NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **30**

EXTENSION OF AASHO ROAD TEST PERFORMANCE CONCEPTS

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

HIGHWAY RESEARCH BOARD 1966

Officers

J. B. McMORRAN, *Chairman*
EDWARD G. WETZEL, *First Vice Chairman*
DAVID H. STEVENS, *Second Vice Chairman*
W. N. CAREY, JR., *Executive Director*

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)
JOHN C. KOHL, *Executive Secretary, Division of Engineering, National Research Council* (ex officio)
WILBUR S. SMITH, *Wilbur Smith and Associates* (ex officio, Past Chairman 1964)
DONALD S. BERRY, *Chairman, Department of Civil Engineering, Northwestern University* (ex officio)
E. W. BAUMAN, *Managing Director, National Slag Association*
MASON A. BUTCHER, *County Manager, Montgomery County, Md.*
J. DOUGLAS CARROLL, JR., *Executive Director, Tri-State Transportation Committee, New York City*
C. D. CURTISS, *Special Assistant to the Executive Vice President, American Road Builders' Association*
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*
EUGENE M. JOHNSON, *Chief Engineer, Mississippi State Highway Department*
PYKE JOHNSON, *Retired*
LOUIS C. LUNDSTROM, *Director, Automotive Safety Engineering, General Motors Technical Center, Warren, Mich.*
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, *President, Rassweiler Consultants, Short Hills, N.J.*
T. E. SHELBURNE, *Director of Research, Virginia Department of Highways*
DAVID H. STEVENS, *Chairman, Maine State Highway Commission*
JOHN H. SWANBERG, *Chief Engineer, Minnesota Department of Highways*
EDWARD G. WETZEL, *The Port of New York Authority, New York City*
J. C. WOMACK, *State Highway Engineer, California Division of Highways*
K. B. WOODS, *Goss Professor of Engineering, School of Civil Engineering, Purdue University*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Advisory Committee

J. B. McMORRAN, *New York State Department of Public Works, Chairman*
DONALD S. BERRY, *Northwestern University*
A. E. JOHNSON, *American Association of State Highway Officials*
JOHN C. KOHL, *National Research Council*
DAVID H. STEVENS, *Maine State Highway Commission*
EDWARD G. WETZEL, *The Port of New York Authority*
REX M. WHITTON, *Bureau of Public Roads*

Advisory Panel on Design

TILTON E. SHELBURNE, *Virginia Department of Highways, Chairman*
W. B. DRAKE, *Kentucky Department of Highways*
F. N. WRAY, *Highway Research Board*

Section on Pavements (FY '63 and FY '64 Register)

W. F. ABERCROMBIE, *State Highway Department of Georgia*
HAROLD ALLEN, *Consulting Engineer*
H. D. CASHELL, *Bureau of Public Roads*
JAMES H. HAVENS, *Kentucky Department of Highways*
LOUIS LUNDSTROM, *General Motors Proving Ground* (Resigned 1965)
GEORGE W. McALPIN, *New York State Department of Public Works*
CARL L. MONISMITH, *University of California*
R. L. PEYTON, *State Highway Commission of Kansas*
F. H. SCRIVNER, *Texas A & M University*
JAMES F. SHOOK, *The Asphalt Institute*
ELDON J. YODER, *Purdue University*

Program Staff

W. A. GOODWIN, *Program Engineer*
K. W. HENDERSON, JR., *Assistant Program Engineer*
H. H. BISSELL, *Projects Engineer*
L. F. SPAINE, *Projects Engineer*
W. L. WILLIAMS, *Assistant Projects Engineer*
HERBERT P. ORLAND, *Editor*
M. EARL CAMPBELL, *Advisor*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **30**

EXTENSION OF AASHO ROAD TEST PERFORMANCE CONCEPTS

M. E. HARR AND W. J. HEAD
PURDUE RESEARCH FOUNDATION
PURDUE UNIVERSITY

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION
OF STATE HIGHWAY OFFICIALS IN COOPERATION
WITH THE BUREAU OF PUBLIC ROADS

SUBJECT CLASSIFICATION:
PAVEMENT DESIGN
PAVEMENT PERFORMANCE

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1966

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 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, nonprofit 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 issued 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 research plan. 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.

The opinions and conclusions expressed or implied in these reports are those of the research agencies that performed the research. They are not necessarily those of the Highway Research Board, the National Academy of Sciences, the Bureau of Public Roads, the American Association of State Highway Officials, nor of the individual states participating in the Program.

NCHRP Project 1-4(2) FY '64
NAS-NRC Publication 1475
Library of Congress Catalog Card Number: 66-62660

FOREWORD

By Staff

Highway Research Board

Research engineers concerned with advancing the current level of knowledge in respect to reliable theories which will adequately predict the performance of pavements under the most general conditions will be interested in this report. On the theory that pavement performance could be approached from a purely mechanistic viewpoint, data from the AASHO Road Test and elsewhere were utilized in the examination of existing hypotheses of pavement performance as related to the fundamental physical laws of engineering mechanics and materials science. By application of mechanistic theory (stresses, strains, displacements) it was felt possible by the researcher that extension of Road Test performance concepts could have general application. Particular emphasis was placed on the need for a mechanistic theory as free as possible of all factors which would limit its applicability under arbitrary combinations of loading, materials, and ambient conditions. A useful product of this research consists of an ordering and classification of the information obtained through an extensive literature survey and its presentation in a format facilitating the rapid and easy identification of limitations of reported works.

The highway engineering profession is at a disadvantage because the present level of knowledge does not embody a theory which will permit the adequate prediction of pavement performance under the most general conditions. In the main, current theories represent solutions of particular problems, or particular parts of the over-all problem of performance versus design, many of which have never been properly evaluated because of the high cost of performance testing. Other solutions exist, again for parts of the over-all problem, which have been verified but have received but little attention from highway designers. In the interest of relating the wealth of AASHO Road Test information to other locations throughout the United States, a comprehensive overview of all theories is needed for the general determination of the relationships which are necessary and sufficient for a broad and adequate description of pavement performance. Specifically, it is felt that additional work is warranted to establish new and test old theories which involve the fundamentals of materials and pavement behavior. For example, extension of the successful models for stress prediction is needed to relate the engineering properties of materials and structural elements of pavements directly to pavement performance.

This problem has been researched by conducting an extensive literature survey, codifying and/or cataloging the pertinent literature, and analyzing certain data from the AASHO Road Test in an effort to find relationships between pavement performance and the predictions of mechanistic theory; i.e., theoretical stresses and/or deflections. The objective of the literature survey was to ascertain those mechanistic models which might be useful in the prediction of pavement performance. The primary concern of the cataloging effort was to make the profession at large aware of what has been done in the area of pavement performance and to indicate the limiting framework of what has been done in this area—for example, various assumptions relative to the nature of the materials and boundary conditions. The objective of the analysis phase was to determine the reliability of mechanistic theories in predicting pavement performance.

The researchers have concluded that the present state of the art is deficient from the standpoint of an adequate definition of materials parameters (i.e., those numbers which characterize the response of highway paving materials to load) and that little is known about changes in parameters with time and ambient conditions. The researchers have emphatically recommended that future work be directed to meeting this deficiency because of the opinion that in the mechanistic approach the materials parameters are considered to be the means by which results can be extended from one location to another.

This document constitutes a final report on the research and represents another step in the solution to the general problem of translating AASHO Road Test results to local conditions. The accomplishments are significant in respect to the provision of a comprehensive critique of the publications on the performance of highway pavements, with emphasis having been given to many of the myriad variables, and the information is presented in a manner readily usable by all levels of interest in the profession. Finally, the work is of value because indications have been made of an existence of a direct relationship between mechanistic theory and performance and of the problems which must be solved before Road Test information can be translated elsewhere.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

M. E. Harr, Professor of Soil Mechanics, Purdue University, was the project director in over-all charge of the work reported herein, and W. J. Head, Instructor in Civil Engineering, was concerned with the literature search and the analysis of the data.

Grateful acknowledgment is made to J. F. McLaughlin, Professor of Civil Engineering, Purdue University, for his encouragement and assistance. Thanks also are extended to G. Baladi, P. Glon, and S. Lucas, who assisted materially in the preparation of the report.

The facilities used were those of Civil Engineering Department of Purdue University, and the project was under the general administration of the Purdue Research Foundation.

EXTENSION OF AASHO ROAD TEST PERFORMANCE CONCEPTS

SUMMARY

Pavement performance, defined as the trend of PSI (present serviceability index) with increasing axle applications, was found to be functionally related at the AASHO Road Test to stresses and displacements. The well-known Boussinesq solution was used in the determination of stresses and normalized deflections. A more sophisticated (although not necessarily more correct) multi-layer theory was found to be no more useful than the simple Boussinesq solution in determining the relationships between stresses, displacements, and performance.

Plots of weighted number of axle applications versus stresses and normalized deflections disclosed the approximate relationship

$$N_W = U\, F_B{}^V$$

in which N_W is the weighted number of axle applications; F_B is the Boussinesq vertical normal stress, shear stress, or normalized deflection; and U and V are parameters that are functions of F_B and PSI.

The precise form of this equation was not determined due, at least in part, to a large amount of scatter in the data. Possible reasons for data scatter were considered to include the following:

1. The subjective nature of the PSI concept and the relative sensitivity of PSI to F_B.

2. The quantitatively unknown effect of seasonal and diurnal changes on AASHO Road Test pavements.

3. The dissimilar behavior of a number of replicate pavement sections at the AASHO Road Test.

4. The lack of complete data on those pavement sections which did withstand the entire Road Test program.

No relationships were found between N_W and F_B for thin pavements subjected to the 6,000-lb single-axle load. Adverse ambient conditions were believed to have played a major role in the rapid failure of such pavements.

In an attempt to provide a firm basis for extrapolation of data, it was assumed that the embankment (that material whose composition and thickness was constant and common to all AASHO Road Test pavements) could withstand one axle application before falling to some undetermined, but low, PSI. Accordingly, in a number of the graphs a point was plotted whose coordinates were "maximum F_B occurring under one tire, 1." These points were found to be essentially collinear with points three decades above (double logarithmic plots) in the main bodies of the graphs. In addition, little deviation in the relationships between N_W and F_B occurred if the ordinates of the points were assumed to be, say, ten instead of unity. In addition to greatly enhancing the basis for possible data extrapolation, these facts helped support the major hypothesis of the research; namely, that performance and theoretical stresses and/or deflections were functionally related.

Plots involving N_W and stress predicted by three-layer theory were analyzed but proved no more definitive than those involving stresses predicted by the homogeneous Boussinesq solution.

It was found that at the present state of the art, material parameters are poorly defined and little is known about changes in these parameters with time and ambient conditions. Because material parameters are the means by which test results can be extended to other locations on a rational basis, it is most important that work be done to define and determine these parameters and to assess their changes under various loading, diurnal, and seasonal conditions. This work is considered a most necessary first step in extending AASHO Road Test results to other locations where conditions (loads, materials, climate) differ from those at the Road Test site in Ottawa, Ill.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

The objectives of the project are found in the project statement, as follows:

> To examine existing hypotheses and to develop new hypotheses of pavement performance as related to fundamental principles of engineering mechanics and materials science and to test these hypotheses with data at hand from the AASHO Road Test and elsewhere.

It was not anticipated that all of the objectives would be met under the terms of the present contract. Several hypotheses have, however, been examined in some detail with the hope that pavement performance could be approached from a mechanistic, in contrast to a statistical, point of view. It is believed that extension of Road Test performance concepts must come from a mechanistic approach if the concepts are to have general application. The alternative is to continue testing (e.g., the Satellite Testing Program), probably on a smaller scale than the AASHO Road Test, at all those locations where conditions (climate, materials, type and frequency of loading, etc.) differ from those at the Road Test site. In addition, more tests would be needed if pavements or paving materials were modified or if it became necessary to predict performance for some presently unforeseen condition. Clearly, then, a mechanistic view of pavement performance is both desirable and necessary.

The prediction of the performance of pavements (and their subsequent design) has been based largely on theories which either contain serious limitations or have been at best only partially verified, or are significantly altered in their application by empirical factors. At the present level of knowledge, the profession knows of no theory that will adequately and reliably predict the performance of pavements.

Inherent in the problem of predicting pavement performance is perhaps the more fundamental problem of defining pavement failure. At least two types of failure are recognized; these are structural failure and functional failure (*1*). In brief, structural failure results in the inability of the pavement to sustain imposed loads while functional failure (for highways) results in passenger discomfort. The two types of failure are not necessarily related. In addition, the entire matter is clouded by valid questions of "degree."

Closely related to the problem of defining failure is the matter of differentiating between index properties which correlate well with ability to build and material parameters of the pavement system which characterize the response of the system to load. Because considerations of material parameters are still in their early development relative to considerations of index properties, investigators who attempt to evaluate tests (such as the AASHO Road Test) from a mechanistic standpoint must avail themselves of index properties and/or make grossly simplifying assumptions. One might expect, therefore, considerable data scatter and variations in results. At the present level of knowledge, poor results do not necessarily imply poor theory or inappropriate mechanisms. Poor results may well imply imperfect and/or incomplete knowledge of material parameters.

It is apparent from the preceding discussion that among the needs of the profession are clear, unambiguous definitions of performance and failure. Such definitions, relative to the system under consideration, may be embodied in the present serviceability concept as first reported by Carey and Irick (*2*). Many engineers have adopted the trend of present serviceability index (PSI) of a particular pavement section with increasing number of axle applications as a definition of performance of that section (*3; 4,* report *5*). In addition, a pavement whose PSI is 3.5 is generally conceded to be a "good" pavement while a pavement whose PSI is 1.5 is considered to be a "poor" pavement. "Failure," as such, still lacks a rigid definition. The PSI concept has at least produced a frame of reference and has been used throughout this report as the measure of performance.

It is not the purpose of this report to investigate the PSI concept; it should be noted, however, that the nature of the concept is essentially one of functional failure or functional performance. As a result, one cannot expect distinctive relationships, *a priori,* between the predictions of mechanistic theory (stresses, strains, displacements) and pavement performance or pavement "failure" as defined by some arbitrary value of PSI. Nevertheless, the research did disclose some discernable trends, which are discussed subsequently.

In the course of the research, the connection between two links in a phenomenological chain was sought. The first link was considered to be an input of vehicles and ambient conditions on the highway. The second link, the output, was performance. It was hypothesized that the connecting mechanisms or transfer functions were stress and displacement. The input and output of a mechanistic approach is the same as the statistical study (*4*) but the statistical approach does not necessarily attempt to relate input and output through physical laws. In the mechanistic approach, on the other hand, it is assumed that the transfer functions can be obtained from governing laws. It is within this framework that the mechanistic approach introduces the concepts of stresses and displacements as measures of the transfer of boundary loadings and ambient conditions within the pavement body. It is reasoned that loads (including considerations of ambient effects) cause stresses and displacements within the pavement system which, at least in theory, are determinable. Loads are empirically related to performance and performance, in turn, is a function of PSI. Performance (and therefore PSI) is thus related to stress and displacements. In sum, given a loading input, stresses and displacements within the pavement are determined and should relate to the over-all performance (i.e., the PSI output) of the pavement system.

RESEARCH APPROACH

The general approach reported herein to the problem of extending the road test performance concepts consisted of the following three phases:

1. A detailed survey and review of the literature.
2. Cataloging of existing theories and design procedures.
3. Checking, where possible, the reliability of theory in light of the results of the AASHO Road Test.

Phase 1—Surveying and Reviewing the Literature

The objective of the first phase was to become familiar with those mechanistic models which might be useful in the prediction of pavement performance. To this end, a list of the literature was compiled. The list was comprised of approximately 500 articles and papers. It should be noted that although the number of basic mechanistic models is relatively small, accounts of expanded theoretical analyses, together with reports of empirical work on pavement problems and experimental studies of theory, have resulted in an enormous volume of literature. In the face of the inevitable problem of selection, the literature survey was terminated when it was felt that the most pertinent references and mechanistic models had been considered.

Phase 2—Cataloging Existing Theories and Design Procedures

The objective of the second phase was to order and classify the information obtained in the first phase. This was accomplished by cataloging the literature. It was not considered necessary for purposes of this project to catalog all the literature. In addition, upon closer examination not all the articles and papers listed were of interest.

Of primary concern was that the catalog format facilitate the rapid and easy identification of the limitations (such as theoretical assumptions) of the work reported in the literature. If a general mechanistic theory of pavement performance is ever to be evolved, it is evident that the theory must necessarily contain few limitations as to its applicability under arbitrary combinations of loading, materials, and ambient conditions. It is, then, of utmost importance that the profession be aware not only of what has been done in the area of pavement performance, but also of the limiting framework (such as assumptions relative to the nature of the materials and boundary conditions) of what has been done within this framework.

To identify the limitations of the work reported in the literature and to provide a basis for retrieval of information, a coding system was devised. The coding system, used with a standard bibliographical notation of author's name, publication, title, date, page numbers, etc., enables an article to be classified by means of symbols and symbol position on a standard 5-by-8-in. index card. The symbols of the coding system are explained in detail in Appendix B. Each article was classified relative to five main categories which appeared on the cards, with a sixth category being included for possible future use. The symbol appearing under Category I indicates the general nature of the article. Likewise, symbols under Categories II, III, IV, and V give, respectively, indications of assumptions made relative to the properties of the materials involved, the compositions of the materials, the type and position of loading, and what ambient effects were considered.

It was anticipated that the coding system would not be universally applicable. Some literature was of the survey type; other articles were difficult to classify and were subjected to arbitrary classification. Nevertheless, it was felt that in the main some degree of consistency in codification was attained and that the system served its purpose. Appendix B contains the codified literature.

Phase 3—Checking the Reliability of Theory in Light of the AASHO Road Test

The objective of the third phase was to determine, where possible, the reliability of mechanistic theories in predicting pavement performance. Data from the AASHO Road Test were analyzed.

It was assumed that performance could be determined by the trend of the present serviceability index with increasing number of axle applications. It was then hypothesized that theoretical stresses and/or deflections were functionally related to performance.

From the results of the first two phases of this project it was apparent that all existing theories embodied some concept of material parameters; i.e., numbers such as modulus of elasticity or Poisson's ratio which in some way characterize the response of materials to load as opposed to index properties (such as Atterberg limits, grain size distribution, and strength tests) which correlate well only when used with particular analytical procedures. In general linear elastic theory, for example, 21 independent constants relate stress and strain at a point. Considerations of homogeneity (all points identical) and isotropy (no change with direction) reduce the number of constants within a body to two. In viscoelastic theory, the behavior of a material is characterized by time-independent elements and viscous elements. Material parameters are expressed in terms of equivalent spring and dashpot constants. In the theory of critical or limiting equilibrium, "strength" parameters are considered to typify the material. These strength parameters commonly take the form of an angle of internal friction ($\tan^{-1}$ of the Mohr envelope) and a cohesion (intercept of the Mohr envelope on the shear axis).

It should be noted that all material parameters are in fact parameters of mathematical models which attempt to simulate the action of real materials. In some materials (notably metals) the simulation has been very successful. In other materials the simulation has been less successful due, at least in part, to the lack of definition of meaningful parameters. In addition, if it is assumed that material parameters can characterize a material, other questions immediately arise. For example,

1. What parameter(s) should be measured?
2. How may the parameter(s) be determined? As a corollary, what similitude exists between a laboratory specimen and the prototype?
3. Do the parameters vary with time and ambient conditions?

If so, how?

These questions are by no means new, but in the course of conducting the research for this project it became apparent that they still remain unanswered. The state of the art is so confused that even when it is agreed to measure a certain parameter, differences of opinion arise on the one hand as to how the parameter is to be measured, and on the other hand in interpreting the resulting values. In addition, few attempts have been made to assess time variations of parameters.

An indication of differences that exist when attempts are made to measure parameters of the same materials is apparent from even a cursory study of the results of the cooperative testing program (*5*). Considering, for example, the embankment soil, values* of ϕ, the angle of internal friction, ranged from 23° to 0°, while values of *c*, cohesion, ranged from 35 psi to 2 psi. Variations in ϕ and *c* on the same order were obtained for the subbase and base course materials. Difficulties in determining other material parameters have been reported elsewhere (*6*).

