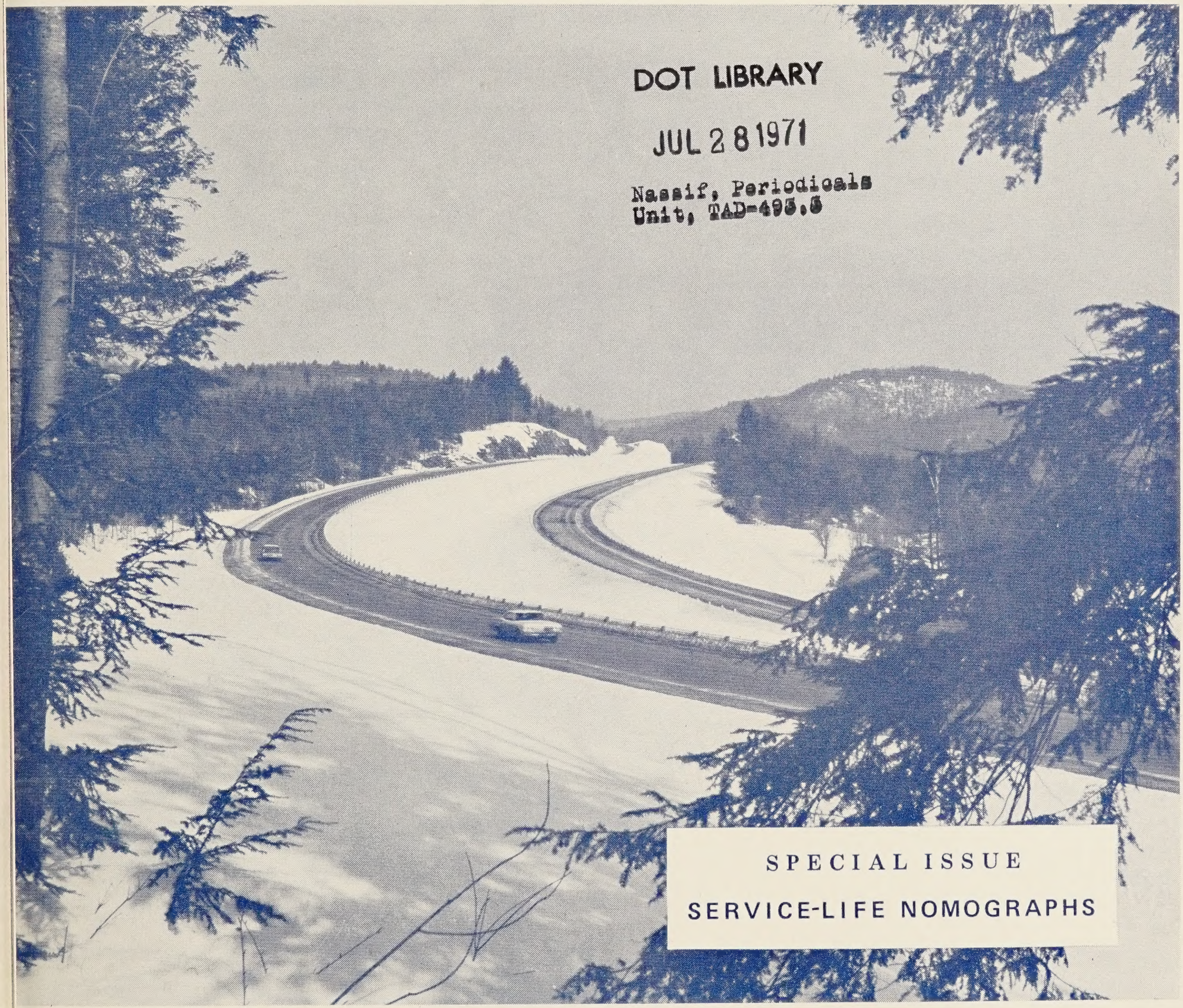
Vol. 36/No. 5 December 1970

Public Roads

A JOURNAL OF HIGHWAY RESEARCH



SPECIAL ISSUE

SERVICE-LIFE NOMOGRAPHS

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

Published Bimonthly

Harry C. Secrest, *Managing Editor* ● Fran Faulkner, *Editor*

December 1970/Vol. 36, No. 5

U.S. DEPARTMENT OF TRANSPORTATION
JOHN A. VOLPE, Secretary
FEDERAL HIGHWAY ADMINISTRATION
F. C. TURNER, Administrator

CONTENTS

A System for Estimating Present Surface Condition and Remaining Service Life of Existing Pavement Sections, by Ivano E. Corvi and Bill G. Bullard 93

Publications

Highway Research and Development Reports Available From National Technical Information Service 119

Federal Highway Administration publications .... Inside back cover

Map

National System of Interstate and Defense Highways—Status of System Mileage, September 1970 120

COVER

Adirondack Northway, Interstate Highway 87, Warren County, N.Y. (Photo courtesy of New York Department of Transportation.)

FEDERAL HIGHWAY ADMINISTRATION
U.S. DEPARTMENT OF TRANSPORTATION
Washington, D.C. 20591

FHWA REGIONAL OFFICES

No. 1. 4 Normanskill Blvd., Delmar, N.Y. 12054.
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont, and Puerto Rico.
No. 2. 1633 Federal Building, 31 Hopkins Place, Baltimore, Md. 21201.
Delaware, District of Columbia, Maryland, Ohio, Pennsylvania, Virginia, and West Virginia.
No. 3. 1720 Peachtree Rd., N.W., Atlanta, Ga. 30309.
Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee.
No. 4. 18209 Dixie Highway, Homewood, Ill. 60430.
Illinois, Indiana, Kentucky, Michigan, and Wisconsin.
No. 5 6301 Rockhill Road, Kansas City, Mo. 64131
Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota.
No. 6. 819 Taylor St., Fort Worth, Tex. 76102.
Arkansas, Louisiana, Oklahoma and Texas.
No. 7. 450 Golden Gate Ave., Box 36096, San Francisco, Calif. 94102.
Arizona, California, Hawaii, and Nevada.
No. 8. 412 Mohawk Bldg., 222 SW. Morrison St., Portland, Oreg. 97204.
Alaska, Idaho, Montana, Oregon, and Washington.
No. 9. Denver Federal Center, Bldg. 40, Denver, Colo. 80225.
Colorado, New Mexico, Utah, and Wyoming.
No. 15. 1000 N. Glebe Rd., Arlington, Va. 22201.
Eastern Federal Highway Projects
No. 19. Apartado Q, San Jose, Costa Rica.
Inter-American Highway: Costa Rica, Guatemala, Nicaragua, and Panama.

Public Roads, A Journal of Highway Research, is sold by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402, at $2.00 per year (50 cents additional for foreign mailing) or 40 cents per single copy. Subscriptions are available for 1-, 2-, or 3-year periods. Free distribution is limited to public officials actually engaged in planning or constructing highways and to instructors of highway engineering. There are no vacancies in the free list at present.
Use of funds for printing this publication has been approved by the Director of the Bureau of the Budget, March 16, 1966.

A System for Estimating Present Surface Condition and Remaining Service Life of Existing Pavement Sections

BY THE OFFICE OF
HIGHWAY PLANNING

**Reported by IVANO E. CORVI, Highway Research Engineer, and
BILL G. BULLARD, Chief, Highway Investments Branch
Statewide Highway Planning Division**

Those concerned with the condition of highway surfaces and how long pavements will last before they need resurfacing will be interested in the system presented here for estimating present surface condition and remaining service life of existing highway pavements. The authors used findings from the AASHO Road Test at Ottawa, Ill., to develop the system which features a set of nomographs to speed up calculations. The procedure, based on the serviceability–performance concept established in the Road Test, is intended to minimize subjective judgment, commonly termed "the human factor" in evaluations of pavement condition and in estimates of remaining service life.

The authors review the pertinent research findings from the AASHO Road Test, which, in addition to the pavement serviceability–performance concept, include pavement performance equations and an equivalent axle-load concept. Proceeding from concept to practical method they then outline requirements for developing a system and describe use of the service-life nomographs.

Introduction

DURING the last 20 years, several National and statewide highway studies—classi- cation, needs, and fiscal—have been con- ucted in an attempt to provide solutions to he physical and financial needs of the highway etwork. Unfortunately, it has been shown y these studies that existing highway-user evenues are inadequate and have failed to vercome the backlog and accruing physical eficiencies resulting from increased travel nd heavy axle-load demands. Consequently, ghway administrators are constantly search- g for better priority techniques to schedule ghway improvements that will be responsive the public's most urgent needs.

This report, directed at one aspect of the ghway needs appraisal process, is concerned ith a procedure for estimating present urface condition and remaining service life highway pavements—a procedure that so may be useful in priority programing of avement resurfacing projects. Past planning ocedures for determining pavement con- tion and remaining life have been based rgely on judgment. Because evaluations by vo people are subject to variance, the human ctor should be minimized in the procedures. he AASHO Road Test produced refined gineering equipment and techniques that, ry definitely, can be applied to highway anning activities. The practical system esented here for estimating the present rface condition and remaining service life existing highway pavement sections is sed on the pavement serviceability-per- rmance concept established in the AASHO oad Test.

The AASHO Road Test, conceived and onsored by the American Association of ate Highway Officials, was a study of the rformance of highway pavement structures known thickness under moving loads of own magnitude and frequency. It did not ovide for the study of grades, alinement, rface texture, or other such characteristics d the test was said to be a study of the vement rather than of the highway. Essential pavement research findings from the test included a pavement serviceability-performance concept, pavement performance equations, and an equivalent axle-load concept.

Based on results of the AASHO Road Test, the AASHO Committee on Design developed interim guides for the design of rigid and flexible pavement structures, which include a set of design nomographs that apply not only to conditions similar to those at the Road Test, but to other conditions as well.

Pavement Serviceability–Performance Concept

From the AASHO Road Test came definitions (*1, 2, 3*)[1] that provide the basis on which the conditions and performance of existing pavement sections can be evaluated. To fulfill the requirements of the AASHO Road Test, rather ordinary terms were given specific definitions, as follows:

Present serviceability.—The ability of a specific section of pavement in its existing condition to serve high-speed, high-volume, mixed (truck and automobile) traffic. This definition applies only to the existing condition at the time of rating—*not to the assumed condition the next day or at any future or past date.*

Present serviceability rating (PSR).—The present serviceability of a specific section of roadway made by marking the appropriate point on a scale as shown in figure 1a. For the Road Test application, the rater was instructed to exclude from consideration all features not relative to the pavement itself—right-of-way width, grade, alinement, shoulder, ditch condition, etc.

PSR was the mean of the individual ratings made by members of a specific panel selected by the Highway Research Board. This panel, intended to represent all highway users, included experienced men, long associated with highways, who represented a wide variety of interests, such as highway administration, highway maintenance, a Federal highway agency, highway materials supply (cement and asphalt), trucking, highway education, automotive manufacture, highway design, and highway research.

Present serviceability index (PSI).—A mathematical combination of values obtained from certain physical measurements of a large number of pavements, formulated to predict the PSR of those pavements within prescribed limits.

The Road Test staff developed two equations, one for flexible pavement and one for rigid pavement, that enabled physical measurements related to the condition of the pavement surface to be combined to produce a

---

[1] Italic numbers in parentheses identify references listed on p. 106.

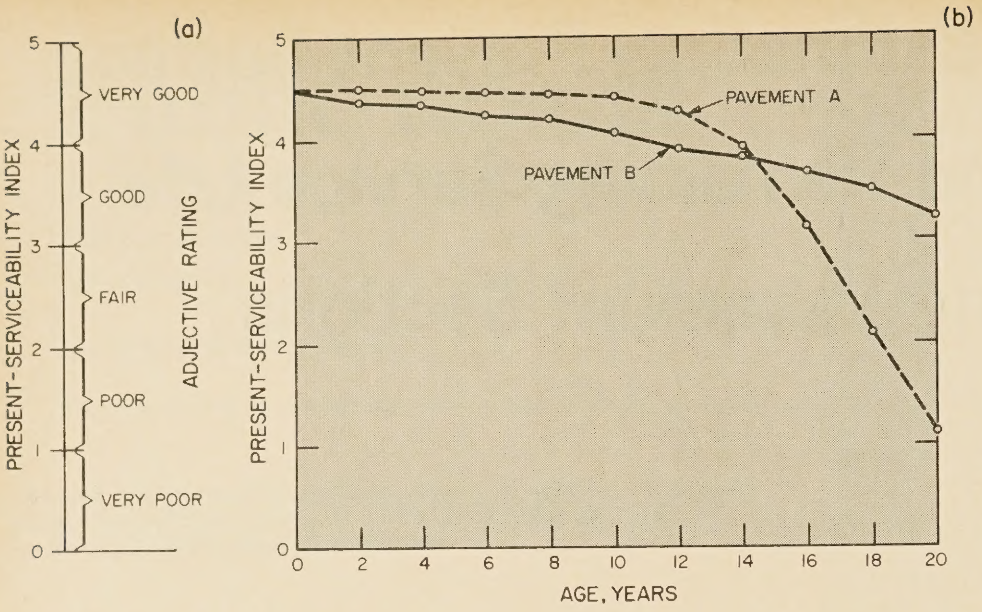


Figure 1.—Serviceability-performance concept—(a) rating form, (b) serviceability-performance history.

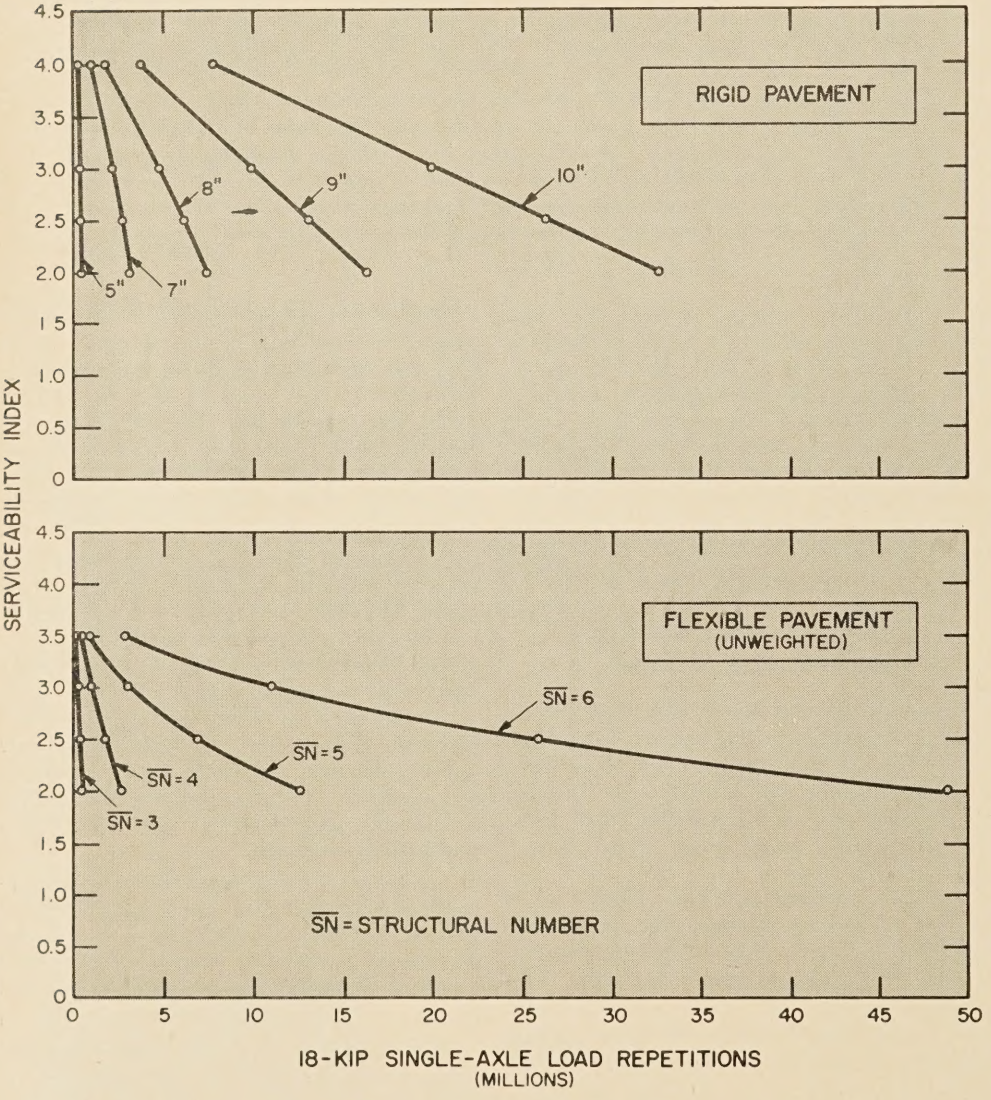


Figure 2.—Relation among serviceability index, structural thickness, and 18-kip axle-load repetitions.

PSI corresponding to the average determinations made by the rating panel.

The formula for *rigid pavements* is

$$PSI=5.41-1.80 \log (1+\overline{SV})-0.09\sqrt{\overline{C}+\overline{P}}$$

Where,

$\overline{C}$ is the length of substantial cracking, whether sealed or not, and is expressed in lineal feet of projected length per 1,000 square feet of pavement area.

