ATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **2A**

GUIDELINES FOR SATELLITE STUDIES OF PAVEMENT PERFORMANCE

GHWAY RESEARCH BOARD NATIONAL ACADEMY OF SCIENCES - NATIONAL RESEARCH COUNCIL

HIGHWAY RESEARCH BOARD 1964

Officers

WILBUR S. SMITH, *Chairman*
DONALD S. BERRY, *First Vice Chairman*
J. B. MCMORRAN, *Second Vice Chairman*
D. GRANT MICKLE, *Executive Director*
W. N. CAREY, JR., *Deputy Executive Director*
FRED BURGGRAF, *Consultant*

Executive Committee

REX M. WHITTON, *Federal Highway Administrator, Bureau of Public Roads* (ex officio)
A. E. JOHNSON, *Executive Secretary, American Association of State Highway Officials* (ex officio)
LOUIS JORDAN, *Executive Secretary, Division of Engineering and Industrial Research, National Research Council* (ex officio)
R. R. BARTELSMEYER, *Vice President, H. W. Lochner & Co., Chicago* (ex officio, Past Chairman 1962)
C. D. CURTISS, *Special Assistant to the Executive Vice President, American Road Builders' Association* (ex officio, Past Chairman 1963)
E. W. BAUMAN, *Managing Director, National Slag Association*
DONALD S. BERRY, *Chairman, Department of Civil Engineering, Northwestern University*
W. A. BUGGE, *Parsons Brinckerhoff-Tudor-Bechtel, San Francisco*
MASON A. BUTCHER, *County Manager, Montgomery County, Md.*
J. DOUGLAS CARROLL, JR., *Deputy Director, Tri-State Transportation Committee, New York City*
HARMER E. DAVIS, *Director, Institute of Transportation and Traffic Engineering, University of California*
DUKE W. DUNBAR, *Attorney General of Colorado*
JOHN T. HOWARD, *Head, Department of City and Regional Planning, Massachusetts Institute of Technology*
PYKE JOHNSON, *Retired*
LOUIS C. LUNDSTROM, *Director, General Motors Proving Grounds*
BURTON W. MARSH, *Executive Director, Foundation for Traffic Safety, American Automobile Association*
OSCAR T. MARZKE, *Vice President, Fundamental Research, U. S. Steel Corporation*
J. B. MCMORRAN, *Superintendent of Public Works, New York State Department of Public Works*
CLIFFORD F. RASSWEILER, *Vice President for Research, Development and Engineering, Johns-Manville Corporation*
M. L. SHADBURN, *State Highway Engineer, Georgia State Highway Department*
T. E. SHELBURNE, *Director of Research, Virginia Department of Highways*
WILBUR S. SMITH, *Wilbur Smith and Associates, New Haven, Conn.*
JOHN H. SWANBERG, *Chief Engineer, Minnesota Department of Highways*
EDWARD G. WETZEL, *The Port of New York Authority, New York City*
K. B. WOODS, *Head, School of Civil Engineering, and Director, Joint Highway Research Project, Purdue University*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Advisory Committee

T. E. SHELBURNE, *Virginia Department of Highways*
A. E. JOHNSON, *American Association of State Highway Officials*
FRANCIS C. TURNER, *Bureau of Public Roads*
BRUCE E. FOSTER, *National Bureau of Standards*
ALGER F. MALO, *City of Detroit*
R. L. PEYTON, *State Highway Commission of Kansas*
THOMAS J. SEBURN, *Yale University*
E. A. WHITEHURST, *University of Tennessee*

Advisory Panel on Design—Pavements

R. L. PEYTON, *State Highway Commission of Kansas*
W. F. ABERCROMBIE, *State Highway Department of Georgia*
HAROLD ALLEN, *Bureau of Public Roads*
G. BRYCE BENNETT, *Idaho Department of Highways*
M. E. HARR, *Purdue University*
A. W. JOHNSON, *Highway Research Board*
LOUIS C. LUNDSTROM, *General Motors Proving Ground*
GEORGE W. MCALPIN, *New York State Department of Public Works*
F. H. SCRIVNER, *Texas A & M University*
T. E. SHELBURNE, *Virginia Department of Highways*
F. N. WRAY, *Highway Research Board*
E. J. YODER, *Purdue University*

Program Staff

M. EARL CAMPBELL, *Program Engineer*
W. A. GOODWIN, *Assistant Program Engineer*
E. A. MUELLER, *Assistant Program Engineer*
EARLE W. JACKSON, *Editor*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 2A

GUIDELINES FOR SATELLITE STUDIES OF PAVEMENT PERFORMANCE

BY PAUL E. IRICK, PRINCIPAL INVESTIGATOR, AND
W. RONALD HUDSON, RESEARCH ASSISTANT
HIGHWAY RESEARCH BOARD

PROJECT 1-1 ADVISORY COMMITTEE

JAMES H. HAVENS, Kentucky Department of Highways, Chairman
VIRGIL L. ANDERSON, Purdue University
ROBERT F. BAKER, U. S. Bureau of Public Roads
W. E. CHASTAIN, Sr., Illinois Division of Highways (deceased)
FRANK H. SCRIVNER, Texas A and M University

HIGHWAY RESEARCH BOARD OF THE DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
NATIONAL ACADEMY OF SCIENCES - NATIONAL RESEARCH COUNCIL 1964

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs the highway administrators of the American Association of State Highway Officials initiated in 1962, an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by Highway Planning and Research funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Commerce.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, non-profit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

This report is one of a series of reports issuing from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of an effectual dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

NCHRP Project 1-1, FY '63

FOREWORD

By Staff
Highway Research Board

In recent years considerable effort has been devoted to the development of rational procedures of pavement design. One approach has been through research on large-scale road tests. Although several such tests have been conducted, the most recent and comprehensive was the AASHO Road Test at Ottawa, Illinois. All of these have been principally devoted to studying pavement design and its relationship to performance. They have involved investigations into the influence of designs, loads, materials, and climatic conditions. The results of these tests are applicable only to conditions comparable to those existing at the road test sites.

In order to achieve widespread utility for the research findings from the AASHO Road Test, it is necessary to translate them into local conditions. This may be done by small-scale road tests which can be considered as satellites to the one conducted at Ottawa. Studies for the translation may be made either on existing pavements or on newly constructed pavements. For the studies to be meaningful, guidelines are required to provide for uniform research studies so that comparisons may be made. Although individual studies may be conducted within states, it is also desirable to have related studies conducted regionally and on a nationwide basis.

This research project was undertaken to provide such guidelines. The final report contains principles and rules that can be used to design selected pavement sections and relate their behavior to similarly designed sections on the AASHO Road Test. In addition, the guidelines provide a basis for merging data of individual studies with data collected in the overall program. The paramount purpose of these guidelines is to provide means for translation of the Road Test findings to local conditions. They should also aid, however, in evolving design theories useful to all states.

The guidelines present a method of studying the interrelationships of performance variables and design variables. Three types of design variables are discussed: the structural variable which describes the strength characteristics of pavement layers, the load variable reported in terms of accumulated axle loads, and the climatic or regional variable which describes external influences. Performance variables are discussed in terms of surface behavior and include deformation and deterioration.

Report 2, "An Introduction to Guidelines," gives a brief, informative discussion of Report 2A, "Guidelines for Satellite Studies of Pavement Performance," and provides the perspective for this more technical treatise. The introduction discusses desired minimum basic measurements for satellite test installations and contains a statistical design for one typical test installation. Report 2A contains concepts, terminology and specific guides for experiment design, measurement programs and data processing. Illustrative studies are given for existing pavements and new experimental pavements. The appendices contain details about structural, load, climatic, and performance variables to be measured throughout the satellite studies, noting types of tests and measurements to be taken. Illustrations for a number of procedures for developing performance equations are given along with the performance index variables for all AASHO Road Test sections. The guidelines contain guides rather than "recipes" for the conduct of particular projects. They provide specific recommendations for coordination of satellite studies with one another and with the AASHO Road Test, yet maintain a flexibility in selection of pavement type and design in satellite installations.

Report 2A is provided in loose leaf Xerox format to allow for up-dating as experience gained in the future indicates needed modifications and additions.

This project is one of several relating to the extension of Road Test findings.

Other studies include the determination of factors influencing pavement performance regionally and locally, and an investigation into the extension of the AASHO Road Test performance concepts. A study is also under way to develop a prototype measurement team for obtaining standard measurements on the satellite program. It is expected that these research studies will ultimately provide a better knowledge and understanding of pavement design and a further utilization of the major findings of the AASHO Road Test.

The highway engineer will find these guides particularly useful in setting up individual studies whether they are on existing pavements or new experimental pavements. He will be able to include his studies in a nationwide program whereby an overall coordination and analysis is provided.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Tables (Cont.)

CHAPTER 1

Background and Purpose of the Guidelines

Since 1950 there have been three large-scale road tests in the United States, the most recent and comprehensive of which was the AASHO Road Test at Ottawa, Illinois[1]. All these tests were devoted to the study of pavement behavior as controlled and repeated loadings were applied to various pavement designs. While loads and pavement thicknesses were varied over a wide range in the AASHO Road Test, the findings related specifically only to the soil and pavement materials, construction procedures, climatic conditions, and loading conditions that existed in the test.

In order to learn how generally applicable are these findings, and to determine what modifications are necessary for extending the findings to different materials, procedures, climate, and loading, a series of pavement performance studies--satellite to the AASHO Road Test--is envisioned for the coming years. The satellite research program will cover two major types of studies: existing pavement studies in which the pavement units are selected highway sections that existed before the research began; and field tests in which new sections are constructed to introduce controls and variations for factors that cannot be suitably observed in existing pavements.

While individual satellite studies may be sponsored by particular states, or by two or more neighboring states that may decide to combine their satellite research efforts, the Highway Research Board, within the National Cooperative Highway Research Program, has established a series of interrelated research projects to help coordinate the satellite program. These projects are in Area 1 of the NCHRP, and the first such project, called NCHRP Project 1-1, involves the preparation of guidelines for translating AASHO Road Test findings to local conditions through satellite studies of both existing pavements and new experimental pavements. Other projects in Area 1 involve techniques for measurement of serviceability and other pavement features, the identification of factors that influence pavement performance, and a study of pavement design in terms of fundamental relationships.

---

[1] Findings of the AASHO Road Test pavement research are given in Highway Research Board Special Report 61E.

The guidelines required of Project 1-1 have two purposes:

(1) To set out principles and rules that can be used to define and observe pavement units in satellite studies, and to present procedures for relating the observations to the AASHO Road Test findings.

(2) To provide bases for data from individual studies to become part of an overall pattern of related observations that are pertinent to the testing of hypotheses and theories of pavement design.

Thus the first purpose is concerned with ways by which Road Test findings may be extended to local conditions. The second purpose is concerned with the substantiation and evolution of pavement design theories on a nationwide basis. If the guidelines fulfill these purposes and if the guidelines are implemented by satellite studies which encompass a wide range of conditions, it can be expected that information from the studies will lead to widely applicable pavement design and performance relationships.

While the guidelines reflect many of the considerations and procedures that existed at the AASHO Road Test, considerable effort has been made to incorporate concepts and information derived from existing outlines and recommendations and from many discussions with highway researchers who are directly or indirectly concerned with the satellite studies. Reports of the Highway Research Board Committees on flexible, rigid and composite pavement design, AASHO Interim Guides for the design of rigid and flexible pavements, and plans of existing and proposed satellite projects have all been very useful in the preparation of the present guidelines. Additional guidance has been obtained from highway engineers in all parts of the United States and from the Highway Research Board Advisory Committee for NCHRP Project 1-1.

CHAPTER 2

Rationale for the Guidelines

It is assumed that the primary objective of any satellite study is to investigate the dependency of pavement performance upon pavement design variables for wider conditions than prevailed in the AASHO Road Test. Other objectives are assumed to be the study of interrelationships among performance variables or among design variables.

A general basis for the study of one pavement type, e.g., flexible or rigid pavement, is outlined in Table 1. Three types of design variables are shown: TAB 1

(1) Structural variables which describe the strength characteristics of pavement layers and roadbed material[1], the thicknesses of pavement layers, other design features, and the overall or composite strength of the pavement.

(2) Load variables in terms of accumulated axle loads, the number of years over which the accumulation has taken place, and the general rate of axle load accumulation. Load applications will ordinarily be expressed as equivalent 18,000-lb axle loads.

(3) Climatic and regional variables which describe external influences other than load, which can lead to performance differences among test sections that have the same load and initial structural conditions. Measures of relative strength and regional factors are included for the indirect evaluation of these influences.

Performance variables are shown in terms of surface behavior. These variables include individual manifestations of surface deformation and deterioration as well as a present serviceability index which combines certain of the individual elements of surface behavior into a variable that is related to user judgment of the current level of the pavements' ability to serve traffic. An index of performance is assumed to be given by the number of equivalent axle load applications that a test section carries before its present serviceability is at a specified relatively low value.

---

[1] See "AASHO Highway Definitions", 1962. Roadbed material includes all soils or other materials that are below the pavement structure and affect the supporting power of the pavement structure.

TABLE 1: GENERAL BASIS FOR STUDIES OF ONE PAVEMENT TYPE

DESIGN VARIABLES	
Structural Pavement Structure Surface Courses Base Courses (if any) Subbase Courses (if any) Roadbed Material	Strength Characteristics Thicknesses of Pavement Courses Other Design Features Composite Strength
Load	Accumulated Axle Loads Years of Service Rate of Accumulation
Climatic and Regional	Conditions of Precipitation, Moisture, Temperature and Frost Topography Relative Strength in different climates Regional Factors
PERFORMANCE VARIABLES	
Surface Behavior	Deformation and Deterioration Present Serviceability Performance

Note: See Appendix E for glossary of terms

To have a more explicit basis for the guidelines, concepts and terminology for the variables shown in Table 1 are developed in Chapter 3. After discussing the relative advantages of existing or new pavement studies, the remainder of the guidelines is concerned with recommendations and illustrations for four activities that follow the establishment of objectives for any satellite study:

(1) Development of experiment designs which specify design variable levels for the test sections to be used in the study.

(2) Selection or construction of test sections.

(3) Measurement programs for the evaluation of design and performance variables.

(4) Data processing and analysis procedures for the study of relationships among variables.

These activities are discussed for both existing and new pavement studies, and for either type study, discussion is devoted to both individual (e.g., within-state) studies and nationwide cooperative studies.

For an individual study of existing pavements of a particular type, the experiment designs may involve tens or perhaps hundreds of test sections, and a certain number of these are expected to be part of a nationwide design that involves over two hundred sections.

Individual studies of new experimental pavements will ordinarily involve less than twenty sections at any test site, and perhaps four or more of these will fit into a nationwide pattern that involves over one hundred sections.

The guidelines assume that regional or national measurement teams will be formed to produce a minimal set of "common denominator" measurements across all satellite projects. These teams would be equipped, trained and calibrated to give standardization and continuity to a coordinated measurement program that might span many years of observation. It is recognized that measurement programs in individual projects will often go beyond that undertaken by the measurement teams. It is assumed that an individual project will have representation on the measurement team when project test sections are being measured by the team. General guides are given for the evaluation of variables implied by Table 1.

Procedures given for data processing and analysis pay particular attention to ways by which AASHO Road Test relationships might be modified or extended. It is recognized that there are many alternatives to the procedures described and that alternative analyses are vital to the further understanding of pavement performance. While the guidelines do not actually include analytical procedures for testing existing pavement theories, it is intended that experiment designs and measurement programs provide adequate data for the testing of virtually any pavement design hypothesis or theory.

Numerical illustrations are given in the last chapter of the guidelines. Reference and supplemental information is given in several appendixes, the last of which is a glossary of terms and symbols that are used throughout the guidelines.

CHAPTER 3

Concepts and Terminology

The aim of this chapter is to provide notation and definitions for terms and concepts that are used throughout later chapters. In general, the concepts and terms apply to studies of either existing or new experimental pavements.

3.1 Design Variables

All those variables which describe structural, load, and environmental factors are considered to be design variables. It is not the intent of the guidelines to discuss the large number of variables that could be listed, but rather to concentrate on those which are considered to be most relevant and practical for the satellite research program. In particular satellite projects in some areas attention will often be given to variables not discussed in the guidelines.

3.1.1 Structural Variables

Study units in the satellite studies are suitably long test sections one traffic lane in width. Since pavement structures contain two or more traffic lanes, more than one study unit can be selected from a given length of pavement. Test section length will be discussed in Section 4.2. Terminology for test section structure is indicated in Figure 1 which shows that the FIG 1
section is defined to include its roadbed material and successive courses of subbase, base and surfacing materials. Any course may have more than one layer; and in some pavement types, the base and/or subbase course may be absent. All layers above the roadbed material have definite thicknesses denoted by h_1 for surfacing thickness, h_2 for base thickness, and h_3 for subbase thickness. Whenever it is necessary to distinguish among layers in the same course, a second subscript will be used. For example,

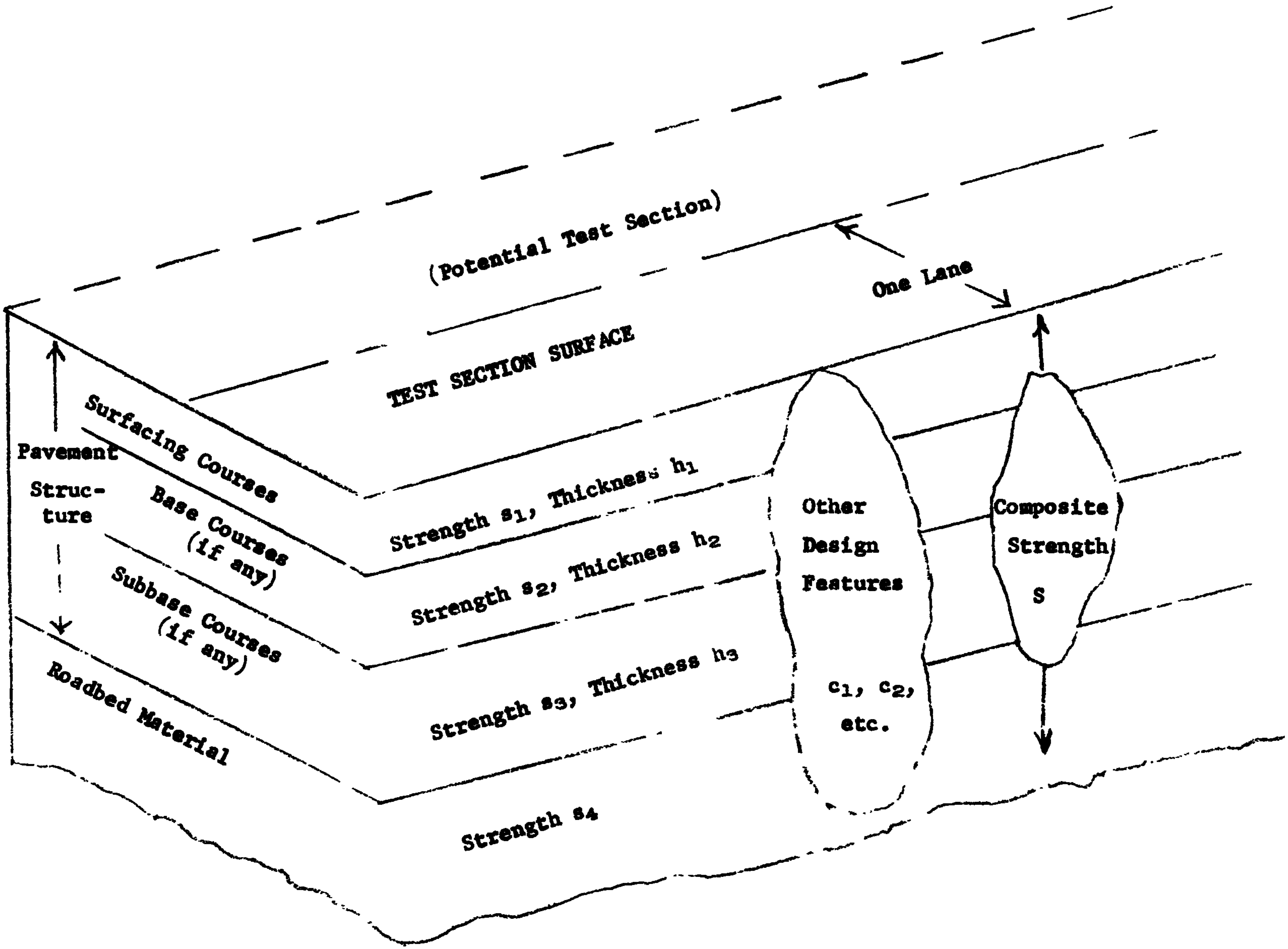


Figure 1: Terms and notation for structural variables

h_{11} and h_{12} would be used to represent the respective thicknesses of surface mix and binder mix in a two layer asphaltic concrete surfacing course.

The term strength will be used as a generic term to connote the engineering properties of any layer. The symbols s_1, s_2, s_3, and s_4 represent the respective strengths of surfacing, base, subbase, and roadbed materials--with the possibility that double subscripts may be needed if more than one layer is involved. It is recognized that several basic properties may be involved in any s and that a particular test or measurement may only partially reflect one or more basic properties. Measurement programs for s_1, s_2, s_3 and s_4 are discussed in Section 4.3.1 and in Appendix A.

Major considerations for measurements to represent s_1, etc., are that:

(a) initial strengths and strength changes can be estimated.

(b) strengths are relatable to those of corresponding materials used in AASHO Road Test sections.

It is convenient to introduce the term composite strength, denoted by S, for the resistance of the overall pavement system to a single load application. Indicators for S might include surface or subsurface strains or deflections, for example.

Factors or variables which reflect controlled variations in other design features will be denoted by c_1, c_2, etc., where the subscripts do not necessarily apply to a particular pavement layer. For example, c_1, might refer to joint spacing in the surfacing course of a rigid pavement, or to the difference between a trench section and a full width section of flexible pavement.

Depending upon the objectives of a particular study, the factors c_1, c_2, etc., can be viewed either as control factors in the study or as a basis for separating pavement types. For example, one project might separate plain concrete from continuously reinforced concrete in separate experiment designs for the two pavement types. In another study, however, the reinforcing factor might be used as a controlled variable within a single experiment as at the AASHO Road Test.

All structural variables are subject to variations from point to point within a test section, or from one time to another at a particular point. Moreover, strength characteristics can be evaluated under both laboratory and field conditions. Guideline context, rather than symbols, will be used to distinguish among these various situations.

3.1.2 Load Variables

A complete description of the load experience for a test section would include many variables such as lateral placement, speed, spacings among axles and vehicles, loaded areas, etc. Minimal information on the load experience of any test section is assumed to include estimates of the number of axle loads that pass over the section each year in each of several (perhaps broad) weight classes. Programs for obtaining load data are discussed in Section 4.3.2 and in Appendix B. It is recommended that the load data be represented by the variables

ΣL = the accumulated number of equivalent 18,000-lb single axle loads from the time of construction to the date of observation.

Y = years of service

$ADL = \Sigma L/365Y$ = average daily equivalent loads to date

A major result of the AASHO Road Test was the determination of performance equivalencies among a large variety of axle loads, both single and tandem. Equivalency factors thus derived are given in Appendix B for flexible and rigid type pavements and make it possible to calculate ΣL by accumulating the products of factors and observed axle loads. For example, the axles shown in Figure 2 might convert to 3.2 equivalent 18-kip axle loads. FIG 2

The variables Y and ADL will be used as a basis for experiment designs in Chapter 4, serving to distinguish between pavements that accumulate the same number of axle loads but over quite different periods of time.

It is recognized that ADL is not indicative of the steady increase of daily loads that most pavements experience nor of the seasonal load variations that may be highly important when coupled with seasonal variations in environmental factors. Special experiment designs and measurement programs may be required to investigate the latter situation.

3.1.3 Climatic and Regional Variables

In addition to the structural and load variables which have been discussed, there are other variables whose general effect on pavement performance is different from one geographical region to another. If, for example, two duplicate sets of test sections were to be located throughout two well-defined regions, then any average difference in performance between the two sets of sections would be a regional effect--where it is assumed that the duplication covers load variables and initial conditions for all structural variables. The situation just described will be approximated in certain satellite studies where a major objective is to obtain a regional factor, RF, as an indicator of average regional effect. If the sections in a satellite study region are structurally comparable to a set of AASHO Road Test sections and if the loading can be compared, then RF for the region will be defined to be

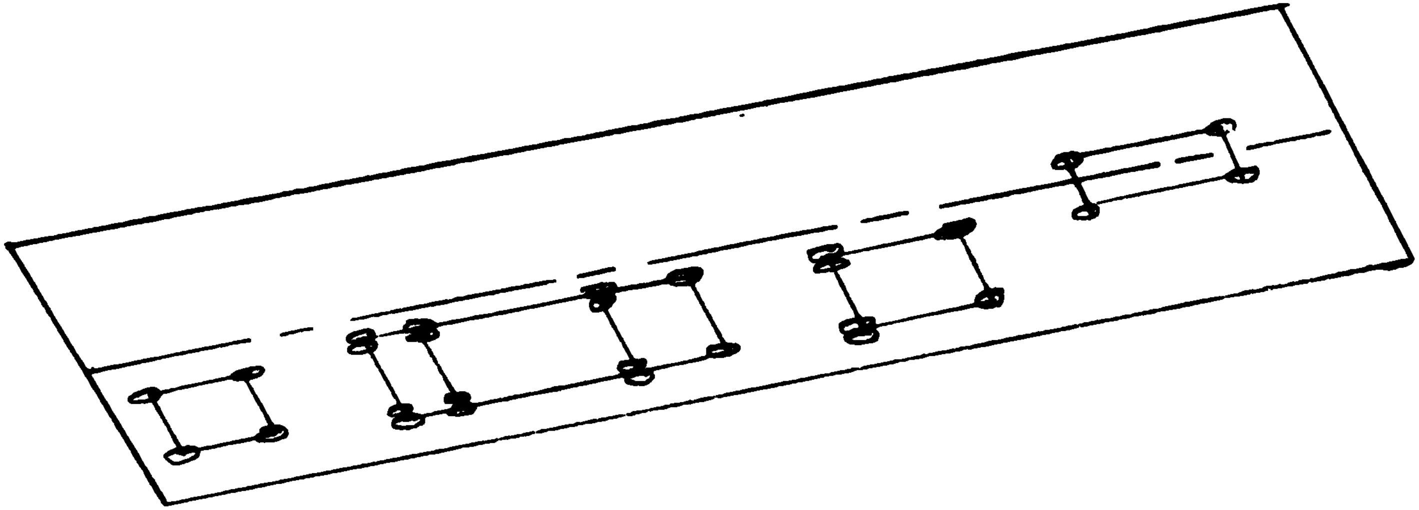


Figure 2: Test section loads

the difference between the average performance index (to be defined later) of satellite sections and corresponding AASHO Road Test sections. Thus RF = 0 for any set of AASHO Road Test sections, and is positive (or negative) for regions wherein section performance is better than (or worse than) that of corresponding Road Test sections.

It is assumed that regional effects on performance are largely the reflection of different component and composite strength changes from initial conditions. Thus in one region the changes from initial strengths may be quite different than in another region. If strengths undergo seasonal changes, then there may be a regional difference in the degree of seasonal change. It is supposed that the most relevant variables for explaining strength changes which are environmentally induced are those which represent climatic conditions.

Direct evaluation of climatic conditions will include measurements of precipitation, temperature, freezing and thawing, and variations (daily, monthly, seasonal, etc.) of these variables. Climatic variables will be denoted by v_1, v_2, v_3, etc.

In the nationwide satellite studies it is expected that certain test sections will be essentially alike with respect to initial structural conditions and load experience, but will be subjected to quite different climatic condition. For these sections it is proposed that climatic and other regional effects be quantified by an index of relative composite strength, RS. For example, surface deflections of flexible pavements having similar durability characteristics can be used as indicators of their composite strength. Then the ratio of deflections (under a given load) taken on the same test sections under two different climatic conditions will indicate the relative strength of the section for the two conditions.

To have a reference point for climatic and regional variables, it is recommended that AASHO Road Test conditions in the fall months of 1958-1960 be used, and that relative strength indexes be defined as unity for these conditions. For more favorable conditions, e.g., completely frozen subsurface materials, the relative strength will be greater than one and for extremely unfavorable conditions RS may approach zero. For the Road Test flexible pavements, surface deflections were generally doubled ($RS = {}^1/2$) during spring thaw conditions, and were reduced to one tenth or less (RS = 10 or more) of the reference values during frozen conditions.

Both RF and RS are indirect indicators of regional and climatic variables, the first in terms of geographical regions only and the second in terms of strength changes that may be induced by these variables between or within geographical regions. It is expected that the satellite research will provide a means for relating both indicators to the observed variations in v_1, v_2, v_3, etc. If v_1 is the fraction of spring thaw already passed[1], for example, it can be shown that RS for AASHO Road Test flexible pavements is highly associated with v_1.

---

[1] Painter, L.J. "Analysis of AASHO Road Test Asphalt Pavement Data by the Asphalt Institute." Highway Research Board 43rd Annual Meeting, Washington, D. C., January 1964.

3.2 Performance Variables

All structural variables discussed in section 3.1.1 represented subsurface conditions in terms of strengths, thicknesses, and construction practices. Variables to be discussed in this topic will be called performance variables and represent surface conditions that can:

(a) affect the degree to which the pavement serves its users, and

(b) be attributed to structural, load and environmental factors.

3.2.1 Surface Deformation and Deterioration

The basic performance variables are deformations and deteriorations which represent undesirable changes in the pavement surface. Deformations include longitudinal and lateral variations from desired pavement profiles in terms of rutting, faulting, waviness, bumps or sags, or other elevation changes. Surface deterioration implies visible loss of pavement continuity in terms of undesirable openings at cracks or joints, patching, spalling scaling, ravelling, etc. The many measures of surface deformation and deterioration will be denoted by x_1, x_2, x_3, etc. Recommendations for the measurement of performance variables are discussed in Section 4.3.4 and in Appendix D.

3.2.2 Present Serviceability

While any one of the surface conditions discussed in section 3.2.1 might be used as a basic indicator of pavement performance, it is recognized that all these conditions may affect the degree to which the pavement serves traffic. For this reason, a present serviceability index was developed at the AASHO Road Test[1] (for each pavement type) so that measurements of the surface variables could be related to a present serviceability scale which ranges

---

[1] See HRB Special Report 61E, Appendix F

from zero (very poor) to five (very good). After a panel of raters had provided an average (user) rating for the serviceability of a large number of pavement sections, surface measurements were combined by a formula that could satisfactorily reproduce the ratings. As shown in Appendix 4, the serviceability index formulas require measurements of transverse and longitudinal distortion along with measures of cracking and patching[1].

As is the case with any of the surface measurements that enter the formula, the present serviceability index applies only to conditions at the time of measurement and does not indicate the past or future performance of the pavement. If serviceability index values of a test section are plotted against accumulated loads at successive points in time, however, the resulting graphs represent performance records for the section. Different structures, load rates, and climates or regions may thus produce different performance records. If these differences are satisfactorily explained by the design variables, then serviceability and performance are predictable from specified conditions. In other words, serviceability can be related to structure, load, and climate or region. A practical use of such a relationship involves the specification that serviceability should remain above a stated level until a given number of loads have been accumulated. Then for a given environment in which the pavement is to be placed, the relationship should yield a range of structural possibilities that will match the given conditions of serviceability, load, and environment.

The symbol p will be used for the present serviceability of a test section. Initial serviceability will be denoted by p_o.

---

[1] Certain refinements and extensions of these indexes are expected to result from research being done in NCHRP Project 1-2.

3.2.3 Performance

The complete performance record of a test section is described by its present serviceability values plotted against corresponding values of accumulated equivalent 18 kip axle loads, $\Sigma\bar{L}$. Experience with the present serviceability index has shown that most new pavements have serviceability index values in the range from 4 to 5 (very good) and that an average terminal serviceability level[1] is about half the initial level, between 2.0 and 2.5 (fair). While no particular performance index was specified at the AASHO Road Test, the pavement research report discussed performance in terms of the number of axle load applications at which a test section's serviceability was either 2.5 or 1,5. In order to introduce a common performance index for the satellite studies it is proposed that a performance index, P, be defined as the logarithm of the number of equivalent 18,000-lb axle loads that correspond to serviceability of 2.5. Thus a test section that had an initial serviceability index of 4.4, and whose serviceability index had reached 2.5 after one million equivalent 18,000-lb axle load applications, would have a performance index of 6.0, the logarithm of one million.

It is to be noted that the definition of the performance index does not imply that p = 2.5 is a terminal serviceability value since the latter can be either above or below 2.5, depending upon the type of highway involved as well as other circumstances. It is considered important, however, to define the performance index in terms of a serviceability value that represents a drop of at least 1.0 from the initial value, p_0. In the cases where serviceability loss has occurred but p is not yet 2.5, then

---

[1] Rogers, C.F., Cashell, H.D. and Irick, P.E., "Nationwide Survey of Pavement Terminal Serviceability", 42nd Annual Meeting of the Highway Research Board, January 1963, Washington, D.C.

it is assumed that P can be estimated by extrapolation methods to be discussed in Section 4.4. For reference purposes, Appendix D gives performance index values for every AASHO Road Test section. It will be seen that the observed performance index values of the test sections ranged from about 2 to 7, that is, from about one hundred to ten million equivalent 18,000-lb single axle load applications. Estimates of "ultimate life" for any highway pavement rarely exceed fifty million equivalent 18,000-lb applications, and this estimate corresponds to a performance index value of about 7.7.

3.3 Relationships Among Variables

Relationships among variables may be expressed in terms of single comparisons, tables, graphs or equations that are developed from the observed data. It is assumed that virtually all relationships to be developed in the satellite program are found among:

(a) relationships between one performance variable and one or more design variables, including the important case of performance vs. indicators of composite strength such as strains or deflections.

(b) relationships between one design variable and one or more other design variables.

(c) relationships between one performance variable and one or more other performance variables.

These three types of relationships will be discussed in terms of Table 2 which is a re-arrangement of Table 1, expanded TAB to include notation that has been introduced.

3.3.1 Performance Variables vs. Design Variables

The relationship between any variable on the left and one or more variables on the right side[1] of Table 2 is an association between a measure of pavement perform-

---

[1] An exception is that P is not to be related to ΣL since the definition of P is actually in terms of accumulated loads.

TABLE 2: GENERAL BASIS FOR RELATIONSHIPS AMONG VARIABLES FOR ONE PAVEMENT TYPE

PERFORMANCE VARIABLES	DESIGN VARIABLES	
Measures of Surface Deformation and Deterioration	Structural	
	Thicknesses	h_1, h_2, h_3
	Strength Characteristics	s_1, s_2, s_3, s_4
x_1, x_2, x_3, etc.	Other Design Features	c_1, c_2, c_3, etc.
	Composite Strength	S
Present Serviceability Index		
	Load and Time	ΣL, ADL, Y
$p \; (x_1, x_2, x_3$, etc.)		
	Climatic or Regional	
Performance Index	Climatic Variables	$v_1, v_2, v_3, \ldots$
	Relative Strength	RS
$P \; (p_o, \Sigma L$ when $p = 2.5)$	Regional Factor	RF

Note: Variables outside parentheses are defined by variables inside the parentheses.

ance and pavement design variables. The development of any such relationship must necessarily represent either empirical studies or tests of hypotheses since theories have not yet been evolved for performance variables as given in Table 2.

At the AASHO Road Test, emphasis was placed on empirical relationships between serviceability index (or x_1 = cracking, etc.) and various design variables. In the main flexible pavement experiments, h_1, h_2, h_3, ΣL, and a measure of relative strength were used to develop relationships in the form of equations (see Appendix 4). For the special base studies in flexible pavements, s_2 was an important variable in graphical relationships. In rigid pavement studies the relationships involved h_1, h_3, c_1 (reinforcement factor) and ΣL.

The extension and modification of all these relationships to cover more design variables and wider ranges is considered to be a major objective for the satellite research program.

Another important relationship is the association of P with S, that is, the association between an overall performance index and an indicator of composite strength, where the latter represents initial structural conditions or perhaps weakest structural conditions (over seasonal variations). At the AASHO Road Test such relationships were in the form of number of applications to $p = 2.5$ or $p = 1.5$ versus fall and spring deflections for flexible pavements or initial strains and deflections for rigid pavements. To the extent that these relationships give strong associations between P and indicators of S, the latter become useful predictors of pavement performance. Another reason for the study of P vs. S is that virtually all pavement theories lead to predictions of S, so the P vs. S relationships can form a link between theory and ultimate performance.

Among the many other relationships in this class are associations between individual x's (e.g., cracking) and strengths measured at various times during the life of the pavement.

3.3.2 Relationships Among Performance Variables

Perhaps the most important relationships in this class are those which are used to associate present serviceability with surface conditions x_1, x_2, x_3, etc. These serviceability index formulas show how individual surface manifestations affect the index of "user satisfaction".

Interrelationships among x's are also of interest. For example, the association between measures of roughness and extent of cracking can be investigated.

3.3.3 Relationships Among Design Variables

Interrelationships among variables on the right side of Table 2 are important because they can describe the structural system at a point in time--or describe structural changes between two points in time. For example, if deflection produced by a single load is used as an indicator of composite strength, S, then a number of theories exist for relating this measure of S to the corresponding values for component strengths and thicknesses. Moreover, if any of the component strengths are altered through environmental changes, the theories will indicate the extent to which S will change.

Other relationships among design variables may involve pavement response to dynamic loads for specified structural conditions. It is assumed throughout the guidelines that experiment designs and measurement programs for satellite studies should provide data that are required for checking existing theories for interrelationships among design variables when the pavement is subjected to static and dynamic loads. It can be hoped that these relationships will be extended to account for pavement performance when the structure is subjected to a complex ensemble of load and environmental forces over many years of service.

CHAPTER 4

Guides for Satellite Studies

In this chapter the terms and concepts of Chapter 3 will be used in presenting guides for experiment designs, measurement programs and data processing. The exact nature of these activities in a particular satellite project must depend upon specific objectives that may vary considerably from project to project. In view of this fact, most of the guides are directed at the general objective of relating pavement performance to pavement design variables, an objective which is assumed to be common to all satellite studies.

4.1 Classification of Studies

As implied by the title of the guidelines, satellite projects are of two general types, those in which test sections are selected from existing highways and those in which sections are new pavements constructed to be part of the satellite research program.

A special case of the existing pavement studies might be called a record study of existing pavements as opposed to the more general field study. In some states, for example, it may be that data files already contain adequate information on behavior, loads, environment and structure--at least for certain highway sections. In such a case, the data have already been acquired and the satellite research can proceed from this point.

Field tests of new experimental sections will ordinarily involve controlled variations in pavement design factors, such as thickness variations or variations in strength of materials that are used.

A special type of field test, however, may consist of the selection of test sections from a newly constructed pavement which does not include the same roadbed or aggregate materials over its entire length. In this case it may be possible to select test sections whose performance differences, if any, can be attributed to measured differences in the characteristics of the structural materials. Still another possibility is to add a relatively small number of special study sections at the end of regular construction that is underway.

In a sense, every section in the highway system can be regarded as candidate for satellite program research, but one purpose of the guidelines is to suggest how essential information can be obtained through the study of relatively few sections and test sites. There should be a planned sequence of investigation in any state proposing to carry out satellite research, usually beginning with a study of existing pavements. If rather firm pavement design procedures exist in a given state, these procedures may already reflect what is known about the behavior of existing pavements--in terms of their performance for different loads, environmental, and structural conditions. In other states, however, it may be advantageous to perform studies of existing pavements in order to obtain new data that can be more directly useful in extending AASHO Road Test findings to local conditions. A major advantage of an existing pavement study is that a wide range of load and performance can be studied at the outset--as opposed to many years that may be required for the complete observation of new pavements.

There are several inherent difficulties associated with using only existing pavements. In the first place it may be virtually impossible to find suitable sections of pavement to represent local variations that can be used either to support or to modify the performance relationships that were developed at the Road Test. For example, it might be desirable to see whether the effect of surfacing thickness on performance is similar to the Road Test results, but if there is little or no variation in surfacing thickness in the whole system of pavements within a state, no such effect can be studied. It is rather clear that a number of relationships developed at the Road Test cannot be completely checked or translated by existing pavement studies--mainly because certain Road Test structural conditions are not existent in the local highway system.

It may be quite difficult to obtain reliable traffic and load data for existing pavement sections. Since performance is defined in terms of accumulated loads, adequate load histories are quite essential to the study of performance.

Another problem is the determination of initial serviceability and strength conditions for an existing pavement. Although laboratory tests of currently existing materials can indicate present and potential strengths, there may be no clear estimate of the extent to which the initial strengths have changed.

Another difficulty that will be encountered in the study of existing pavements is that any nominal conditions of loading, environment, or structure will likely be accompanied by a rather long list of variables (e.g., construction variations) whose separate effects cannot be identified. Thus any reliable analysis may require the average performance of rather large numbers of sections having the same nominal characteristics.

Several obvious advantages are inherent in studies of new experimental pavements. The objectives for such a study can set out very specific relationships to be studied with the precision that is built into the experiment design and construction control for the test sections involved. Thus it is likely that experimental sections will be more adequately identified than existing pavement sections and that less extraneous variation will be connected with the study. As a result, it may be expected that, with fewer test sections, answers to specific questions will be more definitive than can be determined from existing pavement studies.

Another major advantage to satellite research with new experimental test sections is that interesting factors not appearing in existing pavements can be introduced. Outstanding examples in structural design include the increasing practice of base stabilization or the interest in composite pavement design.

As with the AASHO Road Test itself, every experimental study is surrounded by limitations. One disadvantage of a new pavement performance experiment is that years may be required to observe the ultimate performance of test sections--especially for those sections that are over-designed relative to their expected traffic and environmental experience. If the structural variables of the experimental sections are all at high levels, and cover a very narrow range, then the differential effects of experimental factors on performance may not be observable for perhaps ten years or more and, in fact, may not be of any practical significance. In all studies, however, it will be possible to analyze section to section variations in composite strength.

In summary it is assumed that there are good reasons, as well as disadvantages, for conducting studies of both existing pavements and new pavements; and that the first type of research will usually precede and suggest the general nature of new pavement studies that should be made. Moreover, the results of tests on new pavements will often uncover questions that can be studied in existing pavements, e.g., the AASHO Road Test itself.

4.2 Experiment Designs

The concept of an experiment design can best be explained in geometrical terms. If all conceivable structural, load, and environmental variables were to be shown in a single coordinate system, with one axis for each variable, then each test section in any study would have a set of coordinate values and would therefore fall at some point in the coordinate system. An experiment design for a set of test sections is a plan that specifies how the test sections are to be positioned in this coordinate system.