In summary, it was felt that reliable information on parameters of materials used in the AASHO Road Test were either lacking or so inconsistent as to render rational choice impossible. It was apparent that any subsequent analyses would of necessity be of a nondimensional form or of a form which required no distinct material parameters.

Because of the problems previously noted and because multi-layer theory seemed to offer no particular advantages from the standpoint of accuracy of prediction (*6*), it was decided to analyze‡ performance on the basis of the Boussinesq equations† for stresses and deflections occurring under a uniformly loaded circular area. The analysis was thus based on a theory which presupposes a homogeneous, isotropic, elastic system. Extensive use was made of tabular values (*10*) to facilitate solutions of the equations.

The Boussinesq equations were derived for a static load. Some question might therefore arise concerning the applicability of the Boussinesq relationships to a situation where loads were dynamically applied, as in the AASHO Road Test. It should be noted that stresses and displacements seem to be related to vehicular speed in a reasonably consistent manner (*11*, *12*), so that one might assume that the actual stresses and displacements caused by the test vehicles (whose speed was a constant 35 mph) at Ottawa were related to the Boussinesq stresses and displacements by a constant. Such an assumption was made in the analysis reported herein. Because the purpose of the analysis was simply to investigate the possibility of obtaining functional relationships between input and output, it was felt that the assumption was justified. Another question concerning the applicability of the Boussinesq relationships might arise in regard to the assumption of a homogeneous, isotropic, elastic pavement system. The authors feel that this assumption is no more restrictive for purposes of analysis than is the inherent assumption in multi-layer theories concerning the transmission of shear stress or displacement across layer boundaries.

As previously noted, the purpose of the analysis was to investigate the possibility of obtaining functional relation-

---

* Values of ϕ and *c* were either reported directly by the agencies conducting the tests or were determined by Shook and Fang (*5*) from data submitted by the agencies.

‡ Only data from selected flexible pavement sections at the AASHO Road Test were analyzed herein. To assess the response of rigid pavements mechanistically, it is necessary to have some indication of pavement support conditions (*7*, *8*, *9*). In view of the lack of such information, rigid pavements at the AASHO Road Test were excluded from the analysis.

† In subsequent work, references to Boussinesq stresses and deflections imply results of the Boussinesq equations (unless otherwise noted) for stresses and deflections for homogeneous, isotropic, elastic systems.

ships between input (number of axle applications) and output (performance). To this end, stresses and normalized deflections (the product of vertical deflection at the top of the embankment and modulus of elasticity) were computed for single-axle loads of 6,000, 18,000 and 30,000 lb. Number of axle applications to two levels of serviceability (3.5 and 1.5) were considered. The data are given in tabular form in Appendix A.

SYMBOLS

The following symbols are used throughout this report. Each is defined where it first appears and is included in the following alphabetical listing for easy reference.

Symbol	*Meaning*
c	Cohesion; intercept of the Mohr rupture envelope on the shear stress axis.
F_B	Boussinesq vertical normal stress, shear stress, or normalized deflection.
N_u	Number (unweighted or actual) of axle applications.
N_w	Number (weighted) of axle applications.
PSI	Present serviceability index.
psi	Pounds per square inch.
U, V	Parameters relating N_w to F_B.
W_zE	Boussinesq normalized vertical deflection.
$W_{z_1}E$	Boussinesq normalized vertical deflection at top of embankment and beneath centerline of a dual-tire assembly.
$W_{z_2}E$	Boussinesq normalized vertical deflection at top of embankment and beneath center of one tire of a dual-tire assembly.
μ	Poisson's ratio.
σ_z	Boussinesq vertical normal stress.
σ_{z_1}	Boussinesq vertical normal stress at top of embankment and beneath centerline of a dual-tire assembly.
σ_{z_2}	Boussinesq vertical normal stress at top of embankment and beneath center of one tire of a dual-tire assembly.
$\sigma_{z3\text{-}L}$	Vertical normal stress predicted by three-layer theory at top of embankment beneath center of a circular contact area.
τ_{rz}	Boussinesq radial-vertical shear stress at top of embankment and beneath centerline of a dual-tire assembly.
ϕ	Tan^{-1} of the Mohr rupture envelope.

CHAPTER TWO

FINDINGS

The findings reported herein were obtained from analyses of numerous plots on which number of axle applications was plotted as a function of theoretical stresses, combinations of stresses, and normalized deflections. As an aid to comprehension, the data were plotted on various types of coordinate paper—arithmetic, semilogarithmic, and logarithmic. Most of the plots in this report are of the latter type.

Plots were made of actual number of axle applications, N_u, versus stress or normalized deflection for two levels (3.5 and 1.5) of serviceability; the plots were examined and trends (if any) noted. A typical plot appears in Figure A-20. In an attempt to consider ambient effects, additional plots were made of weighted* number of axle applications, N_w, versus stress and normalized deflection; some improvements in trends were noticed (see Figs. A-2 to A-10 and A-12 to A-17). An unsuccessful attempt was made to extend the concept of a sinusoidal variation of creep-speed deflections with time (*13*) to a similar variation of modulus of elasticity with time. No further attempt was made to consider the time dependency of material parameters.

In addition to the plots previously described, a plot of N_w versus vertical stress at the subbase-embankment interface was made which employed three-layer theory and data which appeared elsewhere (*14*). This plot appears in Figure A-21. It was decided that three-layer theory represented no significant improvement over Boussinesq theory, hence the three-layer theory was excluded from further consideration.

In summary, the plots may be placed into three categories, the first of which consisted of N_w plotted against σ_z, the Boussinesq vertical normal stress. It should be noted that the concept of stress as a measure of the transmission of forces through a medium was considered basic to a mechanistic interpretation of Road Test data.

The second category of plots included N_w plotted against Boussinesq shearing stress τ_{rz}, or some combination of normal stress and shearing stress. This second set of data was analyzed with the hope that a more definitive trend could

---

* AASHO procedure.

be established than that which existed between N_w *and* σ_z.

Some of the computations involved assumptions as to the value of μ, Poisson's ratio. Different values (0, 0.3, 0.5) of μ were tried; however, variations in μ had the effect of merely shifting the plots horizontally in a rigid manner with no decrease in scatter of the data. Because the choice of 0.5 for μ had some computational advantages, that value was assumed for subsequent analyses.

The third category of plots involved N_w plotted against W_zE, normalized Boussinesq deflection. It was thought that deflections might be used as a predictor of N_w, particularly in view of the following statement:

> The performance of the flexible sections was predicted with essentially the same precision from load-deflection data as from load-design information (*4*, report 5).

It should be noted that in Figures A-2 to A-10 and A-18 to A-23 all stresses and normalized deflections were computed beneath the center of a dual-tire assembly at the subbase-subgrade interface (top of embankment). The subscript "1" implies calculations beneath the center of a dual-tire assembly; thus, σ_{z_1} denotes the Boussinesq vertical normal stress calculated at the point shown in Figure A-1 (a). In Figures A-12 to A-17, the computations refer to a point beneath the center of one tire at the top of the embankment. The subscript "2" implies calculations beneath the center of one tire; thus, $W_{z_2}E$ denotes normalized Boussinesq vertical deflection at the point shown in Figure A-1(b).

MAJOR FINDINGS

Figures A-2 to A-10 and A-12 to A-17 represent the major findings of this phase of this project. Several important facts emerged from detailed study of these figures, as follows:

1. The mechanisms of vertical stress, shear stress, and vertical deflection are not the primary controlling factors in thin flexible pavements subjected to light loads (see Figs. A-2, A-5, A-8, and A-15). A major cause of rapid failure of such pavements is undoubtedly adverse ambient conditions. At present, the effects of ambient conditions are not amenable to analysis from a mechanistic standpoint; that is, there is no way of assessing the number of axle applications under one condition which corresponds to a number of axle applications under another condition. It should be noted, however, that the "seasonal weighting function" (*4*, report 5) used in the determination of N_w was based on mechanistic considerations (relative deflections) and proved useful in this project in making relationships between axle applications and stresses or displacements more discernible, especially with the heavier loads and thicker pavements. In the case of the 6,000-lb single-axle load and the thinner pavements, the seasonal weighting function was of little value; perhaps other considerations, such as punching shear, are more critical than deflections with such pavements. Here again, insufficient and inconclusive information prohibited further and perhaps more meaningful analyses.

2. The remaining figures in this group indicated trends which are characterized by the following relationship within the range of practical interest:

$$N_w = U\, F_B{}^V \qquad (1)$$

in which

N_w = weighted number of axle applications;
F_B = Boussinesq vertical normal stress, shear stress, or normalized deflection; and
U,V = parameters.

The following observations appear warranted:

1. The general slopes of the trends (the parameter V on logarithmic paper) are of the anticipated sign (i.e., negative), so that the higher the value of F_B, the lower the value of N_w at a given serviceability level. This observation is not profound; nevertheless, it is of interest to note that the trends conform to physical reality.

2. The shapes of the trends are insensitive to the horizontal location of F_B. The abscissas of Figures A-3 and A-4 depict σ_z at the top of the embankment and midway between the tires of a dual set; Figures A-13 and A-14 portray the same information, but σ_z was computed beneath the center of one tire of a dual set. The shapes of the trends in both sets of figures are practically the same; similar statements apply to Figures A-9 and A-10 when compared with Figures A-16 and A-17. These phenomena are manifestations of the well-known fact that at a sufficient distance from the point of loading, the effects of boundary loads between tires are essentially the same as those under one tire.

3. In general, there was little horizontal spread between serviceability levels of 3.5 and 1.5; apparently, the serviceability index is quite sensitive to changes in a given F_B; that is, for a given N_w a relatively small change in F_B results in a change in PSI from 3.5 (good) to 1.5 (poor).

4. The data are reasonably reproducible, at least insofar as similar stresses or displacements at a given level in the pavement resulted in about the same value of N_w irrespective of the total load at the surface of the pavement.

5. The slope, V, is a function of F_B (i.e., V varies as the abscissa changes from σ_z *to* τ_{rz} to W_zE) and, in the strict sense, is also a function of the serviceability index. However, at present for all practical purposes V could be considered independent of the serviceability index.

6. The intercept, U, is a function of F_B and of the serviceability index. As a given F_B approaches zero, N_w becomes very large. If U is assumed to approach infinity as F_B approaches zero, the form of Eq. 1 would change. Within the range of practical interest (large but finite N_w) Eq. 1 appears adequate and offers some advantages from the standpoint of extrapolation of data.

7. In Figures A-12 to A-17 a point was shown whose ordinate is unity (0.001x10^3). These points were determined by assuming that the embankment material alone could withstand only one axle application before its serviceability index fell to some undetermined but low value. The abscissa was considered to be the maximum value of a given F_B that could occur immediately beneath the tire. In the case of vertical normal stress and normalized vertical deflection,

the maximum value of F_B occurred beneath the center of one tire. After plotting these points, it was observed that in general they were essentially collinear with those points three decades above in the main portion of the graph. In addition, little deviations were introduced in the trends if the low value of serviceability was assumed to occur after, say, ten axle applications instead of one application. It was felt that this observation provided a somewhat firmer basis for any extrapolation of the trends and helped greatly to affirm the basic hypothesis of this project.

MINOR FINDINGS

1. Two figures were included herein to illustrate the trends which resulted when N_w was plotted against vertical normal stress on arithmetic paper (Fig. A-18) and against shear stress on semi-logarithmic paper (Fig. A-19) for the 18,000-lb single-axle load.
2. Figure A-20 shows N_u, unweighted number of axle applications, plotted against σ_z on arithmetic paper for the 18,000-lb single-axle load. A comparison of this figure with Figure A-18 illustrates the advantage of using N_w rather than N_u as the ordinate.
3. Figure A-21 shows the relationship between N_w and σ_z computed on the basis of the three-layer theory of Jones and Peattie (*15, 16*). A comparison of Figures A-21 and A-13 revealed that no particular advantage resulted from the use of the more sophisticated but not necessarily more correct three-layer theory. In a strict sense, the figures are not comparable because the results shown in Figure A-13 were obtained on the assumption that the principle of superposition was valid and hence the effects of the dual-tire loading were additive, whereas the results shown in Figure A-21 were obtained by considering the 9,000-lb wheel load to be distributed over one circular area.
4. Figures A-22 and A-23 represent attempts to obtain a more definitive relationship between N_w and the results of the Boussinesq equations. It was felt that although the plots did portray some trends, they were no more pronounced than those shown on previous plots; hence, no further efforts were made to analyze the relationships.

CHAPTER THREE

CONCLUSIONS

In view of the findings of this research, the following conclusions appear warranted:

1. Theoretical stresses and displacements are functionally related to performance, where performance is defined as the trend of PSI with increasing axle load applications.
2. Material parameters—their definition, determination, and change with time and ambient conditions—are the "missing links" in the problem of extending AASHO Road Test results to other locations where ambient conditions, loading patterns, and construction materials differ from those at Ottawa.

In regard to the first conclusion, it should be noted that the precise forms of the functional relationships between stresses, displacements, and performance remain undetermined. This is due, at least in part, to the large amount of scatter exhibited by the data. Possible causes for the observed scatter of data are as follows:

1. The present serviceability index is essentially a subjective concept; in addition, the index proved to be quite sensitive to stresses and deflections.
2. Seasonal and diurnal changes had a marked but quantitatively unknown effect on AASHO Road Test pavements. This is readily evidenced by the failures associated with the spring thaw periods.
3. Some data on number of axle load applications to any given level of serviceability were inconsistent, as evidenced by pronounced dissimilar behavior of some replicate pavement sections in the AASHO test.
4. Some pavement sections in the AASHO test withstood the entire testing program; hence, complete information on the performance of those sections was not available.

The essence of the second conclusion is not new; in fact, the conclusion is simply on the state of the art at the present time. The conclusion merely states, in a manner directed to a particular problem, what is at least implicit in much of the literature. The second conclusion is most important, however, especially in light of the first, because the first has indicated the existence of a direct relationship between mechanistic theory and performance at the one location while the second indicates the problems to be solved before information obtained at Ottawa can be transferred elsewhere.

CHAPTER FOUR

SUGGESTED RESEARCH

In order to extend the AASHO Road Test results on any rational basis, the following additional research is needed:

1. Extensive and definitive work on material parameters, especially with regard to changes in parameters induced by time and variations in ambient conditions.
2. Experimental work to determine the *real* nature of stress and/or displacement transfer across multi-layered system boundaries.
3. Experimental work to determine the support conditions of loaded pavements. That pavements are often unsupported over large portions of their areas is well established; rational analysis requires a comprehensive knowledge of the manner and form of pavement support when the pavement is loaded.
4. Experimental and theoretical work in which vehicle motion is considered in conjunction with properties of materials under dynamic loading conditions.
5. Experimental work on the effects of controlled, mixed traffic on performance; this might be accomplished by means of satellite road tests. The traffic at the AASHO Road Test was essentially homogeneous in nature in any given lane.

REFERENCES

1. Yoder, E. J., *Principles of Pavement Design.* Wiley (1959).
2. Carey, W. H., Jr., and Irick, P. E., "The Pavement Serviceability-Performance Concept." *HRB Bull. 250,* pp. 40-58 (1960).
3. Yoder, E. J., and Milhous, R. T., "Comparison of Different Methods of Measuring Pavement Condition." *NCHRP Report No. 7* (1964).
4. "The AASHO Road Test." *HRB Spec. Report 61,* 7 reports (1962).
5. Shook, J. F., and Fang, H. Y., "Cooperative Materials Testing Program at the AASHO Road Test. "*HRB Spec. Report 66,* pp. 59-102 (1961).
6. Vesic, A. S., and Domaschuk, L., "Extension of Road Test Performance Concepts—Flexible Pavements." *NCHRP Report No. 10* (1964).
7. Harr, M. E., and Leonards, G. A., "Warping Stresses and Deflections in Concrete Pavements." *Proc. HRB,* pp. 286-320 (1959).
8. Wiseman, J. F., Harr, M. E., and Leonards, G. A., "Warping Stresses and Deflections in Concrete Pavements: Part II." *Proc. HRB,* pp. 147-171 (1960).
9. Reddy, A. S., Leonards, G. A., and Harr, M. E., "Warping Stresses and Deflections in Concrete Pavements: Part III." *Highway Res. Record No. 44,* pp. 1-24 (1963).
10. Ahlvin, R. G., and Ulery, H. H., "Tabulated Values for Determining the Complete Pattern of Stresses, Strains, and Deflections Beneath a Uniform Circular Load on a Homogeneous Half-Space." *HRB Bull. 342,* pp. 1-13 (1962).
11. Sanborn, J. L., "An Experimental Analysis of Transient Vehicle Loads and Response of Flexible Pavements." Ph.D. Thesis, Purdue University (1965).
12. Whiffin, A. C., and Lister, N. W., "The Application of Elastic Theory to Flexible Pavements." *Proc. Internat. Conf. on Struct. Design of Asphalt Pavements,* pp. 499-521 (1962).
13. Kondner, R. L., and Krizek, R. J., "Factors Influencing Pavement Performance." *NCHRP Report No. 22* (1966).
14. Skok, E. L., and Finn, F. N., "Theoretical Concepts Applied to Asphalt Concrete Pavement Design." *Proc. Internat. Conf. on Struct. Design of Asphalt Pavements,* pp. 412-440 (1962).
15. Jones, A., "Tables of Stresses in Three-Layer Elastic Systems." *HRB Bull. 342,* pp. 176-214 (1962).
16. Peattie, K. R., "Stress and Strain Factors for Three-Layer Elastic Systems." *HRB Bull. 342,* pp. 215-253 (1962).

APPENDIX A

TABULAR SUMMARIES AND GRAPHICAL REPRESENTATIONS OF DATA

TABLE A-1

NUMBER OF AXLE APPLICATIONS AND COMPUTED STRESSES[1] AND NORMALIZED DEFLECTIONS[1] (TOP OF EMBANKMENT) FOR THE 6,000-POUND SINGLE-AXLE LOAD,[2] LOOP 2, LANE 2, DESIGN 1, AASHO ROAD TEST

SECTION NUMBER	THICKNESS (IN.)			AXLE APPLICATIONS (1,000's)				VERTICAL NORMAL STRESS,[3] σ_{z_1} (psi)	RADIAL-VERTICAL SHEAR STRESS,[3] τ_{rz} (psi)	NORMALIZED VERTICAL DEFLECTION,[3] $W_{z_1}E$ (LB/IN.)	VERTICAL NORMAL STRESS,[4] σ_{z_2} (psi)	NORMALIZED VERTICAL DEFLECTION,[4] $W_{z_2}E$ (LB/IN.)	RATIO OF STRESSES, σ_{z_1}/τ_{rz}	RATIO OF STRESSES,[5] $\sigma_1 - \sigma_2/\tau_{rz}$
				WEIGHTED		UNWEIGHTED								
	SURFACE	BASE	SUBBASE	PSI = 3.5	PSI = 1.5	PSI = 3.5	PSI = 1.5							
722	1	0	0	0.90	2.25	0.70	2.05	0.26	1.22	115	43.7	238	0.21	2.01
728	1	0	4	1.35	2.70	1.15	2.50	5.85	6.23	121	18.2	147	0.94	2.20
744	1	3	0	7.02	28.2	7.05	69.5	4.82	6.21	122	23.4	164	0.78	2.14
718	1	3	4	10.8	43.2	11.4	72.8	6.46	4.64	111	9.1	113	1.40	2.43
756	1	6	0	12.4	144.6	32.1	106.2	6.57	5.31	115	11.2	123	1.24	2.35
720	1	6	4	12.4	476.4	32.8	570.2	5.40	2.93	96	5.9	93	1.85	2.72
772	2	0	0	28.3	49.1	69.5	74.1	1.46	3.65	119	38.2	218	0.40	2.03
730	2	0	4	19.5	104.7	62.8	87.1	6.47	5.85	118	14.3	135	1.11	2.28
760	2	3	0	148.1	306.2	108.4	249.5	5.85	6.23	121	18.2	147	0.94	2.20
732	2	3	0	96.6	163.3	84.7	120.2	5.85	6.23	121	18.2	147	0.94	2.20
742	2	3	4	146.2	529.7	107.2	582.1	6.16	4.02	106	8.1	105	1.53	2.52
710	2	3	4	2.70	—	2.50	—	6.16	4.02	106	8.1	105	1.53	2.52
776	2	6	0	102.1	—	85.9	—	6.46	4.64	111	9.1	113	1.40	2.43
758	2	6	0	432.5	—	543.2	—	6.46	4.64	111	9.1	113	1.40	2.43
738	2	6	4	173.4	—	127.4	—	4.97	2.57	92	5.2	89	1.93	2.78
712	2	6	4	4.50	—	4.30	—	4.97	2.57	92	5.2	89	1.93	2.78
770	3	0	0	73.3	141.3	79.2	104.2	3.24	5.40	122	30.8	192	0.60	2.09
740	3	0	4	58.1	144.6	76.0	106.2	6.57	5.31	115	11.2	123	1.24	2.37
774	3	3	0	369.9	801.7	356.4	709.6	6.47	5.85	118	14.3	135	1.11	2.28
746	3	3	4	102.1	—	85.9	—	5.85	3.47	101	7.0	99	1.69	2.62
750	3	6	0	68.2	—	78.3	—	6.16	4.02	106	8.1	105	1.53	2.52
764	3	6	4	—	—	—	—	4.60	2.21	89	4.6	84	2.08	2.85

[1] Boussinesq quantities.