$\overline{P}$ is the area of patches expressed as square feet per 1,000 square feet of pavement surface.

$\overline{SV}$ is the slope variance and is an indication of wheel path roughness as measured by the Road Test Longitudinal Profilometer. For the wheel path the profilometer produces a continuous record of pavement slope sensed by wheels 9 inches apart that take measurements in 6-inch increments.

The formula for *flexible pavements* is

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

Where,

$\overline{C}$ is the sum of the area affected by class 2 and 3 cracking expressed in square feet per 1,000 square feet of pavement.

$\overline{RD}$ is the average rut depth in inches.

$\overline{P}$ and $\overline{SV}$ are the same as for rigid pavements.

The rut depth was determined by measuring between the point of maximum vertical displacement on the pavement wheel path and the midpoint of a 4-foot straight edge placed transversely on the pavement. These measurements were taken at 25-foot intervals in both wheel paths.

More recent research (*4*) provides quantitative comparisons between the procedure described above and other procedures o pavement condition evaluation.

Performance history.—A record of th pavement's serviceability ratings or indices against time or accumulated axle-load applications. Performance history can be considered summary of the ability of a pavement section to serve traffic from the day of completed construction to any given day of analysis. A example of performance history is illustrated in figure 1b.

AASHO Road Test Performance Equations

The following equations were developed a the AASHO Road Test to estimate performance of pavements in terms of the number o axle-load applications:

$$\log W_t=\log \rho+\frac{G_t}{\beta}$$

Where,

W_t=number of applications to time t.

G_t=a function, the logarithm, of the ratio o the loss in serviceability at time t t the total potential loss taken to th point at which the pavement wa removed from test (PSI=1.5).

ρ=a function of design variables and loa variables that denotes the expecte number of axle-load applications to serviceability index of 1.5.

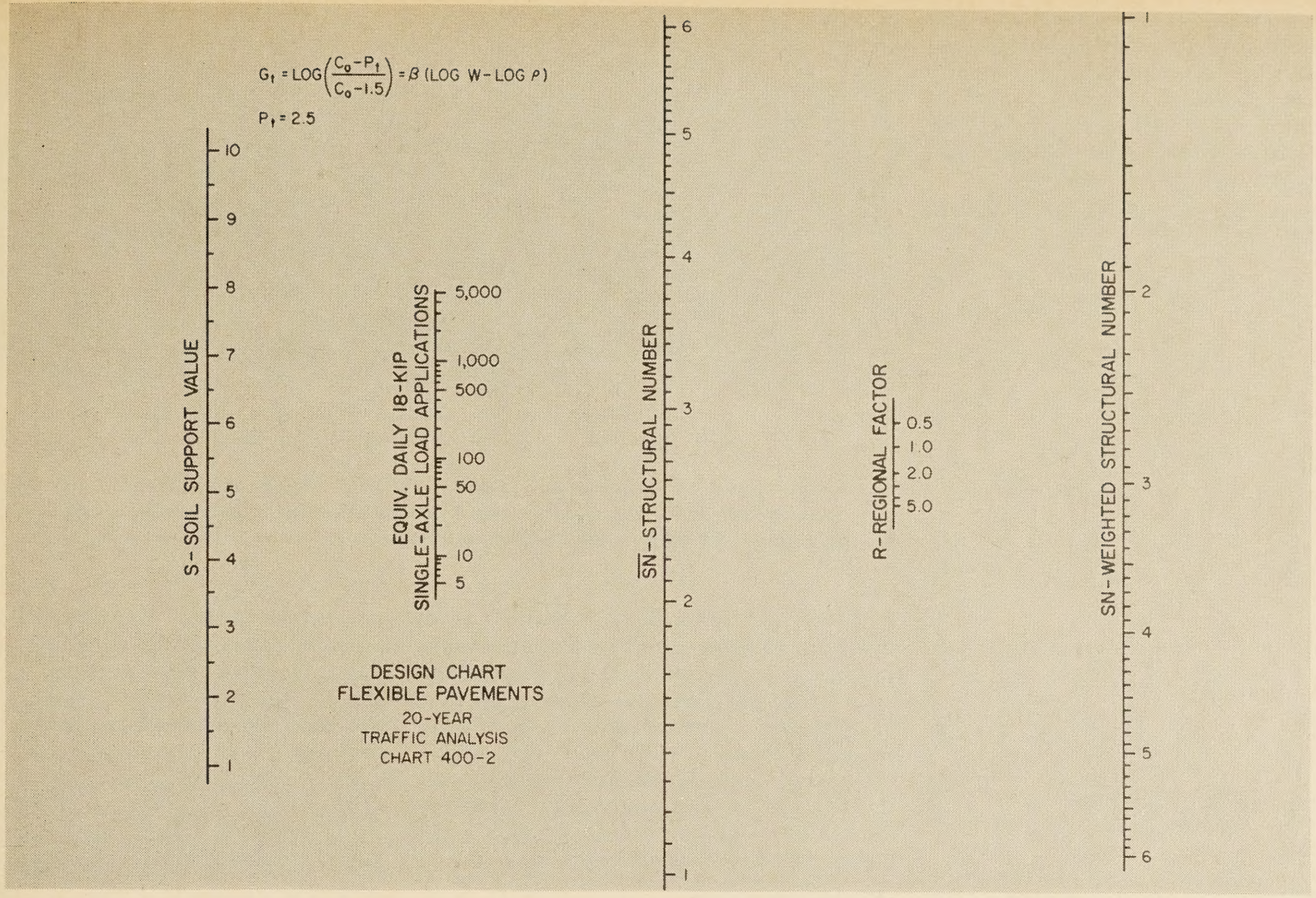


Figure 3.—Flexible-pavement design chart.

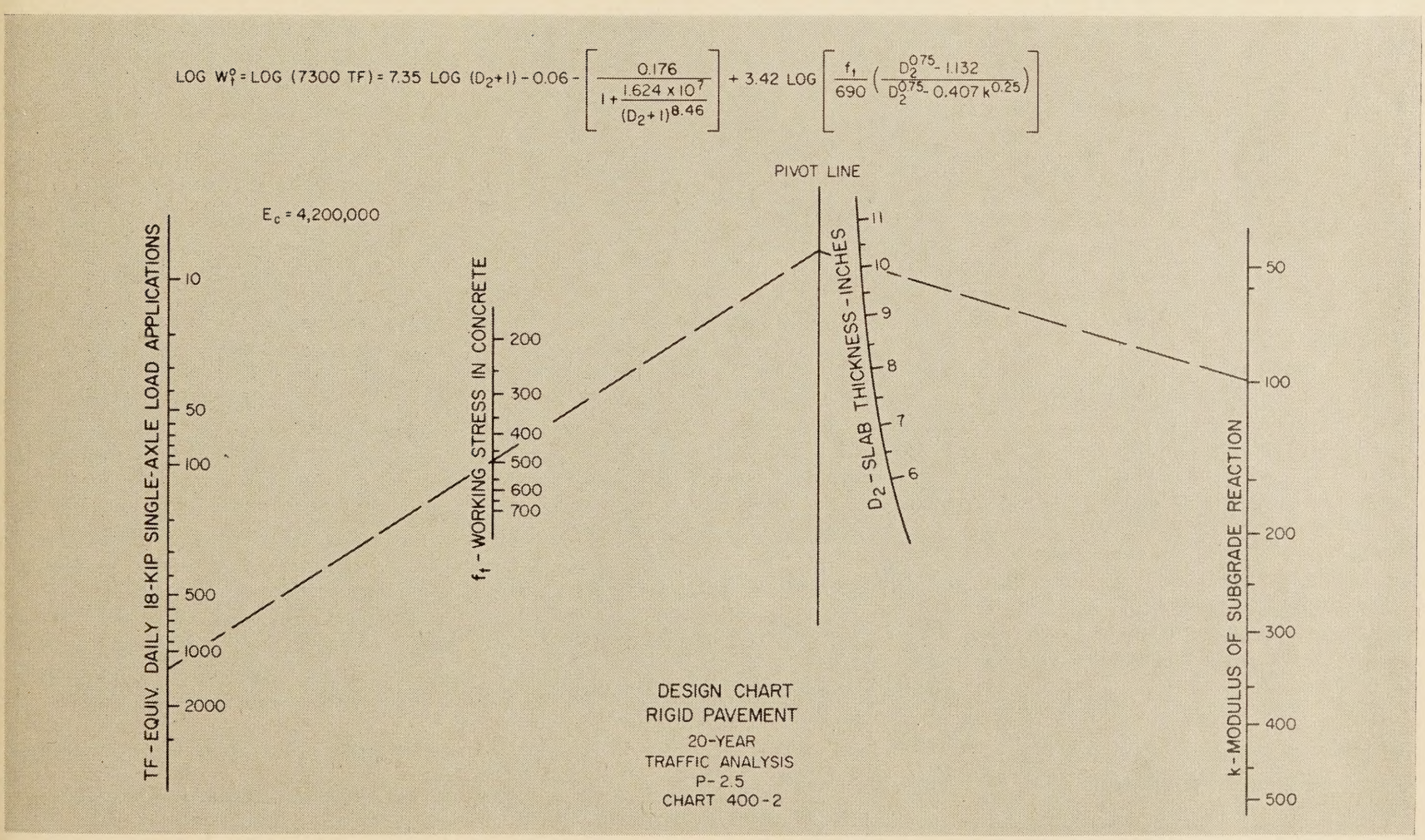


Figure 4.—Rigid-pavement design chart.

β= a function of design variables and load variables that influences the shape of the ρ versus W serviceability curve for a pavement.

Separate expressions of G_t, ρ, and β were developed at the Road Test for rigid and flexible pavement types, respectively.

Rigid pavements.—The following expressions apply to rigid pavements:

$$G_t = \log\left(\frac{4.5-P_t}{4.5-1.5}\right) = \log\left(\frac{4.5-P_t}{3.0}\right)$$

Where,

P_t=the present serviceability index at time t.

$$\log \rho = 5.85 + 7.35 \log (D_2+1) - 4.62 \log (L_1+L_2) + 3.28 \log L_2$$

$$\beta = 1.00 + \frac{3.63(L_1+L_2)^{5.20}}{(D_2+1)^{8.46}\, L_2^{3.52}}$$

Where,

D_2+1=design term.

D_2=portland cement concrete slab thickness in inches.

L_1=load in kips on one single axle or on one tandem-axle set.

L_2=relates to the axle configuration:

$L_2=1$ for single axles

$L_2=2$ for tandem axles

Flexible pavements.—For flexible pavements on the subgrade soil at the Road Test, the expressions for G_t, ρ and β for weighted axle-load application are:

$$G_t = \log\left(\frac{4.2-P_t}{4.2-1.5}\right) = \log\left(\frac{4.2-P_t}{2.7}\right)$$

Where,

P_t=the present serviceability index at time t.

$$\log \rho = 5.93 + 9.36 \log (\overline{SN}+1) - 4.79 \log (L_1+L_2) + 4.33 \log L_2$$

$$\beta = 0.40 + \frac{0.081(L_1+L_2)^{3.23}}{(\overline{SN}+1)^{5.19} L_2^{3.23}}$$

Where,

$\overline{SN}+1$=design term.

$\overline{SN}=a_1D_1+a_2D_2+a_3D_3$.

D_1=asphaltic surface thickness in inches.

D_2=base thickness in inches.

D_3=subbase thickness in inches.

a_1, a_2, and a_3 vary with the type of material.

L_1 and L_2 are the same as defined for rigid pavement.

The AASHO Road Test equations are illustrated graphically in figure 2, in which it is shown that only one performance curve can be developed for each pavement-thickness index.

Modifications by the AASHO Committee on Design

The Interim Guides (*5, 6*) developed by the AASHO Committee on Design for the design of both rigid and flexible pavements were based on conditions at the AASHO Road Test. But because conditions differ from area to area, nomographs like those in figures 3 and 4 for flexible and rigid pavements, respectively, make the design procedure applicable to other conditions as well.

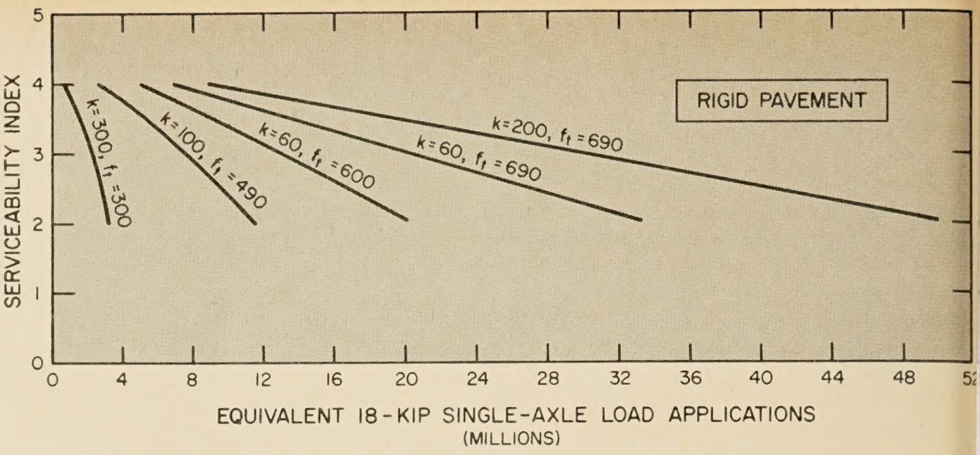


Figure 5.—Relation among serviceability index; 18-kip single-axle load applications working stress in concrete, f_t; and modulus of subgrade reaction, k, for a selecte pavement thickness-slab thickness, D,=10 in.

Following, first for flexible pavement and then for rigid pavement, are excerpts from the AASHO Interim Guide, which list the limitations of the nomographs.

Flexible pavement

- "It has been necessary to assume a scale for the soil support value on Charts 400–1 and 400–2. Point 3.0 on the scale represents the silty clay roadbed soils on the Road Test. It is a firm and valid point. Point 10.0 represents crushed rock base material such as used on the Road Test. It is a reasonable valid point. All other points on the scale are assumed."
- "The soil support scale must be correlated with test data obtained by one of several methods. The user must develop this correlation based on the specific soil test method he is using. General correlations are given in Appendix E[2] as a possible guide in developing the proper scales."
- "Coefficients for converting the thicknesses of surface, base, or subbase to the structural number ($\overline{SN}$) are given on page 22 of the guide. Careful consideration must be given by the user to those cofficients not established in the Road Test."
- "Included in the design analysis is a regional factor which permits adjustments for environmental conditions. The user must give careful consideration to this factor. A method of estimating the factor is given in Appendix G[2]."
- "A traffic analysis period of 20 years has been used for the sake of convenience. It must not be confused with pavement life, which is affected by many factors in addition to traffic loading."

Rigid pavement

- "The scales on Charts 400–1 and 400–2 for working stress in concrete (f_t) and modulus of subgrade reaction (k) are derived from th Spangler modifications of the Westergaar theory of stress distribution in rigid slabs Further research will be required to full establish the applicability of the Spangle equation."
- "A working stress of 0.75 S_c has bee used in the guide. Further research ma indicate some adjustment in the percentage i required. The user may make such an adjustment based on experience."
- "An adjustment for environmental conditions has not been included in the desig procedure. The need for such a factor ca only be established by studies over a lon time period."
- "A traffic analysis period of 20 years ha been used for the sake of convenience. must not be confused with pavement lif which is affected by many factors in additio to traffic loading."

Basic significance of modifications

The basic significance of the modificatio of the AASHO Road Test equations by t AASHO Committee on Design is illustrate graphically in figures 5 and 6. Unlike figure which showed only one performance curve f each pavement-thickness index, figures 5 a 6 show a family of curves for each pavemen thickness index. The authors were able develop the curves from the assumptions a theory used to develop the AASHO desi nomographs. Thus, although the AASH Committee did not develop a family performance curves for each pavemen thickness index, it implicitly expanded t range of performance curves from the re tively small number that applied to conditio at the AASHO Road Test to a relative large number that apply also to conditio encountered elsewhere.

Equivalent Axle-Load Concept

The general performance equations veloped at the AASHO Road Test are sing axle-load equations that describe the behavi of pavements subjected to repeated applic

---

[2] AASHO Interim Guide.

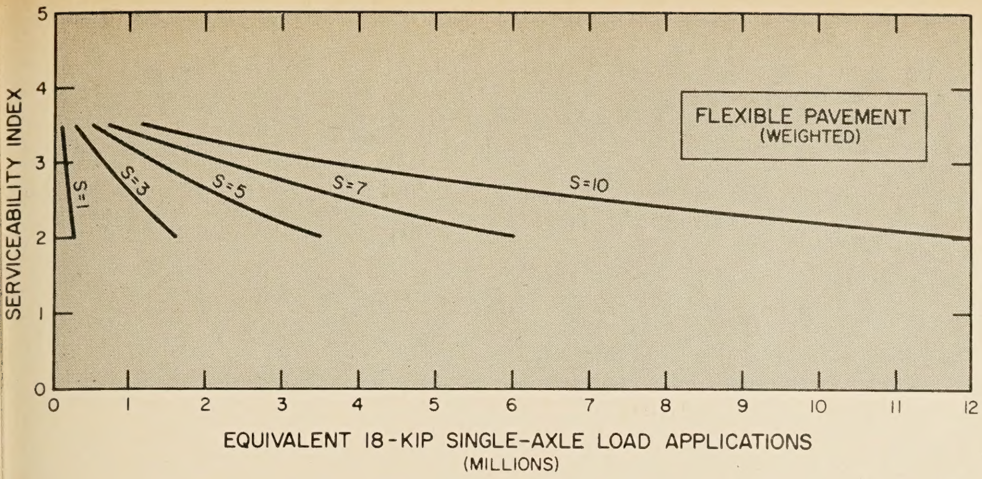


Figure 6.—Relation among serviceability index, 18-kip single-axle load applications, and soil support values for a selected structural number—$\overline{SN}=4.0$.

ions of axle loads of any one type and weight. They do not directly yield information on the ehavior of pavements subjected to mixed raffic—normal highway traffic that imposes oads from both single and tandem axles and variety of weights. Because most States have legal load limit of 18-kips for single-axle oads and 32-kips for tandem-axle loads, the erformance equations are usually resolved nto the equivalent number of 18-kip single-xle loads.