Test sections should be positioned on design variable axes so that it will be possible to observe the linear and curvilinear performance effects of each design variable as well as interacting effects of any two design variables.

A very simple case is shown in Figure 3 where one axis is for roadbed strength and the other for overall pavement thickness. Both axes are subdivided into three intervals--for low, medium and high levels of the two factors. Thus there are nine positions for test sections in the coordinate system, LL for low thickness and low strength, ML for medium thickness and low strength, etc. If only positions HL, MM and LH were used in the experiment design then the effects of the two factors would be confounded or unseparable. This is because one factor decreases when the other increases and there is no way to tell whether changing (or constant) performance is due to one or the other or both of the variables. It is noteworthy that such situations will be difficult to avoid in existing pavement studies since pavement design procedures generally call for more thickness over weaker roadbed material. If positions ML, MM and MH are used it will be possible to observe linear and curvilinear effects of roadbed strength at medium thickness but there will be no way to observe whether these effects are the same at all thickness levels, i.e., whether or not the two factors have interacting effects. If all nine positions are used, the study is a complete factorial experiment in which any level of one factor occurs at all levels of the other factor. Such a design will produce the linear and curvilinear effects of each variable and possible interacting effects of the two variables.

Variations of this type of design will be recommended for the satellite studies.

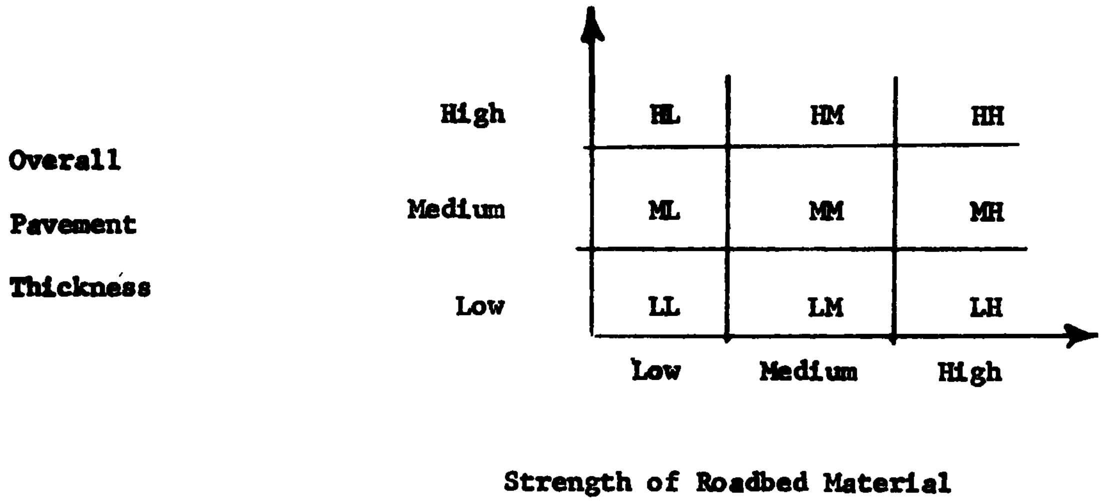


Figure 3: Coordinate region for two design variables

A number of interrelated steps are involved in the development of an experiment design for a satellite study of existing or new experimental pavements.

(1) **Definition of One-Level Factors and Ground Rules**

Many variables will ordinarily be controlled at one level, or within a single range of variation, for all test sections in the study. These variables should be named and their levels given in "ground rules" for the selection of existing pavement sections or in construction control specifications for new pavements. In an existing pavement study, for example, it might be specified that all sections must be at least five years old. In a new pavement study it might be specified that the roadbed material in all sections be compacted to within five percent of a well defined density standard.

The following "ground rules" are recommended for the satellite studies:

(a) Test section length should be in the neighborhood of 1200 feet for existing pavement studies and 600 feet for new pavement studies.

(b) Test sections should not contain transitions between cuts and fills. Unless cut and fill is a factor being studied, no section should be located in deep cuts or on high fills.

(c) In order to provide uniformity and to preclude difficult working conditions, test sections should not be influenced by vertical or horizontal curves nor by drainage structures.

(d) There should be no qualitative changes in structural variables (including roadbed materials) throughout the section and quantitative changes should be random with a coefficient of variation[1] not greater than twenty-five percent. This rule includes variations in strength, density, moisture content, and thicknesses of structural components.

(e) Adjacent test sections should be separated by sufficient distance to provide for their independent behavior. AASHO Road Test experience indicated that there should be a minimum of forty feet transition between successive test sections.

(f) Traffic data evaluation prior to the selection of existing pavement sections should provide reason to believe that accumulated equivalent axles can be estimated with no more than twenty-five percent uncertainty.

(g) Maintenance of test sections should not be such as to change the structural characteristics (e.g., overlay) as long as the section is considered to be "in test". Seal coats, crack seals, and patches (up to ten percent of the test section area) are permissible on the assumption that all such maintenance will be of high quality. Records should be kept of all maintenance performed on test sections. (See Appendix A)

---

[1] The coefficient of variation of a set of measurements is their standard deviation divided by their arithmetic mean, expressed as a percent. It is a conventional measure of variation (relative to the mean) that is not controlled in the experiment.

(2) Selection of Multi-Level Factors

The second step is to name all variables that will be controlled at more than one level among the study sections, and to state the number of levels to be associated with each such variable. For example, surfacing thickness might be selected for variation at two levels and roadbed strength might be selected as a four-level factor in the study.

Zero is a permissible level for certain variables. For example, base thickness might be controlled at two levels, zero (no base) and six inches.

(3) Selection of Combinations of Levels

After multi-level factors and the number of levels for each have been stated, it is necessary to select those combinations of levels which are to appear in the study. For the example given in step 2 there are 2 x 4 = 8 possible combinations of surfacing thickness and roadbed strength. It must be decided which of these are to be used, and in what combinations with other multi-level factors.

Three general patterns are proposed for experiment designs in satellite studies. All three are based on principles of factorial experimentation[1].

(a) Complete Factorial Experiments

If all possible combinations of the selected factor levels occur, the study is a complete factorial experiment. If a study were to involve surfacing thickness at two levels, base strength at three levels, and roadbed strength at four levels, then 2 x 3 x 4 = 24 test sections would be required

---

[1] For a comprehensive treatment of these principles see, for example, Chapters 7 - 11 of Design and Analysis of Industrial Experiments, Davies, O.L. (Editor), Oliver and Boyd, London, 1954 (also Hafner, New York).

for the complete factorial experiment. In many cases complete factorial experiments involve only two or three levels for any experimental factor. Table 3A shows a TAB 3 2 x 2 x 2 x 3 x 3 = 2^3 x 3^2 factorial experiment with five factors. Two-level variables are shown at low and high levels, while three-level variables are shown at low, medium, and high levels.

Only two levels are needed to study the linear effects of a factor, but three levels are required to study curvilinear effects. If the linear (or curvilinear) effects of one factor are not the same at all levels of a second factor, there is said to be an interacting effect of the two factors. In a complete factorial experiment it is possible to study the interactions of all combinations of factors.

(b) Fractional Factorial Experiments

It is often very useful to select only a fraction of the total number of combinations required for a complete factorial experiment--especially if the latter involves a large number of test sections and if the only pertinent interaction effects are among the factors taken two at a time. Table 3B shows, for example, how a 2^6 = 64 complete factorial experiment containing six two-level factors can be separated into four quarters (Sets A,B,C and D) of sixteen sections each. Any quarter of the complete experiment, say Set A, can be used to determine the main effects of the six factors as well as certain two factor interaction effects. It will be found that the Set A sections are balanced

TABLE 3: ILLUSTRATIVE EXPERIMENT DESIGNS

A. Complete $2^3 \times 3^2$ Factorial Design

Variables			V_1	Lo			Med			Hi		
V_5	V_4	V_3	V_2	Lo	Med	Hi	Lo	Med	Hi	Lo	Med	Hi
Lo	Lo	Lo		x	x	x	x	x	x	x	x	x
		Hi		x	x	x	x	x	x	x	x	x
	Hi	Lo		x	x	x	x	x	x	x	x	x
		Hi		x	x	x	x	x	x	x	x	x
Hi	Lo	Lo		x	x	x	x	x	x	x	x	x
		Hi		x	x	x	x	x	x	x	x	x
	Hi	Lo		x	x	x	x	x	x	x	x	x
		Hi		x	x	x	x	x	x	x	x	x

B. Four Fractions of a 2^6 Complete Factorial Design

Variables			V_1	Lo				Hi			
			V_2	Lo		Hi		Lo		Hi	
V_6	V_5	V_4	V_3	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi
Lo	Lo	Lo		A	C	C	A	B	D	D	B
		Hi		D	B	B	D	C	A	A	C
	Hi	Lo		B	D	D	B	A	C	C	A
		Hi		C	A	A	C	D	B	B	D
Hi	Lo	Lo		D	B	B	D	C	A	A	C
		Hi		A	C	C	A	B	D	D	B
	Hi	Lo		C	A	A	C	D	B	B	D
		Hi		B	D	D	B	A	C	C	A

Note:

Each of sets A,B,C or D is a balanced quarter of the full factorial experiment.

C. Four Factor Composite Design (z = 1.22)

Variables		V_1	Lo			Med			Hi		
V_4	V_3	V_2	Lo	Med	Hi	Lo	Med	Hi	Lo	Med	Hi
Lo	Lo		x		x				x		x
	Med						y				
	Hi		x		x				x		x
Med	Lo						y				
	Med			y		y	0	y		y	
	Hi						y				
Hi	Lo		x		x				x		x
	Med						y				
	Hi		x		x				x		x

Note:

Factorial sections x form a 2^4 factorial. Centroid section 0 is at the medium level of all factors. Extension sections y are at medium levels of all but one factor, and are extended z times as far as regular levels from the centroid.

with respect to every factor, there being eight sections at the low level and eight sections at the high level of each factor. It is also possible to separate the 64 sections of Table 3B into balanced halves or eighths. Tables are available[1] for the fractionation of many types of factorial experiments when it is desired to study a relatively large number of factors with relatively few experimental units.

(c) Composite Experiment Designs

When a number of factors, say k, are to be studied at three levels it is possible to select a fraction of the complete 3^k experiment, but it is often more economical to use a so-called composite experiment design (not to be confused with a composite pavement design). In a composite experiment design all k factors are run at two levels to give 2^k units or some fraction of this number, then additional units are provided for each factor that is to be studied at three levels. Table 3C is an illustrative composite design that involves k = 4 factors. The $2^4 = 16$ sections marked x form a complete factorial experiment at the low and high levels of all factors. Each factor is also assigned a medium level (between low and high) an "extra low" level and an "extra high" level. The section having medium levels for all factors is called the centroid section of the design, denoted by a circle in Table 3C. For each factor the "extra low" and

---

[1] Fractional Factorial Experiment Designs for Factors at Two Levels, Three Levels, Two and Three Levels--National Bureau of Standards, Applied Mathematics Series.

"extra high" levels provide two sections (denoted by y in Table 3C) that are at medium levels on all other factors. Thus for each factor there are three sections, two at extended levels and one at the centroid, which are used for observing the factor's curvilinear effect. Altogether there are $2^k + 2k + 1 = 25$ section, of which $2^k = 16$ form a factorial experiment, and $2k = 8$ provide sections for three-level effects through the centroid section. To study all curvilinear and interacting effects of four variables in a complete factorial experiment, $3^4 = 81$ sections would be required.[1]

The composite design with fractional replication will be proposed for the nationwide satellite studies.

(4) Definition of Levels

Each factor level that appears in steps 1 and 3 must be defined to the point that there is no ambiguity in the selection of an existing pavement section or the construction of a new section. Some factors may have qualitative levels, others may have specific numerical levels and others may have levels which are relatively broad intervals. For example, surface reinforcement might be present or absent, surface thickness might be four or six inches, and roadbed strength might be 2-6, 6-15, 15-30 and over 30 on some strength scale. Levels for strength characteristics may be obtained indirectly. For example, the strength levels of a subbase course may be regulated to a certain degree by specifying various gradations and qualities for the materials to be used at the different strength levels.

---

[1] Although the composite design gives information on curvilinear effects with far fewer test sections than a complete factorial experiment, it must be recognized that the curvilinear effects are all obtained at medium levels of the remaining factors. Thus the composite design cannot show curvilinear effects of one variable at high or low levels of the remaining variables. It must be supposed, therefore, that sufficient information on curvilineanty is obtained at the medium levels. It is also true that estimates of curvilinear effects are obtained with less precision than in a complete factorial experiment.

(5) Provision for Uncontrolled Design Variables

All design variables that are not explicitly named in the previous steps are uncontrolled. If the uncontrolled variables are not inextricably correlated with the controlled variables, then randomization procedures can "spread out" uncontrolled effects over all test sections so that controlled effects will not be biased. The specific nature of randomization procedures to be used will depend upon the pattern that has been selected in step 3.

To measure the extent of uncontrolled variation it is necessary to include some form of replication. In individual satellite studies it is recommended that six or more of the test sections be duplicated.

(6) Provision for Comparisons and Extensions with AASHO Road Test Findings

A satellite study should include some test sections whose structural and environmental characteristics are as close as possible to those of some AASHO Road Test sections. To the extent that this is possible the satellite study will contain sections whose performance can be compared directly with AASHO Road Test sections.

The study should provide controlled variations for at least one factor that was varied at the Road Test, e.g., subbase thickness. Thus it will be possible to compare the effects of variables in the satellite study with the corresponding effects observed at the AASHO Road Test.

In order to extend the Road Test findings the satellite study should provide controlled variations for one or more factors that were not varied in the AASHO Road Test, e.g., initial strength of roadbed material.

To provide a reference for this step, Table 4 shows the general levels and ranges of design variables for AASHO Road Test sections. TAB 4

TABLE 4: GENERAL LEVELS OF DESIGN VARIABLES FOR AASHO ROAD TEST SECTIONS[1]

STRUCTURE		Flexible							Rigid		
		Road-bed	Sub-base	Base				Sur-facing	Road-bed	Sub-base	Sur-facing
				Stone	Gravel	Bit.	Cem.				
Laboratory Characteristics											
AASHO Class		A-6							A-6		
CBR		5	58	100+					5	58	
R Value		21	78	83					21	78	
Kansas Modulus		1300	8000	10000					1300	8000	
Texas Class		5.6	3.7	2.3					5.6	3.7	
Maximum Density		116	133	138	140				116	133	
Optimum Moisture		14.7	7.7	7.6					14.7	7.7	
Marshall Stability						1600		2000			
Compressive Str. (7 day)							840				3600
Flexural Strength											620
Field Tests											
Elastic Modulus											
Plate Bearing -	Fall	120	300	600					100	140	
	Spring	80	200	400					60	80	
Shell Vibrator	Fall	1500	7500	30000				100000			
	Spring	600									
CBR	Fall	3.5	30	36					2.5	8.0	
	Spring	2.0	10	18					1.5	2.5	
Moisture Content	Fall										
	Spring										
Density	Fall										
	Spring										
Thickness Ranges	Low	Over	0	0	2	2	2	1	Over	0	2.5
	High	36	16	17	18	18	13	6	36	9	12.5

LOAD

ΣL: Accumulated 18 kip equivalent axle loads: from less than 10 for earliest failure to about 10 million for surviving sections in Loop 6

Y: Years of service: from less than one month to about two years

ADL: Daily rate of accumulation: from less than one in Loop 2 to over 10,000 in Loop 6

CLIMATE

Climatic conditions of precipitation, temperature and frost are given in Appendix C.

RS for flexible pavements from about 0.5 in spring to 1.0 in fall to over 10 in frozen periods.

---

[1] Values given in this table have been selected from HRB Special Reports 61B and 61E and should be interpreted in the light of details given in the reports.

4.2.1 Experiment Designs for Existing Pavement Studies

For a satellite study of a particular type of existing pavement it is recommended that the design variables shown in Table 2 be separated into two classes, primary controls and secondary controls. The primary controls will be multi-level factors whose combinations of levels form a complete factorial experiment. In general, it is suggested that one primary control should deal with climatic or regional classification and that one should pertain to a strength characteristic. For example, a minimal study of this nature might involve two regions, or climates, and two levels of strength of a structural component. For each of the four combinations in this 2 x 2 experiment Table 5 suggests that eight test sections be selected, TAB 5 to give a study that involves 32 pavement sections. Although this study is balanced with respect to the primary controls, it may be quite unbalanced with respect to one or more of the remaining design variables. For example, surfacing thickness might be eight inches in one region and nine inches in the other--so that surfacing thickness effects are completely confused (confounded) with regional or climatic effects. To reduce the occurrence of such confoundings it is recommended that those design variables of Table 2 that are not used for primary control be used as "balancing factors" or secondary controls. High and low levels are assigned to every secondary control in such a way that (from prior information) it should be possible to find existing pavement sections at both levels of every secondary control for every combination of the primary control levels. Then the effort can be made to select sections that will give balance on the secondary controls as well as on the primary controls. As an example, let region, initial roadbed strength and subbase thickness be three primary control factors at two, three and two levels respectively. The 2 x 3 x 2 = 12 combinations of these factors are shown at the left side of Table 6. TAB 6

TABLE 5: SUGGESTED NUMBERS OF TEST SECTIONS FOR INDIVIDUAL STUDIES OF ONE EXISTING PAVEMENT TYPE

Number of Combinations of Levels of Primary Control Factors	Number of Test Sections to be Selected per Combination	Total Number of Test Sections
4 - 9	8	32 - 72
10 - 26	4	40 - 104
27 - 81	2	54 - 162

TABLE 6: ILLUSTRATIVE EXPERIMENT DESIGN FOR AN EXISTING PAVEMENT STUDY

PRIMARY CONTROL COMBINATIONS			Secondary Controls and Number of Test Sections at Each Secondary Control Level																
Climatic factor or Region	Initial Roadbed Strength s_4	Subbase Thick-ness h_3	h_1		h_2		s_1		s_2		s_3		c_1		ADL		Y		Total Number of Sections
			Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	
Region One	Low	Low																	4
		High																	4
	Med	Low																	4
		High																	4
	High	Low																	4
		High																	4
Region Two	Low	Low																	4
		High																	4
	Med	Low																	4
		High																	4
	High	Low																	4
		High																	4
Number of Sections																			48

Note: See section 5.1, Table 20, for a numerical illustration of this type of summary.

From Table 5 it is decided to include four test sections for each of the twelve primary combinations--as shown at the right side of Table 6. All remaining design variables that are considered for secondary control are listed across the top of Table 6, and a low and high level is defined for each. The two levels of a secondary variable may not differ appreciably, but the same definition applies to all primary control combinations.

The maximum balance that can be attained by means of Table 6 will occur when every individual cell contains two test sections and when every total across the bottom of the table has 24 sections. It is supposed that test section selection will never result in this degree of balance, but that original selections will be discarded and replaced until the maximum attainable balance has been achieved.

Information sources for the selection of sections may include construction records, pavement evaluation records, traffic and load study records, and recollections of those who are most familiar with certain regions and the highways within them. As data are acquired from these sources the experiment design can progress from a tentative to a more firm basis. It may be that factors and levels will have to be revised from time to time--especially after the design variables are actually measured.

The foregoing recommendations are concerned with the first four steps previously given for the development of an experiment design. In connection with step 5 it appears that little can be done in the way of random ization except in those cases where one or two sections are to be selected from several suitable alternative sections. It is assumed that the numbers of sections given by Table 5 already provide replication with respect to the primary control factors.

For step 6 it is supposed that the primary controls include factors both for comparison with and extension of Road Test findings, and that one level of any factor has been selected to be as similar as possible to a Road Test level of the same factor.

4.2.2 Experiment Designs for Studies of New Experimental Pavements

Individual satellite studies (e.g., within-state) of new experimental pavements will ordinarily involve a relatively small number of test sections at one or more test sites. Test sites will be determined by roadbed material, climatic or regional variables and by expected rate of load applications. At each site certain pavement structure variables will be held at one level while others will be varied according to the experiment design. Recommendations for experiment designs will be given in terms of the six steps listed at the beginning of Section 4.2. The entire discussion relates to the study of one pavement type, e.g., flexible or rigid pavement.

For this discussion it will be supposed that s_4, ADL and a climatic or regional variable will be used to determine test sites. The roadbed strength factor, s_4, might be assigned either one, two or three levels (ranges of variation) and it is recommended that ADL have either one or two levels. The third factor can be either a climatic factor which is of local interest and which can be quantified in ranges of variation (e.g., mean annual rainfall or days of thawing), or it can be a regional classification as was suggested for individual studies of existing pavements. It is recommended that the climatic or regional variable have either one, two or three levels (or regions). With these recommendations, there might be only one test site (all three factors at one level) or as many as eighteen sites (3 x 2 x 3). While the choice of levels, and thus sites, will be determined largely by the local objectives, it is recommended that at least one selected site should fall within the nationwide experiment design to be described in the next topic.

At any site it is recommended that either two, three or four pavement structure variables (s_1, s_2, s_3, h_1, h_2, h_3, c_1, c_2, etc.) be chosen as multi-level variables. If more than one test site is chosen to give controlled variations on site factors, then the same pavement structure variables should be selected for each test site so that the effects of site factors can be studied in conjunction with the effects of structural variables. If different sites are used but all have the same roadbed strength, climate, and ADL, then it may be desirable to select different structural variables at different sites. For example, subbase strength might be a factor at one site but not at another. It has been recommended that at least one of the structure variables be an AASHO Road Test variable (see Table 4) and that at least one variable be one that was not varied at the Road Test. In this way the satellite study can produce data for both the modification (if needed) and extension of the Road Test findings to local conditions and variables of interest. For example, the selection of subbase thickness and strength as factors would satisfy these recommendations since h_3 was varied at the Road Test but s_3 was not.

If only two structure variables are selected as multilevel factors, it is recommended that the minimum number of levels be 2 x 3 for the two factors. For three or four factors the respective minimum number of levels should be 2 x 2 x 2 and 2 x 2 x 2 x 2, but it is recommended that not more than two factors appear at three levels. In this topic it will be assumed that more than three levels are not needed for the satisfactory study of any factor, but it is recognized that local objectives will sometimes require more than three levels for some factor. For example, there might be local interest in the comparative performance of four base materials, all with somewhat different strengths.

The foregoing recommendations can result in individual satellite studies of as few as two factors (two pavement and no site factors) or as many as seven factors (four pavement and three site factors).

Once the multi-level factors have been selected, then all other site and pavement variables are at one level. These levels, or ranges of variation, apply to every test section in the study and are needed for the complete description of the experiment.

It is supposed that the basic experiment design for an individual study of new pavements will be found within the framework of Table 7. In some cases test sections TAB 7
may fall outside this pattern, either because of special studies or because certain sections that are constructed to be part of the nationwide design do not fit the local pattern. Roadbed strength and climatic or regional variables are shown at low = L, medium = M, and high = H levels, while ADL is shown only at low and high levels across the top of Table 7. The left side of the table includes possibilities for as many as four pavement structure variables, but for only two of these at three levels.

At any site it is recommended that a full factorial experiment be used for the selected levels of pavement structure variables. When a complete factorial experiment contains as many as sixteen factor level combinations, duplication of combinations is considered optional. For smaller experiments there is more need for duplication, and if there are fewer than ten combinations it is recommended that six duplications be provided. When more than one site is used, somewhat different factorials may be used at different sites, but at least a 2 x 2 factorial on pavement structure variables should appear in common at all test sites. Thus at least four test sections will be available for evaluating the effects of site factors on performance.

TABLE 7: GENERALIZED EXPERIMENT DESIGN FOR STUDIES OF NEW EXPERIMENTAL PAVEMENTS OF ONE TYPE

PAVEMENT STRUCTURE^1				TEST SITES^2																		
				L						M						H						V_5
				L		M		H		L		M		H		L		M		H		V_6
V_4	V_3	V_2	V_1	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	V_7
L	L	L	L	F	F																	
			M	F	F						A				A		A				A	
			H	F	F						A				A		A				A	
		M	L																			
			M																			
			H																			
		H	L																			
			M								A				A		A				A	
			H								A				A		A				A	
	H	L	L	F	F																	
			M	F	F						A				A		A				A	
			H	C	F						A				A		A				A	
		M	L																			
			M																			
			H																			
		H	L	D																		
			M								A				A		A				A	
			H								A				A		A				A	
M	M	M		E																		
H	L	L	L																			
			M																			
			H	D																		
		M	L																			
			M																			
			H																			
		H	L	C																		
			M																			
			H																			
	H	L	L																			
			M																			
			H																			
		M	L																			
			M																			
			H																			
		H	L																			
			M																			
			H																			

1 Variables V_1, V_2, V_3 and V_4 selected from s_1, s_2, s_3, h_1, h_2, h_3, c_1, c_2, etc.

2 Variable V_5 is either a climatic variable or represents regional classification.
V_6 is a selected characteristic of roadbed material strength.
V_7 is anticipated ADL.

High levels of V_1 – V_4 and V_6 imply better pavement performance than low levels.
High levels of V_5 and V_7 imply lower serviceability than the low level, all else equal.

Sections A form an experiment design that is independent of any nationwide design.

One of the most critical steps is the selection of levels for pavement structure variables. As in the case of existing pavement studies, it is supposed that levels for strength characteristics should include the corresponding Road Test level (if feasible) and that strength levels should differ from one another by at least twenty-five percent on whatever strength scale is used. For example, if base strength is varied at three levels according to laboratory deformation moduli, the levels might be centered at 350, 500, and 650 psi where 500 is an AASHO Road Test level.

Once levels have been set for strength characteristics, local design criteria will ordinarily provide a set of standard thicknesses for the pavement layers, and thickness levels can be specified so that a number of sections in the factorial experiment are at or near the standard design. The remaining sections will include some which have less than standard thicknesses and some which have more. In this way it becomes possible to study thickness effects. If all thickness levels are greater than are called for by conventional design procedures, it may be difficult to show the performance effects of thickness variables.

When all thickness and strength levels have been set every pavement structure is defined, and the experiment design should call for the structures to be constructed in random order at every test site. This step reduces the risk that any variations in construction procedures or roadbed material will be confused with the intended variations in pavement structure.

Exceptions to some of the recommendations given above will occur in connection with the nationwide experiment designs. For example, if only the sections that belong to the nationwide experiment design are constructed at a test site, then it may be that only two or five sections are required (section 4.2.3), so that neither case gives a factorial experiment at the test site. On the other hand, if the nationwide design test sections are constructed, it is always possible to complete a factorial experiment that contains one or more of these sections. Although more examples will be described in Chapter 5, Table 7 shows two illustrations for individual studies, the second of which includes sections that fall within the nationwide experiment design.

In the first example of Table 7, eight test sections designated by the letter A appear at each of four test sites. Two of the sites are in one region (or at medium climatic conditions) while the other two are in a second region (or at high climatic conditions). At either level of V_5 both low and high roadbed strengths, V_6, are included, and all four sites are shown to be at high levels for ADL = V_7.

It can be seen that the experiment design includes M and H levels for V_1, L and H levels for V_2, and L and H levels for V_3.

The second illustration shown in Table 7 involves five test sections, labelled C, D and E, that are part of a nationwide design that calls for these sections to occur under site conditions L - L - L in Table 7.[1]

---

[1] In this illustration it is presumed that all levels are defined in the same way for both the local study and the nationwide study. While there are advantages to using nationwide design levels for variables in an individual experiment, all that is needed is a correspondence between levels in the two studies. For example, the medium level for V_3 in the nationwide design might correspond to a high level in an individual study.

Sections C are at low levels for two other structure variables, V_8 and V_9, while sections D are at high levels for these variables.

Section E represents a pavement design that is common to all test sites in the nationwide experiment design, and has medium levels for V_1 - V_4, V_8 and V_9 in the nationwide design.[1]

Sections C and D together represent only one fraction of a much larger experiment, and do not in themselves give a complete factorial arrangement. Any one of sections C, D or E, however, could be used as part of a local experiment design. For example, when sections F are included with section C, then the effects of V_1 and V_3 can be studied at two sites which have different levels for ADL = V_7. Thus this design includes ten sections at one site and six at a second site.

It would be desirable to have at least two pairs of duplicate sections at each site in the examples of Table 7.

---

[1] See footnote page 38

4.2.3 Nationwide Experiment Designs

Composite experiment designs are recommended for nationwide studies of existing and new experimental pavements. The same general design is applicable to the study of any pavement type. For any of these studies, six design variables, V_1, V_2,..., V_6 have been reserved for describing features of the pavement structure above the roadbed material. The next five variables, V_7, V_8..., V_{11} are called test site variables in that they describe the roadbed material, the climatic and regional features of the test site, and the rate of load accumulation at the test site. In the case of existing pavement studies one more site variable, V_{12}, is included to indicate the number of years that the pavement has been in service.

As was discussed in connection with Table 4C, the factorial part of a composite experiment design requires that low and high levels, L and H, be defined for each selected factor. The factorial part of the experiment can then be used to determine linear effects and interacting effects of the design variables. For the study of curvilinear effects a medium level, M, an "extra low" level, L', and an "extra high" level, H', is defined for each factor. Thus the composite design requires that three levels, L, M and H, be provided for each factor, and that two more levels, L' and H', be provided for all factors whose curvilinear effect is to be studied.

Test Site Variables

Table 8 shows tentative definitions for site variables, V_7, V_8, V_9, V_{10}, V_{11} and V_{12}, and levels for these variables. Two variables have been allocated to roadbed material, V_7, to describe the quality of the material as reflected by its AASHO designation, and V_8 to describe an engineering property (to be designated) that varies within AASHO classes. It is assumed that the various combinations of levels of V_7 and V_8 will repre- TAB 8 sent a wide range of roadbed conditions as measured by tests that evaluate s_4, the initial strength of the roadbed material.

Climatic variables V_9 and V_{10} are represented by v_1 = mean annual rainfall in inches and by v_2 = frost index (Corps of Engineers) in degree days. It is assumed that various combinations of levels for v_1 and v_2 will introduce a wide range of climates for the nationwide studies.

Daily equivalent 18-kip axle loads, V_{11} = ADL, represent the last site factor for studies of new experimental pavements, and years of service at the time an existing pavement is initially observed (in the satellite program) is the last site variable, V_{12} = Y, for studies of existing pavements.

For each site variable, Table 8 indicates the levels which prevailed for that variable at the AASHO Road Test site.

Pavement Structure Variables

Definitions for six pavement structure factors and their levels are given in Table 9 for two pavement types, flexible and rigid. The first selected factor is surfacing thickness, so that $V_1 = h_1$ for either type of pavement. For the flexible pavement designs, $V_2 =$ h_2 = base thickness, and two more variables, V_3 and V_4, are allocated to the base material in order to provide a range of base strength, s_4. The variable V_2 is called base quality and refers to the type as well as the engineering properties of the untreated material. Levels for V_2 will be further specified in terms of soundness, gradation, and other characteristics. These same considerations apply to V_6 = subbase quality for both flexible and rigid pavement designs. It is assumed that the final specifications for base and subbase quality will result in levels such that s_2 and s_3 will generally increase TAB 9

TABLE 8: SUGGESTED FACTORS AND LEVELS FOR TEST SITE VARIABLES IN EXPERIMENT DESIGNS FOR NATIONWIDE STUDIES

VARIABLES			LEVELS				
Code		Representing	L'	L	M	H	H'
	Roadbed Material						
V_7	Quality (AASHO Class)	c_4	A-7	A-6 (Road Test)	A-4	A-2 P	A-2 NP
V_8	Engineering Property	s_4	Low Performance	← To be determined	→	High Performance	
	Climate						
V_9	Mean Annual Rainfall (inches)	v_1	0-10	10-25	25-35 (Road Test)	35-50	50-60
V_{10}	Frost Index (Corps of Engineers)	v_2	0	1-300	300-700	700-1000 (Road Test)	Over 1000
	Load and Time						
V_{11}	Daily Equivalent 18-kip Axle Loads	ADL	10-30	30-100	100-300	300-1000	1000-3000
			<	----	(Road Test Traffic Lanes)	----	>
V_{12}	Years Service at time of initial observation (Used only in existing pavement studies	Y		Under 15		Over 15	20-25

TABLE 9: SUGGESTED FACTORS AND LEVELS FOR PAVEMENT STRUCTURE VARIABLES IN EXPERIMENT DESIGNS FOR NATIONWIDE STUDIES OF FLEXIBLE AND RIGID PAVEMENTS

VARIABLES			LEVELS				
Code		Representing	L'	L	M	H	H'
Flexible Pavements							
V_1	Surfacing Thickness (inches)	h_1	2	3	4	5	6
			←	(Road Test)	→		>
V_2	Base Thickness (inches)	h_2	3	6	9	12	15
			←	(Road Test)			>
V_3	Base Quality[1]	s_2	Sand	Sand-Gravel	Gravel	Limestone	Hard Stone
					←	Road Test →	
V_4	Base Stabilization		None	None	Bituminous (low)	Bituminous (high)	Cement (high)
			←		(Road Test) →		>
V_5	Subbase Thickness (inches)	h_3	0	6	12	18	24
			←	Road Test	→		
V_6	Subbase Quality[1]	s_3	Sand	Sand	Sand-Gravel (Road Test)	Gravel	Limestone
Rigid Pavements							
V_1	Surfacing Thickness (inches)	h_1	4	6	8	10	12
			←	(Road Test)			→
V_2	Surfacing Reinforcement and dowels	c_1	Plain with no dowels	Plain with dowels	Ordinary Reinf. with dowels	Continuous Reinf..5 °/o	Continuous Reinf. 1.0 °/o
				← (Road Test)	→		
V_3	Surfacing Strength (ksi compressive)	s_1	2.5-3.0	3.0-3.5	3.5-4.0 (Road Test)	4.0-4.5	4.5-5.0
V_4	Subbase Stabilization ↘		None	None	Cement (low)	Cement (high)	Bituminous (high)
				(Road Test)			
V_5	Subbase Thickness	h_3	0	4	6	8	12
			←		Road Test		→
V_6	Subbase Quality →	s_3	Sand	Sand	Sand-Gravel (Road Test)	Gravel	Limestone

---

1 Base and Subbase quality refers to the untreated materials which will be further specified in terms of soundness, gradation, etc.

from level L' through level H'. Variable V_4 in Table 9 refers to the stabilization of base materials for flexible pavements and to subbase stabilization for rigid pavements. For either variable, level L' and level L have the same meaning--that the material is unstabilized. For flexible pavements, level M and level H of variable V_4 refer to bituminous stabilized base, with the implication that level H leads to higher s_2 than does level M. Level H' for V_4 is used to introduce cement stabilization, but there is no presumption that s_2 is any higher or lower for level H' than for level H. In the rigid pavement case it will be seen that levels M and H for V_4 refer to cement treated subbase, and that the H' level of this variable represents a change to bituminous stabilization.

The variable V_5 refers to subbase thickness for either type of pavement. In the rigid pavement case the two remaining variables are used in connection with the surfacing course. Surfacing strength is varied according to levels for V_3, and reinforcement, V_2, has been given five levels that range from L' = plain undowelled concrete to H' = continuously reinforced concrete with one percent steel.

It is recognized that Tables 8 and 9 do not completely specify all levels of all factors, and that many one-level factors need to be specified (e.g., compactive effort, etc). The tables do indicate, however, the general nature of the nationwide experiment designs that are being proposed in the current guidelines.

Pattern of Design Factor Combinations

The selected pattern of factor levels for the nationwide experiment designs is shown in Table 10. The factorial part of the design involves eleven factors (twelve for existing pavement studies) each at low and high levels. If all 2^{11} (or 2^{12}) combinations of these levels were included there would be 2048 (or 4096) test sections for the study of a given pavement type. Instead, a one-sixteenth TAB 10

TABLE 10: NATIONWIDE EXPERIMENT DESIGN FOR STUDIES OF ONE PAVEMENT TYPE

Site Code	V_7	V_8	V_9	V_{10}	V_{11}	PAVEMENT STRUCTURES FOR SITE CONDITIONS Parentheses contain V_1-V_6 levels for one test section					Structure Code
111	L	L	L	L	L	(LLLLLL)	(HHHHLL)	(HHLLHH)	(LLHHHH)	(MMMMMM)	1-4, 0
112	H	H	L	H	L	(HHHLLL)	(LLLHLL)	(LLHLHH)	(HHLHHH)	(MMMMMM)	5-8, 0
113	L	H	H	L	L	(HLHLHH)	(LHLHHH)	(LHHLLL)	(HLLHLL)	(MMMMMM)	9-12, 0
114	H	L	H	H	L	(LHLLHH)	(HLHHHH)	(HLLLLL)	(LHHHLL)	(MMMMMM)	13-16, 0
115	H	H	L	L	H	(LLHLHL)	(HHLHHL)	(HHHLLH)	(LLLHLH)	(MMMMMM)	17-20, 0
116	L	L	L	H	H	(HHLLHL)	(LLHHHL)	(LLLLLH)	(HHHHLH)	(MMMMMM)	21-24, 0
117	H	L	H	L	H	(HLLLLH)	(LHHHLH)	(LHLLHL)	(HLHHHL)	(MMMMMM)	25-28, 0
118	L	H	H	H	H	(LHHLLH)	(HLLHLH)	(HLHLHL)	(LHLHHL)	(MMMMMM)	29-32, 0
121	L	L	L	L	H	(LHHLHL)	(HLLHHL)	(HLHLLH)	(LHLHLH)	(MMMMMM)	33-36, 0
122	H	H	L	H	H	(HLLLHL)	(LHHHHL)	(LHLLLH)	(HLHHLH)	(MMMMMM)	37-40, 0
123	L	H	H	L	H	(HHLLLH)	(LLHHLH)	(LLLLHL)	(HHHHHL)	(MMMMMM)	41-44, 0
124	H	L	H	H	H	(LLHLLH)	(HHLHLH)	(HHHLHL)	(LLLHHL)	(MMMMMM)	45-48, 0
125	H	H	L	L	L	(LHLLLL)	(HLHHLL)	(HLLLHH)	(LHHHHH)	(MMMMMM)	49-52, 0
126	L	L	L	H	L	(HLHLLL)	(LHLHLL)	(LHHLHH)	(HLLHHH)	(MMMMMM)	53-56, 0
127	H	L	H	L	L	(HHHLHH)	(LLLHHH)	(LLHLLL)	(HHLHLL)	(MMMMMM)	57-60, 0
128	L	H	H	H	L	(LLLLHH)	(HHHHHH)	(HHLLLL)	(LLHHLL)	(MMMMMM)	61-64, 0
131	H	L	L	L	H	(HHHHHH)	(LLLLHH)	(LLHHLL)	(HHLLLL)	(MMMMMM)	61-64, 0
132	L	H	L	H	H	(LLLHHH)	(HHHLHH)	(HHLHLL)	(LLHLLL)	(MMMMMM)	57-60, 0
133	H	H	H	L	H	(LHLHLL)	(HLHLLL)	(HLLHHH)	(LHHLHH)	(MMMMMM)	53-56, 0
134	L	L	H	H	H	(HLHHLL)	(LHLLLL)	(LHHHHH)	(HLLLHH)	(MMMMMM)	49-52, 0
135	L	H	L	L	L	(HHLHLH)	(LLHLLH)	(LLLHHL)	(HHHLHL)	(MMMMMM)	45-48, 0
136	H	L	L	H	L	(LLHHLH)	(HHLLLH)	(HHHHHL)	(LLLLHL)	(MMMMMM)	41-44, 0
137	L	L	H	L	L	(LHHHHL)	(HLLLHL)	(HLHHLH)	(LHLLLH)	(MMMMMM)	37-40, 0
138	H	H	H	H	L	(HLLHHL)	(LHHLHL)	(LHLHLH)	(HLHLLH)	(MMMMMM)	33-36, 0
141	H	L	L	L	L	(HLLHLH)	(LHHLLH)	(LHLHHL)	(HLHLHL)	(MMMMMM)	29-32, 0
142	L	H	L	H	L	(LHHHLH)	(HLLLLH)	(HLHHHL)	(LHLLHL)	(MMMMMM)	25-28, 0
143	H	H	H	L	L	(LLHHHL)	(HHLLHL)	(HHHHLH)	(LLLLLH)	(MMMMMM)	21-24, 0
144	L	L	H	H	L	(HHLHHL)	(LLHLHL)	(LLLHLH)	(HHHLLH)	(MMMMMM)	17-20, 0
145	L	H	L	L	H	(HLHHHH)	(LHLLHH)	(LHHHLL)	(HLLLLL)	(MMMMMM)	13-16, 0
146	H	L	L	H	H	(LHLHHH)	(HLHLHH)	(HLLHLL)	(LHHLLL)	(MMMMMM)	9-12, 0
147	L	L	H	L	H	(LLLHLL)	(HHHLLL)	(HHLHHH)	(LLHLHH)	(MMMMMM)	5-8, 0
148	H	H	H	H	H	(HHHHLL)	(LLLLLL)	(LLHHHH)	(HHLLHH)	(MMMMMM)	1-4, 0
211	L'	M	M	M	M	(MMMMMM)	(MMMMMM)				0, 0
212	H'	M	M	M	M	(MMMMMM)	(MMMMMM)				0, 0
221	M	L'	M	M	M	(MMMMMM)	(MMMMMM)				0, 0
222	M	H'	M	M	M	(MMMMMM)	(MMMMMM)				0, 0
231	M	M	L'	M	M	(MMMMMM)	(MMMMMM)				0, 0
232	M	M	H'	M	M	(MMMMMM)	(MMMMMM)				0, 0
241	M	M	M	L'	M	(MMMMMM)	(MMMMMM)				0, 0
242	M	M	M	H'	M	(MMMMMM)	(MMMMMM)				0, 0
251	M	M	M	M	L'	(MMMMMM)	(MMMMMM)				0, 0
252	M	M	M	M	H'	(MMMMMM)	(MMMMMM)				0, 0
300	M	M	M	M	M	(L'MMMMM) (MML'MMM) (MMMML'M)	(H'MMMMM) (MMH'MMM) (MMMMH'M)	(ML'MMMM) (MMML'MM) (MMMMML')	(MH'MMMM) (MMMH'MM) (MMMMMH')	(MMMMMM)	65-76, 0

32 factorial sites, 111-148. Factorial structures 1-64 repeated at sites 111-128 and 131-148.
Each factorial site has four factorial structures and the centroid structure, 0. 160 sections.
10 extension sites, 211-232, each with duplicate centroid structures. 20 sections.
One centroid site, 300, with 12 extension structures, 65-76, and structure 0. 13 sections.