[2] Nominal tire pressure = 45 psi; radius of assumed circular contact area = 3.26 in.; assumed c-c spacing between tires = 13 in.

[3] Computed beneath centerline of dual tires.

[4] Computed beneath center of one tire.

[5] $\mu = 0.5$.

TABLE A-2

NUMBER OF AXLE APPLICATIONS AND COMPUTED STRESSES[1] AND NORMALIZED DEFLECTIONS[1] (TOP OF EMBANKMENT) FOR THE 18,000-POUND SINGLE-AXLE LOAD,[2] LOOP 4, LANE 1, DESIGN 1, AASHO ROAD TEST

SECTION NUMBER	THICKNESS (IN.)			AXLE APPLICATIONS (1,000's)				VERTICAL NORMAL STRESS,[3] σ_{z_1} (psi)	RADIAL-VERTICAL SHEAR STRESS,[3] τ_{rz} (psi)	NORMALIZED VERTICAL DEFLECTION,[3] $W_{z_1}E$ (LB/IN.)	VERTICAL NORMAL STRESS,[4] σ_{z_2} (psi)	NORMALIZED VERTICAL DEFLECTION,[4] $W_{z_2}E$ (LB/IN.)	VERT. NORMAL 3-LAYER STRESS, $\sigma_{z3\text{-}L}$ (psi)	RATIO OF STRESSES, σ_{z_1}/τ_{rz}	RATIO OF STRESSES, $\sigma_1 - \sigma_3/\tau_{rz}$
				WEIGHTED		UNWEIGHTED									
	SURFACE	BASE	SUBBASE	PSI = 3.5	PSI = 1.5	PSI = 3.5	PSI = 1.5								
633	3	0	4	—	1.80	—	1.60	20.4	15.0	342	29.7	349	15.0	1.36	2.07
607	3	0	8	23.9	40.2	66.2	72.1	16.2	8.3	284	16.7	270	8.7	1.95	2.41
571	3	0	12	68.2	85.7	78.2	82.0	12.0	4.7	236	11.0	221	5.5	2.55	2.94
569	3	0	12	64.9	156.7	77.5	115.1	12.0	4.7	236	11.0	221	5.5	2.55	2.94
599	3	3	4	31.2	49.2	70.2	74.3	17.6	9.8	298	18.8	287	10.0	1.80	2.33
573	3	3	8	75.0	85.7	79.6	82.0	12.9	5.4	246	12.1	231	6.0	2.39	2.82
617	3	3	12	115.6	529.7	91.8	582.1	9.3	3.2	209	8.3	195	4.0	2.91	3.81
585	3	6	4	43.2	75.0	72.8	79.6	13.8	6.2	259	13.3	242	6.8	2.23	2.74
623	3	6	8	58.1	115.6	76.0	91.8	10.1	3.6	216	9.1	203	4.5	2.81	3.11
601	3	6	12	129.7	—	97.7	—	7.4	2.2	187	6.7	174	3.2	3.36	3.73
583	4	0	4	59.8	68.2	76.4	78.1	19.8	13.2	329	25.5	326	12.0	1.50	2.12
619	4	0	8	99.3	146.2	85.3	107.1	15.0	7.2	270	15.0	255	7.0	2.08	2.53
603	4	0	12	91.2	395.4	83.4	425.6	11.1	4.1	225	10.0	212	4.7	2.71	3.07
627	4	3	4	61.5	104.8	76.7	87.1	16.2	8.3	284	16.7	270	8.0	1.95	2.41
589	4	3	8	93.8	132.7	84.0	99.5	12.0	4.7	236	11.0	221	5.2	2.55	2.94
597	4	3	8	99.3	151.4	85.3	111.2	12.0	4.7	236	11.0	221	5.2	2.55	2.94
575	4	3	12	400.9	1222.0	443.6	1109.2	8.7	2.8	200	7.7	188	3.6	3.11	3.43
595	4	6	4	64.9	110.2	77.5	89.5	12.9	5.4	246	12.1	231	5.8	2.39	2.82
577	4	6	8	570.2	—	591.6	—	9.3	3.2	208	8.3	195	3.8	2.91	3.31
625	4	6	12	388.2	—	391.7	—	6.9	1.9	182	6.3	169	2.8	3.63	4.00
605	5	0	4	63.2	107.4	77.1	88.3	18.6	11.4	313	21.6	305	8.8	1.63	2.21
587	5	0	8	129.4	161.8	97.7	119.1	13.8	6.2	258	13.3	242	5.8	2.23	2.74
621	5	0	12	141.3	774.5	104.3	676.1	10.1	3.6	216	9.1	203	3.8	2.81	3.11
579	5	3	4	115.6	169.1	91.8	124.4	15.0	7.2	270	15.0	255	6.5	2.08	2.53
631	5	3	8	88.5	557.2	82.8	587.5	11.1	4.1	225	10.0	212	4.4	2.71	2.47
593	5	3	12	121.3	570.2	94.2	591.6	8.1	2.4	194	7.2	180	2.9	3.38	3.75
629	5	6	4	424.6	732.8	518.8	639.7	12.0	4.7	236	11.0	221	4.8	2.55	3.94
615	5	6	4	121.3	644.2	94.2	611.0	12.0	4.7	236	11.0	221	4.8	2.55	3.94
591	5	6	8	—	—	—	—	8.7	2.8	200	7.7	188	3.6	3.11	3.43
581	5	6	12	136.5	—	101.6	—	6.4	1.7	175	5.9	169	2.4	3.76	3.88

[1] Boussinesq quantities unless otherwise noted.

[2] Nominal tire pressure = 75 psi; radius of assumed circular contact area = 4.37 in.; assumed c-c spacing between tires = 13 in.

[3] Computed beneath centerline of dual tires.

[4] Computed beneath center of one tire.

[5] Vertical normal stress predicted by three-layer theory.

[6] $\mu = 0.5$.

TABLE A-3

NUMBER OF AXLE APPLICATIONS AND COMPUTED STRESSES[1] AND NORMALIZED DEFLECTIONS[1] (TOP OF EMBANKMENT) FOR THE 30,000-POUND SINGLE-AXLE LOAD,[2] LOOP 6, LANE 1, AASHO ROAD TEST

SECTION NUMBER	THICKNESS (IN.)			AXLE APPLICATIONS (1,000's)				VERTICAL NORMAL STRESS,[3] σ_{z_1} (psi)	RADIAL-VERTICAL SHEAR STRESS,[3] τ_{rz} (psi)	NORMALIZED VERTICAL DEFLECTION,[3] $W_{z_1}E$ (LB/IN.)	VERTICAL NORMAL STRESS,[4] σ_{z_2} (psi)	NORMALIZED VERTICAL DEFLECTION,[4] $W_{z_2}E$ (LB/IN.)	RATIO OF STRESSES, σ_{z_1}/τ_{rz}	RATIO OF STRESSES, $\sigma_1 - \sigma_3/\tau_{rz}$
				WEIGHTED		UNWEIGHTED								
	SURFACE	BASE	SUBBASE	PSI = 3.5	PSI = 1.5	PSI = 3.5	PSI = 1.5							
269	4	3	8	7.02	37.2	7.05	71.4	19.4	7.2	392	19.0	384	2.69	2.78
299	4	3	12	101.9	384.6	85.9	371.4	14.1	4.3	331	13.6	323	3.28	3.49
317	4	3	16	75.1	182.8	79.6	134.0	10.6	2.8	280	10.3	275	3.79	3.74
329	4	3	16	59.9	113.0	76.4	90.6	10.6	2.8	280	10.3	275	3.79	3.74
303	4	6	8	40.2	85.7	72.1	82.0	15.2	4.9	346	14.8	336	3.10	3.16
323	4	6	12	58.1	88.5	76.0	82.8	11.2	3.0	294	11.0	287	3.73	3.79
253	4	6	16	136.2	446.7	101.4	550.8	8.6	2.2	252	8.5	248	3.91	3.89
321	4	9	8	26.7	83.0	68.4	81.5	12.2	3.4	304	11.8	298	3.59	3.50
267	4	9	12	85.7	366.4	82.0	352.3	9.2	2.4	261	8.9	256	3.83	3.83
309	4	9	16	466.7	—	563.6	—	7.0	1.7	230	7.0	226	4.12	4.12
319	5	3	8	59.8	68.2	76.4	78.2	17.9	6.4	376	17.5	368	2.80	2.90
261	5	3	12	68.2	134.6	78.2	100.5	13.1	3.9	318	12.7	310	3.36	3.38
315	5	3	16	138.1	489.8	102.3	572.8	9.8	2.6	270	9.5	266	3.77	3.79
259	5	6	8	68.2	132.7	78.2	99.5	14.1	4.3	331	13.6	323	3.28	3.42
307	5	6	12	141.3	724.5	104.2	633.9	10.6	2.8	280	10.2	275	3.79	3.69
305	5	6	12	99.3	391.7	85.3	411.1	10.6	2.8	280	10.2	275	3.79	3.69
327	5	6	16	366.5	—	352.3	—	8.0	2.0	244	8.0	241	4.00	3.93
313	5	9	8	110.2	583.4	89.5	594.3	11.2	3.0	294	11.0	287	3.73	3.63
331	5	9	12	121.4	811.0	94.2	717.8	8.6	2.2	252	8.5	248	3.91	3.89
265	5	9	16	769.2	—	669.9	—	6.7	1.6	222	6.3	220	4.19	4.28
297	6	3	8	88.5	189.7	82.8	140.9	16.0	5.5	361	16.1	351	2.91	3.05
335	6	3	12	59.9	153.1	76.4	112.5	12.2	3.4	304	11.8	298	3.59	3.50
255	6	3	16	158.1	701.5	116.4	626.6	9.2	2.4	261	8.9	256	3.83	3.83
325	6	6	8	129.4	144.6	97.7	106.2	13.1	3.9	318	12.7	310	3.36	3.38
257	6	6	12	138.2	—	102.6	—	9.8	2.6	270	9.6	266	3.77	3.79
301	6	6	16	516.4	—	579.4	—	7.5	1.9	236	7.5	234	3.95	4.03
263	6	9	8	131.2	690.3	98.6	623.8	10.6	2.8	280	10.2	275	3.79	3.69
271	6	9	8	282.5	—	224.9	—	10.6	2.8	280	10.2	275	3.79	3.69
311	6	9	12	220.3	—	166.7	—	8.0	2.0	244	8.0	241	4.00	2.63
333	6	9	16	275.4	—	216.8	—	6.3	1.6	217	6.3	214	3.94	4.15

---

[1] Boussinesq quantities.

[2] Nominal tire pressure = 80 psi; radius of assumed circular contact area = 5.46 in.; assumed c-c spacing between tires = 13 in.

[3] Computed beneath centerline of dual tires.

[4] Computed beneath center of one tire.

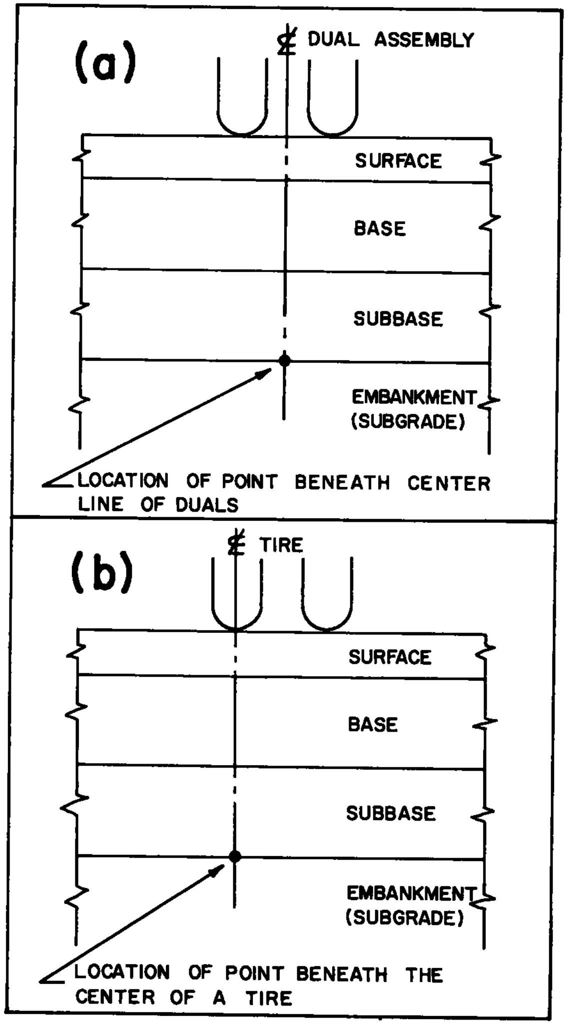

Figure A-1. Points in pavement at which stresses and deflections were computed.

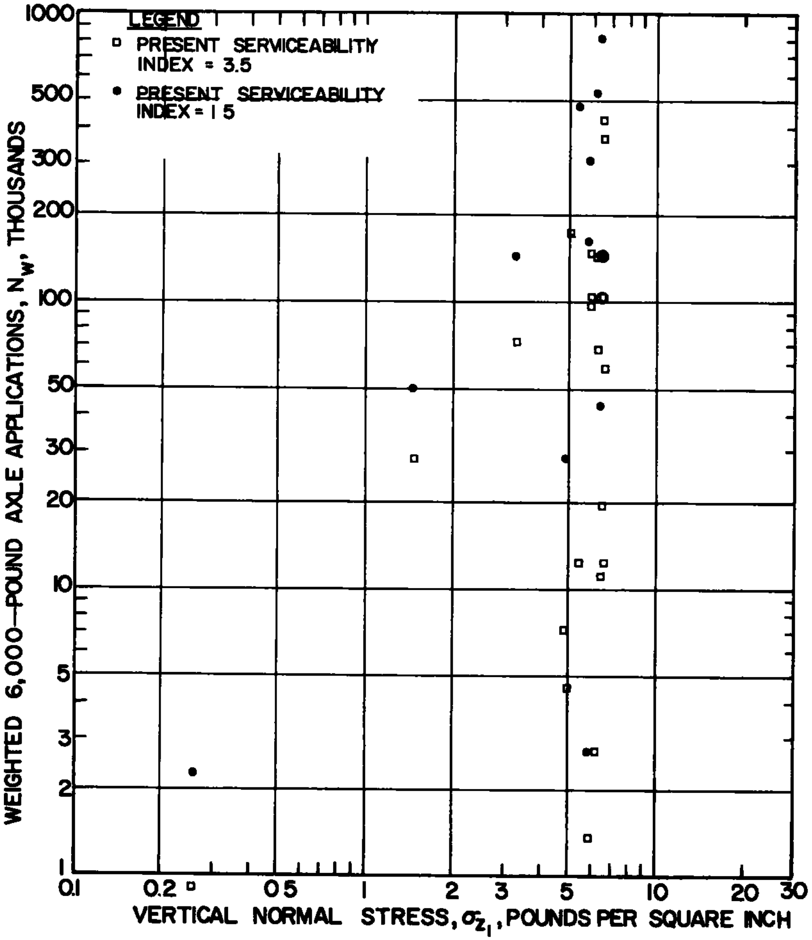

Figure A-2. Weighted number of 6,000-lb single-axle applications versus vertical normal stress.

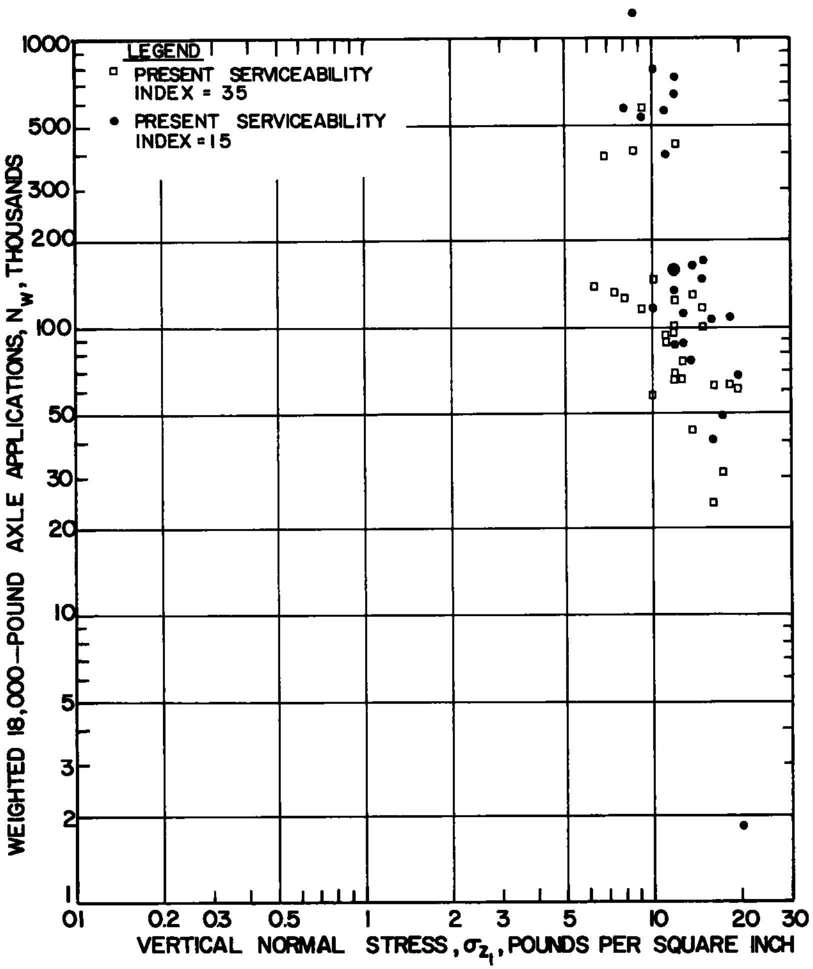

Figure A-3. Weighted number of 18,000-lb single-axle applications versus vertical normal stress.