To apply the AASHO Road Test pavement performance equations to practical pavement-structure design, a method was needed to reduce single- and tandem-axle loads of mixed traffic into equivalent 18-kip single-axle loads. The AASHO Committee on Design developed a method for computing, from the performance equations, 18-kip equivalency factors that reduce the loads of mixed axles of various weights in a given traffic volume to an equivalent number of 18-kip single-axle load applications. This equivalent axle-load concept for a flexible pavement at a level of PSI=2.5 and $\overline{SN}=5$ is illustrated graphically in figure 7, which shows the relation between the 18-kip equivalency factors and variable axle-loads for both single and tandem axles.

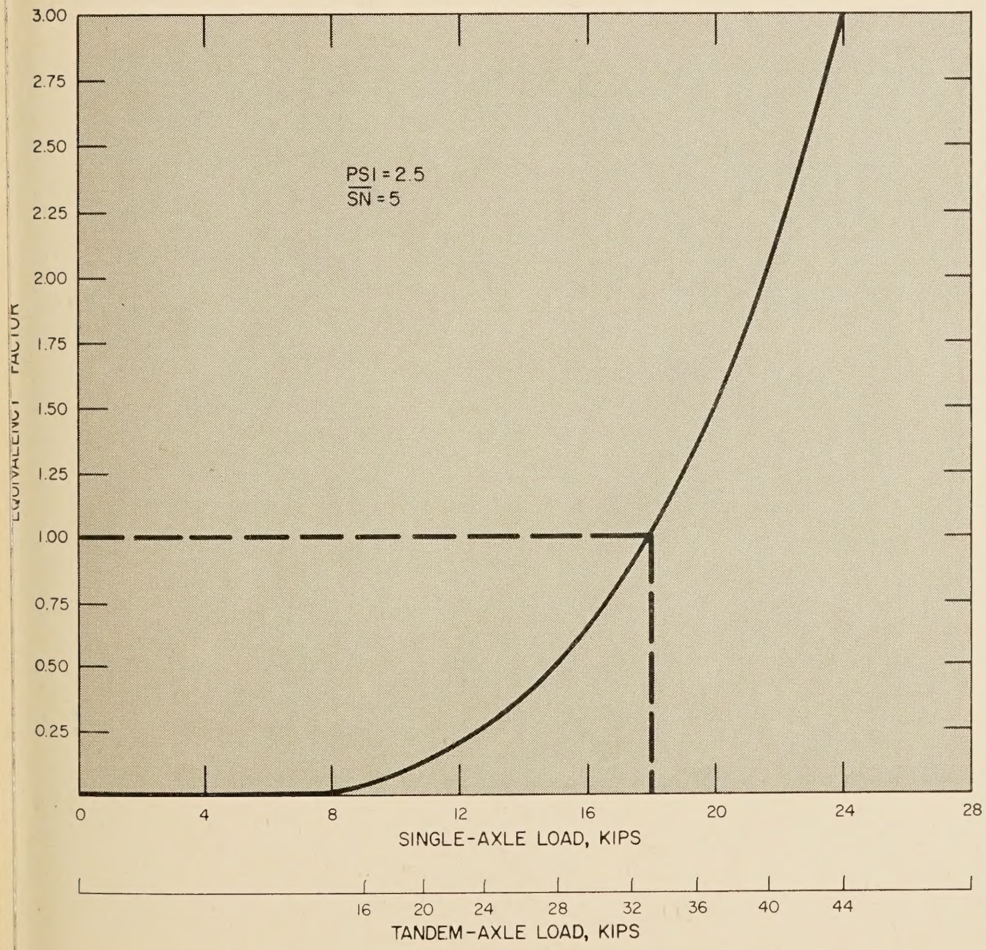


Figure 7.—Equivalent single-axle load concept.

For pavement design, the AASHO Committee on Design developed equivalency factors at terminal serviceability levels of 2.0 and 2.5 for structural numbers ($\overline{SN}$) ranging from 1.0 to 6.0 and for slab thicknesses ($\overline{D}$) ranging from 6 to 11 inches.

From Concept to Practical Method

The conceptual approach described here for estimating the remaining service life of existing pavement sections is firmly based on the findings from the AASHO Road Test. The method presented for applying the conceptual approach incorporates the practical modifications of the AASHO Committee on Design.

Conceptual approach

According to the equations developed at the AASHO Road Test, pavement performance is directly related to pavement design and axle loads. Consequently, these equations can be used to estimate the following values when the pavement design $\overline{SN}$ or $\overline{D}$ is given:

ELA_P.—The equivalent 18-kip single-axle load applications associated with a present-serviceability index.

ELA_T.—The equivalent 18-kip single-axle load applications associated with a selected terminal-serviceability level.

ELA_R.—The remaining equivalent 18-kip single-axle load applications associated with the present-serviceability index, PSI, and selected terminal-serviceability level, TSI.

This statement is shown in its simplest form, by the following equation:

$$ELA_T - ELA_P = ELA_R$$

Where,

ELA_P=The accumulated number of equivalent 18-kip single-axle load applications from the time that the pavement was opened to traffic to the present time.

ELA_T=The accumulated number of equivalent 18-kip single-axle load applications from the time that the pavement is placed in service to the time that it requires resurfacing or reconstruction.

ELA_R=The accumulated number of equivalent 18-kip single-axle load applications remaining before the pavement requires resurfacing or reconstruction.

The concept described above is illustrated in figure 8. The curve represents the performance of a specific pavement design at the AASHO Road Test. A family of curves can be developed, each of which represents one pavement design for either flexible or rigid pavement. If $\overline{SN}$, PSI, and TSI are given, the remaining service life in equivalent 18-kip single-axle load applications can be extracted from the appropriate curve.

The remaining years of service life can be estimated by dividing the $\mathrm{ELA_R}$ by the present annual equivalent 18-kip single-axle load applications, EALA. Practical methods for estimating the $\mathrm{ELA_R}$ and EALA are discussed later.

A method of application

If the general conditions in the various States were the same as those at the AASHO Road Test, the conceptual approach would be relatively simple to apply. But conditions vary significantly not only from State to State, but also from region to region within the States. Consequently, the conceptual approach must be modified to reflect the effect of conditions—pavement materials, climate, subgrade soils, and construction procedures—that are different from those at the AASHO Road Test.

Because the design nomographs in the AASHO Committee's interim guide reflected conditions other than those at the AASHO Road Test as well as conditions at the Test, they implicitly recognized a large number of performance curves that could fit a wide range of conditions. These nomographs, with modifications, provide a practical solution to two difficult tasks:

- Selecting a performance curve that reasonably represents the actual performance curve of a specific pavement section.
- Estimating the remaining life of the pavement section based on the selected curve.

The design nomographs were developed for terminal serviceability levels of 2.0 and 2.5, and the equivalent 18-kip axle loads were expressed in terms of a 20-year design period. However, for this report, *service life nomographs* were developed for various levels of serviceability from 4.0 to 2.0 for rigid pavements and from 3.8 to 2.0 for flexible pavements. The equivalent 18-kip single-axle load applications for the service life nomographs were expressed without reference to a time period. With these exceptions and one other modification, which will be discussed later, the nomographs were developed on the basis of the procedures suggested by the AASHO Committee on Design. The complete set of service life nomographs and a brief description of their development is given in the last part of this article.

In the discussion that follows, a method to select a performance curve and estimate pavement life using the service life nomographs is described, first for flexible pavements and then for rigid pavements. With the exception of slab thickness, D, for rigid pavements, both methods require the following basic input data:

- Present-serviceability rating or index.
- Accumulated equivalent 18-kip single-axle load applications.
- Selected terminal-serviceability level.

Flexible pavements.—The method for flexible pavements is described by using an example in which the following input data are given:

$$\mathrm{PSI}=3.5$$
$$\mathrm{ELA_P}=1{,}000{,}000$$
$$\mathrm{TSI}=2.5$$

The first step is to select a performance curve from the appropriate service life nomograph based on the given PSI and $\mathrm{ELA_P}$, as follows (refer to fig. 9):

(1) Locate the point on the traffic load scale where $\mathrm{ELA_P}=1{,}000{,}000$.

(2) Using a straight edge, connect this point and a point on the structural number scale for an assumed $\overline{SN}$ (in the example, the assumed $\overline{SN}=2.85$).

(3) Locate the point on the soil support scale intersected by the straight edge. This point, $S=30$, is an equivalent S that, together with the assumed $\overline{SN}$, describes a performance curve for the input data of $\mathrm{PSI}=3.5$ and $\mathrm{ELA_P}=1{,}000{,}000$.

The next step is to determine the $\mathrm{ELA_T}$ based on the performance curve from the previous step and the selected TSI, as follows (refer to fig. 10):

(1) Locate points $\overline{SN}=2.85$ and $S=30$ on their respective scales.

(2) Connect the two points, extending the straight edge to the traffic load scale.

(3) Read the traffic load scale at the intersection to obtain $\mathrm{ELA_T}=4{,}700{,}000$.

The final step is to determine the $\mathrm{ELA_R}$ from the results of the previous two steps and the following equation:

$$\begin{aligned}\mathrm{ELA_R}&=\mathrm{ELA_T}-\mathrm{ELA_P}\\&=4{,}700{,}000-1{,}000{,}000=3{,}700{,}000\end{aligned}$$

Rigid pavements.—The method for rigid pavements is also described by use of an example in which the following input dat are given:

$$\mathrm{PSI}=4.0$$
$$\mathrm{ELA_P}=900{,}000$$
$$D=8\text{ in.}$$
$$\mathrm{TSI}=2.5$$

The first step is to select a performanc curve based on the given PSI, $\mathrm{ELA_P}$, and I as follows (refer to fig. 11):

(1) Locate the point $\mathrm{ELA_P}=900{,}000$ o the traffic load scale.

(2) Connect this point and a point on th f_t scale for an assumed f_t (working stress i concrete), extending the straight edge to th pivot line (in the example, the assumed f_t= 490).

(3) Connect the point of intersection c the pivot line and point $D=8$ in. on the sla thickness scale, extending the straight edg to the modulus of subgrade reaction, K scal

(4) The intersecting point $K=150$ is a equivalent K that, together with the assume f_t, describes a performance curve for tl input data of $\mathrm{PSI}=4.0$, $\mathrm{ELA_P}=900{,}000$, ar $D=8$ in.

The next step is to determine the ELA from the performance curve of the previo step and the selected TSI, as follows (refer fig. 12):

(1) Connect the two points $K=150$ ar $D=8$ in., extending the straight edge to tl pivot line.

(2) Connect the point of intersection on tl pivot line and the point $f_t=490$, extending tl straight edge to the traffic load scale.

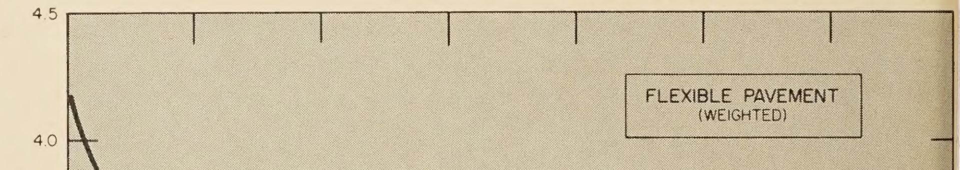


Figure 8.—Performance curve.

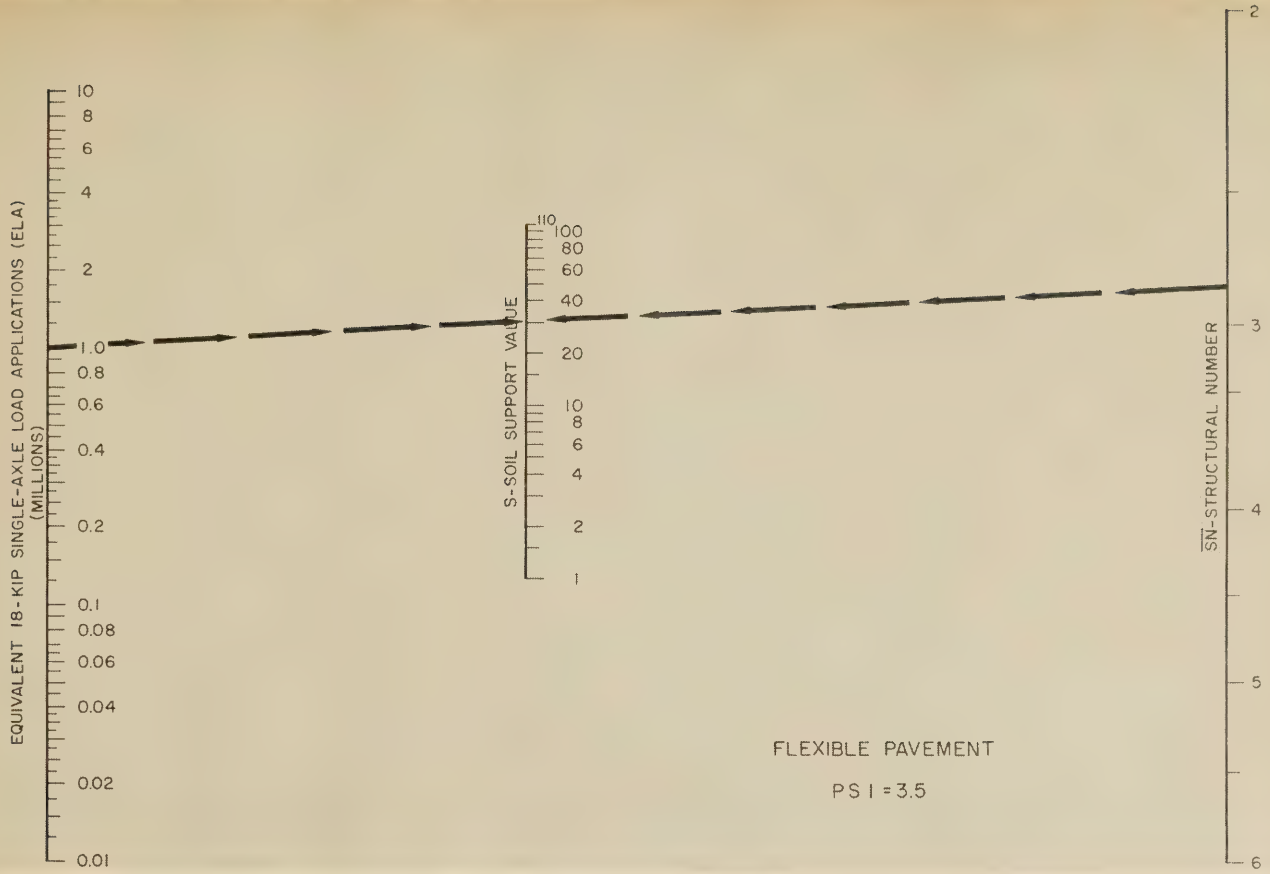


Figure 9.—Flexible-pavement service-life nomograph, PSI=3.5.