New pavement studies: 193 test sections
Existing pavement studies: 386 sections, one at L and H levels for V_{12} for each design combination.

fraction has been selected so that the factorial part of the design involves $2^{11}/16 = 128$ sections to cover two levels of V_1 - V_{11}. On the left side of Table 10 are the $2^5 = 32$ possible combinations of L and H levels for test site factors V_7 - V_{11}. Each row of the table thus defines a test site, and five test sections are shown in parentheses for each test site. Each parenthesis contains the appropriate combination of levels for V_1 - V_6, and the first four sections shown give 4 x 32 = 128 test sections for the factorial part of the design. The fifth section shown as (MMMMMM) at each test site is the centroid structure defined by medium levels of all factors in Table 9. Although there is normally only one centroid for a composite design (see Table 4C) it has been decided to include the centroid pavement structure at each test site. This inclusion will make it possible to study site variable effects on a direct comparison basis. Thus the nationwide design involves 32 factorial test sites, each having five test sections. The experiment design of Table 10 is arranged in such a way that certain effects of the design variables can be estimated from only the first eight sites (site codes 111 - 118), and so that still more effects will be estimable after observations are available from the next eight sites (site codes 121 - 128). It can be noted in Table 10 that the second set of sixteen sites involves the same structures (structure codes 1 - 64) as does the first set of sixteen sites. In a sense then, the design contains a duplication of sixty-four pavement structures--exclusive of the centroid structure.

The remaining test sections in Table 10 require eleven additional sites. The first ten of these (site codes 211 - 252) provide "extra" high and "extra" low levels, H' and L' for the five site variables, V_7 - V_{11}, and the last site (test site code 300) is the centroid site defined by medium levels of all site factors in Table 8.

The centroid structure, (MMMMMM), appears in duplicate at all "extension" sites, 211 - 252, and once at the centroid site, 300. At the latter site there are also twelve test sections for L' and H' levels of all pavement structure variables, V_1 - V_6.

To implement the experiment design of Table 10 for studies of new experimental pavements, it is thus necessary to select 43 test sites, 32 of which will have five sections, ten of which will have two sections, and one centroid site to have 13 test sections--for a total of 193 sections.

For studies of existing pavements it is proposed that the sections of Table 10 be doubled to give one set of sections at the low level of V_{12} = Y and another set at the high level of V_{12}. Thus an existing pavement study will have a nationwide experiment design which involves 2 x 193 = 386 test sections.

It is noted that for existing pavement studies, the test sections allocated to any particular site code in Table 10 will very probably be found at different geographical locations. Moreover, it is not expected that existing pavements can be found to comply with all the conditions of Tables 8, 9 and 10. It is hoped, however, that at least fifty percent of the indicated combinations can be found, and that analysis of observations from these will become a tentative basis for conclusions to be reached from the corresponding studies of new experimental pavements-studies whose observations may not be completed for as long as twenty years from the time of test section construction.

With proper implementation, it is felt that the experiment designs implied by Tables 8, 9 and 10 will provide adequate data for rather far-reaching extensions of the AASHO Road Test studies.

4.3 Measurements Program

As discussed in Chapter 3, there are four classes of variables which are to be measured as a part of any pavement study; structure, load, environment and performance. Herein one subsection is devoted to each of the four measurement categories.

In each category are many variables that are amenable to measurement, and for each variable there may be many alternative measurement procedures each of which gives a certain amount of information about the variable being measured. As in practically any physical situation, no pavement variable can be measured directly. The results are dependent on the devices and procedures that are used to produce the data.

It has been pointed out early in these guidelines that an important aspect of the satellite studies is to study available theories of pavement design. In accordance with such objectives it will be necessary to include in the measurements program techniques for obtaining parameters required by the theories.

Thus two questions are presented: "What is a necessary and sufficient set of variables to be measured", and "What devices and procedures are necessary and sufficient to obtain adequate information on each variable?" It seems safe to assume that there are neither unique nor universally accepted answers to either of these questions. Based on this assumption, and for each measurement category, the guidelines attempt only to provide a reasonable answer to the first question and a rather narrow set of reasonable alternatives to the second. It is to be understood that recommendations for each measurement category are made in the interest of obtaining "common denominator" data that have high acceptability both from the standpoint of existing pavement design theories and from the standpoint of past experience in pavement research. No particular effort will be made to list all the variables and measurement procedures that might be useful in individual projects nor is it implied that the recommended measurements are the only measurements that should be made. On the contrary it is suggested that the recommendations be supplemented in every project by measurements which are known to have value for the explanation of pavement performance.

Standard testing procedures should be employed in satellite studies as much as possible to facilitate exchange of information. In particular, the nationwide studies will require a high degree of standardization.

A set of minimal measurement categories will be suggested for use with the nationwide studies. This minimal list has been derived largely from discussion with those agencies interested in pavement studies. It should be noted that any list of existing measurement techniques may need to be updated from time to time as new equipment and ideas become available.

Ideally, theory would tell exactly what should be measured about a pavement system and technology would tell exactly how to measure it. These two problems have not been completely solved.

In an attempt to select the proper variables for measurement, an intelligent compromise appears to be the answer. A careful study should be made of available methods and then two or three should be selected which appear to provide the data required for pavement design procedures and theories. It is important to note that theories involving new measurements must be propounded during the planning of a study in order that appropriate techniques for quantifying the necessary variables can be developed.

In many instances there are several methods available for making a given determination. e.g., density; nuclear, balloon, or sand cone. In such cases the method used should be reported to provide more complete data for study of between method variations. Appendix A gives references for a number of measurement procedures.

4.3.1 Structural Variables

The major categories of structural variables are shown in Chapter 2, Table 1. In addition there are numerous "other variables" which are helpful in classifying the studies and which may prove useful in the analyses. In most cases this information can be supplied with little or no additional cost.

In several instances the variables shown below can be measured both destructively and non-destructively, e.g., densities with volumeter require excavation but nuclear measurements do not. Several experimental methods such as the vibrator equipment developed by Shell Oil and currently being investigated by the Waterways Experiment Station, Corps of Engineers and others, are available for non-destructive strength analysis of materials in place. It is strongly recommended that such methods be employed in any satellite study. It is assumed that at least one such method, preferably more, will be investigated in NCHRP Project 1-6 and used in the nationwide program.

A. Section Variables--The following data should be included in each study.

1. Pavement Type: HMAC, Reinforced PCC, continuously reinforced PCC, etc.
2. Dimensions: Length and width of study section.
3. Lane in which the section appears.
4. Date Constructed: Sequence if not completed in one year. Dates of additions if stage construction.
5. Composite Strength: It is desirable to find some measurement procedure which will provide an index for the composite strength of each test section. These measurements represent the reaction of the entire structure acting under the applied load. It is recommended that each study include measurements such as Benkelman beam deflections under an 18-kip axle load.
6. Several photographs of each test section to show general characteristics of the section and locale as well as surface texture and condition.

7. Any special features or construction not mentioned above, e.g., culvert crossing the section, etc.

Of these factors the minimal required information is (1) pavement type, (2) the length and width of the test section, (3) lane, (4) date of construction, and (5) composite strength. The remaining factors are felt to have some bearing on pavement performance and if reported could be correlated with performance.

It is recommended that all seven items above be recorded for any nationwide study in an effort to provide as many methods as possible for correlation.

B. Surfacing--(Average and variations should be given for all factors.)

1. Thickness; (h_1) Average and range.

2. Strength Characteristics (s_1):

   (a) Flexible pavements--stability, cohesion, elastic parameters by plate load or vibration techniques.

   (b) Rigid Pavements--flexural strength, compressive strength, tensile strength.

   As a minimum this value must be related to the field, as-built conditions of the material. Non-destructive testing is applicable and some such method should be included.

3. Composition of paving mix: aggregates, type, gradation, uniformity, °/o asphalt cement or water cement ratio, penetration of asphalt.

4. Other Characteristics (c_1, c_2, etc.): e.g., load transfer, °/o steel reinforcement, seal coats, subseal.

5. Construction Practice Factors: e.g., slip form, machine laid, compaction techniques, etc.

6. Any special details not covered above such as later additions or modifications, dates, etc.

The minimal information required for an individual experiment is (1) thickness range and average, (2) a measure of the as-constructed strength of the layer, and (3) information as to other construction factors such as steel reinforcement and load transfer.

It is recommended that all six factors listed above be provided for the nationwide studies. It is quite probable that other factors will be suggested by the findings of NCHRP Project 1-3, and that these will be later recommended for inclusion in the measurements program.

C. Base and/or Subbase--The base and subbase will be discussed together since the same identification properties apply to both. It is understood that where both layers are present, data shall be gathered for each layer. If two slightly different layers are combined to comply with the layer concept used in these guidelines, the properties of each of these sublayers should be recorded separately. Averages and ranges should be given for all data when possible.

1. Thickness: (h_2 and/or h_3) Average and range.

2. Base or Subbase Type, e.g., crushed stone, bituminous stabilized, cement stabilized-percent stabilizing agent, etc.

3. Strength Characteristics (s_2, s_3): Many ways of determining s_2 and s_3 have been proposed in theory and practice. The applicability of the many methods may vary with the composition of the materials, e.g., stabilized vs. granular. In all cases s_2 and/or s_3 should include information which relates them to the as-constructed condition of the materials, not merely to the standards of a given laboratory test. Methods presently in use include CBR, Stabilometer tests (R value), triaxial measurements (Texas and Kansas variations), Group Index, plate loads, and North Dakota cone among others. At least one non-destructive method should be employed (e.g., determination of elastic moduli by vibration techniques).

4. Other Characteristics: In-place density, moisture content, gradations, plasticity index, etc.

5. Construction techniques including construction methods, dates of construction, mixing methods, and dates of any subsequent modifications.

6. Any special details not covered above which are felt to influence the performance of the section.

The minimal information required for any individual experiment is (1) layer thicknesses, h_2 and/or h_3, range and average, (2) base type, (3) a measure of strength, s_2 and/or s_3, and (4) other characteristics which might affect the type of analysis used. A considerable amount of work has been done to compare the performance of different types of base materials used at the Road Test in terms of strength tests. No test has been found that can be used for the direct comparison of different base types. Additional work will undoubtedly be required in the nationwide study since many types of stabilized bases will be encountered. It is recommended that data in all the six categories listed above be included in any nationwide study.

D. Roadbed Material: In the concepts of these guidelines the roadbed material is described as being of such thickness as influences the load carrying capacity of the pavement structure. This thickness is normally two to four feet and identification should be made for this full depth. In many cases any variations will merely occur as a range for the recorded variable. In other cases definite layers of materials with different classifications will be noted. In the latter case two sets of data should be provided with applicable depths shown. In many cases it is the practice to modify the top six inches of roadbed by rolling or admixture prior to adding any construction. In such cases this layer with a definite thickness shall be considered a subbase layer.

1. Strength Characteristics (s_4): e.g., triaxial, CBR, plate load tests, R value, etc., including field information. At least one nondestructive method should be employed.

2. Classification Data: gradations, liquid limit, plasticity index, maximum density and optimum moisture content.

3. Measurements of Swell.

4. Construction Practice Factors: In-place density and moisture content, compaction technique.

5. Modifications: This can include modification of one or more layers, e.g., addition of lime or increase of natural density by rolling. Depth of any such changes in s_4. Some additional clarification of this factor is needed since some states stabilize, some roll and water, while some do almost nothing to the natural ground.

6. Any other special details which are felt to influence the performance of the section.

The minimal information required for any individual experiment includes (1) the strength characteristic of the material including major layer variations and swell characteristics, (2) AASHO classification, and (3) any modifications made, such as additives or material processing, e.g., rolling.

It is felt that information in all six categories listed above should be provided in any nationwide study in order to relate all possible factors to pavement performance.

The sampling program must include some method of establishing sampling locations. If the study is to continue past the initial measurements program destructive sampling should not be done within the section itself. Every effort should be made to insure that there is no abrupt change immediately adjacent to the section ends. In other words, a section could be taken as say 1,100 feet long with the center 1,000 feet for observation and the two outer fifty (50) feet portions for destructive sampling with twenty-five (25) feet clear space reserved adjacent to each section end to minimize the possibility of destructive effect on the section (See Figure 4). FIG 4

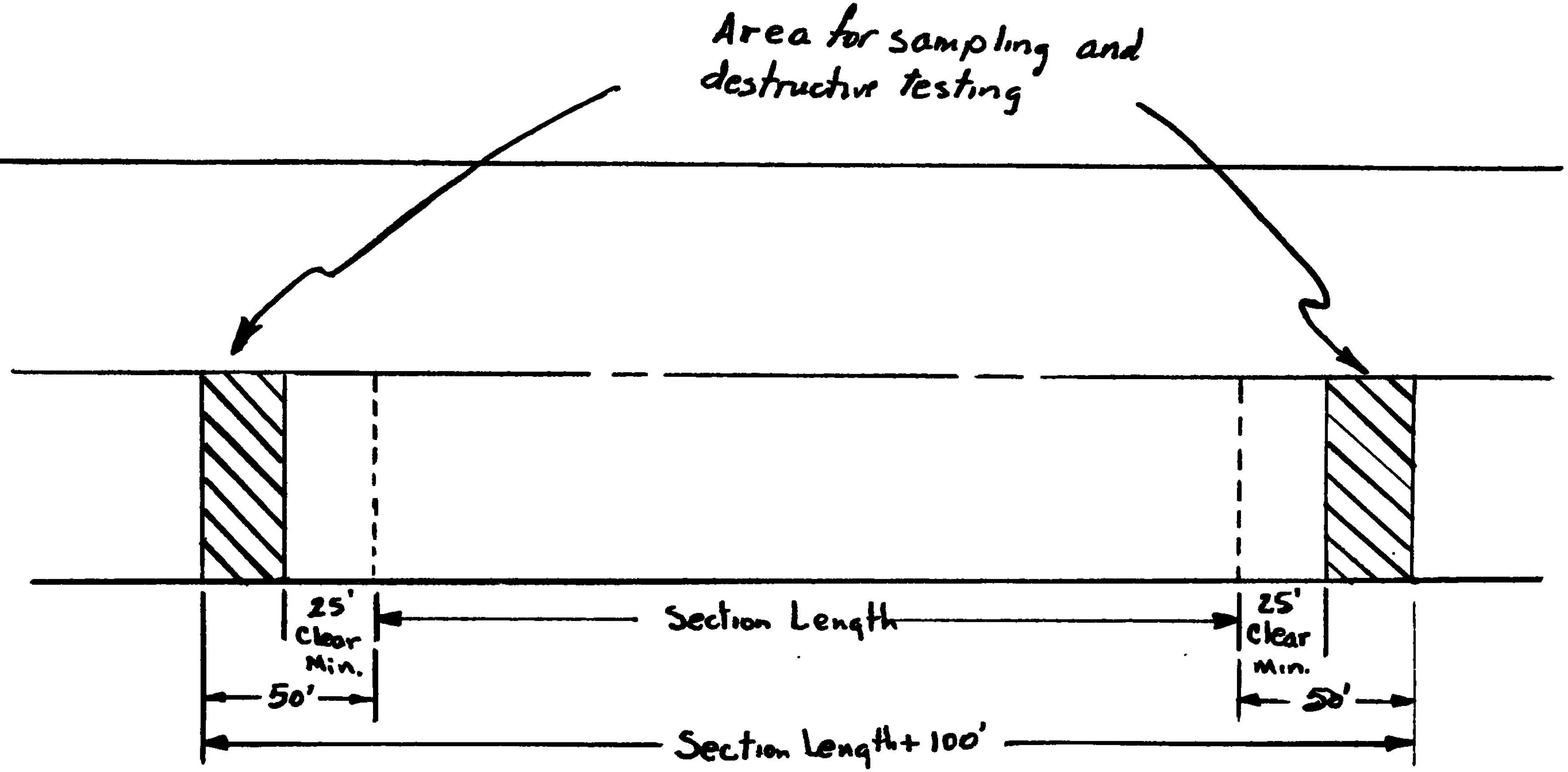


Figure 4

Typical Test Section

This is a necessary compromise of proper random sampling techniques. Three or four spots within the allotted area should be sampled. Others may want to split the test section with an additional sampling location in the center 100 feet.

In making the sample excavation, effort should be made to obtain the material in its natural state. It is very difficult, for example, to sample a stone-base material without degrading it. Likewise a cement-stabilized or treated material is difficult to sample and test. Careful hand methods should be employed to remove the material where necessary and other techniques should be developed as needed. In any event, the possible difference between the sampled material and the material as it was originally placed (or as it might be placed if specified for new construction) must often be considered.

4.3.2 Load Variables

Two major load variables should be evaluated in any study (see Appendix B).

1. Total number of equivalent axle load applications accumulated by the section. For further work in these guidelines 18-kip is taken as the standard load and the accumulation is abbreviated ΣL.
2. The years of service over which these load applications were accumulated (Y).

From these two variables the average daily equivalent loads can be calculated for the period of interest (abbreviated ADL).

$$ADL = \frac{\Sigma L}{365Y}$$

The ADL, or an early approximation of it, is sometimes helpful in selecting study sections because it is often desirable to study low vs. high load volume roads. It should always be remembered that ADL is only meaningful when the time period for which it is applicable is known.

There are several ways that traffic data can be combined in equivalencies. The equivalency factors presented in the AASHO interim design guides appear to have high acceptability in most states. They are reproduced in Appendix B and are recommended for use in the nationwide study.

If any studies are developed using a different method of combining traffic it is recommended that the report of such studies include traffic data, giving number of accumulated axles by weight category. This basic data could then be converted to "common denominator" measures of ΣL for all test sections in nationwide studies.

Any procedure for determining load variables involves a sampling procedure. In most cases the sample is a very small one percentage wise. The procedure involves many counting stations and relatively few vehicle classification stations and weighing stations. Preliminary studies of the situation indicate that routine predictions of traffic from such a narrow base are not accurate enough for experimental studies. This is not conclusive because very little data seems to be available on the day - day, month - month, season - season, road to road in the same class, variation of loads. Traffic counts appear to be adequate but load studies are only now developing to the point needed to apply the AASHO Road Test findings.

It is recommended that every effort be made to reduce the prediction or estimation error involved with ΣL on the study sections. Perhaps preliminary studies of the errors described above are warranted. In any case at least some weight studies should be made on every study section, (e.g., projections should not be made solely from the system). Enough samples to make reasonably good statistical predictions should be gathered.

Any measuring or sampling technique for loads may produce biased estimates of the true picture. Various studies indicate that overloaded (legal limits) vehicles are hesitant to pass through any weigh station for fear it might be connected with an enforcement authority. In the national program a set procedure for studying and handling this bias should be developed for general use.

4.3.3 Climatic and Regional Variables

As discussed in paragraph 3.1.3 the knowledge of variables involved in climatic and regional factors is incomplete. Experience shows certain influences on a gross scale. For example, performance of pavements under frozen conditions is certainly different from unfrozen conditions--all other factors being equal. Any list of measured variables should reflect local experience to insure inclusion of all important ones.

A. Suggested Climatic Factors
  1. Precipitation, yearly averages and distribution within the year.
  2. Temperature information, daily high, low, and average.
  3. Frost information
    a. Depth
    b. Number of annual freeze-thaw cycles and duration.
    c. Rate of penetration of freeze.
    d. Corps of Engineers Frost Index

B. Topographic Features
  1. Depth to water table.
  2. General character of drainage and surrounding land, e.g., cut, fill, side hill cut, large mountain, river valley, etc.
  3. Lateral Factors: shoulder or adjacent lane type and condition.

4. Grades: these should be less than 2 °/o for general experiments unless a specific study of the effect of grades is being made.

5. Other Factors: depth from top of pavement crown to bottom of ditch, cross-slope, super elevation, etc.

4.3.4 Performance Variables

The performance concept is discussed in Chapter 3. Several performance criteria have been used in recent years in the highway field. The one with widest applicability and perhaps the broadest acceptance is the present serviceability index used at the AASHO Road Test. Other methods which have been used include cracking indexes, sufficiency ratings and so-called economic ratings.

A. Surface Behavior - The performance of a pavement inevitably manifests itself at the surface of the road. The following factors should be measured (see Appendix D for details).

1. Surface roughness - The type of equipment used to measure roughness should be correlated with the AASHO Road Test equipment, if possible.

2. Cracking - The major fractures of the pavement surface, those which have been maintained or are in need of maintenance, should be recorded.

3. Patching - Repairs to the pavement surface in the form of seal, chip-seal or patching should be properly recorded. Miscellaneous sealing and spalling, etc., which is in need of repair, should also be included.

4. Rut Depth - On flexible pavements it is advisable to record the average rut depth in the wheelpaths under a sufficiently long straight edge.

5. Surface Texture - On flexible pavements the face texture has been found to exert an influence on present serviceability ratings and upon various instruments that are used to obtain longitudinal profiles. One device for making such measurements is discussed in Appendix A[1].

B. Serviceability - While each of the five variables above are useful in describing the pavement behavior, studies have shown that none alone does as good a job as the combination of all five (three or four for rigid pavements) into a serviceability index. Appendix D gives the details of the serviceability index formula that was developed at the AASHO Road Test. Other versions are also given as modified from the NCHRP Project 1-2 in July, 1963.

Some such serviceability index will be useful in any satellite study. It is recommended that one of the Road Test based indexes be adopted for the national program and that correlation between indexes used by the individual states and the "standard" index be provided.

Initial serviceability - For new studies the as-constructed condition will provide initial serviceability data. The problem is not so simple in studies of existing pavements. Some method of estimating the initial conditions must be adopted. One such method is to measure the serviceability of several new pavements and poll a panel of highway personnel as to their recollection of how these compare with roads constructed 5 - 10 years earlier, e.g., the time the pavements being studied were built.

---

[1] Scrivner, F.H. and Hudson, W.R. "A Modification of AASHO ROAD TEST Serviceability Index to Include Surface Texture". Presented at the 43rd Annaul Meeting of the Highway Research Board, Washington, D. C., January 13-17, 1964

Serviceability History - In order to minimize error and provide the best possible data, it will normally be necessary to repeat serviceability determinations on test sections each year for several years or at least until a trend begins to develop.

C. Performance - As used in the AASHO Road Test and as concerned for these guidelines, performance is some function or trend of serviceability, e.g., the number of applications required for the section to reach p of 2.5. In this context no direct measurement of performance will be made. It will merely be necessary to select the form of serviceability index and function to be used.

It is recommended that the national study adopt the logarithm of the number of applications, ΣL, to reach 2.5 as a performance index, P. Several other choices could be made. Table 11 summarizes the minimum measurements suggested for use in any study. The third column of this table gives methods of measuring or quantifying these variables. TAB 11

TABLE 11: SUGGESTED MEASUREMENT PROGRAM

VARIABLES	FACTORS	SUGGESTED METHODS	SCHEDULE
Structure Class			
A. Test Section	1. Pavement type	Known	Initial
	2. Location and dimension	Measurements	Initial
	3. Dates of construction	Construction records	Initial
	4. Composite strength	Deflection, strains, Shell vibration	Initial, plus seasonally
B. Surfacing	1. Thickness	Core pavement, if possible, construction records not accurate enough	Initial
	2. Existing field strength	Dynamic deflection or Shell vibration	Initial - seasonal
	3. As-built strength	Undisturbed or lab molded speciman	Initial
	4. Other characteristics (e.g., reinforcing, dowels)	Records and observations	Initial
C. Base and/or Subbase	1. Thickness	Cores from existing pavements	Initial
	2. Existing field strength	Dynamic deflection or Shell vibration	Initial - seasonal
	3. As-built strength	Lab test on reconstructed specimen	Initial
	4. Other characteristics (e.g., stabilization)	Records and observations	Initial
D. Roadbed Soil	1. Initial strength and swell characteristics	Undisturbed or lab molded specimen	Initial
	2. Existing field strength	Dynamic deflection or Shell vibration	Initial - seasonal
	3. Geologic and Pedalogic Class	Lab data	Initial
	4. Modification or additives	Records or observations	Initial

TABLE 11: SUGGESTED MEASUREMENT PROGRAM (Cont.)

VARIABLES	FACTORS	SUGGESTED METHODS	SCHEDULE
Load Class			
A. Total equivalent 18^k axle loads (L)	1. Estimated traffic and loads	Loadometer, counts, classification studies - projections	Annual
	2. Equivalency used	Recommend AASHO guide	Initial
B. Years of Service(Y)			Annual
Climatic and Regional Class			
A. Climatic factors	1. Precipitation	Weather records	(Previous 10 years)
	2. Temperatures	" "	" " "
	3. Frost	Records, field measurements	Annual
B. Topography	1. General Character of drainage	Observations	Initial
	2. Lateral factors (e.g., type and condition if adjacent lane and/or shoulders)	Observations, records Measurement	Initial, plus any subsequent change
C. Environment index	1. Relative strength deflection, strains, Shell vibration		Seasonal
Performance Class			
A. Surface behavior	1. Roughness	Chloe profilometer	Annual
	2. Condition surveys (Cracking, patching, rutting)	See Appendix 4	"
	3. Surface texture	" " "	"
B. Serviceability	1. p	See Appendix 4	"
C. Performance	log ΣL to p= 2.5	See Appendix 4	"

4.4 Data Processing and Analysis

This topic deals with a relatively few standard procedures that are recommended for summarizing and analyzing data that arise from the satellite research program. As results are obtained, and as new concepts are developed for data analysis, it is expected that updating will be needed for a number of recommendations that are included in this topic.

4.4.1 Data Summarization

TAB 12

A generalized format for summarizing the data from one test section is shown in Table 12. Since there are so many possibilities for actual measurements the table shows practically none of the details that would be included in an actual table. Space for test section code number and other identification data (see Section 4.3.1) is provided at the top of the form. Successive lines of the table provide for the various types of measurements that represent structural, load, climatic and regional, and performance data. Columns of the table provide for different dates of evaluation and thus for a time history of measurements that are made more than once.

It is recommended that laboratory and field data on the strengths of pavement components be obtained in the initial measurements program at a time which is most representative of year-round conditions. If significant seasonal strength variations are known to occur in the test section environment, then the strength measurement program should produce data at the "heights" and "depths" of seasonal changes, especially for variables which are indicators of composite strength. It is supposed that initial data on thicknesses and other design features are generally sufficient for the evaluation of these variables. A summary form such as Table 12 should show the average and range of the data (within the test section) for each variable at each time of evaluation.

TABLE 12: GENERALIZED DATA SUMMARY FOR ONE TEST SECTION

TEST SECTION ______________ IDENTIFICATION DATA ______________

Measured Variables		Dates of Measurement
Structural Data		
Strengths		
Laboratory	s_4	
	s_3	
	s_2	Initial and Seasonal Data
	s_1	
Field	s_4	(Averages and Ranges)
	s_3	
	s_2	
	s_1	
Indicators of S		
	etc.	
Thicknesses	h_1	
and	h_2	Initial Data
	h_3	
Other Design Features	c_1	(Averages and Ranges)
	etc.	
Loads	ΣL	
	Y	
	ΔD	Once or twice per year
	etc.	
Climatic and Regional	v_1	
	v_2	Seasonal Data
	v_3	
	etc.	
Performance		
Surface Behavior	x_1	
	x_2	Once or twice per year
	etc.	
Present Serviceability Index	p	
Performance Index	P	Projected estimates each year, final when p = 2.5

Although there will be many subsidiary records of test section data, the remaining discussion will be confined to data analysis that might follow the preparation of a data summary such as Table 12 for each test section in the study. Moreover, the discussion will be limited to only a few of the possible relationships that were described in Section 3.3.

4.4.2 Testing of Structural Theories

If composite strength, S, is evaluated by deflections, strains, or perhaps pressures that occur at one or more points in the test section when the latter is subjected to a given loading condition, then a number of structural theories exist for predicting the observations from thicknesses, strengths, and elastic properties of the pavement components. Thus when appropriate values are given for s_1, s_2, s_3, s_4, h_1, h_2 and h_3, observed pavement responses (measures of S) can be compared with theoretical values. It is recommended that one or more existing structural theories be thus tested in every satellite project, and especially in the nationwide studies--for the satellite research program can provide what is perhaps the widest range of conditions that has ever been available for this purpose.

4.4.3 Performance vs. Structural Design

In one sense, no data analysis is needed for determining which structural designs can be expected to give satisfactory performance in a given region--for if the performance of a set of test sections is observed for a sufficiently long period of time, and if the sections encompass all design variables of local interest, then the study should produce all practical results that are needed for the region in which the test sections occur. It is supposed that virtually all individual satellite projects will yield this important type of finding and with little or no data analysis.

To the extent that generalizations are to be drawn from the observations, however, it is supposed that relationships will be developed between performance and structural design, and it is the purpose of this topic to suggest ways for developing such relationships. The first relationship to be discussed is between present serviceability, p, and accumulated equivalent axle loads, ΣL, for any test section.

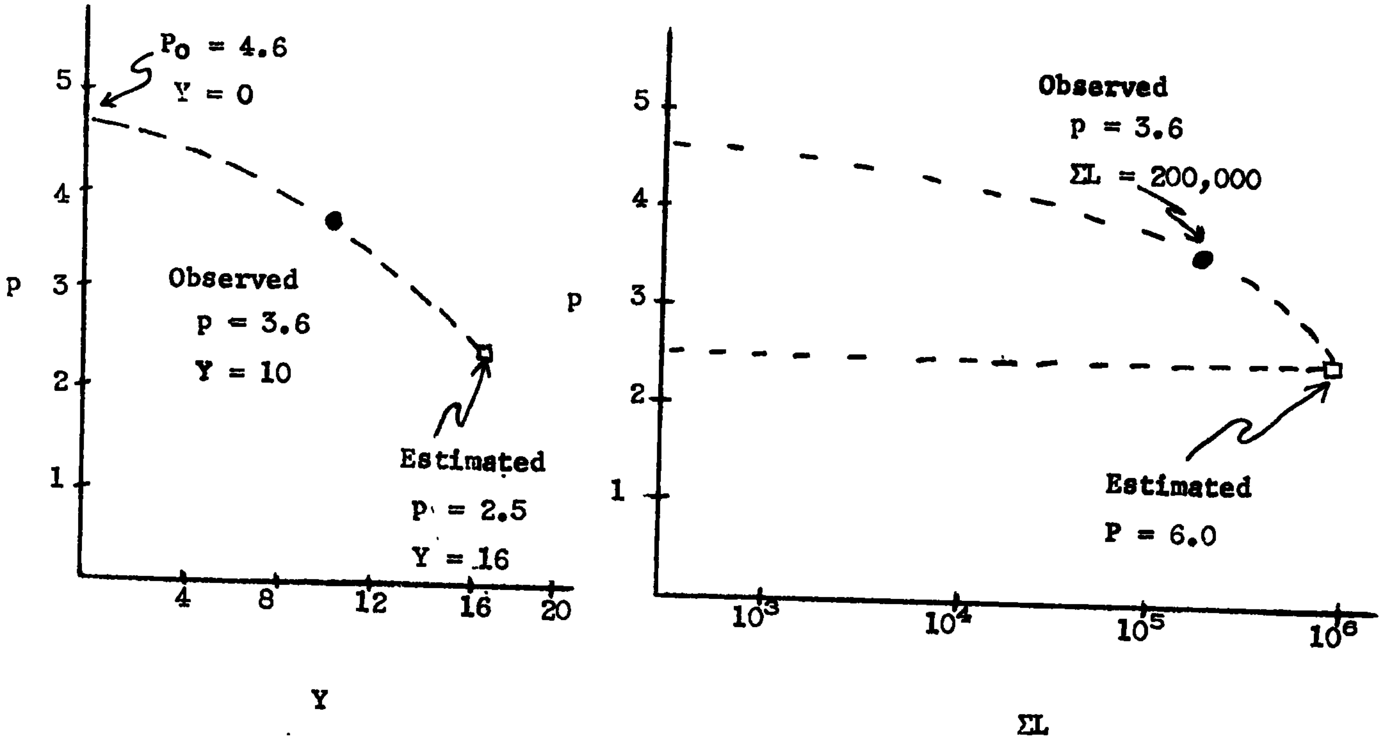
If the data implied by Table 11 are used to plot p versus Y, the resulting graph will contain one or more points of the section's serviceability history. If p is plotted against ΣL, then points on the section's performance record are obtained.

In existing pavement studies it is likely that the value of p_o will have to be assumed for most test sections, and that only one or two points will be observed for the performance record of any test section.

If one of the observed points on a section's performance record is at $p = 2.5$, the logarithm of the corresponding ΣL will be called an <u>observed</u> performance index. If, as in Figure 5, the performance record has to be extended from observed points (in either direction) to reach $p = 2.5$, then the extended curve yields an <u>estimated</u> performance index, i.e., P is log ΣL at $p = 2.5$ on the extended curve.

Figure 5 shows a serviceability history and performance record for a test section whose initial $p_o = 4.6$ and which reached $p = 2.5$ after $Y = 16$ years of service and $\Sigma L = 10^6$ 18-kip equivalent axle load applications. By definition, the section's estimated performance index is $P = \log \Sigma L = 10^6$ or $P = 6.0$. In existing pavement studies it is likely that only one point for either graph will be available for any particular test section--as illustrated by the circled points at $p = 3.6$, $Y = 10$, and $\Sigma L = 200{,}000$ in Figure 5. FIG 5

Curves that are used for performance records might be drawn by eye, but it is recommended that one (or both) of two general algebraic expressions be used to determine



Serviceability History

Performance Record

Figure 5 : Illustrative performance data for one test section

estimated performance index values. These models are

(1) $p = p_o - (po - 1.5)\ (\Sigma L/\rho)^{\beta}$

and

(2) $p = p_o\ 10^{-(\Sigma L/r)^{b}}$

Both these models have been found to give satisfactory fits to the AASHO Road Test performance data. The quantities ρ and r depend on pavement design variables, while the quantities β and b can be given fixed values or can also depend on design variables.

In logarithmic form the models become

(3) $\log \Sigma L = \log \rho + \frac{1}{\beta} \log \left[(p_o - 1.5)/(p_o - p)\right]$

and

(4) $\log \Sigma L = \log r + \frac{1}{b} \log \log (p_o/p)$

In these forms it can be seen that if values are assumed for β or b, then a set of values for p_o, p and log ΣL will determine log ρ or log r. Substitution of the log ρ or log r back into (3) or (4) along with p = 2.5 will then determine $P = \log \Sigma L$ when p = 2.5. Formulas and illustrations are given in Appendix D for determining estimates of P from one or more observed points on a test section performance record. When two or more points have been observed it is not necessary to assume values for β or b. As may be inferred from Figure 5, estimated performance index values cannot be considered to be very reliable unless the section has experienced, say, a full point of serviceability loss.

As soon as performance index values have been observed or estimated for all test sections in a satellite study, it is recommended that they be compared with observed values for comparable AASHO Road Test sections (given in Table D3). Such comparisons will often indicate the extent to which the Road Test findings need to be modified or extended to fit the satellite observations.

The remaining discussion of this section applies to those satellite studies in which it is desired to develop performance equations from the satellite test data.

Setting p = 2.5 in models (3) and (4) gives

(5) $P = \log \rho + \frac{1}{\beta} \log \left[(p_o-1.5)/(p_o-2.5)\right]$

and

(6) $P = \log r + \frac{1}{b} \log \log (p_o/2.5)$

Appendix D gives formulas for log ρ and β that were presented in AASHO Road Test reports--in terms of thicknesses of structural components. This appendix also gives expressions for log r and b that were developed by Painter[1] and somewhat different expressions that were developed at the Highway Research Board after the Road Test reports were published. In all these developments it is supposed that log ρ or log r can be expressed in terms of a structural index, D, which depends upon structural parameters and which contains constants to be determined by performance data analysis. In the guideline notation, the structural index is

(7) $D = f(s_1, c_1, h_1; s_2, c_2, h_2; s_3, c_3, h_3;$

$s_4, c_4; a_1, a_2, \ldots)$

where $a_1, a_2, \ldots$ are coefficients to be determined by analysis.

In AASHO Road Test reports equation (7) was developed as

(8) $D = .44h_1 + .14h_2 + .11h_3 + 1.00$

for flexible pavements having crushed stone bases, and

(9) $D = h_1 + 1$

for rigid pavements having 3, 6 or 9 inches of sand-gravel subbase.

Without minimizing other possibilities it is suggested that a simple linear approximation be used for (7),

---

[1] Painter, loc. cit.

$$(10)\quad D = a_1f_1h_1 + a_2f_2h_2 + a_3f_3h_3 + a_4f_4$$

where f_1, f_2, f_3 and f_4 are functions of the strength and classification characteristics of surfacing, base, subbase, and roadbed materials. One hypothesis for these functions is that they involve ratios of elastic moduli for the structural components.

It is suggested that (10) be used with (6) in the general form

$$(11)\quad P = A_o + A_1F_1\ (D) + A_2F_2\ (RS \text{ or } RF) + A_3F_3\ (Y \text{ or } ADL) + \frac{1}{b} \log \log\ (p_o/2.5)$$

Thus the first four terms of (11) represent log r in (6) and involve a structural factor, a relative strength or regional factor, a rate of applications factor, and constants A_o, A_1, A_2 and A_3 to be determined by analysis. The last term involves the section's initial serviceability index, p_o, and an assumed constant, b, that determines the general shape of all serviceability curves. One possibility for the functions F_1, F_2 and F_3 is that they be logarithms of the quantities they modify.

Appendix D gives specific results that have been obtained when (11) was fitted to AASHO Road Test performance data, and Chapter 5 describes numerical procedures that can be used to determine the performance equation. It is recommended that analysis of variance and regression analysis be used to the fullest extent in developing the relationships.

After a performance equation has been developed, substitution of all required parameters yields a calculated performance index. Differences between calculated and observed (or estimated) performance index values are residuals that are not explained by the parameters--at least in terms of the model that is used for the explanation. In Appendix D and in Chapter 5, the average absolute residual is used as a measure of agreement between calculated and observed (or estimated) values. Tables in Appendix D give observed (or estimated) and calculated values for P for every AASHO Road Test section, and show that the average absolute residual was about .20 in the Road Test analyses. Differences in P between two replicate sections (same structure and load) averaged to be about .15.

4.4.4 Performance vs. Composite Strength

The last type of analysis to be discussed concerns relationships between P and measures of S. If surface deflections or strains are used as indicators of composite strength, then

$$(12)\quad P = A_0 - A_1 \log S$$

has been shown to be a satisfactory model for fitting performance data to composite strength data. For the AASHO Road Test flexible pavements this relationship turned out to be

$$(13)\quad P = 11.1 - 3.25 \log d$$

where d is a Benkelman beam deflection (in thousandths of inches) under an 18-kip axle load during the severe spring climatic conditions.

For rigid pavements corresponding relationships were

$$(14)\quad P = 13.4 - 4.66 \log \epsilon$$

where ϵ is dynamic edge strain in microinches per inch, and

$$(15)\quad P = 10.2 - 3.15 \log d$$

where d is slab edge deflection (in thousandths of inches) at a particular temperature condition.

As was discussed in Section 3.3.1, results such as equations (13), (14) and (15) can provide a link between pavement performance and theories which predict measures of S from pavement design variables. For example, deflections predicted by a particular theory might be substituted in equations such as (13) or (15) in order to obtain predicted performance, P.

One relationship that should be the object of study throughout the satellite research effort is the association between measures of relative strength, RS, and climatic factors, v_1, v_2, etc., when all other factors are fixed. In the nationwide studies, and to some extent in local studies, the most pertinent data are those from sections whose structure and load characteristics are nominally the same, but which serve under different climatic conditions. One possible hypothesis for this study is that

$$(16)\quad \log RS \text{ (or } RF) = A_o + A_1f_1(v_1) + A_2f_2(v_2) + \ldots$$

If it can be assumed that accumulated loads do not in themselves alter the relative strength of a section, then relationships such as (16) can be developed from data obtained from any given section at times of the year when climatic factors have different levels.

CHAPTER 5

Illustrative Studies

This chapter contains numerical examples for individual satellite studies of existing and new pavements. The examples are intended to illustrate experiment designs, measurements programs, and data processing and analysis techniques which could be used to fulfill the objectives of a particular satellite test. In each illustration only one pavement type is included.

5.1 Individual Studies of Existing Pavements

In an effort to incorporate the AASHO Road Test findings into its pavement design method, Agency Q performed a satellite study. In order to obtain the needed information as rapidly as possible, the decision was made to study existing flexible pavements on the highway system as, at least, a first step. The factors listed below were of greates concern:

1. Roadbed Quality	(3 levels)
2. Base Quality	(3 levels)
3. Service Life - rate of accumulation of applications	(2 levels)
4. Local Environment	(2 levels)
5. Surfacing Thickness	(2 levels)
6. Base Thickness	(2 levels)

Other factors were considered to be less important and were controlled at a single level (fixed) or left uncontrolled. These included surfacing quality, subbase quality, subbase thickness and accumulated applications. The number of control levels used for each factor is shown in parentheses above.

TAB 13

As can be seen in Table 13, the study of these factors in a complete factorial would require 144 test sections (3 x 3 x 2 x 2 x 2 x 2) with no replicates. With replicates such a study would involve over 250 test sections.

TABLE 13: ILLUSTRATIVE STUDY OF EXISTING FLEXIBLE PAVEMENTS

Experiment Design — Test Section Numbers

		Region	Better than Road Test		Equal to Road Test	
		Traffic ADL	Light	Heavy	Light	Heavy
Surfacing Thickness	Roadbed Material	Base Quality				
Thick	Better R.T.	B	101	102	137	138
		ERT	103	104	139	140
		WRT	105	106	141	142
	Equal R.T.	BRT	107	108	143	144
		ERT	109	110	145	146
		W	111	112	147	148
	Worse R.T.	BRT	113	114	149	150
		ERT	115	116	151	152
		WRT	117	118	153	154
Thin	Better R.T.	BRT	119	120	155	156
		ERT	121	122	157	158
		WRT	123	124	159	160
	Equal R.T.	BRT	125	126	161	162
		ERT	127	128	163	164
		WRT	129	130	165	166
	Worse R.T.	BRT	131	132	167	168
		ERT	133	134	169	170
		WRT	135	136	171	172

After some consideration it was decided that a study of this magnitude was beyond the scope of the budget set up for such work by this agency. A composite experiment design such as that indicated by the circles in Table 4C was considered feasible as was the reduced factorial design described below.

Priority item number six was deleted to reduce the number of combinations to seventy-two. Some consideration was given to deleting priority item number five to reduce the number of cells to thirty-six. However, general recommended procedure for a study of this size is to have two test sections per cell, since it is impossible to obtain exact duplicates. In accomplishing this it was decided to vary item five, at high and low levels, to give seventy-two cells.

