT, UNWEIGHTED APPLICATIONS

| | | | | | | | | INDEX DAY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | | | (x.xxx) | | | | | (x.x) | | | | (in.) | | |
| 2 | 1 | 733 | | | | 3470 | 3677 | | | | | | 0 | 0 | 00 | 733 |
| 2 | 1 | 751 | | | 3809 | 4458 | 4498 | | | | | | 0 | 0 | 00 | 751 |
| 2 | 1 | 753 | | | 2845 | 4315 | 4836 | | | | | | 0 | 0 | 04 | 753 |
| 2 | 1 | 723 | | | | 3204 | 3398 | | | | | | 0 | 0 | 04 | 723 |
| 2 | 1 | 725 | | | 3398 | 4775 | 4855 | | | | | | 0 | 3 | 00 | 725 |
| 2 | 1 | 767 | | | 4270 | 4766 | 4901 | | | | | | 0 | 3 | 00 | 767 |
| 2 | 1 | 765 | | | 4478 | 4706 | | 11 | 17 | 16 | 12 | 12 | 0 | 3 | 04 | 765 |
| 2 | 1 | 715 | | | 3919 | 4516 | | 13 | 18 | 17 | 11 | 11 | 0 | 3 | 04 | 715 |
| 2 | 1 | 747 | | | 4336 | | | 17 | 19 | 19 | 17 | 17 | 0 | 6 | 00 | 747 |
| 2 | 1 | 735 | | | 2845 | 4863 | | 12 | 14 | 15 | 14 | 14 | 0 | 6 | 00 | 735 |
| 2 | 1 | 761 | | | 4270 | | | 19 | 18 | 18 | 20 | 19 | 0 | 6 | 04 | 761 |
| 2 | 1 | 713 | | | 4219 | 4855 | | 14 | 16 | 17 | 17 | 19 | 0 | 6 | 04 | 713 |
| 2 | 2 | 734 | | | 3061 | 3312 | 3470 | | | | | | 0 | 0 | 00 | 734 |
| 2 | 2 | 752 | | | 3061 | 3204 | 3312 | | | | | | 0 | 0 | 00 | 752 |
| 2 | 2 | 754 | | | | 3061 | 3312 | | | | | | 0 | 0 | 04 | 754 |
| 2 | 2 | 724 | | | | | 2623 | | | | | | 0 | 0 | 04 | 724 |
| 2 | 2 | 726 | 2845 | 3204 | 3312 | 3398 | 3470 | | | | | | 0 | 3 | 00 | 726 |
| 2 | 2 | 768 | | | 3716 | 3849 | 3980 | | | | | | 0 | 3 | 00 | 768 |
| 2 | 2 | 766 | | | 4843 | 4851 | 4859 | | | | | | 0 | 3 | 04 | 766 |
| 2 | 2 | 716 | | | 3204 | 3398 | 3532 | | | | | | 0 | 3 | 04 | 716 |
| 2 | 2 | 748 | | | 4851 | 4855 | 4859 | | | | | | 0 | 6 | 00 | 748 |
| 2 | 2 | 736 | | | 4534 | 4843 | 4874 | | | | | | 0 | 6 | 00 | 736 |
| 2 | 2 | 762 | | | 4863 | 5763 | | 19 | 19 | 21 | 11 | 13 | 0 | 6 | 04 | 762 |
| 2 | 2 | 714 | | | 4219 | 4660 | 4878 | 9 | 13 | 11 | | | 0 | 6 | 04 | 714 |

*BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.
**BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

## SERVICEABILITY TREND EXPERIMENT—DESIGN 1
## FLEXIBLE PAVEMENT, LOOP 1, INNER LANE

| | | | INDEX DAY | | | | | STRUCTURE DESIGN | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 11 | 22 | 33 | 44 | 55 | | | |
| LOOP | LANE | SECTION | SERVICEABILITY TREND VALUES ON INDEX DAY (x.x) | | | | | $D_1$ | $D_2$ (in.) | $D_3$ |
| 1 | 1 | 857 | 33 | 5 | 10 | 8 | 3 | 1 | 0 | 00 |
| 1 | 1 | 867 | 32 | 36 | 36 | 33 | 32 | 1 | 0 | 08 |
| 1 | 1 | 833 | 29 | 30 | 30 | 29 | 30 | 1 | 0 | 16 |
| 1 | 1 | 841 | 26 | 24 | 21 | 20 | 20 | 1 | 0 | 16 |
| 1 | 1 | 827 | 28 | 28 | 24 | 26 | 27 | 1 | 6 | 00 |
| 1 | 1 | 847 | 36 | 36 | 34 | 35 | 36 | 1 | 6 | 08 |
| 1 | 1 | 839 | 32 | 32 | 26 | 33 | 33 | 1 | 6 | 16 |
| 1 | 1 | 859 | 30 | 25 | 28 | 26 | 26 | 3 | 0 | 00 |
| 1 | 1 | 863 | 33 | 33 | 32 | 34 | 32 | 3 | 0 | 00 |
| 1 | 1 | 869 | 32 | 33 | 31 | 32 | 31 | 3 | 0 | 08 |
| 1 | 1 | 829 | 34 | 34 | 32 | 35 | 34 | 3 | 0 | 08 |
| 1 | 1 | 837 | 34 | 35 | 34 | 37 | 37 | 3 | 0 | 16 |
| 1 | 1 | 825 | 36 | 36 | 38 | 37 | 37 | 3 | 6 | 00 |
| 1 | 1 | 851 | 35 | 34 | 34 | 33 | 33 | 3 | 6 | 00 |
| 1 | 1 | 875 | 38 | 39 | 38 | 40 | 40 | 3 | 6 | 08 |
| 1 | 1 | 819 | 38 | 38 | 38 | 37 | 39 | 3 | 6 | 08 |
| 1 | 1 | 821 | 38 | 38 | 37 | 37 | 38 | 3 | 6 | 16 |
| 1 | 1 | 823 | 41 | 43 | 40 | 42 | 41 | 5 | 0 | 00 |
| 1 | 1 | 865 | 39 | 39 | 39 | 37 | 37 | 5 | 0 | 08 |
| 1 | 1 | 877 | 38 | 34 | 35 | 39 | 39 | 5 | 0 | 16 |
| 1 | 1 | 871 | 40 | 42 | 44 | 43 | 44 | 5 | 6 | 00 |
| 1 | 1 | 849 | 39 | 39 | 39 | 39 | 38 | 5 | 6 | 08 |
| 1 | 1 | 879 | 26 | 24 | 28 | 28 | 26 | 5 | 6 | 16 |
| 1 | 1 | 873 | 43 | 42 | 38 | 41 | 41 | 5 | 6 | 16 |

# FACTORIAL EXPERIMENT—DESIGN 1
# RIGID PAVEMENT, UNWEIGHTED APPLICATIONS

| | | | SERVICEABILITY TREND LEVEL | | | | | INDEX DAY | | | | | STRUCTURE DESIGN *** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | |
| | | | | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | | (in.) | | |
| 2 | 1 | 805 | | | | | | 42 | 41 | 43 | 43 | 43 | 0 | 25 | 0 | 805 |
| 2 | 1 | 791 | | | | | | 42 | 40 | 42 | 44 | 44 | 0 | 25 | 3 | 791 |
| 2 | 1 | 785 | | | | | | 44 | 45 | 45 | 45 | 44 | 0 | 25 | 6 | 785 |
| 2 | 1 | 813 | | | | | | 44 | 43 | 44 | 45 | 42 | 0 | 35 | 0 | 813 |
| 2 | 1 | 811 | | | | | | 43 | 42 | 43 | 42 | 40 | 0 | 35 | 3 | 811 |
| 2 | 1 | 787 | | | | | | 45 | 43 | 44 | 44 | 42 | 0 | 35 | 6 | 787 |
| 2 | 1 | 801 | | | | | | 43 | 42 | 42 | 42 | 41 | 0 | 50 | 0 | 801 |
| 2 | 1 | 797 | | | | | | 42 | 41 | 41 | 42 | 39 | 0 | 50 | 3 | 797 |
| 2 | 1 | 777 | 6000 | | | | | 44 | 42 | 40 | 39 | 35 | 0 | 50 | 3 | 777 |
| 2 | 1 | 803 | | | | | | 43 | 43 | 43 | 43 | 41 | 0 | 50 | 6 | 803 |
| 2 | 1 | 781 | | | | | | 43 | 42 | 43 | 42 | 42 | 1 | 25 | 0 | 781 |
| 2 | 1 | 799 | | | | | | 43 | 42 | 44 | 43 | 42 | 1 | 25 | 3 | 799 |
| 2 | 1 | 789 | | | | | | 42 | 42 | 43 | 44 | 44 | 1 | 25 | 6 | 789 |
| 2 | 1 | 793 | | | | | | 43 | 44 | 45 | 45 | 44 | 1 | 35 | 0 | 793 |
| 2 | 1 | 815 | | | | | | 40 | 39 | 40 | 41 | 41 | 1 | 35 | 3 | 815 |
| 2 | 1 | 779 | | | | | | 45 | 45 | 46 | 46 | 45 | 1 | 35 | 3 | 779 |
| 2 | 1 | 783 | | | | | | 45 | 45 | 45 | 45 | 45 | 1 | 35 | 6 | 783 |
| 2 | 1 | 807 | | | | | | 43 | 43 | 43 | 43 | 43 | 1 | 50 | 0 | 807 |
| 2 | 1 | 809 | | | | | | 44 | 45 | 45 | 46 | 46 | 1 | 50 | 3 | 809 |
| 2 | 1 | 795 | | | | | | 43 | 43 | 43 | 45 | 43 | 1 | 50 | 6 | 795 |
| 2 | 2 | 806 | 5405 | 5450 | 5489 | 5540 | 5744 | 43 | 39 | 15 | | | 0 | 25 | 0 | 806 |
| 2 | 2 | 792 | 5918 | 5968 | 6035 | | | 43 | 41 | 43 | 36 | 22 | 0 | 25 | 3 | 792 |
| 2 | 2 | 786 | 5976 | | | | | 46 | 44 | 46 | 39 | 31 | 0 | 25 | 6 | 786 |
| 2 | 2 | 814 | | | | | | 44 | 42 | 44 | 43 | 37 | 0 | 35 | 0 | 814 |
| 2 | 2 | 812 | | | | | | 44 | 43 | 44 | 42 | 40 | 0 | 35 | 3 | 812 |
| 2 | 2 | 788 | | | | | | 44 | 41 | 44 | 42 | 40 | 0 | 35 | 6 | 788 |
| 2 | 2 | 802 | | | | | | 43 | 43 | 43 | 43 | 41 | 0 | 50 | 0 | 802 |
| 2 | 2 | 798 | | | | | | 43 | 42 | 43 | 42 | 41 | 0 | 50 | 3 | 798 |
| 2 | 2 | 778 | | | | | | 43 | 42 | 40 | 39 | 36 | 0 | 50 | 3 | 778 |
| 2 | 2 | 804 | | | | | | 45 | 43 | 44 | 42 | 40 | 0 | 50 | 6 | 804 |
| 2 | 2 | 782 | 5497 | 5533 | 5578 | 5654 | 5671 | 44 | 42 | 20 | | | 1 | 25 | 0 | 782 |
| 2 | 2 | 800 | 5889 | 5920 | 5922 | 5922 | 5924 | 44 | 42 | 44 | 30 | | 1 | 25 | 3 | 800 |
| 2 | 2 | 790 | | | | | | 43 | 43 | 44 | 43 | 38 | 1 | 25 | 6 | 790 |
| 2 | 2 | 794 | | | | | | 46 | 44 | 46 | 45 | 41 | 1 | 35 | 0 | 794 |
| 2 | 2 | 816 | | | | | | 41 | 39 | 40 | 41 | 41 | 1 | 35 | 3 | 816 |
| 2 | 2 | 780 | | | | | | 46 | 45 | 46 | 43 | 42 | 1 | 35 | 3 | 780 |
| 2 | 2 | 784 | | | | | | 46 | 46 | 46 | 47 | 46 | 1 | 35 | 6 | 784 |
| 2 | 2 | 808 | | | | | | 45 | 45 | 46 | 46 | 45 | 1 | 50 | 0 | 808 |
| 2 | 2 | 810 | | | | | | 45 | 44 | 45 | 46 | 46 | 1 | 50 | 3 | 810 |
| 2 | 2 | 796 | | | | | | 43 | 42 | 42 | 44 | 43 | 1 | 50 | 6 | 796 |

*BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.
**BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.
***$D_1$ - 0 = NONREINFORCED; 1 = REINFORCED.
$D_2$ - SLAB THICKNESS.
$D_3$ - SUBBASE THICKNESS.

## FACTORIAL EXPERIMENT—DESIGN 1
## RIGID PAVEMENT, UNWEIGHTED APPLICATION
## (Continued)

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | INDEX DAY | | | | | | | | |
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN *** | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | D$_1$ | D$_2$ | D$_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | |
| 3 | 1 | 195 | 5441 | 5487 | 5489 | 5495 | 5497 | 41 | 39 | | | | 0 | 35 | 3 | 195 |
| 3 | 1 | 239 | 5432 | 5441 | 5447 | 5455 | 5461 | 43 | 40 | | | | 0 | 35 | 6 | 239 |
| 3 | 1 | 213 | 5284 | 5329 | 5388 | 5450 | 5461 | 47 | 27 | | | | 0 | 35 | 9 | 213 |
| 3 | 1 | 225 | | | | | | 43 | 41 | 41 | 41 | 37 | 0 | 50 | 3 | 225 |
| 3 | 1 | 245 | 6047 | | | | | 44 | 43 | 42 | 41 | 35 | 0 | 50 | 6 | 245 |
| 3 | 1 | 221 | 5989 | | | | | 46 | 42 | 43 | 38 | 31 | 0 | 50 | 6 | 221 |
| 3 | 1 | 219 | | | | | | 45 | 44 | 42 | 42 | 37 | 0 | 50 | 9 | 219 |
| 3 | 1 | 217 | | | | | | 48 | 47 | 45 | 46 | 44 | 0 | 65 | 3 | 217 |
| 3 | 1 | 193 | | | | | | 42 | 41 | 40 | 40 | 39 | 0 | 65 | 3 | 193 |
| 3 | 1 | 249 | | | | | | 45 | 45 | 45 | 44 | 41 | 0 | 65 | 6 | 249 |
| 3 | 1 | 207 | | | | | | 46 | 46 | 44 | 44 | 42 | 0 | 65 | 9 | 207 |
| 3 | 1 | 201 | | | | | | 46 | 45 | 45 | 46 | 44 | 0 | 80 | 3 | 201 |
| 3 | 1 | 235 | | | | | | 46 | 46 | 45 | 44 | 43 | 0 | 80 | 6 | 235 |
| 3 | 1 | 185 | | | | | | 44 | 42 | 42 | 42 | 40 | 0 | 80 | 9 | 185 |
| 3 | 1 | 209 | 5382 | 5412 | 5429 | 5438 | 5444 | 47 | 37 | | | | 1 | 35 | 3 | 209 |
| 3 | 1 | 205 | 5174 | 5237 | 5405 | 5432 | 5435 | 45 | 26 | | | | 1 | 35 | 6 | 205 |
| 3 | 1 | 231 | 5435 | 5463 | 5482 | 5495 | 5510 | 45 | 43 | | | | 1 | 35 | 9 | 231 |
| 3 | 1 | 251 | 5955 | 6042 | | | | 40 | 39 | 39 | 38 | 28 | 1 | 50 | 3 | 251 |
| 3 | 1 | 203 | | | | | | 45 | 45 | 45 | 44 | 40 | 1 | 50 | 3 | 203 |
| 3 | 1 | 191 | 5849 | 5851 | 5855 | 5856 | 5860 | 44 | 44 | 43 | | | 1 | 50 | 6 | 191 |
| 3 | 1 | 233 | 5998 | | | | | 46 | 45 | 43 | 39 | 33 | 1 | 50 | 9 | 233 |
| 3 | 1 | 199 | | | | | | 45 | 45 | 45 | 46 | 42 | 1 | 65 | 3 | 199 |
| 3 | 1 | 247 | | | | | | 46 | 45 | 43 | 45 | 43 | 1 | 65 | 6 | 247 |
| 3 | 1 | 237 | | | | | | 47 | 46 | 42 | 47 | 45 | 1 | 65 | 6 | 237 |
| 3 | 1 | 241 | | | | | | 46 | 45 | 44 | 44 | 44 | 1 | 65 | 9 | 241 |
| 3 | 1 | 211 | | | | | | 47 | 46 | 44 | 45 | 43 | 1 | 80 | 3 | 211 |
| 3 | 1 | 215 | | | | | | 46 | 45 | 45 | 46 | 42 | 1 | 80 | 6 | 215 |
| 3 | 1 | 197 | | | | | | 46 | 44 | 44 | 43 | 41 | 1 | 80 | 9 | 197 |
| 3 | 2 | 196 | 5484 | 5489 | 5495 | 5497 | 5502 | 41 | 41 | | | | 0 | 35 | 3 | 196 |
| 3 | 2 | 240 | 5280 | 5303 | 5310 | 5314 | 5321 | 43 | | | | | 0 | 35 | 6 | 240 |
| 3 | 2 | 214 | 5291 | 5332 | 5370 | 5422 | 5473 | 46 | 25 | | | | 0 | 35 | 9 | 214 |
| 3 | 2 | 226 | 5674 | 5755 | 5825 | 5836 | 5848 | 46 | 42 | 36 | | | 0 | 50 | 3 | 226 |
| 3 | 2 | 246 | 5987 | 6034 | | | | 46 | 45 | 43 | 43 | 28 | 0 | 50 | 6 | 246 |
| 3 | 2 | 222 | 5736 | 5882 | 5910 | 5933 | 5954 | 46 | 41 | 38 | 26 | | 0 | 50 | 6 | 222 |
| 3 | 2 | 220 | 5811 | 5845 | 5853 | 5863 | 5887 | 45 | 43 | 41 | | | 0 | 50 | 9 | 220 |
| 3 | 2 | 218 | | | | | | 47 | 45 | 46 | 44 | 42 | 0 | 65 | 3 | 218 |
| 3 | 2 | 194 | | | | | | 43 | 42 | 41 | 42 | 40 | 0 | 65 | 3 | 194 |
| 3 | 2 | 250 | | | | | | 46 | 44 | 44 | 43 | 41 | 0 | 65 | 6 | 250 |
| 3 | 2 | 208 | | | | | | 45 | 42 | 44 | 42 | 40 | 0 | 65 | 9 | 208 |
| 3 | 2 | 202 | | | | | | 46 | 45 | 45 | 45 | 43 | 0 | 80 | 3 | 202 |
| 3 | 2 | 236 | | | | | | 46 | 46 | 45 | 43 | 43 | 0 | 80 | 6 | 236 |
| 3 | 2 | 186 | | | | | | 43 | 43 | 43 | 44 | 42 | 0 | 80 | 9 | 186 |
| 3 | 2 | 210 | 5432 | 5435 | 5438 | 5441 | 5444 | 46 | 41 | | | | 1 | 35 | 3 | 210 |
| 3 | 2 | 206 | 5329 | 5367 | 5415 | 5432 | 5438 | 47 | 30 | | | | 1 | 35 | 6 | 206 |
| 3 | 2 | 232 | 5397 | 5435 | 5441 | 5452 | 5468 | 45 | 41 | | | | 1 | 35 | 9 | 232 |
| 3 | 2 | 252 | 5951 | 5995 | 6018 | 6029 | 6041 | 39 | 40 | 40 | 38 | | 1 | 50 | 3 | 252 |
| 3 | 2 | 204 | 5973 | 5994 | 6008 | 6013 | 6019 | 45 | 44 | 45 | 43 | | 1 | 50 | 3 | 204 |
| 3 | 2 | 192 | 5706 | 5734 | 5751 | 5769 | 5799 | 43 | 43 | 40 | | | 1 | 50 | 6 | 192 |
| 3 | 2 | 234 | 5851 | 5874 | 5889 | 5893 | 5899 | 45 | 44 | 39 | | | 1 | 50 | 9 | 234 |
| 3 | 2 | 200 | | | | | | 46 | 44 | 45 | 45 | 41 | 1 | 65 | 3 | 200 |
| 3 | 2 | 248 | | | | | | 46 | 44 | 42 | 45 | 43 | 1 | 65 | 6 | 248 |
| 3 | 2 | 238 | | | | | | 47 | 44 | 41 | 42 | 41 | 1 | 65 | 6 | 238 |
| 3 | 2 | 242 | | | | | | 46 | 45 | 44 | 46 | 44 | 1 | 65 | 9 | 242 |
| 3 | 2 | 212 | | | | | | 45 | 44 | 43 | 42 | 41 | 1 | 80 | 3 | 212 |
| 3 | 2 | 216 | | | | | | 44 | 44 | 43 | 44 | 40 | 1 | 80 | 6 | 216 |
| 3 | 2 | 198 | | | | | | 45 | 44 | 44 | 44 | 43 | 1 | 80 | 9 | 198 |

## FACTORIAL EXPERIMENT—DESIGN 1
## RIGID PAVEMENT, UNWEIGHTED APPLICATION
## (Continued)

| | | | SERVICEABILITY TREND LEVEL | | | | | INDEX DAY | | | | | STRUCTURE DESIGN *** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | |
| | | | | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* (x.xxx) | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** (x.x) | | | | | D1 | D2 (in.) | D3 | SECTION |
| 4 | 1 | 643 | 5540 | 5681 | 5809 | 5849 | 5855 | 46 | 45 | 31 | | | 0 | 50 | 3 | 643 |
| 4 | 1 | 647 | 5452 | 5475 | 5495 | 5512 | 5547 | 45 | 44 | | | | 0 | 50 | 6 | 647 |
| 4 | 1 | 677 | 5412 | 5435 | 5444 | 5455 | 5463 | 45 | 43 | | | | 0 | 50 | 9 | 677 |
| 4 | 1 | 649 | | | | | | 47 | 46 | 46 | 44 | 38 | 0 | 65 | 3 | 649 |
| 4 | 1 | 697 | | | | | | 45 | 44 | 45 | 45 | 44 | 0 | 65 | 6 | 697 |
| 4 | 1 | 655 | | | | | | 46 | 45 | 45 | 46 | 43 | 0 | 65 | 6 | 655 |
| 4 | 1 | 703 | 5984 | 6021 | | | | 46 | 44 | 43 | 44 | 30 | 0 | 65 | 9 | 703 |
| 4 | 1 | 671 | | | | | | 46 | 45 | 46 | 45 | 44 | 0 | 80 | 3 | 671 |
| 4 | 1 | 687 | | | | | | 45 | 45 | 45 | 46 | 45 | 0 | 80 | 3 | 687 |
| 4 | 1 | 683 | | | | | | 47 | 47 | 47 | 46 | 44 | 0 | 80 | 6 | 683 |
| 4 | 1 | 651 | | | | | | 46 | 45 | 44 | 45 | 43 | 0 | 80 | 9 | 651 |
| 4 | 1 | 675 | | | | | | 44 | 42 | 43 | 43 | 42 | 0 | 95 | 3 | 675 |
| 4 | 1 | 701 | | | | | | 47 | 45 | 46 | 47 | 45 | 0 | 95 | 6 | 701 |
| 4 | 1 | 689 | | | | | | 45 | 43 | 43 | 42 | 41 | 0 | 95 | 9 | 689 |
| 4 | 1 | 681 | 5529 | 5549 | 5577 | 5595 | 5618 | 46 | 44 | | | | 1 | 50 | 3 | 681 |
| 4 | 1 | 661 | 5487 | 5502 | 5510 | 5512 | 5512 | 45 | 43 | | | | 1 | 50 | 6 | 661 |
| 4 | 1 | 673 | 5746 | 5758 | 5762 | 5767 | 5772 | 45 | 44 | 39 | | | 1 | 50 | 9 | 673 |
| 4 | 1 | 641 | | | | | | 45 | 46 | 46 | 42 | 38 | 1 | 65 | 3 | 641 |
| 4 | 1 | 705 | | | | | | 46 | 45 | 45 | 43 | 36 | 1 | 65 | 3 | 705 |
| 4 | 1 | 685 | 6042 | | | | | 46 | 45 | 45 | 44 | 34 | 1 | 65 | 6 | 685 |
| 4 | 1 | 653 | 5983 | 6000 | 6015 | 6037 | | 46 | 46 | 44 | 44 | 18 | 1 | 65 | 9 | 653 |
| 4 | 1 | 691 | | | | | | 46 | 45 | 44 | 42 | 39 | 1 | 80 | 3 | 691 |
| 4 | 1 | 669 | | | | | | 47 | 46 | 46 | 47 | 44 | 1 | 80 | 6 | 669 |
| 4 | 1 | 707 | | | | | | 45 | 43 | 42 | 43 | 39 | 1 | 80 | 6 | 707 |
| 4 | 1 | 695 | | | | | | 47 | 46 | 46 | 46 | 43 | 1 | 80 | 9 | 695 |
| 4 | 1 | 645 | | | | | | 45 | 45 | 41 | 41 | 40 | 1 | 95 | 3 | 645 |
| 4 | 1 | 665 | | | | | | 46 | 46 | 45 | 46 | 45 | 1 | 95 | 6 | 665 |
| 4 | 1 | 667 | | | | | | 47 | 47 | 46 | 48 | 48 | 1 | 95 | 9 | 667 |
| 4 | 2 | 644 | 5480 | 5502 | 5516 | 5525 | 5534 | 46 | 44 | | | | 0 | 50 | 3 | 644 |
| 4 | 2 | 648 | 5376 | 5412 | 5463 | 5512 | 5516 | 46 | 37 | | | | 0 | 50 | 6 | 648 |
| 4 | 2 | 678 | 5438 | 5444 | 5450 | 5455 | 5461 | 45 | 42 | | | | 0 | 50 | 9 | 678 |
| 4 | 2 | 650 | 5603 | 5633 | 5671 | 5694 | 5836 | 46 | 45 | 28 | | | 0 | 65 | 3 | 650 |
| 4 | 2 | 698 | 6032 | | | | | 45 | 45 | 45 | 46 | 34 | 0 | 65 | 6 | 698 |
| 4 | 2 | 656 | 5931 | 5950 | 5965 | 5976 | 5999 | 46 | 45 | 45 | 41 | | 0 | 65 | 6 | 656 |
| 4 | 2 | 704 | 5816 | 5843 | 5851 | 5855 | 5858 | 45 | 44 | 44 | | | 0 | 65 | 9 | 704 |
| 4 | 2 | 672 | | | | | | 45 | 44 | 43 | 42 | 41 | 0 | 80 | 3 | 672 |
| 4 | 2 | 688 | | | | | | 45 | 45 | 45 | 44 | 42 | 0 | 80 | 3 | 688 |
| 4 | 2 | 684 | | | | | | 46 | 46 | 45 | 44 | 42 | 0 | 80 | 6 | 684 |
| 4 | 2 | 652 | | | | | | 44 | 44 | 44 | 43 | 41 | 0 | 80 | 9 | 652 |
| 4 | 2 | 676 | | | | | | 42 | 41 | 42 | 41 | 40 | 0 | 95 | 3 | 676 |
| 4 | 2 | 702 | | | | | | 46 | 45 | 45 | 45 | 42 | 0 | 95 | 6 | 702 |
| 4 | 2 | 690 | | | | | | 45 | 44 | 44 | 44 | 42 | 0 | 95 | 9 | 690 |
| 4 | 2 | 682 | 5401 | 5438 | 5447 | 5458 | 5482 | 45 | 40 | | | | 1 | 50 | 3 | 682 |
| 4 | 2 | 662 | 5149 | 5189 | 5222 | 5233 | 5243 | 43 | | | | | 1 | 50 | 6 | 662 |
| 4 | 2 | 674 | 5559 | 5575 | 5585 | 5598 | 5610 | 44 | 44 | | | | 1 | 50 | 9 | 674 |
| 4 | 2 | 642 | 5901 | 5926 | 5953 | | | 44 | 45 | 41 | 34 | 26 | 1 | 65 | 3 | 642 |
| 4 | 2 | 706 | 5867 | 5885 | 5891 | 5895 | 5899 | 46 | 45 | 46 | | | 1 | 65 | 3 | 706 |
| 4 | 2 | 686 | 5887 | 5891 | 5895 | 5897 | 5901 | 46 | 46 | 46 | | | 1 | 65 | 6 | 686 |
| 4 | 2 | 654 | 5956 | 5971 | 5985 | 6001 | 6015 | 44 | 46 | 44 | 44 | | 1 | 65 | 9 | 654 |
| 4 | 2 | 692 | | | | | | 46 | 46 | 46 | 44 | 40 | 1 | 80 | 3 | 692 |
| 4 | 2 | 670 | | | | | | 45 | 46 | 45 | 46 | 44 | 1 | 80 | 6 | 670 |
| 4 | 2 | 708 | | | | | | 45 | 44 | 45 | 44 | 38 | 1 | 80 | 6 | 708 |
| 4 | 2 | 696 | | | | | | 46 | 45 | 45 | 45 | 42 | 1 | 80 | 9 | 696 |
| 4 | 2 | 646 | | | | | | 45 | 45 | 44 | 43 | 40 | 1 | 95 | 3 | 646 |
| 4 | 2 | 666 | | | | | | 45 | 45 | 45 | 46 | 43 | 1 | 95 | 6 | 666 |
| 4 | 2 | 668 | | | | | | 46 | 46 | 46 | 47 | 46 | 1 | 95 | 9 | 668 |

# FACTORIAL EXPERIMENT—DESIGN 1
## RIGID PAVEMENT, UNWEIGHTED APPLICATION
## (Continued)

| | | | | | | | | INDEX DAY | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN *** | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | (in.) | | | |
| 5 | 1 | 513 | 5858 | 5867 | 5872 | 5876 | 5880 | 45 | 44 | 43 | | | 0 | 65 | 3 | 513 |
| 5 | 1 | 517 | 5867 | 5904 | 5931 | 5945 | 5953 | 43 | 43 | 42 | 30 | | 0 | 65 | 6 | 517 |
| 5 | 1 | 505 | 5685 | 5827 | 5834 | 5841 | 5848 | 42 | 41 | 37 | | | 0 | 65 | 9 | 505 |
| 5 | 1 | 547 | | | | | | 41 | 41 | 41 | 41 | 42 | 0 | 80 | 3 | 547 |
| 5 | 1 | 539 | | | | | | 43 | 42 | 41 | 43 | 42 | 0 | 80 | 6 | 539 |
| 5 | 1 | 533 | | | | | | 42 | 42 | 42 | 43 | 41 | 0 | 80 | 6 | 533 |
| 5 | 1 | 507 | 5978 | 5995 | 6012 | 6029 | 6045 | 44 | 44 | 43 | 44 | | 0 | 80 | 9 | 507 |
| 5 | 1 | 511 | | | | | | 44 | 43 | 43 | 44 | 44 | 0 | 95 | 3 | 511 |
| 5 | 1 | 541 | | | | | | 41 | 40 | 42 | 42 | 43 | 0 | 95 | 3 | 541 |
| 5 | 1 | 525 | | | | | | 43 | 42 | 43 | 42 | 37 | 0 | 95 | 6 | 525 |
| 5 | 1 | 535 | | | | | | 44 | 43 | 44 | 45 | 45 | 0 | 95 | 9 | 535 |
| 5 | 1 | 529 | | | | | | 43 | 42 | 42 | 44 | 41 | 0 | 110 | 3 | 529 |
| 5 | 1 | 497 | | | | | | 45 | 43 | 43 | 45 | 45 | 0 | 110 | 6 | 497 |
| 5 | 1 | 509 | | | | | | 43 | 42 | 42 | 43 | 45 | 0 | 110 | 9 | 509 |
| 5 | 1 | 523 | 5867 | 5893 | 5917 | 5934 | 5953 | 43 | 43 | 43 | 27 | | 1 | 65 | 3 | 523 |
| 5 | 1 | 491 | 5480 | 5505 | 5521 | 5542 | 5566 | 42 | 41 | | | | 1 | 65 | 6 | 491 |
| 5 | 1 | 549 | 5790 | 5813 | 5830 | 5841 | 5849 | 42 | 42 | 39 | | | 1 | 65 | 9 | 549 |
| 5 | 1 | 519 | 5874 | 5904 | 5945 | 6021 | 6042 | 42 | 42 | 42 | 30 | | 1 | 80 | 3 | 519 |
| 5 | 1 | 521 | | | | | | 43 | 43 | 43 | 43 | 43 | 1 | 80 | 3 | 521 |
| 5 | 1 | 501 | | | | | | 43 | 42 | 42 | 43 | 40 | 1 | 80 | 6 | 501 |
| 5 | 1 | 531 | | | | | | 46 | 45 | 45 | 46 | 46 | 1 | 80 | 9 | 531 |
| 5 | 1 | 553 | | | | | | 43 | 42 | 43 | 43 | 43 | 1 | 95 | 3 | 553 |
| 5 | 1 | 543 | | | | | | 43 | 43 | 43 | 44 | 45 | 1 | 95 | 6 | 543 |
| 5 | 1 | 503 | | | | | | 43 | 43 | 42 | 42 | 43 | 1 | 95 | 6 | 503 |
| 5 | 1 | 499 | | | | | | 44 | 45 | 44 | 46 | 44 | 1 | 95 | 9 | 499 |
| 5 | 1 | 515 | | | | | | 44 | 43 | 43 | 44 | 41 | 1 | 110 | 3 | 515 |
| 5 | 1 | 545 | | | | | | 42 | 42 | 41 | 43 | 44 | 1 | 110 | 6 | 545 |
| 5 | 1 | 495 | | | | | | 43 | 42 | 42 | 44 | 44 | 1 | 110 | 9 | 495 |
| 5 | 2 | 514 | 5484 | 5492 | 5500 | 5507 | 5525 | 46 | 45 | | | | 0 | 65 | 3 | 514 |
| 5 | 2 | 518 | 5500 | 5514 | 5527 | 5533 | 5566 | 43 | 43 | | | | 0 | 65 | 6 | 518 |
| 5 | 2 | 506 | 5543 | 5574 | 5600 | 5790 | 5843 | 42 | 41 | 22 | | | 0 | 65 | 9 | 506 |
| 5 | 2 | 548 | | | | | | 42 | 41 | 40 | 41 | 42 | 0 | 80 | 3 | 548 |
| 5 | 2 | 540 | | | | | | 43 | 43 | 42 | 42 | 37 | 0 | 80 | 6 | 540 |
| 5 | 2 | 534 | | | | | | 42 | 42 | 42 | 43 | 42 | 0 | 80 | 6 | 534 |
| 5 | 2 | 508 | 5938 | 5943 | 5946 | 5950 | 5953 | 45 | 45 | 45 | 43 | | 0 | 80 | 9 | 508 |
| 5 | 2 | 512 | | | | | | 45 | 45 | 44 | 41 | 43 | 0 | 95 | 3 | 512 |
| 5 | 2 | 542 | | | | | | 41 | 41 | 42 | 42 | 42 | 0 | 95 | 3 | 542 |
| 5 | 2 | 526 | | | | | | 46 | 45 | 45 | 42 | 40 | 0 | 95 | 6 | 526 |
| 5 | 2 | 536 | | | | | | 41 | 42 | 42 | 43 | 38 | 0 | 95 | 9 | 536 |
| 5 | 2 | 530 | | | | | | 42 | 42 | 42 | 43 | 43 | 0 | 110 | 3 | 530 |
| 5 | 2 | 498 | | | | | | 43 | 43 | 44 | 44 | 45 | 0 | 110 | 6 | 498 |
| 5 | 2 | 510 | | | | | | 44 | 44 | 44 | 44 | 44 | 0 | 110 | 9 | 510 |
| 5 | 2 | 524 | 5820 | 5830 | 5836 | 5841 | 5848 | 43 | 43 | 42 | | | 1 | 65 | 3 | 524 |
| 5 | 2 | 492 | 5438 | 5452 | 5465 | 5475 | 5484 | 43 | 41 | | | | 1 | 65 | 6 | 492 |
| 5 | 2 | 550 | 5470 | 5500 | 5538 | 5633 | 5790 | 42 | 42 | 20 | | | 1 | 65 | 9 | 550 |
| 5 | 2 | 520 | 5869 | 5893 | 5919 | 5954 | 5961 | 43 | 43 | 42 | 28 | | 1 | 80 | 3 | 520 |
| 5 | 2 | 522 | | | | | | 43 | 43 | 42 | 42 | 43 | 1 | 80 | 3 | 522 |
| 5 | 2 | 502 | 5909 | 5940 | 5945 | 5950 | 5954 | 45 | 45 | 44 | 36 | | 1 | 80 | 6 | 502 |
| 5 | 2 | 532 | 6042 | | | | | 44 | 44 | 43 | 44 | 32 | 1 | 80 | 9 | 532 |
| 5 | 2 | 554 | | | | | | 42 | 43 | 42 | 43 | 41 | 1 | 95 | 3 | 554 |
| 5 | 2 | 544 | | | | | | 42 | 43 | 43 | 43 | 43 | 1 | 95 | 6 | 544 |
| 5 | 2 | 504 | | | | | | 45 | 44 | 45 | 44 | 45 | 1 | 95 | 6 | 504 |
| 5 | 2 | 500 | | | | | | 45 | 44 | 45 | 45 | 46 | 1 | 95 | 9 | 500 |
| 5 | 2 | 516 | | | | | | 45 | 45 | 42 | 42 | 43 | 1 | 110 | 3 | 516 |
| 5 | 2 | 546 | | | | | | 43 | 42 | 42 | 43 | 43 | 1 | 110 | 6 | 546 |
| 5 | 2 | 496 | | | | | | 42 | 41 | 42 | 43 | 44 | 1 | 110 | 9 | 496 |

# Factorial Experiment—Design 1
# Rigid Pavement, Unweighted Application
# (Continued)

| | | | | | | | | INDEX DAY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN*** | | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** | | | | | $D_1$ | $D_2$ | $D_3$ | SECTION |
| | | | (x.xxx) | | | | | (x.x) | | | | | | (in.) | | |
| 6 | 1 | 353 | 5878 | 5919 | 5940 | 5941 | 5943 | 40 | 39 | 40 | 32 | | 0 | 80 | 3 | 353 |
| 6 | 1 | 393 | | | | | | 46 | 44 | 44 | 45 | 39 | 0 | 80 | 6 | 393 |
| 6 | 1 | 369 | 6011 | | | | | 42 | 41 | 41 | 39 | 34 | 0 | 80 | 9 | 369 |
| 6 | 1 | 351 | | | | | | 41 | 38 | 41 | 40 | 36 | 0 | 95 | 3 | 351 |
| 6 | 1 | 367 | | | | | | 43 | 42 | 43 | 44 | 43 | 0 | 95 | 6 | 367 |
| 6 | 1 | 389 | | | | | | 43 | 41 | 42 | 42 | 43 | 0 | 95 | 6 | 389 |
| 6 | 1 | 375 | | | | | | 42 | 41 | 42 | 42 | 42 | 0 | 95 | 9 | 375 |
| 6 | 1 | 377 | | | | | | 42 | 42 | 41 | 43 | 42 | 0 | 110 | 3 | 377 |
| 6 | 1 | 363 | | | | | | 43 | 42 | 43 | 44 | 44 | 0 | 110 | 3 | 363 |
| 6 | 1 | 397 | | | | | | 43 | 41 | 42 | 43 | 42 | 0 | 110 | 6 | 397 |
| 6 | 1 | 365 | | | | | | 43 | 41 | 42 | 43 | 43 | 0 | 110 | 9 | 365 |
| 6 | 1 | 395 | | | | | | 43 | 42 | 42 | 44 | 42 | 0 | 125 | 3 | 395 |
| 6 | 1 | 349 | | | | | | 41 | 40 | 40 | 41 | 40 | 0 | 125 | 6 | 349 |
| 6 | 1 | 379 | | | | | | 43 | 42 | 42 | 43 | 42 | 0 | 125 | 9 | 379 |
| 6 | 1 | 341 | 5867 | 5887 | 5889 | 5891 | 5893 | 44 | 43 | 42 | | | 1 | 80 | 3 | 341 |
| 6 | 1 | 385 | 5889 | 5912 | 5934 | 5982 | 5988 | 42 | 42 | 41 | 31 | | 1 | 80 | 6 | 385 |
| 6 | 1 | 347 | 5820 | 5839 | 5851 | 5858 | 5885 | 44 | 44 | 44 | | | 1 | 80 | 9 | 347 |
| 6 | 1 | 381 | | | | | | 43 | 43 | 42 | 44 | 45 | 1 | 95 | 3 | 381 |
| 6 | 1 | 371 | 5917 | 5937 | 5964 | 5978 | | 43 | 43 | 44 | 38 | 16 | 1 | 95 | 3 | 371 |
| 6 | 1 | 403 | | | | | | 43 | 42 | 43 | 44 | 40 | 1 | 95 | 6 | 403 |
| 6 | 1 | 339 | 5899 | 5919 | 5953 | | | 45 | 44 | 44 | 34 | 22 | 1 | 95 | 9 | 339 |
| 6 | 1 | 391 | | | | | | 42 | 41 | 43 | 44 | 44 | 1 | 110 | 3 | 391 |
| 6 | 1 | 337 | | | | | | 42 | 42 | 42 | 43 | 40 | 1 | 110 | 6 | 337 |
| 6 | 1 | 345 | | | | | | 43 | 43 | 44 | 44 | 43 | 1 | 110 | 6 | 345 |
| 6 | 1 | 343 | | | | | | 42 | 41 | 42 | 42 | 42 | 1 | 110 | 9 | 343 |
| 6 | 1 | 359 | | | | | | 43 | 43 | 43 | 44 | 44 | 1 | 125 | 3 | 359 |
| 6 | 1 | 355 | | | | | | 44 | 43 | 44 | 44 | 42 | 1 | 125 | 6 | 355 |
| 6 | 1 | 357 | | | | | | 43 | 43 | 42 | 43 | 45 | 1 | 125 | 9 | 357 |
| 6 | 2 | 354 | 5998 | 6022 | 6036 | 6045 | | 40 | 38 | 39 | 38 | 18 | 0 | 80 | 3 | 354 |
| 6 | 2 | 394 | | | | | | 45 | 44 | 44 | 44 | 41 | 0 | 80 | 6 | 394 |
| 6 | 2 | 370 | 5951 | 5991 | 6019 | 6035 | 6046 | 40 | 40 | 40 | 39 | | 0 | 80 | 9 | 370 |
| 6 | 2 | 352 | 6015 | | | | | 42 | 40 | 41 | 37 | 31 | 0 | 95 | 3 | 352 |
| 6 | 2 | 368 | | | | | | 44 | 42 | 43 | 43 | 43 | 0 | 95 | 6 | 368 |
| 6 | 2 | 390 | | | | | | 44 | 44 | 44 | 44 | 43 | 0 | 95 | 6 | 390 |
| 6 | 2 | 376 | | | | | | 43 | 42 | 43 | 43 | 43 | 0 | 95 | 9 | 376 |
| 6 | 2 | 378 | | | | | | 44 | 43 | 43 | 43 | 43 | 0 | 110 | 3 | 378 |
| 6 | 2 | 364 | | | | | | 45 | 44 | 44 | 43 | 43 | 0 | 110 | 3 | 364 |
| 6 | 2 | 398 | | | | | | 43 | 43 | 44 | 42 | 43 | 0 | 110 | 6 | 398 |
| 6 | 2 | 366 | | | | | | 43 | 42 | 43 | 43 | 43 | 0 | 110 | 9 | 366 |
| 6 | 2 | 396 | | | | | | 43 | 42 | 43 | 43 | 43 | 0 | 125 | 3 | 396 |
| 6 | 2 | 350 | | | | | | 43 | 41 | 42 | 42 | 42 | 0 | 125 | 6 | 350 |
| 6 | 2 | 380 | | | | | | 43 | 42 | 42 | 43 | 44 | 0 | 125 | 9 | 380 |
| 6 | 2 | 342 | 5625 | 5661 | 5690 | 5729 | 5790 | 44 | 43 | 32 | | | 1 | 80 | 3 | 342 |
| 6 | 2 | 386 | 5573 | 5595 | 5610 | 5614 | 5618 | 44 | 43 | | | | 1 | 80 | 6 | 386 |
| 6 | 2 | 348 | 5772 | 5781 | 5786 | 5790 | 5795 | 45 | 45 | 43 | | | 1 | 80 | 9 | 348 |
| 6 | 2 | 382 | | | | | | 43 | 43 | 44 | 44 | 44 | 1 | 95 | 3 | 382 |
| 6 | 2 | 372 | | | | | | 44 | 43 | 44 | 43 | 41 | 1 | 95 | 3 | 372 |
| 6 | 2 | 404 | | | | | | 43 | 42 | 43 | 41 | 40 | 1 | 95 | 6 | 404 |
| 6 | 2 | 340 | 5910 | 5946 | 5956 | 5958 | 5960 | 45 | 46 | 45 | 36 | | 1 | 95 | 9 | 340 |
| 6 | 2 | 392 | | | | | | 43 | 43 | 42 | 44 | 44 | 1 | 110 | 3 | 392 |
| 6 | 2 | 338 | | | | | | 43 | 42 | 43 | 42 | 41 | 1 | 110 | 6 | 338 |
| 6 | 2 | 346 | | | | | | 45 | 44 | 45 | 42 | 42 | 1 | 110 | 6 | 346 |
| 6 | 2 | 344 | | | | | | 44 | 43 | 44 | 44 | 41 | 1 | 110 | 9 | 344 |
| 6 | 2 | 360 | | | | | | 43 | 42 | 42 | 42 | 43 | 1 | 125 | 3 | 360 |
| 6 | 2 | 356 | | | | | | 45 | 44 | 44 | 45 | 44 | 1 | 125 | 6 | 356 |
| 6 | 2 | 358 | | | | | | 43 | 42 | 42 | 43 | 42 | 1 | 125 | 9 | 358 |

## SPECIAL PAVED SHOULDER-SUBBASE STUDIES—DESIGN 3
## RIGID PAVEMENT, UNWEIGHTED APPLICATIONS

| | | | | | | | | INDEX DAY | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11 | 22 | 33 | 44 | 55 | | | |
| | | | | | | | | APPLICATIONS THROUGH INDEX DAY - THOUSANDS | | | | | | | |
| | | | | | | | | 80 | 233 | 445 | 807 | 1114 | | | |
| | | | SERVICEABILITY TREND LEVEL | | | | | LOG APPLICATIONS THROUGH INDEX DAY | | | | | STRUCTURE DESIGN*** | | |
| | | | 3.5 | 3.0 | 2.5 | 2.0 | 1.5 | 4.901 | 5.368 | 5.648 | 5.907 | 6.047 | | | |
| LOOP | LANE | SECTION | LOG UNWEIGHTED APP. TO SERVICEABILITY LEVEL* (x.xxx) | | | | | SERVICEABILITY TREND VALUE ON INDEX DAY** (x.x) | | | | | D1 (in.) | D2 | D3 |
| 3 | 1 | 189 | 5292 | 5325 | 5346 | 5364 | 5383 | | | | | | 0 | 35 | 0 |
| 3 | 1 | 239 | 5433 | 5442 | 5447 | 5456 | 5461 | | | | | | 0 | 35 | 6 |
| 3 | 1 | 229 | | | | | | 45 | 43 | 43 | 43 | 42 | 0 | 65 | 0 |
| 3 | 1 | 249 | | | | | | 45 | 45 | 45 | 44 | 41 | 0 | 65 | 6 |
| 3 | 1 | 223 | 5056 | 5076 | 5095 | 5114 | 5127 | | | | | | 1 | 35 | 0 |
| 3 | 1 | 243 | 5423 | 5450 | 5466 | 5480 | 5493 | | | | | | 1 | 35 | 6 |
| 3 | 1 | 227 | | | | | | 45 | 43 | 43 | 44 | 35 | 1 | 65 | 0 |
| 3 | 1 | 187 | | | | | | 44 | 42 | 41 | 41 | 41 | 1 | 65 | 6 |
| 3 | 2 | 190 | 5247 | 5276 | 5299 | 5318 | 5336 | | | | | | 0 | 35 | 0 |
| 3 | 2 | 240 | 5280 | 5303 | 5311 | 5314 | 5322 | | | | | | 0 | 35 | 6 |
| 3 | 2 | 230 | | | | | | 44 | 43 | 43 | 42 | 40 | 0 | 65 | 0 |
| 3 | 2 | 250 | | | | | | 46 | 44 | 44 | 43 | 41 | 0 | 65 | 6 |
| 3 | 2 | 224 | 5056 | 5076 | 5091 | 5105 | 5118 | | | | | | 1 | 35 | 0 |
| 3 | 2 | 244 | 5358 | 5380 | 5401 | 5426 | 5444 | | | | | | 1 | 35 | 6 |
| 3 | 2 | 228 | 5891 | 5914 | 5935 | 5950 | 5962 | | | | | | 1 | 65 | 0 |
| 3 | 2 | 188 | | | | | | 45 | 44 | 44 | 44 | 40 | 1 | 65 | 6 |
| 4 | 1 | 659 | 5426 | 5447 | 5463 | 5478 | 5490 | | | | | | 0 | 50 | 0 |
| 4 | 1 | 647 | 5453 | 5475 | 5495 | 5512 | 5547 | | | | | | 0 | 50 | 6 |
| 4 | 1 | 663 | | | | | | 45 | 43 | 43 | 44 | 42 | 0 | 80 | 0 |
| 4 | 1 | 683 | | | | | | 47 | 47 | 47 | 46 | 44 | 0 | 80 | 6 |
| 4 | 1 | 693 | 5475 | 5493 | 5508 | 5529 | 5547 | | | | | | 1 | 50 | 0 |
| 4 | 1 | 679 | 5582 | 5675 | 5746 | 5848 | 5881 | | | | | | 1 | 50 | 6 |
| 4 | 1 | 699 | | | | | | 47 | 44 | 45 | 46 | 36 | 1 | 80 | 0 |
| 4 | 1 | 657 | | | | | | 46 | 46 | 45 | 46 | 43 | 1 | 80 | 6 |
| 4 | 2 | 660 | 5401 | 5419 | 5436 | 5447 | 5458 | | | | | | 0 | 50 | 0 |
| 4 | 2 | 648 | 5377 | 5412 | 5463 | 5512 | 5516 | | | | | | 0 | 50 | 6 |
| 4 | 2 | 664 | | | | | | 44 | 43 | 43 | 43 | 24 | 0 | 80 | 0 |
| 4 | 2 | 684 | | | | | | 46 | 46 | 45 | 44 | 42 | 0 | 80 | 6 |
| 4 | 2 | 694 | 5450 | 5468 | 5485 | 5503 | 5518 | | | | | | 1 | 50 | 0 |
| 4 | 2 | 680 | 5533 | 5540 | 5547 | 5557 | 5564 | | | | | | 1 | 50 | 6 |
| 4 | 2 | 700 | 5960 | 5977 | 5997 | 6017 | 6034 | | | | | | 1 | 80 | 0 |
| 4 | 2 | 658 | | | | | | 47 | 46 | 47 | 46 | 43 | 1 | 80 | 6 |
| 5 | 1 | 537 | 5914 | 5938 | 5947 | 5955 | 5962 | | | | | | 0 | 65 | 0 |
| 5 | 1 | 517 | 5868 | 5905 | 5931 | 5945 | 5953 | | | | | | 0 | 65 | 6 |
| 5 | 1 | 493 | | | | | | 41 | 40 | 39 | 40 | 37 | 0 | 95 | 0 |
| 5 | 1 | 525 | | | | | | 43 | 42 | 43 | 42 | 37 | 0 | 95 | 6 |
| 5 | 1 | 555 | 5056 | 5522 | 5540 | 5562 | 5579 | | | | | | 1 | 65 | 0 |
| 5 | 1 | 489 | 5648 | 5926 | 5940 | 5953 | 5963 | | | | | | 1 | 65 | 6 |
| 5 | 1 | 551 | | | | | | 43 | 43 | 43 | 43 | 43 | 1 | 95 | 0 |
| 5 | 1 | 527 | | | | | | 44 | 44 | 44 | 45 | 47 | 1 | 95 | 6 |
| 5 | 2 | 538 | 5800 | 5823 | 5832 | 5841 | 5850 | | | | | | 0 | 65 | 0 |
| 5 | 2 | 518 | 5500 | 5514 | 5527 | 5533 | 5567 | | | | | | 0 | 65 | 6 |
| 5 | 2 | 494 | 5749 | 5779 | 5793 | 5804 | 5816 | | | | | | 0 | 95 | 0 |
| 5 | 2 | 526 | | | | | | 46 | 45 | 45 | 42 | 40 | 0 | 95 | 6 |
| 5 | 2 | 556 | 5114 | 5442 | 5463 | 5482 | 5500 | | | | | | 1 | 65 | 0 |
| 5 | 2 | 490 | 5526 | 5574 | 5651 | 5699 | 5779 | | | | | | 1 | 65 | 6 |
| 5 | 2 | 552 | | | | | | 43 | 42 | 43 | 42 | 43 | 1 | 95 | 0 |
| 5 | 2 | 528 | | | | | | 44 | 43 | 44 | 45 | 45 | 1 | 95 | 6 |
| 6 | 1 | 373 | 5819 | 5830 | 5841 | 5852 | 5858 | | | | | | 0 | 80 | 0 |
| 6 | 1 | 393 | | | | | | 46 | 44 | 44 | 45 | 39 | 0 | 80 | 6 |
| 6 | 1 | 383 | | | | | | 42 | 41 | 41 | 42 | 42 | 0 | 110 | 0 |
| 6 | 1 | 397 | | | | | | 43 | 41 | 42 | 43 | 42 | 0 | 110 | 6 |
| 6 | 1 | 361 | | | | | | 46 | 44 | 46 | 43 | 27 | 1 | 80 | 0 |
| 6 | 1 | 401 | | | | | | 42 | 41 | 40 | 42 | 37 | 1 | 80 | 6 |
| 6 | 1 | 399 | | | | | | 43 | 40 | 41 | 42 | 42 | 1 | 110 | 0 |
| 6 | 1 | 387 | | | | | | 42 | 40 | 41 | 42 | 41 | 1 | 110 | 6 |
| 6 | 2 | 374 | 5567 | 5603 | 5744 | 5768 | 5791 | | | | | | 0 | 80 | 0 |
| 6 | 2 | 394 | | | | | | 45 | 44 | 44 | 44 | 41 | 0 | 80 | 6 |
| 6 | 2 | 384 | 5891 | 5915 | 5937 | 5955 | 5968 | | | | | | 0 | 110 | 0 |
| 6 | 2 | 398 | | | | | | 43 | 43 | 44 | 42 | 43 | 0 | 110 | 6 |
| 6 | 2 | 362 | 5855 | 5864 | 5872 | 5881 | 5889 | | | | | | 1 | 80 | 0 |
| 6 | 2 | 402 | 5526 | 5695 | 5848 | 5887 | 5930 | | | | | | 1 | 80 | 6 |
| 6 | 2 | 400 | | | | | | 44 | 40 | 42 | 40 | 22 | 1 | 110 | 0 |
| 6 | 2 | 388 | | | | | | 43 | 42 | 42 | 43 | 43 | 1 | 110 | 6 |

*BLANK IF TREND DID NOT INCLUDE SERVICEABILITY LEVEL.
**BLANK IF TREND REACHED 1.5 BEFORE INDEX DAY.