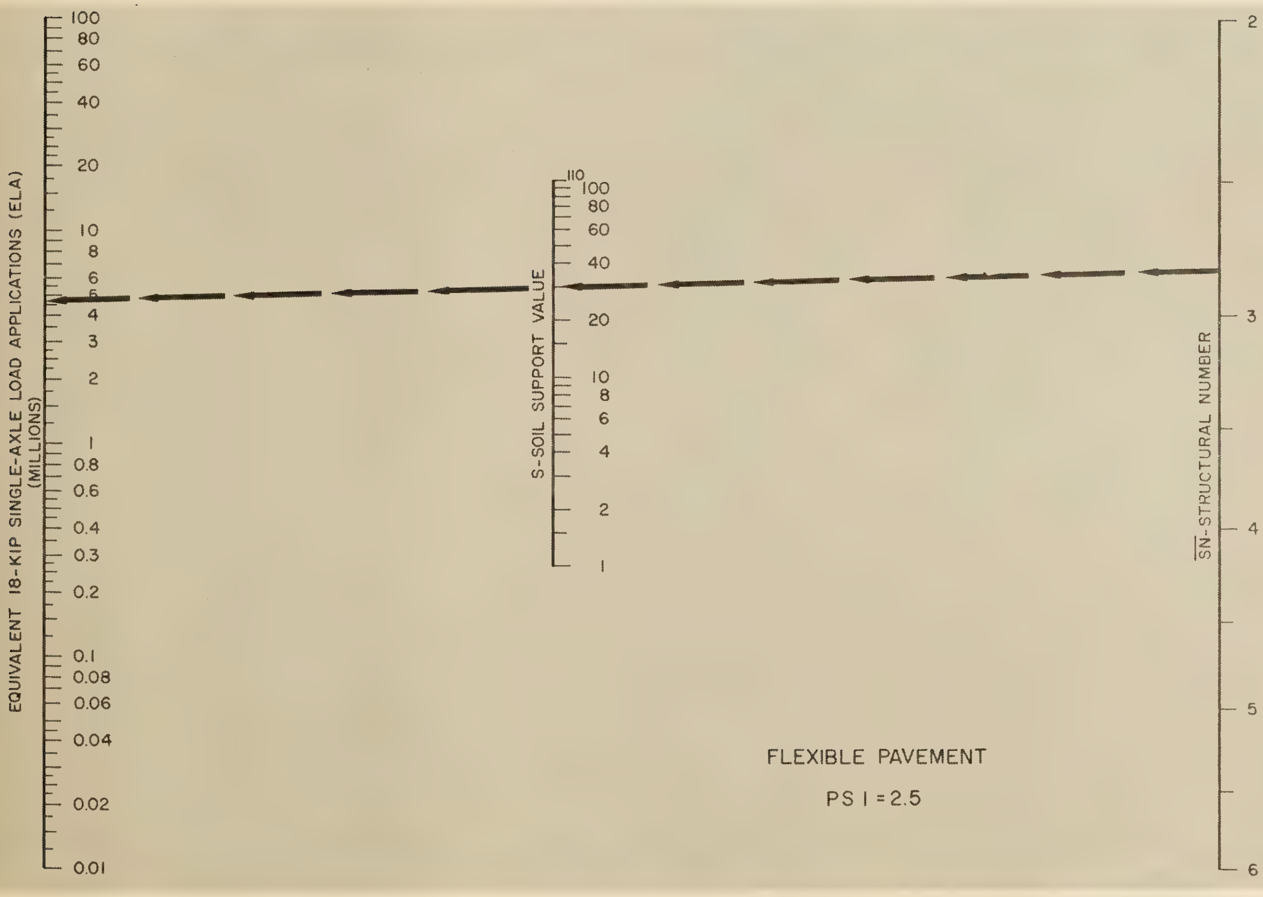


Figure 10.—Flexible-pavement service-life nomograph, PSI=2.5.

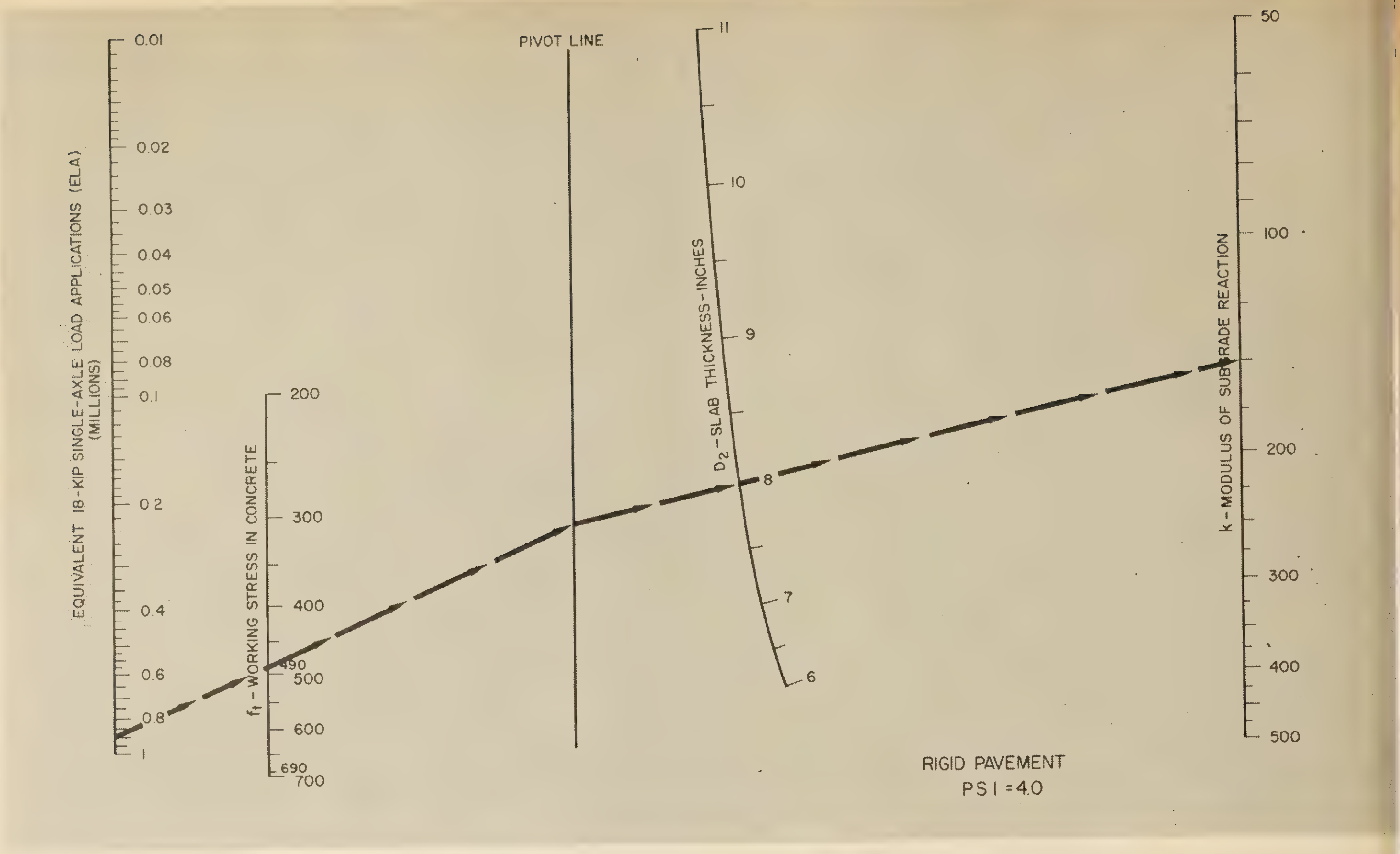


Figure 11.—Rigid-pavement service-life nomograph, PSI=4.0.

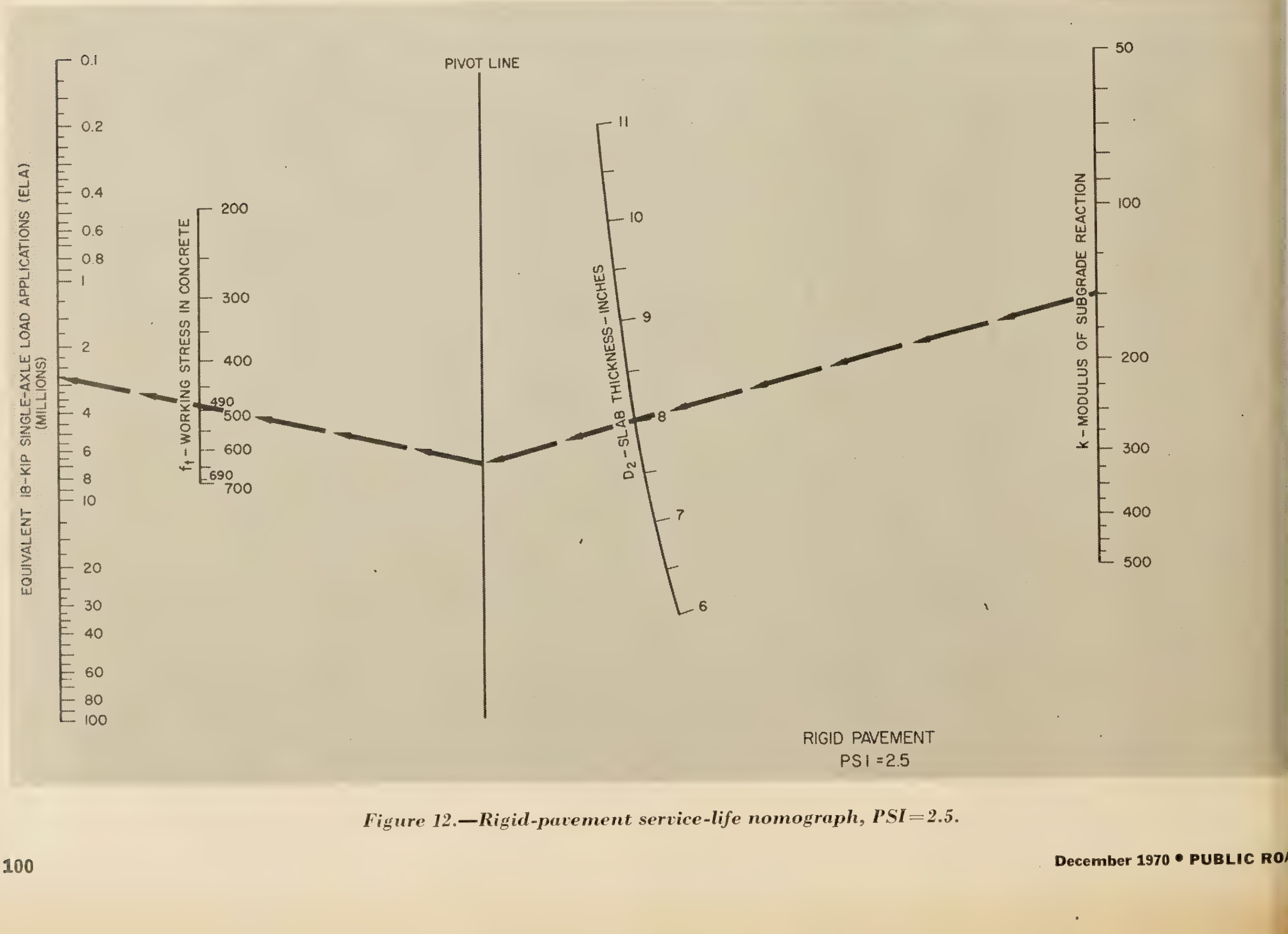


Figure 12.—Rigid-pavement service-life nomograph, PSI=2.5.

(3) At the point of intersection on the traffic load scale read $ELA_T = 2{,}750{,}000$.

The final step is to determine the ELA_R from the results of the previous two steps and the following equation:

$$ELA_R = ELA_T - ELA_P = 2{,}750{,}000 - 900{,}000 = 1{,}850{,}000$$

General comments.—An equivalent S or K based on an assumed $\overline{SN}$ or f_t is suggested because the actual $\overline{SN}$ or f_t may be difficult to determine for existing pavement sections. Also the actual $\overline{SN}$, S, K, or f_t may not be compatible with the traffic load scale because of other factors, such as extreme climatic conditions and construction practices.

Although the equivalent S or K based on an assumed $\overline{SN}$ or f_t is suggested, actual or easonably good estimates of the $\overline{SN}$ or f_t re preferable, provided that the traffic load cale is compatible with the input data. The ctual $\overline{SN}$ or f_t together with an equivalent S or K may be very helpful in the design of verlays for pavement sections.

Requirements for Developing a System

As for the conceptual approach, the system escribed here for estimating present surface ondition and remaining life of existing pavement sections is based on the findings of the AASHO Road Test, as well as on supplemental information from the papers and reports commenting on these findings. It also reflects the modifications and recommendations suggested by the AASHO Committee on Design.

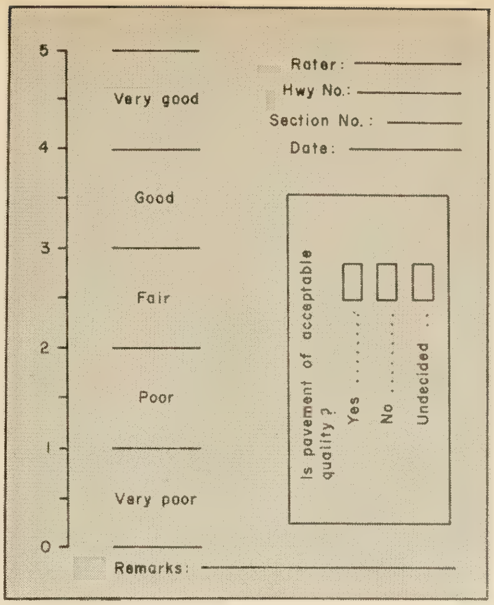
The system is evolved by developing methods to accomplish the following steps:

- Determine present condition of the pavement surface.
- Determine equivalent 18-kip single-axle load applications.
- Convert remaining equivalent 18-kip single-axle load applications into remaining years.
- Evaluate the accuracy of the remaining -kip single-axle load applications.

Determining present condition

Because the States may not be able to measure pavement roughness, cracking, and patching on their entire highway systems, owing to insufficient time and lack of resources, the PSI of each section may be difficult to determine by the PSI equations. It is suggested that the determination be based on the PSR concept and that the PSI concept be used for random checks. This provides a practical and reliable method that is compatible with the procedures used at the AASHO Road Test.

The previously discussed PSR concept developed at the Road Test was based on the average findings of a rating panel that traveled and rated large sections of roads in actual service. The Present Serviceability Rating Form shown in figure 13 was used in AASHO panel's ratings. Use of this rating form to determine the PSR is described in the Asphalt Institutes MS–17 (7).



5

Very good

4

Good

3

Fair

2

Poor

1

Very poor

0

Rater: ____________

Hwy No.: ____________

Section No.: ____________

Date: ____________

Is pavement of acceptable quality?

Yes .... ☐

No .... ☐

Undecided .. ☐

Remarks: ____________

Figure 13—Present-serviceability rating form.

Although pavement sections at the Road Test were not considered out of test until the present serviceability reached 1.5—corresponding to the midpoint of the poor rating—results of a nationwide survey (*8*) showed that present serviceability of highway pavements scheduled for resurfacing was about 2.0. Pavements in the very poor and poor category are inadequate and should be resurfaced or reconstructed. However, pavements in the very good, good, and fair categories have remaining life that can be estimated using the service life nomographs in the last part of this article.

If current sufficiency ratings of pavement conditions—excluding geometric design elements, such as width, alinement, and similar factors—are available, a correlation between the sufficiency rating scale and PSR scale may be established to transform the sufficiency ratings to PSR with sufficient precision. For example, on the sufficiency rating scale of a given State, if the highest possible rating is 20 and a rating of 5 or less denotes a pavement in very bad condition, the two rating systems might compare as follows:

Sufficiency rating—	PSR
20	5
15	4
10	3
5	2
0	1
	0

In this comparison a sufficiency rating of 5 is equated with a PSR of 2.0 because these are the points on the two rating scales at which pavements are in need of resurfacing or reconstruction. As a precaution, it is suggested that random checks using PSI equations be made to ascertain and control accuracy of the PSR.

Those States that have Roughometers from which PSI equations have been developed can readily use Roughometer readings to determine the PSI. Even if a Roughometer has not been calibrated with the Road Test Profilometer, it may be possible to use Roughometer values to good advantage by equating the approximate Roughometer reading at which pavements are resurfaced to a PSI of 2.0, and assuming a straight-line relation between Roughometer and PSI values.

Procedures for determining the PSI from pavement roughness measurements obtained by mechanical devices, like the Roughometer and Profilometer, are described in the literature (*4, 7, 9*).

Determining equivalent 18-kip single-axle load applications

As stated previously, the general performance equations developed at the AASHO Road Test are single-axle load equations that describe the behavior of pavements subjected to repeated applications of an axle load of any one type and weight. They do not directly yield information on the behavior of pavements acted upon by mixed traffic—normal highway traffic that consists of both single and tandem axles of a variety of weights. The problem of converting single and tandem axles of different weights into equivalent 18-kip single-axle load applications was solved by developing equivalency factors that reduce given single or tandem axles of known weights to equivalent 18-kip single-axle load applications.