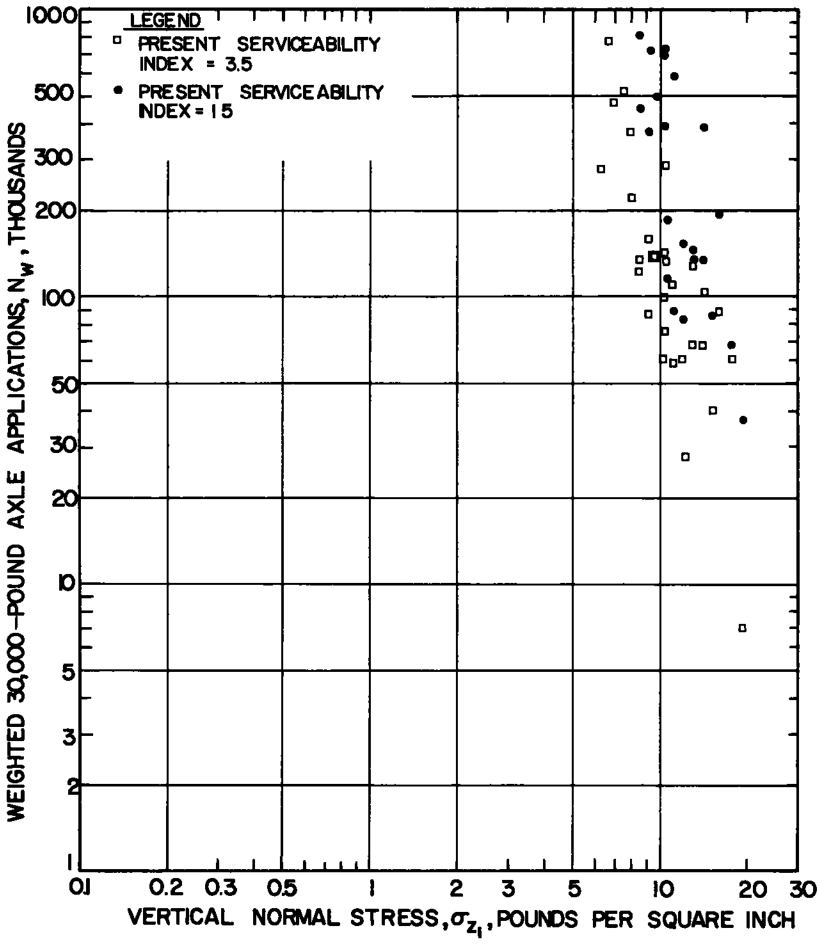

Figure A-4. Weighted number of 30,000-lb single-axle applications versus vertical normal stress.

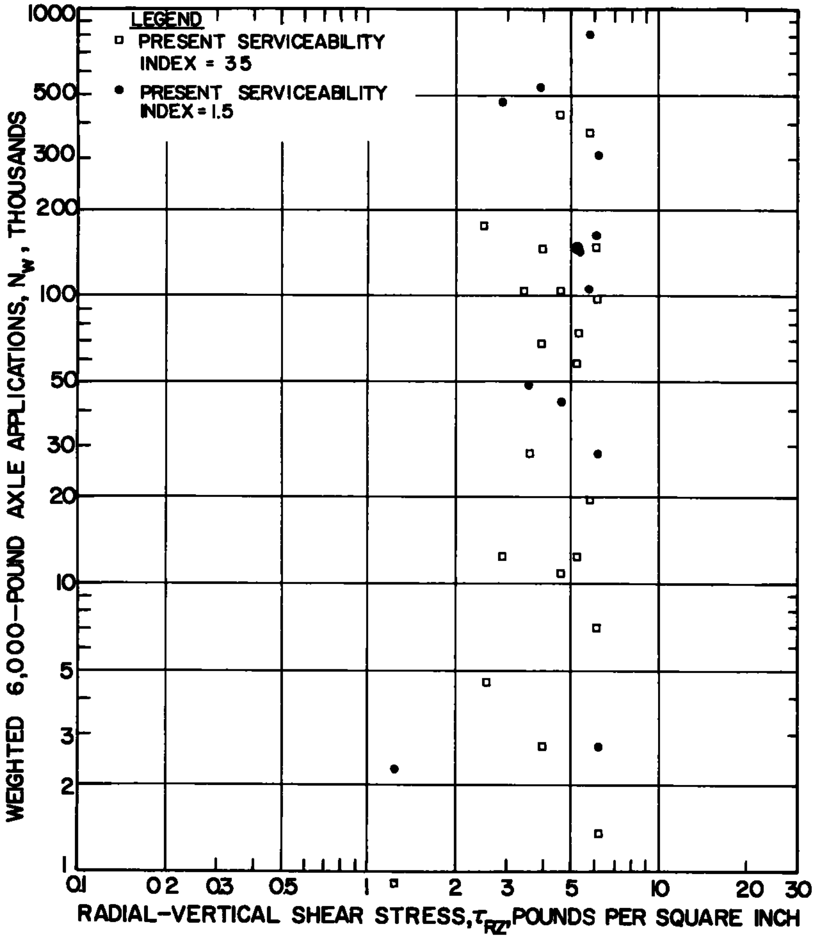

Figure A-5. Weighted number of 6,000-lb single-axle applications versus radial-vertical shear stress.

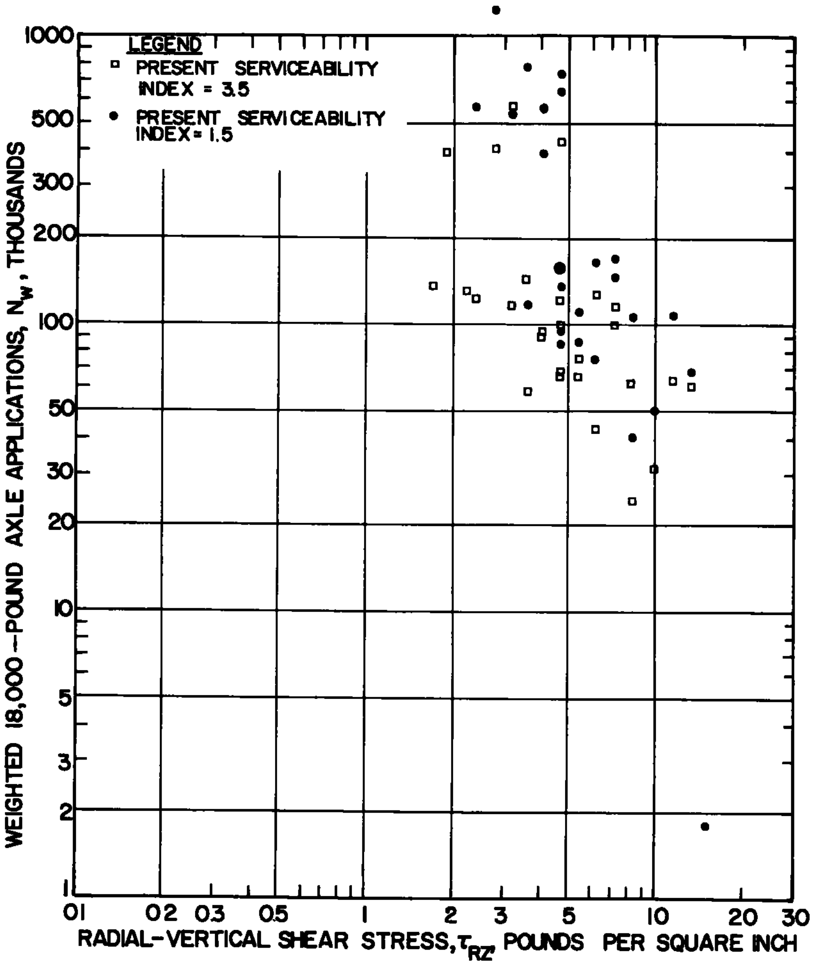

Figure A-6. Weighted number of 18,000-lb single-axle applications versus radial-vertical shear stress.

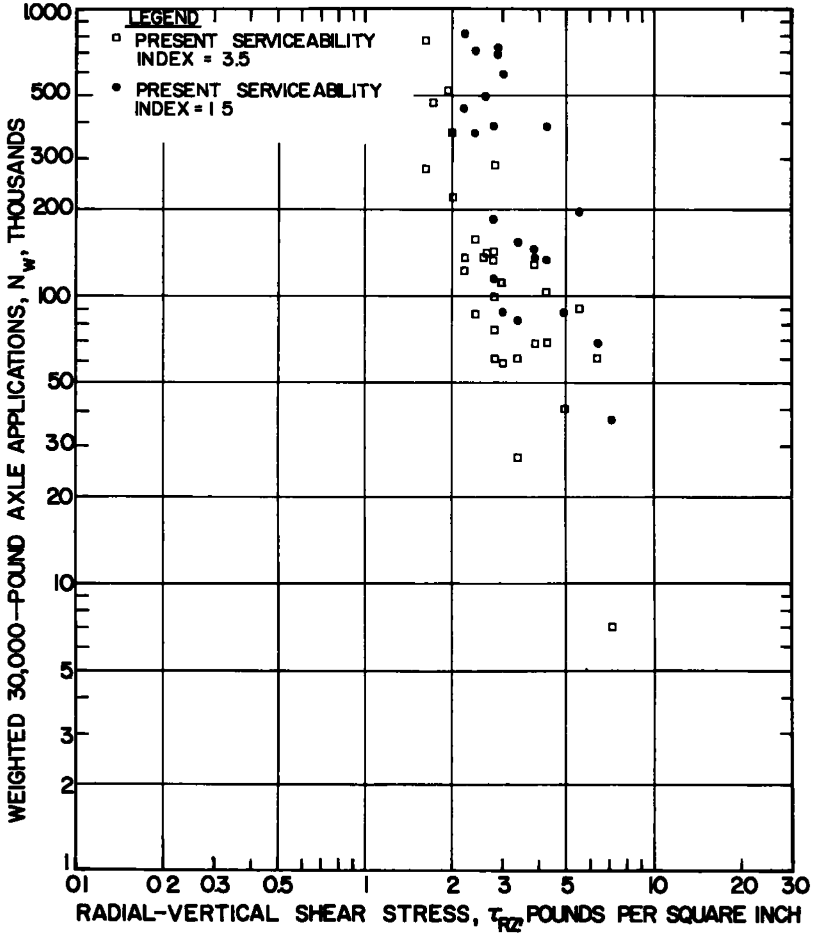

Figure A-7. Weighted number of 30,000-lb single-axle applications versus radial-vertical shear stress.

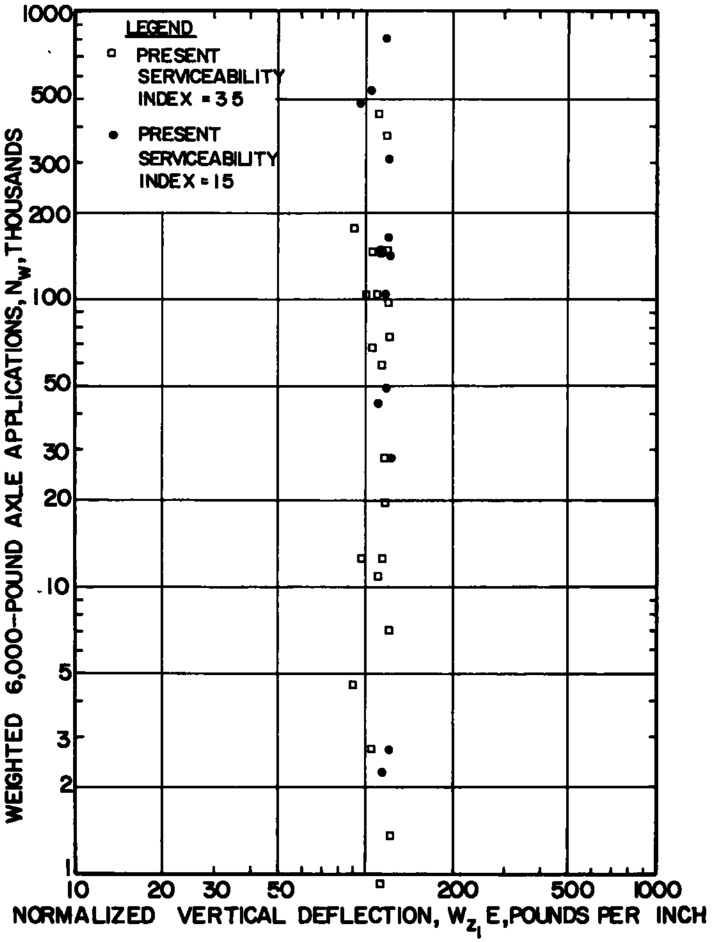

Figure A-8. Weighted number of 6,000-lb single-axle applications versus normalized vertical deflection.

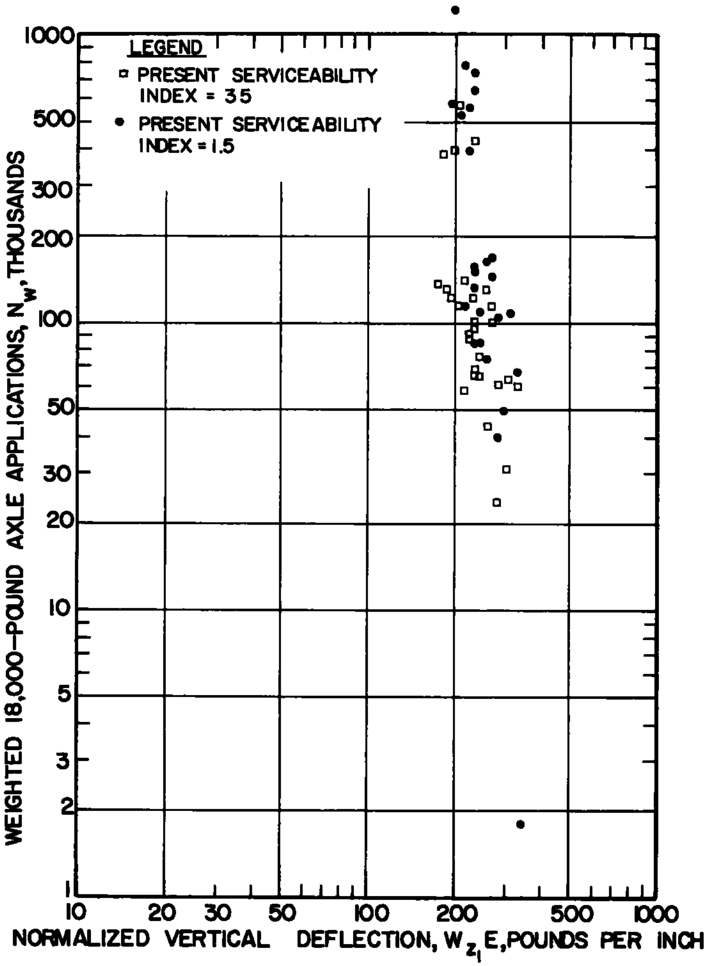

Figure A-9. Weighted number of 18,000-lb single-axle applications versus normalized vertical deflection.

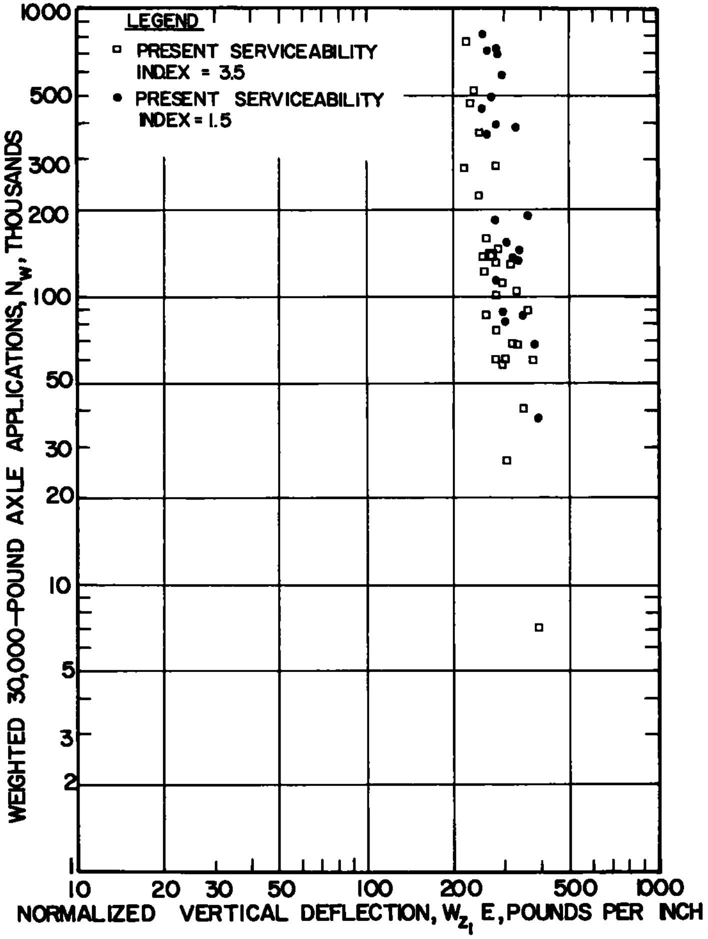

Figure A-10. Weighted number of 30,000-lb single-axle applications versus normalized vertical deflection.

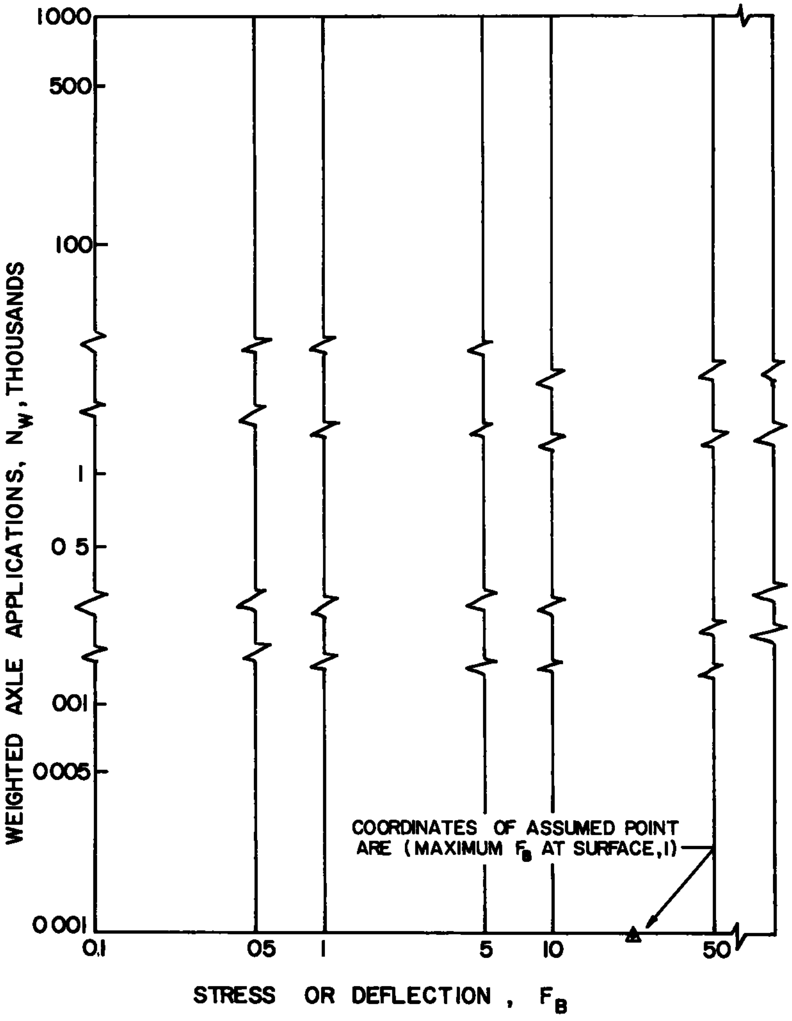

Figure A-11. Schematic diagram showing relative position of assumed point.

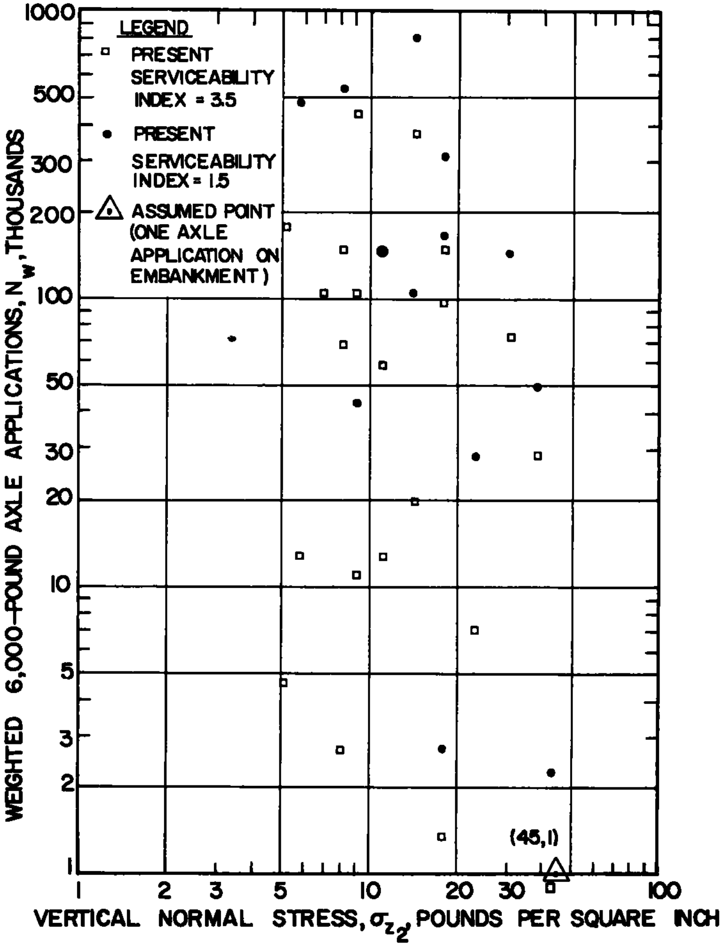

Figure A-12. Weighted number of 6,000-lb single-axle applications versus vertical normal stress.