***$D_1$ - 0 = NONREINFORCED; 1 = REINFORCED
$D_2$ - SLAB THICKNESS
$D_3$ - SUBBASE THICKNESS.

### SERVICEABILITY TRENDS EXPERIMENT—DESIGN 1
### RIGID PAVEMENT, LOOP 1, INNER LANE

| | | | INDEX DAY | | | | | STRUCTURE DESIGN* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 11 | 22 | 33 | 44 | 55 | | | |
| LOOP | LANE | SECTION | SERVICEABILITY TREND VALUE ON INDEX DAY (x.x) | | | | | $D_1$ | $D_2$ (in.) (x.x) | $D_3$ |
| 1 | 1 | 935 | 43 | 43 | 44 | 44 | 44 | 0 | 25 | 0 |
| 1 | 1 | 933 | 40 | 32 | 38 | 36 | 35 | 0 | 25 | 6 |
| 1 | 1 | 889 | 39 | 42 | 37 | 43 | 38 | 0 | 50 | 0 |
| 1 | 1 | 923 | 48 | 44 | 44 | 47 | 49 | 0 | 50 | 0 |
| 1 | 1 | 925 | 47 | 47 | 48 | 45 | 48 | 0 | 50 | 6 |
| 1 | 1 | 891 | 48 | 47 | 47 | 50 | 49 | 0 | 50 | 6 |
| 1 | 1 | 919 | 47 | 44 | 45 | 44 | 46 | 0 | 95 | 0 |
| 1 | 1 | 917 | 47 | 44 | 45 | 46 | 44 | 0 | 95 | 6 |
| 1 | 1 | 885 | 45 | 42 | 41 | 45 | 42 | 0 | 125 | 0 |
| 1 | 1 | 881 | 48 | 47 | 44 | 48 | 46 | 0 | 125 | 0 |
| 1 | 1 | 909 | 45 | 44 | 44 | 48 | 47 | 0 | 125 | 6 |
| 1 | 1 | 913 | 46 | 47 | 45 | 48 | 46 | 0 | 125 | 6 |
| 1 | 1 | 895 | 43 | 40 | 41 | 43 | 43 | 1 | 25 | 0 |
| 1 | 1 | 897 | 43 | 40 | 40 | 41 | 41 | 1 | 25 | 0 |
| 1 | 1 | 931 | 47 | 42 | 46 | 48 | 47 | 1 | 25 | 6 |
| 1 | 1 | 899 | 45 | 43 | 43 | 44 | 45 | 1 | 25 | 6 |
| 1 | 1 | 905 | 46 | 45 | 43 | 47 | 45 | 1 | 50 | 0 |
| 1 | 1 | 927 | 44 | 43 | 45 | 44 | 45 | 1 | 50 | 6 |
| 1 | 1 | 907 | 48 | 47 | 47 | 48 | 49 | 1 | 95 | 0 |
| 1 | 1 | 921 | 46 | 45 | 46 | 47 | 47 | 1 | 95 | 0 |
| 1 | 1 | 915 | 45 | 43 | 41 | 44 | 44 | 1 | 95 | 6 |
| 1 | 1 | 887 | 47 | 47 | 47 | 48 | 47 | 1 | 95 | 6 |
| 1 | 1 | 883 | 48 | 46 | 47 | 50 | 48 | 1 | 125 | 0 |
| 1 | 1 | 911 | 46 | 42 | 43 | 42 | 45 | 1 | 125 | 6 |

*$D_1$ - 0 = NONREINFORCED; 1 = REINFORCED
$D_2$ - SLAB THICKNESS
$D_3$ - SUBBASE THICKNESS

# Miscellaneous Data

| TIME | | | | | APPLICATIONS | | CLIMATIC DATA | | | | | DEFLECTIONS OF LOOP 1 FLEXIBLE SECTIONS USED IN SEASONAL WEIGHTING FUNCTION (THOUSANDTHS OF INCHES) | | | | | | | | | FLEXIBLE PAVEMENT WEIGHTED APPLICATIONS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CALENDAR DAY | | | INDEX DAY | DAY NO. | MEAN AXLE APP. (100's) | ACCUMULATED MEAN AXLE APP. (100's) | MEAN MAXIMUM TEMP. (°F.) | MEAN MINIMUM TEMP. (°F.) | PRECIPITATION (INCHES) | ACCUMULATED PRECIPITATION (INCHES) | MEAN FROST DEPTH (INCHES) | (DESIGN: SURFACE - BASE - SUBBASE) | | | | | | | | MEAN | SEASONAL WEIGHTING FUNCTION | WEIGHTED APPLICATIONS (100's) | ACCUMULATED WEIGHTED APPLICATIONS (100's) |
| | | | | | | | | | | | | 3-0-8 | 3-0-16 | 3-6-8 | 3-6-16 | 5-0-8 | 5-0-16 | 5-6-8 | 5-6-16 | | | | |
| 11 | 3 | 58 | 855 | 1 | 7 | 7 | 62 | 41 | 1.39 | 1.4 | | 35 | 15 | 17 | 14 | 18 | 13 | 15 | 13 | 17 | 1.28 | 9 | 9 |
| 11 | 19 | 58 | 871 | 2 | 45 | 52 | 60 | 40 | 1.56 | 3.0 | | 48 | 15 | 17 | 15 | 16 | 13 | 14 | 12 | 19 | 1.00 | 45 | 54 |
| 12 | 3 | 58 | 885 | 3 | 62 | 114 | 38 | 21 | .27 | 3.2 | 4 | 17 | 12 | 11 | 12 | 10 | 8 | 9 | 8 | 11 | .87 | 54 | 108 |
| 12 | 17 | 58 | 899 | 4 | 103 | 217 | 19 | - 4 | .39 | 3.6 | 14 | 24 | 14 | 18 | 14 | 12 | 10 | 12 | 10 | 14 | .11 | 11 | 119 |
| 12 | 31 | 58 | 913 | 5 | 69 | 287 | 41 | 21 | .38 | 4.0 | 18 | 4 | 6 | 1 | 6 | 4 | 2 | 5 | 4 | 4 | .07 | 5 | 124 |
| 1 | 14 | 59 | 927 | 6 | 70 | 356 | 29 | 6 | .51 | 4.5 | 22 | | 7 | 8 | 5 | 7 | 5 | 4 | 4 | 3 | 0 | 0 | 124 |
| 1 | 28 | 59 | 941 | 7 | 101 | 457 | 25 | 1 | .90 | 5.4 | 30 | | | | | | | | | | 0 | 0 | 124 |
| 2 | 11 | 59 | 955 | 8 | 127 | 584 | 31 | 9 | 1.35 | 6.8 | 34 | | 1 | | | | | | | | .11 | 14 | 138 |
| 2 | 25 | 59 | 969 | 9 | 112 | 696 | 40 | 23 | 1.05 | 7.8 | 33 | 24 | 10 | 13 | 8 | 8 | 7 | 4 | 5 | 10 | 1.28 | 144 | 282 |
| 3 | 11 | 59 | 983 | 10 | 66 | 762 | 42 | 29 | 1.04 | 8.9 | 16 | 34 | 28 | 22 | 25 | 19 | 14 | 16 | 10 | 21 | 4.55 | 300 | 582 |
| 3 | 25 | 59 | 997 | 11 | 35 | 797 | 45 | 26 | 1.63 | 10.5 | 6 | 48 | 40 | 34 | 34 | 26 | 25 | | 15 | 32 | 4.84 | 169 | 751 |
| 4 | 8 | 59 | 1011 | 12 | 63 | 860 | 55 | 34 | 1.21 | 11.7 | | 42 | 28 | 30 | 30 | 30 | 26 | 22 | 20 | 28 | 4.27 | 269 | 1020 |
| 4 | 22 | 59 | 1025 | 13 | 118 | 978 | 56 | 33 | .43 | 12.1 | | 47 | 26 | 20 | 18 | 32 | 26 | 20 | 17 | 26 | 2.35 | 277 | 1297 |
| 5 | 6 | 59 | 1039 | 14 | 94 | 1072 | 77 | 52 | 1.77 | 13.9 | | 45 | 24 | 20 | 14 | 31 | 19 | 16 | 14 | 23 | 1.78 | 167 | 1464 |
| 5 | 20 | 59 | 1053 | 15 | 133 | 1205 | 71 | 51 | 3.11 | 17.0 | | 37 | 19 | 17 | 14 | 27 | 18 | 17 | 11 | 20 | 1.28 | 171 | 1635 |
| 6 | 3 | 59 | 1067 | 16 | 136 | 1341 | 77 | 57 | 1.14 | 18.1 | | 36 | 21 | 15 | 14 | 22 | 14 | 14 | 11 | 18 | 1.44 | 196 | 1831 |
| 6 | 17 | 59 | 1081 | 17 | 171 | 1512 | 85 | 58 | 1.68 | 19.8 | | 36 | 18 | 14 | 10 | 25 | 16 | 13 | 9 | 18 | 1.00 | 171 | 2002 |
| 7 | 1 | 59 | 1095 | 18 | 174 | 1686 | 85 | 60 | 2.96 | 22.8 | | 32 | 16 | 12 | 10 | 23 | 12 | 13 | 10 | 16 | 1.28 | 223 | 2225 |
| 7 | 15 | 59 | 1109 | 19 | 134 | 1820 | 86 | 57 | .46 | 23.2 | | 32 | 17 | 14 | 11 | 23 | 16 | 12 | 10 | 17 | 1.00 | 134 | 2359 |
| 7 | 29 | 59 | 1123 | 20 | 172 | 1992 | 86 | 64 | 2.22 | 25.5 | | 30 | 15 | 14 | 10 | 20 | 15 | 12 | 9 | 16 | 1.14 | 196 | 2555 |
| 8 | 12 | 59 | 1137 | 21 | 177 | 2169 | 85 | 66 | .69 | 26.2 | | 30 | 17 | 16 | 10 | 22 | 14 | 11 | 10 | 16 | 1.14 | 201 | 2756 |
| 8 | 26 | 59 | 1151 | 22 | 162 | 2331 | 92 | 70 | 1.63 | 27.8 | | 29 | 15 | 14 | 12 | 21 | 13 | 13 | 10 | 16 | .87 | 141 | 2897 |
| 9 | 9 | 59 | 1165 | 23 | 168 | 2499 | 69 | 64 | .16 | 27.9 | | 24 | 15 | 13 | 11 | 18 | 14 | 11 | 9 | 14 | 1.00 | 168 | 3065 |
| 9 | 23 | 59 | 1179 | 24 | 211 | 2710 | 77 | 51 | .91 | 28.9 | | 24 | 15 | 13 | 10 | 17 | 13 | 12 | 10 | 14 | .54 | 114 | 3179 |
| 10 | 7 | 59 | 1193 | 25 | 181 | 2891 | 69 | 55 | 5.96 | 34.8 | | 21 | 14 | 12 | 10 | 14 | 10 | 10 | 8 | 12 | .75 | 136 | 3315 |
| 10 | 21 | 59 | 1207 | 26 | 162 | 3053 | 62 | 40 | .26 | 35.1 | | 22 | 17 | 13 | 11 | 14 | 12 | 10 | 9 | 13 | .54 | 87 | 3402 |
| 11 | 4 | 59 | 1221 | 27 | 186 | 3239 | 58 | 42 | 2.33 | 37.4 | | 16 | 13 | 10 | 8 | 9 | 8 | 8 | 6 | 10 | .44 | 83 | 3485 |
| 11 | 18 | 59 | 1235 | 28 | 144 | 3383 | 43 | 23 | .38 | 37.8 | 2 | 18 | 14 | 11 | 10 | 11 | 8 | 8 | 8 | 11 | .54 | 77 | 3562 |
| 12 | 2 | 59 | 1249 | 29 | 144 | 3527 | 44 | 28 | .45 | 38.2 | 2 | 20 | 13 | 16 | 12 | 10 | 8 | 7 | 8 | 12 | .75 | 108 | 3670 |
| 12 | 16 | 59 | 1263 | 30 | 202 | 3729 | 50 | 34 | .61 | 38.8 | 1 | 20 | 14 | 14 | 11 | 11 | 8 | 7 | 7 | 12 | .87 | 176 | 3846 |
| 12 | 30 | 59 | 1277 | 31 | 124 | 3853 | 45 | 31 | 1.25 | 40.1 | 1 | 23 | 18 | 15 | 13 | 11 | 10 | 10 | 9 | 14 | .22 | 27 | 3873 |
| 1 | 13 | 60 | 1291 | 32 | 225 | 4078 | 48 | 31 | 1.76 | 41.9 | 9 | 6 | 4 | 6 | 5 | 4 | 4 | 4 | 5 | 5 | .16 | 36 | 3909 |
| 1 | 27 | 60 | 1305 | 33 | 368 | 4446 | 24 | 8 | .52 | 42.4 | 10 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | .28 | 105 | 4014 |
| 2 | 10 | 60 | 1319 | 34 | 354 | 4800 | 31 | 22 | 1.02 | 43.4 | 17 | 25 | 20 | 20 | 17 | 11 | 13 | 11 | 10 | 16 | .44 | 157 | 4171 |
| 2 | 24 | 60 | 1333 | 35 | 255 | 5055 | 23 | 7 | .43 | 43.8 | 21 | 10 | 8 | 10 | 4 | 5 | 6 | 5 | 4 | 7 | .22 | 56 | 4227 |
| 3 | 9 | 60 | 1347 | 36 | 342 | 5397 | 18 | 1 | 1.64 | 45.5 | 27 | 1 | | 1 | 1 | 2 | 1 | 1 | | 1 | .16 | 55 | 4282 |
| 3 | 23 | 60 | 1361 | 37 | 302 | 5699 | 29 | 11 | .27 | 45.7 | 29 | 24 | 20 | 19 | 15 | 8 | 10 | 6 | 7 | 13 | 1.60 | 484 | 4766 |
| 4 | 6 | 60 | 1375 | 38 | 315 | 6014 | 49 | 28 | .54 | 46.3 | 12 | 46 | 31 | 30 | 24 | 20 | 18 | 16 | 16 | 25 | 4.27 | 1345 | 6111 |
| 4 | 20 | 60 | 1389 | 39 | 326 | 6340 | 63 | 40 | 2.27 | 48.5 | | 52 | 31 | 25 | 22 | 32 | 25 | 24 | 18 | 29 | 3.48 | 1136 | 7247 |
| 5 | 4 | 60 | 1403 | 40 | 352 | 6692 | 75 | 51 | 1.05 | 49.6 | | 41 | 22 | 21 | 14 | 23 | 18 | 16 | 14 | 21 | 1.28 | 452 | 7699 |
| 5 | 18 | 60 | 1417 | 41 | 355 | 7047 | 63 | 43 | 2.34 | 51.9 | | 26 | 18 | 14 | 11 | 13 | 11 | 11 | 9 | 14 | .75 | 267 | 7966 |
| 6 | 1 | 60 | 1431 | 42 | 289 | 7336 | 78 | 58 | 1.36 | 53.3 | | 30 | 20 | 16 | 12 | 19 | 9 | 14 | 11 | 17 | 1.00 | 289 | 8255 |
| 6 | 15 | 60 | 1445 | 43 | 377 | 7713 | 79 | 56 | 2.68 | 56.0 | | 31 | 20 | 15 | 11 | 19 | 13 | 14 | 10 | 17 | 1.78 | 670 | 8925 |
| 6 | 29 | 60 | 1459 | 44 | 355 | 8068 | 81 | 60 | 1.08 | 57.0 | | 34 | 21 | 17 | 14 | 24 | 17 | 17 | 13 | 19 | 1.44 | 511 | 9436 |
| 7 | 13 | 60 | 1473 | 45 | 261 | 8329 | 89 | 56 | .66 | 57.7 | | 36 | 20 | 16 | 10 | 24 | 18 | 16 | 12 | 19 | 1.78 | 464 | 9900 |
| 7 | 27 | 60 | 1487 | 46 | 348 | 8677 | 86 | 61 | .80 | 58.5 | | 32 | 19 | 14 | 12 | 24 | 16 | 14 | 12 | 18 | 1.28 | 447 | 10347 |
| 8 | 10 | 60 | 1501 | 47 | 337 | 9014 | 85 | 62 | 2.48 | 61.0 | | 30 | 22 | 13 | 11 | 22 | 15 | 14 | 10 | 17 | 1.14 | 384 | 10731 |
| 8 | 24 | 60 | 1515 | 48 | 277 | 9291 | 84 | 57 | 2.47 | 63.4 | | 27 | 19 | 14 | 11 | 18 | 13 | 12 | 10 | 15 | 1.00 | 277 | 11008 |
| 9 | 7 | 60 | 1529 | 49 | 221 | 9512 | 93 | 66 | | 63.4 | | 28 | 16 | 13 | 10 | 21 | 16 | 14 | 11 | 16 | .87 | 192 | 11200 |
| 9 | 21 | 60 | 1543 | 50 | 326 | 9838 | 76 | 53 | 1.05 | 64.5 | | 26 | 17 | 12 | 11 | 16 | 13 | 12 | 9 | 15 | 1.00 | 326 | 11526 |
| 10 | 5 | 60 | 1557 | 51 | 318 | 10156 | 72 | 47 | .79 | 65.3 | | 24 | 17 | 12 | 11 | 14 | 12 | 11 | 8 | 14 | .75 | 239 | 11765 |
| 10 | 19 | 60 | 1571 | 52 | 340 | 10496 | 70 | 43 | .30 | 65.6 | | 21 | 15 | 12 | 10 | 13 | 11 | 10 | 8 | 13 | .64 | 218 | 11982 |
| 11 | 2 | 60 | 1585 | 53 | 309 | 10805 | 59 | 40 | 1.67 | 67.2 | | 19 | 14 | 11 | 10 | 12 | 8 | 9 | 8 | 11 | .54 | 166 | 12148 |
| 11 | 16 | 60 | 1599 | 54 | 191 | 10996 | 55 | 37 | .79 | 68.0 | | 19 | 15 | 11 | 11 | 10 | 8 | 8 | 7 | 11 | .28 | 54 | 12202 |
| 11 | 30 | 60 | 1613 | 55 | 142 | 11138 | 55 | 36 | .21 | 68.2 | | 15 | 11 | 10 | 8 | 9 | 8 | 8 | 7 | 9 | .44 | 63 | 12265 |
| 12 | 5 | 60 | 1618 | | | | | | | | | 23 | 20 | 14 | 14 | 12 | 8 | 10 | 8 | 14 | | | |

# FALL CREEP SPEED DEFLECTION DATA;
# MEAN OF TESTS—OCTOBER 8 AND NOVEMBER 19, 1958

| LOOP 2 | | LOOP 3 | | | LOOP 4 | | | | LOOP 5 | | | | LOOP 6 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LANE | | LANE | | | LANE | | | | LANE | | | | LANE | | |
| DESIGN S BASE SUB | 2 | DESIGN | 1 | 2 | DESIGN | 1 | 1 | 2 | DESIGN | 1 | 1 | 2 | DESIGN | 1 | 1 | 2 |
| | 6 KS | | 12 KS | 12 KS | | 12 KS | 18 KS | 12 KS | | 12 KS | 22.4 KS | 12 KS | | 12 KS | 30 KS | 12 KS |
| in. | $10^{-3}$ in. | | $10^{-3}$ in. | $10^{-3}$ in. | | $10^{-3}$ in. | $10^{-3}$ in. | $10^{-3}$ in. | | $10^{-3}$ in. | $10^{-3}$ in. | $10^{-3}$ in. | | $10^{-3}$ in. | $10^{-3}$ in. | $10^{-3}$ in. |
| 1-0-0 | 70 | 2-0-0 | 38 | 41 | 3-0-4 | 69 | 121 | 50 | 3-3-4 | 47 | 99 | 43 | 4-3-8 | 30 | 86 | 24 |
| 1-0-4 | 71 | 2-0-4 | 78 | 61 | 3-0-8 | 46 | 72 | 33 | 3-3-8 | 44 | 64 | 32 | 4-3-12 | 13 | 33 | 14 |
| 1-3-0 | 20 | 2-0-8 | 34 | 35 | 3-0-12 | 26 | 47 | 19 | 3-3-12 | 23 | 35 | 19 | 4-3-16 | 16 | 46 | 18 |
| 1-3-4 | 75 | 2-0-8R | 28 | 30 | 3-0-12R | 20 | 29 | 16 | 3-3-12R | 32 | 50 | 26 | 4-3-16R | 19 | 48 | 20 |
| 1-6-0 | 19 | 2-3-0 | 34 | 34 | 3-3-4 | 39 | 62 | 30 | 3-6-4 | 44 | 67 | 34 | 4-6-8 | 18 | 47 | 18 |
| 1-6-4 | 28 | 2-3-4 | 40 | 28 | 3-3-8 | 29 | 43 | 26 | 3-6-8 | 30 | 54 | 25 | 4-6-12 | 21 | 58 | 22 |
| 2-0-0 | 17 | 2-3-8 | 35 | 33 | 3-3-12 | 20 | 30 | 23 | 3-6-12 | 24 | 33 | 19 | 4-6-16 | 16 | 37 | 17 |
| 2-0-4 | 42 | 2-6-0 | 36 | 31 | 3-6-4 | 46 | 72 | 35 | 3-9-4 | 40 | 61 | 33 | 4-9-8 | 22 | 63 | 18 |
| 2-3-0 | 10 | 2-6-4 | 38 | 40 | 3-6-8 | 32 | 47 | 23 | 3-9-8 | 33 | 51 | 30 | 4-9-12 | 18 | 57 | 20 |
| 2-3-0R | 17 | 2-6-8 | 24 | 25 | 3-6-12 | 22 | 32 | 18 | 3-9-12 | 26 | 42 | 27 | 4-9-16 | 14 | 40 | 20 |
| 2-3-4 | 22 | 3-0-0 | 44 | 33 | 4-0-4 | 39 | 77 | 27 | 4-3-4 | 65 | 130 | 45 | 5-3-8 | 18 | 58 | 17 |
| 2-3-4R | 28 | 3-0-4 | 28 | 26 | 4-0-8 | 23 | 37 | 21 | 4-3-8 | 24 | 47 | 26 | 5-3-12 | 15 | 42 | 16 |
| 2-6-0 | 11 | 3-0-8 | 24 | 23 | 4-0-12 | 22 | 32 | 17 | 4-3-12 | 27 | 43 | 26 | 5-3-16 | 15 | 41 | 16 |
| 2-6-0R | 14 | 3-3-0 | 71 | 57 | 4-3-4 | 32 | 53 | 26 | 4-6-4 | 28 | 44 | 29 | 5-6-8 | 19 | 55 | 20 |
| 2-6-4 | 21 | 3-3-4 | 29 | 27 | 4-3-8 | 28 | 42 | 21 | 4-6-8 | 29 | 50 | 29 | 5-6-12 | 11 | 35 | 18 |
| 2-6-4R | 25 | 3-3-4R | 41 | 42 | 4-3-8R | 27 | 47 | 23 | 4-6-8R | 30 | 46 | 28 | 5-6-12R | 13 | 36 | 18 |
| 3-0-0 | 20 | 3-3-8 | 32 | 29 | 4-3-12 | 19 | 31 | 18 | 4-6-12 | 24 | 36 | 22 | 5-6-16 | 15 | 35 | 16 |
| 3-0-4 | 22 | 3-6-0 | 35 | 35 | 4-6-4 | 34 | 57 | 30 | 4-9-4 | 34 | 57 | 34 | 5-9-8 | 15 | 44 | 16 |
| 3-3-0 | 11 | 3-6-4 | 36 | 34 | 4-6-8 | 25 | 37 | 22 | 4-9-8 | 28 | 45 | 25 | 5-9-12 | 16 | 39 | 16 |
| 3-3-4 | 17 | 3-6-8 | 31 | 25 | 4-6-12 | 23 | 31 | 17 | 4-9-12 | 19 | 30 | 21 | 5-9-16 | 14 | 39 | 18 |
| 3-6-0 | 12 | 4-0-0 | 54 | 42 | 5-0-4 | 45 | 74 | 25 | 5-3-4 | 38 | 63 | 30 | 6-3-8 | 13 | 40 | 14 |
| 3-6-4 | 14 | 4-0-4 | 37 | 32 | 5-0-8 | 29 | 50 | 21 | 5-3-8 | 28 | 49 | 23 | 6-3-12 | 14 | 36 | 14 |
| | | 4-0-8 | 50 | 37 | 5-0-12 | 20 | 32 | 15 | 5-3-12 | 20 | 31 | 19 | 6-3-16 | 13 | 36 | 13 |
| | | 4-3-0 | 36 | 26 | 5-3-4 | 25 | 36 | 21 | 5-6-4 | 35 | 66 | 33 | 6-6-8 | 14 | 50 | 19 |
| | | 4-3-4 | 43 | 30 | 5-3-8 | 24 | 34 | 18 | 5-6-8 | 26 | 48 | 23 | 6-6-2 | 12 | 38 | 15 |
| | | 4-3-8 | 28 | 23 | 5-3-12 | 24 | 32 | 16 | 5-6-12 | 21 | 33 | 18 | 6-6-16 | 10 | 30 | 12 |
| | | 4-6-0 | 28 | 27 | 5-6-4 | 25 | 38 | 16 | 5-9-4 | 23 | 41 | 22 | 6-9-8 | 15 | 47 | 16 |
| | | 4-6-0R | 29 | 32 | 5-6-4R | 25 | 38 | 20 | 5-9-4R | 24 | 40 | 23 | 6-9-8R | 18 | 54 | 17 |
| | | 4-6-4 | 28 | 28 | 5-6-8 | 19 | 33 | 18 | 5-9-8 | 23 | 35 | 20 | 6-9-12 | 12 | 35 | 14 |
| | | 4-6-8 | 20 | 19 | 5-6-12 | 19 | 30 | 17 | 5-9-12 | 23 | 35 | 18 | 6-9-16 | 14 | 35 | 15 |

R = Replicate

Appendix C

# SPRING CREEP SPEED DEFLECTION DATA; MEAN OF TESTS—MARCH 9 AND MARCH 31, 1959

| LOOP 2 | | LOOP 3 | | | LOOP 4 | | | | LOOP 5 | | | | LOOP 6 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DESIGN | LANE | DESIGN | LANE | | DESIGN | LANE | | | DESIGN | LANE | | | DESIGN | LANE | | |
| S BASE SUB | 2 | | 1 | 2 | | 1 | 1 | 2 | | 1 | 1 | 2 | | 1 | 1 | 2 |
| | 6 KS | | 12 KS | 12 KS | | 12 KS | 18 KS | 12 KS | | 12 KS | 22.4 KS | 12 KS | | 12 KS | 30 KS | 12 KS |
| in. | $10^{-3}$ in. | | $10^{-3}$ in. | $10^{-3}$ in. | | $10^{-3}$ in. | $10^{-3}$ in. | $10^{-3}$ in. | | $10^{-3}$ in. | $10^{-3}$ in. | $10^{-3}$ in. | | $10^{-3}$ in. | $10^{-3}$ in. | $10^{-3}$ in. |
| 1-0-0 | 130* | 3-0-0 | 76 | 70* | 3-0-4 | 142* | 182* | 132* | 4-3-4 | 85* | 110* | 62* | 4-3-8 | 70* | 147* | 49 |
| 1-0-4 | 110* | 3-0-4 | 56 | 44 | 3-0-8 | 80* | 120* | 65* | 4-3-8 | 50 | 80 | 48 | 4-3-12 | 28 | 60 | 28 |
| 1-3-0 | 90* | 3-0-8 | 52 | 66 | 3-0-12 | 52 | 77 | 46 | 4-3-12 | 40 | 76 | 45 | 4-3-16 | 42 | 92 | 30 |
| 1-3-4 | 77 | 3-3-0 | 72* | 78* | 3-0-12R | 48 | 56 | 40 | 4-6-4 | 71 | 90 | 58 | 4-3-16R | 46 | 97 | 36 |
| 1-6-0 | 62 | 3-3-4 | 46 | 38 | 3-3-4 | 80* | 120* | 78* | 4-6-8 | 44 | 78 | 46 | 4-6-8 | 50 | 88* | 31 |
| 1-6-4 | 44 | 3-3-4R | 63 | 72 | 3-3-8 | 70 | 86 | 57 | 4-6-8R | 40 | 62 | 43 | 4-6-12 | 62 | 141 | 48 |
| 2-0-0 | 70* | 3-3-8 | 51 | 68 | 3-3-12 | 36 | 45 | 29 | 4-6-12 | 32 | 50 | 30 | 4-6-16 | 37 | 59 | 26 |
| 2-0-4 | 56 | 3-6-0 | 74 | 55 | 3-6-4 | 75* | 112* | 90* | 4-9-4 | 54 | 97 | 50 | 4-9-8 | 64 | 109* | 38 |
| 2-3-0 | 32 | 3-6-4 | 54 | 56 | 3-6-8 | 57 | 66 | 46 | 4-9-8 | 40 | 71 | 42 | 4-9-12 | 40 | 82 | 33 |
| 2-3-0R | 40 | 3-6-8 | 44 | 37 | 3-6-12 | 34 | 48 | 33 | 4-9-12 | 28 | 44 | 26 | 4-9-16 | 27 | 56 | 28 |
| 2-3-4 | 32 | 4-0-0 | 69 | 65* | 4-0-4 | 74 | 83 | 70* | 5-3-4 | 51 | 95 | 44 | 5-3-8 | 52 | 96 | 33 |
| 2-3-4R | 28 | 4-0-4 | 67 | 66 | 4-0-8 | 32 | 44 | 40 | 5-3-8 | 40 | 60 | 34 | 5-3-12 | 37 | 76 | 27 |
| 2-6-0 | 24 | 4-0-8 | 70 | 74 | 4-0-12 | 34 | 38 | 30 | 5-3-12 | 29 | 48 | 25 | 5-3-16 | 30 | 65 | 26 |
| 2-6-0R | 28 | 4-3-0 | 59 | 46 | 4-3-4 | 65 | 79 | 61 | 5-6-4 | 46 | 72 | 40 | 5-6-8 | 44 | 87 | 32 |
| 2-6-4 | 26 | 4-3-4 | 54 | 56 | 4-3-8 | 49 | 62 | 46 | 5-6-8 | 29 | 57 | 28 | 5-6-12 | 32 | 64 | 26 |
| 2-6-4R | 26 | 4-3-8 | 39 | 36 | 4-3-8R | 44 | 53 | 42 | 5-6-12 | 24 | 43 | 24 | 5-6-12R | 30 | 64 | 24 |
| 3-0-0 | 30 | 4-6-0 | 46 | 44 | 4-3-12 | 35 | 42 | 31 | 5-9-4 | 31 | 54 | 30 | 5-6-16 | 22 | 47 | 23 |
| 3-0-4 | 36 | 4-6-0R | 59 | 57 | 4-6-4 | 60 | 63 | 51 | 5-9-4R | 33 | 60 | 32 | 5-9-8 | 38 | 72 | 27 |
| 3-3-0 | 24 | 4-6-4 | 39 | 38 | 4-6-8 | 36 | 47 | 31 | 5-9-8 | 21 | 47 | 26 | 5-9-12 | 28 | 54 | 24 |
| 3-3-4 | 22 | 4-6-8 | 31 | 25 | 4-6-12 | 31 | 40 | 29 | 5-9-12 | 24 | 36 | 22 | 5-9-16 | 26 | 54 | 22 |
| 3-6-0 | 21 | | | | 5-0-4 | 48 | 58 | 38 | | | | | 6-3-8 | 25 | 56 | 22 |
| 3-6-4 | 18 | | | | 5-0-8 | 38 | 41 | 42 | | | | | 6-3-12 | 30 | 62 | 22 |
| | | | | | 5-0-12 | 26 | 34 | 27 | | | | | 6-3-16 | 24 | 58 | 18 |
| | | | | | 5-3-4 | 38 | 44 | 40 | | | | | 6-6-8 | 33 | 78 | 26 |
| | | | | | 5-3-8 | 29 | 44 | 30 | | | | | 6-6-12 | 25 | 54 | 20 |
| | | | | | 5-3-12 | 28 | 36 | 29 | | | | | 6-6-16 | 18 | 36 | 17 |
| | | | | | 5-6-4 | 30 | 42 | 30 | | | | | 6-9-8 | 31 | 66 | 24 |
| | | | | | 5-6-4R | 30 | 38 | 30 | | | | | 6-9-8R | 26 | 65 | 22 |
| | | | | | 5-6-8 | 30 | 36 | 29 | | | | | 6-9-12 | 23 | 51 | 21 |
| | | | | | 5-6-12 | 28 | 32 | 26 | | | | | 6-9-16 | 17 | 40 | 18 |

R = REPLICATE
* = ESTIMATED VALUE

# Appendix D

## TEST PROCEDURES AND EQUIPMENT

### FLEXIBLE PAVEMENT DEFLECTION TEST*

All deflections in the flexible pavement experiment were measured with either the Benkelman beam or the linear variable differential transformer (LVDT). Schematic drawings of the Benkelman beam and the LVDT are shown in Figures 1-D and 2-D.

#### *Benkelman Beam Deflections*

Two procedures were employed in tests with the beam. In one, termed "creep speed normal," the probe arm of the beam was inserted between the dual tires of a loaded test vehicle to a distance of about 4½ ft, lining up the arm by eye in such a position that rubbing of the probe arm and the tires would not occur. While the truck was standing, the buzzer was turned on and the initial reading of the dial taken. The vehicle was then moved slowly forward (creep speed) until it was at least 10 ft past the tip of the beam. While the vehicle was being moved forward, a maximum dial reading was recorded which occurred when the dual tires were opposite the contact point. When the vehicle had moved well past the contact point of the probe arm and the dial hand had come to rest, the final reading was recorded. The difference between the initial and load reading multiplied by two was the deflection.

In the other procedure, termed "creep speed rebound," the probe was inserted between the tires to a distance of about 1½ ft, a load reading taken as the wheels passed the probe and a final reading taken with the load out of range of influence. Here the difference in the two readings multipled by two was the deflection.

#### *LVDT Pavement Deflections*

The LVDT equipment consisted of a small transformer tubing, a steel reference rod and a perforated steel plate. The perforated plates were placed at the pavement layer interfaces and in the embankment during construction. After the pavement was completed, a hole was formed down to each plate and a section of tubing was inserted. The lower part of the tubing was of a special flexible type. The upper part, extending to the top of the surface

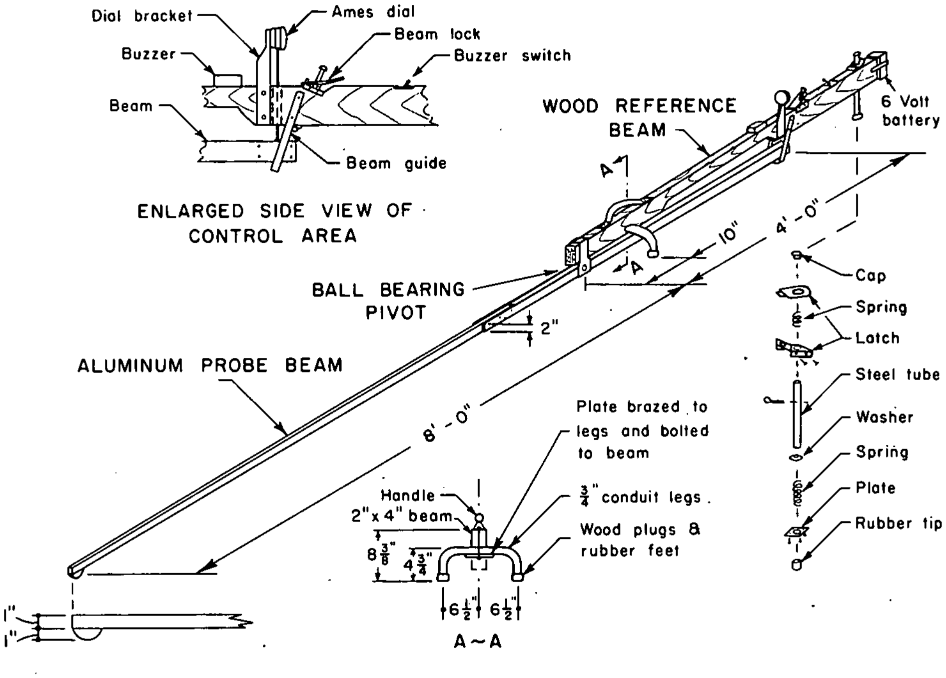

**Figure 1-D. Benkelman deflection beam.**

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* For description of deflection tests made on rigid pavements see Section 3.3.1.

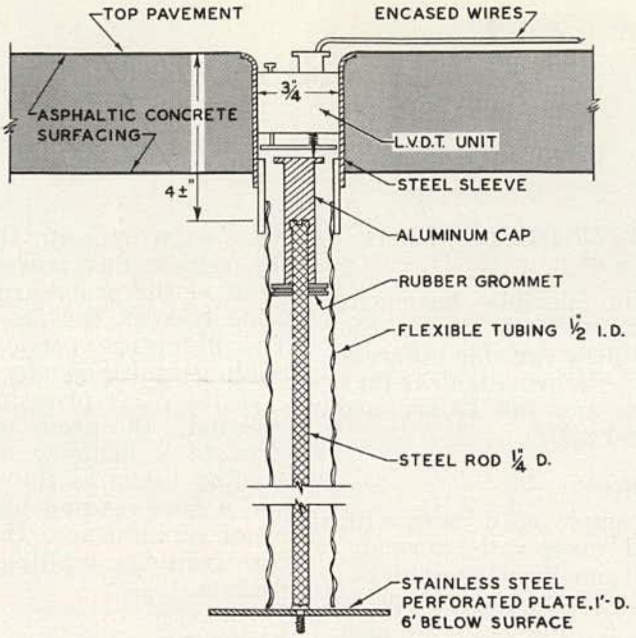

Figure 2–D. LVDT deflection assembly.

consisted of a steel sleeve that was bonded to the surfacing with epoxy resin. The steel rod with a sheet metal screw attached to one end was screwed into the plate. For cases where the perforated plates could not be located the steel rods were secured at the desired depth with cement mortar. An aluminum cap was cemented to the top of the road at a level slightly beneath the pavement surface. When in use the LVDT was anchored to the steel sleeve and the core of the LVDT unit maintained contact with the aluminum cap by means of a small coil spring. When not in use the LVDT unit was removed and the hole was sealed with a special type of stopper.

An instrument van contained all the necessary electronic equipment for operating the LVDTs and recording the deflection. Figures 3-D and 4-D show the exterior and interior of the van.

Measurements were made with the loaded test vehicle driven at a selected speed so that the center of the dual wheels passed, as closely as possible, over the transformer. Either a continuous record of the vertical movement of the transformer relative to the plate was recorded on graph paper or the maximum vertical movement was recorded on punched tape.

### *Plate Load Tests*

Basic equipment consisted of: (1) reaction trailer; (2) hydraulic ram and jack; (3) various sizes of steel spacers for use in trenches of different depths; (4) a 12-in. diameter cylindrical steel loading frame cut out on two sides to allow use of center deflection dial; (5) spherical bearing block; (6) 1-in. thick

TABLE 1–D

Plate Sizes and Pressures, Plate Load Test

The following plate sizes and their corresponding pressures were used for routine plate load testing on Loop 1 and in trenches on the main loops:

| Layer | Plate Diameter (in.) | Pressures (psi) | Notes |
|---|---|---|---|
| (*a*) Flexible Pavement | | | |
| Surface | 12 | 16, 32, 48 | 1, 2, 3 |
| | 12 | 16, 48, 70 | 1, 3, 4 |
| | 18 | 16, 32, 48 | 3 |
| | 24 | 10, 20, 28 | 3 |
| Base | 12 | 16, 32, 48 | |
| | 18 | 16, 32, 48 | 1 |
| | 24 | 10, 20, 28 | |
| Subbase | 18 | 10, 20, 28 | |
| | 24 | 10, 20, 28 | 1 |
| | 30 | 5, 10, 15 | |
| Embankment | 18 | 5, 15, 25 | |
| | 24 | 5, 15, 25 | 1 |
| | 30 | 5, 10, 15 | |
| (*b*) Rigid Pavement | | | |
| Surface | 12 | 35, 70, 105 | 1 |
| Subbase | 24 | 5, 10, 25 | |
| | 30 | 5, 10, 15 | 1 |
| Embankment | 18 | 5, 15, 25 | |
| | 24 | 5, 10, 15 | |
| | 30 | 5, 10, 15 | 1 |

[1] Plate and pressures used for all routine testing.

[2] Used on 3–0–0, 3–6–0 and 3–0–8 design sections.

[3] Instructions were that total gross deflection should not exceed 0.20 in.

[4] Used on 3–6–8, 3–6–16 and 3–0–16 design sections.

Figure 3–D. Exterior view of instrument van.

steel plates, 12, 18, 24 and 30 in. in diameter; (7) 16-ft long aluminum reference beam. A schematic diagram of the apparatus is shown in Figure 5-D.

The reaction trailer was of the flat-bed type, having no springs and four sets of dual wheels on the rear. For the tests on the AASHO Road Test a cantilever beam protruding from the rear of the trailer was used as a reaction. The distance load to rear wheels was 8 ft. A maximum reaction of about 12,000 lb could be obtained with a 17,000-lb loaded rear axle.