In order to fulfill this study, key decisions were required concerning the measurements involved with each variable. Table 14 summarizes the measurement methods chosen for this study. The major decisions are discussed below. TAB 14

1. Roadbed Material Strength

   Referring to Section 4.3, we see that there are many choices for quantifying this variable. Agency Q presently uses the California stabilometer for determining strength of roadbed material and has been using it for the past five years. Because they have this experience to rely on and because they feel that this test has good qualities, it was chosen as the method of quantifying roadbed material strength.

TABLE 14

MEASUREMENTS TO BE MADE IN AGENCY Q STUDY OF EXISTING FLEXIBLE PAVEMENTS

CLASS	VARIABLES	FACTORS	MEASUREMENT OR SOURCE
Structure	A. Test Section	1. Pavement type	Flexible
		2. Location and dimensions, Lane	12' x 1000' - Location shown on map
		3. Date of construction	District records
		4. Composite strength	a. Benkelman Beam deflection b. Shell vibrator
	B. Surfacing	1. Thickness	6 cores to each section
		2. Existing field strength	Shell vibrator - dynamic modulus
		3. As-built strength	a. Stabilometer and b. Cohesiometer on samples cored from the pavement
		4. Other characteristics	a. Density b. Asphalt content
	C. Base and Subbase	1. Thickness	Bore 6 cores each test section
		2. Existing field strength	Vibration techniques
		3. As-built strength	R value run on recompacted specimen at density and w/c found in place gradation
		4. Other characteristics	Density, gradation, w/c in place
	D. Roadbed Soil	1. Initial strength	R value run of reconstructed specimen at density, gradation and w/c in place
		2. Existing field strength	Shell vibrator - dynamic modulus
		3. Swell characteristics	?
		4. Modification or additives	a. Record rolling specimens b. Some section line stabilizer

TABLE 14 (Cont.)

CLASS	VARIABLE	FACTOR	MEASUREMENT OR SOURCE
Load	A. Total Equivalent 18^k axle loads (ΣL)	1. Estimated traffic and loads	Routine counts and classification from plan survey plus 1-4 special load studies each test section to be repeated each subsequent year
		2. Equivalency used	$(L/18)^4$ single: $(L/33)^4$ tandem
	B. Years' Service	3. Years	Construction records
Climatic and Regional	A. Climatic factors	1. Precipitation	Weather records
		2. Temperatures	" "
		3. Frost	Field measurements, correlations
	B. Topography	1. General character	Observations - good, fair, poor
		2. Lateral factors	Each side, paved, good fair, poor.
	C. Relative strength		Seasonal variations in deflections
Performance	A. Surface behavior	1. Roughness	Chloe SV
		2. Condition survey	Same as Road Test. Rut depth, crack, patch (see Appendix 4)
		3. Surface texture	Texture measurements (Appendix 4)
	B. Serviceability Index	1. Use Road Test p	See Appendix 4
	C. Performance Index	2. ΣL, $p = 2.5$	Projected (see data analysis)

2\. - 3. Base and Subbase Strength

The stabilometer is also applicable here and was chosen as the primary method of evaluating base and subbase strength, particularly for selecting test sections. This choice was of particular importance because the selection of the test factorial depended to a large extent on the value of roadbed and base strength.

4. Environment was not an easy factor to use as a basis for experiment design. Agency Q had no well developed information about its pavement performance. Based on general opinion the state was split in two to provide general geographic regions. Part of the study served to investigate various Regional Factor and Relative Strength evaluations of environment. No effort was made to design the experiment around rainfall or frost records except in a general way.

5. All thickness data were taken from field investigations. In fact, early satellite studies have indicated the need for this data in selecting test sections because uniformity of layer thickness is very important if other design factors are to be properly evaluated. Layer depths of normally constructed pavements showed to have coefficients of variation of 10 - 30 percent.

6. Surface quality was evaluated by the cohesiometer and stabilometer in an effort to obtain sections with very little variation in this factor. This was not a big problem since recent design procedures for this agency have been aimed at a fixed surfacing specification.

It was very important to determine the rate of load accumulations on the study sections. This was done as in most states by an analysis of traffic count and weigh station data. It was considered necessary to make a loadometer study on every test section possible as soon as feasible after it was brought into consideration. These studies served to establish the ADL at a given time and provided additional data which was helpful in determining the ΣL for each test section selected for final inclusion in the study.

The ground rules listed on pages 24 and 25 were followed as closely as possible in this study. The next step was the selection of test sections to be included. Exhaustive studies of the existing highway system revealed a list of those sections which appeared to meet the specification of one or more of the test cells in the study. These sections were listed in summary form and from these summary forms and the additional data which was included such as core hole depths, sections were selected for final inclusion into the project.

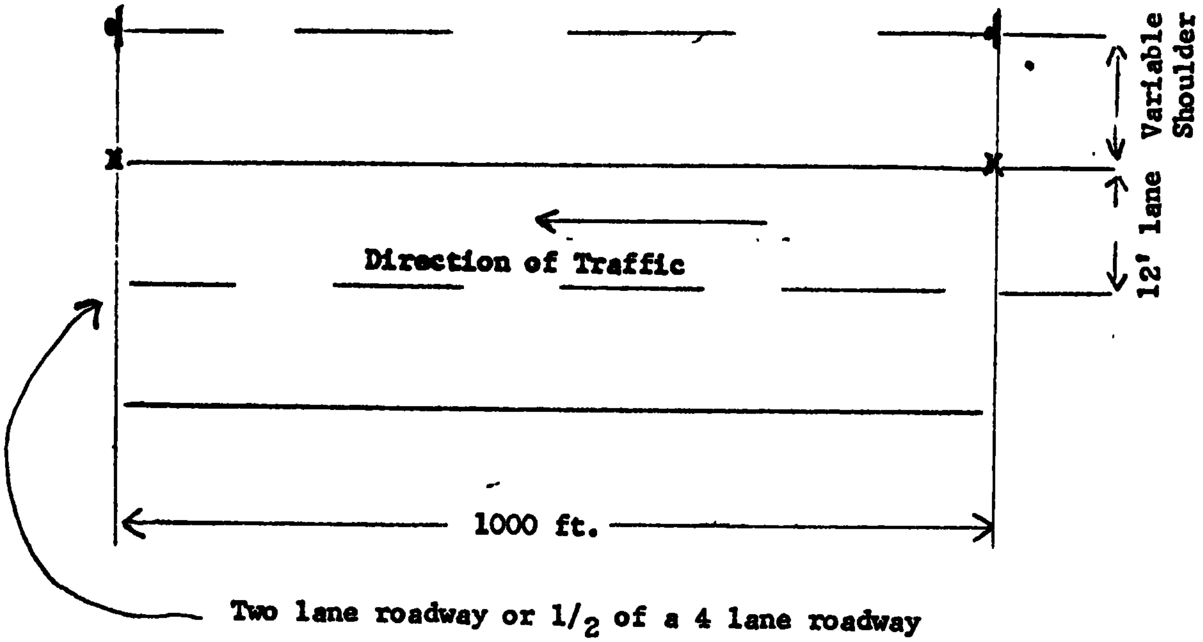
This selection was accomplished in the field with soil maps, construction plans, and expert advice to help choose locations which met the ground rules as well as the factorial design desired. No effort was made to choose a section based on the uniformity of the surface appearance, since this would have been pre-judging uniformity. Hand auger samples were taken adjacent to the pavement as necessary to check the uniformity of the subgrade material.

FIG 6

Test sections, 1,000 feet in length, were laid out as indicated in Figure 6. Marker signs were placed on the edge of the shoulder to spot the locations for measurement crews, maintenance forces and interested visitors. A one-inch diameter rod with a flat bronze top one-quarter inch thick and three inches in diameter was embedded at the edge (or on the center line) of the test section beginning and end to serve as a permanent marker for each section.

These permanent signs and markers were installed only on those test sections which were found to meet the requirements of the factorial after soil testing and depth measurements. When originally selected in the field each section was marked on the pavement with paint and an appropriate section identification number was assigned to it and immediately marked on the section.

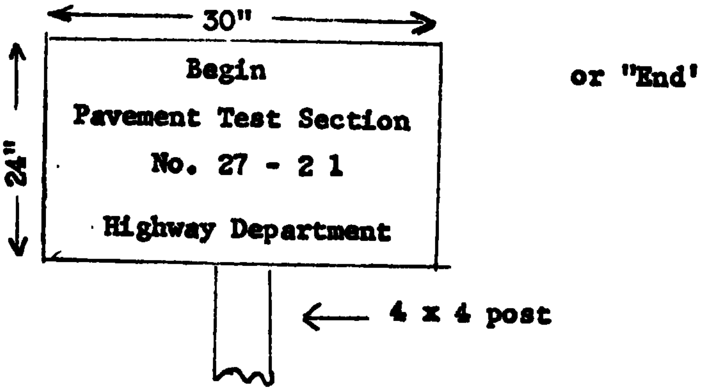
Figure 6: Sample test section layout



Two lane roadway or 1/2 of a 4 lane roadway

X Marker to be embedded in the edge of shoulder at the beginning and end of each test section.

◖ Sign to be placed on the outer edge of the shoulder or on right-of-way line at beginning and end of each test section.



These special marking precautions were made so that the serviceability of the test sections could be re-evaluated and observations continued one or more years subsequent to the initial evaluation. Such subsequent checks do not preclude the analysis and use of data from the first run, but it is expected that more accurate predictions can be made with two points on the performance curve for each test section. In some cases, test sections will be evaluated 5 - 10 years hence in order to add additional information to the study being conducted.

Many sections were examined before a proper one could be found for some of the factorial blocks. This was due to the extreme nature of some of the combinations involved (e.g., weak base material under heavy traffic). However, it is important to continue searching for a section to fill each experimental cell. Even then unforeseen future variations removed some sections from test in spite of every effort made to maintain the factorial (e.g., accidental overlay of a section by routine maintenance forces).

After collection of the basic list of possible sections, this list was narrowed down to 2 or 3 possible choices for each cell in the experiment design; that is, three that fit the cell as closely as could be determined at that stage.

Each of the test sections in each cell was rated first, second or third choice based on whatever type of information was available at that stage of the project. For example, if information indicated that the layer thicknesses were more uniform in section A than in section B or C, then this was taken as a logical reason to make section A first choice in the factorial. Section B might have had no subbase which made it a less "normal" section than section C; therefore, section C would be second choice and so forth down the line. Another factor was "which section has suffered more loss in serviceability and therefore has more information to offer to the project?", e.g., has lived a larger percent of its life.

From this point on it was necessary to begin measurements on the test sections to establish the information needed in the analysis. Table 14 is a special case of Table 11 and measurements which were used in this study. Table 15 is included TAB 15 to give more detailed information in the materials testing program.

One of the major problems in this existing pavement study was that of trying to determine what the design or original as-built conditions were. Some additional study was required in an attempt to evaluate this factor. Some helpful information along this line was developed as part of the analysis of laboratory vs. field variables shown in Table 15. The agency conducted an analysis involving both field and laboratory values of s_1, s_2, etc.

Many decisions had to be made in setting up the final measurements program. It was decided, for example, that laboratory testing was to be performed at conditions approximating the material conditions found in the roadbed. Certain careful procedures for taking samples in the field had to be developed. Choices were required concerning measurements of S and of RS as an indication of climatic and regional effects.

Great care was taken with the first round of data to insure uniform procedures and accuracy of data. The data processing phase provided for rechecking of all data to insure accuracy. Several summary data sheets from typical test sections are shown as Table 16. TAB 16

After completion of the first round of measurements for each test section, it was necessary to re-evaluate and re-arrange the sections within the factorial. Evaluation of the factors showed some of the test sections to be misplaced in the factorial. As far as possible, this re-arranging was done to put each section in its proper box and to keep fair balance between all boxes. In cases where a box became vacant, the second or third choice section was brought in to take its place. This required some additional testing for evaluation of these second choice sections and a repeat check to see that the section remained in its cell with the revised test results.

TABLE 15

DETAILS OF MATERIAL TESTS

VARIABLE	SYMBOL	TEST METHOD	OUTPUT	DETAILS AND/OR CONDITIONS	SCHEDULING
Surfacing Field Strength	s_1	Shell Vibrator	Dynamic modulus	Run test at each spot to be destructively sampled plus 3 or 4 spots in the section proper to check uniformity	Season for first year of test
Laboratory	s_1	California	R value	To be run on samples cored from the test section at 4 spots, 2 on each end, 1 in each wheelpath and the other 2 between wheelpaths	Season for first year of test
		Cohesiometer	C value	Same as R value	Same
Base and/or Subbase	s_2-s_3	Shell Vibrator	Dynamic modulus	Same as for s_1 above	See s_1 above
Laboratory Strength	s'_2-s'_3	California Stabilometer	R value	Samples to be recompacted in the lab from material taken in field samples. M/C density and gradation shall be such that checks on the tested sampled equal those found in the roadway	M/C, and density to be resampled seasonally. If wide variations are noted the effect of these changes on R value must be investigated
Roadbed Material Field Strength	s_4	Shell Vibrator	Dynamic modulus	Same as s_1 above	See s_1 above
Laboratory	s'_4	California Stabilometer	R value	Same as s'_2 and s'_3 above	" " "
Swell Property	c_2	Swell Pressure	?	" " " " " "	
Composite Strength	S_1	Benkelman Beam	Deflection	5 measurements taken in each wheelpath	Seasonal minimum - More often on some selected sections to provide data for formulation of EI

TABLE 16A: STUDY OF EXISTING FLEXIBLE PAVEMENTS

Hypothetical Data Summary Sheet

Section No. 101 Location SB SH32 Jones Co Date Constructed July '59

Lane Outside SB Shoulder Open Stone

	Dates of Measurements		
	July '62	Jan '63	
STRUCTURE VARIABLES			
Surfacing - Field Str.: Vibr. Mod. (psi)			
Lab Str. : Cohesiometer	200		
Thickness : Inches	3.6		
Base Course Field Str.: Vibr. Mod. (psi)	450,000	420,000	
Lab Str. : R value	96		
Thickness : Inches	9.5		
Stabilization : Agent, °/o	0		
Subbase - Field Str.: Vibr. Mod.			
Lab Str. : R value			
Thickness : Inches	0		
Composite Str.-BB Defl: Inches	.036	.020	
Roadbed Material			
Field Str.: Vibr. Mod. (psi)	20,000	1,000,000	
Lab Str. : R value	24		
Swell : Expansion Pressure	2.0 psi		
LOAD VARIABLES			
Accumulated 18^k appls.: $\Sigma L/1000$	270	310	
Years of Service : Y	3.0	3.5	
Avg. daily 18^k appls. : ADL	77	243	
CLIMATIC AND REGIONAL VARIABLES			
Mean annual rainfall : Inches	22		
Avg. annaul temp. : Degrees	75		
Frost Index : C of E	350		
General Character - Drainage:			
PERFORMANCE DATA			
Texture : TX	2.1	2.0	
Surface Roughness : CSV	9.8	15.5	
Cracking - Patching : C + PA	10	10	
Rut Depth : RD	0	0	
Serviceability Index : p Eqn. 101-105			
Po = ______			
Performance Index : P Eqn. (D10) (Estimated) B=1	5.73	5.60	

TABLE 16B: STUDY OF EXISTING FLEXIBLE PAVEMENTS

Hypothetical Data Summary Sheet

Section No. 120 Location US180, Jones Co. Date Constructed July 1956

Lane Middle EB (6 lane Div.) Shoulder Curb + Gutter

	Dates of Measurements		
STRUCTURE VARIABLES	June '62	Dec. '62	
Surfacing - Field Str.: Vibr. Mod. (psi)			
Lab Str. : Cohesiometer	255		
Thickness : Inches	2.2		
Base Course-Field Str.: Vibr. Mod. (psi)	500,000	600,000	
Lab Str. : R value	90		
Thickness : Inches	14		
Stabilization : Agent, °/o	None		
Subbase - Field Str.: Vibr. Mod.	120,000	105,000	
Lab Str. : R value	60		
Thickness : Inches	10		
Composite Str.-BB Defl: Inches	.026	.016	
Roadbed Material	25,000	50,000	
Field Str.: Vibr. Mod. (psi)			
Lab Str. : R value	25		
Swell : Expansion Pressure	2.3 psi		
Geol. and Pedologic Class	Fair		
LOAD VARIABLES			
Accumulated 18^k appls.: ΣL (thousands)	2380	2400	
Years of Service : Y	6.0	6.5	
Avg. daily 18^k appls. : ADL	382	1012	
CLIMATIC and REGIONAL VARIABLES			
Mean annual rainfall : Inches	22		
Avg. annual temp. : Degrees	75		
Frost Index : C of E	350		
Relative Strength : RS			
General Character - Drainage:	Good		
PERFORMANCE DATA			
Texture : TX	4.2	4.0	
Surface Roughness : CSV	16	20.6	
Cracking - Patching : C + P	50	55	
Rut Depth : RD	0.2	0.2	
Serviceability Index : p Eqn. 101-105 Po = 4.1	2.8	2.6	
Performance Index : P Eqn. (D10), B=1 (Estimated)	6.45	6.42	

At some point the search for additional sections to fill vacant cells provides diminishing returns and it was necessary to settle for a study with some vacant boxes. Table 17 shows TAB 17 the final set of sections for which data were gathered to enter the analysis phase. Preliminary trial analyses were begun much earlier with the incomplete data in an effort to develop analysis techniques and data trends. It was necessary that all these measurements be repeated the second year of the study. Considerably better information was then available for developing the performance relationships.

In order to perform any analyses it was necessary to develop some method of predicting an initial serviceability for the test sections. Readings were made on many new pavements during the course of this study. It was noted from these data that the initial serviceability of newly constructed flexible pavements ranged from 3.8 to 4.5 with the average being 4.1. A large majority of the sections fell between 4.0 and 4.3. It was decided that using the average of 4.1 was a satisfactory estimate of initial serviceability conditions for the test sections included in this study.

All data in Tables 16 and 17 are ficticious and have been supplied simply to have a numerical basis for illustrating several analyses that can be used to reach conclusions from an individual study of existing pavements. Since the hypothetical data may be far from realistic, the methods to be described do not necessarily lead to typical conclusions from such a study.

It can be seen that Table 17 contains values for nearly all the variables that have been mentioned in previous chapters of the guidelines, but that not all data given in Table 16 are shown in Table 17. Structural indexes, , and performance indexes, P, have been computed from the indicated formulas in Appendix D.

TABLE 17: ILLUSTRATIVE STUDY OF EXISTING FLEXIBLE PAVEMENTS - Data Summary (Hypothetical) for all sections.

Experiment Design Variables					Other Design Variables							Performance Data			
Regions	Sur Th. h_1	Road bed s_4 (R values)	Base Str. s_2	Loads ADL	Test Sec. No.	Subb Str. s_3 (R)	Base Th. h_2	Subb Th. h_3	Yrs. Ser. Y	Acc. Lds. $\Sigma L/1000$	BB Defl.	Serv. Index P_o=4.1	Performance Index Values Obs. or (Est) by Eqn (D10)	Calculated by Eqn (D6) D	P
	3.6	24	96	243	101	x	10	0	3.5	310	36	2.8	5.60	4.5	5.13
	x	x	x	x	102	No suitable test sec.				x	x	x	x	x	x
Region	4.1	30	76	283	103	67	9	6	6.0	620	20	2.4	5.76	5.5	5.87
A	4.0	21	71	251	104	x	12	0	3.0	275	22	3.2	5.74	5.1	5.59
	5.2	32	61	149	105	x	10	0	9.0	490	24	2.3	5.62	5.4	5.78
(BRT)	3.6	26	65	272	106	60	14	4	5.0	497	30	2.5	5.70	5.8	6.03
	4.1	15	90	198	107	48	9	5	14.0	1010	30	2.7	6.08	5.3	5.73
	3.2	21	91	364	108	x	11	0	4.0	532	27	2.3	5.66	4.5	5.15
	4.0	17	81	249	109	50	8	6	6.5	590	29	2.5	5.77	5.4	5.76
Mean	4.0	14	82	535	110	70	10	6	5.5	1075	26	2.5	6.03	5.7	5.96
	5.1	23	60	119	111	45	9	6	9.0	392	34	3.1	5.84	6.0	6.16
Rain-	5.1	18	60	559	112	53	6	6	2.5	510	31	2.7	5.78	5.6	5.91
fall	3.2	10	91	345	113	62	11	7	12.5	1575	45	2.3	6.13	5.4	5.81
	3.2	13	100	480	114	57	12	8	6.0	1052	32	3.0	6.22	5.8	6.02
22 in.	3.5	12	73	122	115	65	8	6	4.5	200	54	2.7	5.38	4.9	5.49
	x	x	x	x	116	No suitable test sec.				x	x	x	x	x	x
	4.1	13	68	276	117	60	10	6	6.0	605	52	2.5	5.78	5.7	5.95
Frost	4.1	11	63	617	118	54	13	8	7.1	1600	43	1.9	6.01	6.3	6.33
	2.6	23	97	44	119	x	9	0	7.0	112	40	2.1	4.92	3.8	4.60
Index	2.2	21	90	1012	120	60	14	10	6.5	2400	26	2.6	6.42	5.8	6.07
350	2.1	21	80	16	121	x	10	0	10.5	60	50	1.8	4.56	3.8	4.54
	2.1	27	76	137	122	x	12	0	2.0	100	44	2.3	4.93	4.0	4.76
	2.4	30	62	60	123	52	11	4	3.5	77	36	2.6	4.92	4.7	5.28
	2.4	32	67	106	124	61	11	7	2.5	97	32	3.2	5.29	5.0	5.50
	(.8)	25	98	46	125	62	12	4	7.0	117	45	3.0	5.27	4.0	4.74
Avg.	1.7	18	87	528	126	81	9	10	3.5	675	31	1.9	5.64	4.8	5.38
for	(.5)	15	69	30	127	56	10	6	2.5	27	49	2.4	4.40	3.7	4.50
	2.0	21	74	346	128	62	13	6	4.0	505	41	2.2	5.60	5.0	5.53
Sects.	1.6	17	67	39	129	51	9	6	3.5	50	39	2.8	4.81	4.1	4.86
101	2.4	14	61	125	130	57	10	7	3.0	137	38	3.5	5.36	4.9	5.43
	2.6	12	93	187	131	51	9	8	4.5	307	53	2.9	5.64	5.0	5.51
to	(.5)	7	95	134	132	81	11	10	4.0	196	46	2.6	5.33	4.4	5.10
137	1.4	10	83	55	133	62	10	8	5.5	110	49	1.9	4.85	4.4	5.08
	(.7)	14	79	274	134	49	13	6	1.5	150	57	1.9	4.98	4.3	4.96
	(.7)	6	63	34	135	57	12	8	6.0	74	71	2.6	4.91	4.5	5.13
	2.0	10	73	64	136	57	11	5	3.5	82	61	2.5	4.91	4.6	5.23

[1] (.8) denotes 0.8 inches surface treatment

TABLE 17: ILLUSTRATIVE STUDY OF EXISTING FLEXIBLE PAVEMENTS - Data Summary [illegible] cont'd)

Experiment Design Variables					Other Design Variables							Performance Data			
Regions	Sur Th. h_1	Road bed s_4 (R values)	Base Str. s_2	Loads ADL	Test Sec. No.	Subb Str. s_3 (R)	Base Th. h_2	Subb Th. h_3	Yrs. Ser. Y	Acc. Lds $\Sigma L/1000$	BB Defl.	Serv. Index P_o=4.1	Performance Index Values		
													Obs or (Est) by Eqn (D10)	Calculated by Eqn (D6)	
														D	P
	x	x	x	x	137	No	suitable	test	sec.	x	x		x		
	3.1	27	91	340	138	x	12	0	6.0	746	29	1.8	5.65	4.5	5.18
	5.2	35	78	200	139	x	7	0	4.0	290	49	2.0	5.30	4.9	5.48
Region	3.4	31	77	202	140	62	12	4	4.0	295	37	3.1	5.72	5.3	5.75
B	4.9	26	55	125	141	52	6	4	6.5	295	47	2.6	5.51	5.2	5.67
	3.6	33	65	388	142	49	13	5	3.5	497	34	2.3	5.63	5.7	6.01
(ERT)	3.1	23	96	182	143	x	9	0	3.0	198	40	2.5	5.30	4.1	4.88
	3.6	17	87	400	144	82	12	7	6.5	950	30	2.9	6.13	5.8	6.07
	3.6	25	87	41	145	x	6	0	4.0	60	60	2.4	4.74	3.9	4.68
	4.1	19	75	420	146	50	10	8	9.0	1390	25	2.6	6.18	6.0	6.15
Mean	4.0	16	60	65	147	53	9	5	4.5	106	37	2.8	5.14	5.2	5.68
Rain-	4.5	25	61	222	148	43	12	6	12.0	975	40	2.5	5.99	6.2	6.29
	3.1	11	100	279	149	76	9	6	8.5	865	36	1.9	5.75	5.0	5.55
fall	4.2	7	93	335	150	x	12	0	13.5	1650	21	2.4	6.18	5.2	5.68
35 in.	4.2	13	90	52	151	x	8	0	4.5	85	51	3.0	5.13	4.5	5.20
	3.6	8	81	316	152	71	13	7	6.5	750	29	2.7	5.95	6.0	6.14
	4.6	6	62	113	153	60	10	6	10.0	410	43	2.6	5.65	5.8	6.05
	3.4	12	71	206	154	62	14	4	7.0	525	61	1.9	5.53	5.7	5.96
	x	x	x	x	155	No	suitable	test	sec.	x	x	x	x	x	x
Frost	(.7)	30	102	110	156	x	12	0	2.5	100	41	1.6	4.72	3.3	4.10
Index	(.5)	24	73	17	157	x	11	0	4.0	25	61	1.9	4.21	3.0	3.77
	(.5)	25	82	185	158	61	16	7	5.5	370	57	1.8	5.35	4.8	5.40
700	1.6	31	53	16	159	42	13	8	3.5	21	64	2.2	4.22	4.9	5.49
	2.1	32	69	160	160	53	14	7	3.0	175	49	2.5	5.24	5.4	5.78
	(.7)	21	86	44	161	83	9	8	6.0	97	59	1.6	4.71	3.9	4.65
	3.0	26	92	810	162	53	14	6	10.5	3110	21	2.4	6.46	5.7	6.00
Avg.	(.6)	20	80	60	163	72	11	7	3.0	65	42	2.7	4.89	4.1	4.83
	(.5)	21	78	192	164	61	15	7	3.0	210	57	2.0	5.16	4.7	5.28
for	1.4	16	65	39	165	61	11	9	4.0	57	49	2.9	4.91	4.8	5.40
Sects.	1.5	14	67	178	166	49	12	10	3.5	227	47	1.9	5.16	5.2	5.64
	(1.0)	6	97	23	167	x	9	0	3.5	29	61	1.9	4.27	3.0	3.76
137	2.4	10	102	250	168	61	13	6	6.5	595	37	3.0	5.97	5.3	5.70
to	1.5	11	90	28	169	45	8	9	10.3	105	61	2.2	4.92	4.4	5.08
	1.4	9	86	67	170	59	10	8	4.5	110	59	2.5	5.04	4.4	5.10
172	2.2	9	71	25	171	61	11	5	7.5	71	47	2.4	4.82	4.7	5.31
	x	x	x	x	172	No	suitable	test	sec.	x	x	x	x	x	x
AASHO R. T.		21	83	x	x	78	x	x	x	x	x	x	x	x	x

Conclusions from Selected Sections

It is supposed that a primary concern in any satellite study is to decide which designs are best suited to the regions that have been sampled. If, for example, a performance index of P = 6.0, is considered to be a minimal requirement for satisfactory performance, then Table 18 shows which sections have performed at this level in either region. In practice, performance index requirements will undoubtedly vary with the purposes being served by the various highway sections. TAB 18

Table 18 shows one section in each region whose performance is clearly superior to that of all other sections in the region. Through study of the characteristics of the better performing sections it is presumably possible to determine the nature of designs which are adequate for the region. On the other hand, there should be considerable interest in the shortcomings of those designs whose performance was not satisfactory, e.g., all test sections not included in Table 18.

If the satellite project includes test sections whose climate and materials are similar to those of certain AASHO Road Test sections, it is recommended that direct comparisons be made between satellite and AASHO Road Test performance. TAB 19 Table 19 shows such a comparison for the example. Sections are all within 25 percent of the corresponding values at the Road Test. This criterion produces ten sections in Region A and nine sections in Region B. Sections are grouped according to the AASHO Road Test structural index for flexible pavements shown in Table 17. The last column of Table 19 shows that a rather large number of test sections existed at the Road Test in each of the structural index classes. The sections used for comparison have been selected from Table D3 in Appendix D.

For each structural index class of Table 19, estimated values for P are given for the satellite test sections. For the corresponding Road Test sections only observed P values are considered, so

TABLE 18: TEST SECTIONS WITH P GREATER THAN 6.0

Estimated P	Region A	Region B
6.00 - 6.09	118, 100, 107	
6.10 - 6.19	113	144, 146, 150
6.20 - 6.29	114	
6.30 - 6.39		
6.40 - 6.49	120	162

TABLE 19: DIRECT COMPARISON OF SATELLITE AND AASHO ROAD TEST SECTIONS

Structural Index	Sections with s_4 = 16-26, s_2 = 62-104, s_3 = 58-98				AASHO Road Test Sections				
Class	Region A		Region B		Table	Observed P			
Eqn. (D6)	Test Section	Est. P	Test Section	Est. P	D3 Listing	No.	Mean	Max.	Min.
3.0 - 3.1			157	4.21	720 through 136	6	4.00	4.30	3.69
3.8 - 4.1	119 121 125	4.92 4.57 5.28	145 161 163 143	4.74 4.73 4.89 5.30	111 through 450	22	4.67	5.23	3.93
4.5 - 4.6	101 108	5.61 5.66			559 through 106	6	5.08	5.25	4.94
4.7 - 4.8	126	5.65	164 165 158	5.17 4.92 5.36	155 through 588	35	5.22	5.76	4.92
5.0 - 5.1	128 104	5.60 5.77			279 through 560	10	5.47	5.78	5.03
5.8 - 5.9	106 120	5.70 6.42	144	6.14	625 through 298	20	5.91	6.41	5.58
Average Difference from Road Test P		.30		.13					

that no question of extrapolation enters in, and average minimum and maximum values are shown for the performance indexes observed at the AASHO Road Test. Thus the comparisons in Table 19 do not involve predictions from AASHO Road Test performance equations.

If enough sections, say around ten or more, are involved in direct comparisons such as shown in Table 19, it should be possible to reach a tentative conclusion as to how the satellite test sections in a given region performed relative to AASHO Road Test sections. In Table 19, performance indexes in Region B are generally higher than in either Region A or at the Road Test. The last line of Table 19 shows that the average difference between satellite and Road Test performance is .30 for Region A and .13 for Region B. It can be shown that only the first of these differences is statistically significant at the five percent level. This conclusion is in agreement with the original experiment design which implied that Region A had a climate better than that of the AASHO Road Test, while Region B was presumed to have conditions nearly equal to that of the Road Test.

Adjustment of AASHO Road Test Relationships to Local Conditions

The main outcome of the comparisons in Table 19 was that performance in Region A was appreciably higher than that which was observed at the AASHO Road Test, and that performance in Region B was slightly higher than corresponding Road Test performance. In order to study the regional and other design variable effects for all test sections in the study, it is recommended that data for design and performance variables be averaged for each level of each experiment design variable as illustrated in Table 20. TAB 20

The last column of the table contains average residuals, i.e., differences between P as calculated by the AASHO Road Test equation and as observed or estimated.

TABLE 20: AVERAGES FOR DESIGN AND PERFORMANCE VARIABLES IN TABLE 17

Experiment Design Variable and Level		Exp. Design Variables					Other Design Variables							Calculated P minus
		Region	h_1	s_4	s_2	ADL	s_3	h_2	h_3	Y	ΣL/ 1000	defl.	Est. P	Estimated P
Regions	A	A	2.9	18	77	255	59	10.6	5.2	5.4	513	40	5.50	-.03
	B	B	2.6	20	79	177	59	10.9	4.7	5.7	441	45	5.28	.05
Surface Thickness	Hi	A	4.0	18	76	330	57	10.3	4.6	6.3	734	33	5.83	-.02
		B	4.0	20	78	227	60	10.1	3.4	6.5	576	39	5.60	.06
		A+B	4.0	19	77	278	58	10.2	4.0	6.4	655	36	5.71	.02
	Lo	A	1.7	18	79	180	60	10.9	5.9	4.5	293	39	5.17	-.04
		B	1.3	19	81	127	59	11.7	5.9	5.0	306	51	4.96	.04
		A+B	1.5	18	80	154	60	11.3	5.9	4.8	300	48	5.06	.00
Roadbed Strength	Hi	A	3.2	26	76	235	60	11.1	2.6	5.1	443	33	5.43	-.04
		B	2.6	29	75	163	53	11.1	2.9	4.2	261	47	5.09	.07
		A+B	2.9	28	75	199	56	11.1	2.8	4.7	352	39	5.26	.01
	Med.	A	2.9	18	77	262	58	9.7	5.8	5.4	468	35	5.54	-.12
		B	2.6	20	78	221	61	10.8	6.2	5.8	620	42	5.40	.06
		A+B	2.7	19	77	241	59	10.3	6.0	5.6	544	39	5.47	-.02
	Lo	A	2.5	11	79	267	59	10.9	7.3	5.7	629	51	5.51	.06
		B	2.8	9	86	147	62	10.7	4.9	7.2	442	46	5.35	.03
		A+B	2.6	10	82	207	60	10.8	6.1	6.5	536	49	5.43	.05
Base Strength	Hi	A	2.6	18	92	319	63	10.7	5.3	6.3	713	37	5.72	-.32
		B	2.6	20	91	249	71	10.7	2.8	6.2	721	38	5.38	-.32
		A+B	2.6	19	92	284	66	10.7	4.0	6.3	717	37	5.55	-.32
	Med.	A	2.7	18	76	243	59	10.6	4.9	4.9	443	40	5.33	.03
		B	2.4	20	81	148	60	10.6	4.8	5.2	313	49	5.22	.02
		A+B	2.6	19	79	196	60	10.6	4.8	5.0	378	45	5.27	.02
	Lo	A	3.2	19	64	202	55	10.5	5.5	5.1	384	41	5.43	.20
		B	2.9	19	65	134	54	11.2	6.4	5.8	289	47	5.23	.46
		A+B	3.1	19	65	168	54	10.9	6.0	5.4	337	44	5.34	.33
Average Daily Load	Lo	A	2.9	18	78	139	56	9.7	4.9	6.7	374	42	5.35	-.02
		B	2.7	20	77	84	60	9.1	3.8	5.3	171	50	4.94	.10
		A+B	2.8	19	78	112	58	9.4	4.3	6.0	273	46	5.14	.04
	Hi	A	2.9	18	76	371	61	11.5	5.6	4.1	653	37	5.65	-.04
		B	2.6	20	81	270	58	12.6	5.6	6.2	710	40	5.62	.01
		A+B	2.7	19	78	320	60	12.0	5.6	5.1	682	38	5.63	-.02
All Test Sections			2.8	19	78	216	59	10.7	4.9	5.6	478	38	5.39	.01
											Mean Absolute Residual			.27

It is recommended that each category of Table 20 be examined in some detail before any further analysis is attempted. From this table can be seen not only how much effect the experiment design variables have on P and on the residuals, but also the extent to which there are intercorrelations among the design variables.

Table 20 shows that Region A averages to have 5.50-5.28 =.22 higher performance index than Region B, about the same as for the selected sections of Table 19. Regional averages for the remaining variables are fairly equal except for ADL which is higher in Region A than in Region B. Thus the question is whether regional performance effects would have been any different had the ADL values been more nearly equal. Average residuals in the last column show how the performance equation would have to be modified to give a mean residual of zero for the two regions. The equation, for example, would have to be made .03 greater for Region A and .05 less for Region B in order to produce average residuals of zero for the two regions.

The equation appears to account properly for the effect of h_1 since mean residuals are about the same for both levels of surface thickness.

Roadbed strength is intercorrelated with several of the design variables, and the average effect of s_4 is not regular for either P or the residuals. In the illustrative data, sections with low s_4 average to have greater structural thickness than sections with high s_4. For this reason any real effect of s_4 is perhaps masked by thickness effects. Base strength, s_2, is noticeably intercorrelated with ADL, s_3 and h_3. However, the average residuals for different levels of s_2 are quite pronounced. Thus equation (D6) can presumably be adjusted to account for base strength.

Table 20 shows that changing from low to high ADL corresponds to a total change in h_2 and h_3 of about four inches. Taken at face value, average P is about 5.63-5.14 = .51 higher for ADL = 320 than for ADL = 112, but this is also about the amount that four extra inches of base or subbase can be expected to contribute to P. In short, the experimental data are such that it is not possible to infer any separate effect of ADL upon the performance index--nor to adjust the equations for the ADL effect. This example clearly shows that selected experiment design factors in an existing pavement study are likely to be interrelated with one another and with other factors--simply because the basic principles of pavement design imply that relative weakness in one structural component must be compensated for by relative strength in another component. While the factorial experiment design helps to reduce these inherent correlations, it is virtually certain that many intercorrelated design variables will appear in existing pavement studies. In the present example, any conclusion about the effect of ADL will have to be determined from other studies, preferably from a study of new experimental pavements.

It is perhaps worth pointing out that when design variables are intercorrelated it will generally be invalid to plot values of a performance variable against values of any single design variable and suppose that the resulting graph shows the underlying relationship between the two variables.

The last two lines of Table 20 show average residuals, algebraic and absolute, for the equation whose adjustment is being considered. It is seen that the mean absolute residual is .27 as contrasted with about .20 for the AASHO Road Test sections.

In summary, Table 20 indicates that the performance equation for calculating P may be adjusted for the regional effect and for the effect of base strength. Had the roadbed strength effect been more regular there would be value in adjusting the equations for s_4. Very little adjustment seems to be needed for surface thickness, h_1. The intercorrelations between ADL and other design variables are so high that it does not seem warranted to try to infer the real effect of this variable upon performance. Finally it is clear that even minor adjustments to the equations will bring them to a closer fit of the illustrative data than to the original AASHO Road Test data.

While graphical and trial and error procedures might be used to adjust one or more of the equations to local conditions it is suggested that analysis of variance and regression analysis will lead to the desired result with more generality and objectivity. No analysis of variance will be shown here, but if the variances of estimated P's and residuals are analyzed, much the same conclusions will be reached as have been observed by inspection of Table 20. This type of analysis will be illustrated in Section 5.2 of the guidelines.

The following special cases of equations (10) and (11), given in Section 4.4.3, will be used as models for fitting the illustrative performance data:

$$P = A_o + A_1 \log D + A_2 RF + \log \log (p_o/2.5)^4$$

where RS is simply a regional code whose value is .5 in Region A and -.5 for Region B, and where the structural index is

$$D = a_1 h_1 + a_2 \sqrt{\frac{s_2}{83}}\, h_2 + a_3 \sqrt{\frac{s_3}{78}}\, h_3 + 1.0$$

The factors for base and subbase strength are relative to the corresponding AASHO Road Test values. It is assumed that surfacing strength is not a factor and that the roadbed strength is so highly correlated with other factors that its effect cannot be determined.

It is not possible to determine values for a_1, a_2, a_3, A_o, A_1 and A_2 by a direct regression analysis because of the non-linear model, so a two-stage procedure will be used.

In the first stage A_o and RF are ignored, and A_1 is assumed to be 8.0 as in the Road Test equation (D6). Then, since $\log \log (po/2.5) = \log \log (4.1/2.5) = -.50$, it is supposed that

$$\exp \left[(P + .50)/8\right] = a_1 h_1 + a_2 \sqrt{\frac{s_2}{83}}\, h_2 + a_3 \sqrt{\frac{s_3}{78}}\, h_3 + a_4$$

where exp is the exponential function such that $\exp x = 10^x$. A linear regression analysis for this model produces

$$\exp \left[(P + .50)/8\right] = .51 h_1 + .20 \sqrt{\frac{s_2}{83}}\, h_2 + .10 \sqrt{\frac{s_3}{78}}\, h_3 + .93$$

so the structural index is now assumed to be

$$D = .51 h_1 + .20 \sqrt{\frac{s_2}{83}}\, h_2 + .10 \sqrt{\frac{s_3}{78}}\, h_3 + 1.0$$

A second regression analysis gives the final performance equation,

$$P = 7.95 \log D \begin{bmatrix} +.08 \text{ in Region A} \\ -.08 \text{ in Region B} \end{bmatrix} + \log \log (p_o/2.5)^4 \pm .16$$

The new equation accounts for regional performance differences as well as variations in base strength, and may be considered to be generally applicable to the (hypothetical) conditions of the satellite study. Residuals in P average to be zero and have a mean absolute value of .16.

If desired, regional differences can be expressed in terms of a relative strength measurement, RS. For example, if deflections of AASHO Road Test sections (Table C2) are divided by deflections of comparable satellite sections (Tables 17 and 19) it will be found that the average ratio is RS = 1.46 in Region A and RS = 1.04 in Region B. An approximate replacement of the regional factors ±.08 would then be log (RS/1.2).

One final relationship will be developed from the hypothetical data of Table 17, between performance index values and corresponding deflections. A linear regression of P on log d gives

$$P = 9.90 - 2.81 \log d \pm .27$$

from which deflection values may be used to predict the performance indexes of the satellite test sections.

It can be seen that the average absolute residual for predicting P from d is about twice that for predicting P from D and RF or RS (.27 vs. .16). At the AASHO Road Test, both these average residuals were slightly over .20.

There are many other analyses of the data in Tables 16 and 17 that could prove useful in the local study of existing flexible pavements, but the main intent of the example has been to show rather explicitly how pavement performance relationships developed at the AASHO Road Test can be adjusted to climates and materials that may be found among the satellite study sections--at least for those design variables whose intercorrelations are reasonably low. Effects of design variables which cannot be suitably studied in the existing pavement sections will presumably be investigated in studies of new experimental pavements.

5.2 Individual Study of New Experimental Pavements

A hypothetical rigid pavement study will be used to illustrate the guides that are given in Chapter 4 for the study of new experimental pavements. There is no implication that the factors and levels selected for the illustration are those that would be selected in any particular satellite study.

The general experiment design for the study is shown in Table 21. TAB 21

Three pavement structure factors have been selected:

1. Surfacing thickness at two levels, 6 in. and 8 in.,
2. Surfacing reinforcement at two levels, non-reinforced and continuously reinforced,
3. Subbase quality at three levels, lime stabilized soil, gravel, and bituminous treated gravel.

All 2 x 2 x 3 = 12 combinations of these factor levels are constructed at two test sites, Site 1 and Site 2, and two replicate sections appear at each site. The major difference between test sites is in the roadbed soil characteristics, it being assumed that both sites have about the same climate as prevailed at the AASHO Road Test.