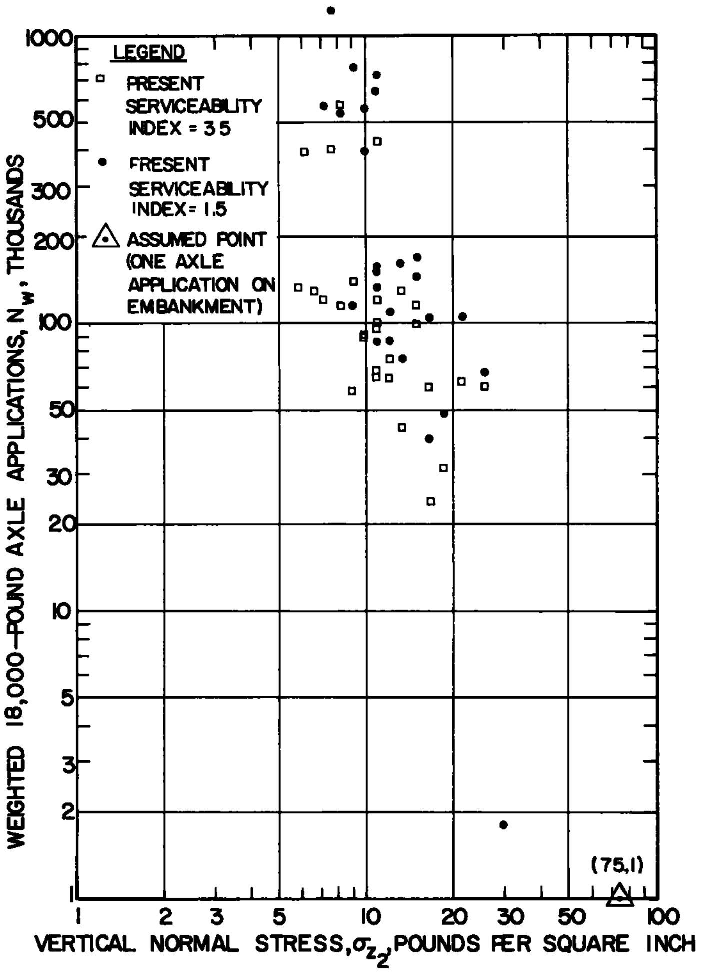

Figure A-13. Weighted number of 18,000-lb single-axle applications versus vertical normal stress.

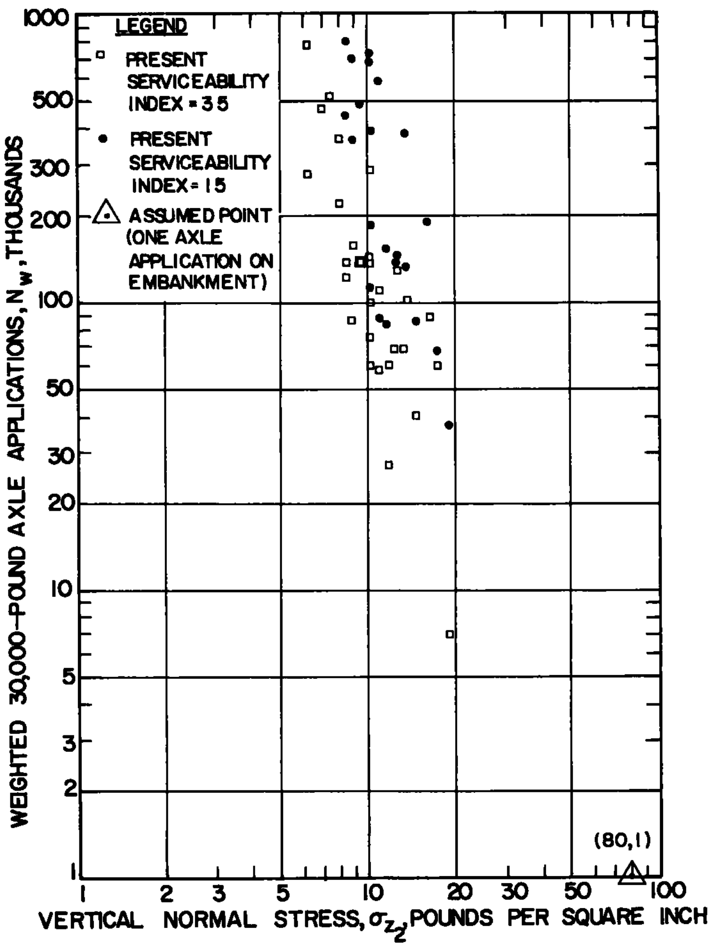

Figure A-14. Weighted number of 30,000-lb single-axle applications versus vertical normal stress.

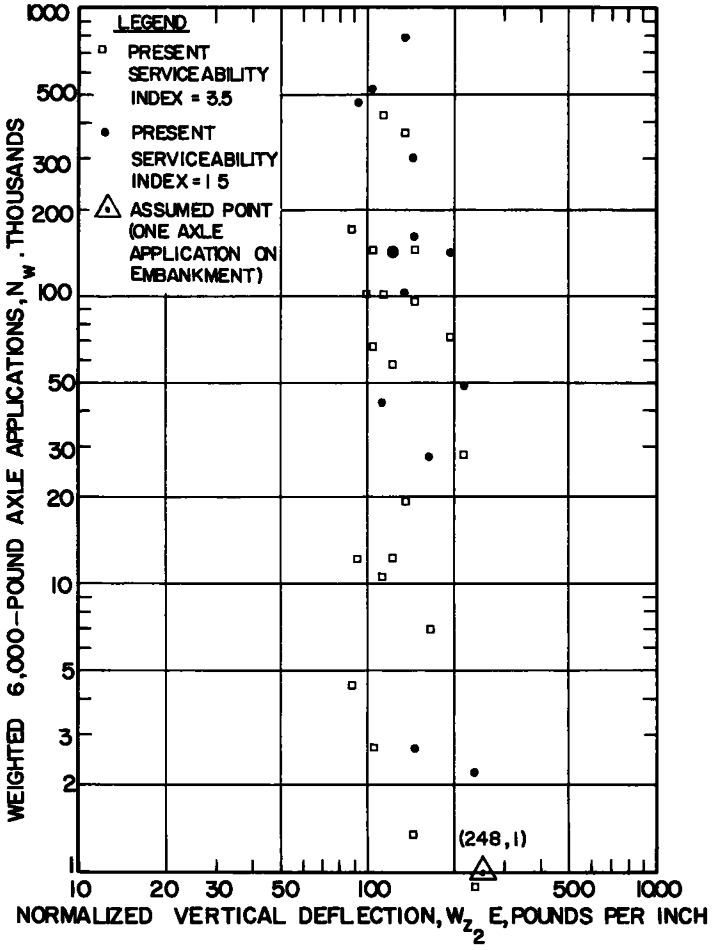

Figure A-15. Weighted number of 6,000-lb single-axle applications versus normalized vertical deflection.

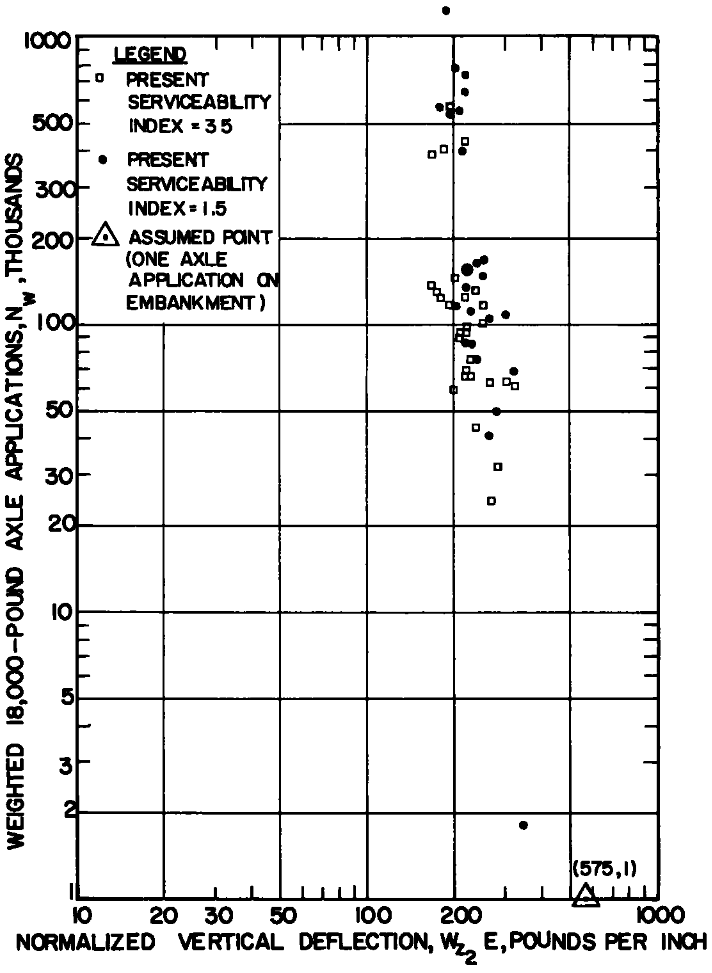

Figure A-16. Weighted number of 18,000-lb single-axle applications versus normalized vertical deflection.

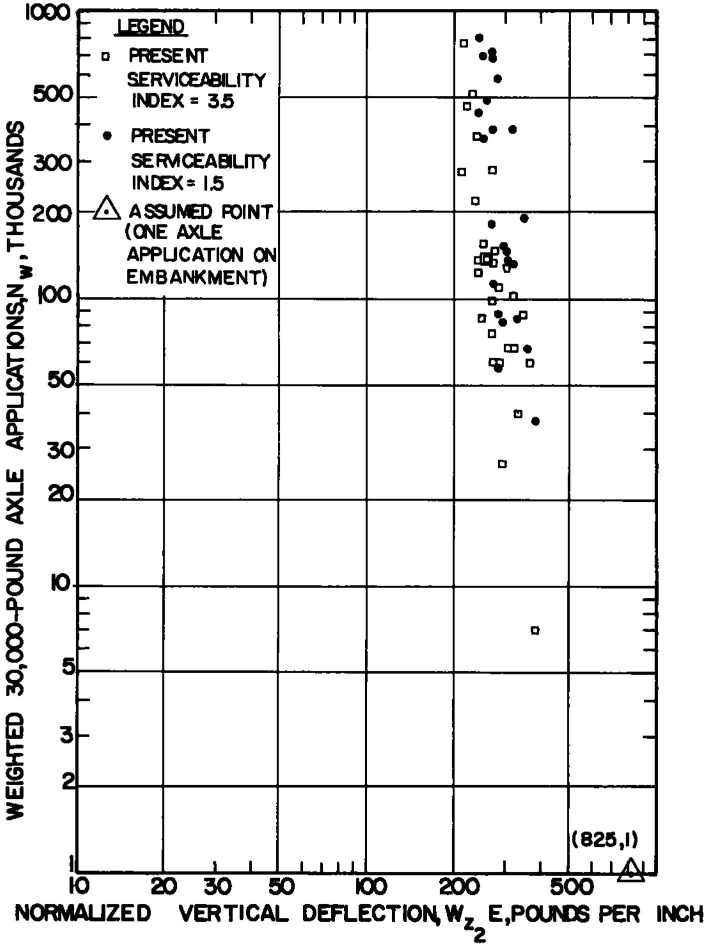

Figure A-17. Weighted number of 30,000-lb single-axle applications versus normalized vertical deflection.

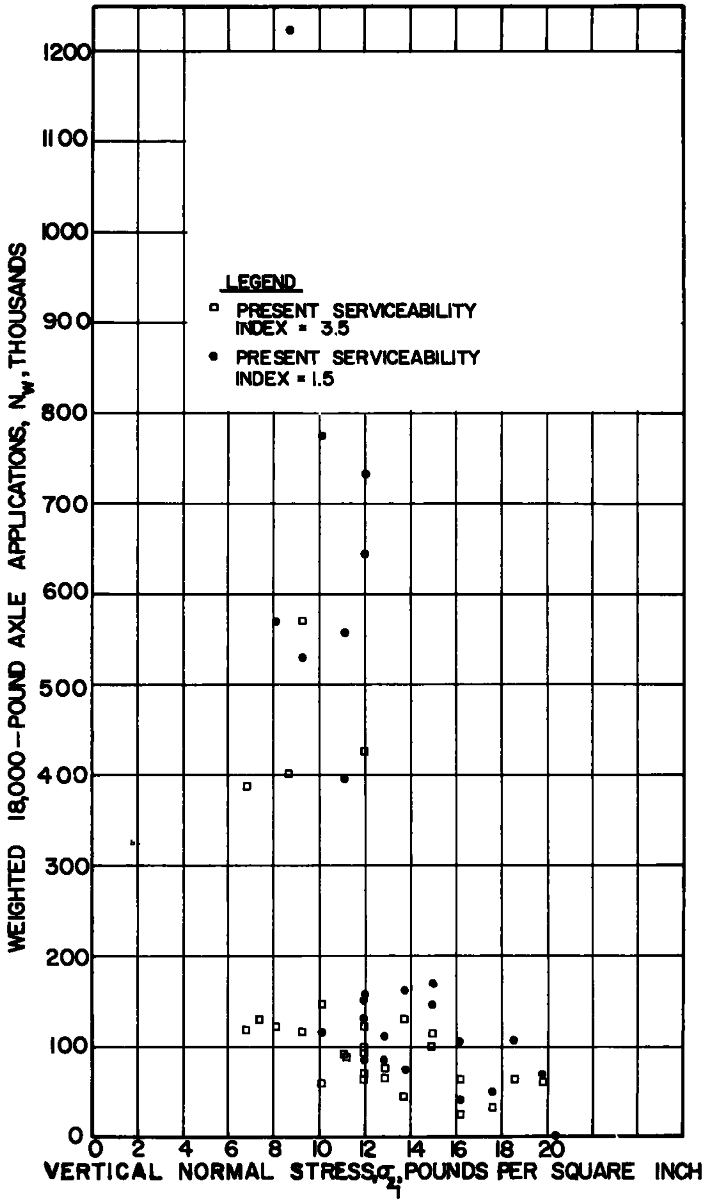

Figure A-18. Weighted number of 18,000-lb single-axle applications versus vertical normal stress.

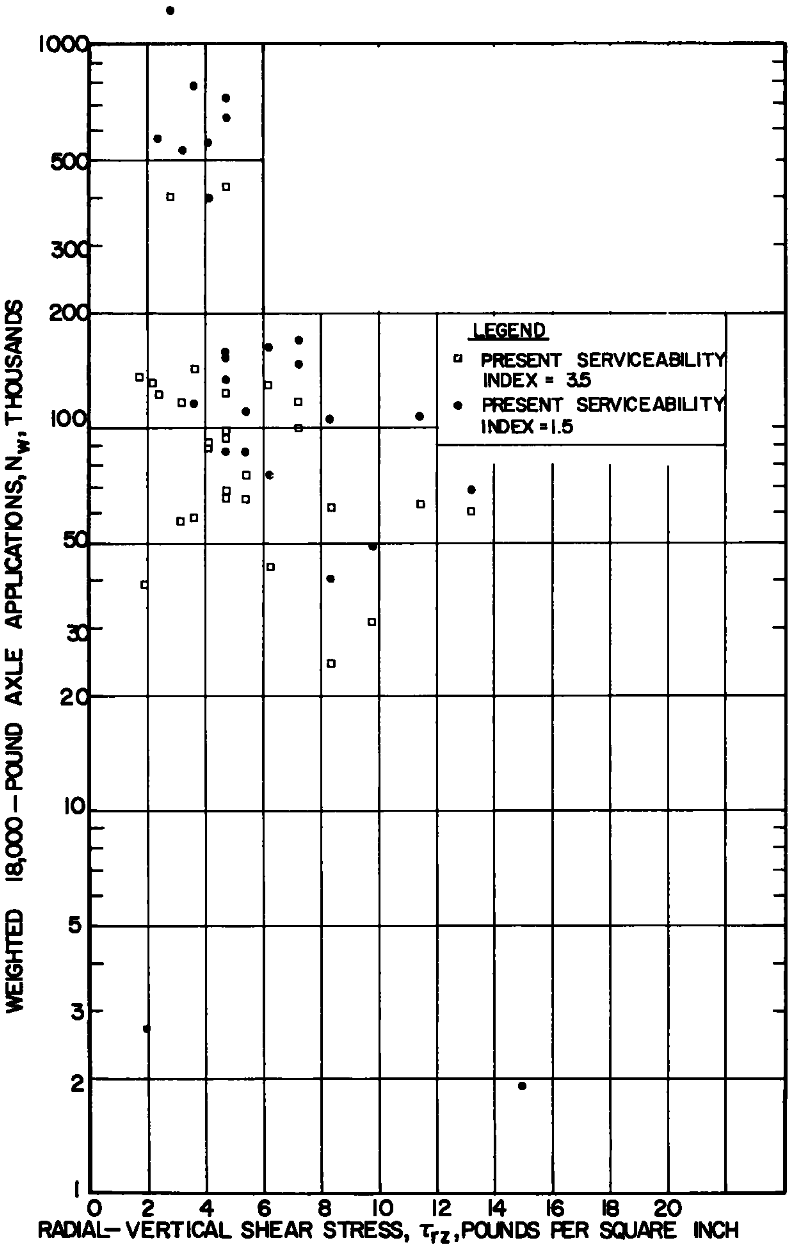

Figure A-19. Weighted number of 18,000-lb single-axle applications versus radial-vertical shear stress.

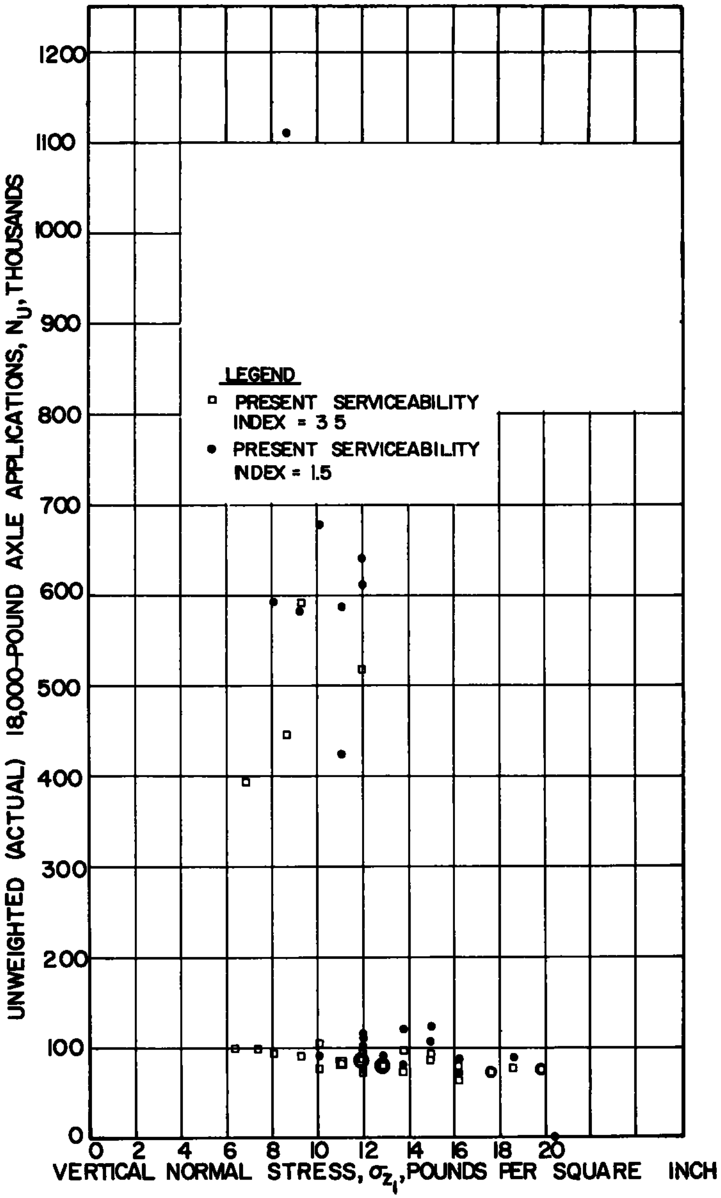

Figure A-20. Unweighted (actual) number of 18,000-lb single-axle applications versus vertical normal stress.