A standard hydraulic ram was used to apply the load. A calibration curve, which was checked periodically, was used to convert gage pressures to load in pounds. The load was applied to the plates through the 12-in. diameter steel loading frame and the spherical bearing block. Deflection was measured with a dial gage (Fig. 4-D).

The weight of the loading frame and plates was allowed to act as a seating load for which no correction was made.

Tests were made in trenches about 3 to 4 ft wide. The procedure provided for the application and release of three different psi loads and for measurement of the downward and upward movement of the plates. The loads

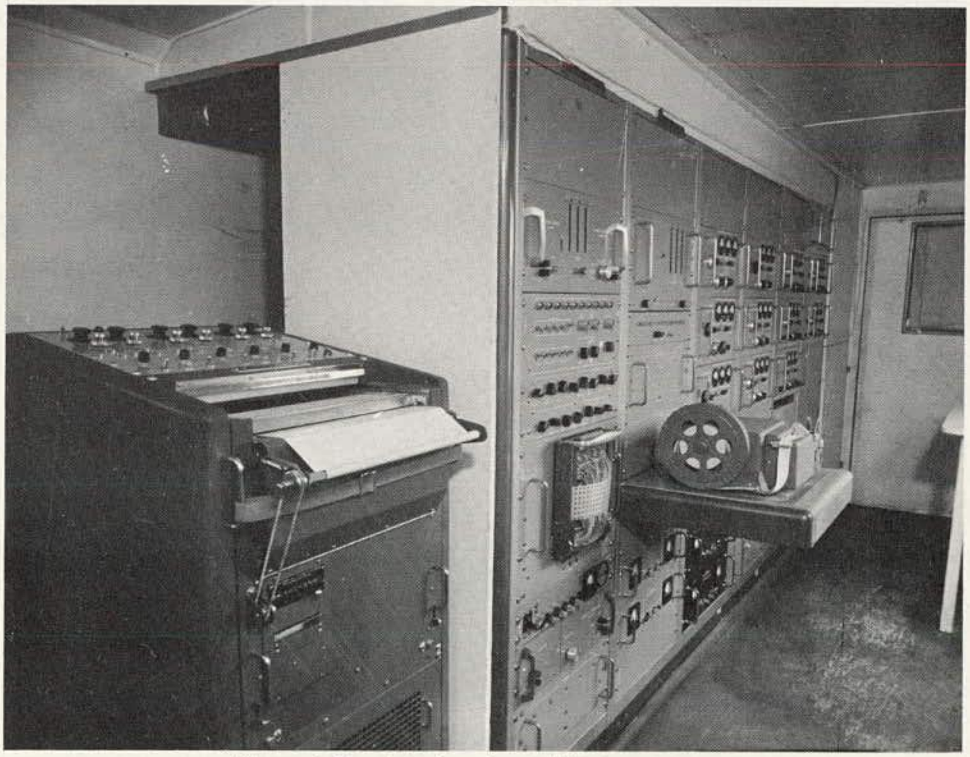

Figure 4–D. Interior view of instrument van.

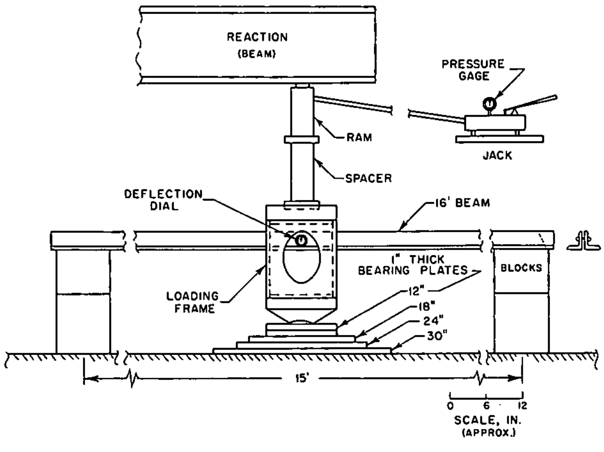

Figure 5–D. Apparatus for plate load test.

were applied slowly with no provision for the deformation to come to equilibrium.

Plate sizes and pressures used for routine measurements are given in Table 1-D. For studies of effect of plate size, other plates and pressures were used. Basic steps in the procedure were:

1. Test area was covered with fine silica sand and leveled by rotating the plate. Sand was not used when the pavement surface was level.
2. Equipment was set in place (Fig. 5-D).
3. A seating pressure of 2 psi was applied and released. Dial gages were set to zero.
4. First increment of pressure was applied, held 15 sec and dial gage read.
5. Load was then released and dial gage read at end of 15-sec period.

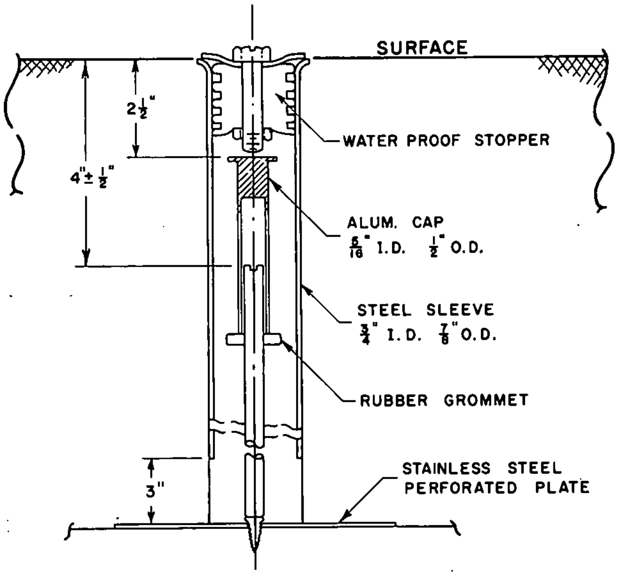

Figure 6–D. Typical settlement rod installation.

6. Load was reapplied and released in the same manner three times.
7. Steps 4 through 6 were repeated for second and third increments of psi load.
8. Gross and elastic deflections were computed from dial gage readings.

Values of $k$ were computed as follows: (a) Elastic $k$-value: $k_E$ = the unit load divided by the elastic deformation at each application of the incremental load, pci. The reported $k_E$ was an average of all nine of these computations; (b) Gross $k$-value, $k_G$ = the unit load divided by the maximum gross deflection. The reported $k_G$ was an average of all three of these computations, pci.

*CBR Tests*

CBR test procedures were (1) laboratory test using static compaction, (2) laboratory test using drop-hammer compaction, and (3) field in-place test.

*Laboratory CBR Test Using Static Compaction.*—The test procedure used followed closely that described by T. E. Stanton in "Suggested Method of Test for Bearing Ratio and Expansion of Soils," Procedures for Testing Soils, American Society for Testing Materials, Philadelphia, September 1944. This is a standard test of the Illinois Division of Highways.

This test required that samples of material, soil or granular base, be prepared to several moisture conditions which bracketed the maximum density condition. Specimens were prepared in a 6-in. diameter mold by compressing the material under a 2,000-psi static load. After four days of soaking in water, the specimen was penetrated with a piston 1.95 in. in diameter. The unit load, in psi, required to cause 0.1-in. penetration into the specimen, expressed as a percent of the number 1,000—*i.e.,* $\frac{\text{load} \times 100}{1{,}000}$ was called the bearing ratio. The bearing ratio of the sample at maximum density was reported as the CBR value.

A 10-lb surcharge was used during soaking and penetrating in the test reported on Road Test subbase and base materials.

*Laboratory CBR Test Using Drop-Hammer Compaction.*—The test procedure used followed closely that described in "Suggested Method of Test for Moisture-Density Relationships and California Bearing Ratio of Soils," submitted by Corps of Engineers, U. S. Army, in Procedures for Testing Soils, American Society for Testing Materials, Philadelphia, April 1958.

This test required that samples of material, soils or granular base, be prepared at various levels of moisture content and number of blows of the compaction hammer. The specimens were prepared by compacting in a 6-in. mold with a drop hammer, usually hand operated.

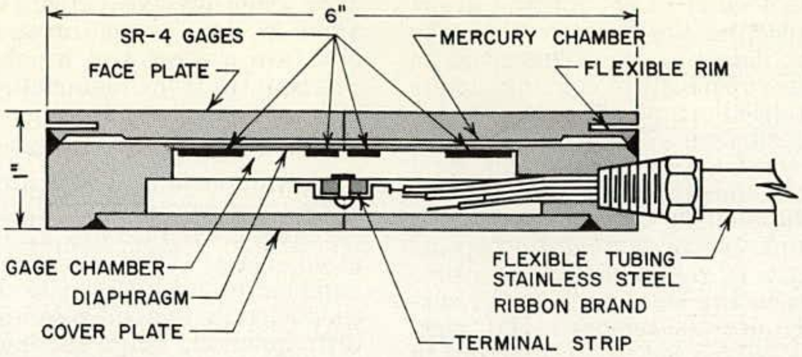

**Figure 7–D. Schematic of W.E.S. earth pressure cell.**

(In some early tests, an automatic compaction hammer with a pie-shaped foot was used.) After soaking four days the specimens were penetrated with a 1.95-in. diameter piston and the load-deformation curve was plotted. This curve was corrected for initial curvature and a "corrected" load determined at 0.1- and 0.2-in. penetration. CBR values reported were the corrected unit loads, in psi, expressed as a percentage to the values 1,000 at 0.1-in. penetration and 1,500 at 0.2-in. penetration. That is,

$$\text{CBR} = \frac{\text{Corr. unit load} \times 100}{1{,}000}$$

in which CBR is measured in 0.1-in., and corrected unit load in psi at 0.1-in. penetration.

Surcharge weights were 10 lb for specimens of subbase and base and 25 lb for specimens of soil, for both soaking and testing.

*Field In-Place CBR Test.*—The test procedure used followed closely that described in "Suggested Method of Test for Moisture-Density Relationships and California Bearing Ratio of Soils," submitted by Corps of Engineers, U. S. Army, in Procedures for Testing Soils, American Society for Testing Materials, Philadelphia, April 1958.

All tests on the AASHO Road Test were run on freshly exposed surfaces of the particular layer being tested, in the natural moisture condition. A 30-lb surcharge weight, including the 10-in. diameter steel ring, was used throughout. Fine silica sand was used to provide smooth seating, in addition to any leveling required to provide a level test area. Load-penetration curves were plotted and "corrected" CBR values computed as described.

## LAYER THICKNESS CHANGES

During construction of the flexible pavement, perforated plates were placed 6 to 8 ft below the embankment level, on the surface of the embankment, and on the surface of the subbase and base in transverse lines across the test pavements. At each location, when the pavement was completed, a hole was formed in the structure to the level of the perforated plate. A rod with a sheet-metal screw soldered to one end was turned into one of the holes of the perforated plate and protective flexible tubing placed in the hole so that the rod moved without restriction. The top of the rod extended to within approximately 2.5 in. of the pavement surface. When not in use the holes were capped with a special stopper.

Figure 6-D shows a typical installation. Throughout the course of the test frequent measurements were made from the pavement surface to the top of these rods. Changes in these measurements indicated changes in the thickness of the structure to the level of the plate. An electronic device used to make these measurements recorded the data electronically.

## PRESSURE CELLS, FLEXIBLE PAVEMENT

The pressure cell used at the Road Test on the embankment surface utilizes SR-4 strain gages as transducers to record the pressure transmitted to the face of the unit. The gages were cemented to a flexible diaphragm mounted in the interior of the cell. A schematic diagram of the cell is shown in Figure 7-D.

Pressures were measured with the loaded wheel (single axle vehicle) stopped at 6-in. intervals from points 2 ft ahead and 2 ft behind the location of the cells. In tests using tandem axle loads, observations began 2 ft ahead of the first wheel and were continued at 6-in. intervals to a point 2 ft behind the second wheel of the assembly.

## DENSITY TESTS

### *Crushed Stone Base*

Tests on the crushed stone base were made with the nuclear density surface probe built on the project. The calibration curve was determined by compacting samples of base into square steel boxes 1 cu ft in volume and about 8 in. deep, and plotting the count-wet density relationship. Wet densities were converted to dry densities by use of moisture contents determined from oven-dried samples.

Seating of the surface gage was no major problem during construction because the steel wheel rollers left a smooth, flat surface on the base layer. In subsequent testing on Loop 1 and the main loops, however, this did become a problem since a very rough surface was produced as the fines in the base stuck to the surfacing layer when it was removed. To overcome this problem which led to large errors in determining density, a procedure was developed whereby a thin layer of minus No. 10 stone dust at about 85 percent moisture was tamped over the test spot to fill air gaps and provide a good seat for the gage.

### *Subbase, Gravel Base, and Cement-Treated Base*

Tests on these materials were made with Rainhart No. 171 rubber balloon volumeters modified to include pressure gages. Three pounds air pressure was standard usage. Holes were generally excavated 4 in. in diameter and 4 to 8 in. deep depending on the layer thickness. Moisture content and weight of material were determined from material excavated.

### *Embankment Soil*

Embankment soil densities were taken with drive-tube samplers of thin-wall tubing, ($3/32$ in. thick), cut into $3\frac{7}{8}$-in. lengths and beveled at one end. They were connected to a drop hammer by a pin for ease of removal. During construction two tube samples constituted one test; however, often during traffic period one tube sample was considered as a test. Moisture tests were taken from the density samples.

### *Maximum Density Tests*

Maximum density for granular materials was determined from full curves of at least three moisture-density points. Soil maximum densities were obtained from one-point tests based on full curves. A full discussion is contained in AASHO Road Test Report 2, "Materials and Construction," Chapter 2 and Appendix B.

# Appendix E

## FORMULAS FROM ELASTIC THEORY USED IN CONNECTION WITH SECTION 3.5.4

Formulas used for converting gage readings to principal strains and for converting principal strains to principal stresses are as follows:

A. Symbols appearing on the formulas are defined as follows:

$\varepsilon_a$, $\varepsilon_b$ and $\varepsilon_c$ are the readings of gages a, b and c, respectively, at a rosette gage point (Fig. 1-E).

$\varepsilon_x$ = strain parallel to $x$-axis;

$\varepsilon_y$ = strain parallel to $y$-axis;

$\gamma_{xy}$ = shear strain in $x$-$y$ plane;

$\varepsilon_1$ = major principal strain;

$\varepsilon_2$ = minor principal strain;

$\phi_1$ = inclination of major principal strain to $x$-axis, measured counterclockwise from $x$-axis;

$\phi_2$ = inclination of minor principal strain to $x$-axis ($\phi_1 = \phi_2 + 90°$);

$E$ = Young's modulus, psi (value used herein was the dynamic modulus for concrete pavement at the Road Test, $= 6.25 \times 10^6$ psi);

$\mu$ = Poisson's ratio (value used was 0.28 for concrete pavement at the Road Test);

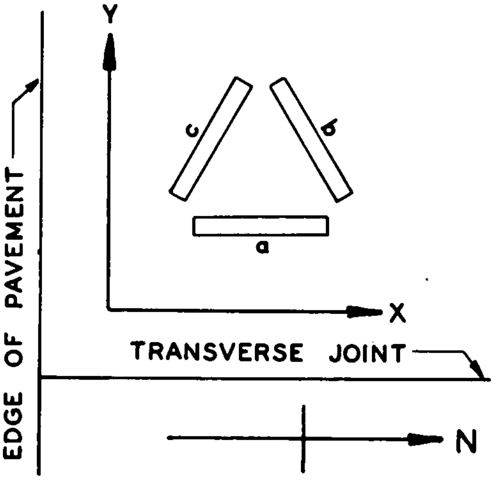

**Figure 1-E. Rosette gage with nomenclature and coordinate system used in connection with strain data described in Section 3.5.4.**

$\sigma_1$ = major principal stress, psi;

$\sigma_2$ = minor principal stress, psi;

Positive values of stresses and strains indicate tension.

B. The strain components $\varepsilon_x$, $\varepsilon_y$ and $\gamma_{xy}$ were obtained from gage readings by the following formulas:

1. *At rosette gage points:*

$$\varepsilon_x = \varepsilon_a$$

$$\varepsilon_y = \frac{1}{3}\,(-\,\varepsilon_a + 2\varepsilon_b + 2\varepsilon_c)$$

$$\gamma_{xy} = \frac{2}{\sqrt{3}}\,(\varepsilon_c - \varepsilon_b)$$

2. *At gage points along transverse joint:*

$\varepsilon_x$ = gage reading

$$\varepsilon_y = -\,\mu\varepsilon_x$$

$$\gamma_{xy} = 0$$

3. *At gage points along edge:*

$\varepsilon_y$ = gage reading

$$\varepsilon_x = -\,\mu\varepsilon_y$$

$$\gamma_{xy} = 0$$

C. $\varepsilon_1$, $\varepsilon_2$ and $\phi_1$ were obtained from $\varepsilon_x$, $\varepsilon_y$ and $\gamma_{xy}$ by the following formulas:

1. *At rosette gage points:*

$$\varepsilon_1 = \frac{1}{2}\,(\varepsilon_x + \varepsilon_y) + \frac{1}{2}\,\sqrt{(\varepsilon_x - \varepsilon_y)^2 + \gamma_{xy}^2}$$

$$\varepsilon_2 = \frac{1}{2}\,(\varepsilon_x + \varepsilon_y) - \frac{1}{2}\,\sqrt{(\varepsilon_x - \varepsilon_y)^2 + \gamma_{xy}^2}$$

$$\phi_1 \text{ (or } \phi_2) = \frac{90}{\pi}\tan^{-1}\frac{\gamma_{xy}}{\varepsilon_x - \varepsilon_y} \text{ degrees.}$$

Whether the last formula yielded $\phi_1$ or $\phi_2$ was determined by testing the value given by the formula against the following relationships:

If $\gamma_{xy} > 0$, $0 < \phi_1 < 90°$.

If $\gamma_{xy} < 0$, $-90° < \phi_1 < 0$.

If $\gamma_{xy} = 0$ and $\varepsilon_x > \varepsilon_y$, $\phi_1 = 0°$.

If $\gamma_{xy} = 0$ and $\varepsilon_x < \varepsilon_y$, $\phi_1 = 90°$.

If $\gamma_{xy} = 0$ and $\varepsilon_x = \varepsilon_y$, $\phi_1$ does not exist.

2. *At gage points along transverse joint:*

If $\varepsilon_x > 0$, then $\varepsilon_1 = \varepsilon_x$, $\varepsilon_2 = \varepsilon_y$, $\phi_1 = 0°$.

If $\varepsilon_x < 0$, then $\varepsilon_1 = \varepsilon_y$, $\varepsilon_2 = \varepsilon_x$, $\phi_1 = 90°$.

If $\varepsilon_x = 0$, then $\varepsilon_1 = \varepsilon_2 = 0$, $\phi_1$ does not exist.

3. *At gage points along edge:*

If $\varepsilon_y > 0$, $\varepsilon_1 = \varepsilon_y$, $\varepsilon_2 = \varepsilon_x$, $\phi_1 = 90°$.

If $\varepsilon_y < 0$, $\varepsilon_1 = \varepsilon_x$, $\varepsilon_2 = \varepsilon_y$, $\phi_1 = 0°$.

If $\varepsilon_y = 0$, $\varepsilon_1 = \varepsilon_2 = 0$, $\phi_1$ does not exist.

D. Formulas for converting principal strains to principal stresses are

$$\sigma_1 = \frac{E}{1 - \mu^2} (\varepsilon_1 + \mu\varepsilon_2)$$

$$\sigma_2 = \frac{E}{1 - \mu^2} (\varepsilon_2 + \mu\varepsilon_1)$$

## REFERENCES

Murray, William M., and Stein, Peter K., "Strain Gage Techniques," MIT, Cambridge, Mass., pp. 537-548 (1956).

Timoshenko, S., and Goober, J. N., "Theory of Elasticity," McGraw-Hill, p. 24 (1951).

# Appendix F

## THE PAVEMENT SERVICEABILITY—PERFORMANCE CONCEPT*

The relative performance of various pavements is a function of their relative ability to serve traffic over a period of time. There have been no widely accepted definitions of performance that could be used in the evaluation of various pavements or that could be considered in the design of pavements. In fact, design systems in general use in highway departments do not include consideration of the level of performance desired. Design engineers vary widely in their concepts of desirable performance. By way of example, two designers are given the task of designing a pavement of certain materials for certain traffic and environment for 20 years. The first might consider his job to be properly done if not a single crack occurred in 20 years while the second might be satisfied if the last truck that was able to get over the pavement made its trip 20 years from the date of construction. There is nothing in existing design manuals to suggest that either man is wrong. This is simply to demonstrate that any design system should include consideration of the level of serviceability to traffic that must be maintained over the life of the road. How long must it remain smooth and how smooth?

One popular design system involves the determination of the thickness of slab required in order to hold certain computed stresses below a certain level. It is clear that cracks will occur if a pavement is overstressed, but nowhere can be found any reference to the effect of such cracks on the serviceability of the pavement. Engineers will agree that cracks are undesirable, and that they require maintenance, but the degree of undesirability seems to have been left dimensionless. It may be apparent that one pavement has performed its function of serving traffic better than another, but a rational answer to the question, "How much better?" has not been available.

To provide dimensions for the term "performance" a system has been devised that is rational and free from the likelihood of bias due to the strong personal opinions of groups or individuals. It is easily conceivable that such a system could be adopted by all departments thus providing for the first time a national standard system for rating highways and pavements.

Before discussing the derivation and a particular application of the pavement serviceability-performance system, it is necessary to set down some fundamental assumptions upon which the system is based.

1. There is a statement attributed to D. C. Greer, State Highway Engineer of Texas: "Highways are for the comfort and convenience of the traveling public." A reasonable inference from this simple statement is that the only valid reason for any road or highway is to serve the highway users. Another opinion is that "a good highway is one that is safe and smooth."

2. The opinion of a user as to how he is being served by a highway is by-and-large subjective. There is no instrument that can be plugged into a highway to tell in objective units how well it is serving the users. The measurement of damage to goods attributed to rough roads may provide an exception to this rule but one of minor importance since a road rough enough to damage properly packed and properly suspended goods would be classed subjectively so low by all users that little could be gained by an objective measure.

3. There are, however, characteristics of highways that can be measured objectively which, when properly weighted and combined, are in fact related to the users subjective evaluation of the ability of the highway to serve him.

4. The serviceability of a given highway may be expressed by the mean evaluation given it by all highway users. There are honest differences of opinion even among experts making subjective evaluations of almost anything. Thus there are differences of opinion as to which automobile in a given price range is best, differences among judges of a beauty contest, and differences as to which bank, broker, grocery store, or bar to patronize. Opinion as to the serviceability of highways is no exception. Economic considerations alone cannot explain these differences.

Therefore, in order for normal differences of opinion to be allowed with the smallest average error for each individual highway user, serviceability, may be expressed in terms of the mean evaluation of all users.

5. Performance is assumed to be reflected by the serviceability trend of a pavement with increasing number of axle load applications. It is assumed that the performance of a pave-

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* An adaption of a paper given at the 39th Annual Meeting of the Highway Research Board.

ment can be described if one can observe its serviceability from the time it was built to the time its performance evaluation is desired and can plot this serviceability record against the traffic the pavement has served. The traffic history must include the number of axle loads and their magnitude sustained by the pavement.

## USE OF THE SERVICEABILITY-PERFORMANCE SYSTEM

A typical example of the system which has been in actual field use at the AASHO Road Test, is described in this section. Definitions and detailed steps in the development and use of a performance index for evaluation of the Road Test pavements are included. It is emphasized that this case is only one of many possible applications of the principles involved. It related to the performance of the pavements only, yet it would have been easy to extend the system to provide a measure of the sufficiency of the entire highway, including grade, alignment, access, condition of shoulders, and drainage, as well as characteristics of the pavement itself.

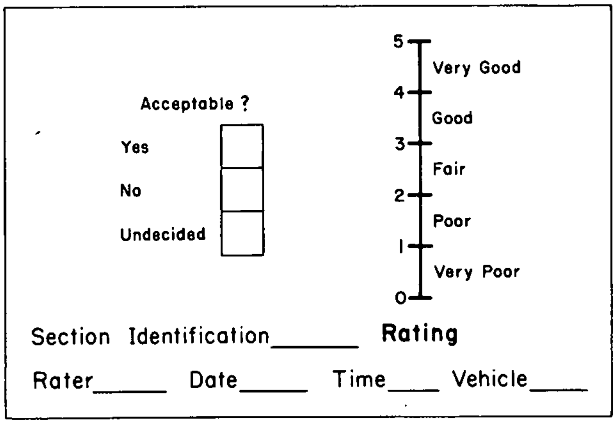
### *Purpose*

The principal objective for the AASHO Road Test calls for significant relationships between performance under specified traffic and the design of the structure of certain pavements. To fulfill this objective an adequate and unambiguous definition of pavement performance was required. None was available.

### *Special Considerations*

In addition to the four primary assumptions, certain special considerations relating to the specific requirements of the Road Test were included. Inasmuch as the project was designed to provide information relating to the pavement structure only, certain aspects of normal pavement serviceability were excluded from consideration. Among these were surface friction and condition of shoulders.

Test sections at the Road Test were as short as 100 ft—too short for a satisfactory subjective evaluation of their ability to serve traffic (most highway users consider a high-speed ride over a pavement necessary before they will rate it). Thus, objective measurements that could be made on the short sections had to be selected and used in such a way that pavements only 100 ft long could be evaluated as though they were much longer.



Acceptable ?

Yes ☐

No ☐

Undecided ☐

5

Very Good

4

Good

3

Fair

2

Poor

1

Very Poor

0

Section Identification______ **Rating**

Rater_____ Date_____ Time____ Vehicle____

**Figure 1–F. Individual present serviceability rating form.**

### *Definitions*

To fulfill the requirements of the Road Test rather ordinary terms were given specific definitions as follows:

Present Serviceability —the ability of a specific section of pavement to serve high-speed, high volume, mixed (truck and automobile) traffic in its existing condition. (The definition applies to the existing condition; that is, on the date of rating, not to the assumed condition the next day or at any future or past date.) Although this definition applies to the Road Test and may apply to any primary highway system, the system could easily be modified for use with city streets, farm roads, etc. Obviously, serviceability must be defined relative to the intended use of the road.

Individual Present Serviceability Rating — an independent rating by an individual of the present serviceability of a specific section of roadway made by marking the appropriate point on a scale on a special form (Fig. 1–F). This form also includes provision for the rater to indicate whether or not the pavement being rated is acceptable as a primary highway. For the Road Test application, the rater was instructed to exclude from consideration all features not related to the pavement itself, such as right-of-way width, grade, alignment, and shoulder and ditch condition.

Present Serviceability Rating (PSR) —the mean of the individual ratings made by the members of a specific panel of men selected for the purpose by the Highway Research Board. This panel was intended to represent all highway users. It included experienced men, long associated with highways, representing a wide variety of interests, such as highway administration, highway maintenance, a federal highway agency, highway materials supply (cement and asphalt), trucking, highway education, automotive manufacture, highway design, and highway research.

Present Serviceability Index (PSI) —a mathematical combination of values obtained from certain physical measurements of a large number of pavements so formulated as to predict the PSR for those pavements within prescribed limits.

Serviceability Trend.—a continuous graph of serviceability plotted against axle load applications.

Performance —the serviceability trend of a section of pavement with increasing number of axle load applications.

*Formulation of a Present Serviceability Index*

A minimum program for the establishment, derivation and validation of a PSI (or any similar index that may be considered for another purpose) is as follows:

1. Establishment of Definitions—There must be clear understanding and agreement among all those involved in rating and in formulation and use of the index as to the precise meanings of the terms used. Exactly what is to be rated, what should be included, and what excluded from consideration?

2. Establishment of Rating Panel—Because the system depends primarily on the subjective ratings of individuals, great care should be taken in the selection of the persons composing the rating group. Inasmuch as serviceability is defined as the mean opinion of this group, it is important that the raters represent highway users, and they should be selected from various segments with divergent views and attitudes.

3. Orientation and Training of Rating Panel —The members of the panel are instructed in the part they are to play; they must understand clearly the pertinent definitions and the rules of the game. It has been found worthwhile to conduct practice rating sessions where the raters can discuss their ratings among themselves. When they make their official ratings they must work independently with no opportunity for discussion of the ratings until the entire session has been completed.

4. Selection of Pavements for Rating—Because ratings are to be made of the serviceability of pavements, a wide range of serviceability should be represented among the pavements that are selected for rating. Moreover, there should be among the sections selected pavements containing all of the various types and degrees of pavement distress that are likely to influence the serviceability of highways. Before a field rating session, engineers study the highway network in the area under consideration (200 mi or less in diameter, for example) and pick sections of roadway so that a reasonable balance is obtained among obviously very good, good, fair, poor and obviously very poor sections. The Road Test system was based on four rating sessions in three different states; 138 sections of pavement were studied. About one-half were flexible pavement; the other half, rigid. The Road Test panel agreed that the minimum desirable length of a pavement to be rated was 1,200 ft; however, in a few cases shorter sections were included. This length was sufficient for the raters to ride over the section at high speed without being influenced by the condition of pavement at either end.

5. Field Rating—The members of the panel are taken in small groups to the sections that are to be rated. They are permitted to ride over each section in a vehicle of their choice (usually one with which they are familiar), to walk the pavement and to examine it at will. Each rater works independently—there is no discussion among the raters. When he is satisfied as to his rating, he marks his rating card and turns it in to a staff representative. The group then moves on to the next section. Each group takes a different route to reduce the possibility of bias over the day (raters may rate differently in the afternoon than in the morning, therefore, the groups are scheduled so that some sections are rated by one or two groups in the morning and the same sections by the other groups in the afternoon). It has been found that, near metropolitan areas, sections with satisfactorily different characteristics can be found close enough together so that the raters can travel routes containing about 20 sections per day. When rating present serviceability of a pavement, raters have found it helpful to ask themselves "How well would this road serve me if I were to drive my own car over roads just like it all day long today?" Here again, of course, serviceability is related to the intended use of the road, primary highway, city street, farm road, etc.

6. Replication—It is necessary to determine the ability of the panel to be consistent in its ratings. The Road Test panel rated many sections twice, first on one day and again on another day near enough to the first so that the section did not change physically, yet remote enough so that all extraneous influences on the raters would be in effect. In general, it might be expected that replicate ratings would differ more when separated by several months than when separated by only one day. For this reason, the replication differences observed in the Road Test rating sessions are perhaps to some degree an underestimate of replication differences in a larger time reference. The difference between repeated ratings on the same section is a criterion for the adequacy of a present serviceability index derived from measurements.

7. Validation of Rating Panel—Because the panel is intended to represent all highway users, it is necessary to test its ability to do so. To a limited extent such validation was obtained for the Road Test panel by selecting other groups of users and having them rate some of the same sections that had been rated by the panel. One such group consisted of two commercial truck drivers who made their ratings based on the rides they obtained when driv-

ing their own fully-loaded tractor-semitrailer vehicles. Another group was made up of ordinary automobile drivers not professionally associated with highways. For the sections involved, these studies indicated that the ratings given pavements by the Road Test panel were quite similar to those that were given by the other user groups. Of course, if a greater number of sample groups had been studied, more positive statements could be made as to how well the panel represented the universe of all users.

8. Physical Measurements—If it is practicable for the panel to rate all roads in the area often enough, no measurements need be taken. Analyses may be based on the PSR itself. Since it was not possible for the panel to rate the Road Test sections (ratings were desired every two weeks), it was necessary to establish a PSI or index that would predict the panel's ratings. To accomplish this, measurements of certain physical characteristics of the pavements were necessary. To determine which measurements might be most useful, the members of the panel were asked to indicate on rating cards which measurable features of the roadway influenced their ratings. It was apparent that present serviceability was a function primarily of longitudinal and tranverse profile with some likelihood that cracking, patching, and faulting would contribute. Therefore, all of these characteristics were measured at each of the 138 sections that were rated by the panel. Several other objective measurements could have been added to the list if other phenomena were permitted consideration by the established rules of the game. Skid resistance, noise under tires, and shoulder and ditch conditions might be in this category.

Measurements fall rather naturally into two categories: those that describe surface deformation and those that describe surface deterioration. Of course, phenomena in the second category may or may not influence measurements in the first category. Measures of surface deformation will reflect the nature of longitudinal and transverse profiles, or may represent the response of a vehicle to the profile, as does the BPR roughometer. Supplemental profile characteristics, such as faulting will ordinarily be measured. Present and past surface deterioration will be reflected through measures of cracking, spalling, potholing, patching, etc., and may include phenomena whose influence on present serviceability ratings range from negligible to appreciable.

9. Summaries of Measurements—There are many different ways to summarize longitudinal and transverse profiles. For example, longitudinal profile may be expressed as total deviation of the record from some base line in inches per mile, number of bumps greater than some minimum, some combination of both of these, or by any number of other summary statistics involving variance of the record, power spectral density analysis, etc. Transverse profile may be summarized by mean rut depth, variance of transverse profile, etc. The variance of rut depth along the wheel paths is also a useful statistic. Cracking occurs in different classes of severity as do other measures of surface deterioration. Measurements in any of these classes may be expressed in one unit or another.

10. Derivation of a Present Serviceability Index—After obtaining PSR's and measurement summaries for a selection of pavements, the final step is to combine the measurement variables into a formula that "gives back" or predicts the PSR's to a satisfactory approximation. Part of this procedure should consist in determining which of the measurement summaries have the most predictive value and which are negligible after the critical measurements are taken into account. The technique of multiple linear regression analysis may be used to arrive at the formula, or index, as well as to decide which measurements may be neglected. For example, a longitudinal profile summary may be sensitive to faulting so that faulting measurements need not appear in the index formula whenever this profile measure is included.

The decisions as to which terms should be in the serviceability formula and which terms should be neglected may be made by comparing the lack of success with which the formula gives back the ratings with a pre-selected criterion for closeness of fit, such as the Panel's replication error. There is no justification for a formula that can predict a particular set of ratings with greater precision than the demonstrated ability of the panel to give the same ratings to the same pavements twice. Therefore, the multiple linear regression analysis will yield a formula that will combine certain objective measurements to produce estimates of the panel's ratings to an average accuracy no greater than the panel's average ability to repeat itself.

### *Performance*

The serviceability index is computed from a formula containing terms related to objective measurements that may be made on any section of highway at any time. At the AASHO Road Test, these measurements were made and the index computed for each test section every two weeks. Thus a serviceability-time history is available for each test section beginning at the time test traffic operation was started. The present serviceability values range in numerical value from 0 to 5 (Fig. 1–F).

To fulfill the first Road Test objective of finding relationships between performance and pavement structure design, some summarization of the serviceability-time history is implied. Performance may be said to be related to the ability of the pavement to serve traffic over a period of time. A pavement with a low serviceability during much of its life would not have performed its function of serving traffic as well as one that had high serviceability during most of its life even if both ultimately reached the same state of repair.

Performance, at the Road Test, was defined as the trend of serviceability with increasing load applications. Analysis of performance was based on mathematical models for expressing the serviceability trend in terms of design, load, and number of load applications. The procedures for analysis are discussed in Appendix G.

## ROAD TEST INDEXES

The techniques previously described were used in the derivation of present serviceability indexes for the AASHO Road Test. This section includes tabulations of the actual data obtained in the field rating sessions by the Road Test Rating Panel and data obtained from the objective measurements of the pavements rated. Relationships among the ratings and various measurements are shown graphically and the results of the regression analyses in which the serviceability indexes were derived are given.

The matter of precision required of an index and precision attained in the Road Test indexes is discussed. Alternate measurement systems are mentioned for the benefit of agencies not able to equip themselves with elaborate instruments.

### *Ratings for Selected Pavements*

After establishing concepts, ground rules, and rating forms for present serviceability ratings, the AASHO Road Test performance rating panel rated 19 pavement sections near Ottawa, Ill. on April 15-18, 1958, 40 sections near St. Paul-Minneapolis on August 14-16, 1958, 40 sections near Indianapolis on May 21-23, 1959, and 39 sections on and near the Road Test on January 20-22, 1960. Ten Illinois sections, 20 Minnesota sections, 20 Indiana sections and 24 sections on and near the Road Test were flexible pavements; all remaining sections were rigid pavements. Each section was 1,200 ft long except those on the Road Test which averaged 215 ft. With the cooperation of the respective state highway departments, sections were selected to represent a wide range of pavement conditions.

Coincident with the rating session, Road Test crews and instruments were used to obtain condition surveys and profile measurements for each section. Summaries for all evaluations of the 74 flexible pavement sections are given in Table 1–F, and corresponding evaluations for the first 49 rigid pavements are given in Table 2–F.

Although the panel members had indicated that rutting in flexible pavement must influence serviceability, the first three rating sessions did not include pavements with rutting severe enough to contribute significantly to the pavement serviceability. Since severe rutting occurred at the Road Test it was necessary to assemble the panel for a fourth session in which sections with severe rutting were rated. Reanalysis of the data from all four sessions then made it possible to determine the effect of rutting on serviceability. A second objective of the fourth session was to rate a small number of rigid pavements only for the purpose of checking present serviceability indexes derived from the first 49 sections. For these reasons, flexible pavements from all four sessions appear in Table 1–F; Table 2–F includes only rigid pavement sections from the first three sessions.

Present serviceability ratings shown in the third column of Tables 1 and 2 are mean values for individual ratings given by the Road Test panel. In general, each mean represents about ten individual ratings. For both pavement types, the PSR values range from about 1.0 to 4.5 with nearly the same number of sections in the poor, fair, good, and very good categories (Fig. 1–F). The grand mean PSR for all rated pavements was slightly less than 3.0 for both pavement types.

Over forty of the sections were revisited by the panel during the same rating session, and differences between first and second mean ratings are shown in the fourth columns of Tables 1 and 2. The replication differences ranged from 0 to 0.5; the mean difference was less than 0.2 for both flexible and rigid pavements. The fifth columns give the standard deviation of individual PSR values for each section. These standard deviations are of the order 0.5, an indication that only about two or three individual ratings (out of ten) were farther than 0.5 rating points from the panel mean PSR.

The mean ratings of the two truck drivers who rated certain Illinois sections are shown in the sixth columns. The seventh columns show mean ratings given to selected Illinois sections by a group of about 20 Canadian raters. The general agreement among the various rating groups is apparent.

The eighth and ninth columns represent summaries of the AASHO Panel response to the acceptability question (Fig. 1–F). The tables give what fraction of the panel decided the present state of a particular pavement section to be acceptable and what fraction decided the

# TABLE 1-F

## DATA FOR 74 SELECTED FLEXIBLE PAVEMENTS

| Pvt. Loc. | Sect. Code | Present Serviceability Ratings | | | | | Acceptability Opinions | | Longitudinal and Transverse Roughness | | | | Major Cracking | | Patching | Transformations | | | PSI 121 | Resid. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AASHO Panel | | | Truck Dr'v'rs | Canad. Raters | AASHO Panel | | $\overline{SV}$ Mean Slope Var'nce in Wh'p'ths ($x10^6$) | $\overline{AR}$ Mean AASHO Ro'm't'r in Wh'p'ths in./mi. @10 mph | $\overline{RD}$ Mean Rut Depth, (in.) | $\overline{RDV}$ Mean Rut Depth Var'nce $in^2 x 100$ | Class 2 + Class 3, $ft^2$/1000$ft^2$ | Long. & Trans. ft./1000$ft^2$ | P $Ft^2$ per 1000 $ft^2$ | Log $(1+\overline{SV})$ | $\overline{RD}^2$ | Sq. rt. C+P | Pres. Serv. Index | Diff. Betw'n PSR & PSI |
| | | 1st PSR | Replic. diff. in PSR | Std. dev. of PSR among raters | PSR | PSR | Fraction Yes | No | | | | | | | | | | | | |
| Ill. | F 3 | 4.3 | | .1 | 4.5 | 4.3 | 1.0 | .0 | 2.8 | | .10 | .7 | 0 | 0 | 0 | .57 | .01 | .0 | 3.9 | .4 |
| | F 4 | 2.4 | | .4 | | 2.0 | .0 | .6 | 20.5 | | .22 | 9.2 | 343 | 0 | 0 | 1.33 | .05 | 18.5 | 2.3 | .1 |
| | F 5 | 3.3 | | .7 | 3.5 | 2.6 | .6 | .2 | 9.2 | | .08 | 3.6 | 8 | 0 | 0 | 1.01 | .01 | 2.8 | 3.1 | .2 |
| | F 6 | 4.4 | .1 | .2 | 3.5 | | 1.0 | .0 | 3.5 | | .08 | .7 | 0 | 0 | 0 | .65 | .01 | .0 | 3.8 | .6 |
| | F 7 | 3.8 | .1 | .6 | 2.5 | 3.6 | .9 | .0 | 15.5 | | .06 | .4 | 0 | 0 | 0 | 1.22 | .00 | .0 | 2.7 | 1.1 |
| | F 8 | 2.6 | .2 | .7 | 2.0 | 2.7 | .3 | .6 | 9.5 | | .08 | 5.7 | 64 | 0 | 0 | 1.02 | .01 | 8.0 | 3.0 | .4 |
| | F 9 | 3.2 | .2 | .6 | 3.0 | 3.0 | .6 | .2 | 14.0 | | .15 | 3.4 | 2 | 0 | 3 | 1.18 | .02 | 2.2 | 2.7 | .5 |
| | F10 | 2.4 | .0 | .5 | 3.0 | 2.2 | .1 | .6 | 16.8 | | .16 | 3.4 | 17 | 0 | 14 | 1.25 | .03 | 5.6 | 2.6 | .2 |
| | F11 | 1.3 | .3 | .5 | 1.5 | | .0 | 1.0 | 42.8 | | .26 | 10.3 | 292 | 0 | 11 | 1.64 | .07 | 17.4 | 1.6 | .3 |
| | F12 | 1.1 | .3 | .2 | 1.0 | 1.7 | .0 | 1.0 | 56.0 | | .19 | 10.9 | 21 | 0 | 2 | 1.76 | .04 | 4.8 | 1.6 | .5 |
| Minn. | 101 | 3.8 | .3 | .4 | | | 1.0 | .0 | 1.9 | | .04 | .4 | 0 | 29 | 0 | .46 | .00 | 5.4 | 4.1 | .3 |
| | 102 | 3.8 | | .6 | | | 1.0 | .0 | 1.5 | | .09 | .3 | 0 | 34 | 0 | .40 | .00 | 5.8 | 4.2 | .4 |
| | 103 | 3.8 | | .4 | | | 1.0 | .0 | 1.7 | | .05 | .2 | 0 | 14 | 0 | .43 | .00 | 3.7 | 4.2 | .4 |
| | 104 | 3.8 | .0 | .4 | | | 1.0 | .0 | 2.1 | | .04 | .4 | 0 | 9 | 0 | .49 | .00 | 3.0 | 4.1 | .3 |
| | 105 | 3.2 | | .4 | | | .6 | .1 | 7.0 | | .14 | .5 | 0 | 0 | 10 | .90 | .02 | 3.2 | 3.3 | .1 |
| | 106 | 1.3 | | .4 | | | .0 | 1.0 | 58.5 | | .07 | 6.6 | 145 | 22 | 35 | 1.77 | .00 | 14.2 | 1.5 | .2 |
| | 107 | 1.3 | .2 | .4 | | | .0 | 1.0 | 58.4 | | .08 | 2.9 | 75 | 12 | 55 | 1.77 | .01 | 11.9 | 1.5 | .2 |
| | 108 | 2.1 | | .6 | | | .0 | .9 | 17.6 | | .13 | 3.2 | 15 | 0 | 5 | 1.27 | .03 | 4.5 | 2.5 | .4 |
| | 109 | 1.5 | .2 | .2 | | | .0 | 1.0 | 36.2 | | .37 | 5.6 | 30 | 2 | 76 | 1.57 | .13 | 10.4 | 1.7 | .2 |
| | 110 | 2.4 | .0 | .9 | | | .0 | .8 | 11.4 | | .07 | 3.2 | 2 | 0 | 3 | 1.09 | .00 | 2.2 | 2.9 | .5 |
| | 111 | 4.2 | | .2 | | | 1.0 | .0 | 1.7 | | .11 | .2 | 0 | 0 | 0 | .42 | .01 | .0 | 4.2 | .0 |
| | 112 | 3.9 | | .4 | | | 1.0 | .0 | 1.4 | | .09 | .2 | 0 | 0 | 0 | .38 | .01 | .0 | 4.3 | .4 |
| | 113 | 3.1 | .1 | .6 | | | .4 | .4 | 7.8 | | .08 | 1.3 | 1 | 68 | 66 | .94 | .01 | 11.6 | 3.1 | .0 |
| | 114 | 2.2 | | .7 | | | .0 | .9 | 27.8 | | .13 | 5.2 | 0 | 1 | 4 | 1.46 | .02 | 2.2 | 2.2 | .0 |
| | 115 | 1.5 | | .6 | | | .0 | 1.0 | 33.4 | | .08 | 5.4 | 0 | 7 | 6 | 1.54 | .01 | 3.6 | 2.0 | .5 |
| | 116 | 2.9 | .5 | .5 | | | .6 | .1 | 6.0 | | .02 | .7 | 0 | 180 | 0 | .85 | .00 | 13.4 | 3.3 | .4 |
| | 117 | 1.6 | .0 | .6 | | | .0 | 1.0 | 39.4 | | .12 | 4.6 | 0 | 0 | 0 | 1.61 | .01 | .0 | 1.9 | .3 |
| | 118 | 4.0 | .2 | .3 | | | 1.0 | .0 | 1.6 | | .04 | .2 | 0 | 0 | 0 | .41 | .00 | .0 | 4.2 | .2 |
| | 119 | 4.2 | | .5 | | | 1.0 | .0 | 1.3 | | .03 | .2 | 0 | 0 | 0 | .36 | .00 | .0 | 4.3 | .1 |
| | 120 | 2.9 | .1 | .5 | | | .3 | .2 | 5.8 | | .01 | 1.4 | 0 | 74 | 0 | .84 | .00 | 8.6 | 3.3 | .4 |
| | 301 | 4.1 | | .6 | | | 1.0 | .0 | 4.6 | 101 | .24 | .4 | 44 | 43 | 0 | .75 | .06 | 9.3 | 3.4 | .7 |
| | 302 | 4.0 | | .5 | | | 1.0 | .0 | 5.4 | 123 | .34 | .5 | 204 | 75 | 0 | .81 | .12 | 16.7 | 3.2 | .8 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ind. | 303 | 3.2 |  | .5 |  |  | .6 | .1 | 20.1 | 146 | .02 | .4 | 12 | 1 | 0 | 1.32 | .00 | 3.6 | 2.5 | .7 |
|  | 304 | 2.4 | .0 | .4 |  |  | .2 | .5 | 29.2 | 134 | .17 | 1.8 | 455 | 0 | 17 | 1.48 | .03 | 21.7 | 2.0 | .4 |
|  | 305 | 2.9 | .1 | .3 |  |  | .4 | .3 | 9.1 | 129 | .10 | 1.2 | 292 | 0 | 32 | 1.00 | .01 | 18.0 | 2.9 | .0 |
|  | 306 | 2.4 | .2 | .5 |  |  | .3 | .5 | 20.5 | 161 | .12 | 2.4 | 816 | 0 | 0 | 1.33 | .01 | 28.6 | 2.2 | .2 |
|  | 307 | 1.7 | .3 | .6 |  |  | .1 | .9 | 95.9 | 383 | .02 | 1.9 | 719 | 0 | 111 | 1.99 | .00 | 28.8 | 1.0 | .7 |
|  | 308 | 1.0 |  | .4 |  |  | .0 | 1.0 | 51.8 | 296 | .03 | 5.1 | 691 | 0 | 161 | 1.72 | .00 | 29.2 | 1.5 | .5 |
|  | 309 | 1.3 |  | .4 |  |  | .0 | 1.0 | 41.2 | 233 | .14 | 7.0 | 613 | 0 | 159 | 1.62 | .02 | 27.8 | 1.6 | .3 |
|  | 310 | 3.2 |  | .6 |  |  | .7 | .1 | 11.5 | 144 | .18 | 2.0 | 17 | 0 | 0 | 1.10 | .03 | 4.1 | 2.8 | .4 |
|  | 311 | 2.7 |  | .4 |  |  | .4 | .4 | 15.0 | 162 | .14 | .8 | 45 | 0 | 0 | 1.20 | .02 | 6.7 | 2.6 | .1 |
|  | 312 | 1.6 |  | .4 |  |  | .0 | 1.0 | 49.8 | 217 | .23 | 2.3 | 502 | 0 | 31 | 1.71 | .05 | 23.1 | 1.5 | .1 |
|  | 313 | 1.4 |  | .4 |  |  | .0 | 1.0 | 42.0 | 182 | .27 | 2.9 | 437 | 0 | 72 | 1.63 | .07 | 22.6 | 1.7 | .3 |
|  | 314 | 2.6 |  | .5 |  |  | .3 | .4 | 19.0 | 127 | .24 | 1.2 | 10 | 64 | 2 | 1.30 | .06 | 8.7 | 2.4 | .2 |
|  | 315 | 3.4 |  | .7 |  |  | .9 | .0 | 6.9 | 107 | .22 | .2 | 183 | 46 | 0 | .90 | .05 | 15.1 | 3.1 | .3 |
|  | 316 | 2.9 |  | .5 |  |  | .5 | .4 | 11.3 | 140 | .09 | .8 | 177 | 0 | 4 | 1.09 | .01 | 13.4 | 2.8 | .1 |
|  | 317 | 4.3 |  | .2 |  |  | 1.0 | .0 | 2.9 | 95 | .01 | .1 | 0 | 0 | 0 | .59 | .00 | .0 | 3.9 | .4 |
|  | 318 | 4.3 |  | .3 |  |  | 1.0 | .0 | 3.3 | 92 | .00 | .0 | 1 | 0 | 0 | .63 | .00 | 1.0 | 3.8 | .5 |
|  | 319 | 4.2 | .0 | .3 |  |  | 1.0 | .0 | 3.8 | 92 | .12 | .2 | 0 | 1 | 0 | .68 | .01 | 1.0 | 3.7 | .5 |
|  | 320 | 3.9 | .3 | .4 |  |  | .9 | .0 | 3.8 | 105 | .16 | .4 | 0 | 2 | 0 | .68 | .03 | 1.4 | 3.7 | .2 |
| Test Road Sect. | 501 | 3.8 |  | .3 |  |  | 1.0 | .0 | 5.8 | 132 | .08 | .3 | 0 | 0 | 0 | .83 | .01 | .0 | 3.4 | .4 |
|  | 502 | 3.4 |  | .6 |  |  | .8 | .1 | 10.3 | 168 | .20 | 2.2 | 51 | 0 | 0 | 1.05 | .04 | 7.2 | 2.9 | .5 |
|  | 503 | 3.1 | .0 | .3 |  |  | .7 | .0 | 7.6 | 129 | .11 | .8 | 17 | 0 | 7 | .93 | .01 | 4.9 | 3.2 | .1 |
|  | 504 | 4.1 |  | .2 |  |  | 1.0 | .0 | 2.6 | 109 | .03 | .2 | 0 | 0 | 0 | .56 | .00 | .0 | 4.0 | .1 |
|  | 505 | 3.4 |  | .2 |  |  | 1.0 | .0 | 3.8 | 89 | .33 | .9 | 14 | 0 | 0 | .68 | .11 | 3.7 | 3.5 | .1 |
|  | 506 | 3.4 |  | .4 |  |  | .9 | .0 | 4.8 | 89 | .24 | .9 | 0 | 0 | 0 | .76 | .06 | .0 | 3.5 | .1 |
|  | 507 | 2.8 |  | .4 |  |  | .6 | .3 | 7.6 | 103 | .43 | 1.4 | 5 | 0 | 25 | .93 | .18 | 5.4 | 2.9 | .1 |
|  | 508 | 3.5 |  | .5 |  |  | .9 | .0 | 4.0 | 75 | .46 | .5 | 0 | 0 | 0 | .70 | .21 | .0 | 3.4 | .1 |
|  | 509 | 3.3 |  | .5 |  |  | .8 | .0 | 2.9 | 84 | .39 | .4 | 9 | 0 | 0 | .59 | .15 | 3.0 | 3.7 | .4 |
|  | 510 | 3.3 |  | .4 |  |  | .9 | .0 | 5.0 | 90 | .44 | 1.0 | 2 | 0 | 0 | .78 | .19 | 1.3 | 3.3 | .0 |
|  | 511 | 3.6 |  | .5 |  |  | 1.0 | .0 | 3.5 | 90 | .47 | .6 | 0 | 0 | 0 | .65 | .22 | .0 | 3.5 | .1 |
|  | 512 | 3.2 |  | .7 |  |  | .8 | .0 | 5.1 | 87 | .53 | 1.3 | 0 | 0 | 0 | .79 | .28 | .0 | 3.1 | .1 |
|  | 513 | 3.4 |  | .5 |  |  | .8 | .0 | 2.6 | 75 | .56 | .5 | 0 | 0 | 0 | .56 | .31 | .0 | 3.5 | .1 |
|  | 514 | 1.8 |  | .5 |  |  | .0 | .9 | 11.1 | 122 | .73 | 5.1 | 80 | 0 | 16 | 1.08 | .53 | 9.8 | 2.1 | .3 |
|  | 515 | 3.3 |  | .7 |  |  | .9 | .0 | 2.5 | 79 | .38 | .5 | 0 | 0 | 0 | .54 | .14 | .0 | 3.8 | .5 |
|  | 516 | 2.6 |  | .6 |  |  | .4 | .3 | 5.4 | 86 | .55 | .6 | 15 | 0 | 0 | .81 | .30 | 3.9 | 3.0 | .4 |
|  | 517 | 3.2 |  | .6 |  |  | .5 | .1 | 5.4 | 83 | .54 | .7 | 1 | 0 | 0 | .81 | .29 | 1.2 | 3.1 | .1 |
|  | 518 | 1.7 |  | .4 |  |  | .0 | .8 | 21.0 | 149 | .92 | 2.8 | 222 | 0 | 0 | 1.34 | .85 | 14.9 | 1.2 | .5 |
|  | 519 | 2.4 |  | .5 |  |  | .1 | .4 | 6.5 | 99 | .53 | 1.5 | 21 | 0 | 0 | .88 | .28 | 4.6 | 2.9 | .5 |
|  | 520 | 3.0 | .2 | .6 |  |  | .6 | .1 | 6.8 | 89 | .46 | 1.1 | 0 | 0 | 0 | .89 | .21 | .0 | 3.0 | .0 |
| Off Site Sect. | 521 | 3.3 |  | .5 |  |  | .7 | .1 | 4.3 | 118 | .09 | .4 | 0 | 0 | 0 | .72 | .01 | .0 | 3.6 | .3 |
|  | 522 | 2.7 |  | .4 |  |  | .6 | .1 | 13.7 | 185 | .11 | 3.8 | 300 | 0 | 1 | 1.17 | .01 | 17.4 | 2.6 | .1 |
|  | 523 | 2.4 |  | .4 |  |  | .2 | .2 | 10.8 | 137 | .22 | 1.3 | 496 | 0 | 52 | 1.07 | .05 | 23.4 | 2.7 | .3 |
|  | 524 | 0.9 |  | .5 |  |  | .0 | 1.0 | 88.1 | 281 | .25 | 6.2 | 392 | 0 | 60 | 1.95 | .06 | 21.2 | 1.0 | .1 |
| Sum |  | 215.4 | 3.9 | 34.2 |  |  |  |  |  |  |  |  |  |  |  | 75.19 | 5.59 | 565.7 | 215.4* | 22.3 |
| Mean |  | 2.91 | .16 | .46 |  |  |  |  |  |  |  |  |  |  |  | 1.02 | .076 | 7.64 | 2.91 | .30 |
| Sum of Squares |  | 66.85 |  |  |  |  |  |  |  |  |  |  |  |  |  | 13.27 | 1.34 | 5255 | 56.42* | 10.42* |
| Sum of Products with PSR |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | -26.69 | -1.51 | -369.3 |  |  |
| Sum of Products with $\underline{\log}(1+\overline{SV})$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | - .166 | 171.63 |  |  |
| Sum of Products with $\overline{RD}^2$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | -- 3.90 |  |  |