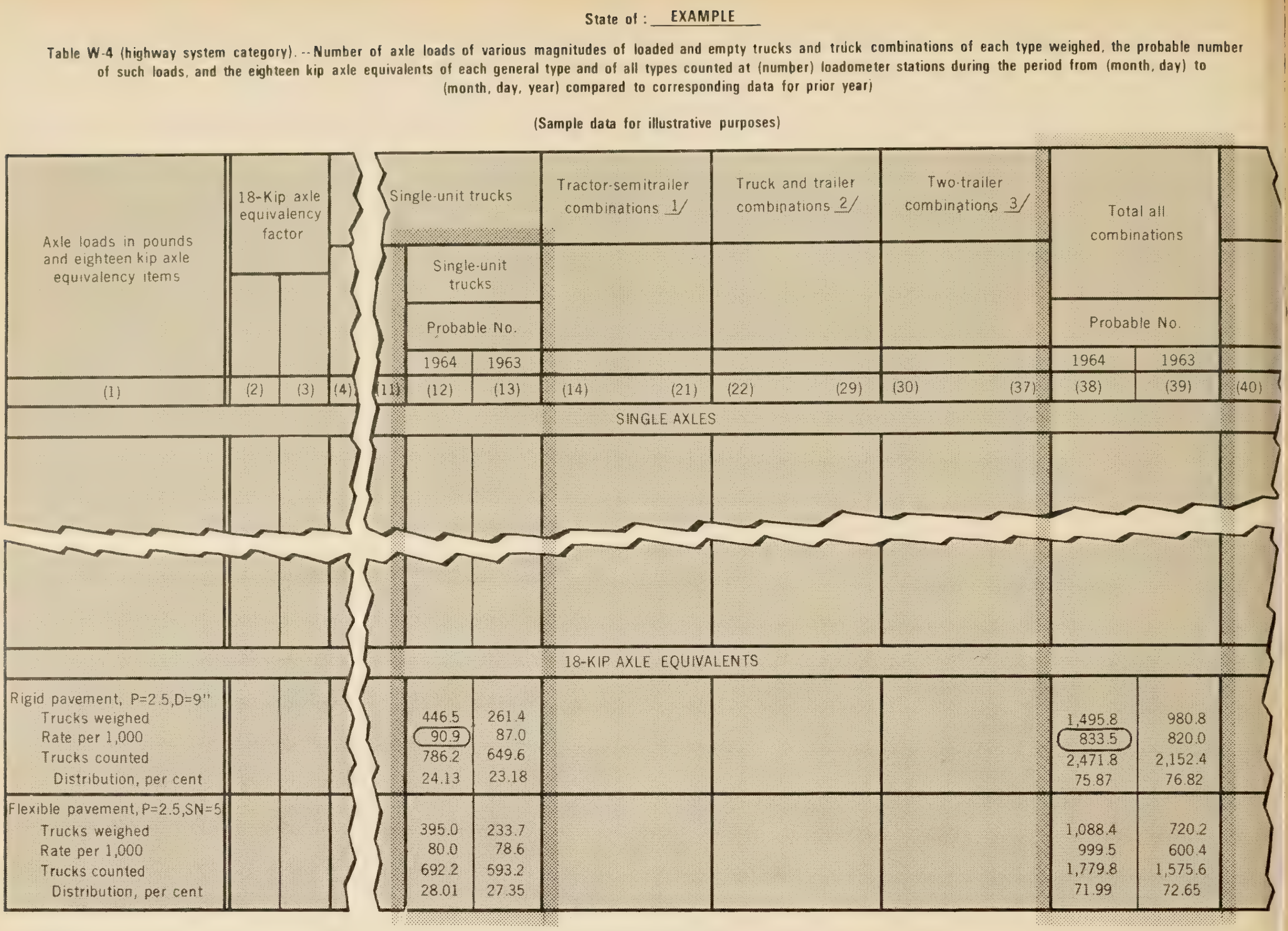
From the AASHO Road Test performance equations, the AASHO Committee on Design developed flexible-pavement equivalency factors for PSI levels of 2.0 and 2.5, for structural numbers, SN, ranging from 1.0 to 6.0 and rigid-payment equivalency factors for PSI levels of 2.0 and 2.5, for slab thicknesses, D, ranging from 6 to 11 inches. These equivalency factors permit the loads from mixed axles of various weights in a given traffic volume to be reduced to an equivalent number of daily 18-kip single-axle load applications (EDLA). The EDLA can be expanded to annual or multiple year projected totals.

The procedures described here for computing EDLA are based on information from truck weight studies conducted in the States in accordance with the Federal Highway Administration's Instructional Memorandum 50–4–66, *Annual Truck Weight Study*.[3] In this annual study a table, table W–4, is compiled from information collected at various stations throughout the States and combined for particular highway systems—*All Main Rural, Rural Interstate, Urban Interstate*, and others.

Conventional computation of EDLA.—The EDLA can be computed directly from information in table W–4 of the truck weight studies. An example of a part of table W–4 is shown in figure 14. The lower portion of the table headed *18-Kip Axle Equivalents* contains a line that lists the equivalent 18-kip rate per 1,000 for each individual type vehicle. The rate per 1,000 can be applied

---

[3] Instructional Memoranda are issued by the Federal Highway Administration to provide interim instructions pending issuance of permanent instructions.



State of : EXAMPLE

Table W-4 (highway system category). --Number of axle loads of various magnitudes of loaded and empty trucks and truck combinations of each type weighed, the probable number of such loads, and the eighteen kip axle equivalents of each general type and of all types counted at (number) loadometer stations during the period from (month, day) to (month, day, year) compared to corresponding data for prior year)

(Sample data for illustrative purposes)

Axle loads in pounds and eighteen kip axle equivalency items	18-Kip axle equivalency factor				Single-unit trucks		Tractor-semitrailer combinations 1/	Truck and trailer combinations 2/	Two-trailer combinations 3/	Total all combinations		
					Single-unit trucks							
					Probable No.					Probable No.		
					1964	1963				1964	1963	
(1)	(2)	(3)	(4)	(11)	(12)	(13)	(14) (21)	(22) (29)	(30) (37)	(38)	(39)	(40)
SINGLE AXLES												
18-KIP AXLE EQUIVALENTS												
Rigid pavement, P=2.5,D=9"												
Trucks weighed					446.5	261.4				1,495.8	980.8	
Rate per 1,000					90.9	87.0				833.5	820.0	
Trucks counted					786.2	649.6				2,471.8	2,152.4	
Distribution, per cent					24.13	23.18				75.87	76.82	
Flexible pavement, P=2.5,SN=5												
Trucks weighed					395.0	233.7				1,088.4	720.2	
Rate per 1,000					80.0	78.6				999.5	600.4	
Trucks counted					692.2	593.2				1,779.8	1,575.6	
Distribution, per cent					28.01	27.35				71.99	72.65	

Figure 14.—Example of a part of Table W–4.

to any traffic mix of similar characteristics to calculate the equivalent daily 18-kip single-axle load applications (EDLA).

Suggested computation of EDLA.—Although the data for the conventional procedure should be readily available, as most States have been conducting the traffic classification and weight studies for some time, the estimation of EDLA can be simplified by using 18-kip equivalent constants rather than the equivalent 18-kip rate per 1,000 for each vehicle type. The 18-kip equivalent constants for single unit and multi-unit trucks can be extracted directly from the truck weight studies. The suggested constant for passenger cars is 0.0008 per vehicle based on an assumed average passenger-car weight of about 3,000 pounds. However, the effect of passenger vehicles on the EDLA is negligible, and a State may wish to eliminate passenger vehicles from the EDLA computation.

In practice the traffic classification count would be furnished as the number of each vehicle type in the traffic stream; therefore, an EDLA equation can be developed as follows:

$$\text{EDLA} = (C_1 \times PC \times P_1) + (C_2 \times SU \times P_2) + (C_3 \times MU \times P_3)$$

Where,

C_1 = Constant for passenger cars.
C_2 = Constant for single units.
C_3 = Constant for mulitple units.
PC = Total passenger car ADT, two directions.
SU = Total single unit ADT, two directions.
MU = Total multiple unit ADT, two directions.
P_1 = Percent passenger car ADT in critical lane.
P_2 = Percent single unit ADT in critical lane.
P_3 = Percent multiple unit ADT in critical lane.

The 18-kip axle equivalent constants for single-unit trucks and combination trucks are taken directly from the columns *Probable No.* and the lines *Rate Per 1,000* in table W–4 (see fig. 14). For example, as shown by the encircled numbers in figure 14, the appropriate constants for rigid pavements are 0.0909 and 0.8335 for single-unit trucks and total all combination trucks, respectively. The decimal points have been moved three places to the left because the values in table W–4 are expressed in terms of rate per 1,000. Using these constants based on the probable number rate per 1,000 and the above equation, the EDLA for the given traffic mix is as follows:

$$\text{EDLA} = (C_1 \times PC \times P_1) + (C_2 \times SU \times P_2) + (C_3 \times MU \times P_3)$$
$$\text{EDLA} = (.0008 \times 3687 \times .30) + (.0909 \times 410 \times .40) + (.8335 \times 423 \times .40)$$
$$\text{EDLA} = 156.9$$

In this example, the EDLA is 4.8 perc t less than the EDLA of 164.9 that would re t from the conventional computation in wh h the rate per 1,000 for individual vehicle t e would be used.

In a limited analysis of truck weight d a from Illinois, California, and Texas, it s found that EDLA's based on the consta s do not vary significantly from those that e based on the rate-per-1,000 method previo y discussed. For convenience, however, use f the constants is suggested.

To further reduce the time and ef t required to apply the suggested method f computing EDLA's, a series of graphs can e developed from the equation. In the exan e shown in figure 15, the EDLA for a r d pavement with four or more lanes can be r d directly from the graph if the ADT in b h directions and percent of multiple unit tru s are known. Figure, 15, however, is a represetive sample only; in practice the ADT ould be as much as 70,000, or more.

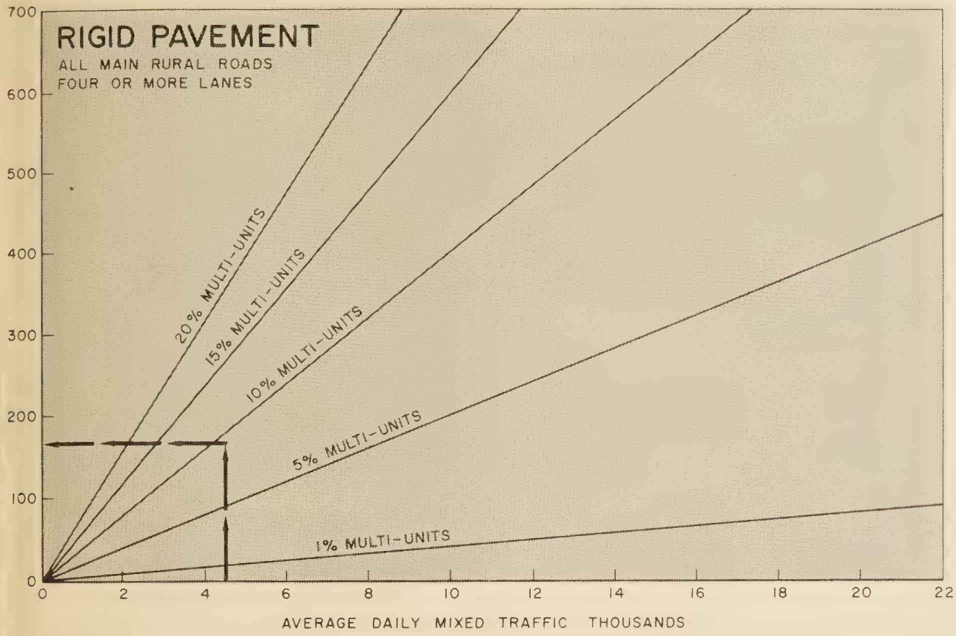
The reason for referencing the graphs to he percent of multiple units in relation to he ADT is reflected in the above example. he effect of passenger cars on the EDLA in roportion to the effect of single and multiple nits is small. Moreover, the effect of multiple nits is eight or nine times greater than the ffect of single units. In the example, multiple nits contribute approximately 89 percent of he equivalent daily 18-kip single-axle load pplications.

Although the graphs represent the effect all vehicles in the traffic stream on EDLA, sers of the graphs need know only the rcentage of multiple units, the major con-ibutors to the EDLA. Graphs for both rigid and flexible pavements would be required for different types of roadways—2, 3, 4, or more lanes.

The use of such graphs to estimate an EDLA and the use of the EDLA to estimate an ELA_P (accumulated 18-kip single-axle-load applications from the time the existing pavement surface was open to traffic to the present) are described in the following example:

Given:

- Rigid pavement, four traffic lanes.
- Existing pavement surface in service for 5 years.
- Initial ADT (both directions) = 4,000.
- Present ADT (both directions) = 5,040.
- Initial and present percent multiple unit trucks = 9.4.



igure 15.—Conversion of average daily traffic to equivalent 18-kip single-axle load applications.

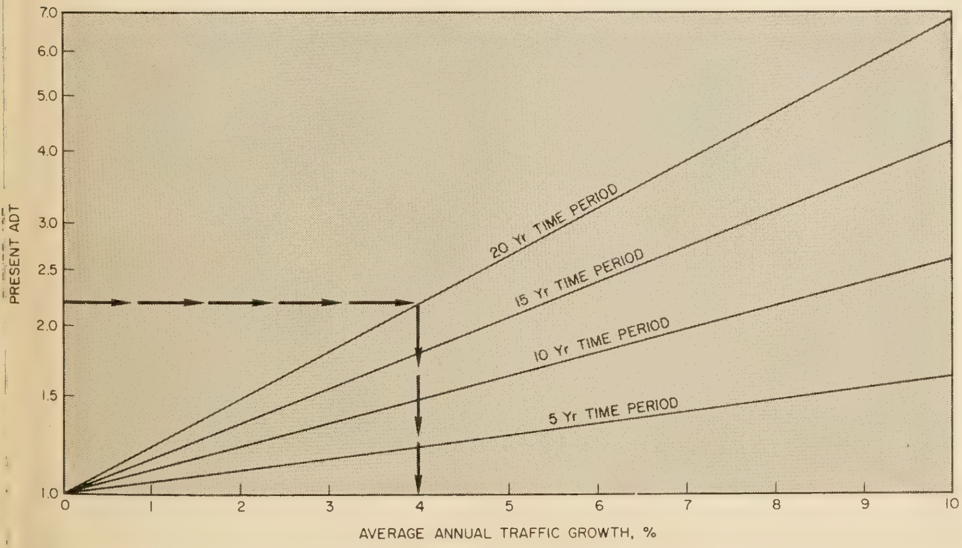


Figure 16.—Conversion of traffic growth ratio to average annual traffic growth rate.

Solution:

(1) Estimate the EDLA for the mean year using the appropriate graph for four lanes or more as follows (refer to fig. 15):

(a) On the horizontal scale, locate the point where the ADT (mean year) = 4,520.

(b) From this point proceed vertically to the approximate point where the percent multiple unit trucks equals 9.4.

(c) From this point of intersection follow horizontally across the graph and read the EDLA on the vertical scale—approximately 165.

(2) Estimate the ELA_P using the following equation:

$$ELA_P = EDLA \text{ (mean year)} \times 365 \text{ days/years} \times \text{years.}$$

$$ELA_P = 165 \times 365 \times 5 = 301{,}125.$$

General comments.—The example for estimating the equivalent daily 18-kip single-axle load applications (EDLA) is based on the hypothetical table W–4 shown in figure 14. Consequently, the equivalent constants from figure 14 would not apply for a specific State. Each State highway department must analyze the equivalent constants in the applicable W–4 tables. Analyses may well indicate that constants and graphs should be applied by highway system category, such as rural Interstate, urban Interstate, main rural roads, and urban streets and expressways.

Also, axle weight distribution trends may have been established from analysis of the truck weight studies conducted over a period of years. These trends can be helpful in estimating historical and projected future equivalent 18-kip load applications and, for example, could indicate a steady replacement of light vehicles with heavier vehicles. Moreover, changes could be occurring in the number of vehicle-types and in the individual categories. Consequently, because of such changes, it could be possible that 18-kip axle equivalent constants developed from present traffic classification and truck weight information may not be satisfactory, and completely new 18-kip axle equivalent constants would have to be developed for both the historical and future years. A good procedure for developing traffic parameters is given in a paper by Eugene L. Skok, Jr. (*10*).

Converting remaining 18-kip single-axle load applications into remaining years

The conversion of the ELA_R into the years of remaining service life can be accomplished by the following relatively simple four-step process:

(1) Estimate the present equivalent annual 18-kip axle-load applications (EALA) by multiplying the present EDLA by 365 days. Use the EDLA equation or graphs, previously discussed, to estimate the present EDLA.

(2) Determine the remaining service life factors (RSLF) by dividing the ELA_R by the EALA:

$$RSLF = \frac{ELA_R}{EALA}$$

(3) Determine the future annual traffic growth rate. If the annual traffic growth rate

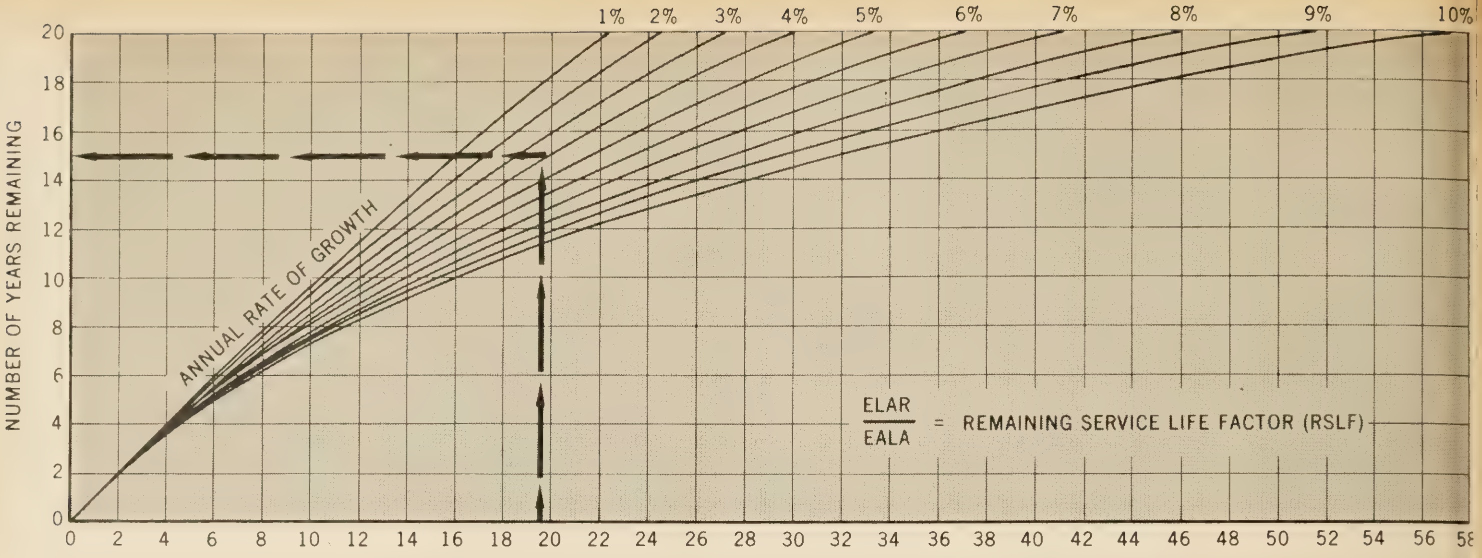


Figure 17.—Conversion of RSLF to RSL.

is not known, determine it on the basis of the traffic growth ratio for a given period using a compound interest table (*11*). A sample compound interest table is shown in figure 16.