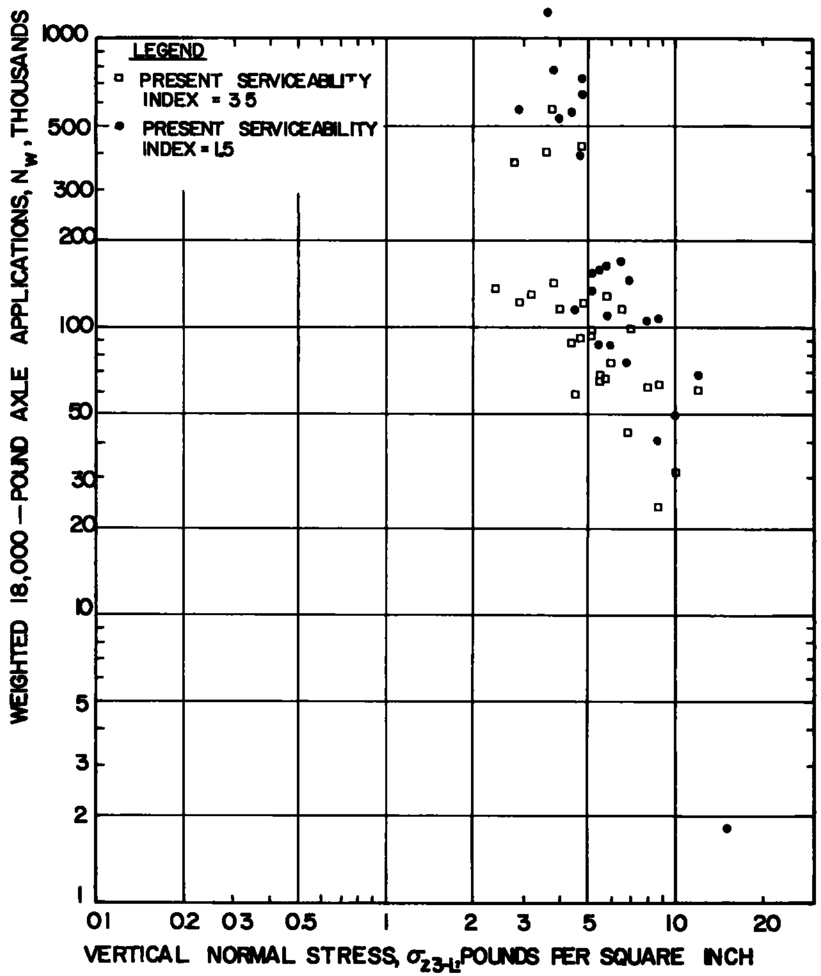

Figure A-21. Weighted number of 18,000-lb single-axle applications versus vertical normal stress predicted by three-layer theory.

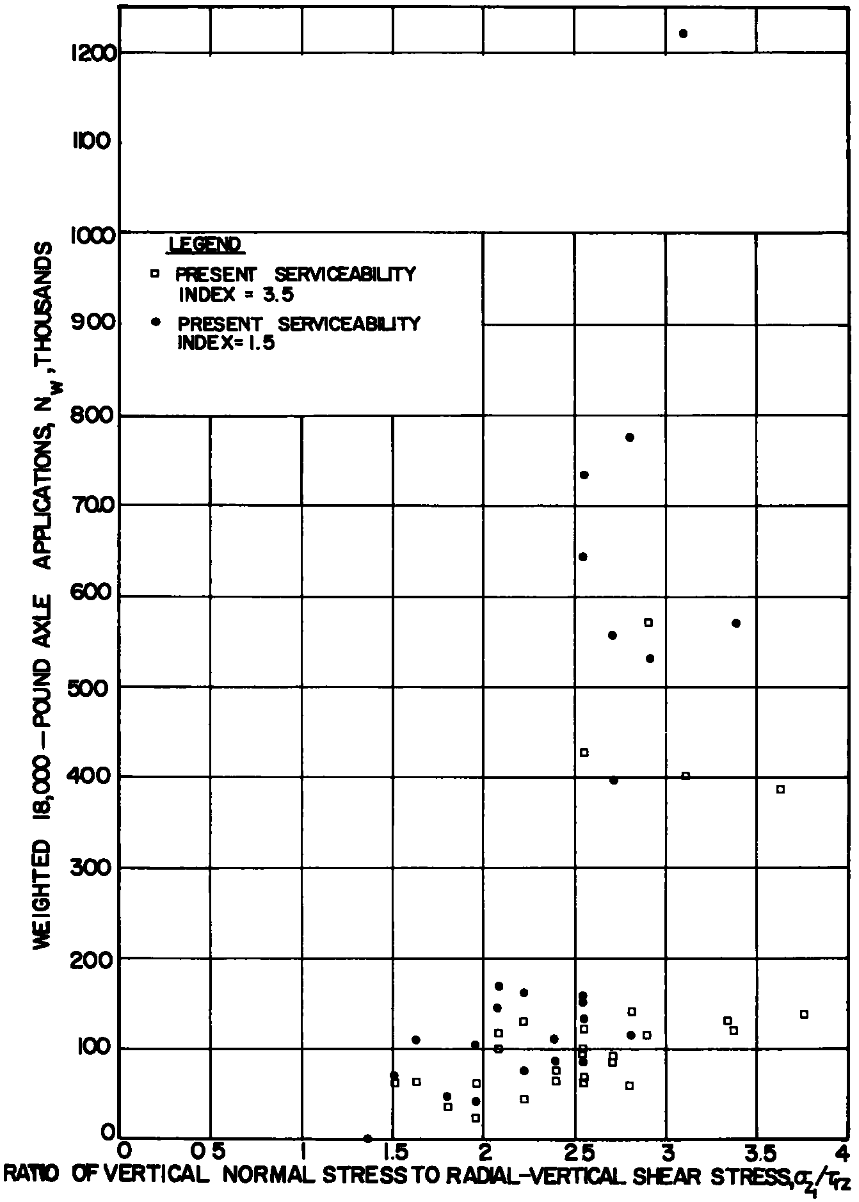

Figure A-22. Weighted number of 18,000-lb single-axle applications versus ratio of stresses.

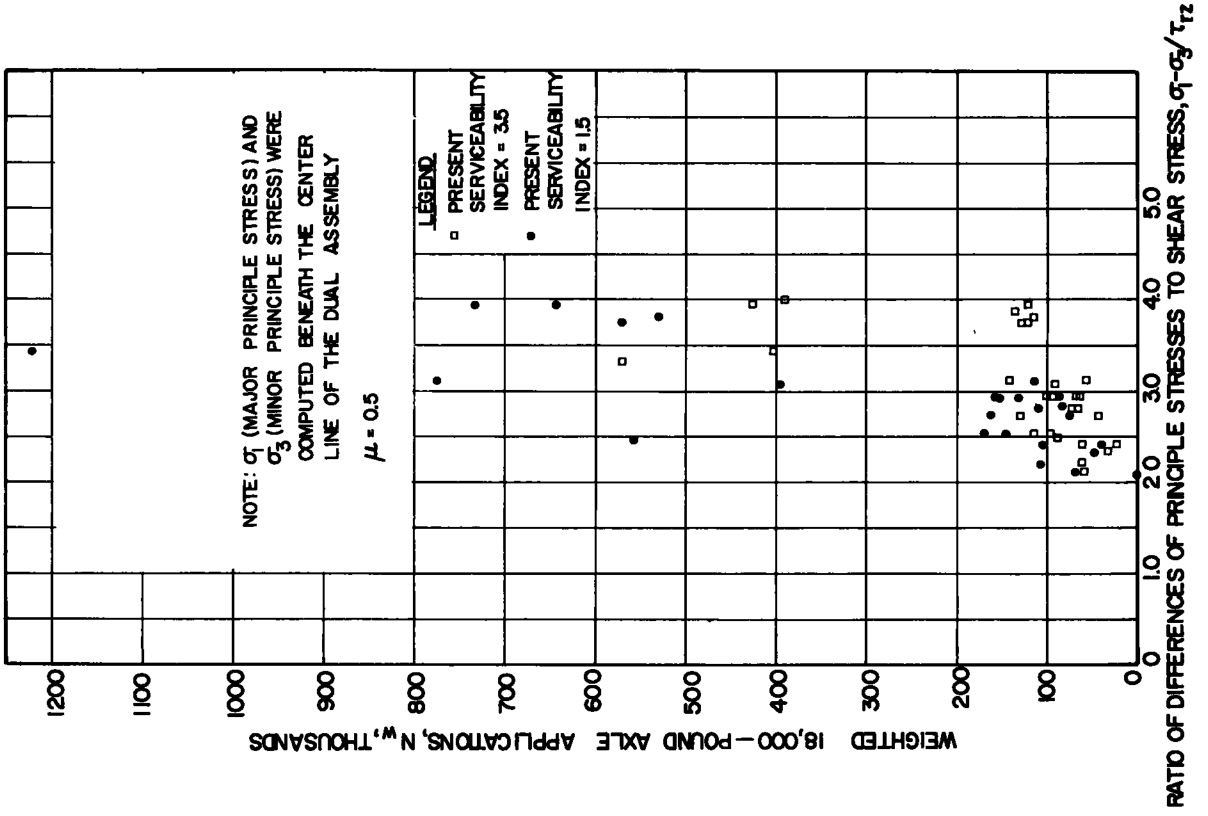

Figure A-23. Weighted number of 18,000-lb single-axle applications versus ratio of stresses.

APPENDIX B

ANNOTATED (CODIFIED) BIBLIOGRAPHY

The following abbreviations and symbols pertain to Phase 2 of the research reported herein, as explained in Chapter One under "Research Approach." The codified literature entries, arranged alphabetically by author, follow the listing of the coding system symbols.

BIBLIOGRAPHIC ABBREVIATIONS

AAPT	Association of Asphalt Paving Technologists
ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
HRB	Highway Research Board
ICSDAP	International Conference on Structural Design of Asphalt Pavements
ICSMFE	International Conference on Soil Mechanics and Foundation Engineering

CODING SYSTEM SYMBOLS

I. *General nature of article; type of problem presented and basic method of solution*

A	Analysis and/or discussion of AASHO Road Test data
$C_v(T_e)$	Combined; experimental results compared with or used to substantiate results predicted by (elastic theory)
$C_v(T_v)$	Combined; . . . (viscoelastic theory)
$C_v(T_l^e)$	Combined; . . . (elastic layered theory)
$C_v(T_l^v)$	Combined; . . . (viscoelastic layered theory)
D	Dimensional analysis
E	Experimental; experimental results presented
S	Survey article
T_e	Theoretical; elastic
T_l	Theoretical; layered system
T_l^{ce}	Theoretical; critical equilibrium of layered system
T_l^e	Theoretical; elastic layered system
T_l^v	Theoretical; viscoelastic layered system
T_{sm}	Theoretical; elementary strength of materials
T_v	Theoretical; viscoelastic

II_A. *Assumptions relative to properties of loaded layer*
II_B. *Assumptions relative to properties of second layer*
II_C. *Assumptions relative to properties of remaining layer(s)*

C	Compression resistance characterized by units of pcf
E	Possesses elastic properties

H	Homogeneous, elastic and isotropic
N	Properties not specified
P - C	Possesses ϕ and c properties
R_f	Rigid surface; friction developed
S	Shearing tendency characterized by units of psf
V	Possesses viscoelastic properties
W	Winkler layer

III_A. *Composition of loaded layer*
III_B. *Composition of second layer*
III_C. *Composition of remaining layer*

A	Asphaltic concrete
AC	Asphalt cement
E	Embankment; material not specified
G	Tar
L	Landing mats
N	Composition not specified
P	Portland cement concrete
P_{ps}	Portland cement concrete, prestressed
PL	Plungers supported by calibrated springs
R	Rock; composition not otherwise specified
RS	Rubber slab
S	Soil; composition not otherwise specified
S_c	Soil; coarse grain—granular
S_{ce}	Soil cement
S_f	Soil; fine grain—clay
S_s	Soil; fine grain—silt
S_{cf}, S_{cs}, S_{fs}, S_{sf}, etc.	Soil; mixed—sandy clay, sandy silt, clayey silt, silty clay, etc.
SL	Slag
SLVS	Steel leaves
SPPC	Steel plates containing pressure-sensitive cells

IV_A. *Type of load*

$D^c(C)$	Dynamic; circular area—constant velocity
$D^n(C)$	Dynamic; concentrated—constant velocity
D_d	Dynamic; dual tires
D_{d-s}	Dynamic; dual tires—single axle
D_{d-t}	Dynamic; dual tires—tandem axle
D_f	Dynamic; friction developed between tires and pavement and between surface layer and base
D^r	Dynamic; rectangular area
D_s	Dynamic; single wheel
D_t	Dynamic; truck
D_{tw}	Dynamic; twin wheel loading
D_{twt}	Dynamic; twin—tandem loading
D_{u-p}	Dynamic; uniform pulse
G	Gravity acting only
I	Impact loads
M	Multi-compartment tires
N	No external load applied
P	Penetration loading—penetrometer driven by falling weight
P_{cbr}	Penetration loading—CBR
PP	Penetrating plunger
R^c	Repetitive; circular area
R_t	Repetitive; triaxial
S^a	Static; any area
S^c	Static; circular area
S_c^c	Static; circular area—conical load
S_d	Static; dual wheels
S_d^c	Static; circular area—dual wheels
S_d^e	Static; elliptical area—dual wheels
S_d^r	Static; rectangular area with rounded ends—dual wheels
S^e	Static; elliptical area
S_e^g	Static; general embankment
S_e^r	Static; rectangular embankment
S_e^t	Static; triangular embankment
S_e^{tr-s}	Static; symmetrical trapezoidal embankment
S_e^{tr-u}	Static; unsymmetrical trapezoidal embankment
S_l	Static; line load
S_m	Static; multiple wheels
S_m^c	Static; circular area—multiple wheels
S^n	Static; concentrated
S_n^c	Static; circular area—nonuniformly applied load
S^p	Static; parabolic area
S^r	Static; rectangular area
S_r	Static; rigid plate
S_s	Static; single wheel
S_s^c	Static; circular area—single wheel
S_s^e	Static; elliptical area—single wheel
S_s^r	Static; rectangular area with rounded ends—single wheel
S^{sc}	Static; semicircular area
S_t	Static; tangential load
S_t^r	Static; rectangular area—tangential load
S_u^c	Static; circular area—uniform load
S_u^r	Static; rectangular area—uniform load
S_u^s	Static; strip—uniform load
S_u^{sc}	Static; semicircular area—uniform load
S_u^{sq}	Static; square area—uniform load
V	Vibrational loading

IV_B. *Position of load*

C	Corner of slab
CH	Channelized
E	Edge of slab
I	Interior of slab
M	Moving
S	Load on surface

V_A. *Ambient effects; temperature*

T	Warping stresses caused by temperature gradients considered
T_g	Temperature gradients controlled to eliminate effects
T_{gr}	Temperature gradients measured
T_o	Temperature changes considered

V_B. *Ambient effects; moisture*

M	Warping stresses caused by moisture gradients considered
M_g	Moisture gradients controlled to eliminate effect
M_o	Moisture changes considered

Aaron, H., Allen, H., Horonjeff, R., Pickett, G., Johannessen, W., "A Comparison of Design Methods for Airfield Pavements", Proc., ASCE, Vol. 78, Separate 163, (1952).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

I. Five pavement design methods considered:
  a. CAA
  b. Corps of Engineers (CBR)
  c. McLeod
  d. Navy
  e. Westergaard

Ahlberg, Harold L. and Barenberg, Ernest J., "The University of Illinois Pavement Test Trade - A Tool for Evaluating Highway Pavements." Highway Research Record No. 13, HRB, pp. 1-21 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S, E	N	N	--	A, *, **	S_c, S_{ce}	--	D_s	S	--	--	

I. Paper contains description of test track.
*. Sand slurry seal
**. Mortar

Ahlvin, R. G., "Direct Measurement of Shear Stresses in Soil Mass", Proc., HRB, Vol. 33, pp. 471-474 (1954)

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_c	--	--	S_u^c	S	--	--	

Ahlvin, R. G. and Ulery, H. H., "Tabulated Values for Determining the Complete Pattern of Stresses, Strains and Deflections Beneath a Uniform Circular Load on a Homogeneous Half Space", Bull. 342, HRB, pp. 1-13 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$_e$	H	--	--	N	--	--	S_u^c	S	--	--	

Allen, Harold, "Report of Committee on Warping of Concrete Pavements", Proc., HRB, Vol. 25, pp. 199-250 (1945)

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	P	*	*	--	--	T, T_o	M, M_o	

* Numerous combinations of materials discussed.

Baker, Robert F., "A Structural Design Procedure for Pavements", Proc., ICSDAP, pp. 465-475 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e, T_1^v	H	E	E	A	N	N	S^c	N	T_o	--	

IV_a. Effects of dynamic loading considered.
V_a. Temperature effects implicit in discussion of complex modulus of elasticity.

Baker, Robert F. and Papazian, Hratch, "The Effect of Stiffness Ratio on Pavement Stress Analysis", Proc., HRB, Vol. 39, pp. 61-85 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$_e$,T_V $_1^e$ $_v(T_e)$	H, V	H	--	A, P	N, SLVS	--	S_r^c,S_s^c S^n,S^r	S, C, I	T	M	

Barber, E. S., "Application of Triaxial Compression Test Results to the Calculation of Flexible Pavement Thickness", Proc., HRB, Vol. 26, pp. 26-39(1946).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$_v(T_e)$	H, P-C	H, P-C	--	A	S	--	S^c	S	--	M_o	

Barber, Edward S., "Shear Loads on Pavements", Proc., ICSDAP, pp. 354-357 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S^c	S	--	--	

Baron, Francis M., "Variables in the Design of Concrete Runways of Airports", Proc., HRB, Vol. 22, pp. 225-239 (1942).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	N	N	--	S_u^c,S_u^e S_u^{sq} S_n^c	I	--	--	

Bastiani, A., "The Explicit Solution of the Equations of the Elastic Deformations for a Stratified Road Under Given Stresses in the Dynamic Case", Proc., ICSDAP, pp. 394-402 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1	H	E	E	N	N	N	$D^n(C)$	N	--	--	

Benkelman, A. C., "Present Knowledge of the Design of Flexible Pavements", Public Roads, Vol. 18, Jan. 1938, pp. 201-212

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Benkelman, A. C., "Report of Committee on Flexible Pavement Design", Proc., HRB, Vol. 23, pp. 90-100 (1943).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Paper describes design methods in use and outlines design method based on large-scale loading tests of trial pavement sections.