*Obtained from Unrounded Calculations

$$PSI\ 121 = 5.03 - 1.91 \log(1+\overline{SV}) - 1.38\overline{RD}^2 - .01 \sqrt{C+P}$$

TABLE 2–F

DATA FOR 49 SELECTED RIGID PAVEMENTS

| Pvt. Loc. | Sect. Code | Present Serviceability Ratings | | | | | Acceptability Opinions | | Longitudinal Roughness | | | Cracking | Spalling | Patching | Transformations | | | PSI 211 | Resid. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AASHO Panel | | | Truck Driv'rs | Canad. Raters | AASHO Panel Fraction | | $\overline{SV}$ Mean Slope Var'nce in wh'pth $(\times 10^6)$ | $\overline{AR}$ Mean AASHO Rom'tr @ 10 mph (in./mi.) | F Fault'g in Wh'pth in in/1000' | C Class 2 and Sealed Cracks ft./1000 ft² | ft²/1000ft² for areas > 3" Dia. | P Patch'd Area ft²/1000 ft² | Log $(1+\overline{SV})$ | Log $\overline{AR}$ | Sq root C+P | Pres. Serv. Index | Diff. Betw'n PSR & PSI |
| | | 1st PSR | Replic. diff. in PSR | std. dev of PSR among raters | PSR | PSR | Yes | No | | | | | | | | | | | |
| Ill. | R1 | 2.0 | .2 | .6 | 1.5 | | .0 | .8 | 52.0 | | 2 | 53 | 4 | 8 | 1.72 | | 7.8 | 1.7 | .3 |
| | R2 | 4.2 | | .3 | 4.5 | | 1.0 | .0 | 6.5 | | 0 | 4 | 0 | 0 | .88 | | 2.0 | 3.7 | .5 |
| | R3 | 2.6 | .3 | .6 | 2.5 | | .2 | .5 | 22.2 | | 0 | 42 | 0 | 11 | 1.37 | | 7.3 | 2.3 | .3 |
| | R4 | 2.3 | .2 | .3 | 2.5 | | .0 | .5 | 26.2 | | 7 | 46 | 0 | 7 | 1.44 | | 7.3 | 2.2 | .1 |
| | R5 | 1.2 | | .4 | 1.5 | | .0 | 1.0 | 47.8 | | 1 | 102 | 0 | 28 | 1.69 | | 11.4 | 1.4 | .2 |
| | R6 | 2.8 | .1 | .6 | 2.5 | 3.0 | .2 | .1 | 25.5 | | 3 | 15 | 2 | 1 | 1.42 | | 4.0 | 2.5 | .3 |
| | R7 | 4.4 | .0 | .3 | 4.5 | 4.4 | 1.0 | .0 | 3.2 | | 0 | 0 | 0 | 0 | .63 | | 0 | 4.3 | .1 |
| | R8 | 1.1 | .2 | .4 | | | .0 | 1.0 | 50.8 | | 3 | 65 | 11 | 5 | 1.71 | | 8.4 | 1.6 | .5 |
| | R9 | 0.9 | .0 | .3 | | | .0 | 1.0 | 76.8 | | 1 | 74 | 19 | 85 | 1.89 | | 12.6 | 0.9 | .0 |
| Minn. | 201 | 1.3 | .1 | .6 | | | .0 | 1.0 | 43.3 | | 1 | 40 | 60 | 59 | 1.65 | | 10.0 | 1.6 | .3 |
| | 202 | 1.8 | | .5 | | | .0 | 1.0 | 24.2 | | 0 | 23 | 4 | 66 | 1.40 | | 9.4 | 2.1 | .3 |
| | 203 | 2.1 | .3 | .6 | | | .1 | .9 | 24.7 | | 0 | 47 | 1 | 41 | 1.41 | | 9.4 | 2.1 | .0 |
| | 204 | 4.1 | | .3 | | | 1.0 | .0 | 2.4 | | 0 | 4 | 0 | 0 | .54 | | 2.0 | 4.3 | .2 |
| | 205 | 3.8 | .3 | .4 | | | 1.0 | .0 | 4.0 | | 0 | 2 | 0 | 0 | .70 | | 1.4 | 4.0 | .2 |
| | 206 | 3.0 | .0 | .5 | | | .6 | .2 | 7.8 | | 1 | 14 | 0 | 1 | .95 | | 3.9 | 3.4 | .4 |
| | 207 | 3.0 | | .6 | | | .4 | .2 | 7.5 | | 1 | 22 | 0 | 0 | .93 | | 4.7 | 3.3 | .3 |
| | 208 | 2.9 | .1 | .6 | | | .3 | .4 | 9.7 | | 0 | 14 | 0 | 0 | 1.03 | | 3.7 | 3.2 | .3 |
| | 209 | 2.5 | | .4 | | | .1 | .6 | 17.6 | | 0 | 34 | 0 | 0 | 1.27 | | 5.8 | 2.6 | .1 |
| | 210 | 1.4 | | .5 | | | .0 | 1.0 | 59.2 | | 0 | 16 | 500 | 12 | 1.78 | | 5.3 | 1.8 | .4 |
| | 211 | 4.3 | | .2 | | | 1.0 | 0 | 3.0 | | 0 | 0 | 0 | 0 | .60 | | 0 | 4.3 | .0 |
| | 212 | 4.3 | .0 | .4 | | | 1.0 | 0 | 4.0 | | 0 | 0 | 0 | 0 | .70 | | 0 | 4.1 | .2 |
| | 213 | 3.7 | | .4 | | | 1.0 | 0 | 5.3 | | 0 | 0 | 0 | 0 | .80 | | 0 | 4.0 | .3 |
| | 214 | 3.6 | .3 | .5 | | | 1.0 | 0 | 4.4 | | 0 | 0 | 0 | 0 | .73 | | 0 | 4.1 | .5 |
| | 215 | 3.9 | | .4 | | | 1.0 | 0 | 5.3 | | 0 | 0 | 0 | 0 | .80 | | 0 | 4.0 | .1 |
| | 216 | 3.9 | .0 | .6 | | | 1.0 | 0 | 6.3 | | 0 | 0 | 0 | 0 | .87 | | 0 | 3.8 | .1 |
| | 217 | 1.3 | .0 | .4 | | | .0 | 1.0 | 32.3 | | 0 | 76 | 2 | 1 | 1.52 | | 8.8 | 1.9 | .6 |
| | 218 | 1.2 | | .4 | | | .0 | 1.0 | 27.8 | | 10 | 64 | 0 | 0 | 1.46 | | 8.0 | 2.1 | .9 |
| | 219 | 2.2 | | .6 | | | .0 | .9 | 25.6 | | 4 | 97 | 0 | 1 | 1.42 | | 9.9 | 2.0 | .2 |
| | 220 | 4.4 | .0 | .3 | | | 1.0 | .0 | 4.0 | | 0 | 0 | 0 | 0 | .70 | | 0 | 4.1 | .3 |
| Ind. | 401 | 4.0 | | .3 | | | 1.0 | 0 | 6.6 | 134 | 2 | 0 | 1 | 0 | .88 | 2.13 | 0 | 3.8 | .2 |
| | 402 | 3.8 | | .4 | | | 1.0 | 0 | 6.6 | 126 | 4 | 11 | 1 | 0 | .88 | 2.10 | 3.3 | 3.5 | .3 |
| | 403 | 3.6 | | .6 | | | .9 | 0 | 6.8 | 113 | 1 | 2 | 4 | 0 | .89 | 2.06 | 1.4 | 3.7 | .1 |
| | 404 | 3.2 | | .6 | | | .6 | .2 | 9.8 | 131 | 4 | 1 | 1 | 2 | 1.03 | 2.12 | 1.7 | 3.4 | .2 |
| | 405 | 2.6 | | .6 | | | .3 | .5 | 14.6 | 167 | 5 | 72 | 13 | 0 | 1.19 | 2.22 | 8.5 | 2.5 | .1 |
| | 406 | 2.8 | | .6 | | | .4 | .3 | 10.4 | 151 | 5 | 70 | 10 | 1 | 1.06 | 2.18 | 8.4 | 2.8 | .0 |
| | 407 | 1.8 | .5 | .6 | | | .1 | .8 | 49.4 | 268 | 1 | 41 | 4 | 29 | 1.70 | 2.43 | 8.4 | 1.6 | .2 |
| | 408 | 1.8 | | .6 | | | .1 | .8 | 54.5 | 245 | 2 | 42 | 8 | 37 | 1.74 | 2.39 | 8.9 | 1.5 | .3 |
| | 409 | 2.1 | | .6 | | | .2 | .8 | 36.6 | 276 | 1 | 50 | 7 | 29 | 1.58 | 2.44 | 8.9 | 1.8 | .3 |
| | 410 | 2.2 | | .5 | | | .2 | .8 | 25.1 | 230 | 2 | 86 | 5 | 33 | 1.42 | 2.36 | 10.9 | 1.9 | .3 |
| | 411 | 1.8 | | .5 | | | .1 | .8 | 45.4 | 286 | 0 | 40 | 6 | 65 | 1.67 | 2.46 | 10.2 | 1.5 | .3 |
| | 412 | 2.7 | | .6 | | | .4 | .4 | 9.9 | 147 | 5 | 81 | 3 | 5 | 1.04 | 2.17 | 9.3 | 2.7 | .0 |
| | 413 | 4.2 | | .4 | | | 1.0 | .0 | 6.1 | 106 | 1 | 0 | 1 | 0 | .85 | 2.03 | 0 | 3.9 | .3 |
| | 414 | 4.3 | | .4 | | | 1.0 | .0 | 5.2 | 112 | 1 | 0 | 0 | 0 | .79 | 2.05 | 0 | 4.0 | .3 |
| | 415 | 4.3 | | .4 | | | 1.0 | .0 | 7.1 | 132 | 1 | 0 | 0 | 0 | .91 | 2.12 | 0 | 3.8 | .5 |
| | 416 | 1.2 | .3 | .6 | | | .0 | .9 | 81.9 | 338 | 8 | 54 | 1 | 219 | 1.92 | 2.53 | 16.5 | 0.5 | .7 |
| | 417 | 2.2 | .0 | .6 | | | .1 | .7 | 32.2 | 252 | 18 | 36 | 1 | 0 | 1.52 | 2.40 | 6.0 | 2.2 | .0 |
| | 418 | 4.3 | .1 | .3 | | | 1.0 | .0 | 4.6 | 113 | 1 | 0 | 0 | 0 | .75 | 2.06 | 0 | 4.1 | .2 |
| | 419 | 2.8 | .0 | .7 | | | .5 | .3 | 12.6 | 126 | 2 | 5 | 2 | 13 | 1.13 | 2.10 | 4.2 | 3.0 | .2 |
| | 420 | 2.7 | .1 | .4 | | | .1 | .3 | 17.8 | 137 | 2 | 5 | 7 | 16 | 1.27 | 2.14 | 4.6 | 2.7 | .0 |
| Sum | | 138.6 | 3.1 | | | | | | | | | | | | 58.23 | | 254.3 | 138.6* | 12.5 |
| Mean | | 2.83 | .13 | | | | | | | | | | | | 1.19 | | 5.19 | 2.83* | .26 |
| Sum of Squares | | 57.92 | | | | | | | | | | | | | 7.55 | | 905.70 | 53.08* | 4.84* |
| Sum of Products with PSR | | | | | | | | | | | | | | | -19.70 | | -206.53 | | |
| Sum of Products with Log $(1+\overline{SV})$ | | | | | | | | | | | | | | | | | 71.71 | | |

*Obtained from Unrounded Calculations

$$PSI\ 211 = 5.41 - 1.80 \log(1+\overline{SV}) - .09\sqrt{C + P}$$

pavement to be unacceptable. By implication the remaining fraction of the panel gave the undecided response.

Figures 2–F through 5–F show the connection between corresponding PSR values and acceptability opinions for the two types of pavement. Freehand curves have been drawn to indicate (Figs. 2–F and 3–F) that the 50th percentile for acceptability occurs when the PSR is in the neighborhood of 2.9; the 50th percentile for unacceptability corresponds roughly to a PSR of 2.5 (Figs. 4–F and 5–F).

*Measurements for Selected Pavements*

Following the acceptability opinion, Tables 1 and 2 give summary values for measurements that were made on the selected pavements. Measurements are shown in three categories: those that describe longitudinal and transverse roughness, those that summarize surface crack-

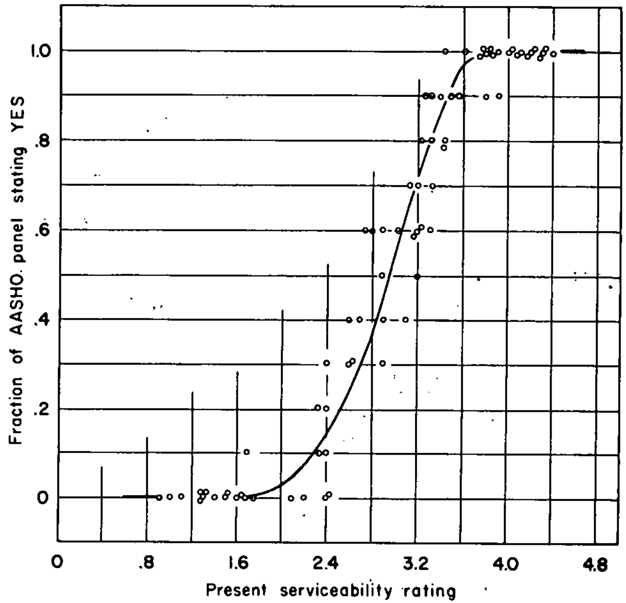


Figure 2–F. Acceptability vs present serviceability rating; 74 flexible pavements.

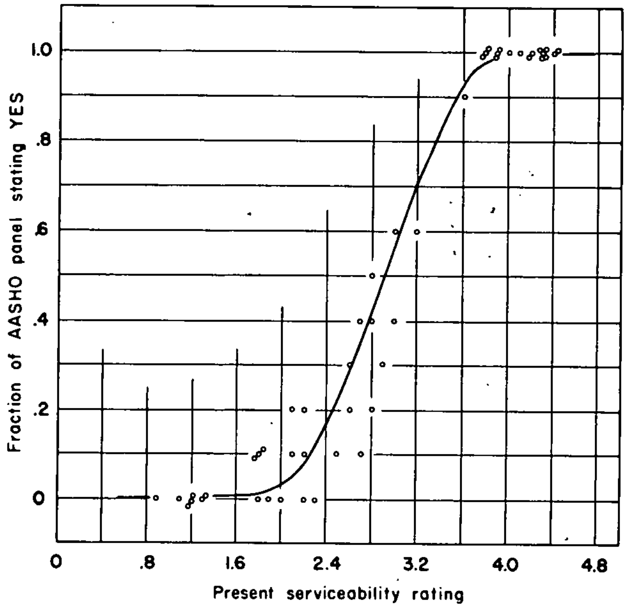


Figure 3–F. Acceptability vs present serviceability rating; 49 rigid pavements.

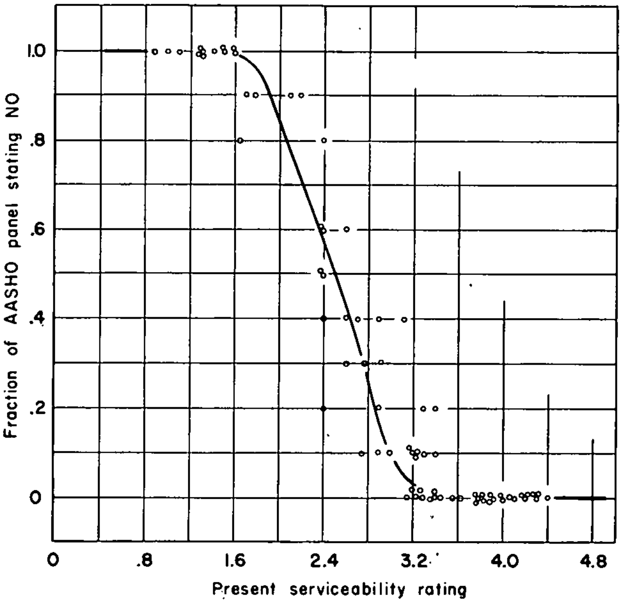


Figure 4–F. Unacceptability vs present serviceability rating; 74 flexible pavements.

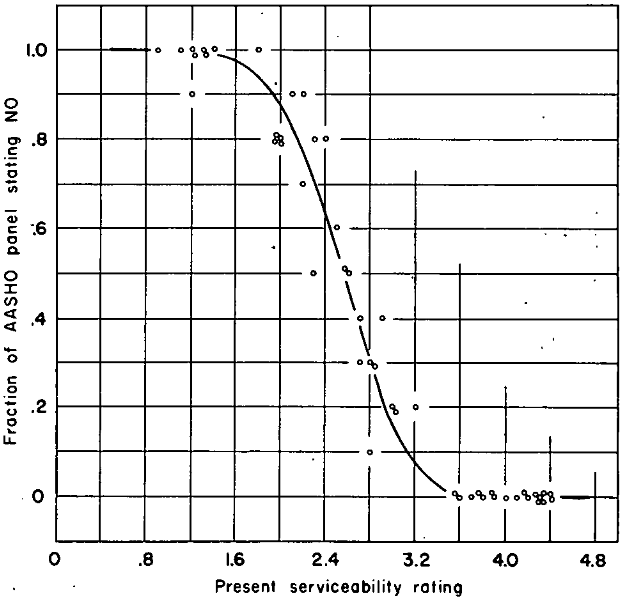


Figure 5–F. Unacceptability vs present serviceability rating; 49 rigid pavements.

ing, and finally a measurement of the patched area found in the section.

The symbol $\overline{SV}$ is used for the summary statistic of wheelpath roughness as measured by the Road Test longitudinal profilometer. For each wheelpath the profilometer produces a continuous record of the pavement slope between points 9 in. apart. For a particular wheelpath, the slopes are sampled, generally at 1-ft intervals, over the length of the record. A variance* is calculated for the sample slopes in each wheelpath, then the two wheelpath slope variances are averaged to give $\overline{SV}$.

A Bureau of Public Roads roughness indicator, or roughometer, was adapted for use at the AASHO Road Test, but this development was not made until just before the Indiana rating session and still more developmental work was done on the AASHO roughometer after the Indiana session. The AASHO roughometer has a modified output and was operated at 10 mph, so that roughometer values shown in Tables 1 and 2 are not the values that would be obtained with the BPR roughometer at 20 mph. Nevertheless, roughometer values in inches per mile are given; the roughometer values averaged for both wheelpaths, $\overline{AR}$, are correlated with the corresponding mean slope variances. Figures 6–F and 7–F show the extent of this correlation for the last two rating sessions.

One other instrument, a rut depth gage, was used to obtain profile characteristics of the flexible pavement sections. This gage is used to determine the differential elevation between the wheelpath and a line connecting two points each 2 ft away (transversely) from the center of the wheelpath. Rut depth measurements were obtained at 20 ft intervals in both wheelpaths. Average rut depth values, $\overline{RD}$, for the flexible sections are given in Table 1–F; the values range from 0 to nearly 1 in. Variances were calculated for the rut depths in each wheelpath, then the two wheelpath variances were averaged to give the $\overline{RDV}$ values (Table 1–F). Figure 8–F shows the correlation between $\overline{SV}$ and $\overline{RDV}$ for the 74 flexible sections.

Profile information for rigid pavements included a measure of faulting in the wheelpaths. These measurements are given in Table 2–F expressed in total inches of faulting (in wheelpaths only) per 1,000 ft of wheelpath.

The remaining measurements for flexible pavement sections are given in Table 1 in terms of area affected by class 2 and class 3 cracking, length of transverse and longitudinal cracks, and patched area, where areas and lengths are expressed per 1,000 square feet of pavement area. Corresponding measurements for rigid pavements are shown in Table 2–F in terms of length of class 2 and sealed cracks, spalled area, and patched area. Lengths for rigid pavement cracks were determined by projecting the cracks both transversely and longitudinally, choosing the larger projection, then expressing the accumulated result in feet per 1,000 sq ft of pavement area. Only spalled areas having more than 3-in. diameters were considered, and both spalling and patching are expressed in square feet per 1,000 sq ft of pave-

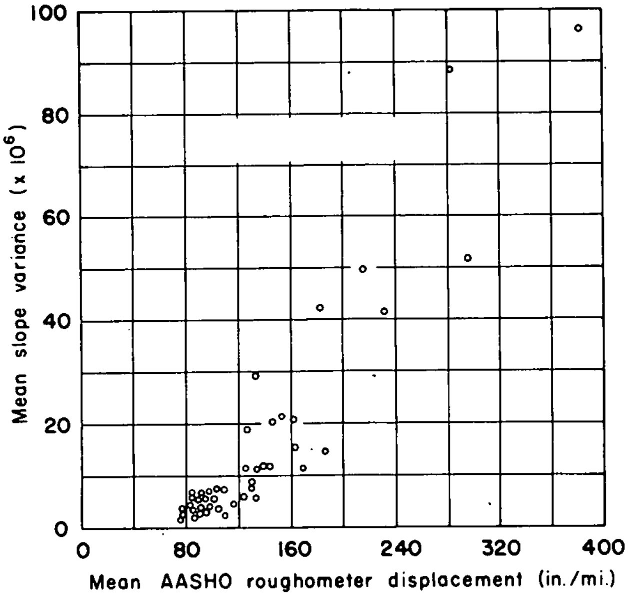


**Figure 6–F. Slope variance vs AASHO roughometer displacement; 44 flexible pavements.**

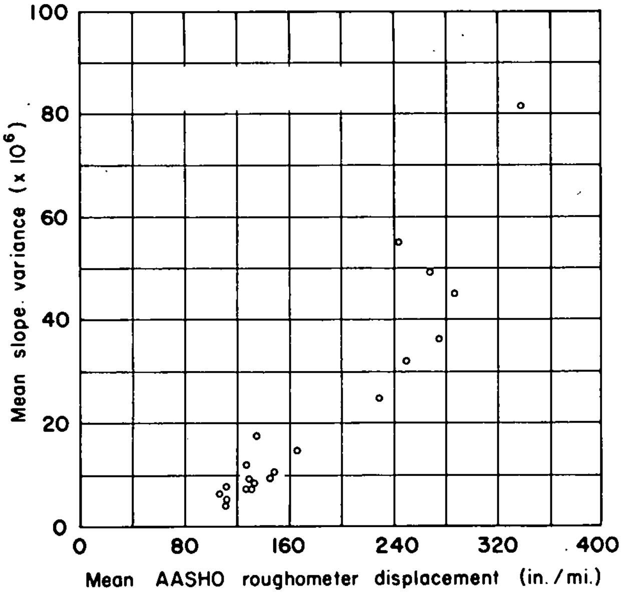


**Figure 7–F. Slope variance vs AASHO roughometer displacement; 20 rigid pavements.**

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* The variance of a set of $N$ sample values, $Y_1$, $Y_2$, . . ., $Y_N$ is defined to be the sum of all $N$ squared deviations from the mean divided by $N - 1$. Thus the variance of $Y$ is $\Sigma\ (Y - \bar{Y})^2/(N - 1)$, where $\bar{Y} = \Sigma\ Y/N$ is the sample mean.

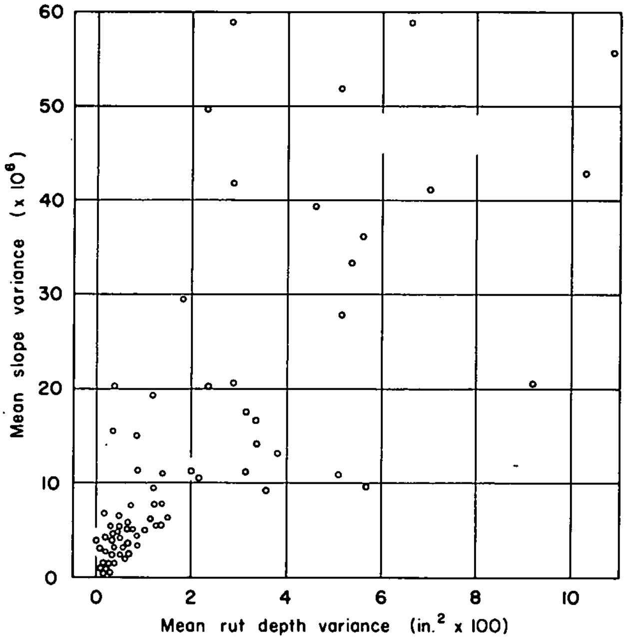

**Figure 8–F.** Rut depth variance vs slope variance; 74 flexible pavements.

ment area. Virtually any pair of measurements are intercorrelated to some degree, some more highly than others. Figures 9–F and 10–F indicate the degree to which $\overline{SV}$ is correlated with the sum of cracking and patching values. A stronger correlation is shown in Figure 10–F than in Figure 9–F. If either correlation were perfect, one or the other of the plotted variables would be redundant in an index of present serviceability.

### *Hypothesis and Assumptions for Present Serviceability Index*

One requirement for an index of present serviceability is that when pavement measurements are substituted into the index formula, the resulting values should be satisfactorily close to the corresponding present serviceability ratings. There are also advantages if the index formula is relatively simple in form and if it depends on relatively few pavement characteristics that are readily measured.

Guided by the discussion of the AASHO rating panel as well as by results from early rating sessions, the general mathematical form of the present serviceability index was assumed to be

$$\text{PSI} = C + (A_1R_1 + A_2R_2 + \ldots) + (B_1D_1 + B_2D_2 + \ldots) \qquad \text{(1–F)}$$

where $R_1$, $R_2$, . . . are functions of profile roughness and where $D_1$, $D_2$, . . . are functions of surface deterioration. The coefficients $C$, $A_1$, $A_2$, . . ., $B_1$, $B_2$, . . . may then be determined by a least squares regression analysis. It is expected, of course, that $A_1$, $A_2$, . . . $B_1$, $B_2$ . . . will have negative signs. To perform the analysis, the PSR for the $j^{\text{th}}$ of a set of sections is represented by

$$\text{PSR}_j = \text{PSI}_j + E_j \qquad \text{(2–F)}$$

in which $E_j$ is a residual not explained by the functions used in the index. Minimizing the sum of squared residuals for all sections in the analysis leads to a set of simultaneous equations whose solutions are the required coefficients. The respective effect of adding or

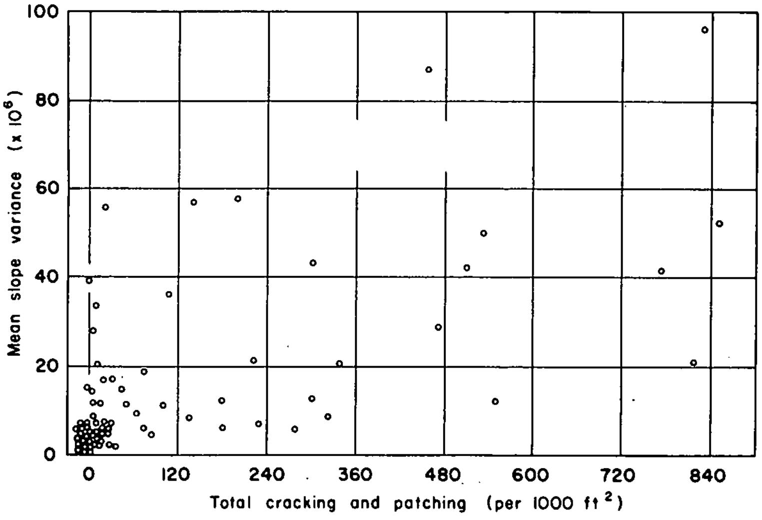

**Figure 9–F.** Mean slope variance vs cracking and patching; 74 flexible pavements.

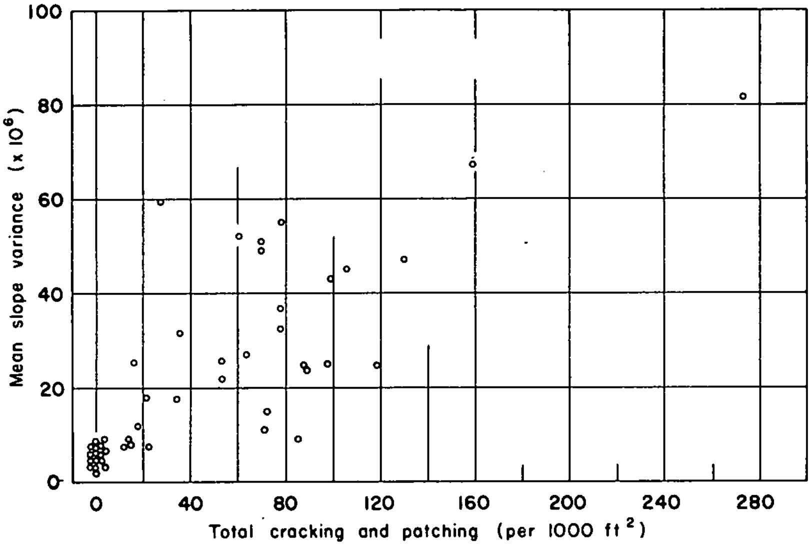

Figure 10–F. Mean slope variance vs cracking and patching; 49 rigid pavements.

deleting terms in Eq. 1–F will be to decrease or increase the sum of squared residuals. The change in residual sum of squares can be used to deduce the significance of adding or dropping terms from the index formula.

The model for PSI is linear in that if all functions save one are given a numerical value, then PSI versus the remaining function represents a straightline relationship. For this reason it is desirable to choose functions $R_1$, $R_2, \ldots$, $D_1$, $D_2, \ldots$, that have linear graphs when plotted with PSR values. For example, logarithms and powers of the original measurements may be used as linearizing transformations.

A present serviceability index developed from observed ratings and measurements can only reflect the characteristics that were actually present in the observed pavements. For any particular characteristic, the index can only reflect the observed range of values for the characteristic. For example, if the selected pavements had no potholes, there is no objective way to infer how potholing would affect the present serviceability ratings, and the index cannot contain a function of potholing. As another example, if faulting in the selected pavements ranged from 0 to 10, there would be no way to infer the effect on PSR of pavements whose faulting was in the range 50 to 100.* This same argument applies to the present serviceability ratings themselves. If PSR's for the selected pavements range only from 2.0 to 4.0, there is no way to infer what pavement characteristics must be like in order to produce a value of 1.0 or 5.0, except to extrapolate the index on the assumption that linearity holds over the full range of pavement characteristics.

For these reasons it has been stated that selected pavements should show all phenomena of interest, the complete range of interest for each phenomenon, and should be associated with PSR values that span the full range of interest. Therefore, pavement selection amounts to the assumption that all interesting phenomena and ranges have been encompassed by the selections. Extrapolations of the index to measured values outside the range of those found in the selected pavements amounts to the assumption that the index formula remains linear in the region of extrapolation.

### *Choice of Functions for the Present Serviceability Index*

Measurements from the Illinois and Minnesota sections were plotted in succession against corresponding PSR values to determine which measurements were essentially uncorrelated with PSR and to deduce the need for linearizing transformations. It was indicated that the mean wheelpath slope variance, $\overline{SV}$ was highly correlated with PSR, though curvilinearly. Figures 11–F and 12–F show the nature of this correlation for all selected pavements. From several alternatives, the transformation

$$R_1 = \log (1 + \overline{SV}) \qquad (3\text{–F})$$

was selected as the first function of profile roughness to appear in the PSI model for both flexible and rigid pavements. The result of this transformation is shown in Figures 13–F and

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* It was for this reason that it was not possible to determine the effect of rutting in flexible pavements after the first three rating sessions which included pavements with rutting ranging from 0 to only 0.37 in. Thus the fourth rating session was necessary to determine the effect of ruts in the range of 0.5 to 1.0 in. deep.

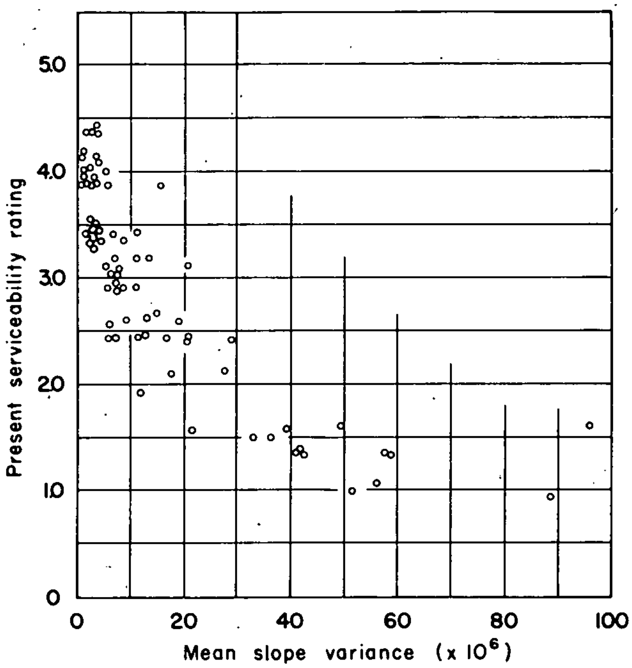

Figure 11–F. Present serviceability rating vs slope variance; 74 flexible pavements.

14–F where PSR values are plotted against $R_1$ for flexible and rigid pavements, respectively.

For the flexible pavements, mean wheelpath rut depth, $\overline{RD}$, was included as a second profile measurement to appear in the PSI equation. The selected function of rut depth was

$$R_2 = \overline{RD}^2 \qquad (4\text{–F})$$

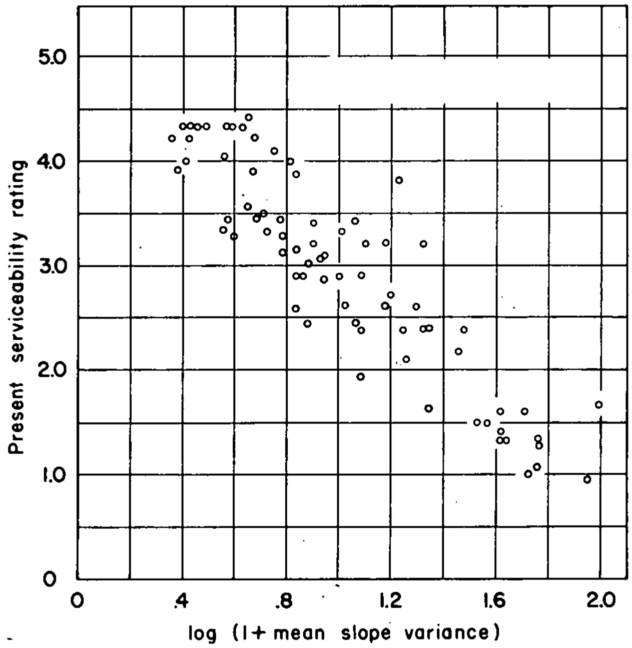

Figure 13–F. Present serviceability rating vs log (1 + mean slope variance); 74 flexible pavements.

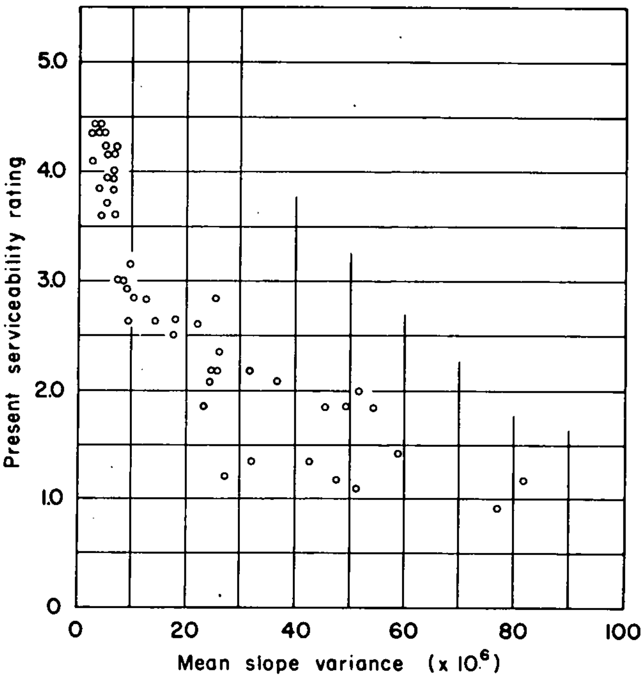

Figure 12–F. Present serviceability rating vs slope variance; 49 rigid pavements.

The scatter diagram of PSR vs $\overline{RD}^2$ is shown in Figure 15–F.

Although preliminary analyses considered the possibility of several functions of surface deterioration, for example, one function for each of the measured manifestations, it was ap-

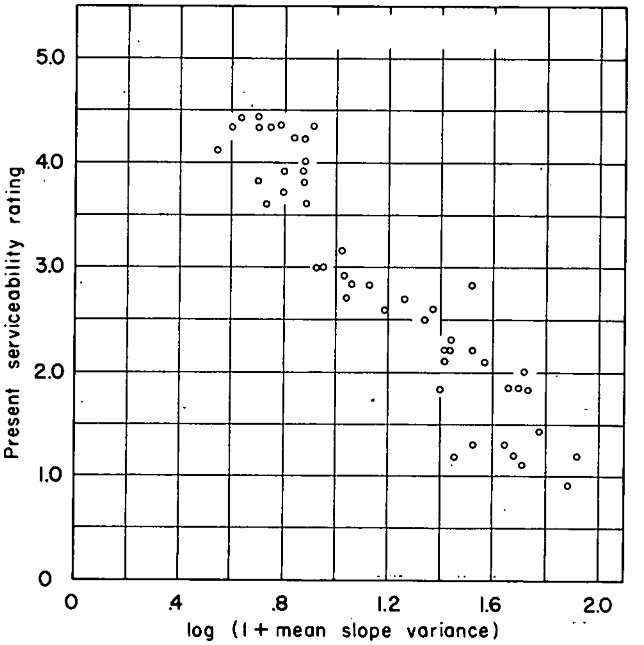

Figure 14–F. Present serviceability rating vs log (1 + mean slope variance); 49 rigid pavements.

parent that no loss would be incurred by lumping all major cracking and patching into a single number to represent surface deteriorations. Values for $C + P$ are not shown in Tables 1–F and 2–F, but may be obtained from the cracking and patching measurements. Scatter diagrams for the PSR versus $C + P$ are shown in Figures 15–F and 16–F.

For whatever reasons, it is apparent that there is little correlation between PSR and $C + P$ for the flexible pavements, but that a fair degree of correlation exists between these variables for the rigid pavements. For both flexible and rigid pavements the transformation

$$D_1 = \sqrt{C + P} \qquad (5\text{–F})$$

was selected as a linearizing transformation for $C + P$ (Figs. 17–F and 18–F).

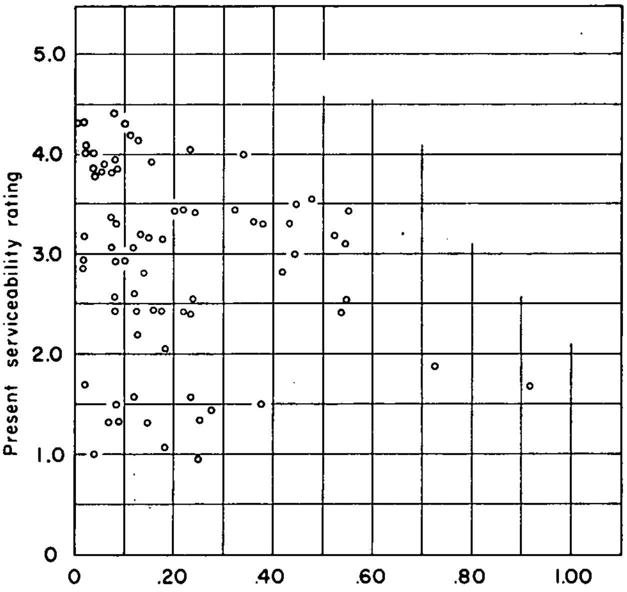

**Figure 15–F. Present serviceability rating vs mean depth squared; 74 flexible pavements.**

Thus the present serviceability index models to be used are

*For flexible pavements:*

$$\text{PSI} = A_0 + A_1R_1 + A_2R_2 + B_1D_1 = A_0 + A_1 \log{(1 + \overline{SV})} + A_2\overline{RD}^2 + B_1 \sqrt{C + P} \qquad (6\text{–F})$$

*For rigid pavements:*

$$\text{PSI} = A_0 + A_1R_1 + B_1D_1 = A_0 + A_1 \log{(1 + \overline{SV})} + B_1 \sqrt{C + P} \qquad (7\text{–F})$$

It is not expected that the coefficients $A_0$, $A_1$, and $B_1$ have the same values for both equations.