Test section numbers in Table 21 refer to two-lane sections. Thus there are 28 (two-lane) structural sections in the experiment design, 14 at each test site, and twice as many one-lane test sections. In this illustration all (hypothetical) data and analysis will be for the outer lane test sections. In an actual experiment it would be better to observe the loads and performance of test sections in both traffic lanes. If loads are essentially equal in the two lanes, average performance in the two lanes should be used in the analysis. If one lane carries considerably more loads than the other, then differences in performance between the two lanes can be attributed to the ADL factor. Thus it is possible to study the effect of ADL within test sites as well as between test sites--provided that adequate load measurements are made.

TABLE 21: INDIVIDUAL STUDY OF NEW EXPERIMENTAL RIGID PAVEMENTS

Experiment Design - Test Section Numbers

Surface Thickness	Surface Reinforcement	Sub-base Qual'y.	Test Site 1	Test Site 2	
			A-6 Roadbed Soil	A-4 Roadbed Soil	
6"	NR	L	211	232 (Replicate)	
		G	212	233	
		B	213	234	
	CR	L	214	235	
		G	215	236	
		B	216 217 (Replicate)	237	
8"	NR	L	218	238	
		G	219 220 (Replicate)	239	
		B	221	240	
	CR	L	222	241	
		G	223	242 243 (Replicate)	
		B	224	244	
Sections per lane			14	14	28

Notes: 1. Subbase Quality: L = Top 6 inches of roadbed soil is lime stabilized.

G = 6 inches of gravel similar to AASHO Road Test subbase.

B = 6 inches of 3 percent bituminous treated pit run gravel.

2. Surface Reinforcement: NR = Non-reinforced, 15 foot joint spacing, doweled.

CR = 0.5 percent continuously reinforced concrete.

As shown in Figure 7, test sections are assumed to be 800 feet long and are placed in random order at each test site. After the randomization, transition pavement between test sections was provided: FIG 7

1. Two hundred foot transitions between adjacent sections of the same type, either NR or CR.
2. Four hundred foot transitions between NR and CR sections, three hundred of which is CR extended into the transition to provide adequate continuous action.

Hypothetical data for Section 201 are given in Table 22, at time of construction and after four and eight years of observation. This section had an initial serviceability index of 4.5, an index of 3.0 after four years, and is shown to have $p = 2.5$ after eight years. TAB 22

Illustrative performance records for Sections 201 and 228 are shown in Figure 8a. It can be seen that both records are concave upwards. Figure 8b shows graphs of p versus log ΣL, and indicates performance indexes of $P = 6.2$ for Section 201 and $P = 6.9$ for Section 248. FIG 8

The performance index for Section 201 was observed after eight years, but as shown in the last line of Table 22, its estimated index after four years was $P = 5.98$. TAB 23

A summary of data for all test sections is given in Table 23. Over half the test sections are shown to be above $p = 2.5$ after eight years. Performance index values for these sections were estimated by the procedures given in Appendix D. The last column of the table gives calculated performance index values for each section, using one of the AASHO Road Test performance equitions given in Appendix D.

General Conclusions

Casual comparison of the last two columns indicates that the satellite study sections have higher performance index values than were predicted from the Road Test equation.

Table 23 brings out that the two sites differ not only in roadbed characteristics but also in ADL and to a lesser extent in s_1, the strength of surfacing material. Thus, with only two sites, it will not be possible to separate the effects of site factors.

Fig 7: Test Section Layouts for Individual Study of New Rigid Pavements

(HYPOTHETICAL)

Transitions 200' between Sections of like reinforcement. 400' between NR + CR, with 300' being CR.

TABLE 22 : STUDY OF NEW EXPERIMENTAL RIGID PAVEMENTS

Test Section - Data Summary Sheet (Hypothetical Data)

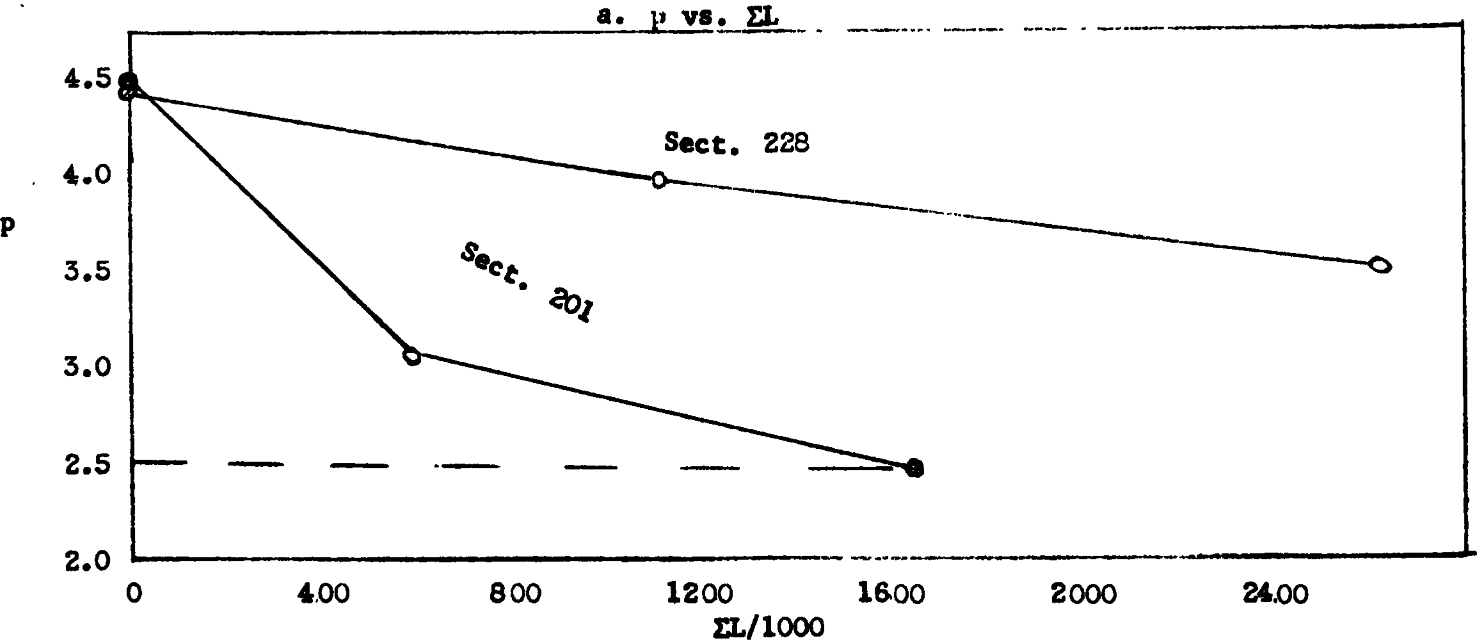
Section No. 211 Location U.S. 89 Tacosa County Date Constructed July '61

Dimensions 800 ft. x 200 Other Site 1 NR

		Dates of Measurement		
		Const. Records	Jan. '65	July '69
STRUCTURE VARIABLES				
Composite Strength: 18^k BB defl., .001"		30	20	28
Surfacing - Mod. of Elas	:	4 x 10⁶		
As-built Str.	: 28 day Flex.	700 psi		
Field Str.	: (Dyn. Mod.)	—		
Reinforcement	: Type + °/o	None		
Load Transfer	: Type, space	Dowels, 12" c-c		
Thickness	: Inches	6.0 ± .4		
Subbase Lab Strength	: Cohesiometer			
Field Str.	: K value(30")	250 ± 20		
Thickness	: Inches	5.8 ± 1.0		
Stabilization, Agent + °/o		Lime		
Roadbed Material				
Lab Strength	: CBR	3		3½
Field Strength:				
Swell	: °/o	3 %		
LOAD VARIABLES				
Accumulated 18^k appls.	: ΣL/1000		656	1660
Years of Service	: Y	0	4.0	8.0
Avg. daily 18^k appls.	: ADL		450	570
CLIMATIC and REGIONAL VARIABLES				
Mean annual rainfall	: Inches	30		
Avg. annual temp.	: Degrees	60		
Frost index	: C of E	500		470
General Character - Drainage		Good		
PERFORMANCE DATA				
Surface Roughness	: Slope Variance	2.1	12.7	20.4
Cracking - Patching	: SF/1000SF	0	20	40
Serviceability Index, p	: (Eqn 201)	4.5	3.0	2.5
Performance Index, P	: (Eqn D10)		5.98	6.22
	Estimates		(est.)	(obs)

Figure 8: Illustrative performance records and estimated performance indexes

a. p vs. ΣL



b. p vs. log ΣL

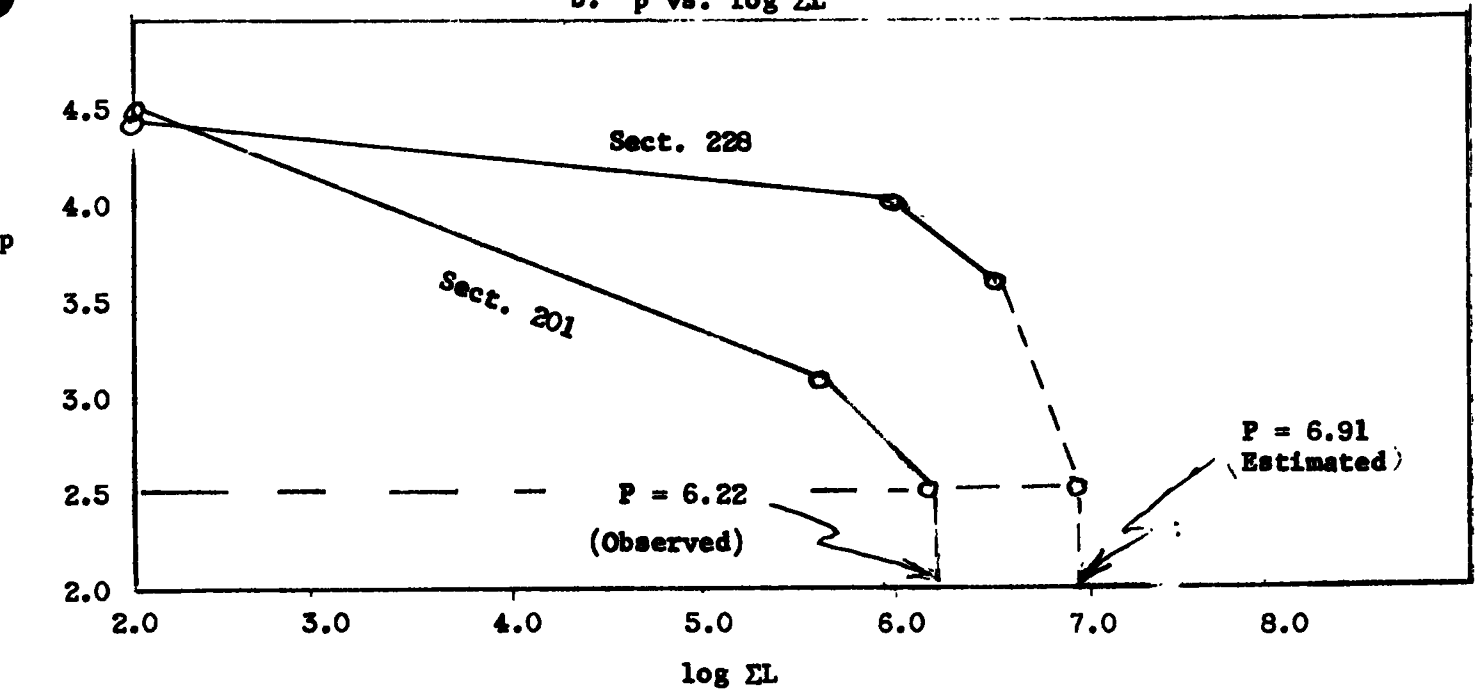


TABLE 23: DATA SUMMARY - ILLUSTRATIVE STUDY OF EXPERIMENTAL RIGID PAVEMENTS (Hypothetical Data)

Experiment Design Variables					Test	Other Design Variables			Load Variables		Performance Variables				
Roadbed Material s_4	Surf. Thick h_1	Surf. Reinf. c_1	Subbase Type and K Value c_3 and s_3		Sect. No.	Surface Strength s_1	Subb. Thick h_3	B.B. Defl. d	ADL and ΣL/1000		Service Index p or (ΣL/1000)			Performance Index	
									Y=4	Y=8	Y=0	Y=4	Y=8	Obs. or Eqn. (D 11)	Calculated Eqn. (B 7)
Site 1	6.0	NR	L	200	201		5.8	29			4.5	3.0	(1650)	6.22	5.96
Class	6.2	NR	G	100	202	Mod. Elas.	6.3	33	ADL		4.3	3.2	2.5	6.22	6.04
A7-6	6.0	NR	B	340	203	4.0 x 10^6	6.0	31			4.3	3.2	2.7	6.35	5.96
	6.1	CR	L	180	204		6.1	34	450	570	4.4	3.3	2.8	6.42	6.00
CBR	5.9	CR	G	90	205	Flex. Str.	5.6	38			4.4	3.4	2.9	6.47	5.92
3.0	6.1	CR	B	340	206	700	6.1	27	ΣL/1000		4.5	3.8	3.1	6.45	6.00
	6.0	CR	B	320	207		5.9	23			4.6	3.9	3.3	6.57	5.96
Swell	8.1	NR	L	210	208		5.9	19	656	1660	4.4	3.6	3.1	6.56	6.69
3 °/o	7.9	NR	G	100	209		6.0	20			4.3	3.7	3.2	6.58	6.63
	8.0	NR	G	90	210		6.2	21			4.4	3.8	3.3	6.62	6.66
	8.3	NR	B	310	211		6.2	15			4.4	3.9	3.4	6.63	6.75
	7.9	CR	L	200	212		6.0	15			4.3	3.9	3.5	6.74	6.63
	8.1	CR	G	90	213		6.2	19			4.5	4.2	3.8	6.78	6.69
	8.0	CR	B	340	214	↓	5.8	12			4.3	4.1	3.8	6.84	6.66
Site 2	6.0	NR	L	240	215		6.3	31			4.4	2.8	(1500)	6.18	5.96
Class	6.0	NR	L	260	216	Mod. Elas.	6.0	33	ADL		4.5	3.0	(1810)	6.26	5.96
A4	6.1	NR	G	120	217	4.2 x 10^6	6.3	26			4.1	2.6	(1500)	6.18	6.00
	6.2	NR	B	350	218		6.1	21	810	900	4.4	3.0	(2000)	6.30	6.04
CBR	6.0	CR	L	240	219	Flex. Str.	6.1	32			4.4	3.4	(2400)	6.38	5.96
9	5.9	CR	G	100	220	720	5.9	27	ΣL/1000		4.3	3.0	(2000)	6.30	5.92
	6.1	CR	B	320	221		6.0	23			4.4	3.8	3.3	6.89	6.00
Swell	8.1	NR	L	250	222		6.0	18	1180	2630	4.4	3.8	3.4	6.91	6.69
0.5 °/o	8.0	NR	G	100	223		6.1	19			4.3	3.7	3.2	6.73	6.66
	8.0	NR	B	330	224		6.3	16			4.5	3.8	3.3	6.79	6.66
	7.9	CR	L	230	225		6.2	17			4.2	4.0	3.6	6.79	6.63
	8.2	CR	G	120	226		6.0	18			4.3	4.0	3.4	6.67	6.72
	8.1	CR	G	110	227		5.8	23			4.5	4.0	3.5	6.81	6.69
	8.0	CR	B	330	228	↓	6.1	19			4.4	4.0	3.6	6.91	6.66

Note: Values in parentheses in serviceability index column are thousands of equivalent axle load applications when p = 2.5

Other conclusions that can be drawn by inspecting the next to last column of Table 23 are that better performance has been obtained at either test site from sections with thicker surfaces, and that the CR sections generally performed better than the NR sections. At each test site there are a number of pavement designs with high performance index values, say, over P = 6.7 (five million equivalent 18-kip applications). It may be supposed that any of these are quite adequate for the test site conditions.

Direct Comparisons With AASHO Road Test Performance

As in Section 5.1 of the guidelines it is recommended that direct comparisons be made between the performance of satellite test sections and comparable AASHO Road Test sections. In this example it is supposed that all NR sections on gravel subbase are directly comparable with the AASHO Road Test NR sections having six inches of subbase. Table 24 shows performance index comparisons, where the satellite section indexes are taken from Table 23 and the Road Test indexes from from Table D3 in Appendix D. TAB 24

It may be concluded from Table 24 that the satellite section performance is not essentially different from the AASHO Road Test performance--especially in view of the Road Test variability---for the particular pavement design that has been used for the comparison.

Adjustment of AASHO Road Test Relationships to Local Conditions

As in the example of Section 5.1, Table 20, it is recommended that mean values be obtained for P at each level of the experiment design variables. For the four experiment design factors of the illustration, Table 25 shows all one-factor and two-factor averages for P. For example, it is seen that the mean difference between 6 inch and 8 inch surfacing is 6.75 - 6.37 = .48, or that the mean difference between Site 2 and Site 1 is 6.60 - 6.53 = .07. To the extent that the .48 difference does not occur at both sites, or that the .07 difference does not occur at both thicknesses, there is interaction between the site and surfacing thickness factors, i.e., a two-factor interaction. The table shows that the mean differ- TAB 25

TABLE 24: PERFORMANCE INDEX COMPARISONS OF SATELLITE AND AASHO ROAD TEST SECTIONS

Surfacing Thickness	Non-reinforced Surfacing and 6 in. Gravel Subbase					
	Satellite Sections (Table 23)			AASHO Road Test Sections (Table D3)		
	Sect. No.	Obs. P	Est. P	Sect. No.	Obs. P	Est. P
6.0 in.	202	6.22		None		
	217	6.18				
	Avg.	6.22				
6.5 in.	None			249		5.67
				187		5.70
				250		6.02
				188		5.98
				697		6.53
				655		6.43
				698		6.36
				656	6.14	
				517	6.31	
				489	6.33	
				518	6.08	
				490	6.26	
				Avg.	6.23	6.10
8.0 in.				235		5.73
	209	6.58		236		6.07
	210	6.62		683		6.44
				657		6.36
	223		6.73	684		6.57
				658		6.72
	Avg.	6.60		539		6.80
				533		6.75
				540		6.81
				534		6.98
				393		7.18
				401		7.16
				394		7.25
				402	6.74	
				Avg.	6.74	6.68

TABLE 25: MEAN VALUES OF PERFORMANCE INDEX ESTIMATES (Hypothetical Data)

Factors and Levels		Site 1	Site 2	Both Sites
6" Surface		6.36	6.38	6.37
8" Surface		6.69	6.81	6.75
NR		6.43	6.52	6.48
CR		6.63	6.67	6.65
Sub-	L	6.48	6.58	6.53
base	G	6.52	6.49	6.50
	B	6.58	6.72	6.65
Site Means		6.53	6.60	6.56

Factors and Levels	Subbase L	 G	 B
6" Surface	6.31	6.29	6.51
8" Surface	6.75	6.71	6.79
NR	6.48	6.43	6.52
CR	6.58	6.57	6.79

Factors and Levels	NR	CR
6" Surface	6.25	6.49
8" Surface	6.70	6.80

ence between CR and NR sections is 6.79 - 6.54 = .27. The L and G levels of subbase have about the same mean values, and that for B is somewhat higher.

After the means table is constructed for P (or any other observations of pavement behavior) it is recommended that an analysis of variance be made to determine the relative amount of variation that can be explained by the experiment design. factors and their interactions. TAB 2

Table 26 gives the analysis of variance for the illustrative performance indexes. The first line of the table shows a total sum of squared deviations (SS) from the overall mean ($\bar{P}$ = 6.56) of 1.42. Of this, 1.17/1.42 = 83 percent is attributable to the main effects of the four factors. Two factor effects account for .14/1.42 = 10 percent additional variation, and seven percent of the total is attributable to three and four factor interactions.

Mean squares (MS) are sums of squares per degree of freedom (df) and are used to infer the significance of the factor effects relative to unexplained variation. In the present example it is assumed that three and four factor interactions (MS = .011) provide a reference for appraising any of the mean squares above this line.

This assumption amounts to the supposition that with more replicates, the mean square for replicates (.005 in the last line) would be similar to the high order interaction mean square.

In order for the main effects and two factor interaction effects to be significant by common statistical standards applied to the present example, they should have mean squares at least three times the reference mean square[1].

---

[1] Procedures for regression analysis, analysis of variance, and statistical tests of significance will not be given in the guidelines since they are available in many texts on the analysis of experimental data.

TABLE 26: ANALYSIS OF VARIANCE FOR PERFORMANCE INDEX VALUES (HYPOTHETICAL DATA)

Source of Variation	df	SS	MS
Total Variation around Grand Mean	23	1.420	
Main Effects			
Sites	1	.027	.027
Surfacing Thickness	1	.866	.866
Reinforcement	1	.177	.177
Subbase Type	2	.102	.051
Two Factor Interactions			
Sites x Surf. Thickness	1	.017	.017
Sites x Reinforcement	1	.003	.003
Sites x Subbase	2	.030	.015
Surf. Thickness x Reinforcement	1	.034	.034
Surf. Thickness x Subbase Type	2	.031	.015
Reinforcement x Subbase Type	2	.030	.015
Three and Four Factor Interactions	9	.103	.011
Replicate Differences	4	.021	.005

By this criterion only one two-factor interaction, surface thickness x reinforcement, approaches statistical significance. Of the four main effects, all but that of the site factor will be considered to be significant, and therefore will be used in the regression analysis of P. It will be found, in Table 26, that the main effects of thickness, reinforcement, and subbase type account for about 80 percent of the total variation.

Before leaving the analysis of variance it is noteworthy that the reference mean square of .011 is very close to the reference mean square in corresponding analyses of AASHO Road Test performance data (about .012).

The following forms of models (10) and (11), given in Section 4.4.3, will be used to fit the illustrative data:

$$P = A_0 + A_1 \log D + \log \log (p_o/2.5)$$

$$D = a_1 h_1 + a_2 c_1 + a_3 k + a_4$$

The three factors whose effects were inferred to be significant in Table 26 appear in the structural index, D. Surfacing thickness is used directly, as h_1, while reinforcement is coded so that $c_1 = 0$ for NR and $c_1 = 1$ for CR pavement sections. Subbase quality is introduced in terms of the modulus k, although it is recognized that the subbase effects shown in Table 25 are more curvilinear than linear with respect to k.

The same two-stage procedure that was used in Section 5.1 will be used to fit the observed data to the models. First the exponential function of $\left[P - \log \log (p_o/2.5)\right]/8$ is regressed on h_1, c_1 and k to obtain an expression for D,

$$D = .36h_1 + .34c_1 + .11k + 3.66$$

Then $P - \log \log (p_o/2.5)$ is regressed on log D to obtain

$$P = .47 + 8.19 \log D + \log \log (p_o/2.5) \pm .08$$

where the error term is a mean absolute residual between calculated and observed (or estimated) values of P. The AASHO Road Test performance equation (D5) in Appendix D has thus been modified to fit the satellite test data, partly in terms of coefficients but mainly through the extension to structural factors that did not appear in the AASHO Road Test.

Performance equations such as the one just developed can be used to determine the structural index, D, that would be required for a specified level of performance, P.

It is supposed that the average absolute residual, .08, will be considered at the time P is specified. The formula for D will then determine alternative combinations of h_1 and c_1 which yield the required D for a given value of k. When used in this way the performance equation may be regarded as a design equation.

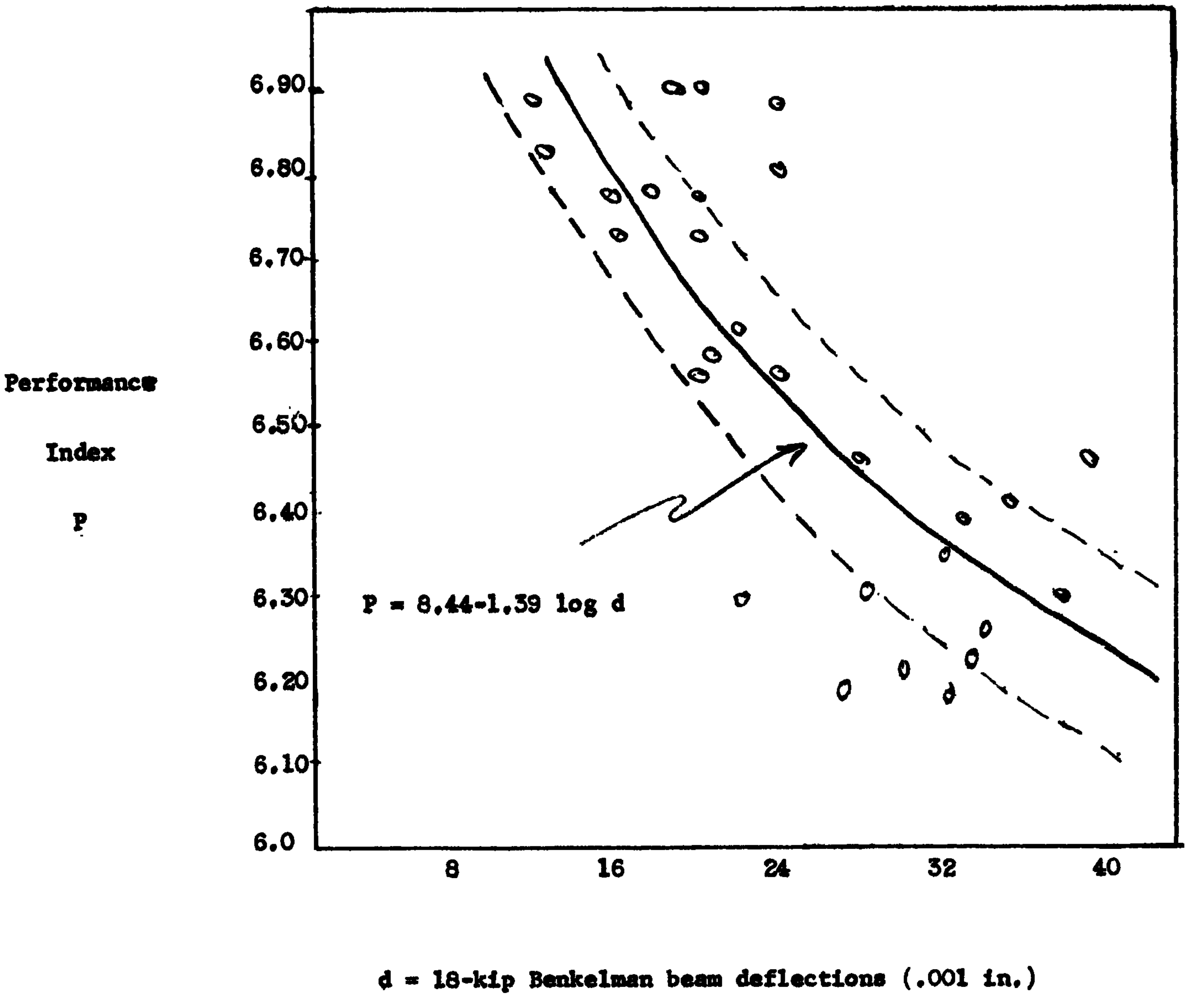
The last relationship that will be considered for the illustrative data is the association between P and d, the Benkelman beam deflections given in Table 23. When P is regressed on log d the resulting equation is

$$P = 8.44 - 1.39 \log d \pm .12$$

Although the error term is larger for this result than for the performance - structure relationship, both are considerably smaller than were the corresponding error terms at the AASHO Road Test. However, it should not be inferred that the results of this example would be borne out in an actual satellite study.

Figure 9 shows performance index and deflection data as well as the derived relationship between these variables. FIG 9
The dotted curves, at distances $\pm$.12 from the central curve, bring out that somewhat over half the observed points will generally be contained within one absolute mean residual of the values given by the equation.

Figure 9: Performance Index versus Deflections (Hypothetical Data)



Appendix A — Structural Variables

OUTLINE

- I Test Section Variables
  - A. Coring and Sampling
  - B. Thicknesses
  - C. Composite or Relative Strength
    - 1. Flexible
    - 2. Rigid
- II Surfacing Variables
  - A. Portland Cement Concrete
    - 1. Cement
    - 2. Aggregate
    - 3. Strength
  - B. Asphaltic Concrete
    - 1. Asphalt
    - 2. Aggregate
    - 3. Strength
    - 4. Durability and Composition
    - 5. Other Characteristics
- III Base and/or Subbases
  - A. Strength
    - 1. Existing - Field
    - 2. As-built
  - B. In-place Density and W/C
  - C. Stabilization or Treatment
  - D. Gradation and Classification
- IV Roadbed
  - A. Strength
    - 1. Existing field
    - 2. As-built
  - B. In-place Density and W/C
  - C. Classification Tests
  - D. Swell
  - E. Modifications or Treatment
- V Maintenance

Appendix A

Structural Variables

The purpose of this appendix is to provide a reference list for the many tests and procedures that may be used to evaluate structural variables that have been mentioned in the main text of the guidelines. These variables are called "strength characteristics" of the pavement components (surfacing courses, base courses, subbase courses, and roadbed materials) and include indicators of overall structural strength or "composite strength" as well as measures of individual strength. It is suggested that whenever possible, standard AASHO or ASTM methods be utilized to minimize the variations in results which occur due to modifications in testing techniques. It is not to be implied that all of these tests are recommended for use. Normally one or perhaps two methods will be chosen from each category for use.

No details are provided for any of the tests involved. Wherever possible, references are provided to nationwide standard tests. In some cases a reference is made to a standard test procedure of one of the state highway departments. The least specific information given will be to tests and procedures which have not yet been adopted as a standard method by anyone, but which have been used extensively, e.g., test procedure at the AASHO Road Test.

It is expected that an important adjunct to the guidelines will take the form of a manual that includes specific directions for evaluating structural, load, and performance variables.

I. Test Section Variables

This category contains variables which apply to the entire test section as a unit or to several parts of the test section separately.

A. Coring and Sampling in Existing Pavements

It is extremely difficult to sample materials in existing pavements without undue degradation of the aggregates or the disturbance of in-place samples, etc. Certain precautions are, therefore, necessary. The measurement team project should provide specific information on the problems involved with sampling of existing pavements. The size of samples will, of course, depend on the particular testing program involved in a given study.

B. Thickness

Coring or other destructive investigations are presently required to obtain reasonable estimates of layer thickness. Several such tests are required to provide information concerning possible thickness variations. This is true for both new and existing pavements.

C. Composite Strength (Relative Strength)

This category contains those variables whose values are obtained from nondestructive tests and which reflect the structure's overall resistance to loads applied at the pavement surface, e.g., load carrying capacity. It is hoped that these values will be helpful as predictors of pavement life or as indicators of relative environment.

1. Flexible Pavement

a. Benkelman beam deflections. This relatively simple tool has proved to be very useful at both the WASHO and AASHO Road Tests. Sample procedures can be found in the following references:

Special Report 61E, AASHO Road Test Report 5 Pavement Research, page 283, Appendix D. Highway Research Board.

Special Report 22, The WASHO Road Test, page 97, Highway Research Board.

Special Report 73, St. Louis Conference on the AASHO Road Test, 1962, pages 103, 104, Highway Research Board.

b. LVDT Deflections. In some instances it will be practical and desirable to install permanent stations for making dynamic deflections. Such measurements were also used at the AASHO Road Test:

Special Report 61E, AASHO Road Test, Report 5, Pavement Research, page 283, Highway Research Board.

c. Dynamic Moduli Testing. An important new nondestructive testing method is now available which should prove to be very helpful. The equipment and methods presently in use vary from agency to agency.

References: U. S. Corps of Engineers, "A Procedure for Determining Elastic Moduli of Soils by Field Vibratory Techniques".

Heukelom, W. and Foster, C.R., "Dynamic Testing of Pavements" Proceedings ASCE, Journal of the Soil Mechanics and Foundations Division, No. SMI, Part I, Volume 86, February 1960.

The AASHO Road Test Report 6, Special Studies, SR61F, page 109, Highway Research Board, 1962.

d. Plate Load Tests - ASTM D1195-57 and D1196-57

2. Rigid Pavements

a. Static Rebound Deflections. At the AASHO Road Test the Benkelman beam was first adopted for use on rigid pavements. The technique proved to be very successful and simple. References are listed below but the publication of standard procedures is still needed.

References: The AASHO Road Test, Report 5, Pavement Research, pp. 180-200, SR 61E, Highway Research Board, 1962.

Hudson, W. R., "The Value of Benkelman Beam Deflections in Rigid Pavement Design", Texas Highway Research, Report No. 62-5, 1963.

b. Dynamic Deflections. On new pavement studies it may be feasible to install the equipment necessary for dynamic deflections. One such measurement method was used at the AASHO Road Test.

Reference: The AASHO Road Test, Report 5, Pavement Research, pp. 180-200, SR 61E, Highway Research Board, 1962.

c. Volumetric Determination of Westergaard K.
The U.S. Corps of Engineers has developed a nondestructive method of determining Westergaard's Foundation Modulus.

Reference: The AASHO Road Test, Report 6, Special Studies, page 107, SR 61F, Highway Research Board, 1962.

d. Pavement Load - Strains. Wherever feasible the rigid pavement sections should be instrumented with strain gages to determine load Stresses.

Reference: The AASHO Road Test, Report 5, Pavement Research, pp. 179-200, SR 61E, Highway Research Board, 1962.

Hudson, W. R. "Comparison of Concrete Pavement Load-Stresses at AASHO Road Test with Previous Work." Highway Research Board, 1963.

II. Surfacing Variables

A. Portland Cement Concrete

1. Strength - considerable variation exists concerning age for new concrete testing. Fourteen-day testing is recommended as a compromise. For existing pavements, age should be specified.

   a. AASHO T97 - 60 (ASTM 78 - 59) Flexural Strength of Concrete (using simple beam with third-point loading). From time to time AASHO and ASTM test methods are revised. Whenever applicable, use latest version of methods in lieu of those listed.

   b. Splitting Tensile Strength of Molded Concrete Cylinders - ASTM C 496 - 62 T.

   c. Compressive Strength of Molded Concrete Cylinders - AASHO T22 - 60 (ASTM C 39 - 59).

2. Durability - Concrete pavements are subjected to extreme temperatures and deicing chemicals during their life. Some evaluation of this property is needed.

   a. Freeze-thaw test ASTM (C 290, C 291, C 292, and C 310) - 61T.

   b. See soundness of aggregates.

   c. Air content - plastic concrete - AASHO T 152 - 57 (ASTM C 231 - 60) and (ASTM C 173 - 58).
   Hardened concrete - ASTM C 457 - 60T

3. Supporting Methods
   a. Making and Curing Concrete Compressive and Flexural Specimens in the Laboratory -- AASHO T126 - 60 (ASTM C 192 - 59).

   b. Making and Curing Concrete Compressive and Flexural Specimens in the Field -- AASHO T23 - 60 (ASTM C 31-59).

   c. Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths-- AASHO T24 - 60 (ASTM C 42 - 60).

4. Cements

5. Aggregates - "Abrasion of Coarse Aggregates by Los Angeles Machine", AASHO T96 - 60.
   "Soundness of Aggregates by Use of Sodium Sulfate", AASHO T104 - 57.
   "Sieve Analysis of Fine and Coarse Aggregates", AASHO T27-60.
   "Unit Weight of Aggregates", AASHO T19 - 56.
   "Plastic Fines in Aggregate, Index of Sand Equivalent", AASHO T176 - 56.

B. <u>Bituminous Concrete</u>

1. Density - In-place determination. "Specific Gravity of Compressed Bituminous Mixtures" ASTM D1188 - 53 (samples cut from roadway). "Bulk Specific Gravity of Test Specimens" AASHO T165 - 55 or ASTM D1075 - 54 (samples cut from roadway).

2. Void Content - "Maximum Specific Gravity of Bituminous Mixtures" ASTM STP 191 or Asphalt Institute Mix Design Manual, Second Edition.

3. Bitumen Content - "Quantitative Extraction of Bitumen from Bituminous Paving Mixtures" ASTM D2172 - 63T.

4. Strength - "Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus" ASTM D1559 - 60T.
   "Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus" ASTM D1560 - 62T.

5. Asphalt Quality and Durability - "Penetration of Bituminous Materials" ASTM D5 - 61, "Recovery of Asphalt from Solution by Abson Method" ASTM D1856 - 63.

"Thin Film Oven Test" AASHO T179 - 60 or ASTM D2170 - 63T.
"Saybolt Viscosity" ASTM D88 - 56 or AASHO T72 - 57.
"Kinematic Viscosity of Asphalts" ASTM D2170 - 63T.
"Absolute Viscosity of Asphalts" ASTM D2171 - 63T.
"Viscosity by Hallikainen Microfilm Viscometer", Texas Transportation Institute Procedure, 1963.
"Viscosity of Asphalt Cement from a Construction Standpoint", NBCA (National Bituminous Concrete Association).
"Proposed Method of Testing for Aging Index of Bituminous Materials", pages 47 - 55, Texas Trans. Inst. - Texas Highway Department Cooperative Research Project 15, Report No. 4, October 1962. (Under ASTM study now).
Hveem, Zube, and Skog, "Determination of Ductibility", Proceedings Association Asphalt Paving Technologists, 32, page 324 (1963).

6. Aggregates - See Portland Cement Concrete

7. Supporting Tests - "Sampling Bituminous Paving Mixtures", AASHO T168 - 55 (ASTM D 979 - 51).

III. Base and Subbase

A. Granular (Identification tests also apply to aggregate portions of stabilized bases)

1. Identification Tests
"Wet Preparation of Disturbed Soil Samples for Test", AASHO T146 - 49.
"Dry Preparation of Disturbed Soil Samples for Test", AASHO T87 - 57.
"Mechanical Analysis of Soils", AASHO T88 - 57.
"Determining the Liquid Limit of Soils", AASHO T89 - 60
"Determining the Plastic Limit and Plasticity Index of Soils", AASHO T90 - 61.
"Plastic Fines in Graded Aggregates and Soils by Use of Sand Equivalent Test", AASHO T176 - 56.

2. Moisture and Density Tests
"Moisture - Density Relations of Soils Using a 10-pound Rammer and an 18-inch Drop", AASHO T180 - 61T.
In-place moisture and density may be determined by a properly calibrated nuclear device.

"Field Method for Determination of In-place Density of Soils and Base Materials", Tex 115 - E.
"Field Moisture Content" - sample shall be appropriately dried in the field or sealed and transported immediately to the lab for oven drying.

3. Strength Tests
"Triaxial Compression Tests for Disturbed Soils and Base Materials", often termed "Texas Triaxial", Tex - 117 - E July 1963.
"Kansas Triaxial Compression Tests" (as described in Bulletin No. 8, HRB, 1947).
"Suggested Method of Test for Moisture Density Relationship and California Bearing Ratio of Soils (CBR)", submitted by Corps of Engineers, U. S. Army, Procedures for Testing Soils, April 1958, ASTM "Suggested Methods".
"Method of Test for Determination of the Resistance "R" value of Treated and Untreated Bases, Subbases, and Basement Soils by the Stabilometer", California 301-D (July 1963).

B. Stabilized Layers - Many of the tests described above are applicable to stabilized layers. In addition, some test should be included to evaluate the bending or tensile strength of the stabilized layer, such as the following:

1. Content of stabilizing agent should be determined and reported.

2. Aggregate - All appropriate identification tests should be run (see granular base and subbase list).

3. Strength - "Method of Test for Cohesiometer Value", California 306-C, July 1963.
"Unconfined Compression Test", ASTM C496 - 62T. This test should be adopted for testing of cores and molded cylinders of stabilized materials.
"Splitting Tensile Strength" - This tentative test has a good theoretical background and has been used successfully in the testing of concrete. It should be investigated as a possible means of evaluating the tensile properties of stabilized bases.

"Making and Curing Soil - Cement Compression and Flexible Test Specimen in the Laboratory" and "Flexural Strength of Soil Cement Using Simple Beam with Third-Point Loading", ASTM D 1632 - 59T and 1635 - 59T.

"Standard Method of Testing Soil Bitumen Mixtures" ASTM D 915 - 61.

IV. Roadbed Material

A. Identification Tests

Preparation of samples - see Granular Base and Subbase
Gradation " " " " "
Liquid Limits " " " " "
Plastic Limits " " " " "
Plasticity Index " " " " "

B. Moisture Density Tests

Moisture Content - see Granular Base and Subbase
Density " " " " "

(It may also be desirable to determine moisture - density relations for weak soils by the AASHO Method T99 - 61T (ASTM D 698 - 58T).

C. Strength Tests - see Base and Subbase

V. Maintenance

The amount and type of structural maintenance a section receives is important to its ultimate performance. A section can receive so much maintenance, for example, as to result in a modified structure, e.g., an asphaltic concrete overlay results in an increased surface thickness. On the other hand, certain types of maintenance operations result in a decrease in p and in a cursory analysis could appear to give decreased performance because of the rapid loss in p, e.g., excessive sealing of cracks or seal coating a section. Excessive patching sometimes results in extra roughness due to the poor quality of the patch job.

In either event the serviceability of the section will have been modified by maintenance. On the other hand, certain basic maintenance is inherent in a highway system and it may be desirable to evaluate the in-service pavements under these "normal maintenance conditions", e.g., many pavements in Texas are sealed every four or five years to offset oxidation of the asphalts. In any case, a set of maintenance ground rules should be set up for uniformity among the sections in any study.

The following general ground-rules are recommended for any study, particularly the nationwide study:

1. Crack sealing and patching repair of potholes are considered to be in the realm of "normally required maintenance". No restriction will be placed on the work, but "normal" schedules should be followed.

2. Seals - Some decision is required here since the effect of seals is known to be important to the life of a pavement.

3. Major Patching - When a section has received a large amount of patching it is considered to be structurally altered. Allowable maintenance at the AASHO Road Test was held to approximately ten percent of the surface area. From observations of existing pavement such a value appears to be reasonable for study of in-service pavements.

4. Overlays - This is considered to be beyond the class of "maintenance" as described for this project, because it results in direct modification of two structural variables, s_1 and h_1. Furthermore, p should be returned to 4.0+ by good overlay and this would destroy any possibility of analysis. Any possible study of such a section would involve the performance of the section prior to the overlay and/or the service received from the modified section after the overlay.

It is recommended that realistic cost records be kept for maintenance of the pavement in each test section along with adequate records of dates and actual work performed.

Appendix B

Load Variables

This appendix contains equivalency factors and computational procedures that may be used to convert actual axle load applications into equivalent numbers of 18-kip single axle load applications.