(4) Based on the RSLF and the annual traffic growth rate, determine the years of remaining service life (RSL) from figure 17, as in the example below.

Example

Given:

- $ELA_R = 1{,}208{,}000$.
- Present EDLA = 175.
- Twenty-year traffic growth ratio = 2.19.

Solution:

(1) $EALA = 175 \times 365 = 63{,}875$.

(2) $RSLF = \frac{1{,}208{,}000}{63{,}875} = 18.91$.

(3) From figure 16, based on a traffic growth ratio of 2.19 for a 20-year time period, the annual traffic growth rate is 4 percent.

(4) From figure 17, based on a RSLF of 18.91 and an annual traffic growth rate of 4 percent, the years of remaining life equals 15 years.

Evaluating the accuracy of the predicted equivalent 18-kip single-axle load applications

Performance of highway pavements of comparable design may vary from State to State because factors related to performance—weather, materials, soils, construction practices, and axle loads—may vary. Although several of these factors, are accounted for when the service life nomographs are used to predict ELA, the nomographs may not be able to account for all the varying conditions in all the States. Consequently, the accuracy of the ELA, as predicted from the service life nomographs, should be evaluated in each State and, when warranted, the predicted ELA should be adjusted to better reflect actual performance. The procedures presented here are suggested for evaluating and adjusting the predicted ELA.

Accuracy of the predicted ELA can be based on comparisons between actual pavement performance history and predicted performance from the service life nomographs. These comparisons require the following information for individual pavement sections:

- PSI or PSR and the accumulated equivalent 18-kip single-axle load applications for two points in time, preferably several years apart.
- Pavement structure thickness—$\overline{SN}$ for flexible pavements and D for rigid pavements.

Two observations in the pavement performance history are required so that the first observation can be used in concert with the service life nomographs to predict the second observation, which can then be compared with the actual observation. The procedure is illustrated in the following example:

Example:

Given:

- Flexible pavement.
- Structural number, $\overline{SN} = 3.0$.
- PSI_1 (earlier) = 3.60.
- ELA_1 (earlier) = 402,000.
- PSI_2 (later) = 3.48.
- ELA_2 (later) = 643,000.

Solution:

First, determine the equivalent S (steps 1–and then use this equivalent to predict th second or later ELA_2 (steps 5–7):

(1) Select the appropriate service life nom graph for PSI = 3.6, corresponding to the PS of 3.60.

(2) On the ELA scale, locate the poi $ELA_1 = 402{,}000$.

(3) Use a straight edge to connect th point and the point $\overline{SN} = 3.0$.

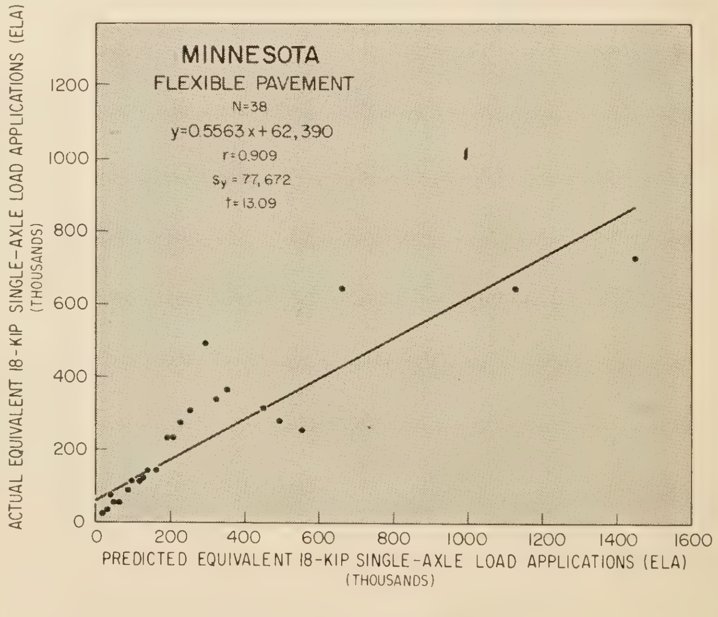


Figure 18.—Actual performance plotted against predicted performance, Minnesota flexib pavement.

(4) Locate on the soil support scale the point, approximately 14, intersected by the straight edge. This is the resultant equivalent S.

(5) Select the appropriate service life nomograph for PSI=3.4 corresponding to the PSI_2 of 3.48.

(6) Connect the point $\overline{SN}=3.0$ on the structural number scale and the point $S=14$ on the soil support scale, extending the straight edge to the ELA scale.

(7) The point intersected by straight edge on the ELA scale is 650,000 which is close to the actual ELA_2 value of 643,000.

This procedure was used to compare actual performance data from two States, Minnesota and Texas, with predicted performance from the nomographs. The data used were developed in studies conducted in the States (*12*)—Minnesota provided usable data for 38 flexible pavement sections; Texas provided usable data for 25 flexible and 26 rigid pavement sections.

The statistical findings from regression and correlation analyses are shown in figures 18 through 20. The equation from plotting the actual performance against the predicted performance and the regression line are shown in these figures together with basic statistical information.

In figure 18, which reflects the evaluation of flexible pavements from Minnesota, the service life nomographs tend to over predict the ELA in relation to the actual ELA. With a correlation coefficient of 0.91, however, the regression line reflects a strong linear relationship between the actual and predicted performance. Furthermore, the value of 13.09 for the t test indicates that the correlation coefficient is highly significant or did not arise as a result of pure chance. The use of the regression equation $y=0.5563\times+63,390$ to estimate the actual performance from the predicted performance would assure that, 95 percent of the time, the actual performance would lie within two standard errors of the estimate of the value obtained from the regression equation. The standard error of the estimate is 77,672, or 43.8 percent of the mean value of y for the Minnesota analysis.

In figure 19, the results of the evaluation of flexible pavements from Texas are similar to the results from the Minnesota flexible pavements, but not quite as good. The service life nomographs again tended to over predict the performance of the flexible pavements. The correlation coefficient of 0.83 and the t test of 7.08 indicate that the linear relationship between actual and predicted performance is highly significant. The regression equation is $y=0.5904\times+98,937$, and the standard error of the estimate is 177,748, or 49.0 percent of the mean value of y.

The evaluation of rigid pavements from Texas was very encouraging. In figure 20, the regression line falls extremely close to a perfect 45 degree correlation line. The correlation coefficient is a very high 0.997 and the t test of 66.5 is highly significant. The regression equation $y=0.93635\times+137,920$ looks very good and has a standard error of the estimate of 84,922, or 6.1 percent of the mean value of y.

Accordingly, it has been shown that the performance predicted from the nomographs has a high degree of correlation with actual performance. The regression equation can be used to adjust the predicted performance when its use significantly improves the predicted values. However, those using the regression equation are cautioned to determine, based on the existing history, whether predictions would more often be improved than made worse by an adjustment. For example, if the regression line is fairly flat, and the plus and minus two standard errors of the estimate range is small, there probably would be very definite advantage to adjusting the predictions. If the regression line is fairly close to a 45° line (perfect correlation) and the associated variation bandwidth is farily wide, an adjustment might not significantly improve the predicted values, and may not be justified.

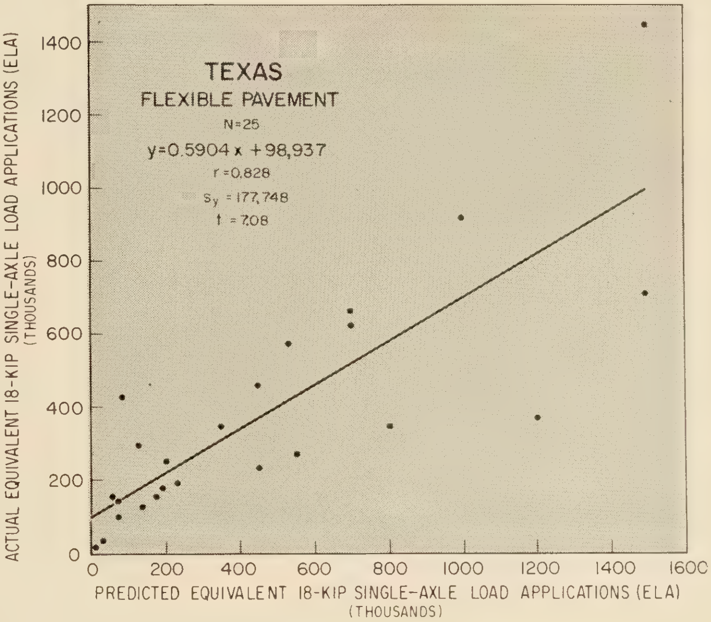


Figure 19.—Actual performance plotted against predicted performance, Texas flexible pavement.

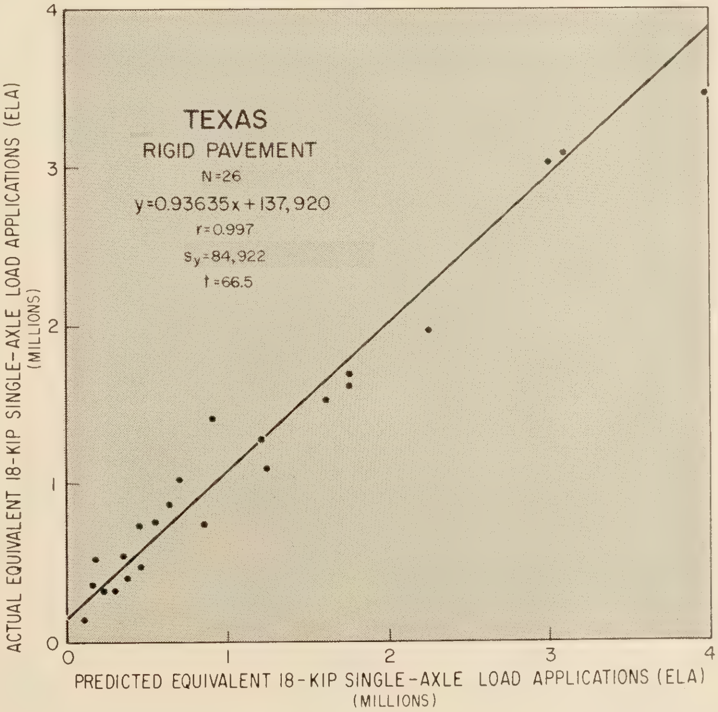


Figure 20.—Actual performance plotted against predicted performance, Texas, rigid pavement.

The regression equation is applicable only throughout the range of performance data for which it was developed. In the above examples, the maximum ELA for flexible pavements was about 1,600,000, and for rigid pavements about 4,000,000. Because pavement performance extends well beyond these values, evaluations should be made over the full range of pavement performance to confirm or refine the basic findings.

Service Life Nomographs

At the end of this article are 23 service life nomographs that can be used to predict pavement service life. The authors based development of these nomographs on the AASHO Road Test performance equations and the modifications suggested by the AASHO Committee on Design. However, unlike the AASHO design nomographs, the scale for equivalent 18-kip single-axle load applications in the service life nomographs was expressed without reference to a time period.

The service life nomographs begin with a serviceability index of 2.0 and increase at intervals of 0.2, up to an including 4.0 for rigid pavements and 3.8 for flexible pavement. Nomographs were not developed beyond these serviceability indices for two reasons: (1) Application of the system is for pavements that have been in existence several years and, therefore, assumed to have PSI's of 4.0 or less and (2) for flexible pavements, it was not possible to obtain a good correlation between nomographs beyond the 3.8 serviceability index. Nomographs for a serviceability index of 2.5 are included for States that use this value as a terminal level.

To use the nomographs it may be necessary to extend the ELA scale to cover some unusually high or low values. The ELA scale is logarithmic and can be extended by the addition of a cycle.

In plotting the soil support scale for the flexible-pavement nomographs, the authors followed the procedure recommended by the AASHO Committee on Design to obtain the first point, $S=3$, and the maximum point. However, they did not, as suggested, assign a value of 10 to the maximum point and assume a linear scale between points 3 and 10 and extend the scale to 1. Rather, they assigned a value of 110 to the maximum point and assumed a logarithmic scale between the value of 3 and 110 and extended the scale to 1.

A logarithmic scale, rather than the linear scale suggested by the AASHO Committee on Design, was used simply because a good correlation between nomographs at the different serviceability levels could not be obtained with a linear scale. When the method of developing design nomographs in Illinois was reviewed, it was noted that a logarithmic scale was used for soil support values. Also, because several of the soil support scales shown in the correlation data in Appendix E of the AASHO Interim Design Guide appeared to be logarithmic, use of a logarithmic scale was considered reasonable.

No attempt was made to develop a regional factor to permit adjustments for environmental conditions. Because the system for estimating service life, described herein, is based on equivalent $\overline{SN}$ and $\bar{S}$ values, the equivalencies may tend to compensate for the omission of the regional factor scale.

The service life nomographs for rigid pavements are similar to the AASHO design nomographs except the scale for the equivalent 18-kip single-axle load application was modified, as mentioned previously.

Full scale duplicates of the service-life nomographs in this article can be obtained by writing to the Managing Editor of PUBLIC ROADS, if a reasonable indication of need is presented.

Conclusions and Recommendations

Although the conclusions and recommendations given here are based on the limited analysis previously described, they are considered basically sound and are therefore generally applicable for the planning purposes intended:

- The proposed method of determining the remaining service life of existing pavement sections has been reasonably validated, as described.
- Each State should evaluate the proposed method by comparing the predicted performance from the service life nomographs with the actual performance of individual pavements. If a good correlation exists between predicted performance and actual performance, and if the predicted performance tends to be significantly higher or lower than the actual performance, the predicted performance should be adjusted through the use of a regression equation, as previously discussed.
- When conducting the evaluation, States should strive for the full range of performance history so that the adjustment equations can be developed accordingly. With a full range of performance history, States may be able to improve accuracy through the use of linear adjustment equations for several increments of performance or an exponential equation for the full range of performance.

ACKNOWLEDGMENTS

The authors wish to express their gratitud to the late Hugo C. Duzan for his technica advice on the results of the AASHO Roa Test; to James E. Gruver for his able as sistance in the development of the servic life nomographs; and to the following o ganizations, which cooperated by providin data and technical advice: Minnesota De partment of Highways, Texas Highwa Department, and Illinois Department o Public Works and Buildings, Division o Highways.

REFERENCES

(*1*) *The Pavement Serviceability–Perforn ance Concept*, by W. N. Cary, Jr., and P. I Irick, Highway Research Board Bulletin 25 1960, pp. 40–58.

(*2*) *The AASHO Road Test, Report Fiv Pavement Research*, Highway Research Boar Special Report 61E, 1962.

(*3*) *The AASHO Road Test*—Proceedings o a Conference held May 16–18, 1962, St. Loui Mo., Highway Research Board Special Repor 73, 1962.

(*4*) *Comparison of Different Methods Measuring Pavement Condition*, Nation Cooperative Highway Research Progra Report 7, Interim Report, Highway Researc Board, 1964.

(*5*) *AASHO Interim Guide for the Design Flexible Pavement Structures*, AASHO Com mittee on Design, October 1961.

(*6*) *AASHO Interim Guide for the Design Rigid Pavement Structures*, AASHO Committe on Design, April 1962.

(*7*) *Asphalt Overlays and Pavement Rehabil tation*, Manual Series No. 17 (MS–17), Th Asphalt Institute, First Edition, Novembe 1969.

(*8*) *Nationwide Survey of Pavement Termin Serviceability*, Highway Research Record N 42, 1963, pp. 26–40.

(*9*) *Standard Measurements for Satelli Road Test Program*, National Cooperati Highway Research Report 59, Highway R search Board, 1968.

(*10*) *Development of Traffic Parameter f Structural Design of Flexible Pavements i Minnesota*, by Eugene L. Skok, Jr., Highwa Research Record No. 291, Highway Researc Board, 1969, p. 104.

(*11*) *Compound Interest Tables*, Union Ca bide Corporation, New York, N.Y., Reprinte 1967.

(*12*) *Application of AASHO Road Te Results to Design of Flexible Pavements i Minnesota*—Summary Report, by M. Kersten and E. L. Skok, June 1968 (P 177375, National Technical Informatio Service).