There are many other possibilities for Eqs. 6–F and 7–F—other instruments might be used to detect deformation and deterioration, and summary values other than $\overline{SV}$, $C + P$ and $\overline{RD}$ might be used. Moreover, different functions of $\overline{SV}$, $C + P$ and $\overline{RD}$ could be chosen, or more functions of pavement measurements could be included.

One of the most important elements of pavement serviceability is its longitudinal profile in the wheelpaths. The profile of the road coupled with the appropriate characteristics of the vehicle (mass, tires, springs, shock absorbers,

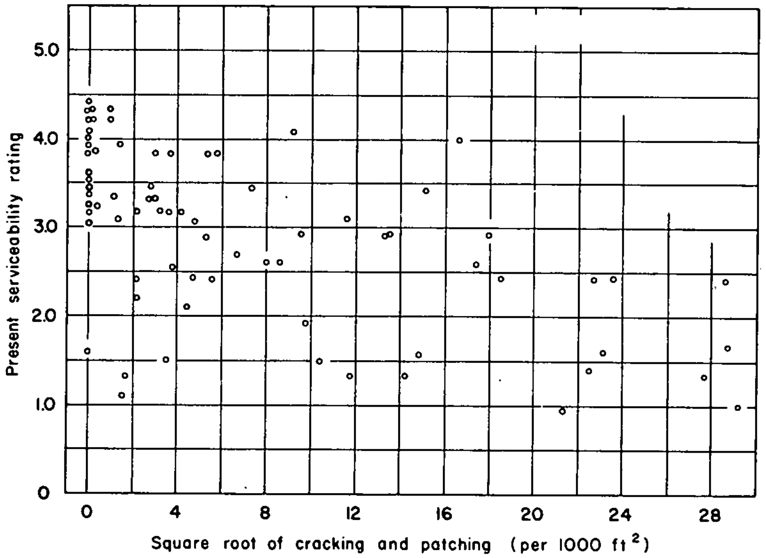

**Figure 16–F. Present serviceability rating vs square root cracking and patching; 74 flexible pavements.**

speed, etc.) produce the "ride" attained in that vehicle over that road. The actual profile of the wheelpath as though taken with rod and level at very close spacing is called the displacement profile, $p$. The first derivative of the displacement profile is the profile of the slope, $p'$. A plot of the slope profile has the same abscissa (distance along the road) as the displacement profile and its ordinate represents the rate of change of displacement, or slope of the road at any point. The second derivative of the displacement profile is the "acceleration" profile, $p''$, and represents the rate of change of slope, and the third derivative is the "jerk" profile, $p'''$, the rate of change of acceleration. It has been suggested that jerk may be more highly

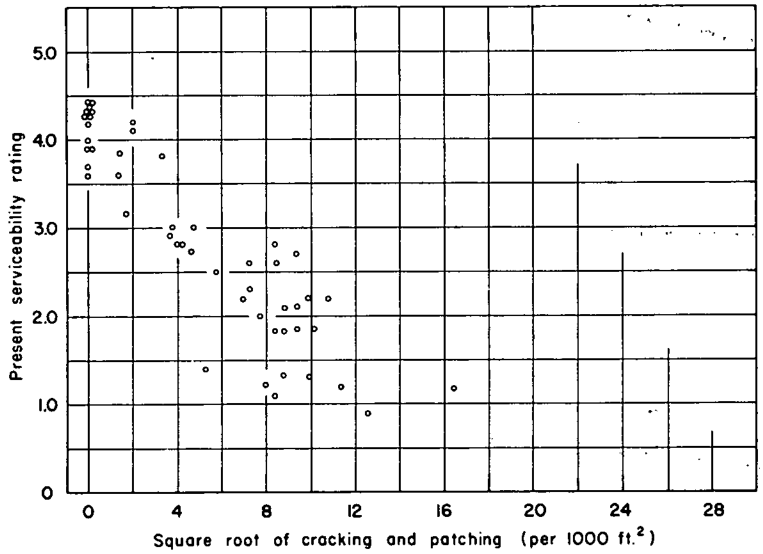

Figure 17–F. Present serviceability rating vs square root cracking and patching; 49 rigid pavements.

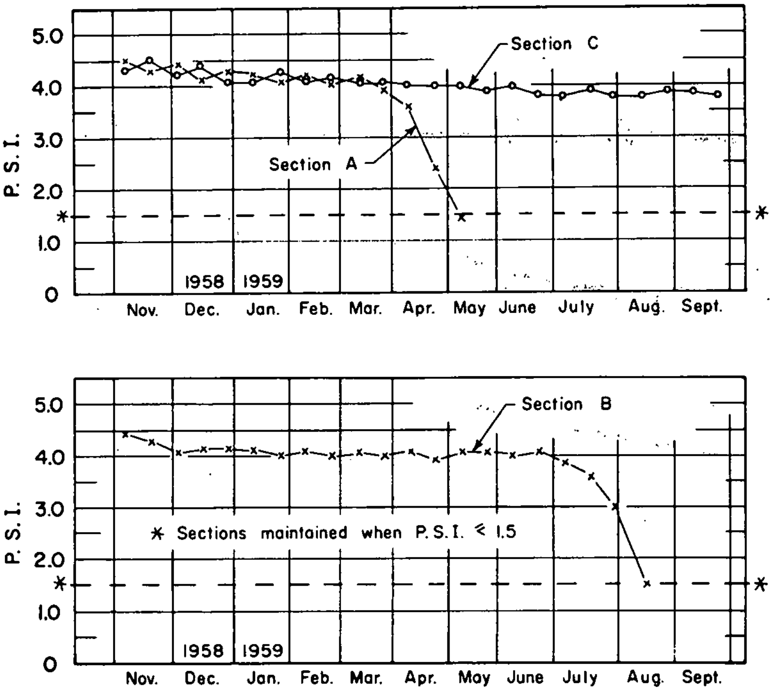

Figure 18–F. Present serviceability history of three selected test sections on the AASHO Road Test.

correlated with a rider's opinion of his ride than any of the other representations. Perhaps this is true if one is seeking to define "ride"—but the efforts at the Road Test were directed towards a definition of the "smoothness of a road" independent of the vehicle that might use it. Considerable effort was spent in studying correlations of the variances of various profile derivatives with the present serviceability ratings, but there was no evidence that elevation variance, acceleration variance, or jerk variance has higher correlation with PSR than the slope variance. On the other hand, when a number of the slope profiles were subjected to generalized harmonic analysis to determine how variance was associated with the wavelength spectrum, there was some indication that slope variance in certain regions of the wavelength spectrum is more highly correlated with PSR than is the total slope variance.

*Coefficients for the Present Serviceability Index*

Substitution of Eq. 6–F into Eq. 2–F gives for flexible pavements

$$\text{PSR}_j = A_0 + A_1 R_{1j} + A_2 R_{2j} + B_1 D_{1j} + E_j \qquad \text{(8–F)}$$

in which

$R_{1j} = \log(1 + \overline{SV}_j)$, $R_{2j} = RD_j{}^2$ and $D_{1j} = \sqrt{C_j + P_j}$ for the $j^{\text{th}}$ pavement.

Least squares estimates for $A_0$, $A_1$, $A_2$ and $B_1$ are found by minimizing the sum of squared residuals, $E_j$, through solving four simultaneous equations for $A_0$, $A_1$, $A_2$ and $B_1$. The solution of these equations gives the index

$$\text{PSI} = 5.03 - 1.91 \log(1 + \overline{SV}) - 1.38\, \overline{RD}^2 - 0.01 \sqrt{C + P} \qquad \text{(9–F)}$$

Because the model for rigid pavement (Eq. 7–F) has only three undetermined coefficients, only three simultaneous equations need be solved. Their solution gives the index

$$\text{PSI} = 5.41 - 1.78 \log(1 + \overline{SV}) - 0.09 \sqrt{C + P} \qquad \text{(10–F)}$$

The multiple squared correlation coefficients for these derivations are $r^2 = 0.844$ for the flexible pavements, and $r^2 = 0.916$ for the rigid pavements.

Therefore, the PSI formulas account for 84.4 percent and 91.6 percent of the variation in PSR for flexible and rigid pavements, respectively. The respective root mean square residuals are about 0.38 and 0.32, respectively.

The last columns of Tables 1–F and 2–F show calculated values for the present serviceability indexes as well as for residuals. At the bottom of the last column, the mean residual was 0.30 for flexible pavements and 0.26 for rigid pavements. In both cases, the mean residual is about twice the mean difference between replicate ratings given by the AASHO rating panel.

From the residual columns, six flexible and three rigid pavement residuals exceeded 0.5, the largest replication difference given by the panel. However, the index formulas span ratings made more than a year apart whereas all replicate ratings were made on successive days. As stated before, it is quite possible that replicate PSR's would be more different when made over longer intervals of time.

When the 15 rigid pavement PSR values from the fourth rating session were compared with PSI values given by Eq. 10–F, the sum of the algebraic deviations was practically 0 whereas mean discrepancy was 0.3. Since only two of the deviations exceeded 0.5, it was inferred that Eq. 10–F fitted the new PSR values to about the same degree as it predicted those from which it was derived.

# Appendix G

## A RATIONALE FOR ANALYSIS OF PAVEMENT PERFORMANCE*

The first objective for the AASHO Road Test is to find significant relationships between pavement performance and certain characteristics of pavement design and applied loads. To carry out this objective detailed specifications are needed in three areas. First, pavement performance must be defined so that performance data can be obtained for every test section in the investigation. Second, there must be experimental designs that give details for pavement design and load characteristics of the sections. Finally, it is necessary to set out definite procedures that lead to the required relationships. Several papers and talks have described Road Test specifications in the first two areas, and it is the main purpose of this paper to discuss specifications in the third area. However, the three sets of specifications are interrelated in that analytical procedures are determined to a large extent by the nature of the experimental designs and by the nature of the performance data. For this reason pavement performance and experimental designs are discussed before turning to a rationale for analysis. A numerical illustration that differs from the AASHO Road Test pavement performance studies in certain details but not in principle is used. As a consequence, rationale for the illustration is applicable to the Road Test, and unless specific reference is made to the illustration, the following discussion pertains to the Road Test.

It is evident that there are alternatives for virtually every specification that may be given in any of the three areas; thus there are many possibilities for the total set of specifications. Because it may be supposed that a number of these possibilities are equally acceptable for meeting the first objective of the Road Test, it cannot be claimed that the rationale to be described represents the best, nor the only way to satisfy the objective, but it is assumed that any other acceptable rationale would produce essentially the same conclusions.

### PAVEMENT PERFORMANCE DATA

Inasmuch as a rationale for analysis is rather meaningless unless the data that go into the analysis are well defined, it is necessary to pin down the specific nature of performance data. The concepts and specifications to be described in this area have evolved after consideration of many alternatives.

It is supposed that the present serviceability history of a pavement section plays a very useful role in performance evaluation. At any particular time the section's present serviceability is a measure of its ability to serve high speed, high volume traffic, and in Appendix F a system for the development of present serviceability index formulas was described. Separate formulas were presented for flexible and for rigid pavements. When appropriate measurements of surface deformation and deterioration are made on day $t$, then substitution of the measurements into the index formula gives an index value $p_t'$ for the index day. The complete serviceability history of a pavement section consists of index values for a series of index days that begins when the section is first constructed and that ends when serviceability loss is such that major maintenance or replacement is required. In both the illustration and the AASHO Road Test, serviceability index values are obtained for every section on biweekly index days, and the serviceability history of a section is considered to be completed if and when its index falls to 1.5 on a scale where maximum serviceability is 5.0. Although not all biweekly index values are plotted, Figure 1–G, which shows the serviceability histories of two sections used in the illustration, indicates a completed history for section 3212 after about 17 index days. As in the case of the AASHO Road Test, it is assumed that the illustrative road test is stopped after 55 index days with the expectation that at least some sections will still have high serviceability at the end of the test. One such section is shown in Figure 1–G where section 3222 has a serviceability index of about 3.2 after 55 index days.

The general continuous pattern of a serviceability history is called a smoothed serviceability history. Smoothed histories for the two sections in Figure 1–G are indicated by the solid lines. The smoothed history for a section is defined by a moving average that includes at least three (generally five) successive index values and that uses the end values for the history as end values for the smoothed history. Smoothed serviceability history values on index days will be denoted by $p_t$.

A second element of performance for a pavement section is its history of load applications.

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* An adaption of a paper given at the 40th Annual Meeting of the Highway Research Board.

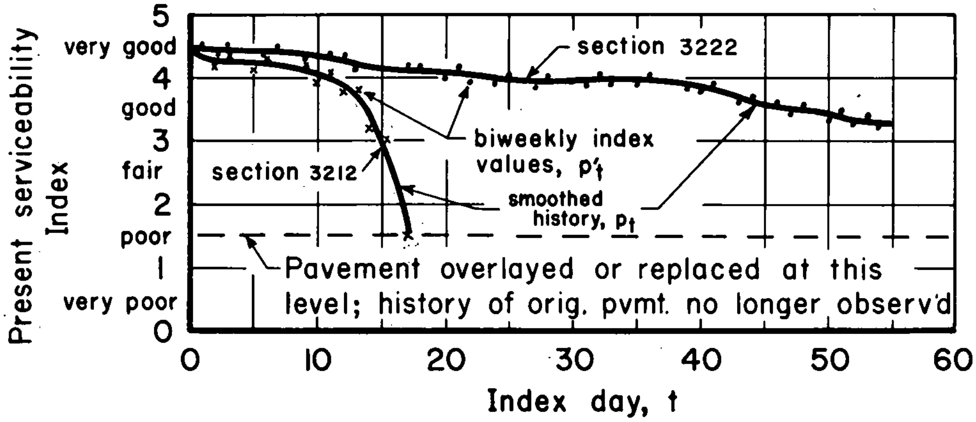

Figure 1–G. Present serviceability histories for two illustrative pavement sections.

Although theories* and procedures exist for dealing with mixtures of axle loads, reference in this paper to any particular number of applications implies that each application represents the same axle weight. For the illustration, Figure 2–G gives both the number of axle load applications between successive index days and the accumulated number of applications for any index day. The respective notation for these two quantities is $n_t$ and $N_t$. If more than one traffic lane is represented by $n_t$ and $N_t$, it is assumed that lane to lane variation in $n_t$ is negligible and $n_t$ is averaged for all lanes before the accumulation, $N_t$. Whenever it is necessary to evaluate accumulated applications between index days, linear interpolation is performed between successive values of $N_t$.

Before specifications are given for performance data, one more history is discussed—a history that is associated with the general state of environmental conditions at any particular time. This history is called a seasonal weighting function. Relative to a specified norm, or base, it may be supposed that the conditions at any time or location are either normal, better than normal, or worse than normal. It is considered that the seasonal weighting function reflects serviceability loss potential, and that any particular section may or may not lose serviceability during a period when the weighting function is high. No specific formula for a weighting function will be given in this paper, but it is supposed that such a formula has been evolved to give values, $q_t$, for every index period (Fig. 3–G). This function presumably depends in general on changes in moisture-temperature states, and has the value $q_t = 1.0$ for normal conditions. A value of zero is considered to be a lower bound at which no serviceability-loss potential exists for any pavement-load combination.

The seasonal weighting function (Fig. 3–G) averages about 1.0, so that environmental conditions for the two years average normal even though there is much seasonal variation. Relative to the selected location, this index might not average 1.0 at a second location, whether

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* Scrivner, F. H., "A Theory for Transforming the AASHO Road Test Pavement Performance Equations to Equations Involving Mixed Traffic." HRB Special Report 66 (1961).

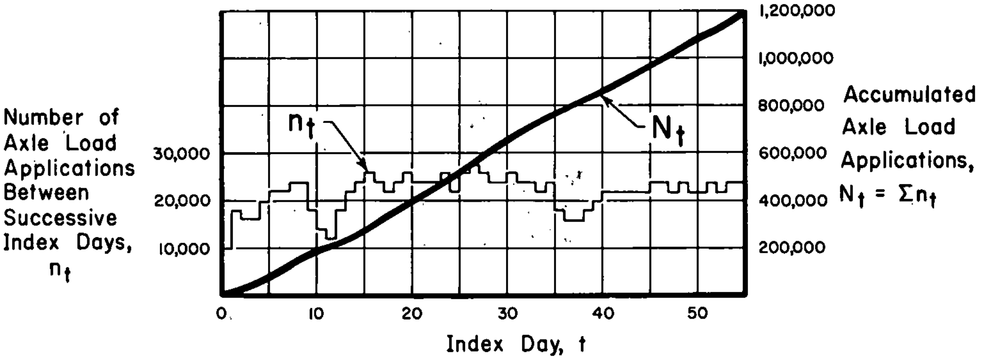

Figure 2–G. Axle load application history for the illustration.

or not the same seasonal variation occurred at the two locations.

For any index period, the product of the weighting function value with axle load application is assumed to be $w_t$, the number of weighted applications for the period; therefore, $w_t = q_t n_t$ can be obtained by multiplication of index day ordinates from Figures 2–G and 3–G. Also, $W_t$ is assumed to be the accumulation of weighted axle load applications through any index day. Graphs for both $w_t$ and $W_t$ are shown in Figure 4–G. If the weighting function were taken to be 1.0 on every index day, then the curve in Figure 3–G would be horizontal at unit height, and Figure 4–G would be identical with Figure 2–G. Thus, $N_t$ is a special case of $W_t$ if $q_t$ is always 1.0. In all the discussion that follows accumulated axle load applications are represented by $W$ but any difference between $W$ and $N$ depends on the values prescribed for $q_t$.

All of the variables have values that are observed and computed at points in time. If smoothed serviceability values for a pavement section are plotted against accumulated axle applications rather than against time, the resultant curve is called the section's serviceability trend. Coordinates of points on the serviceability trend are denoted by $p$ and $W$, and the trend of $p$ with $W$ is defined to be the pavement's performance. In other words, serviceability trends are considered to be performance curves that show how pavements are affected by applied loads.

Trend plots for the two sections of Figure 1–G are shown in Figure 5–G for the case when applications are not weighted; that is, when $v_t = 1$. Coordinates for the trend curves in Figure 5–G were obtained from ordinates of Figures 1–G and 2–G on common index days. Similarly Figure 6–G shows trend curves for the same sections when the seasonal weighting function of Figure 3–G is used to obtain $W$. That is, coordinates for Figure 6–G were obtained from ordinates of Figures 1–G and 4–G on common index days.

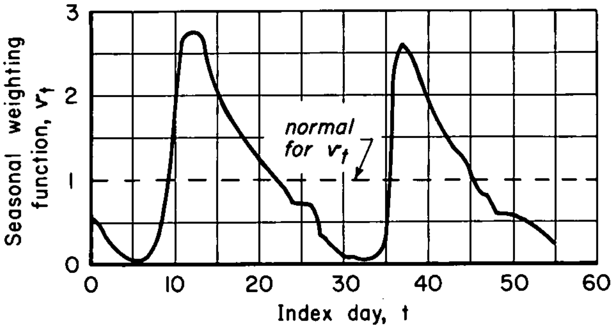

**Figure 3–G. Seasonal weighting function.**

Summarizing the definitions of the various serviceability-time-applications relationships:

*Serviceability history* is the plot of observed values of serviceability $p_t'$ on a time scale;

*Smoothed serviceability history* is the plot of the 5-point moving average of the serviceability history values on a time scale and smoothed history values are designated by $p_t$;

*Serviceability trend* is the plot of smoothed serviceability history values $p$ on an accumulated axle application scale $W$ where axle applications may be weighted or unweighted; and the

*Performance* of a pavement is given by its serviceability trend.

The final step in the specification of performance data is to assume that for numerical analysis a small number of pairs of coordinates from any trend curve can be selected to represent satisfactorily the curve. In the Road Test rationale five pairs of coordinates were selected from every trend. If the trend was complete (*i.e.*, $p$ had fallen to 1.5) then the trend was represented by five values that spanned the range of $p$. Specifically, $W$ was noted when $p$ was 3.5, 3.0, 2.5, 2.0, and 1.5. In the case of incomplete serviceability trends ($p$ at the end of the Road Test was greater than 1.5) the observations were spanned by noting pairs of

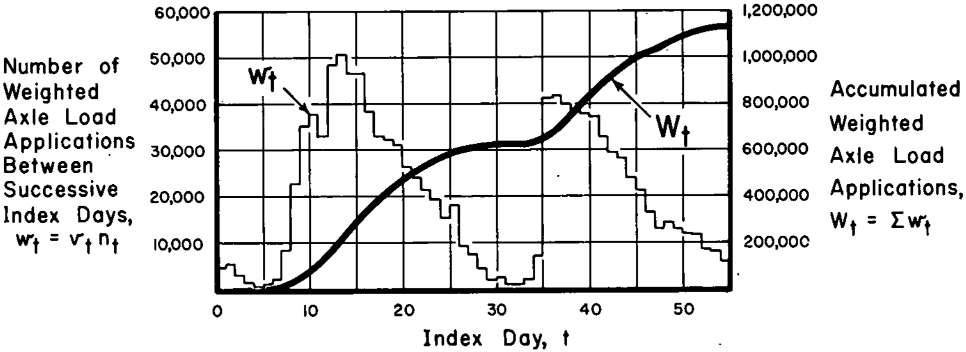

**Figure 4–G. Weighted axle load applications for the illustration (seasonal weighting function from Fig. 3–G).**

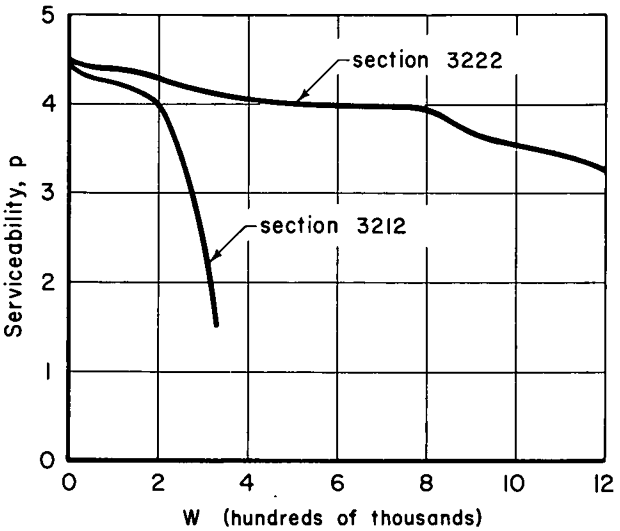

**Figure 5–G. Performance curves for the two illustrative pavement sections of Figure 1–G ($v_t = 1$).**

$W$ and $p$ at specific times (at 11, 22, 33, 44 and 55 index days). In both cases it is more convenient to record and use all $W$ values in logarithmic form so that recorded performance data appear in the form $p$, log $W$. Therefore, if $p = 2.5$ when $W = 200{,}000$ applications, the recorded performance data would be 2.5 and 5.30 for $p$ and log $W$, respectively.

In the example only three pairs of coordinates are used to represent serviceability trends. For the complete curves $W$ is noted when $p = 3.5$, 2.5 and 1.5, and for incomplete trends $W$ and $p$ are noted at 15, 35 and 55 index days. For the two sections shown in Figure 1-G, Table 1-G gives performance data using both weighted and unweighted applications.

TABLE 1–G

PERFORMANCE DATA FOR TWO ILLUSTRATIVE SECTIONS OF FIGURE 1–G

| Section | $t$[1] | Performance Data | | | |
|---|---|---|---|---|---|
| | | For $v_t = 1$ | | For $v_t$ from Fig. 3–G | |
| | | $p$ | log $W$ | $p$ | log $W$ |
| 3212[2] | 13.5 | 3.5 | 5.39 | 3.5 | 5.36 |
| | 16.0 | 2.5 | 5.49 | 2.5 | 5.54 |
| | 17.0 | 1.5 | 5.52 | 1.5 | 5.59 |
| 3222 | 15 | 4.2 | 5.45 | 4.2 | 5.48 |
| | 35 | 4.0 | 5.89 | 4.0 | 5.81 |
| | 55 | 3.2 | 6.08 | 3.2 | 6.05 |

[1] $t$ = Index day at which smoothed serviceability history equals $p$.

[2] Complete history.

[3] Incomplete history.

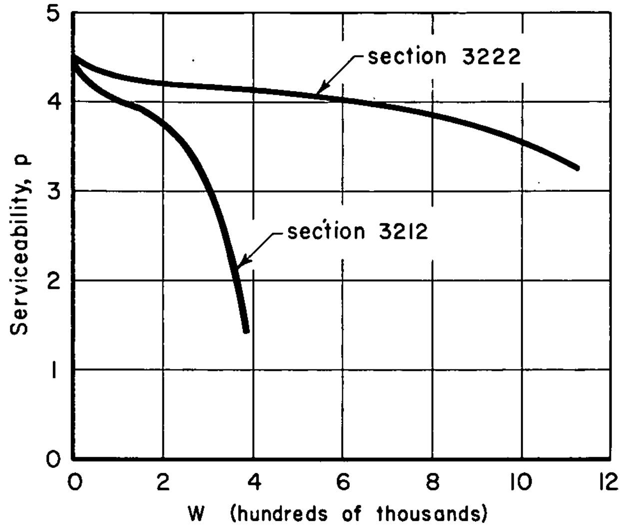

**Figure 6–G. Performance curves for the two illustrative pavement sections of Figure 1–G (seasonal weighting function from Figure 3–G).**

## EXPERIMENTAL DESIGNS FOR PAVEMENTS AND LOADS

As details are given in the second area of specification for the illustration, the reader who is familiar with experimental designs at the AASHO Road Test will recognize that the illustration parallels in principle the main factorial experiments of the Road Test.

It is assumed that the illustrative road test involves three rigid pavement tangents, 1, 2, and 3, each having two 12-ft traffic lanes, 1 and 2, on either side of its centerline. Axle load specifications for the six traffic lanes are as follows: tangent 1, 4-kip single in lane 1, 8-kip single in lane 2; tangent 2, 16-kip single in lane 1, 30-kip tandem in lane 2; tangent 3, 24-kip single in lane 1 and 36-kip tandem axle vehicles in lane 2. Figure 2-G gives the illustrative specifications for frequency of axle load applications over a 2-yr period.

The objective for the illustration is assumed to imply that differences in pavement design for test sections will be determined by only two factors, thickness of portland cement concrete surfacing and thickness of a granular subbase material. All other specifications for basement soil, pavement materials, and construction procedures are assumed identical for every test section.

Three fundamental principles of experimental design are balance, replication, and randomization; these principles are to be used in the design of the illustrative road test. The principle of balance is used to rule out undesired confusion among the effects of experimental factors on performance. The effect of a factor means a change in performance that can be attributed to a change in the factor; for example, a surface thickness effect is a change in performance that is clearly attributable to a change in surface thickness. It is assumed that balance should be maintained in each test tangent for surface thickness and for subbase thickness, so that the analysis can determine whether performance differences are due to one or the other of these factors or possibly to their interacting effect. In the absence of prior knowledge about their interacting effect, a sound experimental design for surface and subbase thickness is the complete factorial experiment that includes all possible combinations of levels selected for these two factors. In each tangent each factor is assigned three levels (that is, three values). Then the complete factorial experiment in each tangent requires 3x3, or nine, different pavement designs. As indicated in Table 2-G, levels for subbase thickness are 3, 6, and 9 in. in each tangent, but levels for surface thickness are selected so that thicker pavements are used for heavier axle loads, there being one common surface thickness, 5.5 in., across all three tangents. Thus, although balance is maintained for surface and subbase thickness in each tangent and loads are balanced with subbase thickness across all tangents, load and surface thickness levels are unbalanced so that extraneous surface thickness-load combinations will not occur. However, the load effect can be observed across the 5.5 in. surface thickness, and if there is no interaction between load and surface thickness effects, the load effect at 5.5-in. surface could serve as the general effect of axle load on performance.

Replication of observations for controlled factor combinations provides a way to find how much the observations are influenced by residual variables that are uncontrolled. Replication can be performed in many categories; for example, the illustrative road test might be repeated in toto at a different location, or at a different time, or both. At a selected location and time, any tangent might be completely replicated by including a fourth tangent that has the same specifications as one of the tangents in Table 2-G. An axle load might be replicated in both lanes of the same tangent, or serviceability index values might be replicated for any index day. If there is sufficient replication in any category where conclusions are to be drawn about the effects of controlled factors within the category, it becomes possible to discern between performance changes that can be attributed to controlled effects and those changes that must be attributed solely to uncontrolled or residual effects. For the latter, replication provides estimates needed to assess the reliability of controlled effects.

In the illustration it is assumed that cost considerations prohibit replication of the whole experiment, replication of tangents, and replication of lanes, but that replication will occur for certain pavement designs within each tangent. Table 2-G indicates that two different pavement designs are to be once replicated within each tangent; thus there are to be eleven test sections in each of the six traffic lanes or 66 test sections in all. More replication might be required if the illustration were an actual road test, as the number of replicates should be sufficient to obtain reliable estimates of residual variation (within tangents).

The third principle, randomization, is closely associated with the principles of balance and

TABLE 2–G

LEVELS FOR EXPERIMENTAL FACTORS IN ILLUSTRATION

| Tangent | Lane | Load (kips) | Factorial Combinations | | | Replicated Combinations | | | Total Number of Test Sections |
|---|---|---|---|---|---|---|---|---|---|
| | | | Slab Thickness (in.) | Subbase Thickness (in.) | Number of Test Sections | Slab Thickness (in.) | Subbase Thickness (in.) | Number of Test Sections | |
| 1 | 1 | 4KS | 2.5 | 3 | | 2.5 | 6 | | |
| | | | 4.0 | 6 | 9 | 4.0 | 6 | 2 | 11 |
| | | | 5.5 | 9 | | | | | |
| | 2 | 8KS | 2.5 | 3 | | 2.5 | 6 | | |
| | | | 4.0 | 6 | 9 | 4.0 | 6 | 2 | 11 |
| | | | 5.5 | 9 | | | | | |
| 2 | 1 | 16KS | 4.0 | 3 | | 4.0 | 6 | | |
| | | | 5.5 | 6 | 9 | 5.5 | 6 | 2 | 11 |
| | | | 7.0 | 9 | | | | | |
| | 2 | 30KT | 4.0 | 3 | | 4.0 | 6 | | |
| | | | 5.5 | 6 | 9 | 5.5 | 6 | 2 | 11 |
| | | | 7.0 | 9 | | | | | |
| 3 | 1 | 24KS | 5.5 | 3 | | 5.5 | 6 | | |
| | | | 7.0 | 6 | 9 | 7.0 | 6 | 2 | 11 |
| | | | 8.5 | 9 | | | | | |
| | 2 | 36KT | 5.5 | 3 | | 5.5 | 6 | | |
| | | | 7.0 | 6 | 9 | 7.0 | 6 | 2 | 11 |
| | | | 8.5 | 9 | | | | | |
| Total | | | | | 54 | | | 12 | 66 |

## TABLE 3–G

### PERFORMANCE DATA (ILLUSTRATION) FOR WEIGHTED APPLICATIONS

| Tangent 1 | | | | | | | | Tangent 2 | | | | | | | | Tangent 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load (kips) | Subbase Thickness (in.) | 2.5-In. Slab | | 4.0-In. Slab | | 5.5-In. Slab | | Load (kips) | Subbase Thickness (in.) | 4.0-In. Slab | | 5.5-In. Slab | | 7.0-In. Slab | | Load (kips) | Subbase Thickness (in.) | 5.5-In. Slab | | 7.0-In. Slab | | 8.5-In. Slab | |
| | | *p* | Log *W* | *p* | Log *W* | *p* | Log *W* | | | *p* | Log *W* | *p* | Log *W* | *p* | Log *W* | | | *p* | Log *W* | *p* | Log *W* | *p* | Log *W* |
| 4KS | 3 | 4.4 | 5.48 | 4.5 | 5.48 | 4.5 | 5.48 | 16KS | 3 | 3.5 | 5.20 | 4.5 | 5.48 | 4.5 | 5.48 | 24KT | 3 | 3.5 | 5.28 | 3.5 | 5.82 | 4.5 | 5.48 |
| | | 4.1 | 5.81 | 4.4 | 5.81 | 4.4 | 5.81 | | | 2.5 | 5.28 | 4.0 | 5 81 | 4.4 | 5.81 | | | 2.5 | 5.31 | 2.5 | 5.93 | 4.3 | 5.81 |
| | | 3.9 | 6.05 | 4.3 | 6.05 | 4.4 | 6.05 | | | 1.5 | 5.30 | 1.8 | 6.05 | 4.0 | 6.05 | | | 1.5 | 5.33 | 1.5 | 6.00 | 3.9 | 6.05 |
| | 6 | 4.5 | 5.48 | 4.5 | 5.48 | 4.5 | 5.48 | | 6 | 3.5 | 5.30 | 4.4 | 5.48 | 4.4 | 5.48 | | 6 | 3.5 | 5.30 | 3.5 | 5.70 | 4.4 | 5.48 |
| | | 4.3 | 5.81 | 4.6 | 5.81 | 4.5 | 5.81 | | | 2.5 | 5.31 | 4.3 | 5.81 | 4.3 | 5.81 | | | 2.5 | 5.33 | 2.5 | 5.85 | 4.2 | 5.81 |
| | | 4.0 | 6.05 | 4.2 | 6.05 | 4.5 | 6.05 | | | 1.5 | 5.31 | 2.8 | 6.05 | 4.1 | 6.05 | | | 1.5 | 5.35 | 1.5 | 6.03 | 3.8 | 6.05 |
| | 6 rep. | 4.6 | 5.48 | 4.5 | 5.48 | | | | 6 rep. | 3.5 | 5.25 | 4.5 | 5.48 | | | | 6 rep. | 3.5 | 5.20 | 3.7 | 5.48 | | |
| | | 4.4 | 5.81 | 4.5 | 5.81 | | | | | 2.5 | 5.35 | 4.1 | 5.81 | | | | | 2.5 | 5.30 | 2.9 | 5.81 | | |
| | | 4.1 | 6.05 | 4.4 | 6.05 | | | | | 1.5 | 5.40 | 2.5 | 6.05 | | | | | 1.5 | 5.38 | 1.8 | 6.05 | | |
| | 9 | 4.4 | 5.48 | 4.4 | 5.48 | 4.6 | 5.48 | | 9 | 3.5 | 5.28 | 3.5 | 5.75 | 4.5 | 5.48 | | 9 | 3.5 | 5.29 | 3.5 | 5.90 | 4.5 | 5.48 |
| | | 4.4 | 5.81 | 4.4 | 5.81 | 4.4 | 5.81 | | | 2.5 | 5.30 | 2.5 | 5.81 | 4.2 | 5.81 | | | 2.5 | 5.31 | 2.5 | 5.95 | 4.4 | 5.81 |
| | | 3.8 | 6.05 | 4.3 | 6.05 | 4.4 | 6.05 | | | 1.5 | 5.31 | 1.5 | 5.86 | 4.2 | 6.05 | | | 1.5 | 5.33 | 1.5 | 6.04 | 4.1 | 6.05 |
| 8KS | 3 | 3.5 | 5.37 | 4.5 | 5.48 | 4.5 | 5.48 | 30KT | 3 | 3.5 | 4.98 | 3.5 | 5.70 | 4.5 | 5.48 | 36KT | 3 | 3.5 | 5.47 | 3.5 | 6.00 | 4.6 | 5.48 |
| | | 2.5 | 5.41 | 4.2 | 5.81 | 4.3 | 5.81 | | | 2.5 | 5.00 | 2.5 | 5.80 | 4.2 | 5.81 | | | 2.5 | 5.48 | 2.5 | 6.02 | 4.3 | 5.81 |
| | | 1.5 | 5.41 | 3.9 | 6.05 | 4.4 | 6.05 | | | 1.5 | 5.02 | 1.5 | 5.90 | 3.7 | 6.05 | | | 1.5 | 5.49 | 1.5 | 6.03 | 4.1 | 6.05 |
| | 6 | 3.5 | 5.18 | 4.4 | 5.48 | 4.5 | 5.48 | | 6 | 3.5 | 5.02 | 3.5 | 5.78 | 4.5 | 5.48 | | 6 | 3.5 | 5.36 | 4.2 | 5.48 | 4.7 | 5.48 |
| | | 2.5 | 5.41 | 4.4 | 5.81 | 4.5 | 4.81 | | | 2.5 | 5.03 | 2.5 | 5.80 | 4.3 | 5.81 | | | 2.5 | 5.54 | 4.0 | 5.81 | 4.4 | 5.81 |
| | | 1.5 | 5.44 | 4.0 | 6.05 | 4.4 | 6.05 | | | 1.5 | 5.04 | 1.5 | 5.82 | 3.9 | 6.05 | | | 1.5 | 5.59 | 3.2 | 6.05 | 4.3 | 6.05 |
| | 6 rep. | 3.5 | 5.17 | 4.6 | 5.48 | | | | 6 rep. | 3.5 | 5.08 | 3.9 | 5.48 | | | | 6 rep. | 3.5 | 5.50 | 3.7 | 5.48 | | |
| | | 2.5 | 5.28 | 4.3 | 5.81 | | | | | 2.5 | 5.11 | 2.8 | 5.81 | | | | | 2.5 | 5.55 | 3.5 | 5.81 | | |
| | | 1.5 | 5.36 | 3.8 | 6.05 | | | | | 1.5 | 5.15 | 1.7 | 6.05 | | | | | 1.5 | 5.58 | 2.8 | 6.05 | | |
| | 9 | 3.5 | 5.35 | 4.5 | 5.48 | 4.4 | 5.48 | | 9 | 3.5 | 4.95 | 3.5 | 5.72 | 4.5 | 5.48 | | 9 | 3.5 | 5.44 | 4.6 | 5.48 | 4.5 | 5.48 |
| | | 2.5 | 5.55 | 4.3 | 5.81 | 4.4 | 5.81 | | | 2.5 | 5.01 | 2.5 | 5.80 | 4.3 | 5.81 | | | 2.5 | 5.46 | 4.4 | 5.81 | 4.3 | 5.81 |
| | | 1.5 | 5.60 | 3.9 | 6.05 | 4.3 | 6.05 | | | 1.5 | 5.03 | 1.5 | 5.85 | 3.9 | 6.05 | | | 1.5 | 5.47 | 1.9 | 6.05 | 3.9 | 6.05 |

3212 Section used in Fig. 1 and others.

3222 Section used in Fig. 1 and others.

replication. Balance is necessary to prevent confusion among controlled factor effects, but it is also important that there be no confusion between controlled effects and residual effects on performance. If for example, the sections in each tangent were constructed so that surface thickness increased from thin to thick along the tangent and if an uncontrolled construction variable that could affect pavement performance (for example, humidity) also increased as the tangent was paved from one end to the other, any conclusion about surface thickness effect would be confused to an unknown degree with effects attributable to humidity during paving. It is well known that systematic uncontrolled variables operate during almost any experimental investigation, so randomization is necessary to minimize the risk that residual effects will be mistaken for controlled effects. As in any sampling situation, randomization is also necessary for obtaining proper estimates of residual variation. For example, if each replicate were constructed adjacent to its companion section, it might be expected that an underestimate of residual variation in the tangent would be obtained.

The eleven sections in each tangent are assigned a random order of occurrence within the tangent. As a result, conclusions about surface and subbase effects are not biased or confused by the presence of systematic residual variation within any tangent.

The major performance studies in the AASHO Road Test have experimental designs that involve balance, replication, and randomization, in much the same way that has been described for the illustration. In addition, still other experimental designs appear in the Road Test to provide for special studies whose objectives are somewhat different from the first Road Test objective.

Specifications have been given for pavement performance data and for experimental designs within which the performance data are obtained. Many alternatives were available for nearly every specification; nevertheless, the net result of the selected specifications for the example is a set of performance data as given in Table 3-G. The performance data consist of three pairs of $p$ and log $W$ values for each of the 66 test sections when the weighting function of Figure 3-G is used. Table 3-G includes data previously given in Table 2-G for sections 3212 and 3222. Section 3212 appears in tangent 3, lane 2, at the first surface thickness level and the second subbase thickness level. Similarly, section 3222 is in the second lane of the third tangent and has the second level of thickness for both surface and subbase. Thus section numbers are codes for factor levels. Any section whose serviceability history was complete has $p$ values of 3.5, 2.5, and 1.5. All remaining sections had incomplete histories.

For the AASHO Road Test, tables that correspond to Table 3-G involve five pairs of $p$ and log $W$ values for each of 284 flexible pavement sections in five tangents, and for each of 264 rigid pavement sections in five other tangents.

## PROCEDURES FOR ANALYSIS

The analysis consists of procedures that produce an empirical formula wherein performance is associated with load and pavement design variables. In order to use mathematical procedures it is necessary to assume some algebraic form, or model, for the association. In addition to the experimental variables the model involves constants whose values are either to be specified or to be estimated from the data. Thus, the analytical procedures are for the estimation of constants whose values are unspecified in the model—constants that indicate the effects of design and load variables upon performance. The procedures also include methods for estimating the precision with which the data fit the assumed model.

In essence the model is an equation for serviceability trends as illustrated by Figures 5-G or 6-G. When pavement design and axle load are specified for a pavement section, the equation presumably predicts the section's serviceability after a given number of applications. The equation should also be useful for predicting the number of applications the section will experience before reaching a preassigned serviceability level.

There are many different mathematical forms that could be used as models for serviceability trends, many of which may fit the data with more or less the same precision. Only one of the numerous models that have been investigated at the Road Test will be used for illustration.

If $p_0$ denotes the initial serviceability trend value for a particular test section, $p_0 - p$ is the serviceability loss experienced by the section when its trend value is at $p$. It is assumed that $p_0$ does not depend upon pavement design variables in the range of interest, and that the best estimate for $p_0$ is $c_0$, the average of all initial trend values for sections considered in the analysis. For the example, $c_0$ will be 4.5.

The assumption used for the nature of serviceability trends is that serviceability loss is a power function of axle load applications,

$$c_0 - p = K\,W^{\beta} \qquad \text{(1-G)}$$

in which $\beta$ is a positive power and $K$ and/or $\beta$ may depend on load and design variables. If $p = c_1$ is a serviceability level such that whenever $p$ for a section falls to $c_1$ the section is "out of test" and no longer observed, the number of applications experienced by the section when $p = c_1$ is called the experimental life of the section. For the example, as at the Road

Test, $c_1 = 1.5$. If $\rho$ is the value of $W$ in Eq. 1-G when $p = c_1$, $c_0 - c_1 = K\rho^\beta$, or $K = (c_0 - c_1)/\rho^\beta$, and Eq. 1-G may be written either

$$c_0 - p = (c_0 - c_1)\left(\frac{W}{\rho}\right)^\beta \qquad \text{(2-G)}$$

or

$$p = c_0 - (c_0 - c_1)\left(\frac{W}{\rho}\right)^\beta, \text{ where } c_1 \leqq p \leqq c_0. \qquad \text{(3-G)}$$

For any particular section, $\beta$ and $\rho$ have fixed values, but it is assumed that if $\beta$ is not constant for all designs and loads, then $\beta$ decreases whenever $\rho$ increases from one section to another. If $\beta > 1$, Eq. 3-G indicates that the serviceability trend will decline along a steeper and steeper curve as applications increase. If $\beta = 1$, the serviceability loss is linear with applications; and if $\beta < 1$, serviceability decreases along a curve that is concave upwards. Graphs of Eqs. 2-G and 3-G are shown in Figure 7-G for three different combinations of $\beta$ and $\rho$. When $\beta = 2.0$ the trend is the right half of a parabola that opens downward, when $\beta = 1$ the trend is linear, and when $\beta = 0.5$ the trend is the lower half of a parabola that opens to the right.

In the first stage of the analysis, performance data for each section are used to obtain preliminary estimates of $\beta$ and $\rho$ for the section. If logarithms are taken on both sides of Eq. 2-G,

$$\log (c_0 - p) = \log (c_0 - c_1) + \beta (\log W - \log \rho) \qquad \text{(4-G)}$$

$$\log \left(\frac{c_0 - p}{c_0 - c_1}\right) = \beta (\log W - \log \rho) \qquad \text{(5-G)}$$

The left side of Eq. 5-G is called $G$; that is,

$$G = \log \left(\frac{c_0 - p}{c_0 - c_1}\right) \qquad \text{(6-G)}$$

in which $G$ is undefined unless $p$ is less than $c_0$. $G$ has a negative value whenever $p$ is between $c_0$ and $c_1$, and $G = 0$ when $p = c_1$. Substituting from Eq. 6-G, Eq. 5-G is

$$G = \beta (\log W - \mathit{log}\ \rho) \qquad \text{(7-G)}$$

In $G$, $\log W$ coordinates, the graph of Eq. 7-G is a straight line whose slope is $\beta$ and whose intercept on the $\log W$ axis is $\log \rho$. Figure 8-G shows graphs of Eq. 7-G for the $\beta$, $\rho$ combinations that appeared in Figure 7-G; therefore, the graphs are linearizations of the performance curves. To show the connection between $G$ and $p$, both scales are shown in Figure 8-G.

For each section, pairs of values for $p$ and $W$ are converted to corresponding values for $G$ and $\log W$, then a straight line is fitted to the $G$, $\log W$ points. Figure 9-G shows transformed data and fitted lines for four sections (Table 3-G). Sections 3212 and 3222 are the previously used illustrative sections whereas sections 1133 and 1233 are included in Figure 9-G to bring out certain rules that are used in the rationale. The fitted lines for sections 3212 and 3222 have slopes $\hat{\beta} = 1.97$ and $\hat{\beta} = 1.09$, respectively; and have $\log W$ intercepts $\log \hat{\rho} = 5.61$ and $\log \hat{\rho} = 6.44$. These estimates are determined by lines that minimize the sum of squared vertical deviations from the data for each section.