The concept of a load equivalency factor rests on the assumption that if N applications of an 18-kip single axle load are required to reduce a pavement's serviceability from p_o to $p = 2.5$, there is a multiplier, K, for some other axle load, L, such that KN applications of load L would also result in serviceability loss from p_o to $p = 2.5$. The multiplier K is called a load equivalency factor. The AASHO Road Test performance equations (see Appendix D) were such that values for K were obtainable from the equations. These values were not only somewhat different for flexible and rigid pavements, especially for tandem axle loads, but also varied with the pavement design itself. Variations in K for different designs are given in the AASHO Interim Guides for flexible and rigid pavement design. Table B1a shows average load equivalency factors, and their logarithms, TAB B for flexible pavement designs whose thickness indexes (see Appendix D) were 4, 5 and 6, and for rigid pavement designs whose surface thicknesses were 8, 9 and 10 inches.

Logarithms of the equivalency factors are given to show how much the performance index, log ΣL to $p = 2.5$, is affected by the equivalency factor. For example, if 10^6 applications of an 18-kip axle load reduced the serviceability of a section to $p = 2.5$, then the section's performance index is $P = \log 10^6 = 6.0$. If these 10^6 applications were all 6-kip axle loads, however, the equivalent applications would be $\Sigma L = .01 \times 10^6$, and $P = 6.0 - 2.00 = 4.0$.

In work that was done at the HRB subsequent to the AASHO Road Test it was noted that if the logarithms of the equivalency factors in Table B1a are plotted against the logarithms of the axle loads, the variations may be represented by the relationships

$$\log K = 4(\log L - \log 18) \text{ or } K = (^L/18)^4 \text{ for single axles}$$

$$\text{(B1)} \qquad \log K = 4(\log L - \log 33) \text{ or } K = (^L/33)^4 \text{ for tandem axles on flexible pavement}$$

$$\log K = 4(\log L - \log 29) \text{ or } K = (^L/29)^4 \text{ for tandem axles on rigid pavement}$$

TABLE B1: FACTORS FOR DETERMINING EQUIVALENT 18 KIP SINGLE AXLE LOADS

Observed Axle Load (kip)	a. AASHO Interim Guides (p = 2.5)				b. Fourth Power Approximations				c. Asphalt Institute Factors	
	Flexible		Rigid		Flexible		Rigid		Flexible	
Single Axle	Factor	Log	Factor	Log	Factor	Log			Factor	Log
2	.0002	-3.70	.0002	-3.70	.00015	-3.82			.054	-1.27
4	.0023	-2.64	.0020	-2.70	.0024	-2.62			.078	-1.11
6	.010	-2.00	.010	-2.00	.012	-1.92			.11	-.96
8	.033	-1.48	.030	-1.52	.039	-1.41			.16	-.80
10	.090	-1.05	.080	-1.10	.095	-1.03			.23	-.64
12	.19	-.72	.18	-.74	.20	-.70			.34	-.47
14	.36	-.44	.34	-.47	.37	-.43			.48	-.32
16	.63	-.20	.60	-.22	.62	-.21			.70	-.15
18	1.0	.00	1.0	.00	1.0	.00			1.0	.00
20	1.5	.18	1.6	.20	1.5	.18			1.4	.15
22	2.2	.34	2.3	.36	2.2	.34			2.1	.32
24	3.1	.49	3.3	.52	3.2	.51			3.0	.48
26	4.2	.62	4.6	.66	4.4	.64			4.3	.63
28	5.5	.74	6.3	.80	5.9	.77			6.2	.79
30	7.2	.86	8.4	.92	7.7	.89			8.9	.95
32	9.2	.96	10.7	1.03	10.0	1.00			11.4	1.06
Tandem Axle	Factor	Log	Factor	Log	Factor	Log	Factor	Log	Factor	Log
10	.01	-2.00	.01	-2.00	.008	-2.10	.014	-1.85	.14	-.84
12	.013	-1.89	.03	-1.52	.017	-1.77	.029	-1.54	.17	-.76
14	.027	-1.57	.05	-1.30	.032	-1.49	.054	-1.27	.21	-.68
16	.050	-1.30	.08	-1.10	.055	-1.26	.093	-1.03	.25	-.60
18	.080	-1.10	.13	-.89	.089	-1.06	.15	-.82	.30	-.52
20	.12	-.92	.21	-.68	.13	-.89	.23	-.64	.36	-.44
22	.19	-.72	.31	-.51	.20	-.70	.33	-.48	.43	-.37
24	.26	-.58	.44	-.36	.28	-.55	.47	-.33	.52	-.28
26	.37	-.43	.62	-.21	.39	-.41	.65	-.19	.62	-.21
28	.50	-.30	.85	-.07	.52	-.28	.87	-.06	.74	-.13
30	.66	-.18	1.1	.04	.68	-.17	1.2	.08	.89	-.06
32	.86	-.07	1.5	.18	.88	-.06	1.5	.18	1.1	.04
34	1.1	.04	1.9	.28	1.1	.04	1.9	.28	1.3	.11
36	1.4	.15	2.4	.38	1.4	.15	2.4	.38	1.5	.18
38	1.7	.23	3.0	.48	1.8	.26	3.0	.48	1.8	.26
40	2.1	.32	3.7	.57	2.2	.34	3.6	.56	2.2	.34
42	2.5	.40	4.5	.65	2.6	.42	4.4	.64	2.7	.43
44	3.0	.48	5.5	.74	3.2	.51	5.3	.72	3.2	.51
46	3.6	.56	6.5	.81	3.8	.58	6.3	.80	3.8	.58
48	4.2	.62	7.7	.89	4.5	.65	7.5	.88	4.6	.66
50	---	---	---	---	5.3	.72	8.8	.94	5.5	.74

These relationships are illustrated in Figure B1 and values obtained from equations (B1) are given in Table B1b. It is suggested that the "fourth power" approximations are sufficiently precise to use in evaluating axle load applications for satellite test sections. FIG B1

Analysis of flexible pavement performance data by the Asphalt Institute produced load equivalency factors as shown in Table B1c and Figure B1. These factors are included since they must be used to arrive at performance index values given by the AI performance equations (see Appendix D). It can be seen that the AI factors are considerably larger than the AASHO factors for small axle loads, and are somewhat larger for relatively heavy axle loads.

Table A22 represents a suggested procedure for determining the two axle load variables, ADL and ΣL for a single test section. In this illustration it is supposed that the section was first observed as a satellite test section after Y = 18 years of service. For each year the table provides for three classes of vehicles (autos, single unit trucks and tractor trailers) for single axle loads ranging from 2 to 30-kip and for tandem axle loads from 16 to 48-kip. In an actual case it may be desirable to include different vehicle classes and/or axle loads than are used for the illustration. TAB B2

Four rows are shown in the table for each vehicle class in each year. The first such row provides for tabulation of the actual distribution of axle loads obtained in loadometer studies carried out during the year. Thus for year 1 the table shows that no loads were actually weighed, but in year 18 weights were obtained for 5000 autos, 500 single unit trucks and 1000 tractor trailer combinations. The observed distribution of the latter is shown to be 100, 300, 100 and 50 for 12-kip, 18-kip, 24-kip and 30-kip single axles, and 100, 200, 100, 40 and 10 for the respective tandem axles shown.

The second row for each vehicle class and year gives the percent distribution by axle loads. If actual frequency distributions are obtained by weighing (as for year 18) the percent distribution is calculated by appropriate arithmetic. For years where no load data are taken, the percent distribution is estimated by projections that have been found to be suitable.

For each vehicle class and year, the third row gives the total number of axles in the last column. These values are presumed to have been obtained by actual counts, or by projections from sample counts in various years. The third row for each vehicle class and year is completed by distributing the total count according to the percent distribution in the second row.

Figure B1: Load equivalency factors vs. axle load

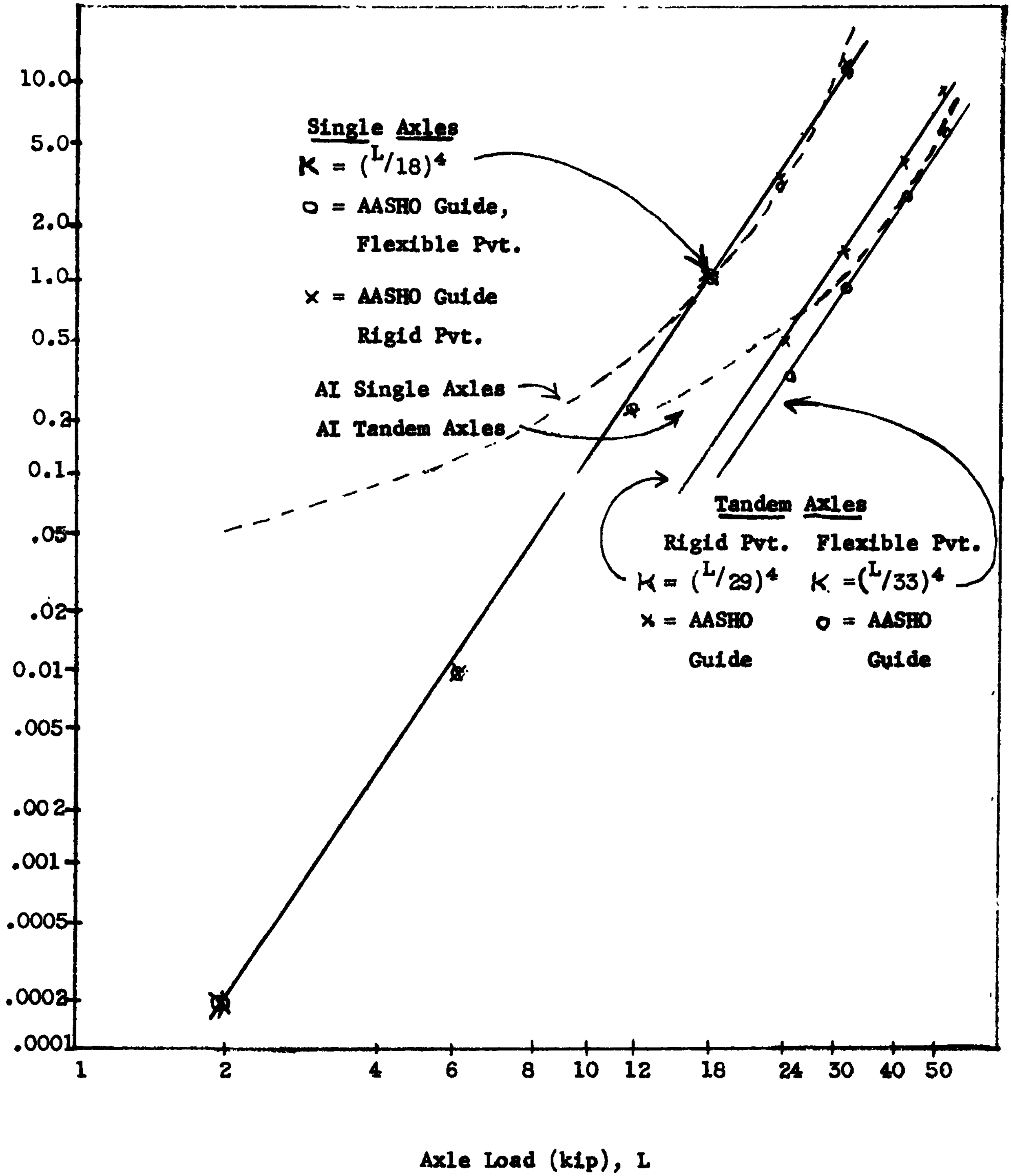


TABLE B2: ILLUSTRATIVE DATA FOR EVALUATING AXLE LOAD VARIABLES FOR ONE TEST SECTION

ear Evaluated Vehicle Class Statistics		Axle Load (kip) / Load Factor	Single Axles 2 .0002	12 .19	18 1.0	24 3.1	30 7.2	Sub Total	Tandem Axles 16 .05	24 .26	32 .86	40 2.1	48 4.2	Sub Total	Totals for Year
ear 1 Autos	Load Study	No. Axles													None
		°/o Dist.	100												
	Counts and Estimates	No. Axles	200,000					200000							200 000
		Equiv. Axles	40					40							40
Single Unit Trucks	Load Study	Freq. Dist.													None
		°/o Dist.		70.0	30.0			100							100
	Counts and Estimates	No. Axles		14,000	6,000			20,000							20,000
		Equiv. Axles		2,700	6,000			8,700							8,700
Tractor Trailers	Load Study	No. Axles													None
		°/o Dist.		20.0	40.0			60.0	10.0	20.0	10.0			40	100
	Counts and Estimates	No. Axles		2,000	4000			6000	1000	2,000	1,000			4,000	10,000
		Equiv. Axles		380	760			1100	50	520	860			1,400	2,500
quiv. Axles for Year			40	3100	6800			9900	50	520	860			1400	11,000
ccumulated Equiv. Axles			40	3100	6800			9900	50	520	860			1400	11,000
. Years 2 - 17															
. Accumulated Equiv. Axles			2700	140,000	800,000	400,000	500,000	1,800,000	8,000	80,000	140,000	100,000	50,000	[illegible]	2,200,000
ear 18 Autos	Load Study	No. Axles	5000					5000							5000
		°/o Dist.	100					100							100
	Counts and Estimates	No. Axles	1,500,000					1,500,000							1,500,000
		Equiv. Axles	300					300							300
Single Unit Trucks	Load Study	No. Axles		300	200			500							500
		°/o Dist.		60.0	40.0			100							100
	Counts and Estimates	No. Axles		60,000	40,000			100,000							100,000
		Equiv. Axles		11,000	40,000			51,000							51 000
Tractor Trailers	Load Study	No. Axles		100	300	100	50	550	100	200	100	40	10	450	1,000
		°/o Dist.		10.0	30.0	10.0	5.0	55.0	10.0	20.0	10.0	4.0	1.0	45.0	100
	Counts and Estimates	No. Axles		20,000	60,000	20,000	10,000	110,000	20,000	40,000	20,000	8,000	2000	90,000	200,000
		Equiv. Axles		3,800	60,000	62,000	72,000	200,000	1000	10,000	17,000	17,000	8,400	53,000	250,000
quiv. Axles for Year			300	15,000	100,000	62,000	72,000	250,000	1000	10,000	17,000	17,000	8,400	53,000	300,000
ccumulated Equiv. Axles			3000	160,000	910,000	460,000	570,000	2,100,000	9000	71,000	160,000	120,000	58,000	440,000	2,500,000

ΣL
ADL=30

ΣL
ADL=360

Note: Load factors from Table B1a flexible pavements

ΣL
ADL=370

After the first three rows of data are completed for each vehicle class and year, load factors (from Table B1) shown at the top of the table are applied to the axle counts in order to obtain equivalent axles as given in the fourth row. The table shows, for example, 11,000 equivalent axle load applications for 12-kip single unit trucks in year 18.

The remaining two rows for each year are for summing equivalent axle loads from all vehicle classes for the year, and for all years to date. For example, the next to last row in the table shows that year 18 produced 17,000 equivalent axle loads from 32 kip tandem axles, and that through all 18 years there was an accumulation of 160,000 equivalent axle loads from 32 kip tandem axles. For any year the entry in the last column and last row is ΣL, the total number of accumulated equivalent 18-kip axle loads 2,500,000 for the example.

When ΣL is divided by 365 Y, a figure is obtained for ADL, the average daily number of equivalent axle load applications. For the example, ADL = 30 in year 1 and rose to ADL = 370 by the end of year 18.

Other formats and computational schemes than just illustrated can be used to evaluate ΣL and ADL for satellite test sections, but the various alternatives will involve essentially the same statistics as are shown in Table B2. For existing pavement studies it is likely that the percent distributions will have to be obtained from historical data and trends that are not closely tied to the individual test section. For this reason all computations in the example have been carried with only two digit accuracy. It is thus supposed that two significant figures are sufficient (and perhaps all that can be obtained) for load data, ΣL and ADL, to be used in the analysis of satellite test section performance.

Appendix C

Climatic and Regional Variables

It has been recommended throughout the guidelines that climatic conditions at the AASHO Road Test be used as a reference point for performance differences (between comparable AASHO Road Test and satellite test sections) that may be attributed to climatic variables. One aim of this appendix is to provide summaries of AASHO Road Test data on these variables. More complete information can be obtained from the various Highway Research Board Special Reports 61A-F.

A second aim for this appendix is to show how one indicator of composite strength, Benkelman beam deflections, changed with different pavement designs at the AASHO Road Test as well as with different climatic conditions for the same pavement design.

Table C1 gives summary values for air temperature, precipitation and freeze-thaw conditions at the AASHO Road Test from November 3, 1958 through November 2, 1960. It is presumed that this table provides sufficient information for quantifying general differences in climate between the AASHO Road Test and any satellite test section site. TAB C1

Tables C2 and C3 show the general trend of beam deflections under 18-kip axle loads with pavement design that were used at the AASHO Road Test. Table C3 shows outer wheelpath deflections in the fall of 1958 and in the spring of 1959 for flexible pavement designs—in terms of the two structural indexes that are described in Appendix D. TAB C2 TAB C3

(D2) $$D = .44h_1 + .14h_2 + .11h_3 + 1.00$$

(D6) $$D = .52h_1 + .16h_2 + .14h_3 + 1.00$$

Each value given in Table C2 is an average obtained from two rounds of measurements on the indicated number of test sections. The scatter of individual test section values about these means gives a coefficient of variation of about fifteen percent.

Table C3 gives average slab edge deflections for two rounds of measurements on rigid pavement sections, for midday deflection and for early morning deflections. It can be seen that daily variations in rigid pavement deflections are of the same order of magnitude as seasonal variations in flexible pavement deflections.

It is presumed that Tables C2 and C3 can be useful in comparing the relative strength of satellite test sections with AASHO Road Test sections, at least when the sections being compared have as-constructed characteristics that are sufficiently similar.

TABLE C1: SUMMARY OF CLIMATIC VARIABLES AT THE AASHO ROAD TEST

Climatic Variables	Nov. 3, 1958 to Nov. 4, 1959	Nov. 3, 1958 to Nov. 2, 1960	Two Year Average
Mean max. daily temp.	61	60	60
Mean min. daily temp.	39	39	39
Annual mean temp.	50	50	50
Weeks mean min. temp. > 32°	34	32	33
Weeks mean max. temp. < 32°	8	10	9
Precipitation (inches)	28.3	30.5	29.4
Weeks precipitation > .5"	30	28	29
Weeks precipitation > 1.0"	8	12	10
Max. frost depth (inches)	34	29	32
Weeks of thawing conditions	12	8	10
Frost Index (C of E)			

TABLE C2: MEAN BENKELMAN BEAM OUTER WHEELPATH DEFLECTIONS FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS (18-kip axle load)

Structural Index, D		No. Test Sect.	Mean deflections (.001") for two rounds	
(D2)	(D6)		Fall, 1958	Spring, 1959
2.3	2.6	11	78	141
2.8	3.2	18	69	127
3.2	3.7	25	69	104
3.6	4.3	30	56	99
4.0	4.7	38	47	71
4.5	5.3	38	40	59
4.9	5.8	34	35	54
5.4	6.5	24	29	42
5.8	6.9	16	27	35
6.3	7.6	8	22	27

(D2) $D = .44h_1 + .14h_2 + .11h_3 + 1.00$

(D6) $D = .52h_1 + .16h_2 + .14h_3 + 1.00$

TABLE C3: MEAN BENKELMAN BEAM SLAB EDGE DEFLECTIONS FOR AASHO ROAD TEST RIGID PAVEMENT SECTIONS

(18-kip axle loads, 3, 6, 9 in gravel subbase)

Structural Index, D		No. Test Sect.	Mean deflection (.001") for two rounds	
h_1 +1.00	$.62h_1$ +1.84		Midday	Early Morning
3.5	3.4	8	40	58
4.5	4.0	20	30	41
6.0	4.9	32	23	28
7.5	5.9	36	19	24
9.0	6.8	48	17	21
10.5	7.7	36	15	19
12.0	8.7	24	12	16
13.5	9.6	12	12	14

Table C4 has been prepared partly as a reference for some of the procedures given in Appendix D, but mainly to indicate the nature of seasonal variations in flexible pavement strength at the AASHO Road Test. For each of 55 biweekly periods the table first shows the accumulated number of actual axle load applications, N, and then logarithms. Next is shown the seasonal weighting function, v_t, used in HRB Special Report 61E as a multiplier to obtain weighted applications, W. The values of log W/N indicate how much greater (or smaller) log W is than log N at any time during the two year period. The weighting function used was essentially the square of the deflection ratio of Loop 1 deflections in the index period to initial Loop 1 deflections. It can be seen that v_t is zero during frozen conditions and rises to nearly five during spring thaw conditions. TAB C4

The remainder of the table gives W, v_t, and log W/N for two other weighting functions that are used in connection with procedures discussed in Appendix D. The first uses v_t as the fourth power of the deflection ratios—giving values that range from zero to more than twelve.

The final weighting function is based on spring thaw duration instead of relative deflection, and has values of 1.00 except during the spring thaw period when v_t rises to more than 26. This weighting function was used in the Painter[1] analyses of AASHO Road Test flexible pavement data.

If satellite test sections are observed for as long as four years, say, it does not appear that seasonal weighting functions need be studied in any detail. After this many years of service, year-round performance differences between geographical locations are presumably explainable (in part) by general climatic variables that reflect the type of variations shown in Table C4.

---

[1] Painter, loc., cit.

TABLE C4: WEIGHTING FACTORS FOR APPLICATIONS ON AASHO ROAD TEST FLEXIBLE PAVEMENTS

Index	Actual		a.			b. Weighted Applications			c.		
Day	Applications		HRB Special Report 61E			v_t = (Rel. defl.)^4			Spring thaw duration		
t	W/10^3	Log N	W/10^3	v_t	Log W/N	W/10^3	v_t	Log W/N	W/10^3	v_t	Log W/N
1	1	2.85	1	1.29	.11	1	1.00	.00	1	1.00	.00
2	5	3.72	5	1.00	.02	8	1.56	.17	5	1.00	.00
3	11	4.06	11	.87	-.01	9	.18	-.10	11	1.00	.00
4	22	4.34	12	.11	-.25	14	.46	-.19	22	1.00	.00
5	29	4.46	12	.07	-.35	14	.00	-.31	29	1.00	.00
6	36	4.55	12	.00	-.45	14	.00	-.41	36	1.00	.00
7	46	4.66	12	.00	-.56	14	.00	-.52	46	1.00	.00
8	58	4.77	14	.11	-.62	14	.00	-.62	58	1.00	.00
9	70	4.84	28	1.29	-.38	15	.12	-.66	172	10.16	.39
10	76	4.88	58	4.54	-.11	30	2.33	-.39	319	22.25	.62
11	80	4.90	75	4.83	-.02	74	12.56	-.02	412	26.49	.71
12	86	4.93	102	4.27	.07	121	7.36	.15	566	24.55	.82
13	98	4.99	130	2.35	.12	185	5.47	.28	805	20.22	.92
14	107	5.03	146	1.78	.14	217	3.35	.31	923	12.55	.94
15	120	5.08	163	1.29	.13	242	1.92	.30	1003	6.02	.92
16	134	5.13	183	1.44	.14	259	1.26	.29	1028	1.83	.88
17	151	5.18	200	1.00	.12	281	1.26	.27	1045	1.00	.84
18	169	5.23	222	1.28	.12	294	.78	.24	1063	1.00	.80
19	182	5.26	236	1.00	.11	308	1.00	.23	1076	1.00	.77
20	199	5.30	256	1.14	.11	321	.78	.21	1093	1.00	.74
21	217	5.34	276	1.14	.10	335	.78	.19	1111	1.00	.71
22	233	5.37	290	.87	.09	348	.78	.17	1127	1.00	.68
23	250	5.40	306	1.00	.09	356	.46	.15	1114	1.00	.66
24	271	5.43	318	.54	.07	365	.46	.13	1165	1.00	.63
25	289	5.46	332	.75	.06	370	.25	.11	1183	1.00	.61
26	305	5.48	340	.54	.05	375	.34	.09	1199	1.00	.59
27	324	5.51	349	.45	.03	378	.12	.07	1218	1.00	.58
28	338	5.53	356	.53	.02	380	.18	.05	1232	1.00	.56
29	353	5.55	367	.75	.02	384	.25	.04	1247	1.00	.55
30	373	5.57	385	.87	.01	389	.25	.02	1267	1.00	.53
31	385	5.59	387	.22	.00	394	.46	.01	1279	1.00	.52
32	408	5.61	391	.16	-.01	395	.01	-.00	1302	1.00	.50
33	445	5.65	401	.29	-.03	395	.00	-.04	1339	1.00	.48
34	480	5.68	417	.44	-.05	422	.78	-.05	1374	1.00	.46
35	505	5.70	423	.22	-.07	423	.03	-.07	1400	1.00	.44
36	540	5.73	428	.16	-.09	423	.00	-.10	1434	1.00	.42
37	570	5.76	477	1.60	-.07	433	.34	-.11	1777	11.37	.49
38	601	5.78	611	4.27	.01	581	4.68	-.01	2335	17.71	.59
39	634	5.80	725	3.49	.06	857	8.47	.13	2710	11.51	.63
40	669	5.83	770	1.28	.06	939	2.33	.15	2816	3.00	.62
41	705	5.85	797	.75	.05	955	.46	.13	2851	1.00	.61
42	734	5.87	826	1.00	.05	984	1.00	.13	2880	1.00	.59
43	771	5.89	892	1.78	.06	1022	1.00	.12	2918	1.00	.58
44	807	5.91	944	1.44	.07	1077	1.56	.13	2953	1.00	.56
45	833	5.92	990	1.78	.08	1118	1.56	.13	2979	1.00	.55
46	868	5.94	1035	1.28	.08	1162	1.26	.13	3014	1.00	.54
47	901	5.95	1073	1.14	.08	1195	1.00	.12	3048	1.00	.53
48	929	5.97	1101	1.00	.07	1212	.61	.12	3076	1.00	.52
49	951	5.98	1120	.87	.07	1229	.78	.11	3098	1.00	.51
50	984	5.99	1153	1.00	.07	1249	.61	.10	3130	1.00	.50
51	1016	6.01	1177	.75	.06	1264	.46	.09	3162	1.00	.49
52	1050	6.02	1198	.64	.06	1275	.34	.08	3196	1.00	.48
53	1080	6.03	1215	.54	.05	1281	.18	.07	3227	1.00	.47
54	1100	6.04	1220	.28	.05	1284	.17	.07	3246	1.00	.47
55	1114	6.05	1227	.44	.04	1285	.08	.06	3260	1.00	.46

Appendix D

Performance Variables

This appendix has three parts. Section DI deals with measurements and formulas for obtaining present serviceability index values. Section DII gives performance equations that were developed from the AASHO Road Test data by the Road Test staff and by other analytical efforts. The third section gives procedures that can be used to estimate performance index values, P, from one or more pairs of values for p and ΣL when no observed value for p is equal to 2.5.

I Measurements and Formulas for Present Serviceability Index

By definition, a serviceability index formula is a weighted combination of functions of surface measurements such that the formula produces values for p that are highly correlated with corresponding average serviceability ratings rendered by a panel of highway engineers. Measurements that have been proved to have significance in index formulas include (1) some measure of longitudinal roughness or riding quality, (2) some measure of transverse roughness, and (3) some measure of cracking, patching or other deteriorations which are not necessarily in the normal wheelpaths of the pavement section. The following list includes all those measures which appear in one or another of the index formulas to be given in this section.

Measures of Longitudinal Roughness

SV = wheelpath slope variance as obtained with the AASHO Road Test profilometer. Each wheelpath slope variance is the average squared deviation from the mean of slope values taken at one foot intervals from a continuous slope record. Values for SV are expressed as 10^6 times actual slope variances.

CSV = wheelpath slope variance as obtained by the CHLOE profilometer. Slopes are obtained at one foot intervals and from these CSV is calculated as for SV. It has been found that CSV is generally higher than SV, especially for rough textured surfaces.

RI = inches per mile of wheelpath roughness as obtained by the BPR roughometer.

MI = roughness index as obtained by the Michigan profilograph.

KI = ride index as obtained by the Kentucky system of accelerometers strapped to a passenger. (40 mph)

TX = an index of surface texture as measured by the Texas device.

F = faulting in inches per 1000 feet of wheelpath.

Measures of Transverse Distortion

RD = average wheelpath rut depth, expressed in inches and generally obtained from a four foot straight edge at ten foot sampling intervals.

Measures of Surface Deterioration

PA = area of patched surface, expressed in square feet of patching per 1000 square feet of pavement area.

C = major cracking, including sealed cracks and unsealed cracks at least .25 inch wide. For areal cracking C is expressed in square feet of cracked area per 1000 square feet of pavement area. For lineal cracks C is feet of projected crack length per 1000 square feet of pavement area. Projected lengths are the longer of the projections to pavement edge or to pavement transverse.

Table D1 shows tentative serviceability index formulas that are subject to the final report for NCHRP Project 1-2. Formulas 101 and 201 are essentially those used at the AASHO Road Test for flexible and rigid pavement respectively, and involve measurements for SV. Formulas 102 and 202 are equivalent to 101 and 201 but utilize an exponential form rather than an additive form for the index model. All four of these formulas are based on sections (74 flexible, 49 rigid) that were rated and measured in the course of the AASHO Road Test, taken together with sections (32 flexible and overlay, 16 rigid) that were rated and measured in NCHRP Project 1-2 at Purdue University in July, 1963.

The remaining formulas in Table D1 are based only on the Purdue measurements and make it possible to substitute other than SV roughness measurements in whichever of formulas 101, 102, 201, or 203 is being used.

TAB
D1

For example, if formula 201 is being used to index rigid pavements, and if roughness measurements are made with a BPR roughometer, then formula 203 may be substituted into formula 201 to determine values for p from values for R, C and PA. It is felt that this indirect process takes full advantage of all ratings and measurements that were made at the AASHO Road Test and in NCHRP Project 1-2.

TABLE D1: PRESENT SERVICEABILITY INDEX FORMULAS

(Subject to revision after NCHRP Project 1-2 Report)

Flexible and Overlay Pavements	Formula	Comments
101	$p = 4.93 - 1.87 \log (1+SV) - .01 \sqrt{C+PA} - 1.23\ RD^2$	Additive formula derived from 74 sections during AASHO Road Test and 32 Purdue sections.
102	$p = \text{antilog} \left[.699 - .068 \sqrt{SV} - .0014 \sqrt{C+PA} - .22\ RD^2 \right]$	Multiplicative formula derived from same data as formula 101.
103	$\log (1+SV) = - 3.4 + 2.2 \log RI$	Roughometer substitutions for SV, derived from 64 sections at Road Test, 32 sections at Purdue.
104	$\sqrt{SV} = + .032\ RI - .47$	
105	$\log (1+SV) = .09 + .97 \log (CSV-1.5) - .17 \log (1+TX)$	CHLOE substitutions for SV, derived from 32 Purdue sections.
106	$\sqrt{SV} = .46 + .86 \sqrt{CSV} - .034\ TX$	
107	$\log (1+SV) = 5.09 + 2.36 \log KI$	Kentucky Index substitutions for SV, derived from 32 Purdue sections.
108	$\sqrt{SV} = + .01\ KI - .74$	
109		Michigan Profilograph substitutions for SV, derived from 32 Purdue sections.
Rigid Pavements		
201	$p = 5.34 - 1.70 \log (1+SV) - .09 \sqrt{C+PA}$	Additive formula derived from 49 sections at AASHO Road Test and 16 Purdue sections.
202	$p = \text{antilog} \left[.742 - .061 \sqrt{SV} - .012 \sqrt{C+PA} \right]$	Multiplicative formula derived from same data as formula 201.
203	$\log (1+SV) = 2.16 \log RI - 3.39$	Roughometer substitutions for SV, derived from 40 sections at Road Test, 16 sections at Purdue.
204	$\sqrt{SV} = + .033\ RI - .49$	
205	$\log (1+SV) = .32 + .68 \log (1+CSV)$	CHLOE substitutions for SV, derived from 14 Purdue sections.
206	$\sqrt{SV} = .70 + .76 \sqrt{CSV}$	
207	$\log (1+SV) = + 3.1 \log KI - 7.3$	Kentucky Index substitutions for SV, derived from 16 Purdue Sections.
208	$\sqrt{SV} = .01\ KI - 2.19$	
209		Michigan Profilograph substitutions for SV, derived from 16 Purdue sections.

II Performance Equations Developed from AASHO Road Test Data

Pavement performance equations given in HRB Special Report 5 pertained to applications, W, of individual axle loads that ranged from 2-kip single to 48-kip tandem axle loads. Since these guidelines are written in terms of equivalent 18-kip single axle load applications, ΣL, all formulas will be written in terms of ΣL rather than W.

The reported Road Test equations reduce to

(D1) $$p = p_o - (p_o - 1.5)\ (\Sigma L/\rho_{18})^{\beta_{18}}$$

where ΣL is obtained from Table B1a of Appendix B, and where

for flexible pavements

$p_o = 4.2$

$\rho_{18} = .638D^{9.36}$

$\beta_{18} = 0.4 + (3.89/D)^{4.73}$

$D = .44h_1 + .14h_2 + 11h_3 + 1.00$

h_1 = inches of asphaltic concrete

h_2 = inches of stone base

h_3 = inches of gravel subbase

for rigid pavements

$p_o = 4.5$

$\rho_{18} = .875D^{7.35}$

$\beta_{18} = 1.0 + (7.12/D)^{8.46}$

$D = h_1 + 1.00$

h_1 = inches of portland cement concrete

In terms of ΣL,

Flexible Pavements (HRB)

(D2) $$\log \Sigma L = 9.36 \log D - .20 - \frac{\log \left[(p_o - 1.5)/(p_o - p)\right]}{0.4 + (3.89/D)^{4.73}}$$

$D = .44h_1 + .14h_2 + .11h_3 + 1.00$ (see footnote)

Rigid Pavements (HRB)

(D3) $$\log \Sigma L = 7.35 \log D - .06 - \frac{\log \left[(p_o - 1.5)/(p_o - p)\right]}{1.0 + (7.12/D)^{8.46}}$$

$D = h_1 + 1.00$

The quantity $.44h_1 + .14h_2 + .11h_3$ is called a flexible pavement thickness index in AASHO Road Test reports.

The Painter[1] analysis of the AASHO Road Test flexible pavement data gave the following result

<u>Flexible</u> <u>Pavements</u> (Painter)

(D4) $\log \Sigma L = D + \log \log (p_o/p) - \log F$

where $D = .34h_1 + .10h_2 + .07h_3 + 4.71$
and where F is a climatic factor which depends upon duration of spring thaw and whose AASHO Road Test value was approximately 4. Log ΣL for this equation is determined from Table B1c of Appendix B.

After the Road Test reports were published, continuing analysis at the Highway Research Board was concerned with fitting the Road Test data with a model in which the only undetermined coefficients were associated with the structural index, D. This model may be written

(D5) $p = p_o \, 10^{-\left[(\Sigma L)/(RS)^4 \, D^8\right]^b/4}$

where ΣL is determined by factors given in Table B1b of Appendix B,

where b = 1 for flexible pavements and b = 2 for rigid pavements,

where RS = 1 for initial conditions at the AASHO Road Test and is determined from deflections as discussed in Appendix C, and where

$$D = a_1r_1h_1 + a_2r_2h_2 + a_3r_3h_3 + r_4$$

In this model for D, r_1, r_2, r_3 and r_4 are presumed to be one for the respective materials used in the AASHO Road Test factorial experiments, and to be less than or greater than one for materials which are relatively weaker or stronger than those used in the factorial experiments.

---

[1] Painter, loc., cit.

When (D5) was fitted to the Road Test data the following results were obtained:

Flexible Pavements (Modified HRB)

(D6) $\log \Sigma L = 8 \log D + 4 \log RS + \log \log (p_o/p)^4$

$D = .54h_1 + .16r_2h_2 + .14h_3 + 1.00$

r_2 = 1.0 for crushed stone base, 0.8 for gravel base, 2.6 for bituminous stabilized base, and 2.1 for cement stabilized base.

Rigid Pavements (Modified HRB)

(D7) $\log \Sigma L = 8 \log D + .5 \log \log (p_o/p)^4$

$D = .62h_1 + .24h'_3 + 1.60$ where $h'3 = 0$ for no subbase and $h'_3 = 1$ for 3, 6 or 9 inches of subbase

It can be seen that the last term in these two equations is essentially $P = 8 \log D$.

Table D2 can be used to calculate performance index values from equations (D2), (D3), (D4), (D6) and (D7) when values are given for p_o and D. Values of D, of course, must be precalculated from the appropriate formula. TAB D2

III Estimation of Performance Index from Observed Pairs of p and ΣL

It is necessary to distinguish among observed, estimated and calculated values for the performance index, P. An observed P is the logarithm of ΣL when $p = 2.5$ has been observed for a test section. An estimated P is obtained from one or more pairs of observed values of p and ΣL when none of the p values are at 2.5. Thus the estimation procedure involves either interpolation or extrapolation (forwards or backwards) on the performance record of a test section. A calculated value of P is obtained by substitution of $p = 2.5$ and other required quantities into performance equations such as were given in Section D2. This section is concerned with the estimation of P from one or more pairs of values for p and ΣL.

One way to estimate P is to plot as many points (p and ΣL) as are available for the performance record, draw an arbitrary curve through these points, then read off the value of $P = \log \Sigma L$ at $p = 2.5$.

TABLE D2: CALCULATED PERFORMANCE INDEX VALUES

p_o and D	Flexible Pavement Equations			Rigid Pavement Equations	
	D2	D4	D6	D3	D7
p_o = 4.80					
D = 1.00	-.20	-.14	.07	-.06	.03
2.00	2.61	.85	2.48	2.15	2.44
3.00	4.23	1.85	3.89	3.44	3.85
4.00	5.31	2.85	4.89	4.36	4.85
5.00	6.12	3.85	5.66	5.07	5.62
6.00	6.79	4.85	6.30	5.63	6.26
7.00	7.37	5.85	6.83	6.09	6.79
8.00	7.89	6.85	7.30	6.46	7.26
9.00	8.36	7.85	7.70	6.82	7.67
10.00	8.78	8.85	8.07	7.14	8.03
11.00	9.16	9.85	8.40	7.44	8.36
12.00	9.51	10.85	8.70	7.72	8.67
13.00	9.84	11.85	8.98	7.97	8.94
p_o = 4.50					
D = 1.00	-.20	-.19	.03	-.06	.01
2.00	2.61	.80	2.43	2.15	2.42
3.00	4.22	1.80	3.84	3.44	3.83
4.00	5.30	2.80	4.84	4.36	4.83
5.00	6.09	3.80	5.62	5.07	5.60
6.00	6.75	4.80	6.25	5.63	6.24
7.00	7.33	5.80	6.79	6.07	6.77
8.00	7.85	6.80	7.25	6.45	7.23
9.00	8.31	7.80	7.66	6.80	7.64
10.00	8.73	8.80	8.03	7.12	8.01
11.00	9.12	9.80	8.36	7.42	8.34
12.00	9.47	10.80	8.66	7.70	8.64
13.00	9.79	11.80	8.94	7.95	8.92
p_o = 4.20					
D = 1.00	-.20	-.24	-.02	-.06	-.01
2.00	2.61	.75	2.38	2.15	2.39
3.00	4.21	1.75	3.79	3.44	3.80
4.00	5.28	2.75	4.79	4.36	4.80
5.00	6.06	3.75	5.56	5.07	5.57
6.00	6.70	4.75	6.20	5.62	6.21
7.00	7.28	5.75	6.73	6.06	6.74
8.00	7.79	6.75	7.20	6.43	7.21
9.00	8.25	7.75	7.61	6.78	7.62
10.00	8.67	8.75	7.97	7.10	7.98
11.00	9.05	9.75	8.30	7.40	8.31
12.00	9.40	10.75	8.60	7.67	8.62
13.00	9.73	11.75	8.88	7.93	8.89
p_o = 3.90					
D = 1.00	-.19	-.31	-.09	-.06	-.04
2.00	2.61	.68	2.31	2.15	2.36
3.00	4.20	1.68	3.72	3.44	3.77
4.00	5.25	2.68	4.72	4.36	4.77
5.00	6.01	3.68	5.50	5.07	5.54
6.00	6.64	4.68	6.13	5.61	6.17
7.00	7.20	5.68	6.66	6.04	6.71
8.00	7.71	6.68	7.13	6.41	7.17
9.00	8.17	7.68	7.54	6.75	7.58
10.00	8.59	8.68	7.90	7.07	7.95
11.00	8.97	9.68	8.24	7.37	8.28
12.00	9.32	10.68	8.54	7.64	8.58
13.00	9.65	11.68	8.82	7.89	8.86

With enough points in the neighborhood of $p = 2.5$ this graphical method would appear to give a satisfactory estimate for P. It is recommended, however, that the following algebraic procedures be used.

Assume that satisfactory estimates of performance index values can be obtained from the equations

$$\text{(D8)} \quad \log \Sigma L = A + B \log \log (p_o/p)$$

and

$$\text{(D9)} \quad P = A + B \log \log (p_o/2.5)$$

If only p_o and one pair of values for ΣL and p are available $A = \log \Sigma L - B \log \log (p_o/p)$ so that

$$\text{(D10)} \quad \text{estimated } P = \log \Sigma L_1 + B \left[\log \log (p_o/2.5) - \log \log (p_o/p_1)\right]$$

To use formula (D10) it is necessary to assume a numerical value for B. Experience with the AASHO Road Test performance data has indicated that suitable approximations for B are

$B = 1$ for performance records that are concave upward
$B = {}^1/_2$ for performance records that are concave downward

If only one point appears on a performance record it may not be possible to deduce the direction of concavity. At the AASHO Road Test the majority of flexible pavement performance records were considered to be concave upwards, while many rigid pavement records were observed to be concave downward. It can be hoped that the satellite research program will help to determine the long-term shape of test section performance curves.

When two or more (well separated) points have been observed for a test section performance record, the following formula may be used to estimate the section's performance index

$$\text{(D11)} \quad \text{estimated } P = \bar{Y} + B \left[\log \log (p_o/2.5) - \bar{X}\right]$$

where $\bar{Y}$ is the arithmetic mean of the observed values $Y = \log \Sigma L$

where $\bar{X}$ is the arithmetic mean of the observed values $X = \log \log (p_o/p)$, and where B is given by the quotient of two summations,

$$B = \frac{\Sigma(Y - \bar{Y})(X - \bar{X})}{\Sigma\,(X - \bar{X})^2}$$

The foregoing estimation procedures are illustrated numerically as follows:

Example 1: Given: $p_o = 4.5$, $p = 3.2$, $\log \Sigma L = 4.60$.
Since only one point is given, formula (D10) will be used.

$$\text{est. } P = 4.60 + B\left[\log\log(4.5/2.5) - \log\log(4.5/3.2)\right]$$

$$\text{est. } P = 4.60 + B\left[-.59 + .83\right] = 4.60 + .24B$$

Thus the estimated P is either 4.84 or 4.72, depending upon whether B is assumed to be 1.0 or 0.5.