Benkelman, A. C. and Williams, Stuart, "The Structural Behavior of Flexible Pavement. An Analysis of Rigid-Plate Bearing Tests on Full-Size Test Sections", Proc., ICSDAP pp. 686-712 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S_c	S_f^{cl}	R^c	S	T_o		

Bradbury, R. D., "Evaluation of Wheel-Load Distribution for the Purpose of Computing Stresses in Concrete Pavements", Proc., HRB, Vol. 14, pp. 225-254 (1934).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	S_s^c,S_s^{sc} S_d^c S_d^{sc}	C, I, E	--	--	

Broms, Bengt B., "Effect of Degree of Saturation on Bearing Capacity of Flexible Pavements." Highway Research Record No. 71, HRB, pp. 1-14 (1965).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T^{ce}	N	N	p-c	A	N	S_f	*	*	--	M_o	

* Applied load assumed to be distributed over an area which increases linearly with distance from the point of loading.

Brown, Philip P., "Analysis of Flexible Airfield Pavements by Surface Plate Loading", Proc., ICSDAP, pp. 680-685 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_1^e$	H	E	--	A	*	*	S^c	S	--	--	

* Various base and subgrade materials tested.

Brzesowsky, R. A. and Vanderveen, C., "An Investigation on the Capacity of Some Flexible Runways at Schiphol Airport", Proc., Third ICSMFE, Vol. 2, pp. 97-102 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S_c	S_c, S_f	R^c	S	--	M_o	

Burggraf, F., "Field Tests on Bearing Capacity, Shearing and Penetration Resistance of Soils", Proc., HRB, Vol. 20, pp. 287-298 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	A, S	S --	S --	P, S^r, S^P	S	--	M_o	

Burmister, Donald M., "The Theory of Stresses and Displacements in Layered Systems and Applications to the Design of Airport Runways", Proc., HRB, Vol. 23, pp. 126-148, (1943).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H, E	E	--	P, A, S	N	--	S_u^c	I, S	--	--	

Burmister, Donald M., "Stress and Displacement Characteristics of a Two-Layer Rigid Base Soil System: Influence Diagrams and Practical Applications", Proc., HRB, Vol. 35, pp. 773-814 (1956).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	H	H	S, A, P	S_f, S_c	-- S_f	S^n, S_u^c S^a S_r^c	S, I	--	--	

Burmister, Donald M., "Applications of Layered System Concepts and Principles to Interpretations and Evaluations of Asphalt Pavement Performances and to Design and Construction", Proc., ICSDAP, pp. 441-453 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^E	H	E	E	A	S_c	N	S^c	S	--	--	

Carlton, Paul F. and Behrmann, Ruth M., "A Model Study of Rigid Pavement Behavior Under Corner and Edge Loadings", Proc., HRB, Vol. 35, pp. 139-146 (1956).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	W	--	P	RS	--	S^c, S^e	C, E	T_g	M_g	

Childs, L. D., "A Study of Slab Action in Concrete Pavements Under Static Loads", Proc., HRB, Vol. 27, pp. 64-84 (1947).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, $C_v(T_e)$	N H	N W	N --	P	S_c	S_c	S_d S^c S_s	E, C	T_g	M_g	

Cholnoky, Thomas, "Prestressed Concrete for Airfields", Journal, ACI, Vol. 28, pp. 59-84, July 1956.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	P	S_c	S_f	S_r^c	I, E	T_{gr}	M_o	

Claudon, J. G., "Study of Stresses in Prestressed Concrete Pavements at Maison-Blanche Airport." Highway Research Record No. 44, HRB, pp. 80-103 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, *	E	N	N	P_{ps}	S_c	S_{ef}	**	--	T_o	M_o	

* Theoretical relationship developed between stresses and hygrothermal changes.

** Stresses induced by additional prestress observed; also observed were variations of stresses with changes in temperature, moisture content, and time.

Colley, B. E. and Nowlen, W. J., "Performance of Subbases for Concrete Pavements Under Repetitive Loading", Bull. 202, HRB, pp. 32-58 (1958).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	P_{ps}	S_c	S_f	P^c	S	--	M_o	

Davis, E. H., "Pavement Design for Roads and Airfields", Road Research, Technical Paper No. 20, Road Research Laboratory, Harmondsworth, England (1951).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

DeKruyf, M., van der Poel, C., Timman, R., "Calculation of Stresses in Road and Runway Construction", Proc., Second ICSMFE, Vol. IV, p. 181 (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	H	H	P	S_c	S_c	S_s S_d S_u^c	S	--	--	

de L'Hortet, R. and Dreyfuss, G., "Bearing Capacity of Flexible Runways", Proc., Third ICSMFE, Vol. II, pp. 107-111 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	N	--	A	S	--	S_u^c	S	--	M_o	

Dingwall, J. C. and Scrivner, F. H., "Application of the Elastic Theory to Highway Embankments by Use of Difference Equations", Proc., HRB, Vol. 33, pp. 474-482 (1954).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	R_f	--	E	N	--	G	--	--	--	

Docker, C. E. and McFeeters, J. N., "Principles on Concrete Runway Design", Proc., Second ICSMFE, Vol. II, pp. 246-256 (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	W	--	P	N	--	S_u^c S_u^e, I	I, E, C	T, T_{gr}	--	

Docker, C. E., McFeeters, J. N., "An Example of Concrete Runway Design With Critical Comments", Proc., Second ICSMFE, Vol. II, p. 263 (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	S_{fs}, P	--	S_s^c	I, E, C	T	--	

Dorman, G. M., "The Extension to Practice of a Fundamental Procedure for the Design of Flexible Pavements", Proc., ICSDAP, pp. 785-793 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	E	E	A	S_c	N	D_d	S	T_o		

Dunlap, Wayne A., and Stark, L. E., "Deflection Tests on Texas Highways", Bull. 269, HRB, pp. 52-65 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S, S_f	S, S_f	S_d	S	T_o	--	

IV_a. Creep speed deflections determined by Benkelman beam.

ell, W. W. and Okubo, S., "Deflections in Slabs on Elastic Foundations", Proc.,
B, Vol. 30, pp. 125-133 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
sm	H	W	--	N	N	--	S^n	I	--	--	

rgus, Stuart M. and Miner, William E., "Distributed Loads on Elastic Foundations:
e Uniform Circular Load", Proc., HRB, Vol. 34, pp. 582-597 (1955).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
e	H	--	--	N	--	--	S_u^c, S_s^c	S	--	--	

ordyce, Phil and Teske, W. E., "Some Relationships of the AASHO Road Test to Concrete
avement Design." Highway Research Record No. 44, HRB. pp. 35-70 (1963)

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	

aper considers only Portland cement concrete sections.

ster, C. R., "Reduction in Soil Strength with Increase in Density", Trans., ASCE,
l. 120, pp. 803-815 (1955).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	L	S_{sf}	--	D_s, D_d	S, M	--	M_o	

ster, Charles R., "Failure Criteria for Flexible Airfield Pavements", Bull. 187,
B, pp. 72-76 (1958).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

ster, Charles R. and Fergus, S. M., "Stress Distribution in a Homogeneous Soil",
ecial Report No. 12-F, HRB, January 1951.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
(T_e)	H	--	--	S_{fs}	--	--	S^c	S	--	--	

$_a$. Single and dual loads applied through flexible plates.

$_b$. Position on surface varied but was specified.

Fox, L., "Computation of Traffic Stresses in a Simple Road Structure", Road Research Technical Paper No. 9, Road Research Laboratory, Harmondsworth, England (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$_e$	H	H	--	N	N	--	S_u^c	S	--	--	

Freeman, Ralph A., "Flexible Pavement Test Sections for 300,000 lb. Airplanes, Stockton, California", Proc., HRB, Vol. 25, pp. 23-44 (1945).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S_c	S_f, --	S_s, D_s	S, M	T_o	--	

Freitag, D. R. and Green, A. J., "Distribution of Stresses on an Unyielding Surface Beneath a Pneumatic Tire", Bull. 342, HRB, pp. 14-23 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	SFPC	--	--	S_s	S	--	--	

IV_a. Various types of tires (no tread) tested.

IV_b. Position of tire specified.

Geldmacher, R. C., Anderson, R. L., Dunkin, J. W., Partridge, G. R., Harr, M. E., and Wood, L. E., "Subgrade Support Characteristics as Indicated by Measurements of Deflection and Strain", Proc., HRB, pp. 479-496 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N, H	N	--	P	S_{ce}, S_c S_f	--	D_d	M E I	T	--	

II_a. Assumption of homogeneity involved in supplementary study.

Gillette, H. S., "Stresses Under Circular Flexible Foundations," Bull. 277, HRB, pp. 61-74 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S_u^c	S	--	--	

Influence charts (stress contours) for Boussinesq problem.

Goldbeck, A. T., "Traffic Stresses Produced in Concrete Roads", Proc., HRB, Vol. 4, pp. 62-63 (1924).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	P	N	--	D_t	M, I E C	--	--	

Goldbeck, A. T., "Studies of Subgrade Pressures Under Flexible Road Surfaces", Proc., HRB, Vol. 19, pp. 164-174 (1939).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	S_c	S_{cf}	S^e, S^c	S^e S^c	S	--		

Goldbeck, A. T., "A Method of Design of Non-Rigid Pavements for Highways and Airport Runways", Proc., HRB, Vol. 20, pp. 258-270 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_{sm}, E	N	N	--	N	S	--	S^e	S	--	--	

Hank, R. J. and Scrivner, F. H., "Some Numerical Solutions of Stresses in Two- and Three-Layered Systems", Proc., HRB, Vol. 28, pp. 457-468, (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_1^e)$, T_1^e	H	H	--, H	S_{ce}, P	A S_f S_c	S_f, --	S_u^c	S, I	--	--	

Hardy, R. M. and Rivard, P. J., "Stress Distributions Below Pavements Under Trolley Bus Loadings", Proc., HRB, Vol. 30, pp. 396-406 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	--	--	A, P	S_c S_f	--	S_s,S_d D_s D_d	S	--	--	

Harr, M. E., Influence of Vehicle Speed on Pavement Deflections", Proc., HRB, Vol. 41, pp. 77-82 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_v, $C_v(T_v)$	V	--	--	N	--	--	D_{u-p} D_t	S, M	--	--	

Harr, M. E. and Leonards, G. A., "Warping Stresses and Deflections in Concrete Pavements", Proc., HRB, Vol. 38, pp. 286-320 (1959).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e, $C_v(T_e)$	H	W	--	P	N	--	N, G	--	T	M	

Harr, M. E. and Lovell, Charles W., "Vertical Stresses Under Certain Axisymmetrical Loadings", Highway Research Record No. 39, HRB, pp. 68-77 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	*	S	--	--	

* Loadings (no shear at surface of contact) considered are: general axisymmetrical loading, uniformly loaded circular area, circular area with parabolic loading function, circular area with conical loading function.

Herner, Raymond C., "Progress Report on Load-Transmission Characteristics of Flexible Paving and Base Courses", Proc., HRB, Vol. 31, pp. 101-120 (1952).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	S_c, A	PL, S_c	--, PL	S_r^c S_s S_d	S	--	--	

IV_b. Position of load specified.

Herner, Raymond C., "Effect of Base-Course Quality on Load Transmission Through Flexible Pavements", Proc., HRB, Vol. 34, pp. 224-233 (1955).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S_c S_{fc} SL,A	PL	S_s, S_r	S	--	--	

IV_b. Position of load specified.

Heukelom, W., and Foster, C. R., "Dynamic Testing of Pavements," Journal of the Soil Mechanics and Foundations Division, ASCE, Part 1, Vol. 86, pp. 1-28 (Feb. 1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e, E	H N	-- N	-- N	A, S	S	S	V, S_u^c	S	T_o	--	

III. Results of tests on numerous types of soil reported.

Heukelom, W. and Klomp, A. J. G., "Dynamic Testing as a Means of Controlling Pavements During and After Construction", Proc., ICSDAP, pp. 667-679 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	*	*	*	V	S	T_o	M_o	

* Properties (dynamic E, elastic stiffness, etc.) of many materials reported.

Hewitt, William L., "Analysis of Stresses in Flexible Pavements and Development of a Structural Design Procedure." Bull. 269, HRB, pp. 66-74 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	H, P-C	H, P-C	--	A, S_f S_c	S_f,	--	S_u^c	S	--	--	

Hittle, J. E. and Goetz, W. H., "Factors Influencing the Road-Carrying Capacity of Base-Subgrade Combination", Proc., HRB, Vol. 26, pp. 521-543 (1946).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	S_c, S_{cf}	S	--	S_r^c	S	--	M_o	

Hogg, A. H. A., "Equilibrium of a Thin Plate, Symmetrically Loaded, Resting on an Elastic Foundation of Infinite Depth," Philosophical Magazine and Journal of Science, Vol. 25, Seventh Series, pp. 576-582 (1938).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S^r, S_u^c	S	--	--	

Holl, D. L., "Shearing Stresses and Surface Deflections due to Trapezoidal Loads", Proc., HRB, Vol. 19, pp. 409-423 (1939).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	R_f	--	N	--, R	--	S_e^t, S_e^r S_e^{tr-s} S_e^{tr-u}, S_e^g	S	--	--	

Holl, D. L., "Stress Transmission in Earths", Proc., HRB, Vol. 20, pp. 709-721 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	E	--	--	N	--	--	S^n, S_t, S_1 S_u^c, S_c^c S_u^r, S_t^r	S	--	--	

Housel, W. S., et. al., "Discussion on Flexible Surfaces", Proc., HRB, Vol. 20, pp. 314-332 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Article presents comments on the following papers contained in Proc., HRB, Vol. 20 (194

1. "Wheel Load Stress Distribution Through Flexible Type Pavements", Spangler and Ustr
2. "Suggested Method of Design of Non-Rigid Pavements", Goldbeck
3. "Required Thickness of Asphalt Pavements in Relation to Subgrade Support", Hubbard and Field.
4. "Soil Displacement Under Circular Loaded Areas', Palmer and Barber.

Hubbard, P. and Field, F. C., "Required Thickness of Asphalt Pavement in Relation to Subgrade Support", Proc., HRB, Vol. 20, pp. 271-278 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	A	S	--	S^c	S	--	--	

Hveem, F. N. and Sherman, G. B., "Thickness of Flexible Pavements by the California Formula Compared to AASHO Road Test Data." Highway Research Record No. 13, HRB, pp. 142-166 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A S											

I. AASHO Road Test results and California design equation compared
Note: Sections include "The Pavement Problem", and "Factors to be Considered in a Design Formula." Figure 2 shows variables affecting performance of an asphalt pavement.

Ivanov, N. N., Birulya, A. K., Babkov, V. F., Puzakov, N. A., "Flexible Pavement Design", Proc., Fourth ICSMFE, Vol. II, pp. 120-125 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e$	H	N	--	A	S	--	S_d	S	T_o	M_o	

Jeuffroy, G. and Bachelez, J., "Note on a Method of Analysis for Pavement", Proc., ICSDAP, pp. 300-309 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1	H	E	E	A	N	N	S_s^c, S_d^e	S	--	--	

Jones, A., "Tables of Stresses in Three-Layer Elastic Systems." Bull. 342, HRB, pp. 176-215 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	H	H	N	N	N	S_c^u	S	--	--	

Jones, R., "Measurement and Interpretation of Surface Vibrations on Soil and Roads," Bull. 277, HRB, pp. 8-29 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, $_v(T_1^e)$	E, E, E,	--, E, E	--, -- E	A, S	S	S	V	S	*	*	

III. Results of experiments on various soils reported.

* Results on same site, various times of the year, reported.

Jones, R., and Whiffin, A. C., "A Survey of Dynamic Methods of Testing Roads and Runways," Bull. 277, HRB, pp. 1-8 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

King, K. H., Pitt, L. C., "Tests to Determine the Behavior of Rail-Track Formations on Various Soil Subgrades with Particular Reference to Clays", Proc., Fourth ICSMFE, Vol. II, pp. 128-133 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	S_f	R	--	D_{u-p}	S	--	M_o	

Krynine, D. P., "Report of Committee on Stress Distribution in Soils" and, "Study of Stress Distribution in Soils from 1920 to 1940", Proc., HRB, Vol. 21, pp. 531-540 (1941).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Kuhn, S. H. and Rigden, P. J., "Measurement of Viscoelastic Properties of Bitumens Under Dynamic Loading", Proc., HRB, Vol. 38, pp. 431-458 (1959).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, T_v	V	--	--	AC, T	--	--	V	--	T_o	--	

Larew, H. G. and Leonards, G. A., "A Strength Criterion for Repeated Loads", Proc., HRB, Vol. 41, pp. 529-556 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_s S_f S_{cf}	--	--	R_t	--	--	--	

Lattes, R., Lions, J. L. and Bonitzer, J., "Use of Galerkin's Method, for the Study of Static and Dynamic Behavior of Road Structures", Proc., ICSDAP, pp. 530-536 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1	V	E, E	V	N	N-N	N	*	S	--	--	

II$_b$. Road assumed to be four-layer system; two middle layers assumed elastic.

* Static and dynamic loads (no further specifications) considered.

Lawton, Warren L., "Static Load Contact Pressure Patterns Under Airplane Tires", Proc., HRB, Vol. 36, pp. 233-239 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	PL	--	--	S_s	S	--	--	

IV$_b$. Position of load specified.

Laxton, H., Beavis, H. M. and McNicholl, M. D., "A Procedure for Evaluating the Influence of the Moisture Content of the Subgrade on the Thickness Required for Flexible Pavements of Airfields", Proc., Second ICSMFE, Vol. II, pp. 218-222 (1948).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	E	N	--	N	S_f	--	P_{cbr}	S	--	M_o	

Livneh, M. and Shklarsky, E., "The Bearing Capacity of Asphaltic Concrete Carpets Surfacing", Proc., ICSDAP, pp. 345-357 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	p-c	p-c	--	A	N, P	--	S^r	S	--	--	

IV$_a$. Static loads of infinite and finite length considered. Load may be vertical or inclined; some consideration of braking stresses; some consideration of dynamic loads.

Maclean, D. J. and Armstrong, M. D., "The Design of Road Foundations", Proc., Third ICSMFE, Vol. II, pp. 118-121 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	A, P	S_s S_f S_c	--	*	S	--	M_o	

* Performance of roads subjected to highway traffic observed.

Maxwell, A. A., Non-Destructive Testing of Pavements," Bull. 277, HRB, pp. 30-36 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	E	E	E	A	S_{cf}	S_{cs}	V	S	--	--	

McCarthy, L. E., "Applications of the Mohr Circle and Stress Triangle Diagrams to Test Data Taken With the Hveem Stabilometer", Proc., HRB, Vol. 26, pp. 100-123 (1946).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Two-part paper. In part one, Mohr's circle developed; various failure theories discussed. In part two, another graphical stress analysis is presented.

McFadden, G., "Airfield Pavement Design of the Corps of Engineers", Proc., ASCE, Vol. 80, Separate 458 (1954).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Corps of Engineers design procedures.

McLeod, Norman W., "The Rational Design of Bituminous Paving Mixtures", Proc., HRB, Vol. 29, pp. 107-159 (1949).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	N	N	A	N	N	S_u^s D_f D^r	S, M	--	--	

McLeod, Norman W., "Influence of Tire Design and Vehicle Mobility", Proc., HRB, Vol. 31, pp. 121-147 (1952).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	P-C	--	A S_f S_c	N, S_f	--	S_s^e,M S_u^s D_f	S	--	--	

McLeod, Norman W., "Rational Design of Bituminous Paving Mixtures with Curved Mohr Envelopes", Proc., AAPT, Vol. 21, pp. 349-437 (1952).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	--	--	A	N	N	S_u^s, S_s, M	S	--	--	

McLeod, Norman W., "Some Basic Problems in Flexible-Pavement Design", Proc., HRB, Vol. 32, pp. 90-118 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	P-C	--	A	S	--	S_u^s	S	--	--	

McLeod, Norman W., "The Design of Bituminous Mixtures with Curved Mohr Envelopes", Proc., AAPT, Vol. 22, pp. 238-283 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^{ce}	P-C	--	--	A	N	N	S_u^s, S_s	S	--	--	

McLeod, N. W., "Airport Runway Design and Evaluation in Canada", Proc., Third ICSMFE, Vol. IV, pp. 122-127 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	N	N	--	R^c	S	--	--	

McLeod, N. W., "Relationships Between Deflection, Settlement and Elastic Deformation for Subgrades and Flexible Pavements Provided by Plate Bearing Tests at Canadian Airports", Proc., Fourth ICSMFE, Vol. II, pp. 151-157 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	S_c, S_f, A	S_f, S_c	--	R^c	S	--	--	

McMahon, T. F. and Yoder, E. J., "Design of a Pressure-Sensitive Cell and Model Studies of Pressures in a Flexible Pavement Subgrade", Proc., HRB, Vol. 39, pp. 650-682 (1960).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$ $C_v(T_1^e)$	H,	H	--	S_c, S_f	S_f	--	S^c	S	--	--	

Mellinger, Frank M., Sale, James P., Wathen, Thurman R., "Heavy Wheel Load Traffic on Concrete Airfield Pavements", Proc., HRB, Vol. 36, pp. 175-189 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	W	--	P	S_f, S_{cs}	--	D_{tw}	M, CH	--	--	

Monismith, Carl L. and Secor, Kenneth E., "Viscoelastic Behavior of Asphalt Concrete Pavements", Proc., ICSDAP, pp. 476-498 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_v $C_v(T_v)$ S	V	W	--	A	*	--	S^c	S	T_o	--	

I. Short survey of literature presented concerning viscoelastic properties of asphalt cement and concrete and the viscoelastic behavior of layered systems.