For section 1133 there is no $G$ value corresponding to the one $p$-value that exceeds $c_0 = 4.5$ (Table 3-G), and the remaining two values are the same, $p = 4.4$. Therefore, $\hat{\beta} = 0$ and $\log \hat{\rho} = \infty$. Section 1233 has $p$-values 4.4, 4.4,

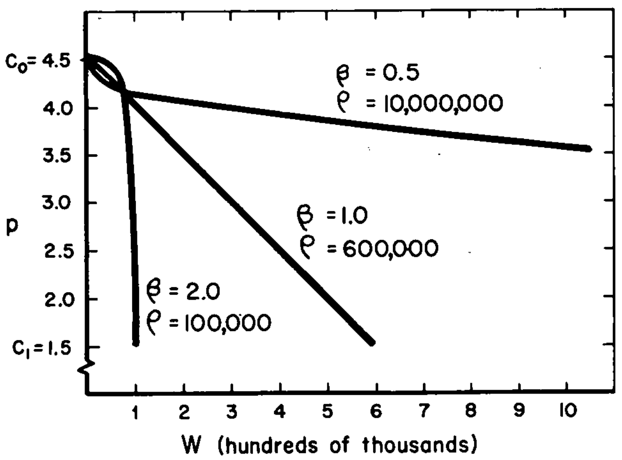

Figure 7-G. Graphs of $p = 4.5 - 3.0 \left(\frac{W}{\rho}\right)^\beta$

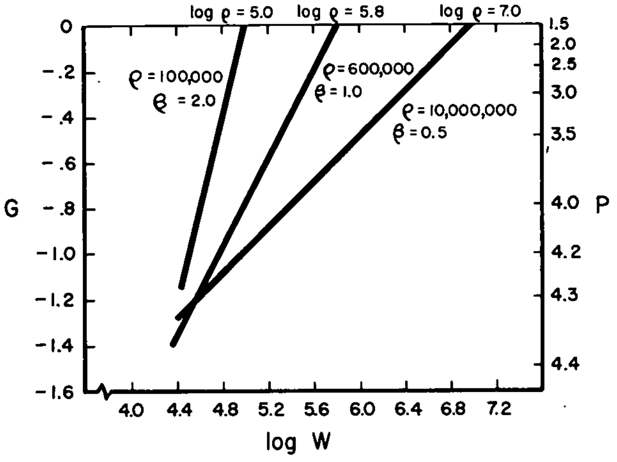

Figure 8-G. $G = \log \left(\frac{4.5 - p}{3.0}\right) = \beta\ [\log W - \log \rho]$

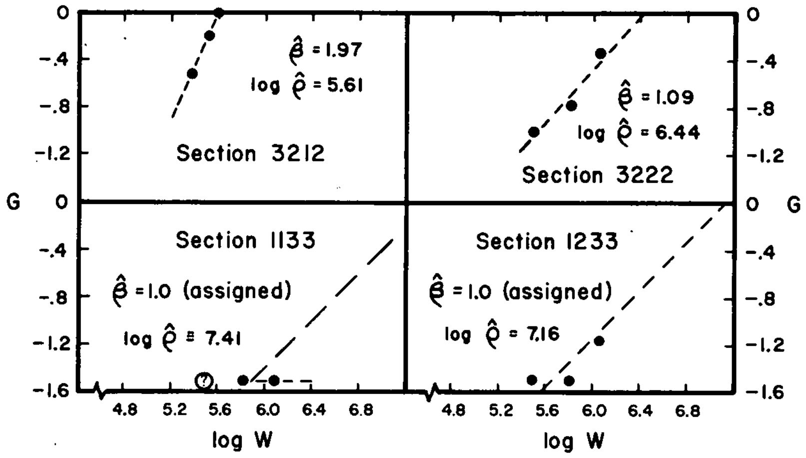

**Figure 9–G. Illustrative estimates for $\beta$ and log $\rho$ from section data.**

and 4.3; therefore, little decrease in serviceability has been observed during the experiment. It is assumed that very little information about $\beta$ and log $\rho$ is given by data and graphs for sections whose serviceability loss is outside the realm of measurement error. Special rules are applied in order to obtain values of $\hat{\beta}$ and $\log \hat{\rho}$ for such sections. After examining all $\hat{\beta}$ values for sections that experienced an appreciable serviceability loss, a minimum value is assumed for $\beta$, and if the data for any section give $\hat{\beta}$ to be less than the assumed minimum, then the minimum $\beta$ is assigned to be the section's $\hat{\beta}$. For the example, minimum $\beta$ is taken to be 1.0, and both sections 1133 and 1233 are given the value $\hat{\beta} = 1.0$. After this assignment, log $\hat{\rho}$ is obtained by fitting a line whose slope is 1.0 to the observed points. Using this rule, $\log \hat{\rho}$ is 7.41 and 7.16, respectively, for sections 1133 and 1233 (Fig. 9-G). If all $p$-values for a section are equal to or greater than $c_0 = 4.5$, as for section 1132 (Table 3-G), $\hat{\beta}$ is assumed to be 1.0, and $\log \hat{\rho}$ is set at the median log $\hat{\rho}$ for all sections that differ only in subbase thickness from the section that has no $G$ data. Table 4-G gives $\hat{\beta}$ and log $\hat{\rho}$ values.

After $\hat{\beta}$ has been determined for each section, the $\hat{\beta}$-values are graphed against pavement design and load variables, and an analysis of variance is made to infer the nature and extent of any dependence of $\hat{\beta}$ upon design and load variables. Neither the graphs nor the analysis of variance are given herein, but both proceed from the assumption that $\beta$ is related to design and load variables according to the model

$$\beta = \beta_0 + \frac{B_0(L_1 + L_2)^{B_2}}{(a_1D_1 + a_2D_2 + a_3)^{B_1} L_2{}^{B_3}} \qquad (8\text{-G})$$

in which

$\beta_0$ = a minimum value for $\beta$;

$L_1$ = nominal load axle weight, in kips (*i.e.*, load values as given in Table 3–G);

$L_2$ = 1 for single axle vehicles, 2 for tandem axle vehicles;

$D_1$ = the first pavement design factor, slab thickness, in in.; and

$D_2$ = the second pavement design factor, subbase thickness, in in.

The remaining symbols on the right side of Eq. 8–G are positive constants whose values are either to be assumed (as is done for $\beta_0$) or estimated from the $\hat{\beta}$ – values. In general, Eq. 8–G implies that $\beta$ will increase as axle load increases and that $\beta$ decreases as pavement design increases for a fixed loading. If there were three pavement design factors, as at the Road Test, then the third factor, $D_3$, would have been introduced in the combination $a_1D_1 + a_2D_2 + a_3D_3 + a_4$. The constant term in the design combination ($a_3$ in Eq. 8–G) appears so that $\beta$ is not necessarily infinite when there is no thickness for $D_1$ and $D_2$, and $L_2$ has been added to $L_1$ so that $\beta$ does not necessarily approach $\beta_0$ as $L_1$ approaches zero.

For the example, graphs and variance analysis for $\hat{\beta}$ show little or no dependency of $\hat{\beta}$ upon subbase thickness, so $a_2$ is taken to be zero. With only one variable, $D_1$, in the design combination, the effect of $D_1$ can be relegated to the exponent $B_1$ by assigning values to $b_1$ and $b_3$. For the illustration, $a_1 = a_3 = 1.0$. Because $\beta_0$ has already been assumed to be 1.0, Eq. 8–G is reduced to

$$\beta = 1.0 + \frac{B_0\ (L_1 + L_2)^{B_2}}{(D_1 + 1)^{B_1} L_2{}^{B_3}} \qquad (9\text{–G})$$

in which only $B_0$, $B_1$, $B_2$ and $B_3$ remain to be estimated from the $\hat{\beta}$ data. Logarithms of both sides of Eq. 9–G give

$$\log\ (\beta - 1.0) = \log B_0 + B_2 \log\ (L_1 + L_2) - B_3 \log L_2 - B_1 \log\ (D_1 + 1) \qquad (10\text{–G})$$

For each lane, Eq. 10–G represents a straight line when log ($\beta$ — 1.0) is graphed versus log ($D_1$ + 1), and linear regressions of log ($\hat{\beta}$ — 1.0) on log ($D_1$ + 1) give lane estimates for the slopes, $B_1$. Omitting lane 1 of tangent 1, since the majority of $\hat{\beta}$ values in this lane were 1.0 by assignment rather than values obtained from performance data, the regression slopes are averaged to give $\hat{B}_1$, the final estimate for $B_1$. The average slope for the remaining lanes is $\hat{B}_1 = 5.90$.

If $B_1$ log ($D_1$ + 1) is transposed to the left of Eq. 10–G,

$$\log (\beta - 1.0) + B_1 \log (D_1 + 1) = \log B_0 + B_2 \log (L_1 + L_2) - B_3 \log L_2 \qquad \text{(11–G)}$$

in which the left side of Eq. 11–G is estimated by log ($\hat{\beta}$ — 1.0) + $\hat{B}_1$ log ($D_1$ + 1) for every section. For any lane, average log ($\hat{\beta}$ — 1.0) + average $\hat{B}_1$ log ($D_1$ + 1) is called an adjusted lane mean, and according to Eq. 11–G the adjusted lane means depend linearly upon log ($L_1$ + $L_2$) and log $L_2$. Figure 10–G shows the six adjusted lane means for the example, and includes lines that are obtained from a linear regression analysis. The common slope of single and tandem axle lines is an estimate, $\hat{B}_2$, for $B_2$. The intercept of the single axle line on the adjusted means axis is an estimate, log $\hat{B}_0$, for log $B_0$, and the difference between intercepts of the single axle and tandem axle lines produces an estimate, $\hat{B}_3$, for $B_3$. For the illustrative data, log $\hat{B}_0 = -0.66$ or $\hat{B}_0 = 0.22$, $\hat{B}_2 = 4.54$, and $\hat{B}_3 = 3.12$. Substitution of these values in Eq. 9–G gives a new estimation formula for $\beta$,

$$\tilde{\beta} = 1.0 + \frac{0.22\ (L_1 + L_2)^{4.54}}{(D_1 + 1)^{5.90}\, L_2^{3.12}} \qquad \text{(12–G)}$$

For each section values for $\tilde{\beta}$ (estimates for $\beta$ from Eq. 12–G) are given in Table 4–G.

The second phase of the analytical procedures begins by using $\tilde{\beta}$ values to obtain new estimates for log $\rho$ from the data for each section. The first estimates for log $\rho$ were denoted by log $\hat{\rho}$ and were obtained as log $W$ intercepts (Fig. 9–G) for lines whose slopes were $\hat{\beta}$. Using the same rules as for obtaining log $\hat{\rho}$, the new estimates, log $\hat{\hat{\rho}}$, are obtained as log $W$ intercepts for lines whose slopes are $\tilde{\beta}$. Table 4–G gives values for log $\hat{\hat{\rho}}$ for each section in the illustration. In essence, the rationale assumes that estimates for $\beta$ from Eq. 12–G are better than estimates based only on individual section performance data, and therefore, log $\hat{\hat{\rho}}$-values represent better estimates for log $\rho$ than do the log $\hat{\rho}$-values.

Log $\hat{\hat{\rho}}$-values are graphed against the design and load variables, and an analysis of variance is made to infer how and with what significance the log $\hat{\hat{\rho}}$-values depend on design and load variables. The algebraic form for the association of log $\rho$ with design and load variables is assumed to be

$$\rho = \frac{A_0 (a_1 D_1 + a_2 D_2 + a_3)^{A_1} L_2^{A_3}}{(L_1 + L_2)^{A_2}} \qquad \text{(13–G)}$$

in which $A_0$, $A_1$, $A_2$, and $A_3$ are positive constants and $a_1$, $a_2$ and $a_3$ are the same constants that appear in Eq. 8–G. Eq. 13–G implies that $\rho$ increases with pavement design and decreases with axle load. The constant $a_3$ is included so that $\rho$ is not necessarily zero in the absence of surface and subbase, and is added to $L_1$ in the denominator so that $\rho$ is not necessarily infinite when $L_1$ is zero.

For the illustrative data, Table 4–G indicates little or no association between log $\hat{\hat{\rho}}$ and subbase thickness, and so $a_2$ is taken to be zero and both $a_1$ and $a_3$ are set at 1.0 as was done in Eq. 8–G. In logarithmic form, Eq. 13–G therefore becomes

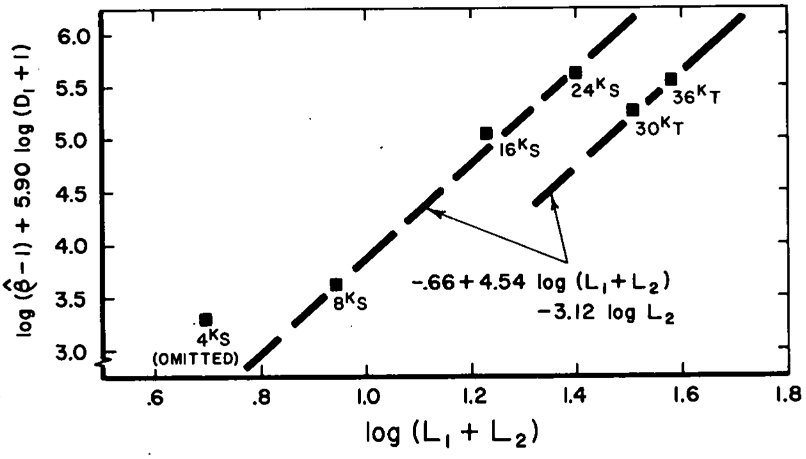

**Figure 10–G. Adjusted mean log ($\hat{\beta}$ – 1) *vs* log ($L_1$ + $L_2$).**

$$\log \rho = \log A_0 - A_2 \log (L_1 + L_2) + A_3 \log L_2 + A_1 \log (D_1 + 1) \qquad (14\text{–G})$$

Figure 11–G shows how log $\hat{\hat{\rho}}$ values vary with corresponding values for log $(D_1 + 1)$ for two lanes. Linear regressions of log $\hat{\hat{\rho}}$ on log $(D_1 + 1)$ in each lane produce slopes that are estimates of $A_1$, and when the slopes are average for all but lane 1 of tangent 1, the estimate obtained for $A_1$ is $\hat{A}_1 = 6.79$.

Transposing $A_1$ log $(D_1 + 1)$ in Eq. 14–G adjusts log $\rho$ for surface thickness, and for each lane, average log $\hat{\hat{\rho}}$ — average $\hat{A}_1$ log $(D_1 + 1)$ is an adjusted lane mean that should depend upon log $(L_1 + L_2)$ and log $L_2$. Figure 12–G shows adjusted lane means versus log $(L_1 + L_2)$ for single and tandem axles and the lines obtained from the regression analysis. As indicated, log $\hat{A}_0 = 5.98$, $\hat{A}_2 = 4.40$, and $\hat{A}_3 = 3.17$. Thus, the procedures have produced a final estimation equation for log $\rho$,

$$\log \hat{\rho} = 5.98 - 4.40 \log (L_1 + L_2) + 3.17 \log L_2 + 6.79 \log (D_1 + 1) \qquad (15\text{–G})$$

or

$$\hat{\rho} = \frac{10^{5.98} (D_1 + 1)^{6.79} L_2^{3.17}}{(L_1 + L_2)^{4.40}} \qquad (16\text{–G})$$

Estimates for log $\rho$ given by Eq. 15–G are shown for each section in Table 4–G.

The results of the analysis can now be summarized. If it is desired to estimate $p$ when $W$ is given, then Eqs. 3–G, 12–G and 15–G or 16–G combine to give

$$\hat{p} = 4.5 - 3.0 \left( \frac{W}{\hat{\rho}} \right)^{\hat{\beta}} \qquad (17\text{–G})$$

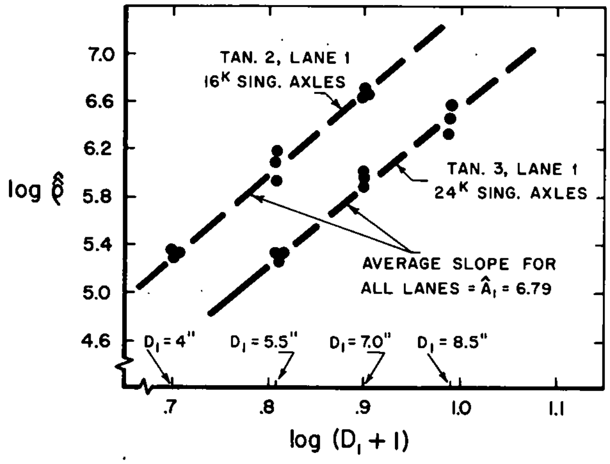

**Figure 11–G.** Log $\hat{\rho}$ vs log $(D_1 + 1)$ for two lanes.

If it is desired to estimate log $W$ when $p$ is given, then Eqs. 5-G, 12-G and 15-G or 16-G combine to give

$$\log \hat{W} = \log \hat{\rho} + \frac{\log \left[ \dfrac{4.5 - p}{3.0} \right]}{\hat{\beta}} \qquad (18\text{–G})$$

Eqs. 17–G and 18–G therefore represent the first goal of the analysis—to associate the performance data with design and load variables.

In the example given there was no need to discuss derivations for the pavement design coefficients, $a_1$, $a_2$, . . . since only one design factor had significant effect on performance. If, as was the case for flexible pavement experiments at the Road Test, more than one

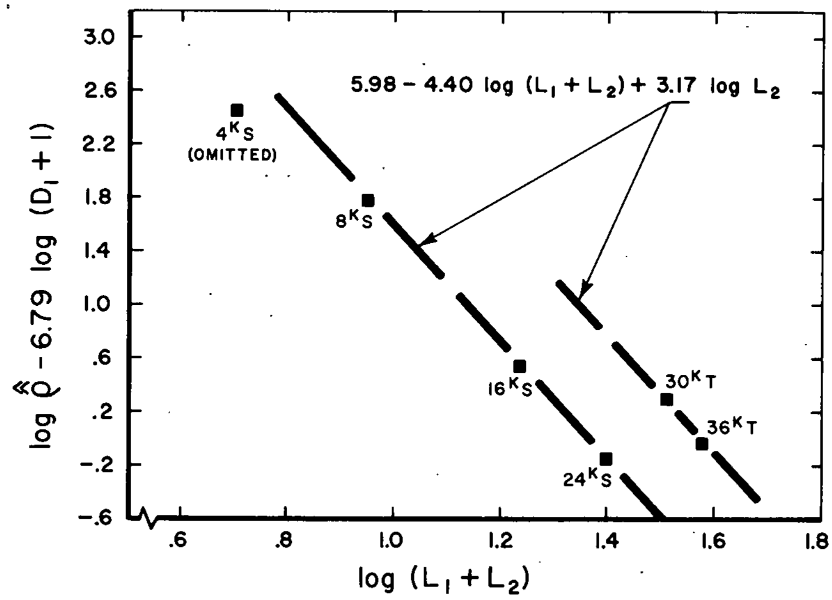

**Figure 12–G.** Adjusted mean log $\hat{\rho}$ vs log $(L_1 + L_2)$.

## TABLE 4–G

### ESTIMATES OF $\beta$ AND LOG $\rho$

| Tangent 1 | | | | | | | | | Tangent 2 | | | | | | | | | Tangent 3 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load (kips) | Thickness (in.) | | log $(D_1 + 1)$ | $\hat{\beta}$ | $\tilde{\beta}$ | log $\hat{\rho}$ | log $\hat{\hat{\rho}}$ | log $\tilde{\rho}$ | Load (kips) | Thickness (in.) | | log $(D_1 + 1)$ | $\hat{\beta}$ | $\tilde{\beta}$ | log $\hat{\rho}$ | log $\hat{\hat{\rho}}$ | log $\tilde{\rho}$ | Load (kips) | Thickness (in.) | | log $(D_1 + 1)$ | $\hat{\beta}$ | $\tilde{\beta}$ | log $\hat{\rho}$ | log $\hat{\hat{\rho}}$ | log $\tilde{\rho}$ |
| | Slab, $D_1$ | Subbase | | | | | | | | Slab, $D_1$ | Subbase | | | | | | | | Slab, $D_1$ | Subbase | | | | | | |
| 4KS | 2.5 | 3 | 0.54 | 1.39 | 1.20 | 6.51 | 6.63 | 6.60 | 16KS | 4.0 | 3 | 0.70 | 4.48 | 7.30 | 5.31 | 5.29 | 5.31 | 24KS | 5.5 | 3 | 0.81 | 9.58 | 8.72 | 5.33 | 5.33 | 5.35 |
| | | 6 | 0.54 | 1.66 | 1.20 | 6.52 | 6.74 | 6.60 | | | 6 | 0.70 | 38.83 | 7.30 | 5.31 | 5.34 | 5.31 | | | 6 | 0.81 | 9.58 | 8.72 | 5.35 | 5.35 | 5.35 |
| | | 6 rep. | 0.54 | 2.51 | 1.20 | 6.40 | 6.91 | 6.60 | | | 6 rep. | 0.70 | 3.16 | 7.30 | 5.40 | 5.36 | 5.31 | | | 6 rep. | 0.81 | 2.66 | 8.72 | 5.38 | 5.32 | 5.35 |
| | | 9 | 0.54 | 1.39 | 1.20 | 6.64 | 6.78 | 6.60 | | | 9 | 0.70 | 15.78 | 7.30 | 5.31 | 5.33 | 5.31 | | | 9 | 0.81 | 11.92 | 8.72 | 5.33 | 5.34 | 5.35 |
| | 4.0 | 3 | 0.70 | 1.25 | 1.02 | 6.99 | 7.22 | 7.65 | | 5.5 | 3 | 0.81 | 3.05 | 2.34 | 6.06 | 6.11 | 6.09 | | 7.0 | 3 | 0.90 | 2.66 | 3.27 | 6.00 | 5.98 | 5.96 |
| | | 6 | 0.70 | 1.00 | 1.02 | 7.05 | 7.03 | 7.65 | | | 6 | 0.81 | 2.08 | 2.34 | 6.24 | 6.19 | 6.09 | | | 6 | 0.90 | 1.43 | 3.27 | 6.01 | 5.93 | 5.96 |
| | | 6 rep. | 0.70 | 1.00 | 1.02 | 7.53 | 7.49 | 7.65 | | | 6 rep. | 0.81 | 2.91 | 2.34 | 6.11 | 6.16 | 6.09 | | | 6 rep. | 0.90 | 1.00 | 3.27 | 6.08 | 5.87 | 5.96 |
| | | 9 | 0.70 | 1.00 | 1.02 | 7.16 | 7.12 | 7.65 | | | 9 | 0.81 | 4.36 | 2.34 | 5.86 | 5.90 | 6.09 | | | 9 | 0.90 | 3.23 | 3.27 | 6.03 | 6.03 | 5.96 |
| | 5.5 | 3 | 0.81 | 1.00 | 1.00 | 7.41 | 7.40 | 8.42 | | 7.0 | 3 | 0.90 | 2.91 | 1.39 | 6.32 | 6.74 | 6.70 | | 8.5 | 3 | 0.98 | 1.99 | 1.82 | 6.40 | 6.44 | 6.47 |
| | | 6 | 0.81 | 1.00 | 1.00 | 7.41[1] | 7.40[1] | 8.42 | | | 6 | 0.90 | 1.05 | 1.39 | 6.90 | 6.62 | 6.70 | | | 6 | 0.98 | 1.48 | 1.82 | 6.48 | 6.35 | 6.47 |
| | | 9 | 0.81 | 1.00 | 1.00 | 7.41 | 7.40 | 8.42 | | | 9 | 0.90 | 1.00 | 1.39 | 6.93 | 6.65 | 6.70 | | | 9 | 0.98 | 2.51 | 1.82 | 6.40 | 6.58 | 6.47 |
| 8KS | 2.5 | 3 | 0.54 | 9.73 | 3.88 | 5.42 | 5.45 | 5.48 | 30KT | 4.0 | 3 | 0.70 | 11.93 | 13.73 | 5.02 | 5.02 | 5.06 | 36KT | 5.5 | 3 | 0.81 | 23.93 | 6.91 | 5.49 | 5.51 | 5.50 |
| | | 6 | 0.54 | 1.64 | 3.88 | 5.48 | 5.40 | 5.48 | | | 6 | 0.70 | 23.85 | 13.73 | 5.04 | 5.05 | 5.06 | | | 6 | 0.81 | 1.97 | 6.91 | 5.61 | 5.53 | 5.50 |
| | | 6 rep. | 0.54 | 2.52 | 3.88 | 5.36 | 5.33 | 5.48 | | | 6 rep. | 0.70 | 6.68 | 13.73 | 5.15 | 5.13 | 5.06 | | | 6 rep. | 0.81 | 5.97 | 6.91 | 5.58 | 5.58 | 5.50 |
| | | 9 | 0.54 | 1.79 | 3.88 | 5.62 | 5.56 | 5.48 | | | 9 | 0.70 | 5.74 | 13.73 | 5.04 | 5.01 | 5.06 | | | 9 | 0.81 | 15.79 | 6.91 | 5.47 | 5.49 | 5.50 |
| | 4.0 | 3 | 0.70 | 1.25 | 1.35 | 6.61 | 6.56 | 6.53 | | 5.5 | 3 | 0.81 | 2.39 | 3.71 | 5.89 | 5.86 | 5.83 | | 7.0 | 3 | 0.90 | 15.83 | 2.74 | 6.03 | 6.10 | 6.12 |
| | | 6 | 0.70 | 1.15 | 1.35 | 6.86 | 6.70 | 6.53 | | | 6 | 0.81 | 11.94 | 3.71 | 5.82 | 5.86 | 5.83 | | | 6 | 0.90 | 1.09 | 2.74 | 6.44 | 6.04 | 6.12 |
| | | 6 rep. | 0.70 | 2.27 | 1.35 | 6.33 | 6.60 | 6.53 | | | 6 rep. | 0.81 | 1.19 | 3.71 | 6.05 | 5.87 | 5.83 | | | 6 rep. | 0.90 | 1.00 | 2.74 | 6.21 | 5.94 | 6.12 |
| | | 9 | 0.70 | 1.99 | 1.35 | 6.40 | 6.62 | 6.53 | | | 9 | 0.81 | 3.68 | 3.71 | 5.85 | 5.85 | 5.83 | | | 9 | 0.90 | 5.90 | 2.74 | 6.06 | 6.21 | 6.12 |
| | 5.5 | 3 | 0.81 | 1.00 | 1.08 | 7.26 | 7.16 | 7.30 | | 7.0 | 3 | 0.90 | 1.78 | 1.80 | 6.37 | 6.37 | 6.44 | | 8.5 | 3 | 0.98 | 1.25 | 1.63 | 6.75 | 6.56 | 6.62 |
| | | 6 | 0.81 | 1.00 | 1.08 | 7.53 | 7.42 | 7.30 | | | 6 | 0.90 | 1.99 | 1.80 | 6.40 | 6.45 | 6.44 | | | 6 | 0.98 | 1.25 | 1.63 | 6.99 | 6.74 | 6.62 |
| | | 9 | 0.81 | 1.00 | 1.08 | 7.16 | 7.06 | 7.30 | | | 9 | 0.90 | 1.99 | 1.80 | 6.40 | 6.45 | 6.44 | | | 9 | 0.98 | 1.99 | 1.63 | 6.40 | 6.50 | 6.62 |

[1] Use median value.

## TABLE 5–G

### ESTIMATED PERFORMANCE DATA (ILLUSTRATION) FOR WEIGHTED APPLICATIONS

| Tangent 1 | | | | | | | | Tangent 2 | | | | | | | | Tangent 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load (kips) | Subbase Thickness (in.) | 2.5-In. Slab | | 4.0-In. Slab | | 5.5-In. Slab | | Load (kips) | Subbase Thickness (in.) | 4.0-In. Slab | | 5.5-In. Slab | | 7.0-In. Slab | | Load (kips) | Subbase Thickness (in.) | 5.5-In. Slab | | 7.0-In. Slab | | 8.0-In. Slab | |
| | | $p$ or $(\hat{p})$ | $(\widehat{\log W})$ or log $W$ | $p$ or $(\hat{p})$ | $(\widehat{\log W})$ or log $W$ | $p$ or $(\hat{p})$ | $(\widehat{\log W})$ or log $W$ | | | $p$ or $(\hat{p})$ | $(\widehat{\log W})$ or log $W$ | $p$ or $(\hat{p})$ | $(\widehat{\log W})$ or log $W$ | $p$ or $(\hat{p})$ | $(\widehat{\log W})$ or log $W$ | | | $p$ or $(\hat{p})$ | $(\widehat{\log W})$ or log $W$ | $p$ or $(\hat{p})$ | $(\widehat{\log W})$ or log $W$ | $p$ or $(\hat{p})$ | $(\widehat{\log W})$ or log $W$ |
| 4KS | 3 | (4.5) | 5.48 | (4.5) | 5.48 | (4.5) | 5.48 | 16KS | 3 | 3.5 | (5.25) | (4.5) | 5.48 | (4.5) | 5.48 | 24KS | 3 | 3.5 | (5.29) | 3.5 | (5.82) | (4.5) | 5.48 |
| | | (4.2) | 5.81 | (4.5) | 5.81 | (4.5) | 5.81 | | | 2.5 | (5.29) | (4.1) | 5.81 | (4.4) | 5.81 | | | 2.5 | (5.33) | 2.5 | (5.91) | (4.4) | 5.81 |
| | | (3.8) | 6.05 | (4.4) | 6.05 | (4.5) | 6.05 | | | 1.5 | (5.31) | (2.1) | 6.05 | (4.1) | 6.05 | | | 1.5 | (5.35) | 1.5 | (5.96) | (4.0) | 6.05 |
| | 6 | (4.5) | 5.48 | (4.5) | 5.48 | (4.5) | 5.48 | | 6 | 3.5 | (5.25) | (4.5) | 5.48 | (4.5) | 5.48 | | 6 | 3.5 | (5.29) | 3.5 | (5.82) | (4.5) | 5.48 |
| | | (4.2) | 5.81 | (4.5) | 5.81 | (4.5) | 5.81 | | | 2.5 | (5.29) | (4.1) | 5.81 | (4.4) | 5.81 | | | 2.5 | (5.33) | 2.5 | (5.91) | (4.4) | 5.81 |
| | | (3.8) | 6.05 | (4.4) | 6.05 | (4.5) | 6.05 | | | 1.5 | (5.31) | (2.1) | 6.05 | (4.1) | 6.05 | | | 1.5 | (5.35) | 1.5 | (5.96) | (4.0) | 6.05 |
| | 6 rep. | (4.5) | 5.48 | (4.5) | 5.48 | | | | 6 rep. | 3.5 | (5.25) | (4.5) | 5.48 | | | | 6 rep. | 3.5 | (5.29) | (4.5) | 5.48 | | |
| | | (4.2) | 5.81 | (4.5) | 5.81 | | | | | 2.5 | (5.29) | (4.1) | 5.81 | | | | | 2.5 | (5.33) | (4.1) | 5.81 | | |
| | | (3.8) | 6.05 | (4.4) | 6.05 | | | | | 1.5 | (5.31) | (2.1) | 6.05 | | | | | 1.5 | (5.35) | Neg.[2] | 6.05 | | |
| | 9 | (4.5) | 5.48 | (4.5) | 5.48 | (4.5) | 5.48 | | 9 | 3.5 | (5.25) | 3.5 | (5.88) | (4.5) | 5.48 | | 9 | 3.5 | (5.29) | 3.5 | (5.82) | (4.5) | 5.48 |
| | | (4.2) | 5.81 | (4.5) | 5.81 | (4.5) | 5.81 | | | 2.5 | (5.29) | 2.5 | (6.01) | (4.4) | 5.81 | | | 2.5 | (5.33) | 2.5 | (5.91) | (4.4) | 5.81 |
| | | (3.8) | 6.05 | (4.4) | 6.05 | (4.5) | 6.05 | | | 1.5 | (5.31) | 1.5 | (6.09) | (4.1) | 6.05 | | | 1.5 | (5.35) | 1.5 | (5.96) | (4.0) | 6.05 |
| 8KS | 3 | 3.5 | (5.35) | (4.5) | 5.48 | (4.5) | 5.48 | 30KT | 3 | 3.5 | (5.02) | 3.5 | (5.70) | (4.5) | 5.48 | 36KT | 3 | 3.5 | (5.43) | 3.5 | (5.94) | (4.5) | 5.48 |
| | | 2.5 | (5.43) | (4.3) | 5.81 | (4.4) | 5.81 | | | 2.5 | (5.05) | 2.5 | (5.78) | (4.4) | 5.81 | | | 2.5 | (5.48) | 2.5 | (6.05) | (4.4) | 5.81 |
| | | 1.5 | (5.48) | (3.8) | 6.05 | (4.4) | 6.05 | | | 1.5 | (5.06) | 1.5 | (5.83) | (3.9) | 6.05 | | | 1.5 | (5.50) | 1.5 | (6.12) | (4.2) | 6.05 |
| | 6 | 3.5 | (5.35) | (4.5) | 5.48 | (4.5) | 5.48 | | 6 | 3.5 | (5.02) | 3.5 | (5.70) | (4.5) | 5.48 | | 6 | 3.5 | (5.43) | (4.5) | 5.48 | (4.5) | 5.48 |
| | | 2.5 | (5.43) | (4.3) | 5.81 | (4.4) | 5.81 | | | 2.5 | (5.05) | 2.5 | (5.78) | (4.4) | 5.81 | | | 2.5 | (5.48) | (4.3) | 5.81 | (4.4) | 5.81 |
| | | 1.5 | (5.48) | (3.8) | 6.05 | (4.4) | 6.05 | | | 1.5 | (5.06) | 1.5 | (5.83) | (3.9) | 6.05 | | | 1.5 | (5.50) | (2.6) | 6.05 | (4.2) | 6.05 |
| | 6 rep. | 3.5 | (5.35) | (4.5) | 5.48 | | | | 6 rep. | 3.5 | (5.02) | (4.5) | 5.48 | | | | 6 rep. | 3.5 | (5.43) | (4.5) | 5.48 | | |
| | | 2.5 | (5.43) | (4.3) | 5.81 | | | | | 2.5 | (5.05) | (3.5) | 5.81 | | | | | 2.5 | (5.48) | (4.3) | 5.81 | | |
| | | 1.5 | (5.48) | (3.8) | 6.05 | | | | | 1.5 | (5.06) | Neg.[2] | 6.05 | | | | | 1.5 | (5.50) | (2.6) | 6.05 | | |
| | 9 | 3.5 | (5.35) | (4.5) | 5.48 | (4.5) | 5.48 | | 9 | 3.5 | (5.02) | 3.5 | (5.70) | (4.5) | 5.48 | | 9 | 3.5 | (5.43) | (4.5) | 5.48 | (4.5) | 5.48 |
| | | 2.5 | (5.43) | (4.3) | 5.81 | (4.4) | 5.81 | | | 2.5 | (5.05) | 2.5 | (5.78) | (4.4) | 5.81 | | | 2.5 | (5.48) | (4.3) | 5.81 | (4.4) | 5.81 |
| | | 1.5 | (5.48) | (3.8) | 6.05 | (4.4) | 6.05 | | | 1.5 | (5.06) | 1.5 | (5.83) | (3.9) | 6.05 | | | 1.5 | (5.50) | (2.6) | 6.05 | (4.2) | 6.05 |

[1] Numbers in parentheses for "out of test" sections are estimates of log $W$ when $p$ is given. Numbers in parentheses for "in test" sections are estimates of $p$ when log $W$ is given.

[2] Negative estimate.

pavement design factor effect is significant, then the analysis procedures include more steps. The variance analysis of the preliminary estimates $\hat{\beta}$ will produce tentative values for $a_1, a_2, \ldots$ which are used to obtain $\log \hat{\rho}$ values for all sections. Variance analysis of $\log \hat{\rho}$ gives a new set of estimates for $a_1, a_2, \ldots$ which are used to obtain a new formula for $\hat{\beta}$. Then $\log \hat{\rho}$ values are redetermined and re-analyzed to reach a third set of estimates for $a_1, a_2, \ldots$. At the Road Test it was found that there were negligible differences between the second and third sets of estimates for the design coefficients and so the iteration process was halted. Thus the same estimates are determined for $a_1, a_2, \ldots$ for both Eqs. 8-G and 13-G.

The remainder of the rationale for analysis is concerned with summarizing the precision with which estimates can be made using Eqs. 17-G and 18-G to estimate $p$ and $\log W$, respectively.

Numbers in parentheses in Table 5-G are either serviceability estimates obtained from Eq. 17-G for all sections whose serviceability did not fall to $c_1 = 1.5$, or are $\log W$ estimates obtained from Eq. 18-G for all sections whose serviceability did reach 1.5. Estimates are given at 15, 35 and 55 index days in the first case and at $p = 3.5$, 2.5 and 1.5 for the second case. Differences between corresponding estimated values (Table 5-G) and observed values (Table 1-G) represent residuals that are not accounted for by Eqs. 17-G and 18-G. Table 6-G gives a summary of mean residuals and mean absolute residuals for both types of estimates—classified both by lane and by index day or serviceability level.

For all sections that were "in test" after 55 index days, the upper half of Table 6-G gives the number of such sections in each lane, and the average residual $\hat{p} = p$, both algebraic and absolute. For the 31 sections involved, the average algebraic residual is 0.02, and the average absolute residual is 0.10. There does not appear to be any trend with respect to load, but in nearly all lanes the residuals increase with time or applications. However, even the largest mean residuals are only 0.2 and 0.3 and it may be concluded that the $p$ estimates are quite close to their respective observations.

In the lower half of Table 6-G, residuals in $\log W$ are summarized from differences obtained by subtracting $\log W$ values in Table 3-G from corresponding $\log \widehat{W}$ values in Table 5-G for all sections whose serviceability fell to $p = 1.5$. The mean algebraic residual in $\log W$ is nearly zero, while the mean absolute residual is about 0.04. These residuals appear to have about the same magnitude at each serviceability level and are not far from being equal in each lane. No $\log W$ residuals are given for lane 1 of tangent 1 since no section was "out of test" in this lane.

Residuals in $\log W$ may be interpreted by noting that if $\Delta LW$ denotes the average absolute residual,

$$\log \widehat{W} - \log W = \log \frac{\widehat{W}}{W} = \pm \Delta LW \qquad (19\text{-G})$$

represents plus or minus one average residual, and

$$\widehat{W} = 10^{\pm \Delta LW}\, W = 10^{\pm 0.05}\, W = 0.89W \text{ to } 1.12W \qquad (20\text{-G})$$

gives an indication of the average error between predicted applications and observed applications. For the example, the average absolute residual represents about a 10 percent deviation from the observed value. More precisely, all observations whose residuals are less than the average residual fall within a range of error that extends from 89 percent to 112 percent of the predicted values. If twice the average residual is considered to represent a practical maximum error, then the corresponding error range extends from 79 percent to 126 percent of the predicted values. In Table 3-G, the average absolute difference in $\log W$ between replicate sections is about 0.09, so that the average deviation of two replicate sections from their own mean is about 0.045. Therefore, the predicted $\log W$ from Eq. 18-G deviates about the same distance from $\log W$ as does $\log W$ from the mean of $\log W$ values observed for the same design and load. For this reason it is unlikely that any appreciable decrease in $\Delta LW$ can be made by fitting the illustrative observations with another model or by using another set of procedures.

Residuals may be used to calculate a correlation index that summarizes the efficacy of a particular model. This statistic measures the agreement between observed and predicted values by subtracting from one the ratio of the sum of squared residuals to the sum of squared deviations of the observations from their own mean. Thus, if all residuals are zero the correlation index is one, and if the variation equals the original variation in the observations the correlation index is zero. The correlation index may be interpreted as the percent of original variation that is explained by predictions from the derived equation. For the example, the correlation index for $\log W$ predictions is 95 percent whereas the correlation index for $p$ predictions is 71 percent. Any improvement in model selection or in fitting procedures would be detected by finding higher correlation indexes than these.

Both Eqs. 17-G and 18-G are rather complex and difficult to use in the form given. However, graphs of these equations can be made for whatever conditions may be useful. Figure 13-G shows the graphs of Eq. 18-G for every combination of surface thickness and loading that were used in the illustration (all for the

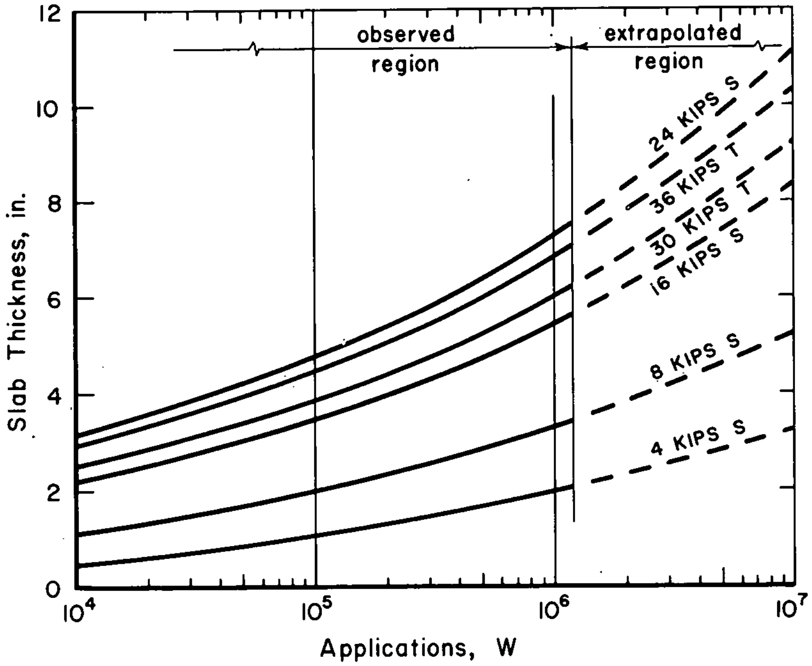

**Figure 13–G. Performance equation (18–G) for test loads ($p$ = 2.5).**

TABLE 6–G

SUMMARY OF RESIDUALS

| | | | Residual | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Lane 11 | Lane 12 | Lane 21 | Lane 22 | Lane 31 | Lane 32 | Average All Sections |
| $p$ residuals | | No. Sect. | 9 | 6 | 5 | 3 | 3 | 5 | |
| | Average ($\hat{p} - p$) | $t = 15$ | 0.00 | 0.01 | 0.02 | −0.01 | 0.02 | −0.03 | 0.00 |
| | | $t = 35$ | 0.01 | 0.01 | 0.03 | 0.09 | 0.08 | 0.07 | 0.04 |
| | | $t = 55$ | 0.06 | −0.05 | −0.08 | 0.09 | 0.05 | 0.03 | 0.01 |
| | | All | 0.02 | −0.01 | −0.01 | 0.06 | 0.05 | 0.03 | 0.02 |
| | Average $\mid \hat{p} - p \mid$ | $t = 15$ | 0.04 | 0.04 | 0.04 | 0.01 | 0.04 | 0.15 | 0.05 |
| | | $t = 35$ | 0.09 | 0.08 | 0.12 | 0.09 | 0.09 | 0.12 | 0.10 |
| | | $t = 55$ | 0.10 | 0.08 | 0.25 | 0.09 | 0.13 | 0.35 | 0.16 |
| | | All | 0.08 | 0.07 | 0.13 | 0.06 | 0.09 | 0.21 | 0.10 |
| $\log W$ residuals | | No. Sect. | 0 | 3 | 4 | 6 | 6 | 4 | |
| | Average ($\log \hat{W} - \log W$) | $p = 3.5$ | — | 0.05 | 0.02 | 0.00 | 0.01 | −0.01 | 0.01 |
| | | $p = 2.5$ | — | −0.03 | 0.04 | 0.01 | 0.00 | 0.00 | 0.01 |
| | | $p = 1.5$ | — | −0.01 | 0.06 | 0.00 | −0.03 | 0.01 | 0.01 |
| | | All | — | 0.01 | 0.04 | 0.00 | 0.00 | 0.00 | 0.01 |
| | Average $\mid \log \hat{W} - \log W \mid$ | $p = 3.5$ | — | 0.06 | 0.07 | 0.04 | 0.04 | 0.04 | 0.05 |
| | | $p = 2.5$ | — | 0.05 | 0.06 | 0.02 | 0.03 | 0.03 | 0.04 |
| | | $p = 1.5$ | — | 0.08 | 0.06 | 0.03 | 0.04 | 0.05 | 0.05 |
| | | All | — | 0.06 | 0.06 | 0.03 | 0.03 | 0.04 | 0.04 |

case that $p = 2.5$). For a particular load, the plotted curve shows the number of applications expected for any surface thickness at the time when the serviceability level has dropped to 2.5. Applications beyond $10^6$ represent extrapolations for all curves, and each load curve has been extended beyond the lower and upper surface thickness level used in the experiment. Corresponding curves, of course, could be graphed for other values of $p$.

To show how close the observations are to the curves of Figure 13-G, Figure 14-G repeats three of the curves from Figure 13-G and includes appropriate data that were given as observations in Table 3-G. Data for only those sections whose $p$ reached 2.5 can be shown in Figure 14-G. The dotted curves represent the band formed by $\pm 0.10$; that is, plus or minus twice the mean absolute residual in log $W$. If residual deviations have a normal frequency distribution about the curves, plus or minus two mean absolute deviations should include about 90 percent of all individual residuals. If the central curves of Figure 14-G are used to estimate the slab thickness required to keep serviceability above 2.5 for a specified number of applications, $W$, the two mean residual bands correspond to approximately ± 4 percent of the slab thickness estimated from the performance equation curve. Thus the error bands for an estimated 6-in. slab requirement would represent ± ¼ in.

Another form of Figure 13-G is shown in Figure 15-G which shows the associated surface thickness and load for selected applications expected when $p = 2.5$. Figure 15-G brings out the effect of load upon surface thickness requirements.

When bands for residual variation are added to the graphs, either or both of Figures 13-G and 15-G constitute a summarization of the data given in Table 3-G, and presumably satisfy (for $p = 2.5$) the objective for the investigation.

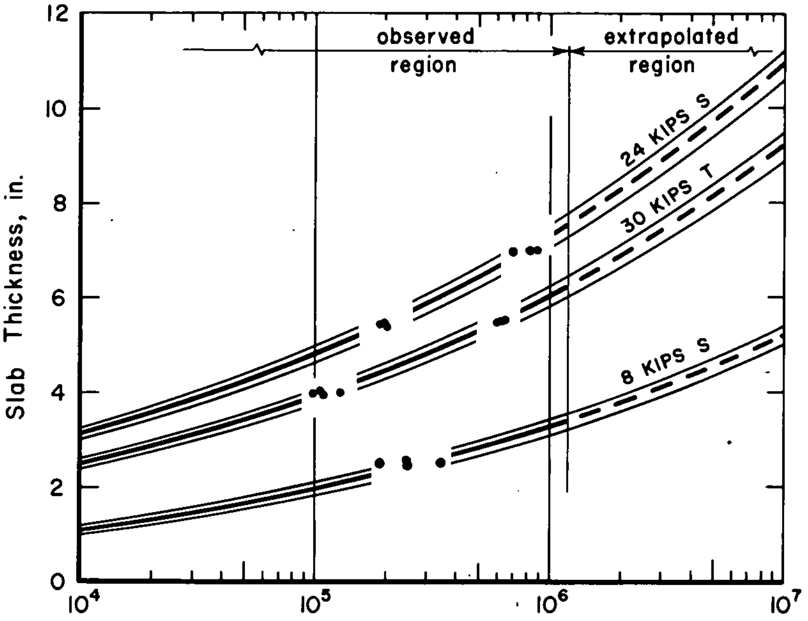

**Figure 14–G. Performance equation (18–G) for three selected loads ($p = 2.5$).**

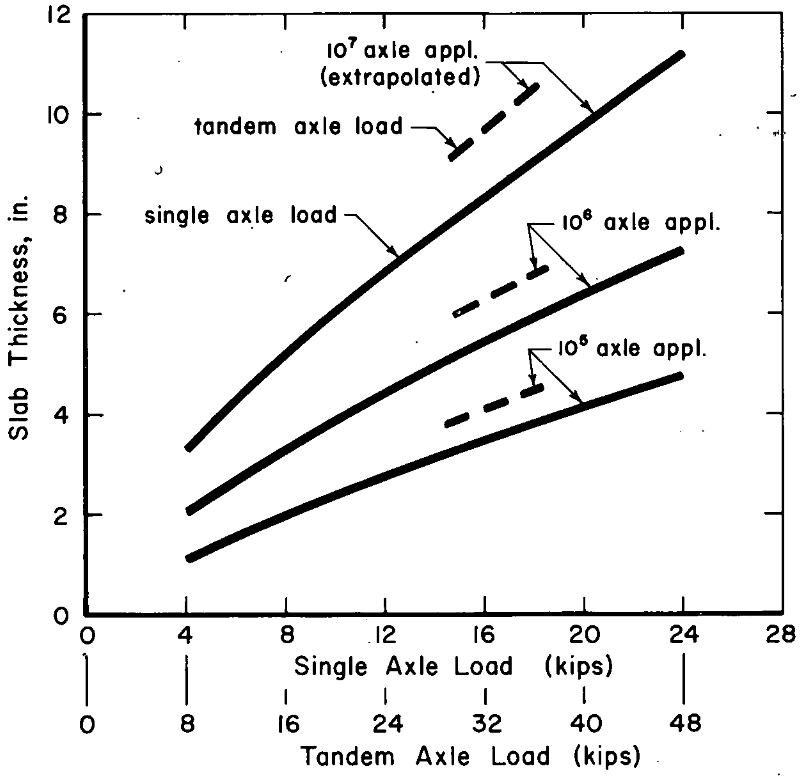

Figure 15–G. Performance equation (18–G) for selected applications ($p = 2.5$).