SERVICE LIFE NOMOGRAPH

SERVICE LIFE NOMOGRAPH

SERVICE LIFE NOMOGRAPH

SERVICE LIFE NOMOGRAPH

SERVICE LIFE NOMOGRAPH

SERVICE LIFE NOMOGRAPH

SERVICE LIFE NOMOGRAPH

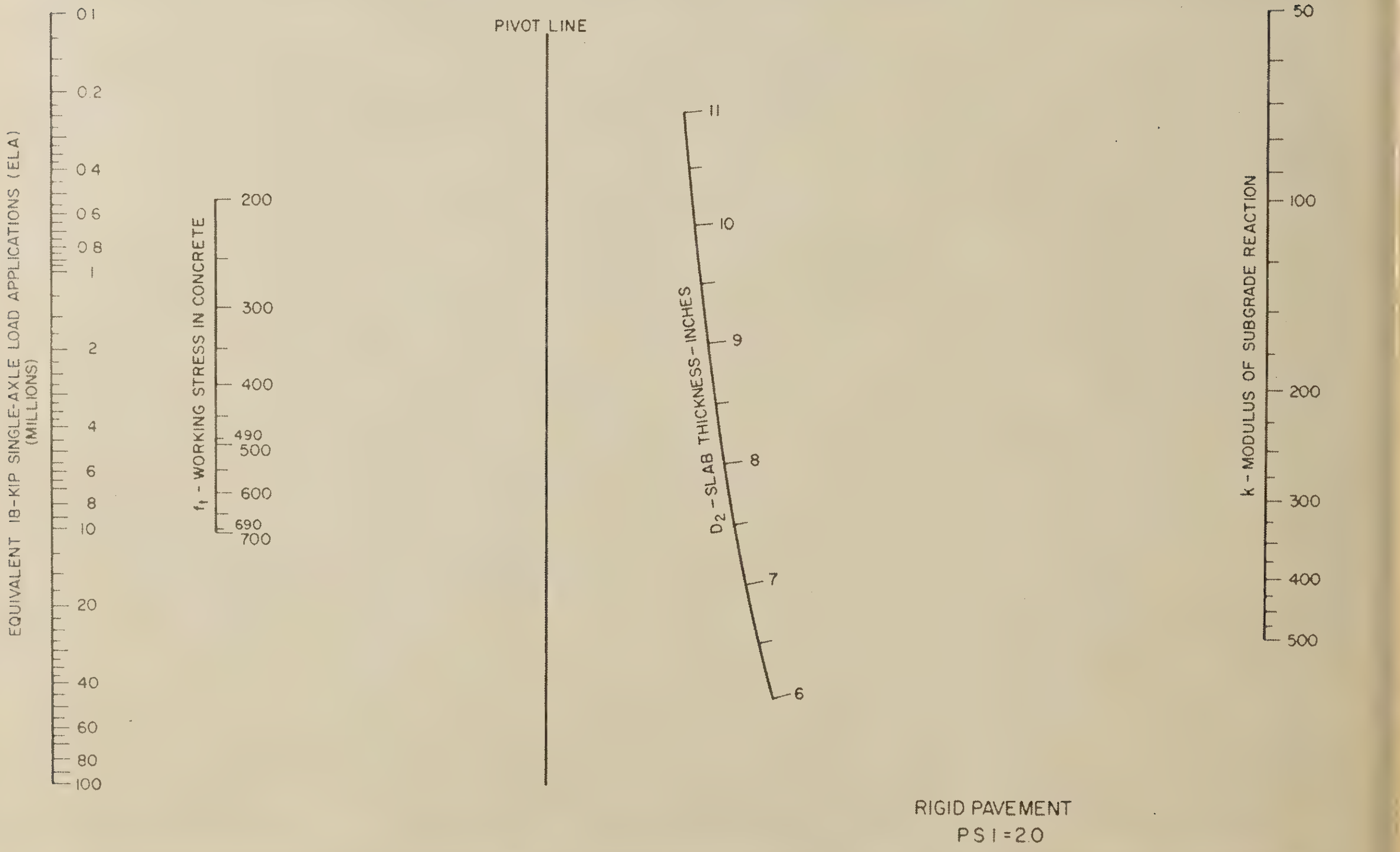
SERVICE LIFE NOMOGRAPH

SERVICE LIFE NOMOGRAPH

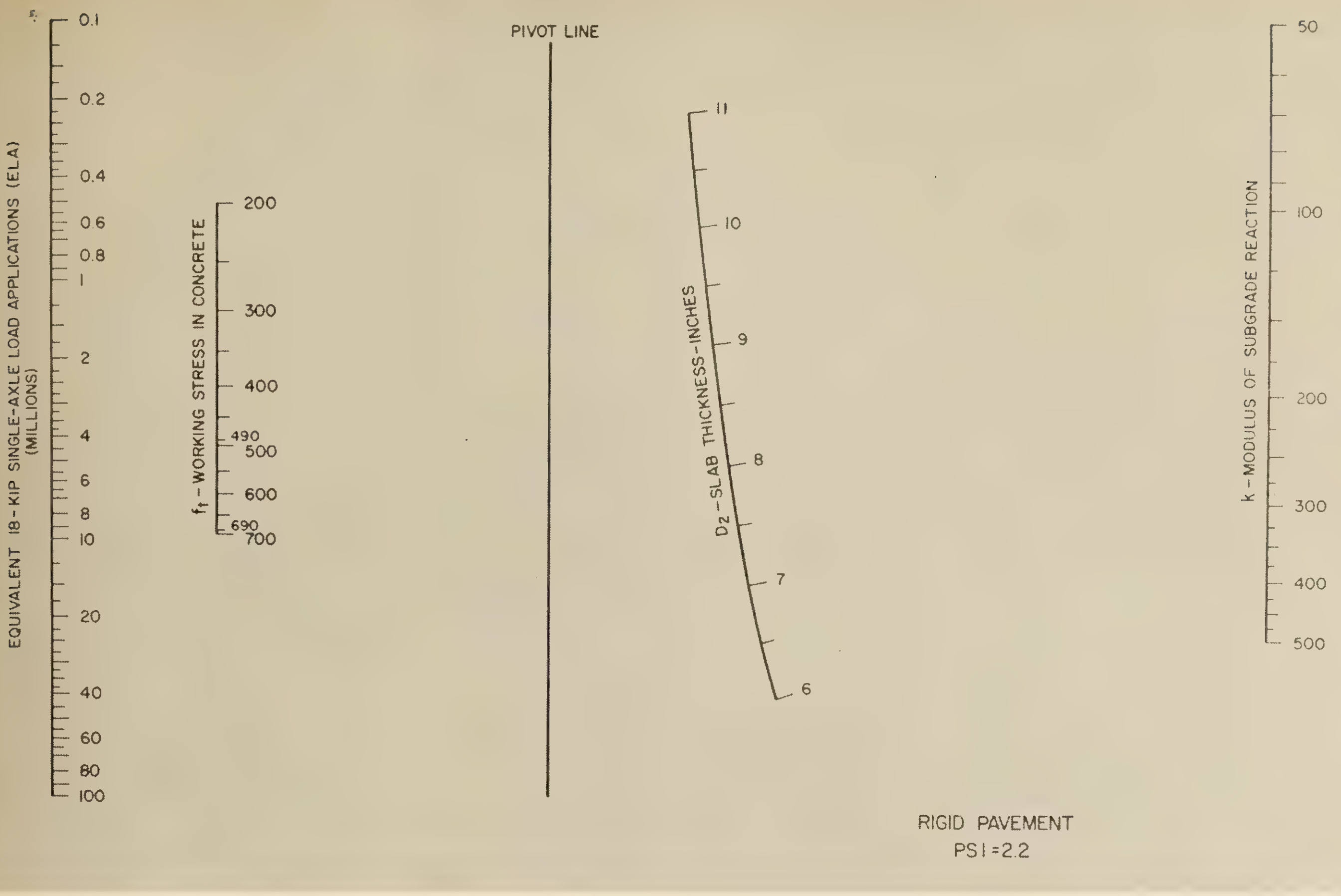
SERVICE LIFE NOMOGRAPH

SERVICE LIFE NOMOGRAPH

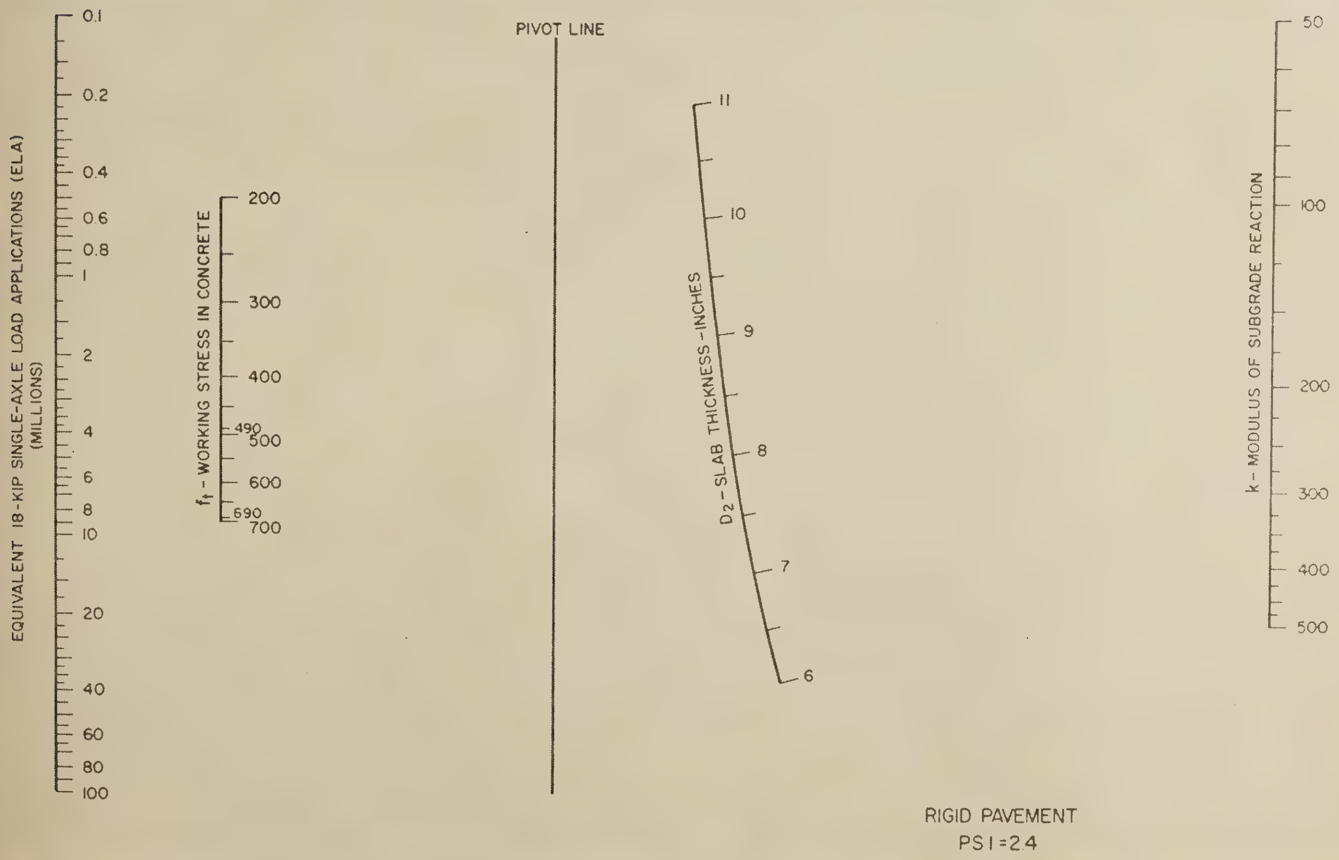
SERVICE LIFE NOMOGRAPH