Example 2: Given: $p_o = 4.5$ and two pairs of observations,
$p = 4.0$ when $\log \Sigma L = 4.90$, and
$p = 3.2$ when $\log \Sigma L = 5.86$

With two points, formula (D11) may be used.

$$\bar{Y} = (4.90 + 5.86)/2 = 5.38$$

$$\bar{X} = \left[\log\log(4.5/4.0) + \log\log(4.5/3.2)\right]/2$$

$$\bar{X} = \left[-1.29 - .83\right]/2 = -1.06$$

$$\Sigma(Y-\bar{Y})(X-\bar{X}) = (4.90 - 5.38)(-1.29 + 1.06) + (5.86 - 5.38)(-.83 + 1.06) = .221$$

$$\Sigma(X-\bar{X})^2 = (-.23)^2 + (.23)^2 = .106$$

$$B = .221/.106 = 2.10$$

$$\text{est. } P = 5.38 + 2.10\left[\log\log(4.5/2.5) + 1.06\right]$$

$$\text{est. } P = 5.38 + 2.10(.47) = 6.37$$

The second example involves a performance record that is concave upward and shows that B can be considerably greater than one. If only the first observation were used in formula (D10), the estimated P for the second example would have been

$$P = 4.90 + 1.0\left[-.59 + 1.29\right] = 5.60$$

much less than the value P = 6.37. This instance serves to emphasize the unreliability of estimates made from only one point, especially if serviceability loss has been small.

Table D3 has been prepared to show observed, estimated and calculated performance index values for every test section in AASHO Road Test traffic lanes. Except for the 18-kip axle load lanes, none of these index values have heretofore been published. The main reason for including this table is to make it possible to compare directly the performance index obtained from a satellite test section with those of one or more AASHO Road Test sections.

The various columns of the table fall in three major groups:

1. Identification

Flexible Pavements: The first column is h_1 = surfacing thickness in inches. The second column is h_2 = base thickness to tenths of inches. The hundredths place in this column designates base type according to the code

.01 = crushed stone
.02 = gravel
.03 = bituminous stabilized gravel
.04 = cement stabilized gravel

The third column is h_3 = subbase thickness in inches. The fourth column gives the Road Test section number and the loop - lane of the section is given in the fifth column. Section numbers with non zero in the tenths position are actually 40 foot subsections in the "wedge" base study. All bases other than crushed stone are found among these subsections.

Rigid Pavements: The first column is h_1 = surfacing thickness to tenths of inches. The hundredths position of this column is used for c_1 = surfacing reinforcement according to the code

.00 = nonreinforced surfacing, eight 15 foot slabs per 120 foot section
.01 = reinforced surfacing, six 40 foot slabs per 240 foot section

The second column gives subbase thickness in inches and the third column gives section number and loop-lane as for flexible pavements.

2. Performance Data

For both flexible and rigid pavements in Table D3 there are three columns for performance data, only two of which have entries. The first column gives p_1, the section's serviceability index about two weeks after the test traffic began, when about 1000 actual axle load applications had occurred in the traffic lanes. This value is used as an approximation for p_o, the section's initial serviceability index.

The second column of performance data is blank if the test section did not have serviceability as low as $p = 2.5$ by the end of the test. In this case the third column gives the section's final serviceability index--after two years of traffic and 1,114,000 actual axle load applications.

If the test section reached $p = 2.5$ before the end of the Road Test, the third performance data column is blank and the second column gives the logarithm of the actual number of axle load applications experienced by the section when $p = 2.5$. For loop 4, lane 1, this value is an observed performance index, $P = \log \Sigma L$, but for all other lanes this value must be adjusted by the load equivalence factors to have an observed performance index.

3. Structural and Performance Indexes

The remaining three columns of Table D3 give respective values for the section's structural index, either an observed or an estimated performance index, and a calculated performance index.

For flexible pavements the structural index and calculated P is obtained from equation (D6). Entries from Table C4b were used to account for 4 log RS in equation (D6).

Rigid pavement structural index values and calculated P values in Table D3 were obtained by direct substitution in equation (D7).

For either type of pavement, observed performance index values are obtained by adjusting the log applications at TAB D3 p = 2.5 by load equivalency factors from Table B1b. It will be noted that there is no adjustment involved for test sections in lane 41, the 18-kip single axle lane. All estimated P values are for sections whose final serviceability index was above p = 2.5, and have been calculated by the one-point procedure explained in Section DIII, using the final value of p in connection with the dorresponding ΣL. TAB D4

Table D4 gives a summary of residuals between calculated and observed (or estimated) performance index values. The table shows that the performance equation residuals average to be about zero and have a mean absolute value of about 0.2 when compared with observed index values. However, the equations do not agree as well with estimated as with observed values for P, especially for sections in lane 21, the 2-kip single axle lane.

This table has significance in the analysis of performance data from satellite projects since it shows the residuals that were obtained in the analysis of the Road Test data itself. If the scatter of satellite test section indexes about those calculated from the Road Test equations is not more than about .20 on the average, it may be supposed that the Road Test equations hold for the satellite test conditions as closely as for the Road Test conditions.

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS

IDENTIFICATION DATA					PERFORMANCE DATA			INDEXES		
SURF THCK	BASE THCK, TYPE	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D6	PERFORMANCE OBS. EST.	CALC. BY EQN D6
1.0	.01	.0	721.0	21	3.7	4.41		1.5	.59	1.13
1.0	.01	.0	722.0	22	3.7	3.02		1.5	1.10	1.33
1.0	3.01	.0	743.0	21	3.9	5.73		2.0	1.91	2.33
1.0	3.01	.0	744.0	22	3.7	4.65		2.0	2.73	2.89
1.0	.01	4.0	727.0	21	3.8	4.87		2.1	1.05	2.44
1.0	.01	4.0	728.0	22	3.8	3.02		2.1	1.10	2.95
2.0	.01	.0	771.0	21	4.0	5.80		2.1	1.98	2.46
2.0	.01	.0	772.0	22	3.8	4.86		2.1	2.94	2.95
2.0	.01	.0	165.0	31	3.5	4.78		2.1	4.08	2.31
2.0	.01	.0	166.0	32	3.7	4.78		2.1	4.23	2.38
1.0	6.01	.0	755.0	21	3.9		2.8	2.5	2.35	3.07
1.0	6.01	.0	756.0	22	3.7	4.91		2.5	2.99	2.92
1.0	3.01	4.0	717.0	21	3.7		2.5	2.6	2.23	3.13
1.0	3.01	4.0	718.0	22	4.0	4.85		2.6	2.93	3.00
2.0	3.01	.0	731.0	21	4.0		2.4	2.6	2.19	3.18
2.0	3.01	.0	759.0	21	4.4		3.8	2.6	2.81	3.26
2.0	3.01	.0	732.0	22	4.1	5.04		2.6	3.12	3.00
2.0	3.01	.0	760.0	22	4.2	5.22		2.6	3.30	3.01
2.0	3.01	.0	113.0	31	4.1	4.80		2.6	4.10	3.20
2.0	3.01	.0	114.0	32	4.1	4.77		2.6	4.22	3.20
2.0	.01	4.0	729.0	21	3.6	5.77		2.6	1.95	3.17
2.0	.01	4.0	730.0	22	3.9	4.90		2.6	2.98	3.05
2.0	.01	4.0	125.0	31	3.4	3.19		2.6	2.49	3.10
2.0	.01	4.0	126.0	32	3.8	3.11		2.6	2.56	3.23
3.0	.01	.0	769.0	21	3.9		3.0	2.6	2.46	3.23
3.0	.01	.0	770.0	22	3.9	5.00		2.6	3.08	3.03
3.0	.01	.0	137.0	31	3.8	.00		2.6	4.18	3.21
3.0	.01	.0	138.0	32	3.7	4.85		2.6	4.30	3.18
1.0	6.01	4.0	719.0	21	4.0		3.2	3.1	2.55	3.80
1.0	6.01	4.0	720.0	22	3.7	5.61		3.1	3.69	3.79
2.0	6.01	.0	775.0	21	3.7		3.4	3.0	2.89	3.70
2.0	6.01	.0	757.0	21	4.0		3.7	3.0	3.01	3.77
2.0	6.01	.0	776.0	22	4.0		3.5	3.0	4.67	3.79
2.0	6.01	.0	758.0	22	4.3		2.5	3.0	4.13	3.80
2.0	6.01	.0	127.0	31	4.1	4.86		3.0	4.16	4.12
2.0	6.01	.0	128.0	32	3.9	4.85		3.0	4.30	4.26
2.0	3.01	4.0	741.0	21	3.9		3.5	3.1	2.84	3.84
2.0	3.01	4.0	709.0	21	3.9		3.3	3.1	2.65	3.84
2.0	3.01	4.0	742.0	22	4.1	5.76		3.1	3.84	3.84
2.0	3.01	4.0	710.0	22	3.6	5.80		3.1	3.88	3.82
2.0	3.01	4.0	135.0	31	3.8	4.85		3.1	4.15	4.16
2.0	3.01	4.0	136.0	32	3.8	4.85		3.1	4.30	4.29
2.0	.01	8.0	143.0	31	4.0	4.85		3.2	4.15	4.18
2.0	.01	8.0	133.0	31	3.8	4.87		3.2	4.17	4.19
2.0	.01	8.0	144.0	32	3.6	4.86		3.2	4.31	4.31
2.0	.01	8.0	134.0	32	3.8	4.85		3.2	4.30	4.32
3.0	3.01	.0	773.0	21	4.3		3.8	3.1	2.87	3.91
3.0	3.01	.0	774.0	22	4.0	5.85		3.1	3.93	3.83
3.0	3.01	.0	147.0	31	3.8	4.85		3.1	4.15	4.16
3.0	3.01	.0	148.0	32	4.1	4.86		3.1	4.31	4.30

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS

IDENTIFICATION DATA					PERFORMANCE DATA			INDEXES		
SURF THCK	BASE THCK, TYPE	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D6	PERFORMANCE	
									OBS. EST.	CALC. BY EQN D6
3.0	.01	4.0	739.0	21	3.9		3.3	3.2	2.65	3.91
3.0	.01	4.0	740.0	22	3.8	5.01		3.2	3.09	3.87
3.0	.01	4.0	163.0	31	4.2	4.93		3.2	4.23	4.19
3.0	.01	4.0	164.0	32	3.9	4.90		3.2	4.35	4.33
3.0	.01	4.0	633.0	41	3.0	2.93		3.2	2.93	3.52
3.0	.01	4.0	634.0	42	3.9	4.06		3.2	4.00	3.91
4.0	.01	.0	119.0	31	3.9	4.88		3.2	4.18	4.19
4.0	.01	.0	120.0	32	3.9	4.85		3.2	4.30	4.32
3.0	3.52	.0	171.4	31	3.9	4.89		3.1	4.19	4.15
3.0	3.52	.0	103.4	31	4.1	4.86		3.1	4.16	4.16
3.0	3.52	.0	172.4	32	3.4	4.85		3.1	4.30	4.27
3.0	3.52	.0	104.4	32	3.8	4.84		3.1	4.29	4.28
3.0	3.51	.0	169.4	31	4.1	4.91		3.2	4.21	4.15
3.0	3.51	.0	105.4	31	4.2	4.85		3.2	4.15	4.15
3.0	3.51	.0	170.4	32	3.9	4.88		3.2	4.33	4.29
3.0	3.51	.0	106.4	32	4.1	4.85		3.2	4.30	4.30
2.0	6.01	4.0	737.0	21	3.9		3.6	3.6	2.97	4.34
2.0	6.01	4.0	711.0	21	4.0		3.3	3.6	2.61	4.36
2.0	6.01	4.0	738.0	22	4.1		3.2	3.6	4.43	4.38
2.0	6.01	4.0	712.0	22	3.6		2.6	3.6	4.18	4.25
2.0	6.01	4.0	157.0	31	3.8	4.94		3.6	4.24	4.18
2.0	6.01	4.0	158.0	32	3.7	4.89		3.6	4.34	4.29
2.0	3.01	8.0	159.0	31	3.4	4.89		3.7	4.19	4.19
2.0	3.01	8.0	160.0	32	3.6	4.89		3.7	4.34	4.33
3.0	6.01	.0	749.0	21	4.2		3.6	3.6	2.75	4.39
3.0	6.01	.0	750.0	22	4.0		3.1	3.6	4.39	4.34
3.0	6.01	.0	117.0	31	4.1	4.93		3.6	4.23	4.19
3.0	6.01	.0	118.0	32	3.8	4.90		3.6	4.35	4.30
3.0	3.01	4.0	745.0	21	4.0		3.8	3.7	3.19	4.42
3.0	3.01	4.0	746.0	22	3.8		2.7	3.7	4.22	4.37
3.0	3.01	4.0	107.0	31	4.1	4.93		3.7	4.23	4.23
3.0	3.01	4.0	115.0	31	3.4	4.90		3.7	4.20	4.19
3.0	3.01	4.0	108.0	32	3.7	4.92		3.7	4.37	4.33
3.0	3.01	4.0	116.0	32	3.9	4.90		3.7	4.35	4.33
3.0	3.01	4.0	599.0	41	4.2	4.86		3.7	4.86	4.85
3.0	3.01	4.0	600.0	42	4.4	4.86		3.7	4.80	4.81
3.0	3.01	4.0	485.0	51	4.2	4.80		3.7	5.18	4.66
3.0	3.01	4.0	486.0	52	4.3	3.19		3.7	3.53	5.15
3.0	.01	8.0	109.0	31	4.1	.00		3.7	4.29	4.27
3.0	.01	8.0	110.0	32	3.8	4.93		3.7	4.38	4.37
3.0	.01	8.0	607.0	41	4.1	4.85		3.7	4.85	4.88
3.0	.01	8.0	608.0	42	4.0	4.86		3.7	4.80	4.82
4.0	3.01	.0	145.0	31	4.4	4.90		3.6	4.20	4.25
4.0	3.01	.0	146.0	32	3.9	4.93		3.6	4.38	4.33
4.0	.01	4.0	141.0	31	3.9	4.89		3.7	4.19	4.25
4.0	.01	4.0	142.0	32	3.8	4.90		3.7	4.35	4.36
4.0	.01	4.0	583.0	41	3.8	4.89		3.7	4.89	4.88
4.0	.01	4.0	584.0	42	4.0	4.91		3.7	4.85	4.82
3.0	3.82	4.0	565.4	41	3.6	3.72		3.7	3.72	4.84
3.0	3.82	4.0	559.4	41	4.1	4.78		3.7	4.78	4.85

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS

IDENTIFICATION DATA					PERFORMANCE DATA			INDEXES		
SURF THCK	BASE THCK, TYPE	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D6	PERFORMANCE OBS. EST.	CALC. BY EQN D6
3.0	3.82	4.0	566.4	42	3.8	3.85		3.7	3.79	4.80
3.0	3.82	4.0	560.4	42	3.6	4.77		3.7	4.71	4.79
3.0	4.92	4.0	467.4	51	3.8	4.28		3.8	4.66	5.16
3.0	4.92	4.0	457.4	51	4.1	4.80		3.8	5.18	5.19
3.0	4.92	4.0	468.4	52	4.1	3.75		3.8	4.09	5.16
3.0	4.92	4.0	458.4	52	4.1	4.86		3.8	5.20	5.16
3.0	6.52	.0	171.3	31	4.0	5.03		3.5	4.33	4.17
3.0	6.52	.0	103.3	31	4.0	4.88		3.5	4.18	4.17
3.0	6.52	.0	172.3	32	3.8	4.88		3.5	4.33	4.30
3.0	6.52	.0	104.3	32	3.7	4.88		3.5	4.33	4.29
3.0	3.81	4.0	567.4	41	4.0	4.88		3.8	4.88	4.85
3.0	3.81	4.0	561.4	41	2.9	4.61		3.8	4.61	4.22
3.0	3.81	4.0	568.4	42	3.8	4.88		3.8	4.82	4.80
3.0	3.81	4.0	562.4	42	3.8	3.99		3.8	3.93	4.80
3.0	6.51	.0	169.3	31	4.3	4.91		3.7	4.21	4.22
3.0	6.51	.0	105.3	31	4.4	4.89		3.7	4.19	4.23
3.0	6.51	.0	170.3	32	3.2	4.90		3.7	4.35	4.28
3.0	6.51	.0	106.3	32	4.0	4.88		3.7	4.33	4.31
3.0	3.13	.0	101.4	31	3.8	5.25		3.9	4.55	4.30
3.0	3.13	.0	167.4	31	3.8	5.23		3.9	4.53	4.30
3.0	3.13	.0	102.4	32	3.6	5.00		3.9	4.45	4.37
3.0	3.13	.0	168.4	32	3.6	5.06		3.9	4.51	4.37
3.0	4.14	4.0	465.4	51	4.3	4.77		4.6	5.15	5.06
3.0	4.14	4.0	461.4	51	4.1	4.90		4.6	5.28	5.04
3.0	4.14	4.0	466.4	52	3.4	4.80		4.6	5.14	4.99
3.0	4.14	4.0	462.4	52	3.9	4.89		4.6	5.23	5.01
2.0	6.01	8.0	111.0	31	4.2	5.79		4.2	5.09	5.01
2.0	6.01	8.0	112.0	32	3.9	5.70		4.2	5.15	4.57
3.0	6.01	4.0	763.0	21	4.1		3.9	4.1	3.22	4.87
3.0	6.01	4.0	764.0	22	4.1		3.6	4.1	4.71	4.87
3.0	6.01	4.0	131.0	31	4.2	5.76		4.1	5.06	5.01
3.0	6.01	4.0	132.0	32	3.7	4.97		4.1	4.42	4.46
3.0	6.01	4.0	585.0	41	4.0	4.90		4.1	4.90	4.85
3.0	6.01	4.0	586.0	42	4.2	4.90		4.1	4.84	4.81
3.0	6.01	4.0	449.0	51	4.3	4.85		4.1	5.23	5.22
3.0	6.01	4.0	450.0	52	4.2	4.86		4.1	5.20	5.18
3.0	3.01	8.0	129.0	31	4.2	5.70		4.2	5.00	5.04
3.0	3.01	8.0	130.0	32	4.4	.00		4.2	4.43	4.86
3.0	3.01	8.0	573.0	41	4.5	4.91		4.2	4.91	4.90
3.0	3.01	8.0	574.0	42	4.1	4.93		4.2	4.87	4.84
3.0	3.01	8.0	451.0	51	4.0	4.85		4.2	5.23	5.24
3.0	3.01	8.0	452.0	52	4.0	4.85		4.2	5.19	5.20
3.0	.01	12.0	571.0	41	3.8	4.91		4.3	4.91	4.92
3.0	.01	12.0	572.0	42	4.1	4.99		4.3	4.93	4.87
3.0	.01	12.0	570.0	42	4.1	5.01		4.3	4.95	4.87
4.0	6.01	.0	161.0	31	3.8	5.08		4.1	4.38	4.61
4.0	6.01	.0	149.0	31	3.8	5.03		4.1	4.33	4.61
4.0	6.01	.0	162.0	32	3.8	5.14		4.1	4.59	4.48
4.0	6.01	.0	150.0	32	3.9	4.95		4.1	4.40	4.51
4.0	3.01	4.0	151.0	31	3.8	5.00		4.2	4.30	4.80

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS

IDENTIFICATION	DATA				PERFORMANCE	DATA		INDEXES		
SURF THCK	BASE THCK, TYPE	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D6	PERFORMANCE OBS. EST.	CALC. BY EQN D6
4.0	3.01	4.0	152.0	32	4.1	4.97		4.2	4.42	4.70
4.0	3.01	4.0	627.0	41	4.2	4.93		4.2	4.93	4.90
4.0	3.01	4.0	628.0	42	4.0	4.95		4.2	4.89	4.84
4.0	3.01	4.0	411.0	51	4.3	4.83		4.2	5.21	5.25
4.0	3.01	4.0	412.0	52	4.2	4.79		4.2	5.13	5.21
4.0	.01	8.0	153.0	31	3.8	5.00		4.3	4.30	4.97
4.0	.01	8.0	154.0	32	4.0	4.93		4.3	4.38	4.77
4.0	.01	8.0	619.0	41	4.3	5.01		4.3	5.01	4.93
4.0	.01	8.0	620.0	42	4.0	5.00		4.3	4.94	4.87
5.0	.01	4.0	605.0	41	3.6	4.94		4.3	4.94	4.90
5.0	.01	4.0	606.0	42	4.3	5.00		4.3	4.94	4.88
3.0	8.62	4.0	467.3	51	3.6	4.77		4.3	5.15	5.22
3.0	8.62	4.0	457.3	51	4.4	4.85		4.3	5.23	5.22
3.0	8.62	4.0	468.3	52	4.2	4.84		4.3	5.18	5.18
3.0	8.62	4.0	458.3	52	4.5	4.88		4.3	5.22	5.18
3.0	9.52	.0	171.2	31	4.0	5.72		3.8	5.02	4.28
3.0	9.52	.0	103.2	31	4.0	5.01		3.8	4.31	4.28
3.0	9.52	.0	172.2	32	4.2	5.04		3.8	4.49	4.37
3.0	7.32	4.0	565.3	41	3.9	4.91		4.1	4.91	4.84
3.0	7.32	4.0	559.3	41	4.0	4.90		4.1	4.90	4.85
3.0	7.32	4.0	566.3	42	4.1	4.90		4.1	4.84	4.80
3.0	7.32	4.0	560.3	42	4.1	4.89		4.1	4.83	4.80
3.0	7.31	4.0	567.3	41	4.0	4.90		4.3	4.90	4.87
3.0	7.31	4.0	561.3	41	4.4	4.89		4.3	4.89	4.90
3.0	7.31	4.0	568.3	42	3.9	4.90		4.3	4.84	4.82
3.0	7.31	4.0	562.3	42	3.4	4.87		4.3	4.81	4.79
3.0	9.51	.0	169.2	31	4.2	5.65		4.1	4.95	4.99
3.0	9.51	.0	105.2	31	3.9	5.68		4.1	4.98	4.88
3.0	9.51	.0	170.2	32	3.3	5.04		4.1	4.49	4.36
3.0	9.51	.0	106.2	32	3.7	4.99		4.1	4.44	4.48
3.0	5.43	.0	167.3	31	4.3		4.1	4.9	6.40	5.47
3.0	5.43	.0	101.3	31	4.5		3.9	4.9	5.96	5.51
3.0	5.43	.0	168.3	32	4.4		3.8	4.9	6.08	5.49
3.0	5.43	.0	102.3	32	3.7		2.7	4.9	5.59	5.21
3.0	3.04	4.0	563.4	41	3.6	4.81		4.2	4.81	4.70
3.0	3.04	4.0	557.4	41	3.4	4.85		4.2	4.85	4.69
3.0	3.04	4.0	564.4	42	3.1	3.54		4.2	3.48	4.63
3.0	3.04	4.0	558.4	42	3.9	4.89		4.2	4.83	4.68
3.0	9.01	4.0	413.0	51	4.6	4.90		4.6	5.28	5.25
3.0	9.01	4.0	414.0	52	4.4	4.90		4.6	5.24	5.20
3.0	6.01	8.0	155.0	31	4.1	5.80		4.7	5.10	5.31
3.0	6.01	8.0	156.0	32	3.9	5.69		4.7	5.14	5.20
3.0	6.01	8.0	623.0	41	4.3	4.92		4.7	4.92	5.06
3.0	6.01	8.0	624.0	42	4.0	5.14		4.7	5.08	4.99
3.0	6.01	8.0	419.0	51	4.4	4.86		4.7	5.24	5.26
3.0	6.01	8.0	420.0	52	4.4	4.88		4.7	5.22	5.22
3.0	3.01	12.0	617.0	41	4.3	5.76		4.8	5.76	5.14
3.0	3.01	12.0	618.0	42	4.3	5.77		4.8	5.71	5.19
3.0	3.01	12.0	415.0	51	4.4	4.93		4.8	5.31	5.30
3.0	3.01	12.0	429.0	51	4.2	4.87		4.8	5.25	5.28

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS

IDENTIFICATION DATA					PERFORMANCE DATA			INDEXES		
SURF THCK	BASE THCK, TYPE	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D6	PERFORMANCE OBS. EST.	CALC. BY EQN D6
3.0	3.01	12.0	416.0	52	4.3	4.93		4.8	5.27	5.25
3.0	3.01	12.0	430.0	52	4.2	4.90		4.8	5.24	5.24
4.0	6.01	4.0	123.0	31	4.2		2.3	4.7	5.28	5.32
4.0	6.01	4.0	124.0	32	4.5	5.79		4.7	5.24	5.23
4.0	6.01	4.0	595.0	41	3.9	4.93		4.7	4.93	4.96
4.0	6.01	4.0	596.0	42	4.1	5.01		4.7	4.95	5.00
4.0	6.01	4.0	473.0	51	4.2	4.90		4.7	5.28	5.26
4.0	6.01	4.0	474.0	52	4.3	4.91		4.7	5.25	5.22
4.0	3.01	8.0	121.0	31	4.0	5.77		4.8	5.07	5.33
4.0	3.01	8.0	122.0	32	4.2	5.70		4.8	5.15	5.24
4.0	3.01	8.0	589.0	41	4.4	4.99		4.8	4.99	5.14
4.0	3.01	8.0	597.0	41	3.9	5.02		4.8	5.02	5.00
4.0	3.01	8.0	590.0	42	4.2	5.04		4.8	4.98	5.12
4.0	3.01	8.0	598.0	42	4.4	5.06		4.8	5.00	5.20
4.0	3.01	8.0	481.0	51	4.4	4.90		4.8	5.28	5.28
4.0	3.01	8.0	482.0	52	4.3	4.90		4.8	5.24	5.25
4.0	3.01	8.0	269.0	61	3.8	4.85		4.8	5.74	5.74
4.0	3.01	8.0	270.0	62	4.1	4.89		4.8	5.54	5.53
4.0	.01	12.0	603.0	41	3.8	5.16		4.8	5.16	5.04
4.0	.01	12.0	604.0	42	4.3	5.76		4.8	5.70	5.26
5.0	3.01	4.0	579.0	41	4.2	5.08		4.7	5.08	5.06
5.0	3.01	4.0	580.0	42	4.3	5.12		4.7	5.06	5.13
5.0	3.01	4.0	439.0	51	4.2	4.89		4.7	5.27	5.28
5.0	3.01	4.0	440.0	52	4.3	4.94		4.7	5.28	5.25
5.0	.01	8.0	587.0	41	4.4	5.05		4.8	5.05	5.20
5.0	.01	8.0	588.0	42	4.2	5.09		4.8	5.03	5.19
3.0	12.52	.0	171.1	31	4.4	5.76		4.2	5.06	5.00
3.0	12.52	.0	103.1	31	3.7	5.72		4.2	5.02	4.89
3.0	12.52	.0	172.1	32	4.1	5.76		4.2	5.21	4.80
3.0	12.52	.0	104.1	32	4.2	5.73		4.2	5.18	4.91
3.0	10.82	4.0	565.2	41	4.1	5.05		4.6	5.05	4.93
3.0	10.82	4.0	559.2	41	3.8	4.97		4.6	4.97	4.91
3.0	10.82	4.0	566.2	42	4.4	5.04		4.6	4.98	4.97
3.0	10.82	4.0	560.2	42	4.2	5.00		4.6	4.94	4.92
3.0	10.81	4.0	567.2	41	3.6	5.03		4.9	5.03	5.03
3.0	10.81	4.0	561.2	41	4.4	5.68		4.9	5.68	5.57
3.0	10.81	4.0	568.2	42	4.2	5.07		4.9	5.01	5.54
3.0	10.81	4.0	562.2	42	4.2	5.13		4.9	5.07	5.54
3.0	12.51	.0	169.1	31	4.1		2.4	4.6	5.31	5.25
3.0	12.51	.0	105.1	31	4.3	5.83		4.6	5.13	5.29
3.0	12.51	.0	170.1	32	4.1	5.77		4.6	5.22	5.15
3.0	12.51	.0	106.1	32	4.0	5.80		4.6	5.25	5.14
4.0	5.01	8.0	279.4	61	4.3	4.89		5.1	5.78	5.76
4.0	5.01	8.0	287.4	61	4.1	4.89		5.1	5.78	5.76
4.0	5.01	8.0	280.4	62	4.1	4.90		5.1	5.55	5.54
4.0	5.01	8.0	288.4	62	3.4	4.89		5.1	5.54	5.51
3.0	5.04	4.0	563.3	41	3.5	5.21		4.9	5.21	5.12
3.0	5.04	4.0	557.3	41	3.9	4.98		4.9	4.98	5.46
3.0	5.04	4.0	564.3	42	4.3	5.05		4.9	4.99	5.42
3.0	5.04	4.0	558.3	42	4.5	5.02		4.9	4.96	5.43

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS

IDENTIFICATION DATA				PERFORMANCE DATA				INDEXES		
SURF THCK	BASE THCK, TYPE	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D6	PERFORMANCE OBS. EST.	CALC. BY EQN D6
3.0	4.63	4.0	463.4	51	4.0	4.93		5.1	5.31	5.32
3.0	4.63	4.0	459.4	51	4.4	5.06		5.1	5.44	5.36
3.0	4.63	4.0	464.4	52	4.1	4.96		5.1	5.30	5.31
3.0	4.63	4.0	460.4	52	4.0	5.05		5.1	5.39	5.30
3.0	9.01	8.0	471.0	51	4.5	4.90		5.2	5.28	5.43
3.0	9.01	8.0	472.0	52	4.3	4.93		5.2	5.27	5.39
3.0	6.01	12.0	601.0	41	3.8	5.79		5.3	5.79	5.73
3.0	6.01	12.0	602.0	42	4.4	5.76		5.3	5.70	5.69
3.0	6.01	12.0	487.0	51	3.7	4.89		5.3	5.27	5.33
3.0	6.01	12.0	488.0	52	4.0	5.66		5.3	6.00	5.38
4.0	9.01	4.0	437.0	51	4.5	4.92		5.2	5.30	5.42
4.0	9.01	4.0	438.0	52	4.1	4.99		5.2	5.33	5.33
4.0	6.01	8.0	139.0	31	4.4		3.6	5.2	5.80	5.75
4.0	6.01	8.0	140.0	32	4.2		3.3	5.2	5.83	5.71
4.0	6.01	8.0	577.0	41	4.1	.00		5.2	5.88	5.74
4.0	6.01	8.0	578.0	42	4.3	5.86		5.2	5.80	5.70
4.0	6.01	8.0	455.0	51	4.4	4.98		5.2	5.36	5.45
4.0	6.01	8.0	453.0	51	4.3	4.96		5.2	5.34	5.43
4.0	6.01	8.0	456.0	52	4.2	4.97		5.2	5.31	5.42
4.0	6.01	8.0	454.0	52	4.4	5.18		5.2	5.52	5.47
4.0	6.01	8.0	303.0	61	4.1	4.90		5.2	5.79	5.75
4.0	6.01	8.0	304.0	62	4.4	5.06		5.2	5.71	5.56
4.0	3.01	12.0	575.0	41	4.1	.00		5.3	5.82	5.76
4.0	3.01	12.0	576.0	42	4.1	5.80		5.3	5.74	5.71
4.0	3.01	12.0	443.0	51	4.1	4.95		5.3	5.33	5.44
4.0	3.01	12.0	444.0	52	4.3	4.99		5.3	5.33	5.53
4.0	3.01	12.0	299.0	61	4.2	5.12		5.3	6.01	5.77
4.0	3.01	12.0	300.0	62	4.4	5.67		5.3	6.32	5.60
5.0	6.01	4.0	629.0	41	4.5	5.78		5.2	5.78	5.73
5.0	6.01	4.0	615.0	41	4.1	5.77		5.2	5.77	5.73
5.0	6.01	4.0	630.0	42	4.0	5.83		5.2	5.77	5.67
5.0	6.01	4.0	616.0	42	4.2	5.77		5.2	5.71	5.68
5.0	6.01	4.0	423.0	51	4.5	4.99		5.2	5.37	5.47
5.0	6.01	4.0	424.0	52	4.4	5.01		5.2	5.35	5.46
5.0	3.01	8.0	631.0	41	3.8	5.46		5.3	5.46	5.74
5.0	3.01	8.0	632.0	42	4.2	5.80		5.3	5.74	5.72
5.0	3.01	8.0	421.0	51	4.5	5.00		5.3	5.38	5.53
5.0	3.01	8.0	422.0	52	4.4	5.03		5.3	5.37	5.53
5.0	3.01	8.0	319.0	61	4.3	4.89		5.3	5.78	5.77
5.0	3.01	8.0	320.0	62	4.1	5.00		5.3	5.65	5.57
5.0	.01	12.0	621.0	41	4.3	5.77		5.4	5.77	5.79
5.0	.01	12.0	622.0	42	4.2	5.80		5.4	5.74	5.73
3.0	12.42	4.0	467.2	51	4.4	4.82		4.8	5.20	5.26
3.0	12.42	4.0	467.2	51	4.4	4.82		4.8	5.20	5.26
3.0	12.42	4.0	457.2	51	4.4	4.90		4.8	5.28	5.26
3.0	12.42	4.0	468.2	52	4.5	4.84		4.8	5.18	5.23
3.0	12.42	4.0	458.2	52	4.4	4.85		4.8	5.19	5.23
3.0	14.32	4.0	559.1	41	3.9	5.58		5.0	5.58	5.35
3.0	14.32	4.0	560.1	42	4.1	5.09		5.0	5.03	5.62
3.0	14.31	4.0	567.1	41	3.6		2.5	5.5	6.05	5.69

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS

IDENTIFICATION DATA					PERFORMANCE DATA			INDEXES		
									PERFORMANCE	
SURF THCK	BASE THCK, TYPE	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D6	OBS. EST.	CALC. BY EQN D6
3.0	14.31	4.0	561.1	41	4.1		3.9	5.5	7.04	5.72
3.0	14.31	4.0	568.1	42	4.0		2.9	5.5	6.15	5.67
3.0	14.31	4.0	562.1	42	4.3		2.9	5.5	6.13	5.88
3.0	7.04	4.0	563.2	41	4.2	5.79		5.5	5.79	5.90
3.0	7.04	4.0	557.2	41	4.5	5.69		5.5	5.69	5.95
3.0	7.04	4.0	564.2	42	4.5	5.72		5.5	5.66	5.95
3.0	7.04	4.0	558.2	42	4.0	5.21		5.5	5.15	5.86
3.0	7.04	4.0	465.3	51	4.6	4.94		5.5	5.32	5.83
3.0	7.04	4.0	466.3	52	4.2	5.01		5.5	5.35	5.78
3.0	6.44	4.0	461.3	51	4.4	5.32		5.3	5.70	5.81
3.0	6.44	4.0	462.3	52	4.1	4.95		5.3	5.29	5.77
3.0	7.63	.0	167.2	31	4.0		3.9	5.8	6.62	6.01
3.0	7.63	.0	101.2	31	4.3		4.1	5.8	6.40	6.07
3.0	7.63	.0	168.2	32	3.8		3.9	5.8	8.00	5.96
3.0	7.63	.0	102.2	32	4.1		3.9	5.8	6.49	6.03
4.0	4.93	4.0	285.4	61	4.2	5.01		5.8	5.90	5.82
4.0	4.93	4.0	283.4	61	4.3	5.07		5.8	5.96	5.83
4.0	4.93	4.0	286.4	62	3.2	4.95		5.8	5.60	5.55
4.0	4.93	4.0	284.4	62	3.7	5.20		5.8	5.85	5.63
4.0	4.34	4.0	289.4	61	4.4	4.85		5.2	5.74	5.57
4.0	4.34	4.0	281.4	61	4.1	4.89		5.2	5.78	5.56
4.0	4.34	4.0	290.4	62	4.2	4.88		5.2	5.53	5.39
4.0	4.34	4.0	282.4	62	4.1	4.94		5.2	5.59	5.38
3.0	9.01	12.0	441.0	51	4.4		2.9	5.7	6.56	6.10
3.0	9.01	12.0	442.0	52	4.2	5.18		5.7	5.52	6.06
4.0	9.01	8.0	417.0	51	4.5	5.23		5.7	5.61	6.10
4.0	9.01	8.0	418.0	52	4.4	5.09		5.7	5.43	6.07
4.0	9.01	8.0	321.0	61	4.1	4.90		5.7	5.79	5.79
4.0	9.01	8.0	322.0	62	4.1	5.08		5.7	5.73	5.70
4.0	6.01	12.0	625.0	41	4.2	5.83		5.8	5.83	6.06
4.0	6.01	12.0	626.0	42	3.9		3.1	5.8	6.27	6.00
4.0	6.01	12.0	425.0	51	4.3	5.70		5.8	6.08	6.12
4.0	6.01	12.0	426.0	52	4.1	5.26		5.8	5.60	6.08
4.0	6.01	12.0	323.0	61	4.4	4.90		5.8	5.79	5.84
4.0	6.01	12.0	324.0	62	4.3	4.93		5.8	5.58	5.83
4.0	3.01	16.0	317.0	61	4.3	4.99		5.9	5.88	5.86
4.0	3.01	16.0	329.0	61	4.3	4.93		5.9	5.82	5.86
4.0	3.01	16.0	318.0	62	4.3	5.76		5.9	6.41	5.91
4.0	3.01	16.0	330.0	62	4.4	5.00		5.9	5.65	5.95
5.0	9.01	4.0	475.0	51	4.5	5.78		5.7	6.16	6.09
5.0	9.01	4.0	483.0	51	4.5	5.69		5.7	6.07	6.09
5.0	9.01	4.0	476.0	52	4.4	5.38		5.7	5.72	6.06
5.0	9.01	4.0	484.0	52	4.2	5.66		5.7	6.00	6.05
5.0	6.01	8.0	591.0	41	4.7		3.6	5.8	6.42	6.14
5.0	6.01	8.0	592.0	42	4.3		2.7	5.8	6.05	6.07
5.0	6.01	8.0	469.0	51	4.3	5.75		5.8	6.13	6.12
5.0	6.01	8.0	470.0	52	4.0	5.57		5.8	5.91	6.08
5.0	6.01	8.0	259.0	61	4.3	4.96		5.8	5.85	5.83
5.0	6.01	8.0	260.0	62	4.0	5.00		5.8	5.65	5.71
5.0	3.01	12.0	593.0	41	4.1	5.76		5.9	5.76	6.08

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS

IDENTIFICATION DATA					PERFORMANCE DATA			INDEXES		
SURF THCK	BASE THCK, TYPE	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D6	PERFORMANCE OBS. EST.	CALC. BY EQN D6
5.0	3.01	12.0	594.0	42	4.4		2.2	5.9	5.90	6.14
5.0	3.01	12.0	479.0	51	4.7	5.79		5.9	6.17	6.15
5.0	3.01	12.0	480.0	52	4.4	5.79		5.9	6.13	6.10
5.0	3.01	12.0	261.0	61	4.4	4.96		5.9	5.85	5.86
5.0	3.01	12.0	262.0	62	4.2	5.06		5.9	5.71	5.84
6.0	3.01	8.0	297.0	61	4.0	5.05		5.8	5.94	5.84
6.0	3.01	8.0	298.0	62	4.2	5.76		5.8	6.41	5.83
4.0	9.01	8.0	279.3	61	4.2	4.95		5.7	5.84	5.80
4.0	9.01	8.0	287.3	61	4.2	4.90		5.7	5.79	5.80
4.0	9.01	8.0	280.3	62	4.3	4.97		5.7	5.62	5.76
4.0	9.01	8.0	288.3	62	4.4	5.06		5.7	5.71	5.80
4.0	6.84	4.0	289.3	61	4.2	4.91		6.0	5.80	6.24
4.0	6.84	4.0	281.3	61	4.2	5.05		6.0	5.94	6.24
4.0	6.84	4.0	290.3	62	4.6	5.02		6.0	5.67	6.12
4.0	6.84	4.0	282.3	62	4.4	5.10		6.0	5.75	6.12
3.0	7.93	4.0	463.3	51	4.3		3.4	6.5	6.79	6.46
3.0	7.93	4.0	459.3	51	4.7		2.4	6.5	6.40	6.53
3.0	7.93	4.0	464.3	52	4.4		3.9	6.5	7.06	6.48
3.0	7.93	4.0	460.3	52	4.3		3.4	6.5	6.75	6.46
3.0	9.93	.0	167.1	31	3.3		3.7	6.7	8.00	6.31
3.0	9.93	.0	101.1	31	4.2		3.6	6.7	5.87	6.58
3.0	9.93	.0	168.1	32	4.0		3.9	6.7	6.77	6.54
3.0	9.93	.0	102.1	32	4.1		3.8	6.7	6.31	6.56
3.0	16.12	4.0	467.1	51	4.3	4.37		5.2	4.75	5.46
3.0	16.12	4.0	457.1	51	4.4	4.90		5.2	5.28	5.49
3.0	16.12	4.0	468.1	52	4.1	4.38		5.2	4.72	5.42
4.0	9.01	12.0	477.0	51	4.5		2.4	6.3	6.40	6.39
4.0	9.01	12.0	478.0	52	4.4		3.0	6.3	6.56	6.38
4.0	9.01	12.0	267.0	61	4.2	5.04		6.3	5.93	6.12
4.0	9.01	12.0	268.0	62	4.2	5.37		6.3	6.02	6.37
4.0	6.01	16.0	253.0	61	4.3	5.65		6.4	6.54	6.23
4.0	6.01	16.0	254.0	62	4.3	5.34		6.4	5.99	6.40
5.0	9.01	8.0	447.0	51	4.3		2.7	6.3	6.49	6.35
5.0	9.01	8.0	448.0	52	4.2		2.6	6.3	6.42	6.33
5.0	9.01	8.0	313.0	61	4.3	5.64		6.3	6.53	6.13
5.0	9.01	8.0	314.0	62	4.1	5.77		6.3	6.42	6.37
5.0	6.01	12.0	581.0	41	4.1		3.3	6.3	6.40	6.35
5.0	6.01	12.0	582.0	42	4.2		2.7	6.3	6.06	6.37
5.0	6.01	12.0	445.0	51	4.4	5.85		6.3	6.23	6.41
5.0	6.01	12.0	446.0	52	4.4		2.4	6.3	6.36	6.41
5.0	6.01	12.0	307.0	61	4.4	5.77		6.3	6.66	6.27
5.0	6.01	12.0	305.0	61	4.2	5.10		6.3	5.99	6.18
5.0	6.01	12.0	308.0	62	4.1	5.70		6.3	6.35	6.39
5.0	6.01	12.0	306.0	62	4.3	5.78		6.3	6.43	6.39
5.0	3.01	16.0	315.0	61	4.2	5.70		6.4	6.59	6.24
5.0	3.01	16.0	316.0	62	4.0	5.77		6.4	6.42	6.41
6.0	6.01	8.0	325.0	61	4.3	5.01		6.3	5.90	6.19
6.0	6.01	8.0	326.0	62	4.2	5.08		6.3	5.73	6.40
6.0	3.01	12.0	335.0	61	3.9	4.98		6.4	5.87	6.08
6.0	3.01	12.0	336.0	62	3.7	5.05		6.4	5.70	6.40