# Appendix H

## EMBANKMENT SOIL TEST DATA CORRELATIONS

### Flexible Pavement Trench Data

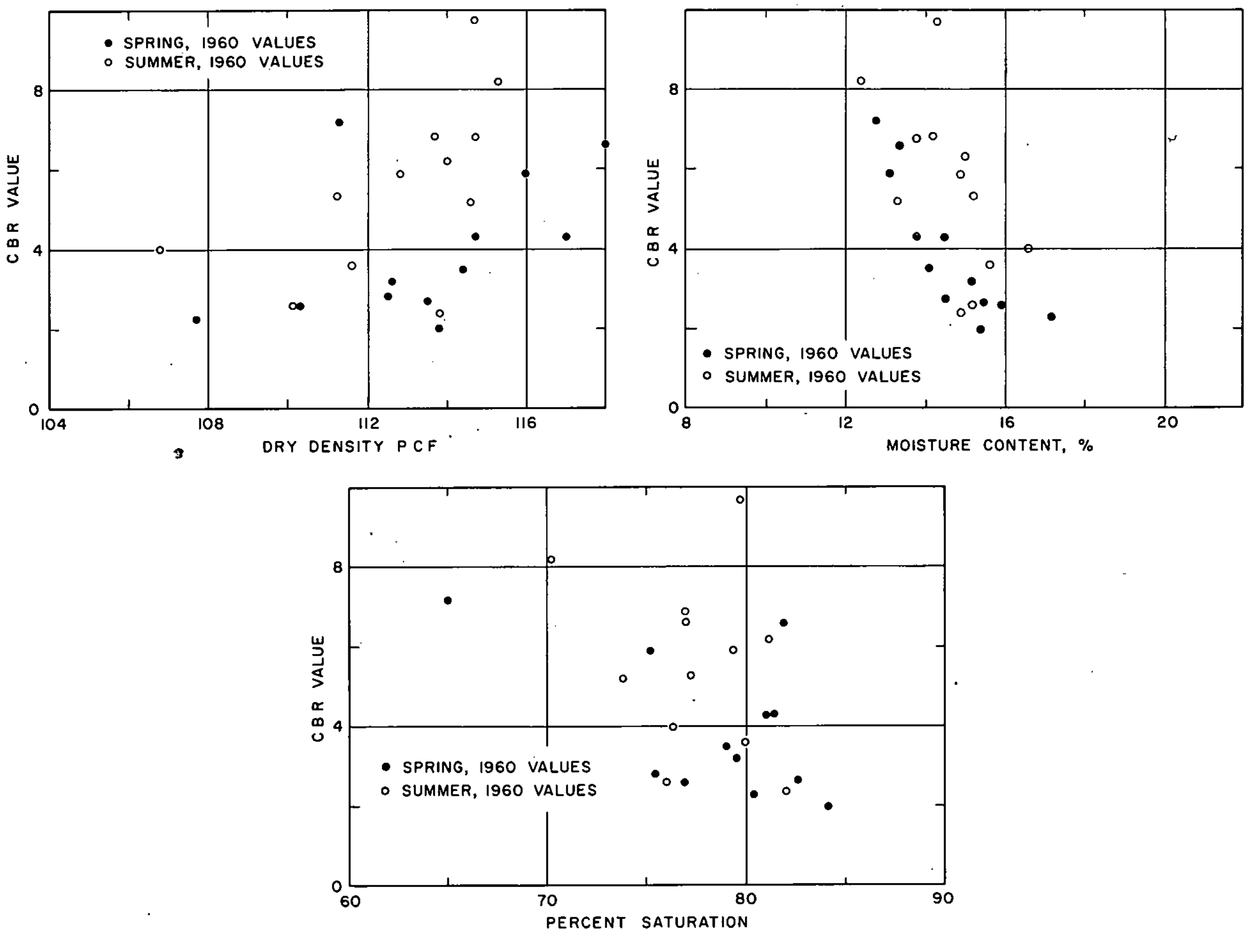

Figure 1–H. Embankment soil test data from trenches, main loop sections.

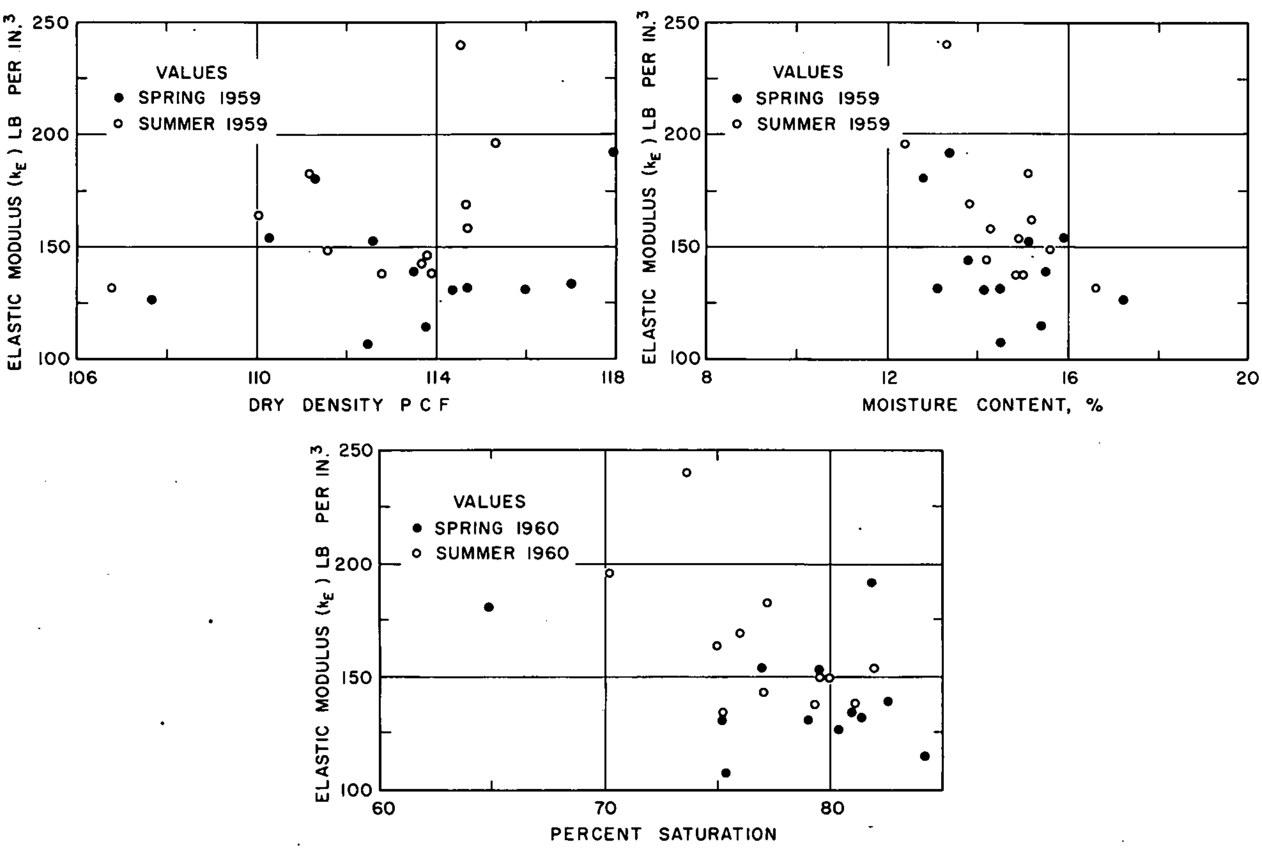

Figure 2–H. Embankment soil test data from trenches, main loop sections.

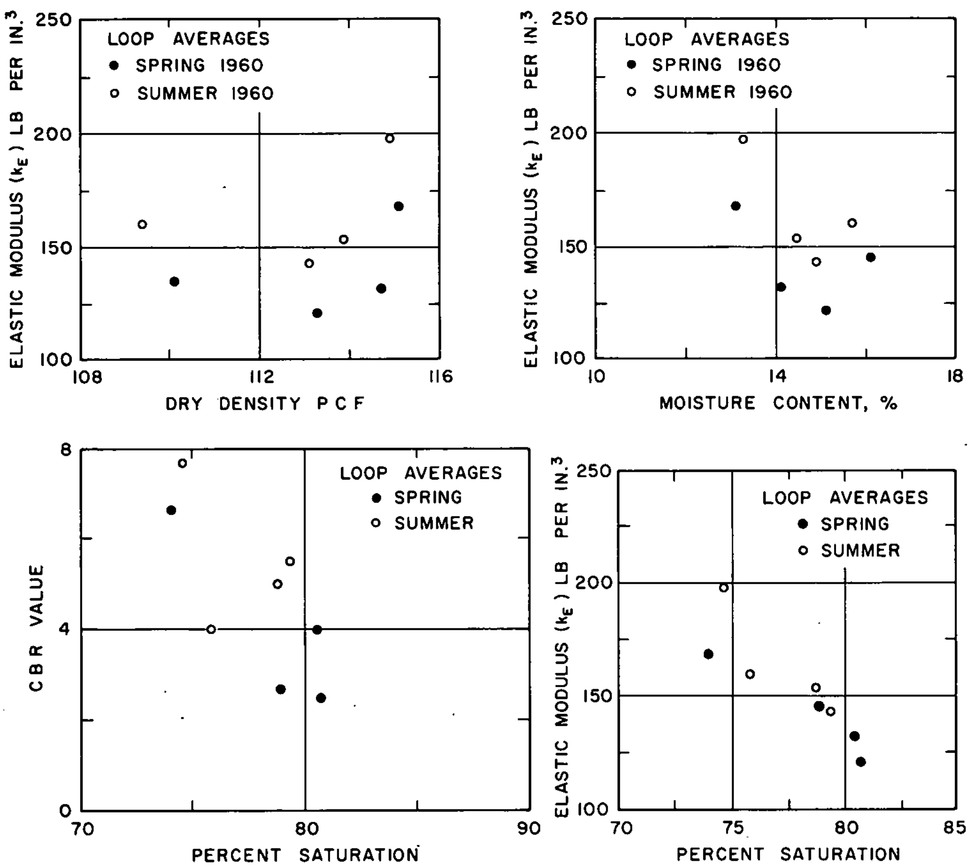

Figure 3–H. Embankment soil test data from trenches, main loop sections, loop averages.

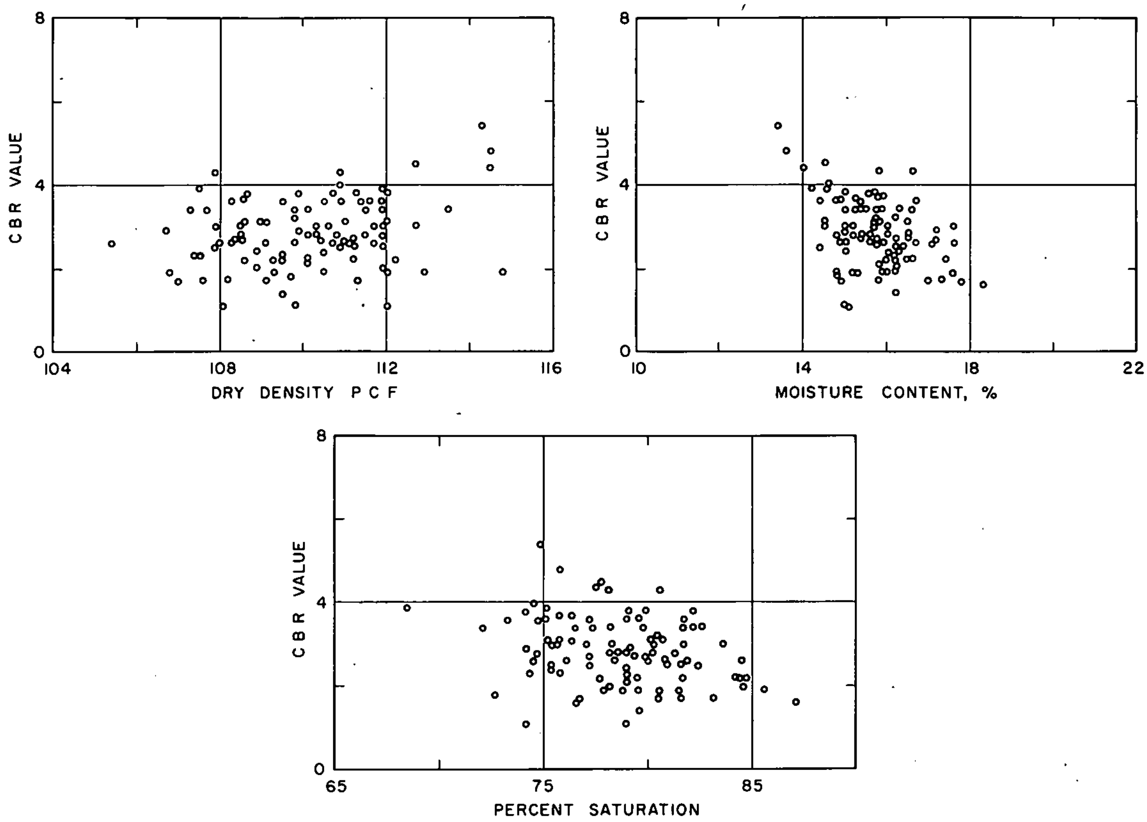

Figure 4–H. Embankment soil test data from trenches, Loop 1.

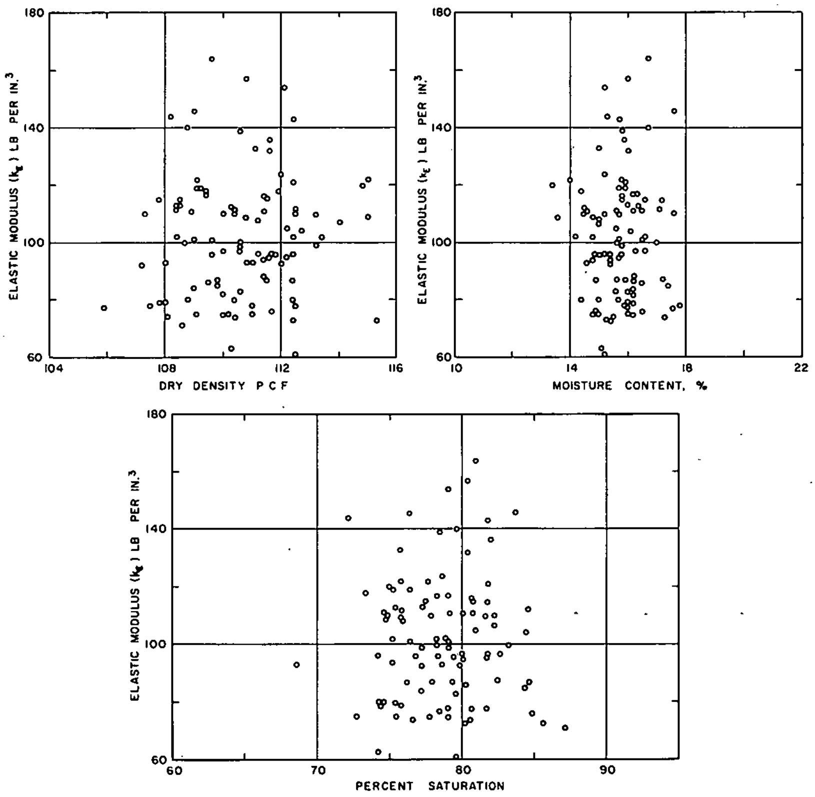

Figure 5–H. Embankment soil test data from trenches, Loop 1.

# Appendix I

## DATA SYSTEMS

This appendix lists all Road Test data systems except those connected with bridge research. Bridge data systems are listed and described in Report 4.

A 4-digit number and a code letter, indicating which Road Test branch was mainly responsible, identify each data system. Branch code letters are as follows:

| Code | Branch |
|---|---|
| B | Bridge |
| D | Data Analysis |
| F | Flexible Pavement |
| I | Instrumentation |
| L | Materials Laboratory |
| M | Maintenance |
| O | Operations |
| R | Rigid Pavement |
| S | Special Assignments |

The data system title, given after the identification code, is followed by a short descriptive paragraph except where the title is considered self-explanatory.

At the end of the descriptive paragraph one or more of the words "folder," "tape," or "printout" are given. A folder includes such material as field data sheets, tabular and graphical summaries, partial or complete analysis, material from related studies, and maps. The one or more folders associated with a data system are stored in branch files. Because of the wide variety of material contained in these folders and the impracticality of describing this material, requests therefor should be preceded either by personal study or by detailed correspondence with the Highway Research Board. When it is determined what folder material is of interest, appropriate reproduction can be made to satisfy the request.

In certain data systems, basic data appear as analog oscillograph chart records (tapes). Requests for tapes or tape reproduction should also be preceded by personal study or detailed correspondence.

Much of the information in data systems has been put on IBM cards. Either cards and/or printouts with a descriptive cover sheet are available from the Highway Research Board.

Requests should be addressed to the Director, Highway Research Board, 2101 Constitution Avenue, N. W., Washington 25, D. C.

Prices will be based on the cost of reproduction.

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1001–D Data Systems Card File

File of 5- x 8-in. cards, one card for each data system. Card includes identification, brief description, items and quantities, and specific location of items.

1020–D IBM Card Layout File

Punched card layout, column by column, for each data system having punched card data. Layout includes explanatory notes, diagrams, etc., when needed. (Folder)

1110–F Purdue Base Materials Study

A Purdue University thesis that reports the results of a laboratory investigation of the behavior of gravel and crushed stone mixtures subjected to repeated loading. Materials were obtained on the site of the AASHO Road Test. (Folder)

1310–L Background for Selection of Pavement Designs

Historical material on design of rigid and flexible pavement sections, 1951-1958. (Folder)

1312–L Preliminary Information on Embankment Soil, 1956 (Folder)

1313–L Miscellaneous Notes on Embankment Construction (Folder)

1316–L Locations of Test Holes in Embankment, Spring 1957 (Folder)

1317–L Miscellaneous Moisture, Density, and Field CBR Tests of Embankment Under Mulch Cover, July 1957 (Folder)

1318–L Moisture Profiles of Embankment Taken Immediately Before Placing Mulch, 1957 (Folder)

| | |
|---|---|
| 1319–L | Effect of Thickness of Mulch Cover on Embankment Moisture Content, Fall 1957 (Folder) |
| 1321–L | Miscellaneous Tests for Moisture and Density of Embankment, Spring 1958 (Folder) |
| 1322–L | Moisture Profiles of Embankment, Spring 1958 (Folder) |
| 1323–L | Moisture Tests on Shoulders of Rigid Pavements, August 1958 (Folder) |
| 1324–L | Summary and Study of Moisture Content of Embankment Through Beginning of Traffic, 1958 (Folder) |
| 1325–L | Information from 1956 Production of Mulch (Folder) |
| 1326–L | Inter-Laboratory Tests, 1956 Production of Mulch (Folder) |
| 1327–L | Subbase Compaction Data, Shoulders (Folder) |
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| 1329–L | Summaries of Various Laboratory Studies of Methods for Stabilizing Original Subbase Material (Folder) |
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| 1336–L | Pilot Section Construction Test Data, Base Course (Folder) |
| 1337–L | Maximum Dry Density of Type A Base Used on Shoulders (Folder) |
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| 1339–L | Type A Base, Plant Gradations (Folder) |
| 1340–L | Miscellaneous Compaction Data from Pilot Section and Turnarounds (Soil, Base and Subbase) (Folder) |
| 1341–L | Report of Routine Modulus of Rupture Tests, Concrete Pavement Construction<br>Tests used to determine length of curing period. (Folder) |
| 1342–L | Daily Reports, Concrete Pavement Construction (Folder) |
| 1343–L | Aggregate Inspection Reports, Concrete Pavement Construction (Folder) |
| 1344–L | Miscellaneous Inspection Reports<br>Darex, water, steel. (Folder) |
| 1345–L | Concrete Control for Bridge Construction<br>Miscellaneous information. (Folder) |
| 1346–L | Field Test Results on Bituminous Concrete Used on Shoulders (Folder) |
| 1347–L | Extraction Test on Material Removed from Pavement, Bituminous Concrete Construction<br>Tests on surface course material replaced at beginning of construction, Loop 3. (Folder) |
| 1348–L | Aggregate Inspection Reports, Bituminous Concrete Construction<br>Tests on material at aggregate producer plants. (Folder) |
| 1349–L | Moisture Content of Concrete Pavement Samples<br>Tests on samples from Loop 1 to determine moisture content of concrete. (Folder) |
| 1350–L | Investigation of Surface Cracks in Concrete Pavement<br>Limited investigation to determine cause of surface cracks in turnaround section of Loop 5. (Folder) |
| 1351–L | A Correlation Between Plastic Limit and Optimum Moisture Content<br>An investigation using data from Data System 2330. (Folder) |
| 1500–1515–O | Operations Branch Records<br>Data not generally available except through special release agreements. Includes such items as tire recap inventories, vehicle failure reports, fuel and lubrication data, accident data, driving schedules, loading diagrams and calculations. (Folders) |
| 1600–D | AASHO Calendar Code<br>Month-by-month calendar that shows both calendar day and AASHO code date, where July 1, 1956 = code day 1, July 2, 1956 = day 2, etc. (Folder) |
| 1800–I | Instrumentation Branch Files<br>Designs and graphs pertinent to certain electronic instrumentation at the AASHO Road Test. (Folder) |
| 2000–L | Construction Plans<br>Blueprints for initial layouts of the AASHO Test Road. (Folder) |

2110–L Field CBR Tests, Flexible Pavements
Tests on embankment soil after compaction before subgrading subbase. (Folder, 1-page printout)

2111–L Moisture Content of Flexible Pavement, Embankment and Subbase
Tests made through core holes prior to test traffic. (Folder)

2119–L Embankment Density, Flexible Pavements
Tests made after subgrading. (Folder)

2120–L Thickness of Base Course, Flexible Pavements
Tests made after subgrading. (Folder, 19-page printout)

2121–L Gravel Base Construction Data, Flexible Pavement Base Type Studies
Construction moisture and density tests, laboratory CBR tests, gradation, liquid and plastic limits. (Folders)

2122–L Cement-Treated Base Construction Data, Flexible Pavement Base Type Studies
Laboratory and field moisture and density tests, compressive strength tests, gradation tests, mixture design information. (Folder)

2123–L Stone Base Construction Data, Flexible Pavements
Field density and compaction test data. (Folder, 25-page printout)

2124–L Tests of Stone Base After Subgrading, Flexible Pavements
Field moisture and density tests, thickness measurements. (Folder, 6-page printout)

2125–L Stone Base Plant Samples, Flexible Pavements
Gradation and moisture content, plant inspector's daily reports. (Folder)

2126–L Stone Base Road Samples, Flexible Pavements
Gradation. (Folder)

2127–L Shoulder (Type A) Base Plant Samples, Flexible Pavements
Gradation, inspector's daily reports. (Folder)

2128–L Shoulder (Type A) Base Road Samples, Flexible Pavements
Gradation. (Folder)

2129–L CBR Tests, Stone Base, Flexible Pavements
Routine tests, construction period. (Folder)

2130–L Thickness of Subbase, Flexible Pavements
Thickness and moisture content after subgrading. (Folder, 18-page printout)

2131–L Construction Test Data, Subbase, Flexible Pavements
Moisture, density, and compaction data, quality control charts. (Folders, 20-page printout)

2132–L Density of Subbase After Subgrading, Flexible Pavements
Moisture, density, and compaction data, after subgrading. (Folder, 9-page printout)

2140–L Marshall Test Results, Bituminous Concrete Construction
Laboratory control tests, quality control charts. (Folders, 15-page printout)

2141–L Extraction Test Results, Bituminous Concrete Construction
Laboratory test results, quality control charts. (Folder, 8-page printout)

2142–L Field Density Tests Results, Bituminous Concrete Construction
Laboratory tests on field density samples. (Folders, 47-page printout)

2143–L Hot-Bin Gradations, Bituminous Concrete Construction
Test data, quality control charts. (Folder)

2144–L Illinois Highway Department Laboratory Test Results, Bituminous Concrete Construction
Illinois Highway Department test reports on bituminous concrete. Extraction, Marshall, high-pressure air meter tests. (Folder)

2145–L Illinois Highway Department Laboratory Test Results on Asphalt, Bituminous Concrete Construction
Illinois Highway Department daily report sheets. Tests at refinery and on Road Test. Penetration, spot test, etc. (Folder)

2146–L Construction Test Data, Bituminous Concrete Base, Flexible Pavement Special Base Experiment
Mix design information. Results of extraction, Marshall and field density tests. (Folder)

2147–L Test Data, Special Stability Mixes on Turnarounds, Bituminous Concrete Construction

Extraction, Marshall, and field density test results. Quality control charts. (Folders)

2148–L Tests on Recovered Asphalt, Bituminous Concrete Construction

Illinois Highway Department Tests. Penetration, ductility, etc. (Folder)

2149–L Bituminous Concrete Mixture Designs, Flexible Pavements

Mixture designs by Road Test Materials Laboratory, Illinois Highway Department, and The Asphalt Institute. (Folder)

2150–F Surfacing Thickness, Bituminous Concrete Construction

Asphaltic concrete thicknesses measured as the pavements were laid. Data at six transverse points for 25-ft longitudinal stations. (Folder, printout)

2151–L Tests on Asphalt by Outside Agencies

Special tests on asphalt by Standard Oil Company of Indiana, Standard Oil Company of Ohio. Complete certified analysis by Standard Oil Company of Indiana. (Folder)

2152–L Reports on Bituminous Concrete by Other Agencies

Hubbard-Field tests by Florida. Observations and reports of tests by Bureau of Public Roads. (Folder)

2153–L Tests on Pilot Sections, Bituminous Concrete Construction

Extraction, Marshall, and field density test data. Quality control charts. (Folders)

2154–L Tests on Bituminous Concrete Shoulders, Bituminous Concrete Construction

Extraction, Marshall, and field density tests. Quality control charts. (Folders)

2155–L Illinois High-Pressure Air Meter Tests on Bituminous Concrete

Reports of tests by Illinois Highway Department Laboratory. Air content of compacted density test samples. (Folder)

2160–L Effect of Test Temperature on Marshall Stability

Results of laboratory study. Samples of binder and surface course mixtures tested over a temperature range from 40° to 160° F. (Folder)

2170–L Effect of Compaction Procedure on Maximum Density of Base

Preliminary studies prior to construction. Includes some field test data. (Folders)

2210–L Field CBR Tests, Rigid Pavements

Tests on embankment soil after compaction prior to subgrading subbase. (Folder, 1-page printout)

2211–L Moisture Content of Rigid Pavement, Embankment and Subbase

Tests through core holes before test traffic. (Folder)

2219–L Embankment Density, Rigid Pavements

Tests after subgrading. (Folder)

2220–L Thickness of Subbase, Concrete Pavements

Thickness and moisture content after subgrading. (Folders, 16-page printout)

2221–L Subbase Construction Data, Concrete Pavements

Construction test data. Moisture, density and compaction data. Quality control charts. (Folders, 15-page printout)

2222–L Density of Subbase After Subgrading, Concrete Pavements

Moisture and density test data. (Folder, 10-page printout)

2230–L Routine Construction Test Data, Concrete Pavement Construction

14-day strength tests, slump, air content, etc. Quality control charts. (Folders, 19-page printout)

2231–L Static and Dynamic Properties of Laboratory Cured Concrete Beams and Cylinders

Tests made on specimens molded during construction of concrete pavements. Moduli of elasticity, Poisson's ratio, flexural and compressive strengths. Summarized in field office report 26. (Folders, 1-page printout)

2232–L Proportioning Plant Reports, Concrete Pavement Construction

Daily reports of proportioning engineer and paving engineer. Tests by Illinois Task Force engineers. (Folders)

2233–L Tests on Aggregate at Proportioning Plant, Concrete Pavement Construction

Daily report sheets of proportioning engineer. Gradation, specific gravity. (Folder)

2234–L Tests on Cement, Concrete Pavement Construction

Routine tests on cement by Illinois Highway Department Laboratory. Autoclave expansion, time of set, compressive strength, etc. (Folders)

2235–L Reports and Results of Laboratory Tests by Bureau of Public Roads, Concrete Pavement Construction

Tests on cement, aggregates and concrete mixture. (Folder)

2236–L Construction Test Data, Turnaround and Pilot Sections, Concrete Pavement Construction

Routine air content, slump, 14-day strength tests. (Folder)

2237–L Characteristics of Concrete Aggregates

Limited tests of specific gravity. Refer to Data Systems 2232, 2233, and 2235 for complete information. (Folder)

2238–R Slab Thickness by Cores

Slab thickness as determined by measurements on cores. (Folder)

2239–R Slab Thickness by Levels

Thickness of slabs determined from levels taken on top of subbase and top of pavement. (Folder, 8-page printout)

2240–L Tests on Cores from Concrete Pavement

Report by Illinois Highway Department Laboratory. Air content by high-pressure air meter, compressive strength, dynamic modulus of elasticity. Also includes copies of thickness measurements, Data System 2238–R. (Folder)

2241–L Freezing and Thawing Tests on Concrete Specimens

Report by Illinois Highway Department Laboratory of freezing and thawing tests on concrete made with coarse aggregate used on the AASHO Road Test. (Folder)

2242–L Effect of Slump, Air Content, and Curing Temperature on Concrete Strength

Correlation analysis on construction test data. (Folder)

2243–L Concrete Mix Design Information

Properties of laboratory mixed concrete. Tests by Portland Cement Association, State of Illinois, and Bureau of Public Roads. (Folder)

2251–L Volume Change Characteristics of Concrete Beam Specimens

Reports of tests by materials laboratory and Portland Cement Association on the thermal volume change properties of concrete beams sawed from test pavements. Also includes tests during cycles of wetting and drying. Linear temperature coefficients of expansion included. (Folder)

2253–L Laboratory Studies of Permeability of Subbase

Results of laboratory tests to relate density and coefficients of permeability of the subbase material. (Folder)

2300–L Cooperative Materials Testing Program, Embankment Soil

Correspondence, original data, and information used in preparing published report. (Folders)

2301–L Cooperative Materials Testing Program, Subbase Material

Correspondence, original data, and information used in preparing published report. (Folders)

2302–L Cooperative Materials Testing Program, Base Material

Correspondence, original data, and information used in preparing published report. (Folder)

2310–L Subgrade Construction Test Data

Rigid and flexible pavements. Field moisture and density tests. Maximum density and optimum moisture content. (Folders, 239-page printout)

2314–L Studies of Moisture Content and Density of Embankment, Winter 1956-57 (Folder)

2315–L Studies of Moisture Content and Density of Embankment, Spring 1957 (Folder)

2316–L Embankment Moisture Profiles, Winter 1957-58

Series of moisture content investigations taken throughout winter on constructed embankment. (Folder)

2320–L Laboratory CBR Studies, Embankment Soil

Results of six separate investigations. (Folder)

2330–L Characteristics of Borrow Pit Soils

Report of routine tests (density, Atterberg limits, hydrometer analysis) on samples obtained from borrow pits. (Folder)

2331–L Subbase Plant Samples, Construction
Inspector's daily report sheets. Gradation tests. (Folder)

2332–L Subbase Road Samples, Construction
Laboratory reports. Gradation tests, CBR, PI. Quality control charts. (Folder)

2333–L Tests on Borrow Pit Soils by Outside Agencies
Reports by State of Michigan, Bureau of Public Roads, University of Minnesota, The Asphalt Institute. Routine tests, triaxial shear, X-ray diffraction. (Folder)

2334–L Soil Core Samples from Centerline of Roadway
Report on original survey by Illinois State Highway Department. Tests on core samples taken along centerline of AASHO Road Test. Routine classification test data. (Folder)

2335–L Tests on Soil by University of California
"A Study of the Deformation Characteristics of the AASHO Road Test Subgrade Under Repeated Loading," C. K. Chan, H. B. Seed. Tests on AASHO Road Test soil compared to silty clay from Vicksburg, Miss., and clayey silt from WASHO Road Test. (Folder)

2336–L Tests on Soil, Subbase, and Base Material by the California Division of Highways
Routine tests. Resilience test. Samples obtained from roadway. (Folder)

2337–L Mineral and Chemical Composition of Road Test Aggregates
Properties of parent materials. (Folder)

2340–L Subgrade Construction Data Analysis Procedures
Various analyses and other information used during construction of earth embankment. Includes statistical acceptance procedures. (Folder)

2341–L One-Point Procedure for Obtaining Maximum Density
Various charts and graphs pertaining to the development of maximum density-optimum moisture content curves used during construction of embankment. (Folder)

2345–L Analysis of Plant Production, Original Sand-Gravel Mulch Placed on Turnarounds in 1956 (Folder)

2351–F Plate Bearing Tests and CBR's, 1956-58
Data sheets for plate bearing, CBR, and moisture content tests on embankment soil. (Folders, printout)

2520–O Vehicle Axle Spacings and Axle Weights
Detailed dimensions and weights for the original 70 vehicles used in test traffic. (3-page printout)

2521–O Axle Loads and Tire Pressures
Detailed loads and tire pressures for the test vehicles. (3-page printout)

2522–O Contact Areas and Tire Prints
Dimensions and prints for the contact area of test vehicle tires. (Folder, 10-page printout)

2523–O Axle Spacings and Axle Weights
Detailed weights and dimensions for all 127 test vehicles. (Folders, 5-page printout)

2130–L Moisture Cells
Miscellaneous information on moisture cells used on rigid pavements. (Folder)

2140–S Frost Depth Data, Flexible Pavements
Description of instrumentation, field layout, and results from frost depth indicators. (Folders, 57-page printout)

2141–F Description of Thermocouple Program
Field layout of thermocouples used in connection with frost depth indicators and for determining isothermal lines. (Folder)

2143–F Loop 1 Thermocouple Program
Field layout and temperature printouts for thermocouples installed in Loop 1 flexible pavement. (Folder)

2147–F Thermocouple Program for Deflection Tests
Field layout and mat temperatures recorded in connection with routine flexible pavement deflections. (Folder)

2148–F Thermocouple Program for Determining Isothermal Lines
Field layout and 24-hr temperature data for thermocouples installed in Loop 1 flexible pavement to obtain temperature isothermals. (Folder)

3200–R Rigid Pavement Adversity Factor Study

Initial efforts to establish rigid pavement adversity factor based on rainfall and frost. (Folder, 1-page printout)

3201–R Rigid Pavement Adversity Factor Study

Further data and formulas for rigid pavement adversity factor based on frost. (Folder, 1-page printout)

3240–S Rigid Pavement Frost Depth Data

Field layout, procedures, and results from frost depth indicators installed in rigid pavements. (Folder, 52-page printout)

3300–S Weather Station Data

Description of instruments, installations, and climatological data obtained during the Road Test. (36-page printout)

3301–S Loop G Weather Data

Daily maximum and minimum temperatures at the top, middle and bottom of rigid and flexible pavements in specially constructed sections near the Road Test administration building. Ground temperature 6 in. below pavement. (Folder, 36-page printout)

3303–S Pavement and Air Temperatures Measured in Loop G

Special project to determine pavement and air temperatures hourly over the 2-year period in rigid and flexible pavements. (Folder, 397-page printout)

3304–S Area Weather Summation

Daily precipitation; maximum, minimum, and mean air temperature; and mean frost depth at the Road Test and in neighboring areas. (Folders, 30-page printout)

3310–S Ground Water Table

Daily ground water table at various installations in the test road tangents. (Folder, 53-page printout)

4100–F Routine Condition Surveys, Flexible Pavements

Field survey maps and summary data obtained from weekly surveys during the traffic phase. Amount and types of cracking and patching. (Folders, 1,480-page printout)

4102–F Initial Condition Survey of Cement-Treated Base Sections

Maps of cement-treated base sections made just after construction and before surfacing. (Folder)

4111–F Correlation Between Slope Variance and Rut Depth

Slope variance plotted against rut depth by loops and lanes. Also rut depth variance against rut depth. (Folder)

4120–F Transverse Profilometer Data, Flexible Pavements

Routine data from the transverse profilometer. (Folder, printouts)

4121–F Rut Depths from Transverse Profilometer

Rut depths computed from nine points of the transverse profilometer records. (Folder, 87-page printout)

4123–F Routine Rut Depths, Flexible Pavements

All rut depth data obtained using the manual gage. (Folders, 395-page printout)

4124–F Special Transverse Rut Depth Data, Flexible Pavements

Special rut depth data obtained with the transverse profilometer. (Folders)

4126–F Rut Depth Studies, Flexible Pavements

Rut depths taken at 5-ft intervals in all paved shoulder and special base experiments. (Folder, 138-page printout)

4127–F Rut Depth Analyses

Special analyses of rut depth for factorial flexible pavement sections. (Folder)

4128–F Comparison of Rut Depth Measurements

Correlations of rut depth by manual gage with those by transverse profilometer. (Folder)

4129–F Final Rut Depth Measurements, Flexible Pavements

Field data sheets for rut depths measured at end of traffic for all sections still in test. Measurements taken at 5-ft intervals in each section. (Folder)

4130–F Subsurface Layer Thickness Changes

Data from settlement rod measurements. (Folder, 129-page printout)

4131–F Transverse Seasonal Profiles

Profiles with transverse profilometer supplemented by precise level measurements. Measurements taken at five locations across pavement and at outside edges. (Folder, printouts)

4132–F Permanent Bench Mark Elevations

Bench mark elevations at 500-ft spacings throughout each loop. (Folder)

4133–F Analysis of Subsurface Thickness Changes

Field layout, procedures, and data summaries of readings obtained from settlement rod installations in flexible pavements, partial analysis. (Folders)

4134–F Subsurface Thickness Changes

Tabulation of biweekly observations of subsurface layer thickness changes as measured from settlement rods. (Folder)

4140–F Vertical Volume Change, Loop 1, Flexible Pavements

Installation details, measurements, and volume change data. (Folder)

4144–F Vertical Volume Changes in Loop 1

Vertical movements at different levels in the embankment before pavement construction. (Folder)

4150–L Routine Subsurface Studies, Loop 1, Flexible Pavement

Moisture and density tests, CBR, plate load tests, etc. (Folders, 32-page printout)

4151–L Consolidated Report, Plate Load Tests

Analyses and summaries of work done under Data Systems 4150, 4250, 4164, 4263, 4166. (Folder)

4161–L Tests in Failed Areas of Flexible Pavements

Preliminary analyses and summaries of data. Moisture and density tests, CBR tests. (Folders, 10-page printout)

4162–L Changes in Bituminous Concrete Pavement Density During Traffic Period

Results of tests on cores drilled from pavement. (Folders, 12-page printout)

4163–L Tests on Asphalt Recovered from Pavement Samples

Tests during traffic period. Asphalt content, penetration, ductility, etc. (Folder)

4164–L Trench Studies in Failed Sections, Flexible Pavements

Profile measurements, moisture and density tests, CBR tests. (Folders, 6-page printout)

4165–L Changes in Bituminous Pavement Stability Under Traffic

Marshall and Hveem stability tests on cores. (Folder)

4166–L ASTM Plate Load Tests

Series of tests on flexible pavements. (Folder)

4167–L Permeability of Bituminous Pavement Using Tentative California Method

Limited tests.. (Folder)

4170–F Asphalt Stability Studies, Flexible Pavement Turnarounds

Experiments and results of studies of stability of various asphalt mixtures used on flexible pavement loop turnarounds. (Folder)

4180–F Trench Study, Main Loops Flexible Pavement, Spring-Summer 1960

Profiles of base, surface, and subbase embankment soil. Moisture content and density of base and subbase. Moisture content and density, saturation, CBR, and plate load test on embankment soil. Gradation and asphalt content of binder and surface mix. Density and thickness of core samples. (Folders, 12–page printout)

4181–F Trenches in Special Base Sections, 1961

Data from trenches in flexible pavement special base sections. (Folders, 12-page printout)

4190–F Prior-to-Maintenance Surveys, Flexible Pavements

Condition surveys, rut depth measurements, longitudinal profile data and serviceability indexes of flexible pavement test sections. Measurements when section required maintenance and just prior to maintenance. (Folders)

4197–F Condition Surveys, Overlays on Rigid Pavement

Field maps and summary printouts of asphaltic concrete overlays on failed rigid pavements. (Folder, 1-page printout)

4198–F Rut Depth, Overlays on Rigid Pavement

Rut depth data for asphaltic concrete overlays on failed rigid pavement sections. (Folder, 8-page printout)

4199–F Historical Records of Flexible Pavement Test Sections

One chart for each flexible pavement section and subsection in the Road Test, showing serviceability history, cracking and patching history, longitudinal profile history, rut depth history, deflection history, and history of any overlay studied after failure of the original section. (Folders)

4200–R Routine Condition Surveys, Rigid Pavements

Weekly measurements of cracking, faulting, patching, spalling, etc. Field maps, special data in failed areas. (Folders, 680-page printout)

4201–R Section Summary of Condition Surveys, Rigid Pavements

Summary by section and index day of measurements taken in Data System 4200. (340-page printout)

4202–R Condition Survey, Section and Panel Average

Same as Data System 4201, but includes cracking index. (Folder, 340-page printout)

4220–R Transverse Profiles with Profilometer

Transverse profile at nine points taken with transverse profilometer, seven times on selected sections over a two-year period. (Folder)

4222–R Transverse Profile, Failed Rigid Pavement Sections

Contours of subbase taken with rod and level in failed sections. (Folder)

4230–R Consolidation of Rigid Pavement Subbase

Measurements intended to detect consolidation of subbase near panel corners. Faulty instrumentation yielded no practical data. (Folders, 126-page printout)

4240, 4241, 4242, 4243–R Rigid Pavement Pumping Surveys

Basic information and pumping scores for each rigid pavement test section after each rain. (Folders, 292-page printout)

4250–L Routine Subsurface Studies, Loop 1, Rigid Pavements

Moisture and density tests, CBR, and plate load test. (Folders, 6-page printout)

4251–L Effect of Weather and Sawing on Concrete Beams

Report of tests on beams from Loop 1. Strength and dynamic test properties. (Folders)

4261–L Test in Failed Areas, Rigid Pavements

Moisture and density tests. (Folders, 7-page printout)

4263–L Trench Studies in Failed Areas, Rigid Pavements

Profile measurements, moisture and density, gradation, CBR, and plate load tests. (Folders)

4290–R Prior-to-Maintenance Rigid Pavement Surveys

Roughometer, cracking and patching data, serviceability values for each section. (Folders)

4292–R History Plots for Rigid Pavement Test Sections

One chart for each rigid pavement section, in the Road Test, showing serviceability, cracking and patching, cracking index, edge strains, static deflections, pumping index. (Folders)

4300–D Routine Longitudinal Profiles

Analog traces of wheelpath slope in each wheelpath of each lane. Biweekly runs throughout period of Road Test. (Tapes)

4305–R Roughometer Data

Roughometer data taken with mechanical counter. Data considered impractical for the short Road Test sections. (Folders)

4306–R Michigan Profilograph Data

Comparison of Road Test profilometer data with Michigan profilograph data taken on Road Test sections. (Folder)

4307–R Roughness by Roughometer

Results of 15 determinations on all factorial sections from June 1959 through November 1960. Roughometer equipped with electronic counter. (Folder, 308-page printout)

4308–R Roughometer Correlation Data

Correlation study made in 1959 between Road Test roughometer and BPR–102 roughometer having electronic counter. (Folder)

4309–R Routine Roughometer Data

Continuation of Data System 4307.

4340–S Skid Resistance Studies
Special skid tests on flexible and rigid pavements at different speeds and when dry and wet. General Motors Corporation skid test equipment. (Folders, 43-page printout)

4341–S Changes in Skid Resistance
Historical trend of coefficients of friction obtained in Data System 4340. (Folders, 20-page printout)

4390, 4391, 4392–R Special Profilometer Studies, Chanute Field Profiles
Data gathered on runways at Chanute Air Force Base using the AASHO Road Test profilometer. Profiles taken with and without horizontal reference. (Tapes)

4600–D Special Studies of WASHO Test Data
Investigation of possibilities for index development using WASHO Road Test information. (Folder)

4620–D Preliminary Studies of Pavement Roughness
Harmonic analysis and other statistics of pavement profiles, determined from pavements in service before 1958. (Folder)

4621–D Pilot Survey for Pavement Roughness
Ride ratings and pavement statistics obtained in pilot study near Ottawa, Ill., 1957. (Folder)

4622–D Special Profiles of Pavements in Service
Longitudinal profiles of certain sections of Connecticut and Indiana highways. (Folder)

4650–D Generalized Harmonic Analysis of Pavement Profiles
Spectral densities for selected portions of AASHO Test Road. (Folder)

5100–F Special Deflection Study, Loop 6
Special program of creep speed deflection test made periodically on Loop 6 during Fall 1958 and Winter 1958-59. (Folder)

5103–F Special Deflection Study, Probe Placement
Study to show the difference between rebound deflections with a routine procedure and deflections recorded when probe of beam was placed 1 ft and ½ ft ahead of the dual wheels. (Folder)

5104–F Comparison of Normal and Rebound Deflections
Deflections in normal manner compared to rebound deflections on two traffic loops. (Folder)

5105–F Correlation of Manual Beam Deflections with Plate Bearing Tests
Plate load and beam deflections on surface of Loop 1 Design 5 sections before trenching. (Folder)

5106–F Special Deflection Study, Operator and Beam Variances
Deflections on two pavement designs using seven operators and six Benkelman beams. (Folder)

5107–F Special Deflection Study, Single and Tandem Axle Loads
Beam deflections in lanes under single axle and tandem axle loads assigned for the regular test. (Folder)

5108–F Special Deflection Study, Beam Deflections at Different Levels in Loop 4
Deflections at different levels on 18-kip single axle lane by settlement rods. (Folder)

5109–F Beam Deflections by Index Periods
Outer and inner wheelpath beam deflections; one value for each wheelpath of each flexible pavement test section for a 2-week index period. Values obtained from Data System 5121. (Folders)

5111–F Special Analysis of Loop 1 Beam Deflections
Computer analysis of variance and regression analysis of deflections taken weekly in Loop 1. (Folder)

5121–F Routine Benkelman Beam Deflections
Deflections with variable loads, 3 to 15 kips, on all loops. Initial deflections in fall 1958. Subsequent deflections on Loops 2, 3, 4, 5, and 6 at 2-week intervals except when pavement was frozen. Weekly deflections on Loop 1. (Folders, 671-page printout)

5122–F Deflections on Surface, Base and Subbase During Construction
Deflection tests on various layers of flexible pavement during construction. (Folders)

5123–F Beam Deflections Prior to Test Traffic
Two series of special deflection tests on all test sections before regular test traffic. Data given also in Data System 5121. (Folder)

5124–F Special Deflection Study, Truck-to-Truck Variation
Deflections on a single section by six different single axle and six different tandem axle vehicles. All vehicles in each set with same nominal load. (Folder)

5125–F Load Deflection Studies

Five single axle loads and four tandem axle loads used on six sections of Loop 6 to determine load-deflection relationships. First study in spring 1955. Another program in fall 1959 on six sections of Loops 4 and 6. (Folder, 7-page printout)

5127–F Within Test Section Variability of Beam Deflections

Includes standard deviation of deflections within test sections, residual deflection total deflection, and histograms of positive and negative residuals for each loop at three different periods. (Folder)

5128–F Electronic Trace Deflections

Special creep-speed deflection tests with 10-ft probe beam equipped to produce analog deflection trace. (Folders)

5129–F Analysis of Routine Deflections

Regression analysis, normal and rebound deflections in fall 1958 and spring 1959. Deflections in all Design 1 test sections under test loads in single axle lanes and less than test loads in all lanes. (Folders, 5-page printout)

5133–F Dynamic Deflection Load Studies

Dynamic deflections from LVDT units in Loop 6, variable loads. (Folder)

5141–F Routine LVDT Deflections

History of dynamic deflections obtained at permanent installations in traffic loops throughout traffic operation period. (Folder, 21-page printout)

5142–F Comparison of Beam and LVDT Deflections

Correlation study between deflections from Benkelman beam and LVDT data. Three studies on Loop 6 and Loop 4. (Folder)

5143–F Deflection-Speed Study

Deflections from creep to nearly 50 mph on three different days for four sections in each of Loops 4 and 6. Two loads in each loop. (Folder, 48-page printout)

5144–F Deflection Contours

Deflections using LVDT units under 18-kip single axle load on selected sections in Loop 4. Data used to determine deflection contours. (Folder)

5151–F Curvature Strips

Curvature strips output records taken during early part of traffic test. (Folder)

5152–F Curvature at Creep Speed

Field data and partial analysis from a limited series of curvature measurements at creep speed. (Folder)

5153–F Correlation of Curvature with Speed, Deflection, Pressure

Curvature strip output from several days operation. Graphical correlations of deflection with speed, pressure and location. (Folder)

5161–F Embankment Pressure at Creep Speed

Routine embankment pressure data obtained under creep-speed conditions each two weeks during traffic test. (Folder, 21-page printout)

5162–F Embankment Pressure Speed

Special study, Loop 4. Deflection speed varied from 2 to 35 mph under different loads. (Folder, 8-page printout)

5163–F Lateral Pressure Study

Series of pressure contours from tests using 18-kip single axle load. Vehicle shifted laterally at 6-in. intervals, normal speed. (Folder)

5190–F Initial Deflection-Temperature Studies

Field data and summaries of fall 1958 study of effect of asphalt surfacing temperatures upon deflection. (Folder, 12-page printout)

5191–F Routine Deflection-24-Hour Temperature Studies, Loop 1

Seven series of deflections made throughout 24-hr temperature conditions, Loop 1, flexible pavements. (Folders, 65-page printout)

5192–F Temperature - Deflection - Pressure Studies

Special Loop 4 studies of mat temperature effects on deflection and embankment pressure. Embankment deflection determined from LVDT's. (Folder, 17-page printout)

5193–F Deflection-Temperature Studies on Special Base Sections

24-hr studies of temperature effects on deflection in special base sections. (Folder, 1-page printout)

5194–F Deflection-Speed-Load-Temperature Study

Special study in Loop 6 to determine relationship of deflection with mat temperature, load, and speed. Single axle loads from all five traffic loops. Dynamic deflections covering temperature range from 37° to 79° F. (Folder, 15-page printout)

5195–F Deflection-Temperature Studies in Loop 1

Special deflection-temperature study in Loop 1 to determine effect of pavement design on relationship between deflection and surface temperature. (Folder)

5196–F Temperature-Deflection Study

Special study in Loop 6 to investigate effect of pavement temperature on pavement deflection. (Folder)

5200–R Surface Strains, Loop 1, Rigid Pavements

Strains measured in Loop 1 on 18 test sections 5.0, 9.5, and 12.5 in. thick. (Folders, tapes, 21-page printout)

5201–R Strain versus Variable Load at Constant Frequency, Loop 1

Dynamic surface strain study on Loop 1 with van 4 and vibrator truck. (Folder, tapes, 6-page printout)

5202–R Strains in Loop 6, Vibrating Loader

Output of edge gages in Loop 6 sections under vibrating loader. (Folder, tapes)

5203–R Temperatures for Data System 5200

Pavement temperatures for all eight rounds of Loop 1 strain data given in system 5200. (17-page printout)

5204–R Variable Frequency Studies, Loop 1

Special study of effect on strains while varying load frequency at constant load amplitude. (Folder, tapes, 2-page printout)

5205–R Summary of Loop 1 Principal Strains and Corresponding Pavement Temperatures

Eight rounds of principal strain data and corresponding pavement temperatures. (17-page printout)

5206–R Summary of Principal Strains and Pavement Temperatures, Loop 1 Variable Load Study (12-page printout)

5207–R Summary of Principal Strains and Pavement Temperatures, Variable Frequency Study in Loop 1

Computer summary of Data System 5204. (Folder, 8-page printout)

5208–R Pavement Temperatures, Variable Load Study in Loop 1

Pavement temperatures taken in Loop 1 during period when data for system 5201 were collected. (Folder, 4-page printout)

5209–R Pavement Temperatures for Variable Frequency Study in Loop 1.