* Experimental base comprised of small coil springs.

IV_a. Static loads applied to test slab; rheologic behavior of the asphalt concrete mixture determined from other tests.

Nascimento, U., Simoes, A., "Relation Between CBR and Modulus of Strength", Proc., Fourth ICSMFE, Vol. II, pp. 166-168 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	H	--	--	R S_s S_c	--	--	S_n^c	S	--	--	

IV_a. CBR plunger used in loading tests.

Nevitt, H. G., "A Mathematical Analysis of Some Phases of the Flexible Surface Design Problem", Proc., HRB, Vol. 23, pp. 149-154 (1943).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
D, T_1^{ce}	C, S	N	--, N	N	N	--, N	S_u^c, S_n	S	--	--	

Nichols, F. P., Jr., "Deflections as an Indicator of Flexible Pavement Performance." Highway Research Record No. 13, HRB, pp. 46-65 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S, S_{ce}	S, S_{ce}	S_d	S	T_o		

IV_a. Creep speed deflections measured.

V_a. Temperature range recorded in data.

Nijboer, L. W., "Mechanical Properties of Asphalt Materials and Structural Design of Asphalt Roads", Proc., HRB, Vol. 33, pp. 185-200 (1954).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Nijboer, L. W. and Van Der Poel, C., "A Study of Vibration Phenomena in Asphaltic Road Constructions", Proc., AAPT, Vol. 22, pp. 197-237 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	S	S	V D_s D_d	S	T_o	--	

IV_a. Road vibration machine discussed.

Painter, A., "Analysis of AASHO Road Test Asphalt Pavement Data by the Asphalt Institute." Highway Research Record No. 71, HRB, pp. 15-38 (1965).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
A											

Palmer, L. A., "Stresses Under Circular Loaded Areas", Proc., HRB, Vol. 19, pp. 397-407 (1939).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--	--	N	--	--	S_u^c	S	--	--	

Palmer, L. A., "Special Procedures for Pavement Design", Trans., ASCE, Vol. 119, pp. 542-560 (1954).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

I. Navy method of pavement design discussed.

Palmer, L. A., and Barber, E. S., "Soil Displacement Under a Circular Loaded Area", Proc., HRB, Vol. 20, pp. 279-286 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	H, --	--	A, S_f, S_c	S_f S_c	--	S_u^c	S	--	--	

Palmer, L. A. and Thompson, J. B., "Pavement Evaluation by Loading Tests at Neval and Marine Corps Air Stations", Proc., HRB, Vol. 27, pp. 125-143 (1947).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, $C_v(T_e)$	N, H	N, H	N, P-C, H	P, A	*	*	S^c	S	--	M_o	

* Many combinations of materials reported.

Papazian, Hratch, "The Response of Linear Viscoelastic Materials in the Frequency Domain With Emphasis on Asphaltic Concrete", Proc., ICSDAP, pp. 454-463 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_v)$	V	--	--	A	--	--	*	--	T_o	—	

* Sinusoidal-stress dynamic tests and constant-stress static tests on laboratory asphaltic concrete test specimens discussed.

Paxson, G. S., "Factors Influencing the Stress in Concrete Pavement from Applied Loads", Proc., HRB, Vol. 25, pp. 59-69 (1938).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	H	W	--	P	N	--	S^r, S^e	I	--	--	

Peattie, K. R., "Stress and Strain Factors for Three-Layer Elastic Systems." Bull. 342, HRB, pp. 215-253 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	H	H	N	N	N	S_c^u	S	--	--	

Peattie, K. R., "A Fundamental Approach to the Design of Flexible Pavements", Proc., ICSDAP, pp. 403-411 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	H	H	A	S_c	N	*, V	S	T_o	--	

*Load is assumed to be applied uniformly over a circular area for the purposes of calculating stresses and displacements; time for which the load is applied to the road is considered.

IV_a. Vibrational tests proposed for determination of layer properties.

Philippe, R. R. and Mellinger, F. M., "Structural Behavior of Heavy-Duty Concrete Airfield Pavements", Proc., HRB, Vol. 31, pp. 87-100 (1952).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
,(T_e)	H	W	W	P	N, S_f	S_f	D_s', D_{twt}	M, S	T_{gr}	--	

Pickett, Gerald, "Stress Distribution in a Loaded Soil With Some Rigid Boundaries", Proc., HRB, Vol. 18, Part II, pp. 35-48 (1938).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	R_f	--	S_f	R	--	S^r S_u^s S_u^c	S	--	--	

Pickett, G. and Ray, G. K., "Influence Charts for Concrete Pavements", Proc., ASCE, Vol. 76, Separate 12 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W, H	--	P	N	--	S^a	I, E	--	--	

Pister, Karl S., and Monismith, Carl L., "Analysis of Viscoelastic Flexible Pavements." Bull. 269, HRB, pp. 1-16 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_v	V	W, --	--	A	N, --	--	*, S^r, **	S	T_o	--	

* Time-dependent load, q(x, t), considered.

** Repeated compressive loading of an unconfined cylinder.

Pister, K. S. and Westmann, R. A., "Analysis of Viscoelastic Pavements Subjected to Moving Loads", Proc., ICSDAP, pp. 522-529 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_v	V	W	--	N	N	--	$D^r(c)$	M, S	T_o	--	

II_a. Analysis concerned with infinite, viscoelastic beam.
III_a. Material properties represented by spring dashpot system.
IV_b. Position specified.

Popov, E. P., "Successive Approximations for Beams on an Elastic Foundation", Proc., ASCE, Vol. 76, Separate 18 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	N	S	--	*	S	--	--	

* Various beam loadings imposed.

Reddy, A. S., Leonards, G. A., Harr, M. E., "Warping Stresses and Deflections in Concrete Pavements: Part III." Highway Research Record No. 44, HRB, pp. 1-24 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_v,	H	V	--	P	N	--	*	S	T	M	

* External forces on slab are gravity and/or a uniformly distributed normal load.
V. Non-linear variations considered.

Schiffman, R. L., "The Numerical Solution for Stresses and Displacements in a Three-Layer Soil System", Proc., Fourth ICSMFE, Vol. II, pp. 169-173 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	H	H	N	N	N	S_u^c	S	--	--	

Schiffman, Robert L., "General Analysis of Stresses and Displacements in Layered Elastic Systems", Proc., ICSDAP, pp. 365-375 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	H	H	N	N	N	*	S	--	--	

* Loads considered are:
(1) General asymmetric system
(2) Flexible
(3) Rigid
(4) Tangential
(5) Slightly inclined, rigid

Schnitter, G. and Jenatsch, R., "Designing Flexible Road Pavements", Proc., ICSDAP, pp. 537-547 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S,	H	--, H	--, H	N	N	N	S^c, *	S	T_o	M_o	

* Design for dynamic situation considered.

Seed, H. B., and Chan, C. K., "Effect of Stress History and Frequency of Stress Application on Deformation of Clay Subgrades Under Repeated Loading." Proc., HRB, Vol. 37, pp. 555-575 (1958).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_{sf}, S_c	--	--	R_t	--	--	M_o	

Seed, H. B., Chan, C. K., Lee, C. E., "Resilience Characteristics of Subgrade Soils and Their Relation to Fatigue Failures in Asphalt Pavements." Proc., ICSDAP, pp. 611-636 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_f, S_{sf}	--	--	R_t, R^c	S	--	M_o	

Seed, H. B., Chan, Clarence K., and Monismith, Carl L., "Effects of Repeated Loading on the Strength and Deformation of Compacted Clay." Proc., HRB, Vol. 34, pp. 541-558 (1955).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	S_{sf}	--	--	R_t	--	--	--	

Skok, Eugene L., Jr., and Finn, Fred N., "Theoretical Concepts Applied to Asphalt Concrete Pavement Design." Proc., ICSDAP, pp. 412-440 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e	H	E	E	A	S_c	N	S^c	S	T_o	--	

I. Elastic theory (three-layers) applied to AASHO and WASHO Road Test data.

Smith, E. B., "Impact and Static Loads on Road Slabs." Proc., HRB, Vol. 4, pp. 42-44 (1924).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	P	N	--	S_s, I	E, C	--	--	

Smith, E. B., "Wheel Load and Impact in Pavement Design." Proc., HRB, Vol. 8, pp. 187-192 (1928).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	P	N	--	S_m,S_s S_d I	S	--	--	

Sowers, George F. and Vesic, Aleksandar, "Vertical Stresses in Subgrades Beneath Statically Loaded Flexible Pavements." Bull. 342, HRB, pp. 90-123 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$, $C_v(T_1^e)$	H, H,	--, H	--, --	A	S_s,S_c S_{ce} A	S_s	S_s, S_d	S	--	M_o	

IV_a. Duals included single axle and tandem axle applications; repetitive application of single tire load also reported.

Spangler, M. G., "Stresses in Concrete Pavement Slabs." Proc., HRB, Vol. 15, pp. 122-146 (1935).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	W	--	P	S_f	--	$S_u{}^c$	C	T_g	--	

Spangler, M. G., "Wheel Load Stress Distribution Through Flexible Type Pavements." Proc., HRB, Vol. 21, pp. 110-117 (1941).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	S_{cf}, S_c	S_{cf}	--	S_s, $S_n{}^c$, S^e	S	--	M_o	

Spangler, M. G., "The Structural Design of Flexible Pavements." Proc., HRB, Vol. 22, pp. 199-219 (1942).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A, S	S	S	S^n, S_s	S	--	M_o	

Spangler, M. G., "Stresses in the Corner Region of Concrete Pavements." Bull. 157, Iowa Engineering Experiment Station, Vol. 41, No. 14 (1942).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E, $C_v(T_e)$	H	W	--	P	S_f	--	S_c	C	T_g		

Spangler, M. G., and Lightburn, F. E., "Stresses in Concrete Pavement Slabs." Proc., HRB, Vol. 17. pp. 215-230 (1937).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E $C_v(T_e)$	E	E, W	--	P	S_f	--	S^c $S_s{}^r$ $S_d{}^r$	C	T_g	M_g	

Spangler, M. G., and Ustrud, H. O., "Wheel Load Stress Distribution Through Flexible Type Pavements." Proc., HRB, Vol. 20, pp. 235-257 (1940).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	S_c, S_{cf}	S_f	S_c	S_s	S	--	--	

Stratton, J. H., "Military Airfields; A Symposium - Construction and Design Problems." Trans., ASCE, Vol. 110, pp. 669-696 (1945).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Corps of Engineers airfield pavement design procedures.

Subbaraju, Bh., "Model Study of Stresses in Asphalt Pavements." Proc., ICSDAP, pp. 324-331 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	A	S_s	--	*	S	--	--	

* Load applied to the model asphalt slab through a small, hard rubber wheel (vertical or inclined) or through the wheel resting on a small, circular steel bearing plate.

Teller, L. W., "Effects of Loads on Pavements as Indicated by Stress Measurements." Proc., HRB. Vol. 7, pp. 172-175 (1927).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	--	P	S	--	D_t, S_s, I	I, E C M	--	--	

Teller, L. W. and Buchanan, J. A., "Determination of Variation in Unit Pressure Over the Contact Area of Tires." Public Roads, Vol. 18, December 1937, pp. 195-198.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	--	--	*	--	--	S_s	S	--	--	

* Tire loaded while resting on a brass bar which in turn rests on a steel plate.

Teller, L. W., and Sutherland, Earl C., "The Structural Design of Concrete Pavements, Parts 1, 2, 3, 4, and 5." Public Roads, Vols. 16, 17, 23 (October, November, December, 1935, October 1936, April, May, June, 1943.)

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	W	--	P	S_f	--	S^c, S^{sc}	C I E	T, T_o	M, M_o	

Thompson, William E., "Analysis of Dynamic Behavior of Roads Subject to Longitudinally Moving Loads." Highway Research Record No. 39, HRB, pp. 1-24 (1963).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e, T_v	H, V	E	--	N	N	--	$D^r(c)$	S, M	--	--	

Tschebotarioff, G. P., and McAlpin, G. W., "Vibratory and Slow Repetitional Loading of Soils." Proc., HRB, Vol. 26, pp. 551-562 (1946).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	N	--	--	S_c, S_f	--	--	PP, V	S	--	--	

Turnbull, W. J., "Mathematical Expression of the CBR (California Bearing Ratio)." Proc., Fourth ICSMFE, Vol. II, pp. 178-180 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	N	N	N	N	N	N	$S_s{}^c$	S	--	--	

Van der Veen, C., "Loading Tests on Concrete Slabs at Schiphol Airport." Proc., Third ICSMFE, Vol. II, pp. 133-142 (1953).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$C_v(T_e)$	H	H, W	H	P, P_{ps}	S_c	S_f	R^c	I E C	--	--	

Van der Veen, C., "Loading Tests on the Airfield at Beck." Proc., Fourth ICSMFE, Vol. II, pp. 186-188 (1957).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
E	N	N	N	A	R	S	S_r^c	S	--	M_o	

Walker, R. D., Yoder, E. J., Spencer, W. T., and Lowry, R., "Significance of Layer Deflection Measurements." Bull. 321, HRB, pp. 63-81 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
$_v(T_e)$	H	--	--	A	S_c	S_f	S_d^c	S	--	--	

Westergaard, H. M., "Computation of Stresses in Concrete Roads." Proc., HRB, Vol. 5, Part I, pp. 90-112 (1925).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	S_s^c S_u^{sc} S_{II}	I, E, C	--	--	

Westergaard, H. M., "Analysis of Stresses in Concrete Pavements due to Variations in Temperature." Proc., HRB, Vol. 6, pp. 201-215 (1926).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	*	--	T	--	

* No external loads considered in analysis.

Westergaard, H. M., "Stresses in Concrete Pavements Computed by Theoretical Analysis." Public Roads, Vol. 7, April 1926, pp. 25-35.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	S^r,S_u^c S_u^{sc},S_s^c S_d^c	I, E, C	--	--	

Westergaard, H. M., "What is Known of Stress." Engineering News Record, Vol. 18, January 7, 1937, pp. 26-29.

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e S T_{sm}	H	W	--	P	N	--	S^r S_u^{sc} S_u^c	C, I	T_o	--	

Westergaard, H. M., "Stresses in Concrete Runways of Airports." Proc., HRB, Vol. 19, pp. 197-205 (1939).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	S_u^c	I	--	--	

Westergaard, H. M., "Stress Concentrations in Plates Loaded Over Small Areas." Trans., ASCE, Vol. 108, pp. 830-886 (1943).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	--, W	--	N, P	N	--	S^n, S_d^e, *	I	--	--	

* Coefficients determined for loaded areas of various geometric shapes (circles, strips, ellipse, triangle, polygon).

Westergaard, H. M., "New Formulas for Stresses in Concrete Pavements of Airfields." Trans., ASCE, Vol. 113, pp. 425-444 (1948)

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_e	H	W	--	P	N	--	S_s^e S_d S^a	I, E	--	--	

Whiffin, A. C., and Lister, N. W., "The Application of Elastic Theory to Flexible Pavements." Proc., ICSDAP, pp. 499-521 (1962).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e, $C_v(T_1^e)$	H	H	H	A	*	*	S_u^c, D_t	S, M	T_o	--	

III_a. Tar surface also considered.

* Various materials considered.

Wilson, G., and Williams, G. M. J., "Pavement Bearing Capacity Computed by Theory of Layered Systems." Proc., ASCE, Vol. 76, Separate 16, pp. 1-17 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
T_1^e, S	H	H, P-C	--	A, P	S_c, S_f	--	S_u^c	S	--	--	

Woods, K. B., "Influence of Heavy Loads on Pavement Design Trends." Proc., ASCE, Vol. 76, Separate 23, pp. 1-18 (1950).

I	II			III			IV		V		VI
	A	B	C	A	B	C	A	B	A	B	
S											

Paper contains large bibliography.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Highway Research Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

NCHRP Report No.	*Title*
—*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Project 4-3(2)) 81 pp. $1.80
1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Project 6-8) 56 pp. $2.80
2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Project 1-1) 19 pp. $1.80
2A	Guidelines for Satellite Studies of Pavement Performance 85 pp.+ 9 figs., 26 tables, 4 app. $3.00
3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Project 3-5) 36 pp. $1.60
4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Project 6-2) 74 pp. $3.20
5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Project 10-3) 48 pp. $2.00
6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Project 3-4) 56 pp. $3.20
7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Project 1-2) 29 pp. $1.80
8	Synthetic Aggregates for Highway Construction (Project 4-4) 13 pp. $1.00
9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Project 3-2) 28 pp. $1.60
10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Project 1-4) 31 pp. $2.80
11	Effect of Control Devices on Traffic Operations—Interim Report (Project 3-6) 107 pp. $5.80
12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Project 4-3(1)) 47 pp. $3.00
13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Project 2-5) 43 pp. $2.80
14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Project 10-5) 32 pp. $3.00
15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Project 4-3(2)) 66 pp. $4.00
16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Project 6-3) 21 pp. $1.60
17	Development of Guidelines for Practical and Realistic Construction Specifications (Project 10-1) 109 pp. $6.00
18	Community Consequences of Highway Improvement (Project 2-2) 37 pp. $2.80
19	Economical and Effective Deicing Agents for Use on Highway Structures (Project 6-1) 19 pp. $1.20
20	Economic Study of Roadway Lighting (Project 5-4) 77 pp. $3.20
21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Project 1-5) 30 pp. $1.40
22	Factors Influencing Flexible Pavement Performance (Project 1-3(2)) 69 pp. $2.60
23	Methods for Reducing Corrosion of Reinforcing Steel (Project 6-4) 22 pp. $1.40
24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Project 7-1) 116 pp. $5.20
25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Project 10-7) 48 pp. $2.00
26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Project 13-1) 33 pp. $1.60
27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Project 6-5) 41 pp. $2.00
28	Surveillance Methods and Ways and Means of Communicating with Drivers (Project 3-2) 66 pp. $2.60
29	Digital-Computer-Controlled Traffic Signal System for a Small City (Project 3-2) 82 pp. $4.00
30	Extension of AASHO Road Test Performance Concepts (Project 1-4(2)) 33 pp. $1.60

---

* Highway Research Board Special Report 80.

THE NATIONAL ACADEMY OF SCIENCES is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by President Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its Congressional charter, the Academy is also called upon to act as an official—yet independent—adviser to the Federal Government in any matter of science and technology. 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 and its activities are not limited to those on behalf of the Government.

THE NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

THE NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U. S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

THE DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

THE HIGHWAY RESEARCH BOARD, organized November 11, 1920, as an agency of the Division of Engineering, is a cooperative organization of the highway technologists of America operating under the auspices of the National Research 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.

Isada, Nelson M.
Detecting variations in load-capacity of flexible pavements.
N.C.H.R.P. Report 21.
NRC pub. 1220.

Isada, Nelson M.

Detecting variations in load-capacity of flexible pavements.

N.C.H.R.P. Report 21.

NRC pub. 1220.