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS

IDENTIFICATION DATA					PERFORMANCE DATA			INDEXES		
SURF THCK	BASE THCK, TYPE	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D6	PERFORMANCE OBS. EST.	CALC. BY EQN D6
4.0	13.01	8.0	287.2	61	4.3		2.7	6.4	7.00	6.35
4.0	13.01	8.0	279.2	61	4.5	5.80		6.4	6.69	6.49
4.0	13.01	8.0	288.2	62	4.5		3.6	6.4	7.12	6.37
4.0	13.01	8.0	280.2	62	4.5		3.6	6.4	7.12	6.37
3.0	8.64	4.0	465.2	51	4.5	5.72		6.1	6.10	6.27
3.0	8.64	4.0	461.2	51	4.5	5.74		6.1	6.12	6.27
3.0	8.64	4.0	466.2	52	4.3	5.79		6.1	6.13	6.24
3.0	8.64	4.0	462.2	52	4.2	5.76		6.1	6.10	6.22
3.0	9.04	4.0	563.1	41	4.0		3.8	6.2	7.01	6.25
3.0	9.04	4.0	557.1	41	4.4		2.8	6.2	6.14	6.33
3.0	9.04	4.0	564.1	42	4.1		4.2	6.2	8.00	6.28
3.0	9.04	4.0	558.1	42	4.1		2.4	6.2	5.95	6.28
4.0	9.01	16.0	309.0	61	4.3	6.01		6.8	6.90	6.64
4.0	9.01	16.0	310.0	62	4.4		3.2	6.8	6.95	6.67
5.0	9.01	12.0	427.0	51	4.5		3.5	6.8	6.80	6.68
5.0	9.01	12.0	428.0	52	4.3		3.2	6.8	6.65	6.64
5.0	9.01	12.0	331.0	61	4.2	5.75		6.8	6.64	6.63
5.0	9.01	12.0	332.0	62	4.2	.00		6.8	6.08	6.63
5.0	6.01	16.0	327.0	61	4.5	5.83		6.9	6.72	6.65
5.0	6.01	16.0	328.0	62	4.3	5.76		6.9	6.41	6.68
6.0	9.01	8.0	263.0	61	4.3	5.71		6.8	6.60	6.64
6.0	9.01	8.0	271.0	61	4.4	5.85		6.8	6.74	6.64
6.0	9.01	8.0	264.0	62	4.2		2.6	6.8	6.73	6.61
6.0	9.01	8.0	272.0	62	4,2	5.79		6.8	6.44	6.61
6.0	6.01	12.0	257.0	61	4.5	5.85		6.9	6.74	6.66
6.0	6.01	12.0	258.0	62	4.3		3.0	6.9	6.87	6.67
6.0	3.01	16.0	255.0	61	4.3	5.74		7.0	6.63	6.66
6.0	3.01	16.0	256.0	62	4.2		2.4	7.0	6.66	6.70
4.0	17.01	8.0	287.1	61	4.4		3.4	7.0	7.28	6.62
4.0	17.01	8.0	279.1	61	4.5		4.0	7.0	7.63	6.63
4.0	17.01	8.0	288.1	62	4.4		4.0	7.0	7.47	6.75
4.0	17.01	8.0	280.1	62	4.4		3.7	7.0	7.21	6.75
4.0	9.34	4.0	289.2	61	4.4	5.42		6.8	6.31	6.68
4.0	9.34	4.0	281.2	61	4.1	5.70		6.8	6.59	6.62
4.0	9.34	4.0	290.2	62	4.3	5.87		6.8	6.52	6.66
4.0	9.34	4.0	282.2	62	4.3		2.4	6.8	6.67	6.66
4.0	8.63	4.0	285.3	61	4.2	5.38		7.3	6.27	6.86
4.0	8.63	4.0	283.3	61	4.3	5.77		7.3	6.66	6.88
4.0	8.63	4.0	286.3	62	3.9	5.98		7.3	6.63	6.79
4.0	8.63	4.0	284.3	62	4.5		2.9	7.3	6.82	6.91
3.0	10.94	4.0	465.1	51	4.3		3.8	6.8	7.07	6.66
3.0	10.94	4.0	461.1	51	4.7		3.6	6.8	6.80	6.72
3.0	10.94	4.0	466.1	52	4.4		4.0	6.8	7.16	6.67
3.0	10.94	4.0	462.1	52	4.5		3.6	6.8	6.81	6.69
3.0	11.13	4.0	463.2	51	4.6		4.4	7.8	7.56	7.16
3.0	11.13	4.0	459.2	51	4.3		3.3	7.8	6.74	7.11
3.0	11.13	4.0	464.2	52	4.3		4.4	7.8	8.00	7.11
3.0	11.13	4.0	460.2	52	4.5		4.2	7.8	7.32	7.14
5.0	9.01	16.0	265.0	61	4.4		3.3	7.4	7.23	6.94
5.0	9.01	16.0	266.0	62	4.3		3.5	7.4	7.12	6.92

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST FLEXIBLE PAVEMENT SECTIONS

IDENTIFICATION DATA				PERFORMANCE DATA				INDEXES		
SURF THCK	BASE THCK, TYPE	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D6	PERFORMANCE OBS. EST.	CALC. BY EQN D6
6.0	6.01	16.0	301.0	61	4.3		3.2	7.4	7.20	6.95
6.0	6.01	16.0	302.0	62	4.2		3.9	7.4	7.54	6.93
6.0	9.01	12.0	311.0	61	4.3		2.8	7.4	7.04	6.91
6.0	9.01	12.0	312.0	62	4.1		2.6	7.4	6.73	6.87
6.0	9.01	16.0	333.0	61	4.2		2.7	7.9	7.01	7.14
6.0	9.01	16.0	334.0	62	4.2		3.6	7.9	7.22	7.14
4.0	11.84	4.0	281.1	61	4.3		3.2	7.7	7.20	7.06
4.0	11.84	4.0	289.1	61	4.1		3.4	7.7	7.36	7.02
4.0	11.84	4.0	282.1	62	4.6		3.1	7.7	6.89	7.11
4.0	11.84	4.0	290.1	62	4.3		3.1	7.7	6.92	7.06
4.0	12.43	4.0	283.2	61	4.4		3.9	8.9	7.61	7.58
4.0	12.43	4.0	285.2	61	4.4		4.0	8.9	7.71	7.58
4.0	12.43	4.0	284.2	62	4.2		4.1	8.9	8.00	7.54
4.0	12.43	4.0	286.2	62	4.1		3.7	8.9	7.38	7.52
3.0	14.43	4.0	463.1	51	4.3		3.8	9.2	7.07	7.67
3.0	14.43	4.0	459.1	51	4.5		4.2	9.2	7.36	7.71
3.0	14.43	4.0	464.1	52	4.4		4.2	9.2	7.47	7.69
3.0	14.43	4.0	460.1	52	4.4		3.8	9.2	6.97	7.69
4.0	16.13	4.0	285.1	61	4.3		3.8	10.4	7.58	8.12
4.0	16.13	4.0	283.1	61	4.2		3.3	10.4	7.27	8.10
4.0	16.13	4.0	286.1	62	4.2		3.7	10.4	7.31	8.10
4.0	16.13	4.0	284.1	62	4.3		3.4	10.4	7.06	8.12

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST RIGID PAVEMENT SECTIONS

IDENTIFICATION DATA				PERFORMANCE DATA			INDEXES		
SURF THCK, REINF	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D7	PERFORMANCE OBS. EST.	CALC.BY EQN D7
2.50	.0	805.0	21	4.6		4.3	3.2	2.70	4.00
2.50	.0	806.0	22	4.6	5.49		3.2	3.57	4.00
2.51	.0	781.0	21	4.4		4.2	3.2	2.77	3.98
2.51	.0	782.0	22	4.7	5.58		3.2	3.66	4.01
2.50	3.0	791.0	21	4.7		4.4	3.4	2.72	4.26
2.50	3.0	792.0	22	4.5	6.04		3.4	4.12	4.25
2.51	3.0	799.0	21	4.5		4.2	3.4	2.69	4.25
2.51	3.0	800.0	22	4.6	5.92		3.4	4.00	4.25
2.50	6.0	785.0	21	4.7		4.4	3.4	2.72	4.26
2.50	6.0	786.0	22	4.8		3.1	3.4	4.21	4.27
2.51	6.0	789.0	21	4.7		4.4	3.4	2.72	4.26
2.51	6.0	790.0	22	4.7		3.8	3.4	4.36	4.26
3.50	.0	813.0	21	4.7		4.2	3.8	2.60	4.63
3.50	.0	814.0	22	4.8		3.7	3.8	4.33	4.64
3.50	.0	189.0	31	4.6	5.34		3.8	4.64	4.62
3.50	.0	223.0	31	4.6	5.13		3.8	4.43	4.62
3.50	.0	190.0	32	4.7	5.30		3.8	4.97	4.63
3.50	.0	224.0	32	4.6	5.13		3.8	4.80	4.62
3.51	.0	793.0	21	4.7		4.4	3.8	2.72	4.63
3.51	.0	794.0	22	4.8		4.1	3.8	4.44	4.64
3.50	3.0	811.0	21	4.7		4.0	4.0	2.52	4.85
3.50	3.0	812.0	22	4.8		4.0	4.0	4.40	4.85
3.50	3.0	195.0	31	4.3	5.49		4.0	4.79	4.81
3.50	3.0	196.0	32	4.5	5.50		4.0	5.17	4.83
3.51	3.0	815.0	21	4.3		4.1	4.0	2.76	4.81
3.51	3.0	779.0	21	4.8		4.5	4.0	2.73	4.85
3.51	3.0	816.0	22	4.6		4.1	4.0	4.49	4.84
3.51	3.0	780.0	22	4.9		4.2	4.0	4.45	4.86
3.51	3.0	209.0	31	4.8	5.43		4.0	4.73	4.85
3.51	3.0	210.0	32	4.9	5.44		4.0	5.11	4.86
3.50	6.0	787.0	21	4.7		4.2	4.0	2.60	4.85
3.50	6.0	788.0	22	4.7		4.0	4.0	4.42	4.85
3.50	6.0	239.0	31	4.6	5.45		4.0	4.75	4.84
3.50	6.0	243.0	31	4.7	5.46		4.0	4.76	4.85
3.50	6.0	240.0	32	4.6	5.31		4.0	4.98	4.84
3.50	6.0	244.0	32	4.7	5.43		4.0	5.10	4.85
3.51	6.0	783.0	21	4.8		4.5	4.0	2.73	4.85
3.51	6.0	784.0	22	4.9		4.6	4.0	4.64	4.86
3.51	6.0	205.0	31	4.5	5.48		4.0	4.78	4.83
3.51	6.0	206.0	32	4.9	5.42		4.0	5.09	4.86
3.50	9.0	213.0	31	4.7	5.51		4.0	4.81	4.85
3.50	9.0	214.0	32	4.9	5.37		4.0	5.04	4.86
3.51	9.0	231.0	31	4.5	5.48		4.0	4.78	4.83
3.51	9.0	232.0	32	4.8	5.44		4.0	5.11	4.85
5.00	.0	801.0	21	4.6		4.1	4.7	2.59	5.39
5.00	.0	802.0	22	4.6		4.1	4.7	4.49	5.39
5.00	.0	659.0	41	4.7	5.46		4.7	5.46	5.40
5.00	.0	693.0	41	4.8	5.51		4.7	5.51	5.40
5.00	.0	660.0	42	4.7	5.43		4.7	5.61	5.40
5.00	.0	694.0	42	4.8	5.51		4.7	5.69	5.40

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST RIGID PAVEMENT SECTIONS

IDENTIFICATION DATA				PERFORMANCE DATA			INDEXES		
SURF THCK, REINF	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D7	PERFORMANCE OBS. EST.	CALC.BY EQN D7
5.01	.0	807.0	21	4.6		4.3	4.7	2.70	5.39
5.00	.0	808.0	22	4.8		4.5	4.7	4.63	5.40
5.00	3.0	797.0	21	4.5		3.9	4.9	2.53	5.55
5.00	3.0	777.0	21	4.6		3.5	4.9	2.40	5.56
5.00	3.0	798.0	22	4.7		4.1	4.9	4.46	5.57
5.00	3.0	778.0	22	4.7		3.6	4.9	4.31	5.57
5.00	3.0	225.0	31	4.3		3.7	4.9	5.63	5.54
5.00	3.0	226.0	32	4.8	5.83		4.9	5.50	5.58
5.00	3.0	643.0	41	4.8	5.81		4.9	5.81	5.58
5.00	3.0	644.0	42	4.8	5.52		4.9	5.70	5.58
5.01	3.0	809.0	21	4.7		4.6	4.9	2.96	5.57
5.01	3.0	810.0	22	4.8		4.6	4.9	4.72	5.58
5.01	3.0	251.0	31	4.0		2.8	4.9	5.41	5.51
5.01	3.0	203.0	31	4.5		4.0	4.9	5.70	5.55
5.01	3.0	252.0	32	4.5	6.02		4.9	5.69	5.55
5.01	3.0	204.0	32	4.7	6.01		4.9	5.68	5.57
5.01	3.0	681.0	41	4.6	5.58		4.9	5.58	5.56
5.01	3.0	682.0	42	4.7	5.45		4.9	5.63	5.57
5.00	6.0	803.0	21	4.7		4.1	4.9	2.56	5.57
5.00	6.0	804.0	22	4.8		4.0	4.9	4.40	5.58
5.00	6.0	245.0	31	4.7		3.5	4.9	5.51	5.57
5.00	6.0	221.0	31	4.6		3.1	4.9	5.44	5.56
5.00	6.0	246.0	32	4.8		2.8	4.9	5.76	5.58
5.00	6.0	222.0	32	4.9	5.91		4.9	5.58	5.58
5.00	6.0	647.0	41	4.8	5.50		4.9	5.50	5.58
5.00	6.0	679.0	41	4.8	5.76		4.9	5.76	5.58
5.00	6.0	648.0	42	4.7	5.46		4.9	5.64	5.57
5.00	6.0	680.0	42	4.8	5.55		4.9	5.73	5.58
5.01	6.0	795.0	21	4.7		4.3	4.9	2.65	5.57
5.01	6.0	796.0	22	4.7		4.3	4.9	4.55	5.57
5.01	6.0	191.0	31	4.4	5.86		4.9	5.16	5.55
5.01	6.0	192.0	32	4.7	5.75		4.9	5.42	5.57
5.01	6.0	661.0	41	4.7	5.51		4.9	5.51	5.57
5.01	6.0	662.0	42	4.6	5.22		4.9	5.40	5.56
5.00	9.0	219.0	31	4.5		3.7	4.9	5.59	5.55
5.00	9.0	220.0	32	4.8	5.85		4.9	5.52	5.58
5.00	9.0	677.0	41	4.6	5.44		4.9	5.44	5.56
5.00	9.0	678.0	42	4.8	5.45		4.9	5.63	5.58
5.01	9.0	233.0	31	4.6		3.3	4.9	5.48	5.56
5.01	9.0	234.0	32	4.9	5.89		4.9	5.56	5.58
5.01	9.0	673.0	41	4.7	5.76		4.9	5.76	5.57
5.01	9.0	674.0	42	4.7	5.59		4.9	5.77	5.57
6.50	.0	229.0	31	4.7		4.2	5.6	5.72	6.02
6.50	.0	227.0	31	4.7		3.5	5.6	5.51	6.02
6.50	.0	230.0	32	4.6		4.0	5.6	6.04	6.02
6.50	.0	228.0	32	4.6	5.95		5.6	5.62	6.02
6.50	.0	537.0	51	4.7	5.91		5.6	6.29	6.02
6.50	.0	555.0	51	4.1	5.55		5.6	5.93	5.97
6.50	.0	538.0	52	4.6	5.83		5.6	6.39	6.02
6.50	.0	556.0	52	4.4	5.48		5.6	6.04	6.00

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST RIGID PAVEMENT SECTIONS

IDENTIFICATION DATA				PERFORMANCE DATA			INDEXES		
SURF THCK, REINF	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D7	PERFORMANCE OBS. EST.	CALC.BY EQN D7
6.50	3.0	217.0	31	4.9		4.4	5.9	5.74	6.18
6.50	3.0	193.0	31	4.6		3.9	5.9	5.63	6.16
6.50	3.0	218.0	32	4.8		4.2	5.9	6.06	6.18
6.50	3.0	194.0	32	4.6		4.0	5.9	6.04	6.16
6.50	3.0	649.0	41	4.8		3.8	5.9	6.27	6.18
6.50	3.0	650.0	42	4.6	5.67		5.9	5.85	6.16
6.50	3.0	513.0	51	4.7	5.87		5.9	6.25	6.17
6.50	3.0	514.0	52	4.7	5.50		5.9	6.06	6.17
6.51	3.0	199.0	31	4.7		4.2	5.9	5.72	6.17
6.51	3.0	200.0	32	4.9		4.1	5.9	6.01	6.18
6.51	3.0	641.0	41	4.9		3.8	5.9	6.26	6.18
6.51	3.0	705.0	41	4.8		3.6	5.9	6.22	6.18
6.51	3.0	642.0	42	4.7	5.95		5.9	6.13	6.17
6.51	3.0	706.0	42	4.8	5.89		5.9	6.07	6.18
6.51	3.0	523.0	51	4.6	5.92		5.9	6.30	6.16
6.51	3.0	524.0	52	4.7	5.84		5.9	6.40	6.17
6.50	6.0	249.0	31	4.7		4.1	5.9	5.68	6.17
6.50	6.0	187.0	31	4.6		4.1	5.9	5.71	6.16
6.50	6.0	250.0	32	4.8		4.1	5.9	6.03	6.18
6.50	6.0	188.0	32	4.7		3.9	5.9	5.98	6.17
6.50	6.0	697.0	41	4.7		4.4	5.9	6.54	6.17
6.50	6.0	655.0	41	4.8		4.3	5.9	6.43	6.18
6.50	6.0	698.0	42	4.8		3.4	5.9	6.37	6.18
6.50	6.0	656.0	42	4.7	5.97		5.9	6.15	6.17
6.50	6.0	517.0	51	4.7	5.93		5.9	6.31	6.17
6.50	6.0	489.0	51	4.6	5.95		5.9	6.33	6.16
6.50	6.0	518.0	52	4.7	5.53		5.9	6.09	6.17
6.50	6.0	490.0	52	4.7	5.70		5.9	6.26	6.17
6.51	6.0	247.0	31	4.8		4.3	5.9	5.73	6.18
6.51	6.0	237.0	31	5.0		4.5	5.9	5.76	6.19
6.51	6.0	248.0	32	4.8		4.3	5.9	6.10	6.18
6.51	6.0	238.0	32	5.0		4.1	5.9	5.99	6.19
6.51	6.0	685.0	41	4.8		3.4	5.9	6.19	6.18
6.51	6.0	686.0	42	4.8	5.90		5.9	6.08	6.18
6.51	6.0	491.0	51	4.6	5.52		5.9	5.90	6.16
6.51	6.0	492.0	52	4.7	5.48		5.9	6.04	6.17
6.50	9.0	207.0	31	4.9		4.2	5.9	5.67	6.18
6.50	9.0	208.0	32	4.8		4.0	5.9	5.99	6.18
6.50	9.0	703.0	41	4.8		3.0	5.9	6.12	6.18
6.50	9.0	704.0	42	4.7	5.85		5.9	6.03	6.17
6.50	9.0	505.0	51	4.5	5.83		5.9	6.21	6.15
6.50	9.0	506.0	52	4.6	5.60		5.9	6.16	6.16
6.51	9.0	241.0	31	4.9		4.4	5.9	5.74	6.18
6.51	9.0	242.0	32	4.9		4.4	5.9	6.11	6.18
6.51	9.0	653.0	41	4.9	6.02		5.9	6.02	6.18
6.51	9.0	654.0	42	4.8	5.99		5.9	6.17	6.18
6.51	9.0	549.0	51	4.6	5.83		5.9	6.21	6.16
6.51	9.0	550.0	52	4.7	5.54		5.9	6.10	6.17
8.00	.0	663.0	41	4.7		4.1	6.6	6.38	6.56
8.00	.0	699.0	41	4.8		3.5	6.6	6.20	6.56

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST RIGID PAVEMENT SECTIONS

IDENTIFICATION DATA				PERFORMANCE DATA			INDEXES		
SURF THCK, REINF	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D7	PERFORMANCE OBS. EST.	CALC.BY EQN D7
8.00	.0	664.0	42	4.7	6.05		6.6	6.23	6.56
8.00	.0	700.0	42	4.7	6.01		6.6	6.19	6.56
8.00	.0	373.0	61	4.7	5.85		6.6	6.74	6.56
8.00	.0	361.0	61	4.8	5.70		6.6	6.59	6.56
8.00	.0	374.0	62	4.8	5.76		6.6	6.64	6.56
8.00	.0	362.0	62	4.7	5.89		6.6	6.77	6.56
8.00	3.0	201.0	31	4.8		4.4	6.8	5.78	6.69
8.00	3.0	202.0	32	4.8		4.3	6.8	6.10	6.69
8.00	3.0	687.0	41	4.8		4.5	6.8	6.55	6.69
8.00	3.0	688.0	42	4.7		4.2	6.8	6.60	6.68
8.00	3.0	672.0	42	4.6		4.1	6.8	6.59	6.67
8.00	3.0	547.0	51	4.4		4.2	6.8	6.97	6.66
8.00	3.0	548.0	52	4.7		4.2	6.8	6.98	6.68
8.00	3.0	353.0	61	4.3	5.94		6.8	6.83	6.65
8.00	3.0	354.0	62	4.3	6.04		6.8	6.92	6.65
8.01	3.0	211.0	31	4.9		4.3	6.8	5.70	6.69
8.01	3.0	212.0	32	4.9		4.1	6.8	6.01	6.69
8.01	3.0	691.0	41	4.8		3.9	6.8	6.30	6.69
8.01	3.0	692.0	42	4.9		4.0	6.8	6.49	6.69
8.01	3.0	519.0	51	4.6	5.95		6.8	6.33	6.67
8.01	3.0	521.0	51	4.5		4.3	6.8	6.98	6.66
8.01	3.0	520.0	52	4.7	5.95		6.8	6.51	6.68
8.01	3.0	522.0	52	4.6		4.3	6.8	7.08	6.67
8.01	3.0	341.0	61	4.7	5.89		6.8	6.78	6.68
8.01	3.0	342.0	62	4.7	5.69		6.8	6.57	6.68
8.00	6.0	235.0	31	4.8		4.3	6.8	5.73	6.69
8.00	6.0	236.0	32	4.9		4.3	6.8	6.07	6.69
8.00	6.0	683.0	41	4.9		4.4	6.8	6.44	6.69
8.00	6.0	657.0	41	4.9		4.2	6.8	6.37	6.69
8.00	6.0	684.0	42	4.8		4.2	6.8	6.57	6.69
8.00	6.0	658.0	42	4.8		4.5	6.8	6.73	6.69
8.00	6.0	539.0	51	4.7		4.2	6.8	6.80	6.68
8.00	6.0	533.0	51	4.7		4.1	6.8	6.76	6.68
8.00	6.0	540.0	52	4.7		3.7	6.8	6.82	6.68
8.00	6.0	534.0	52	4.7		4.2	6.8	6.98	6.68
8.00	6.0	393.0	61	4.8		3.9	6.8	7.19	6.69
8.00	6.0	401.0	61	4.4		3.6	6.8	7.16	6.66
8.00	6.0	394.0	62	4.7		4.1	6.8	7.26	6.68
8.00	6.0	402.0	62	4.3	5.87		6.8	6.75	6.65
8.01	6.0	215.0	31	4.9		4.2	6.8	5.67	6.69
8.01	6.0	216.0	32	4.8		4.0	6.8	5.99	6.69
8.01	6.0	669.0	41	4.9		4.4	6.8	6.44	6.69
8.01	6.0	707.0	41	4.7		3.9	6.8	6.31	6.68
8.01	6.0	670.0	42	4.8		4.4	6.8	6.66	6.69
8.01	6.0	708.0	42	4.7		3.8	6.8	6.46	6.68
8.01	6.0	501.0	51	4.6		4.0	6.8	6.75	6.67
8.01	6.0	502.0	52	4.8	5.95		6.8	6.51	6.69
8.01	6.0	385.0	61	4.6	5.93		6.8	6.82	6.67
8.01	6.0	386.0	62	4.6	5.61		6.8	6.49	6.67
8.00	9.0	185.0	31	4.6		4.0	6.8	5.67	6.67

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST RIGID PAVEMENT SECTIONS

IDENTIFICATION DATA				PERFORMANCE DATA			INDEXES		
								PERFORMANCE	
SURF THCK, REINF	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D7	OBS. EST.	CALC.BY EQN D7
8.00	9.0	186.0	32	4.7		4.2	6.8	6.09	6.68
8.00	9.0	651.0	41	4.8		4.3	6.8	6.43	6.69
8.00	9.0	652.0	42	4.7		4.1	6.8	6.56	6.68
8.00	9.0	507.0	51	4.7	6.01		6.8	6.39	6.68
8.00	9.0	508.0	52	4.8	5.95		6.8	6.51	6.69
8.00	9.0	369.0	61	4.5		3.4	6.8	7.10	6.66
8.00	9.0	370.0	62	4.3	6.02		6.8	6.90	6.65
8.01	9.0	197.0	31	4.8		4.1	6.8	5.66	6.69
8.01	9.0	198.0	32	4.8		4.3	6.8	6.10	6.69
8.01	9.0	695.0	41	4.8		4.3	6.8	6.43	6.69
8.01	9.0	696.0	42	4.8		4.2	6.8	6.57	6.69
8.01	9.0	531.0	51	4.9		4.6	6.8	6.94	6.69
8.01	9.0	532.0	52	4.8		3.2	6.8	6.71	6.69
8.01	9.0	347.0	61	4.7	5.85		6.8	6.74	6.68
8.01	9.0	348.0	62	4.8	5.79		6.8	6.67	6.69
9.50	.0	493.0	51	4.3		3.7	7.5	6.71	6.98
9.50	.0	551.0	51	4.6		4.3	7.5	6.90	7.01
9.50	.0	494.0	52	4.7	5.80		7.5	6.36	7.02
9.50	.0	552.0	52	4.7		4.3	7.5	7.03	7.02
9.50	3.0	675.0	41	4.7		4.2	7.7	6.42	7.13
9.50	3.0	676.0	42	4.5		4.0	7.7	6.58	7.11
9.50	3.0	511.0	51	4.7		4.4	7.7	6.92	7.13
9.50	3.0	541.0	51	4.4		4.3	7.7	7.12	7.10
9.50	3.0	512.0	52	4.8		4.3	7.7	6.99	7.13
9.50	3.0	542.0	52	4.6		4.2	7.7	7.02	7.12
9.50	3.0	351.0	61	4.4		3.6	7.7	7.16	7.10
9.50	3.0	352.0	62	4.3		3.1	7.7	7.04	7.09
9.51	3.0	645.0	41	4.9		4.0	7.7	6.31	7.14
9.51	3.0	646.0	42	4.7		4.0	7.7	6.52	7.13
9.51	3.0	553.0	51	4.7		4.3	7.7	6.85	7.13
9.51	3.0	554.0	52	4.9		4.1	7.7	6.90	7.14
9.51	3.0	381.0	61	4.5		4.5	7.7	8.00	7.11
9.51	3.0	371.0	61	4.6	5.96		7.7	6.85	7.12
9.51	3.0	382.0	62	4.7		4.4	7.7	7.42	7.13
9.51	3.0	372.0	62	4.7		4.1	7.7	7.26	7.13
9.50	6.0	701.0	41	4.9		4.5	7.7	6.50	7.14
9.50	6.0	702.0	42	4.7		4.2	7.7	6.60	7.13
9.50	6.0	525.0	51	4.7		3.7	7.7	6.64	7.13
9.50	6.0	527.0	51	4.7		4.6	7.7	7.16	7.13
9.50	6.0	526.0	52	4.8		4.0	7.7	6.88	7.13
9.50	6.0	528.0	52	4.7		4.5	7.7	7.19	7.13
9.50	6.0	367.0	61	4.7		4.3	7.7	7.36	7.13
9.50	6.0	389.0	61	4.6		4.3	7.7	7.41	7.12
9.50	6.0	368.0	62	4.7		4.3	7.7	7.35	7.13
9.50	6.0	390.0	62	4.7		4.3	7.7	7.35	7.13
9.51	6.0	665.0	41	4.7		4.5	7.7	6.63	7.13
9.51	6.0	666.0	42	4.7		4.3	7.7	6.65	7.13
9.51	6.0	543.0	51	4.7		4.5	7.7	7.01	7.13
9.51	6.0	503.0	51	4.7		4.3	7.7	6.85	7.13
9.51	6.0	544.0	52	4.7		4.3	7.7	7.03	7.13

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST RIGID PAVEMENT SECTIONS

IDENTIFICATION DATA				PERFORMANCE DATA			INDEXES		
SURF THCK, REINF	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D7	PERFORMANCE OBS. EST.	CALC. BY EQN D7
9.51	6.0	504.0	52	4.6		4.5	7.7	7.11	7.13
9.51	6.0	403.0	61	4.4		4.0	7.7	7.32	7.10
9.51	6.0	404.0	62	4.7		4.0	7.7	7.22	7.13
9.50	9.0	689.0	41	4.7		4.1	7.7	6.38	7.13
9.50	9.0	690.0	42	4.7		4.2	7.7	6.60	7.13
9.50	9.0	535.0	51	4.7		4.5	7.7	7.01	7.13
9.50	9.0	536.0	52	4.6		3.8	7.7	6.86	7.12
9.50	9.0	375.0	61	4.6		4.2	7.7	7.35	7.12
9.50	9.0	376.0	62	4.6		4.3	7.7	7.40	7.12
9.51	9.0	667.0	41	4.8		4.8	7.7	8.00	7.13
9.51	9.0	668.0	42	4.8		4.6	7.7	6.82	7.13
9.51	9.0	499.0	51	4.6		4.4	7.7	7.00	7.12
9.51	9.0	500.0	52	4.8		4.6	7.7	7.20	7.13
9.51	9.0	339.0	61	4.7	5.95		7.7	6.84	7.13
9.51	9.0	340.0	62	4.8	5.96		7.7	6.84	7.13
11.00	.0	383.0	61	4.5		4.2	8.4	7.40	7.41
11.00	.0	399.0	61	4.6		4.1	8.4	7.30	7.42
11.00	.0	384.0	62	4.7	5.95		8.4	6.83	7.42
11.00	.0	400.0	62	4.7	6.05		8.4	6.93	7.42
11.00	3.0	529.0	51	4.7		4.1	8.7	6.76	7.52
11.00	3.0	530.0	52	4.6		4.3	8.7	7.08	7.51
11.00	3.0	377.0	61	4.6		4.2	8.7	7.35	7.51
11.00	3.0	363.0	61	4.7		4.4	8.7	7.43	7.52
11.00	3.0	378.0	62	4.6		4.3	8.7	7.40	7.51
11.00	3.0	364.0	62	4.8		4.3	8.7	7.31	7.53
11.01	3.0	515.0	51	4.7		4.1	8.7	6.76	7.52
11.01	3.0	516.0	52	4.8		4.3	8.7	6.99	7.53
11.01	3.0	391.0	61	4.6		4.4	8.7	7.51	7.51
11.01	3.0	392.0	62	4.6		4.4	8.7	7.50	7.51
11.00	6.0	497.0	51	4.8		4.5	8.7	6.93	7.53
11.00	6.0	498.0	52	4.6		4.5	8.7	7.33	7.51
11.00	6.0	397.0	61	4.7		4.2	8.7	7.31	7.52
11.00	6.0	387.0	61	4.5		4.0	8.7	7.29	7.50
11.00	6.0	398.0	62	4.6		4.3	8.7	7.40	7.51
11.00	6.0	388.0	62	4.4		4.2	8.7	7.47	7.50
11.01	6.0	545.0	51	4.6		4.4	8.7	7.00	7.51
11.01	6.0	546.0	52	4.6		4.3	8.7	7.08	7.51
11.01	6.0	337.0	61	4.6		4.0	8.7	7.26	7.51
11.01	6.0	345.0	61	4.7		4.3	8.7	7.36	7.52
11.01	6.0	338.0	62	4.5		4.1	8.7	7.33	7.50
11.01	6.0	346.0	62	4.7		4.2	8.7	7.30	7.52
11.00	9.0	509.0	51	4.6		4.5	8.7	7.15	7.51
11.00	9.0	510.0	52	4.7		4.4	8.7	7.10	7.52
11.00	9.0	365.0	61	4.6		4.3	8.7	7.41	7.51
11.00	9.0	366.0	62	4.6		4.3	8.7	7.40	7.51
11.01	9.0	495.0	51	4.6		4.4	8.7	7.00	7.51
11.01	9.0	496.0	52	4.6		4.4	8.7	7.18	7.51
11.01	9.0	343.0	61	4.6		4.2	8.7	7.35	7.51
11.01	9.0	344.0	62	4.7		4.1	8.7	7.26	7.52
12.50	3.0	395.0	61	4.7		4.2	9.6	7.31	7.87

TABLE D3 : DATA AND INDEXES FOR AASHO ROAD TEST RIGID PAVEMENT SECTIONS

IDENTIFICATION DATA				PERFORMANCE DATA			INDEXES		
SURF THCK, REINF	SUBB THCK	SECT NO.	LOOP LANE	SERV INDEX BEG.	LOG APPL P=2.5	SERV INDEX END	STRUCT BY EQN D7	PERFORMANCE OBS. EST.	CALC.BY EQN D7
12.50	3.0	396.0	62	4.7		4.3	9.6	7.35	7.87
12.51	3.0	359.0	61	4.7		4.4	9.6	7.43	7.87
12.51	3.0	360.0	62	4.5		4.3	9.6	7.48	7.86
12.50	6.0	349.0	61	4.3		4.0	9.6	7.37	7.84
12.50	6.0	350.0	62	4.5		4.2	9.6	7.39	7.86
12.51	6.0	355.0	61	4.7		4.2	9.6	7.31	7.87
12.51	6.0	356.0	62	4.7		4.4	9.6	7.42	7.87
12.50	9.0	379.0	61	4.6		4.2	9.6	7.35	7.87
12.50	9.0	380.0	62	4.6		4.4	9.6	7.50	7.87
12.51	9.0	357.0	61	4.7		4.5	9.6	7.52	7.87
12.51	9.0	358.0	62	4.6		4.2	9.6	7.34	7.87

TABLE D4: SUMMARY OF RESIDUALS BETWEEN CALCULATED AND OBSERVED OR ESTIMATED PERFORMANCE INDEX VALUES FOR AASHO ROAD TEST SECTIONS

Test Sections and Definitions Residuals of Residuals	-2.0 and down	-1.0 to -2.0	-.50 to -1.0	-.20 to -.50	.00 to -.20	00 to .20	.20 to .50	.50 to 1.0	1.0 to 2.0	Over 2.0	No. of Sec	Mean Alg.	Mean Abs.
Flexible Pavements - Factorial sections													
P calc. by (D6) vs. P observed		4	10	8	92	76	25	11	4		230	.03	.20
vs. P estimated by (D10) with B = 1.0			2	9	14	9	3	7	9		53	.28	.48
Flexible Pavements - Special Base sections													
P calc. by (D6) vs. P observed		1	3	12	57	30	15	9	4		131	.08	.19
vs. P estimated by (D10) with B = 1.0		5	11	16	8	4	6	7	1		58	-.25	.52
Rigid Pavements													
P calc. by (D7) vs. P observed				16	31	37	15	3			102	.02	.17
vs. P estimated by (D10) with B = .5			5	16	25	46	56	34	15	13	210	.42	.51
									All in Lane 21				

Appendix E

Glossary of Symbols and Terms

The first part of this appendix gives an alphabetical list of all symbols that are used in the guidelines. Opposite each symbol is a verbal equivalent for the symbol.

The second part of the appendix defines terms that either have special connotations in the guidelines or which are not generally found in pavement design literature.

I. Symbols

A_0, A_1, A_2, etc: Undetermined coefficients in a mathematical model for performance index.

a_1, a_2, a_3, etc: Undetermined coefficients in a mathematical model for structural index.

ADL: Average daily number of equivalent 18-kip single axle load applications.

b or β: A performance equation constant which determines the direction of concavity of a calculated performance record.

c_1, c_2, c_3, etc: Classification variables used to distinguish among various types of structural components.

C: Amount of surface cracking.

CSV: Wheelpath slope variance as measured by a CHLOE profilometer

D: Structural index

h_1, h_2, h_3, etc: Thicknesses of pavement components

H, H': High and extra high levels of an experiment design factor

KI: Kentucky ride index (40 mph)

L, L': Low and extra low levels of an experiment design factor

M: Medium level of an experiment design factor

MI. Michigan profilograph index of surface roughness

p: Present serviceability index

p_o: Initial value of present serviceability index

P: Performance Index

PA: Amount of patched surface area

r or ρ: A performance equation constant that embodies all pavement design variables

RI: Roughness index as measured by a BPR roughometer

RD: Rut depth in wheelpath of pavement surface

RF: Regional factor

RS: Relative strength

s_1, s_2, s_3, s_4: Strength characteristics of structural components

S: Composite strength of a test section.

ΣL: Accumulated number of equivalent 18-kip single axle load applications

SV: Wheelpath slope variance as measured by the AASHO Road Test profilometer

TX: Surface texture as measured by the Texas texture meter

v_1, v_2, v_3, etc: Climatic variables

V_1, V_2, V_3, etc: General symbols for experiment design factors

x_1, x_2, x_3, etc: Surface condition variables

Y: Years of service to date

II Terms

Analysis of Variance: A mathematical procedure for separating the total variation in a set of observations into identifiable effects of experiment design variables and average effects of random uncontrolled variables.

Balance: A property of an experiment design which is introduced to prevent intercorrelations of experiment design factors.

Centroid Section: In a composite experiment design the centroid section has the medium level for all experiment design factors.

Climatic Variables: Measures of temperature, precipitation, and freeze-thaw conditions; and measures of variations in these conditions.

Complete Factorial Experiment: A pattern of test sections that includes all possible combinations of levels selected for the experiment design factors.

Composite Experiment Design: A complete (or fractional) factorial pattern of two-level factors, augmented by test sections which will show three-level effects of any factor when the remaining factors are at medium levels.

Composite Strength: A generic term to denote the effect of a single load on the entire structure as contrasted with the strength of a particular component of the structure.

Confounded Effects: The effects of two experimental variables are confounded if there is a relationship (over all test sections) between the values of one variable and the corresponding average values of the other variable.

Curvilinear Effect: A design variable has a curvilinear effect on a performance variable if the graph of the two variables is not linear.

Design Variables: All experimental variables which are not performance variables, and which, therefore, can be used to determine pavement designs as well as experiment designs.

Effect: The effect of an experimental factor on performance is the change in the latter that is attributable to a change in the former.

Equivalent 18-kip Axle Load Applications: The product of an equivalency factor and the actual number of applications of a given axle load. It is assumed that the same serviceability history would result from a specified number of equivalent axle loads as from this number of 18-kip single axle loads.

Experiment Design: A specification of factor levels for every test section in an experiment.

Extension Sections: Those sections in a composite experiment design which are included for the study of curvilinear effects.

Factorial Sections: Those test sections in an experiment design which are part of a complete (or fractional) factorial experiment.

Factors (in an experiment design): Those variables which have been selected for controlled variation at two or more levels in the experiment design. Variables which are controlled at a single level are sometimes called one-level factors--as contrasted with uncontrolled variables.

Fractional Factorial Experiment: An experiment whose design includes only a particular fraction of all sections that would be required for a complete factorial experiment.

Interaction Effect: Two variables have an interaction effect on a performance variable if the effect of the first variable is not the same at all levels of the second variable.

Level: Levels of an experimental factor are classes, values, or intervals of variation which describe the factor for any test section.

Linear Effect: The linear effect of an experimental factor on performance is the slope of a line fitted to the graph of performance versus the experimental factor.

Linear Model: A mathematical model which can be expressed in the form

$$A_0 + A_1F_1 + A_2F_2 + \ldots = 0$$

where all variables are contained within F_1, $F_2, \ldots$, and where all undetermined constants are among A_0, A_1, A_2, etc.

Non-linear Model: Any model that has one or more undetermined coefficients not expressible in the form of a linear model.

Pavement Structure: That part of a test section which is above the roadbed material.

Performance Index: The logarithm of the number of accumulated equivalent 18-kip axle load applications at the time when the test section's serviceability index is at 2.5.

A performance index may be observed, estimated by projection of the performance record, or calculated from a performance equation.

Performance Record: The graph of present serviceability index versus accumulated equivalent 18-kip axle load applications.

Performance Variables: Variables and indexes that describe or are related to the surface condition of a test section.

Present Serviceability Index (Value): A number between zero (very poor) and five (very good) which is calculated from a formula that involves specific measurements of surface condition.

Regional Factor: A positive, zero, or negative value which applies to the performance index of all test sections in a given region--depending upon whether the sections' performances are concluded to be better than, equal to, or worse in the given region that would have been the case at the AASHO Road Test.

Regression Analysis: A procedure for evaluating undetermined constants in a mathematical model. Least squares linear regression analysis may be used with linear models when it is desired to derive those coefficients which minimize the sum of squared residuals.

Relative Strength: The ratio of the composite strength of one test section to the composite strength of another section, where the sections are equivalent with respect to initial structure and load history. Relative strength is thus assumed to be an indicator of climatic and regional effects.

Residuals (in Performance Index): Differences between performance index values calculated from a derived equation and corresponding values which have been observed or estimated from performance records.

Roadbed Material: All soils or other materials that are below the pavement structure and which can affect the supporting power of the pavement structure.

Serviceability History: The graph of present serviceability index versus time--as opposed to load applications.

Strength Characteristics (or Strength): A generic term to include elastic and non-elastic properties of the structural components or composite structure.

Structural Index: A formula for combining structural variables into a single index.

Structural Variables: Strength characteristics, thicknesses and classifications of materials used in the structure.

Structure: The complete test section--including roadbed material and all components of the pavement structure.

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.