Pavement temperatures taken on Loop 1 during period when data for system 5204 were collected. (Folder, 8-page printout)

5211–R Analysis of Loop 1 Strain Data

Coefficients for orthogonal polynominals; basic data in the form of principal strains. (Folder)

5220–R Curling Studies in Loop 1

Measurements of vertical movement at 16 points on 24 Loop 1 sections, together with pavement temperatures. (Folders, 204-page printout)

5221–R Curling Studies in Loop 1 Without Temperatures

Same as Data System 5220 except that pavement temperatures were not taken. (Folder)

5222–R Corner Movements, Curl

Measurements of vertical displacements at panel corners in Loop 1. Measurements at each corner of 24 panels at 15- to 20-min intervals. (Folder, 203-page printout)

5223–R Curl Movements, Smoothed

Maximum vertical displacements at 16 points on the surface of 24 panels in Loop 1, as air temperature varied from a maximum to the next minimum. Data smoothed after plotting displacement of each point against time. (Folder, 7-page printout)

5224–R Air and Pavement Temperature Statistics for Data System 5220

Changes in air temperature, standard differential, and time involved with displacements in Data System 5220. (Folder, 7-page printout)

5225–R Smoothed Internal Slab Temperatures for Data System 5220

Internal slab temperatures at beginning and end of time intervals corresponding to displacements given in Data System 5220. (Folder, 7-page printout)

5226–R Analysis of Curl Data

Coefficients for orthogonal polynomials; smoothed data. (Folder)

5240–R Internal Temperature of Subgrade and 9.5- and 12.5-Inch Slabs in Loop 1

Temperatures at several points in and under seven slabs over same period of time, usually 24 to 36 hr. (Folder, 157-page printout)

5241–R Internal Slab Temperatures of Subgrade and 2.5- and 5.0-Inch Slabs in Loop 1

Same as Data System 5240 except for different slab thickness. (Folder, 188-page printout)

5242–R Curing Temperatures in Plastic Concrete, Loop 1

Special studies of temperatures and beneath two 12.5-in. slabs in Loop 1 during plastic and hardening phases of freshly poured concrete. (Folder, 12-page printout)

5243–R Temperatures for 24-Hour Study of Strains and Deflections

Temperatures in selected slabs in Loop 1 during special 24-hr studies on traffic loops. (8-page printout)

5250–R Routine Dynamic Strains and Deflections in Traffic Loops

Dynamic edge strains and corner deflections under regular test traffic in routine dynamic measurements program. (Folder, 92-page printout)

5251–R Effect of Vehicle Placement on Dynamic Strain and Deflections

Effect on dynamic strain and deflection of lateral placements on either side of desired load placement. (Folder)

5252–R Uniformity of Dynamic Strain and Deflection in Loop 3

Uniformity of dynamic strains and deflections in sections with constant slab thickness and constant load. (Folder)

5253–R Dynamic Strains and Deflections vs Temperature

Results of three 24-hr studies to determine effect of daily variations in air temperature on strains and deflections. (Folder, 30-page printout)

5254–R Routine Dynamic Strain and Deflection Studies

Same as Data System 5250 except data are recorded on punched tape in van. (Folder)

5255–R Deflection Basin and Strain Influence Study

Special study to determine distance of vehicle from gage point at threshold values of dynamic edge strain, dynamic corner deflections, static rebound edge deflections, and static rebound corner deflections. (Folder)

5256–R Dynamic Strain and Deflection vs Speed

Special study in Loops 4 and 6 at two different times to determine interrelationships of strains, deflections, load, speed, and temperature. (Folders)

5257–R Special Studies of Dynamic Strains

Studies to determine the point at which maximum strain occurs for reinforced and non-reinforced pavement, transverse and longitudinal distribution of strain. (Folder)

5258–R Static and Dynamic Load-Strain, Load-Deflection Studies

Studies to support the theory that strain or deflection is directly proportional to load when other factors are constant. (Folder)

5260–R Maximum Vertical Movements

A study to show the relationship between pavement design and vertical movements due to traffic. (Folder)

5270–R Concrete and Soil Temperatures in Loop G

Special study to determine temperature stress in top and bottom of a concrete pavement specially built near the Road Test administration building. (Folder)

5280–R Routine Static Rebound Deflections

Static rebound corner deflections of PCC pavement under normal loop-load thickness combinations. Benkelman beam probe at edge of pavements, one round every two weeks. (Folder, 291-page printout)

5282–R Static Rebound Deflection-Placement Studies

Study to determine effect of load placement on deflection of PCC pavements. Probe at edge of pavement. (Folder)

5283–R Uniformity of Static Rebound Deflections

Study to compare deflection of all PCC pavements under a uniform 12-kip single axle load on Loops 3, 4, 5, and 6, and with 2-kip single axle load on Loop 2. (Folder, 98-page printout)

5284–R Special Static Rebound Deflection Studies
Comparing deflections of beam on shoulder with beam on pavement, deflection basin study, variability of deflection from trucks all having same nominal load. (Folder)

5285–R Deflection Variation Within Sections
Study to determine variation of deflection within a section of a given design. (Folder)

5286–R Deflection-Load Studies
Special study to determine the relationship of dynamic strains and deflections to static rebound corner and edge deflections. (Folder)

5287–R Deflection-Temperature Studies
Special study of static rebound corner and edge deflections with 24-hr change in temperature. Deflections in Loops 1 and 6. (Folders, 60-page printout)

5288–R Comparison of Static and Dynamic Deflections
Comparison of Benkelman beam deflections with LVDT deflections. (Folder)

5289–R Corner Deflection Summary
Summary and analyses for deflection rounds reported in Special Road Test Report, April 1960. (Folder, 30-page printout)

5290–R Contact Indicators
Method of installing slab-subbase contact indicators before test traffic. System abandoned because of instrument failure. (Folder)

5291–R Carlson Pressure Cells
System to measure static load pressures transmitted from slab to subbase. (Folder)

5293–R Slab Length Measurements, Loop 1
System to investigate expansion of concrete slabs and expansion distribution within the slab. (Folder, 1-page printout)

5294–R Vertical Moisture Gradient in Slab
Vertical moisture distribution in a PCC pavement in the field. (Folder)

5300–R Effect of Speed and Tire Pressure on Strain and Deflection
A limited special study of strain and deflection effects for vehicular speeds from 10 to 35 mph and tire pressures from 40 to 75 psi. (Folder)

6100–F Out of Test Dates and Applications, Flexible Pavements
Listing of index days and applications when sections reached a serviceability level of 1.5 and were removed from test. (Folder, 13-page printout)

6200–R Out of Test Dates and Applications, Rigid Pavements
Dates, applications, and other data on sections removed from main experiment after serviceability level reached 1.5. (Folders, 15-page printout)

6201–R Supplemental Out of Test Data, Rigid Pavements
Supplement to Data System 6200. (9-page printout)

6300–M Section Maintenance Record
Record of all maintenance work on each Road Test section before removal from test; record of major maintenance after removal from test. (39-page printout)

6301–M Section Maintenance History
Basic data for Data System 6300. Each maintenance operation on test sections and adjacent transition. (Folder)

6500–O Application Record
Complete record of daily applications and accumulated applications in each traffic lane of test road. (158-page printout)

6501–O Index Day Application Record
Applications within two-week index period and to each index day, for each traffic lane. (1-page printout)

6503–O Lost Applications Record
Daily, weekly and monthly breakdown of applications lost because of pavement maintenance, vehicle maintenance, traffic balancing, weather, etc. (Folder)

6504–O Test Trailer Mileage Record
Daily mileage record of each test trailer beginning in January 1960; previous mileage same as tractor mileage. (Folder)

6507–O Vehicle Weights
Record of each weighing for each vehicle. (Folder)

6508–O Vehicle Dimensions
Dimension diagrams for each truck and trailer. (Folder)

6522–O Fuel Inventory

Record of gasoline and diesel fuels received each delivery, quantities put in storage tank for each loop, weekly summary of fuel dispensed from each tank. (Folder)

7100–F Present Servicability Ratings of 15 Flexible Pavement Sections

Ratings on selected test road sections by staff on AASHO day 1248. (Folder)

7111–F Serviceability Indexes Computed from Rut Depth Variances

Present serviceability indexes for flexible pavement sections computed from rut depth variance instead of slope variance when profilometer could not be run over test section. (Folder)

7112–F Serviceability Losses from Behavior Components

Special tabulation of serviceability losses in certain sections because of slope variance, rut depth, and cracking and patching. (Folder)

7113–F Comparison of Rut Depth Variance with Slope Variance (Folder)

7115–F Present Serviceability Determined by Rut Depth Variance

Special study to determine rut depth variance using rut depths determined by precise levels at 5-ft spacings. Present serviceability for rut depth variance. (Folder)

7124–F Effects of Overlays and Trenches on Present Serviceability Index

Effect on slope variance of overlays and trenches near ends of test sections. (Folder)

7132–F Section Present Serviceability on Index Days, Flexible Pavements

Present serviceability indexes for each section on 55 index days. (Folder, 38-page printout)

7140–F Flexible Pavement Performance Data, Unweighted Applications

Initial present serviceability and smoothed present serviceability index on index days 11, 22, 33, 44, 55; Designs 1, 2, 4, and 6. Also unweighted applications when serviceability index reached 3.5, 3.0, 2.5, 2.0, and 1.5 (1.0 for Design 6). (Folder, 37-page printout)

7141–F Flexible Pavement Performance Data, Weighted Applications

Same as Data System 7140 except that all applications are weighted by seasonal weighting factor. (Folder, 37-page printout)

7144–F Flexible Pavement Performance Data by Wheelpaths for Loop 1, Design 1

Initial present serviceability; smoothed present serviceability on index days 11, 22, 33, 44, and 55 for each wheelpath of Loop 1 sections in Design 1, lane 1. (Folder, 1-page printout)

7146–F Flexible Pavement Performance Equation Estimates, Unweighted Applications

Performance data estimates and residuals from flexible pavement performance equations given in Report 5. (Folder, 9-page printout)

7147–F Flexible Pavement Performance Equation Estimates, Weighted Applications

Same as Data System 7146 except applications weighted. (Folder, 9-page printout)

7180–F Flexible Pavement Overlays, Performance Summary

Tabulation of data from overlay studies. (Folder)

7182–F Special Base Study

Deflection data for special base sections, graphical analysis of special base performance, miscellaneous material on rutting of special base sections. (Folders)

7183–F Adversity Factor Data

Data for development of a seasonal weighting factor for applications on flexible pavements. (Folder)

7185–F Paved Shoulder Study

Material relative to analysis of performance of sections in paved shoulder experiments. (Folder)

7186–F Analysis of Cracking

Preliminary analysis to show association of cracking with design, load and applications. (Folder)

7232–R Rigid Pavement Present Serviceability Index on Index Days

Present serviceability index for each section on 55 index days. (22-page printout)

7240–R Performance Data for Rigid Pavement

Initial serviceability index and smoothed serviceability index values for Designs 1 and 3 on index days 11, 22, 33, 44, and 55. Applications to serviceability level 3.5, 3.0, 2.5, 2.0, and 1.5. (19-page printout)

7244–R Performance Data for Rigid Pavements, Loop 1, Design 1

Smoothed present serviceability on index days 11, 22, 33, 44, and 55 for each wheelpath of Design 1 sections in Loop 1, lane 1. (1-page printout)

7246–R Rigid Pavement Performance Equation Estimates

Performance data estimates and residuals from rigid pavement performance equation given in Report 5. (9-page printout)

7305–7309–D Present Serviceability Ratings of Selected Pavements

Individual ratings of selected pavements by members of the AASHO Road Test performance rating panel. Ratings from five sessions that included Illinois, Minnesota, Indiana, and Road Test sections. Mean ratings used to develop present serviceability index formulas. (118-page printout)

7315–7319–D Measurements for Rated Pavements

Longitudinal and transverse profile summaries; cracking, patching, and other measures of surface phenomena for all sections rated by the performance rating panel. Measurements used to develop present serviceability index formulas. (Folders, 12-page printout)

7322–D Serviceability Index Data and Associated Measurements for All Test Road Sections

Primary data system for test section performance. Biweekly values for each test section and subsection in every flexible and rigid pavement experiment. Includes cracking, patching, rut depth, slope variance, roughometer data, and present serviceability index for each wheelpath of each section. (1,056–page printout)

7350–D Seasonal Weighting Factor Data for Flexible Pavement

Biweekly deflection values for selected Loop 1 flexible pavement sections; seasonal factor values and weighted applications for each index day. (1-page printout)

7611–D Development of Present Serviceability Index Formulas

Correlations and regression analyses to determine present serviceability index formulas used for rigid and flexible pavement. (Folder)

7620–D Special Index Study

Correlation between different index formulas and different profile statistics for large sample of test road sections. (Folder, printout)

7664–7674–D Development of Flexible Pavement Performance Equations

Graphs, tables, and regression analyses, and formulas for various mathematical models leading to flexible pavement performance equations given in Report 5. (Folders)

7679–F Comparison of WASHO and AASHO Pavement Performance

A comparison of serviceability losses in WASHO test pavements with those predicted by preliminary AASHO Road Test performance equations. (Folder)

7681–7694–D Development of Rigid Pavement Performance Equations

Graphs, tables, regression analyses, and formulas for various mathematical models leading to rigid pavement performance equations given in Report 5. (Folders)

8100–F Initial Plans for Flexible Pavement Instrumentation

Information on installation of settlement rods, curvature strips, pressure cells, deflection gages, frost depth indicators, and thermocouples as proposed during planning stages of the Road Test. (Folder)

8150–F Curvature Strip Calibration

Gage factors determined during calibration of curvature strips. (Folder)

8151–F Curvature Strip Installation

Fabrication and calibration procedures for curvature strips in flexible pavements. (Folder)

8170–L Results of Experiments on Use of AASHO Nuclear Density Gage on Rough Stone Base Surface

Used to establish procedures for trench studies. (Folder)

8171–L Limited Tests on Ability of Nuclear Gage to Determine Density of Asphalt Pavement (Folder)

8172–L Investigation of Methods for Obtaining Density of Bituminous Specimens

Parafin and vacuum saturation methods. (Folder)

8173–L Studies of Extraction Test Procedure

Studies of accuracy of reflex-type extractor. (Folder)

8174–L Calibration of Marshall Compactor

Tests to establish proper test procedure for mechanical compactor. (Folder)

8250–R Calibration of Vans 3 and 4

Detailed calibration procedure for instrumentation in vans 3 and 4, rigid pavement instrumentation. (Folder)

8290–L Investigation of Concrete Testing Procedures

Studies of cylinder molds, capping compound, testing machine, curing pit. (Folder)

8291–L Comparison Between Concrete Testing Crews

Studies of two different testing crews used during construction of concrete pavements. (Folder)

8300–R Slope Wheel Calibration

Calibration records for profilometer slope wheels. (Folder)

8301–R Slope Wheel Calibration, Horizontal Reference

Data System 8300 when horizontal reference is used. (Folder)

8302–R Longitudinal Profile of Special Test Course

Profilometer check runs on special calibration course, for control chart analysis of profilometer system. (Folder)

8303–R Profilometer Calibration Check

Continuation of Data System 8302. (Folder)

8304–R Calibration of Longitudinal Profilometer

Slope wheel calibration using automatic chart reader. (Folder)

8305–R Roughometer Correlation Study

Background information on all roughometers brought to the AASHO Road Test for correlation with the AASHO roughometer and profilometer. (Folder)

8307–R Road Test Profilometer Calibration Constants

Listing of all calibration constants used in converting field readings to slope variance. (Folders, 6-page printout)

8370–L Development of AASHO Model Nuclear Density Gage

Results of studies leading to final model used during construction of base course. (Folder)

8371–L Evaluation of Nuclear Moisture and Density Gages

Results of experiments reported in published paper. (Folders)

8372–L Study of Operator Variability in Determination of Liquid and Plastic Limits of Soils.

Data for report published in *HRB Abstracts,* October 1961. (Folder)

8373–L Methods for Obtaining In-Place Density of Soils and Granular Bases

Results of several investigations made primarily to establish procedures for use during construction. (Folder)

8376–L Study of Variations and Control of Gradation of Granular Bases

Inter-laboratory studies; quality control chart analyses of plant production. (Folder)

8377–L Calibration of Infrared Heat Lamp Oven

Oven used for mass production drying of soil samples during construction of Road Test embankment. (Folder)

8378–L Sonic Apparatus

Information on sonic apparatus built for obtaining fundamental transverse and torsional frequencies of concrete specimens. (Folder)

8379–L One-Point Liquid Limit Procedure

Test data for "Rapid Determination of Liquid Limit of Soils by Flow Index Method," by H. Y. Fang, HRB Bulletin 254, 1960. (Folder)

9100–S Flexible Condition Survey Summary, Loop 2, Post-Traffic Studies

Measurement by wheelpath of cracking, sealed areas, patches, overlays. (Folders, 34-page printout)

9101–S Accumulated Applications and Dates for Sections Out of Test, Loop 2, Post-Traffic Studies

Includes initial present serviceability index, type of tire design (conventional or low-pressure low silhouette), day the section went out of test, accumulated applications for the section. (Folders, 2-page printout)

9121–S Beam Deflections, Loop 2, Post-Traffic Studies

Benkelman beam deflections using AASHO normal procedure with 3-kip wheel load and 32-kip axle load, measured at two locations in each wheelpath. Individual data, range, mean, and mat temperatures. (20-page printout)

9123–S Flexible Pavement Rut Depth Measurements, Loop 2, Post-Traffic Studies

Mean rut depth data for each wheelpath of each section. (Folders, 7-page printout)

9126–S Flexible Pavement Transverse Profiles, Loop 2, Post-Traffic Studies

Rod and level measurements of transverse profiles for flexible pavements, at 12 locations at 1-ft intervals. (Folders, 6-page printout)

9150–S Flexible Pavement Dynamic Deflections, Loop 6, Tire Pressure-Tire Design, Post-Traffic Studies

Total, embankment, and subbase deflections for each combination of axle load, tire pressure, tire size, and cord type. Each deflection value is mean of at least four readings at controlled transverse placement. (Folders, tapes, 14-page printout)

9151–S Flexible Pavement Dynamic Deflection Studies, Loop 2, Post-Traffic Studies

Total, embankment, and subbase deflections for various combinations of axle load, tire pressure, and tire size. Each value is mean of at least four readings at controlled transverse placement. (Folders, 1-page printout)

9152–S Flexible Pavement Dynamic Deflections, Loop 6, Commercial Construction Equipment, Post-Traffic Studies

Total, embankment, and subbase deflections for various combinations of axle load, tire pressure, and vehicle speed. Each value is mean of six field readings at controlled transverse placement. (Folders, 2-page printout)

9153–S Flexible Pavement Dynamic Deflections, Loop 6, Special Suspension Post-Traffic Studies

Total, embankment, and subbase deflections for combinations of axle load and vehicle speed. Each value is mean of six readings at controlled transverse placement. (Folders, 6-page printout)

9154–S Flexible Pavement Dynamic Deflections, Loop 6, Military Vehicle Post-Traffic Studies

Total embankment and subbase deflections for all units except the HETAG and GOER. (Folders, 4-page printout)

9155–S Flexible Pavement Dynamic Deflections, Loop 6, Military Vehicle Post-Traffic Studies

Total, embankment, and subbase deflections for the HETAG and GOER units. (Folders, 3-page printout)

9156–S Flexible Pavement Drop Test, Loop 4, Breaking, Impact and Acceleration Post-Traffic Studies

Total deflections and embankment pressures for combinations of axle load, vehicle speed, and drop distance. (Folders, tapes, 10-page printout)

9165–S Flexible Pavement Embankment Pressure, Loop 4, Military Vehicle Post-Traffic Studies

Embankment pressures for combinations of axle load, vehicle speed, and longitudinal and transverse placements, HETAG and GOER units. (Folders, 38-page printout)

9166–S Flexible Pavement Embankment Pressure, Loop 4, Tire Pressure-Tire Design Post-Traffic Studies

Embankment pressures for combinations of tire pressure, tire size, cord type, vehicle speed, and placement. (Folders, 27-page printout)

9167–S Flexible Pavement Embankment Pressures, Loop 4, Military Vehicle Post-Traffic Studies

Embankment pressures for all units except the HETAG and GOER, combinations of axle load, vehicle speed, longitudinal and transverse placement. (Folders, 10-page printout)

9168–S Flexible Pavement Embankment Pressure, Loop 4, Commercial Construction Equipment, Post-Traffic Studies

Embankment pressures for combinations of axle load, tire pressure, vehicle speed, and placement. (Folders, 25-page printout)

9169–S Flexible Pavement Embankment Pressure, Loop 4, Special Suspension Systems, Post-Traffic Studies

Embankment pressures for combinations of axle load, vehicle speed, and placement. (Folder, 12-page printout)

9170–S Stiffness Measurements, Shell Oil Vibrator Post-Traffic Studies

Measurements of force ratio, dynamic stiffness, and phase angle on pavement by Shell Oil vibrator. (Folder, 38-page printout)

9171–S Velocity Measurements, Shell Oil Vibrator Post-Traffic Studies

Wave length and velocity measurements with Shell Oil vibrator. (Folders, 35-page printout)

9180–S Flexible Pavement Trench Measurements, Before and After Post-Traffic Studies, Loop 2

Moisture content, density, saturation, CBR, plate load tests, and gradations on base, subbase and embankment soil. (Folders, 3-page printout)

9181–S Flexible Pavement Trench Measurements in Failed Areas, Loop 2, Post-Traffic Studies

Moisture content, density, saturation, CBR, and plate load test on base, subbase and embankment soil in Loop 2 failed areas during post-traffic period. (Folders, 1-page printout)

9182–S Flexible Pavement Edge Sampling Measurements, Loop 2, Post-Traffic Studies

Moisture content of base and subbase; moisture content, density, and saturation on embankment soil. All measurements along edge of pavement. (Folders, 4-page printout)

9200–S Rigid Pavement Condition Survey, Loop 2, Post-Traffic Studies

Wheelpath measurements of cracking, patching, faults, corner breaks, and faults at joints. (Folders, 29-page printout)

9201–S Rigid Pavement Condition Survey History, Loop 2, Post-Traffic Studies

Section measurements of cracking, spalling, patching, faults and cracks; corner breaks and faults at joints. (Folders, 15-page printout)

9242–S Rigid Pavement Pumping Survey, Loop 2, Post-Traffic Studies

Pumping scores for Loop 2 test sections. (4-page printout)

9243–S Rigid Pavement Pumping Survey Summary, Loop 2, Post-Traffic Studies

Summation of pumping score for each section after each rain. (4-page printout)

9250–S Rigid Pavement Strains and Deflections, Loop 6, Tire Pressure-Tire Design Post-Traffic Studies

Pavement edge and slab corner strains and deflections for combinations of axle load, tire pressure, tire size, cord type and vehicle speed. (Folders, tapes, 8-page printout)

9251–S Rigid Pavement Routine Strain and Deflection Studies, Loop 2, Post-Traffic Studies

Strains and deflections at pavement edges and corners for combinations of axle load, tire pressure, tire size, and vehicle speed. (Folders, 1-page printout)

9252–S Rigid Pavement Strains and Deflections, Loop 6, Commercial Construction Equipment Post-Traffic Studies

Strains and deflections at pavement edge and corner for combinations of axle load, tire pressure, and vehicle speed. (Folders, 4-page printout)

9253–S Rigid Pavement Strains and Deflections, Loop 6, Special Suspension Systems Post-Traffic Studies

Strains and deflections at pavement edges and slab corners. (Folders, 6-page printout)

9254–S Rigid Pavement Strains and Deflections, Loop 6, Military Vehicle Post-Traffic Studies

Pavement edge and slab corner strains and deflections for all units except the HETAG and GOER. (Folders, 8-page printout)

9255–S Rigid Pavement Strains and Deflections, Loop 6, Military Vehicle Post-Traffic Studies

Pavement edge and corner strains and deflections for HETAG and GOER units. (Folders, 6-page printout)

9256–S Rigid Pavement Drop Test, Loop 6, Braking, Impact and Acceleration Post-Traffic Studies

Compression strain and deflection, tension strain for combinations of axle load, vehicle speed and drop distance. (Folders, tapes, 5-page printout)

9263–S Rigid Pavement Trench Measurements, Loop 2, Before and After Post-Traffic Studies

Moisture content, density, saturation, CBR, plate load tests, and gradations on subbase and embankment soil. (Folders, 3-page printout)

9280–S Rigid Pavement Static Rebound Deflections, Loop 2, Post-Traffic Studies

Corner and edge deflections with 6- and 32-kip axle loads at two locations on each section. (8-page printout)

9282–S Rigid Pavement Edge Sampling Measurements, Loop 2, Post-Traffic Studies

Moisture content of subbase; moisture content, density, and saturation of embankment soil. All measurements taken along pavement edge. (Folders, 2-page printout)

9298–S Rigid Pavement Overlay Condition Survey, Loop 2, Post-Traffic Studies

Wheelpath measurements of cracking, sealed areas, patching and overlay. (1-page printout)

9299–S Rigid Pavement Overlay Rut Depths, Loop 2, Post-Traffic Studies

Rut depth data for each wheelpath of each section. (Folders, 2-page printout)

9301–S Tire Pressure Studies

Calibration curves and measurement procedures associated with tire pressure equipment. For use with computing differential load from tire pressure records. (Folders)

9302–S Tire Pressure Studies

Records and procedures for determining relationships between load changes and tire pressure changes. (Folders, tapes)

9322–S Rigid and Flexible Pavement Performance, Loop 2, Post-Traffic Studies

Cracking, patching, slope variance, rut depth data, and serviceability index values for each test section. (34-page printout)

9400–S Post-Traffic Bridge Study, Tire Pressure-Tire Design Index, Series 0

Stresses computed from measured strains using modulus of elasticity for steel. (Folders, tapes, 20-page printout)

9401–S Post-Traffic Bridge Studies, Tire Pressure-Tire Design Effects, Series 1

Continuation of Data System 9400. (21-page printout)

9402–S Post-Traffic Bridge Studies, Tire Pressure-Tire Design Effects, Summary

Mean values of stresses and deflections by vehicle speeds and vehicle numbers. (10-page printout)

9410–S Post-Traffic Bridge Studies, Special Suspension System with Concentric Loading, Series 0

Stresses computed from measured strains using the modulus of elasticity for steel. (Folders, tapes, 26-page printout)

9411–S Post-Traffic Bridge Studies, Commercial Construction Equipment with Concentric Loading, Series 1

Continuation of Data System 9410. (26-page printout)

9412–S Post-Traffic Bridge Studies, Military Vehicle with Special Suspension System and Concentric Loading, Series 2

Continuation of Data System 9410. (26-page printout)

9413–S Post-Traffic Bridge Studies, Military Vehicle with Concentric Loading, Series 3

Continuation of Data System 9410. (26-page printout)

9414–S Post-Traffic Bridge Studies, HETAG Vehicle with Concentric Loading, Series 4

Continuation of Data System 9410. (26-page printout)

9420–S Post-Traffic Bridge Studies, Commercial Construction Equipment, Dynamic Load Effects on Slab, Series 0

Stresses computed from measured strains. (Folders, tapes, 6-page printout)

9421–S Post-Traffic Bridge Studies, Military Vehicle, Dynamic Load Effect on Slab, Series 1

Continuation of Data System 9420. (6-page printout)

9422–S Post-Traffic Bridge Studies, Commercial Construction Equipment, Dynamic Load Effects on Slab, Series 2

Continuation of Data System 9420. (6-page printout)

9430–S Post-Traffic Bridge Study, Drop Tests, Series 0

Measurements by drop tests of beam stresses and deflections at two locations, off and on bridge. (Folders, tapes, 2-page printout)

9440–S Post-Traffic Bridge Studies, Brake Tests, Series 1

Measurements by break test of bridge beam stresses. Brakes applied when vehicle on test span. (Folder, tapes, 1-page printout)

# Appendix J

## REGIONAL ADVISORY COMMITTEES

These committees were appointed by the Highway Research Board to maintain liaison between the state highway departments and the research project, through the National Advisory Committee. Three members of each Regional Committee were appointed to the National Advisory Committee.

### *Region 1*

F. M. Auer, Planning and Economics Engineer, New Hampshire Department of Public Works and Highways

E. B. Bly, Engineering Assistant to Commissioner, Vermont Department of Highways

T. V. Bohner, Special Assistant, Engineering Department, D. C. Department of Highways and Traffic

W. M. Creamer, Chief, Highway Staff Services, Connecticut State Highway Department

F. W. Hauck, Supervising Civil Engineer (Road Designing), Rhode Island Department of Public Works

C. D. Jensen, Director of Research and Testing, Pennsylvania Department of Highways

G. W. McAlpin, Assistant Deputy Chief Engineer (Research), New York State Department of Public Works

J. F. McGovern, Structures Maintenance Engineer, Massachusetts Department of Public Works

L. W. Novinger, Contract and Design Engineer, Delaware State Highway Department

V. A. Savage, Engineer of Primary Highways, Maine State Highway Commission

W. Van Breemen, Research Engineer, New Jersey State Highway Department

The following were members of the Region 1 Advisory Committee during the years indicated:

H. F. Clemmer, formerly *Chairman;* Consultant, D. C. Department of Highways and Traffic (1956-1960)

R. A. Farley, formerly Deputy Secretary, Engineering, Pennsylvania Department of Highways (1956-1958)

W. C. Hopkins, Deputy Chief Engineer, Maryland State Roads Commission (1956-1961)

F. S. Poorman, Deputy Secretary, Engineering, Pennsylvania Department of Highways (1959)

L. K. Murphy, formerly Construction Engineer, Primary Highways, Maine State Highway Commission (1955-1959)

### *Region 2*

T. E. Shelburne, *Chairman,* Director of Research, Virginia Department of Highways

W. F. Abercrombie, Engineer of Materials and Tests, Georgia State Highway Department

T. L. Bransford, Engineer of Research and In-Service Training, Florida State Road Department

L. D. Hicks, Chief Soils Engineer, North Carolina State Highway and Public Works Commission

G. W. McAlpin, Director, Program Office, and Assistant Chief Engineer, West Virginia State Road Commission

J. D. McMahan, Construction Engineer, South Carolina State Highway Department

A. O. Neiser, Assistant State Highway Engineer, Kentucky Department of Highways

T. W. Parish, Assistant Chief Engineer (Construction), Louisiana Department of Highways

R. S. Patton, Engineer of Surveys and Designs, Tennessee Department of Highways and Public Works

Angel (2) Silva, Director, Puerto Rico Department of Public Works

H. O. Thompson, Testing Engineer, Mississippi State Highway Department

J. F. Tribble, Materials and Research Engineer, Alabama State Highway Department

E. L. Wales, Engineer of Materials and Tests, Arkansas State Highway Commission

The following was a member of the Region 2 Advisory Committee during the years indicated:

J. L. Land, formerly Chief Engineer, Bureau of Materials and Tests, Alabama State Highway Department (1956)

## *Region 3*

W. E. Chastain, Sr., *Chairman,* Engineer of Physical Research, Illinois Division of Highways

J. G. Butter, Consultant, Iowa State Highway Commission

E. A. Finney, Director, Research Laboratory, Michigan State Highway Department

R. A. Helmer, Research Engineer, Oklahoma State Highway Department

J. W. Hossack, State Engineer, Nebraska Department of Roads

C. P. Jorgensen, Manager, Research and Planning, South Dakota State Highway Commission

H. E. Marshall, Research Engineer, Ohio Department of Highways

R. L. Peyton, Assistant State Highway Engineer, State Highway Commission of Kansas

J. S. Piltz, Engineer of Design, Wisconsin State Highway Commission

C. K. Preus, Materials and Research Engineer, Minnesota Department of Highways

F. V. Reagel, Engineer of Special Assignments, Missouri State Highway Commission

W. T. Spencer, Soils Engineer, Indiana State Highway Department

W. A. Wise, Director, Field Division, North Dakota State Highway Department

The following were members of the Region 3 Advisory Committee during the years indicated:

L. N. Ress, formerly State Engineer, Nebraska Department of Roads (1956-1958)

H. G. Schlitt, formerly Deputy State Engineer, Nebraska Department of Roads (1959)

C. W. Allen, formerly Research Engineer, Ohio Department of Highways (1956-1958)

J. H. Swanberg, Chief Engineer, Minnesota Department of Highways (1956-1958)

## *Region 4*

R. E. Livingston, *Chairman,* Planning and Research Engineer, Colorado Department of Highways

J. R. Bromley, Superintendent and Chief Engineer, Wyoming State Highway Department

L. F. Erickson, Assistant Construction Engineer, Idaho Department of Highways

L. B. Fox, Construction Engineer, Montana State Highway Commission

T. S. Huff, Chief Engineer of Highway Design, Texas State Highway Department

F. N. Hveem, Materials and Research Engineer, California Division of Highways

C. W. Johnson, Materials and Testing Engineer, New Mexico State Highway Commission

D. F. Larsen, Chief Materials Engineer, Utah State Road Commission

C. E. Minor, Materials and Research Engineer, Washington Department of Highways

W. G. O'Harra, Materials Engineer, Arizona Highway Department

W. M. Wachter, Highway Engineer, Hawaii Division of Highways

W. O. Wright, State Highway Engineer, Nevada Department of Highways

The following were members of the Region 4 Advisory Committee during the years indicated:

W. T. Holcomb, formerly Assistant State Highway Engineer, Nevada Department of Highways (1956-1959)

I. B. Miller, Operations Engineer, New Mexico State Highway Commission (1956-1958)

B. E. Nutter, formerly Territorial Highway Engineer, Hawaii Territorial Highway Department (1956-1958)

S. B. Sanders, formerly District Engineer, Montana State Highway Commission (1956-1958)

W. C. Williams, State Highway Engineer, Oregon State Highway Commission (1956-1961) (deceased)

# ADVISORY PANELS

These panels were among those appointed by the Highway Research Board to advise and assist the Board and its project staff on matters related to the pavement research. A complete listing of panels is given in AASHO Road Test Report 1 (Special Report 61A).

## Instrumentation

This panel advised on available means for measuring physical phenomena and reviewed the work of the instrumentation systems contractors.

R. C. Hopkins, *Chairman,* Chief, Instrumentation Branch, Bureau of Public Roads
M. P. Cornelius, Electrical Research Engineer, International Harvester Company
D. J. DeMichele, Mechanical Engineering Laboratory, General Electric Company
G. M. Rassweiler, Assistant Head of Physics and Laboratory Division, General Motors Corporation
R. E. Wendt, Jr., Manager, Advanced Manufacturing Techniques, Westinghouse Electric Corporation

## Maintenance

This panel advised on pavement maintenance techniques and formulated criteria for specific types of maintenance.

R. C. Boyd, *Chairman,* Maintenance Engineer, Iowa State Highway Commission
B. W. Davis, Maintenance Engineer, North Carolina State Highway and Public Works Commission
H. E. Diers, Engineer of Maintenance, Illinois Division of Highways
Otto Hess, Engineer-Manager, Kent County, Michigan, Road Commission
G. G. Love, Maintenance Engineer, Massachusetts Department of Public Works
S. E. Ridge, Construction and Maintenance Division, Bureau of Public Roads
J. L. Stackhouse, Maintenance Engineer, Washington Department of Highways

## Performance Rating

This panel advised and aided the staff in the development of a system for rating the performance of the test sections.

T. E. Shelburne, *Chairman,* Director of Highway Investigation and Research, Virginia Department of Highways
H. E. Diers, Engineer of Maintenance, Illinois Division of Highways
A. E. Johnson, Executive Secretary, American Association of State Highway Officials
M. S. Kersten, Professor of Civil Engineering, University of Minnesota
W. J. Liddle, Chief, Highway Engineering Sections, Bureau of Public Roads
R. A. Lill, Chief, Highway Engineering Section, American Trucking Associations, Inc.
R. E. Livingston, Planning and Research Engineer, Colorado Department of Highways
L. C. Lundstrom, Director, General Motors Proving Ground, Automobile Manufacturers Association
R. L. Peyton, Assistant State Highway Engineer, State Highway Commission of Kansas
W. Van Breemen, Research Engineer, New Jersey State Highway Department

The following served as members of this panel during the years indicated:

R. C. Boyd, Maintenance Engineer, Iowa State Highway Commission (Resigned 1959)
A. A. Anderson, Chief Highway Consultant, Portland Cement Association (1956-1960)
J. M. Griffith, Engineer of Research, The Asphalt Institute (1956- Resigned March 31, 1961)

## Statistical

This panel advised on matters relating to experiment design and data analysis.

C. F. Kossack, *Chairman,* Research Staff Member in Charge of Statistics and Operations Research, IBM Corporation

K. A. Brownlee, Associate Professor of Statistics, University of Chicago

W. J. Youden, Applied Mathematics Division, National Bureau of Standards

## Data Analysis

This panel advised on matters relating to the analyses of the AASHO Road Test data and presentation of findings.

M. S. Kersten, *Chairman,* Professor of Civil Engineering, University of Minnesota

W. E. Chastail, Sr., Engineer of Physical Research, Illinois Division of Highways

R. E. Fadum, Head, Civil Engineering Department, North Carolina State College

M. E. Harr, School of Civil Engineering, Purdue University

E. H. Holmes, Assistant Commissioner for Research, Bureau of Public Roads

T. S. Huff, Chief Engineer of Highway Design, Texas Highway Department

F. N. Hveem, Materials and Research Engineer, California Division of Highways

L. C. Lundstrom, Director, General Motors Proving Ground, Automobile Manufacturers Association

R. J. Paquette, Georgia Institute of Technology

R. L. Peyton, Assistant State Highway Engineer, Kansas State Highway Commission

T. E. Shelburne, Director, Highway Investigation and Research, Virginia Department of Highways

C. B. Tompkins, Institute for Defense Analyses, Princeton University

W. J. Youden, Applied Mathematics Division, National Bureau of Standards

# SPECIAL PUBLICATIONS SUBCOMMITTEE FOR ROAD TEST REPORT 5, PAVEMENT RESEARCH

This subcommittee was appointed by the Highway Research Board to advise the staff in the preparation of AASHO Road Test Report 5, "Pavement Research," and recommend approval of the report for publication.

E. H. Holmes, *Chairman,* Assistant Commissioner for Research, Bureau of Public Roads

W. E. Chastain, Sr., Engineer of Physical Research, Illinois Division of Highways

Sidney Goldin, Petroleum Industry; Assistant to Marketing Vice-President, Shell Oil Company

M. S. Kersten, Professor of Civil Engineering, University of Minnesota

C. F. Kossack, Research Staff Member in Charge of Statistics and Operations Research, IBM Corporation

George Langsner, Chairman, AASHO Committee on Design; Assistant State Highway Engineer, California Division of Highways

R. A. Lill, Chief, Highway Engineering, American Trucking Associations

R. E. Livingston, Planning and Research Engineer, Colorado Department of Highways

L. C. Lundstrom, Director, General Motors Proving Ground, Automobile Manufacturers Association

G. W. McAlpin, Assistant Deputy Chief Engineer (Research), New York Department of Public Works

T. E. Shelburne, Director, Highway Investigation and Research, Virginia Department of Highways

E. A. Finney, Director, Research Laboratory, Michigan State Highway Department

D. K. Chacey, Director of Transportation Engineering, Office of the Chief of Transportation, Department of the Army

W. Van Breemen, Research Engineer, New Jersey State Highway Department

# PROJECT PERSONNEL

## Staff During Research Phase

W. B. McKendrick, Jr., Project Director
W. N. Carey, Jr., Chief Engineer for Research
Peter Talovich, Business Administrator
  L. A. Ptak, Accountant
  R. S. Semple, Purchasing Assistant
A. C. Tosetti, Assistant to the Project Director
  W. R. Milligan, Assistant Operations Manager
  D. L. Thorp [1], Shop Superintendent
A. C. Benkelman, Flexible Pavement Research Engineer
  L. E. Dixon, Assistant Flexible Pavement Research Engineer
  H. M. Schmitt, Assistant Flexible Pavement Research Engineer
F. H. Scrivner, Rigid Pavement Research Engineer
  W. R. Hudson, Assistant Rigid Pavement Research Engineer
  R. J. Little, Assistant Rigid Pavement Research Engineer
I. M. Viest, Bridge Research Engineer
  J. W. Fisher, Assistant Bridge Research Engineer
P. E. Irick, Chief, Data Processing and Analysis
  R. C. Hain, Assistant Chief, Data Processing and Analysis
J. F. Shook, Materials Engineer
D. R. Schwartz, Engineer of Reports
  H. R. Hubbell, Assistant Engineer of Reports
H. H. Boswell, Maintenance Engineer
  James Gardner, Maintenance Superintendent
R. C. Leathers, Engineer of Special Assignments
H. C. Huckins, Instrumentation Supervisor
W. J. Schmidt, Chief, Public Information

*Other Engineering Personnel*

O. B. Andersland
T. W. DeVries
E. L. Skok, Jr.
H. Y. Fang
R. K. Williamson
J. F. Reynolds

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[1] H. H. Cole (1958)

## Illinois Division of Highways

## Permanent Task Force During Research Phase

The Illinois Division of Highways established a permanent task force for the project in 1955. The first function of this group was to prepare plans and specifications for construction. Later the group assumed responsibility for construction inspection and direction. With the exception of W. E. Chastain, Sr., the members of the Task Force were absorbed by the research units during the research phase. They resumed their identity as an agency of the Illinois Division of Highways in 1961 when detailed planning for the rehabilitation of the test site was undertaken.

W. E. Chastain, Sr., Engineer of Physical Research
A. C. Tosetti, Assistant to the Project Director
D. R. Schwartz, Assigned to the Research Staff
H. R. Hubbell, Assigned to the Research Staff
R. J. Little, Assigned to the Research Staff
A. J. Wright, Assigned to the Research Staff
L. E. Dixon, Assigned to the Research Staff
D. W. Ballinger, Assigned to the Research Staff
T. E. Hagerman, Assigned to the Research Staff

## U. S. Army Transportation Corps Road Test Support Activity

The AASHO Road Test Support unit furnished truck drivers for all of the test vehicles for the entire traffic phase and during the special studies period following the main traffic test.

| *Commanding Officer* | *Deputy Commander* |
|---|---|
| Col. A. A. Wilson (1958-59) | Maj. W. A. Duncan (1958-60) |
| Lt. Col. R. J. Lombard (1959-61) | Capt. R. G. Farwell (1960-61) |

*Company Commander*

Capt. R. D. Smith (1958-59)

## Resident Staff Consultants and Observers

R. I. Kingham, Canadian Good Roads Association

G. D. Campbell, Canadian Good Roads Association (1956-1957)

B. E. Colley, Portland Cement Association (1956-1960)

F. N. Finn, The Asphalt Institute (1956-1960)

S. M. King, American Trucking Associations (1957-1961)

R. A. Lill, American Trucking Associations (1955-1957)

W. E. Teske, Portland Cement Association (1957-1961)

G. A. Wrong, Province of Ontario, Canada (1958-1959)

## Temporary Personnel

The following engineers were assigned to the project by the Bureau of Public Roads for periods of about six months each. They were assigned to the various branches, where they served in important engineering and technical capacities.

### Materials Branch

E. G. Yemington
J. P. Clark
G. R. Brooks
W. S. Dunbar
H. Marshall
A. R. Cowan
Daniel Dake
G. L. Green
R. L. Lacy
J. R. Bishop
W. H. Bray

### Construction Branch

W. A. Eager
J. C. Becker
T. J. Chipera
R. H. Jones
D. B. Lewis
Donald Jacobsen
Claude Manaton
V. W. Segelke
C. H. Snow
Rothe Davis
G. K. Hossner
G. D. Gibson
R. D. Gingrich
R. C. Kay

### Flexible Pavement Research Branch

R. H. Hogrefe
E. E. Biggs
C. C. Berge
O. M. Stump
W. K. Perry
P. M. Jorgensen
D. K. Phillips
R. G. Shutt
D. C. McConnon
H. Kusumoto
Dallas Vestal
G. S. Katayama

### Bridge Research Branch

J. W. Schmidt
G. N. Lind
V. Buchele
D. C. Briggs
G. C. Hoxie
R. A. Richter
G. W. Million
L. R. Cayes
J. L. Budwig
C. F. Galambos
N. C. Mueller
W. T. Medley
D. J. Philbrick
K. D. Jaeger
J. H. Hatton
R. E. Stanford
N. W. Loeffler

### Rigid Pavement Research Branch

R. W. Hayman
T. E. Difloe
C. W. Friesen
Stewart Spelman
L. L. Humphrey
R. D. Morgan
T. O. Willett
D. W. Briggs
L. P. Lamm
W. G. White
D. G. Ross
W. S. Mendenhall, Jr.
A. R. Montgomery
G. E. Price
D. E. Carlson

### Data Analysis Branch

R. A. Lawrie
R. E. McGuire
R. E. Gish
Robert Talley
R. H. Gausman
R. B. Puckett
J. S. Bowers
D. C. Lewis
N. L. Arthur
N. J. Van Ness

### Maintenance Branch

C. A. Ballinger

### Public Information Branch

R. A. Van de Meulebrocke
D. F. Berwick
H. H. Ridgeway
T. H. Lavender
P. E. Cunningham

### Operations Branch

K. B. Casey
J. S. Wesley
R. L. Diffenderfer

## Photography

Still photography was done by Frank W. Bazzoni of the staff. His work was augmented by and all motion picture photography and the production of motion pictures relating to the project were done by Bureau of Public Roads photographers Roy B. Dame, T. Welby Kines, George Crum, and Charles Ritter.

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THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY-COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.

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