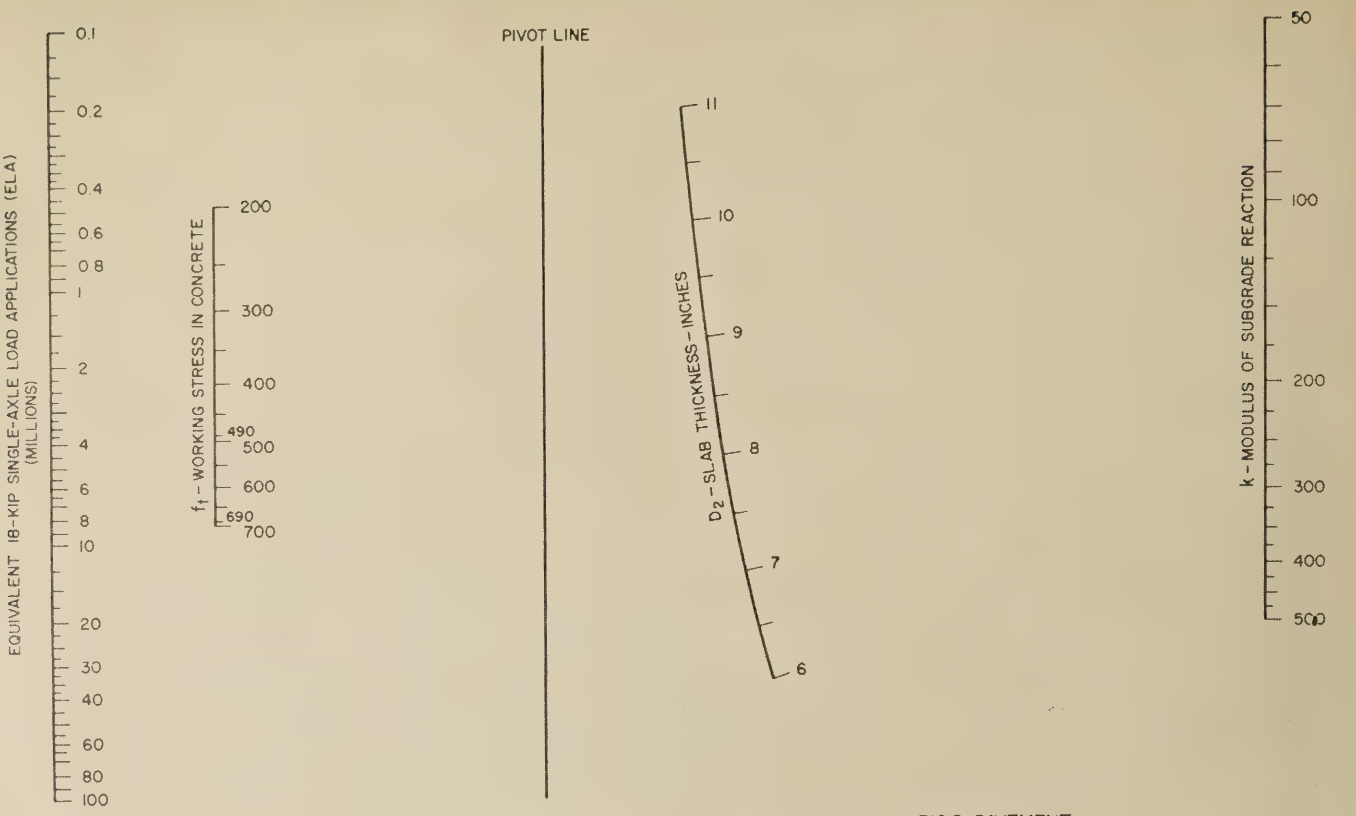
SERVICE LIFE NOMOGRAPH



SERVICE LIFE NOMOGRAPH

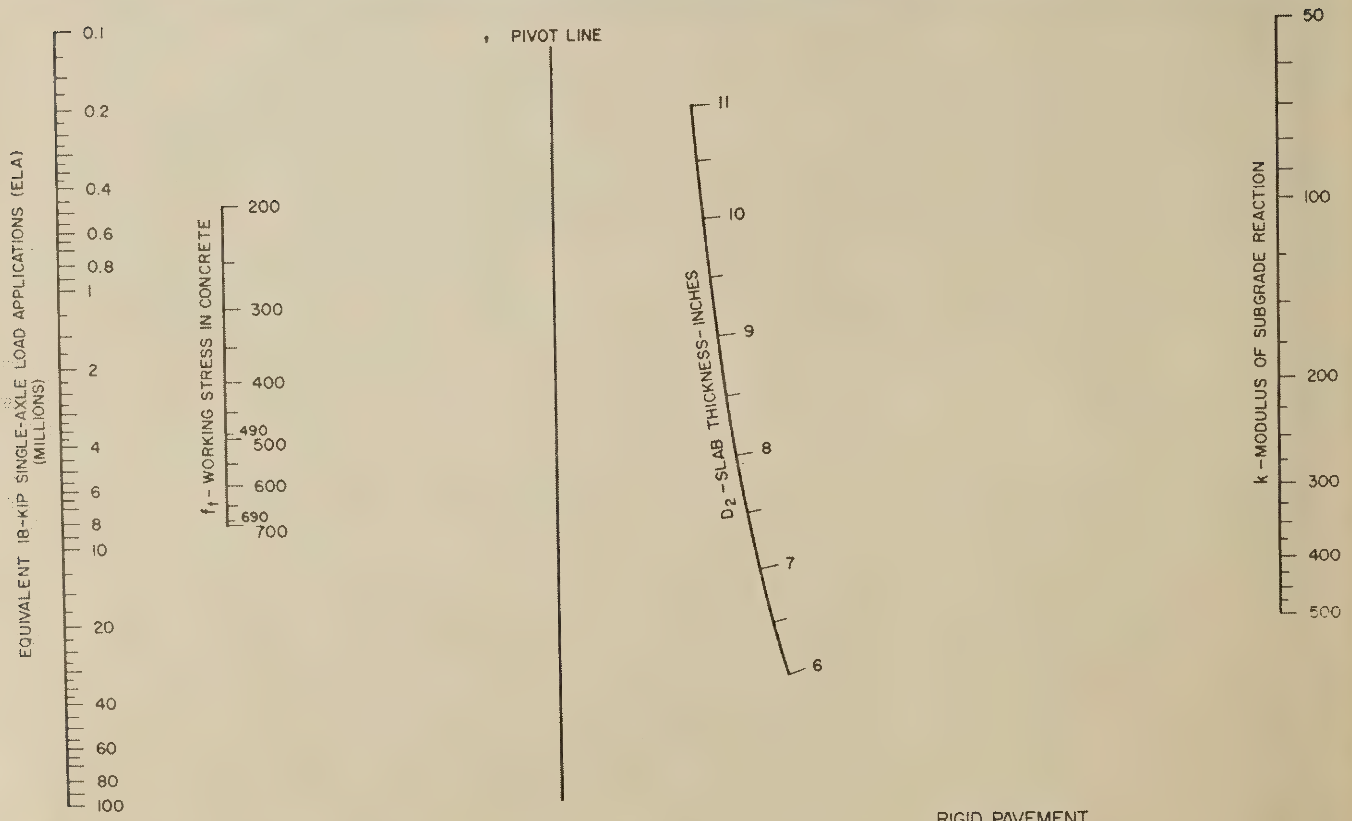


SERVICE LIFE NOMOGRAPH

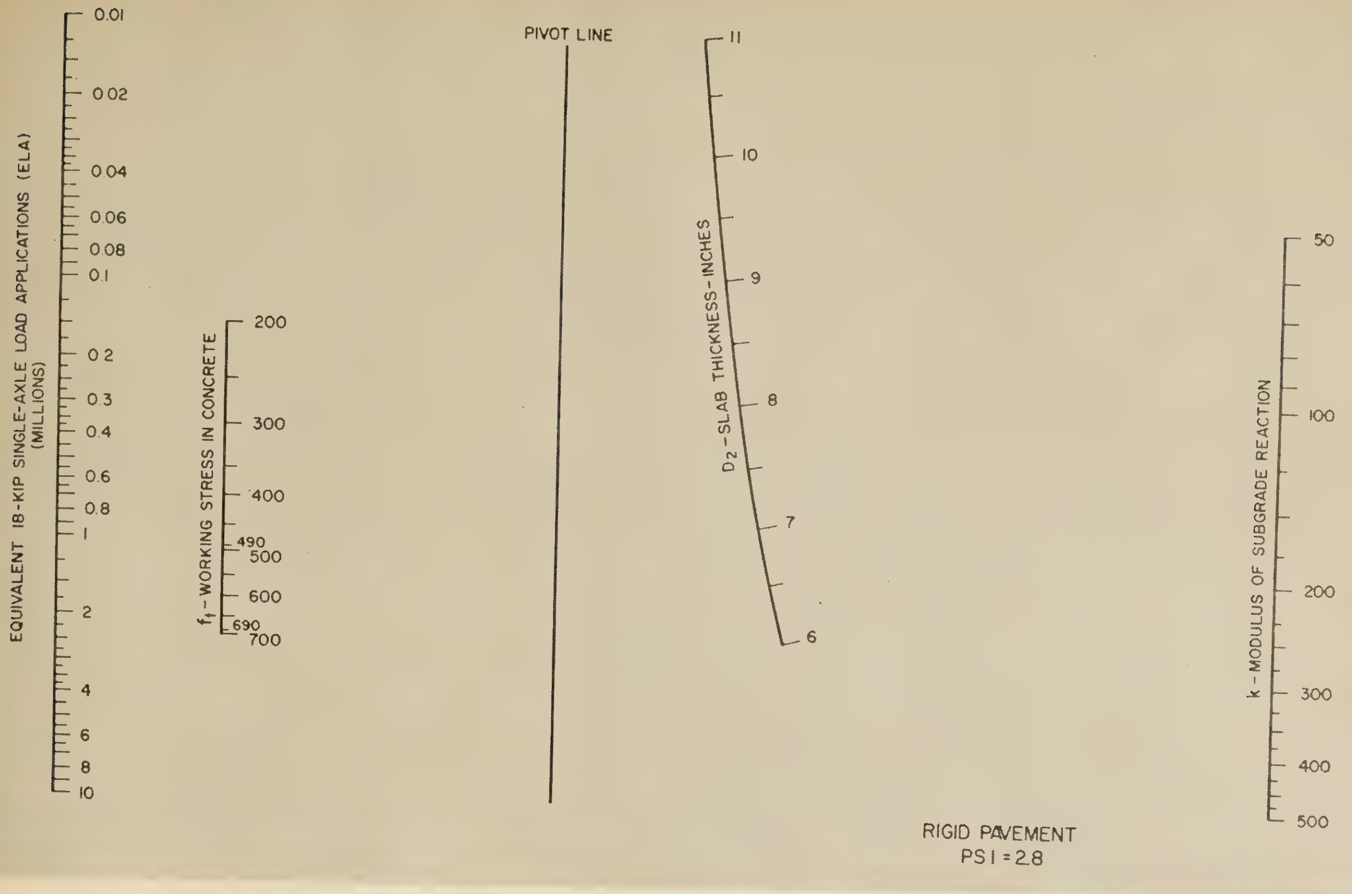


RIGID PAVEMENT
PSI = 2.5

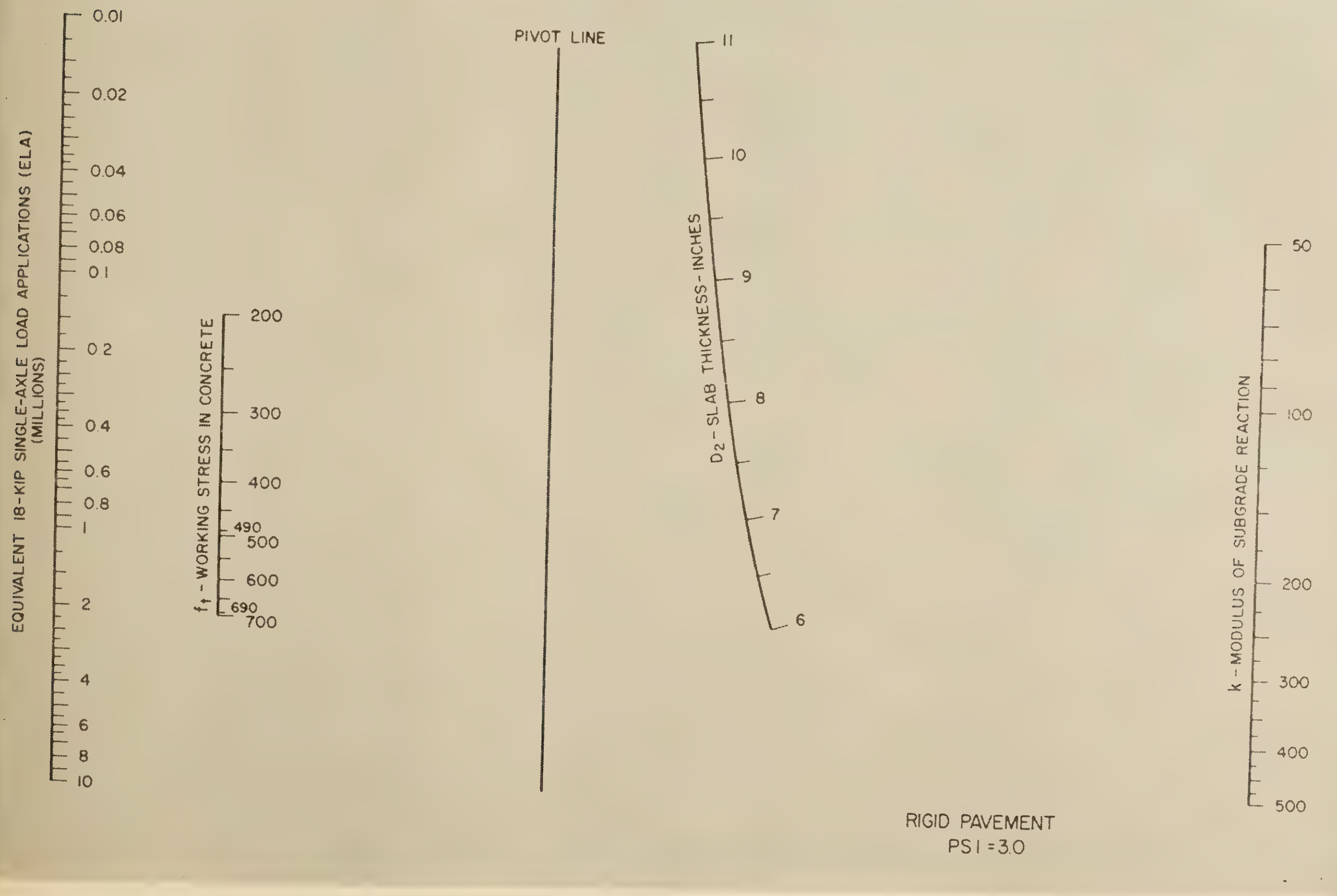
SERVICE LIFE NOMOGRAPH



RIGID PAVEMENT
PSI = 2.6

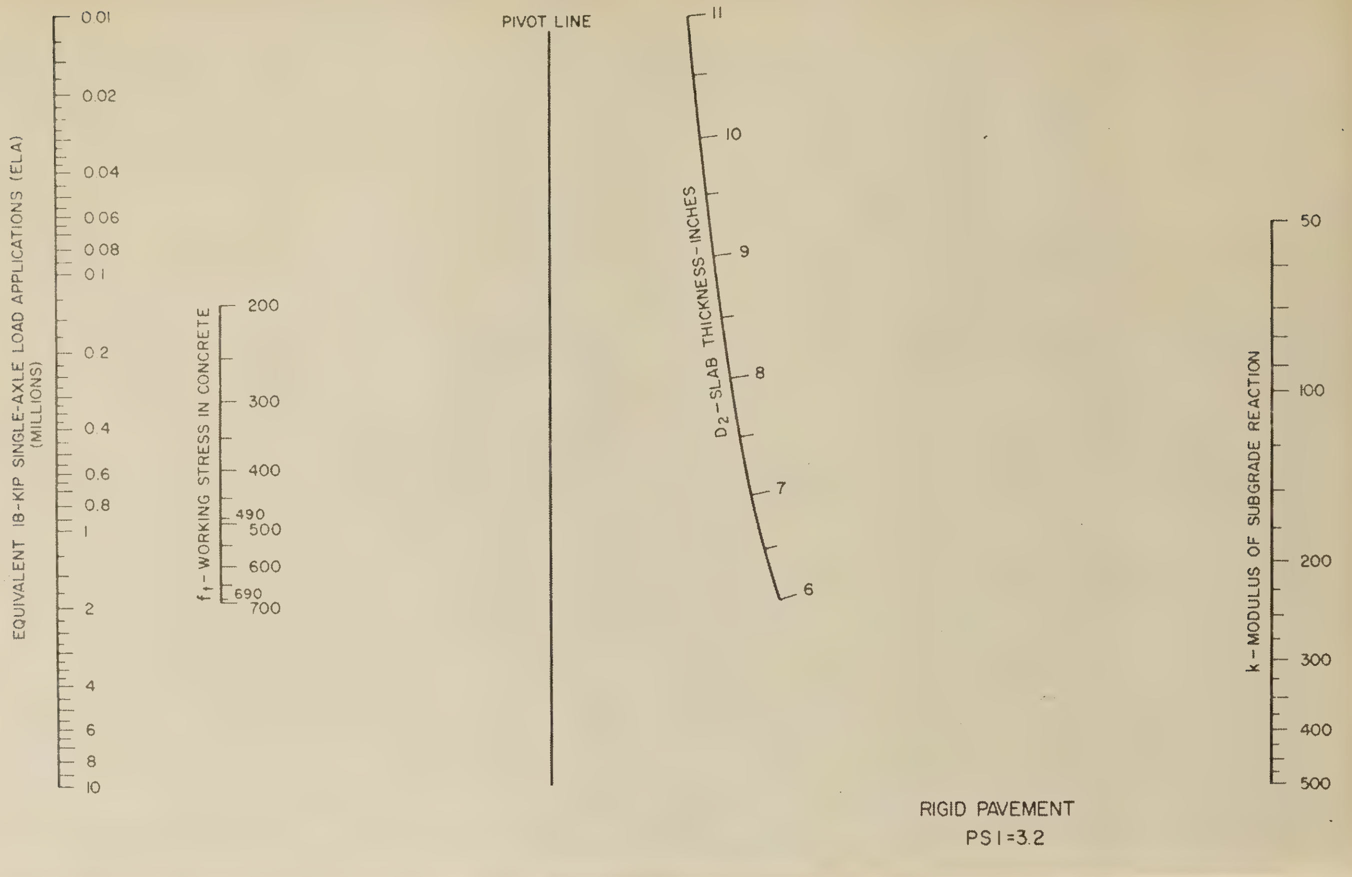


SERVICE LIFE NOMOGRAPH

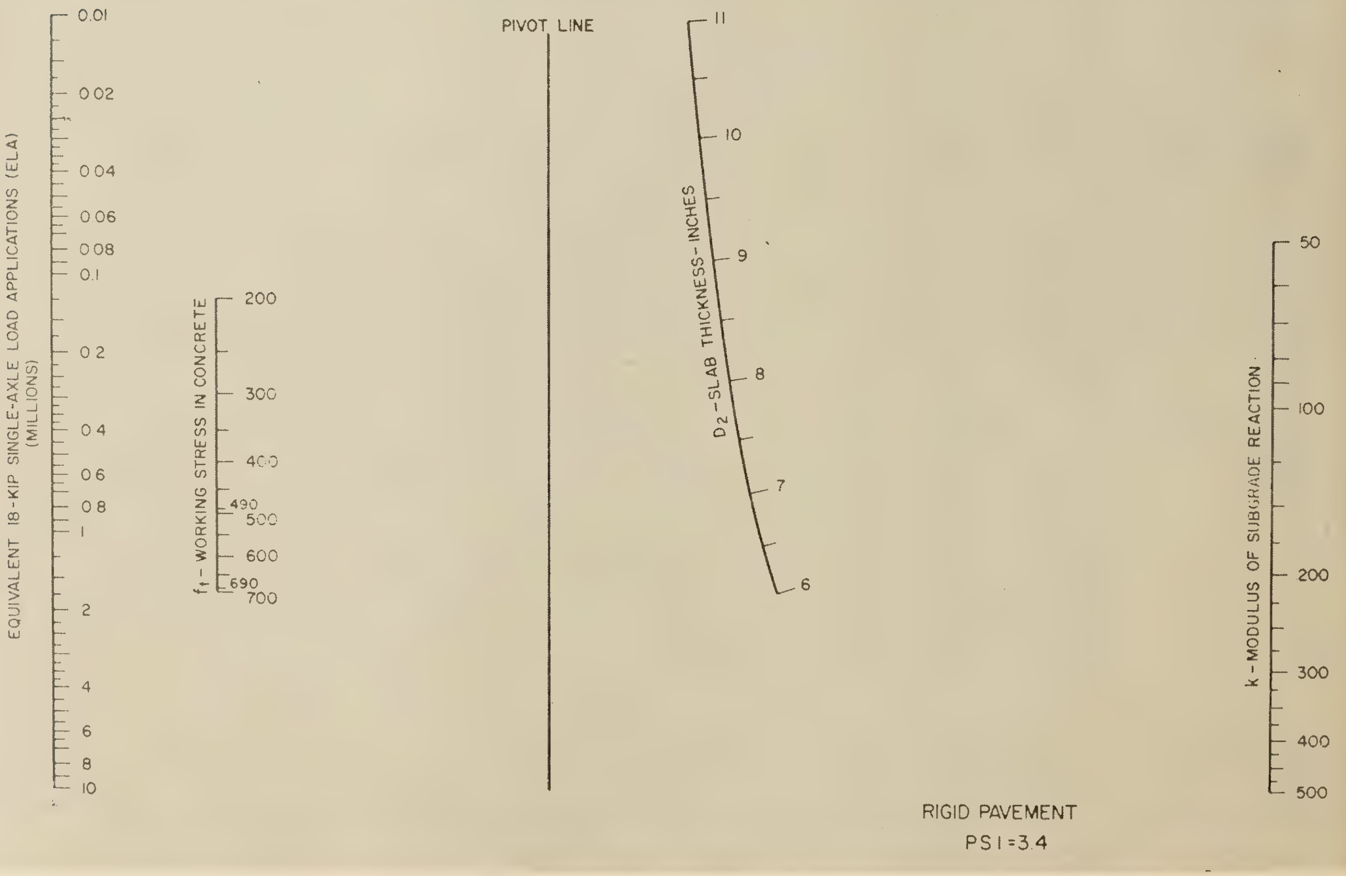


SERVICE LIFE NOMOGRAPH

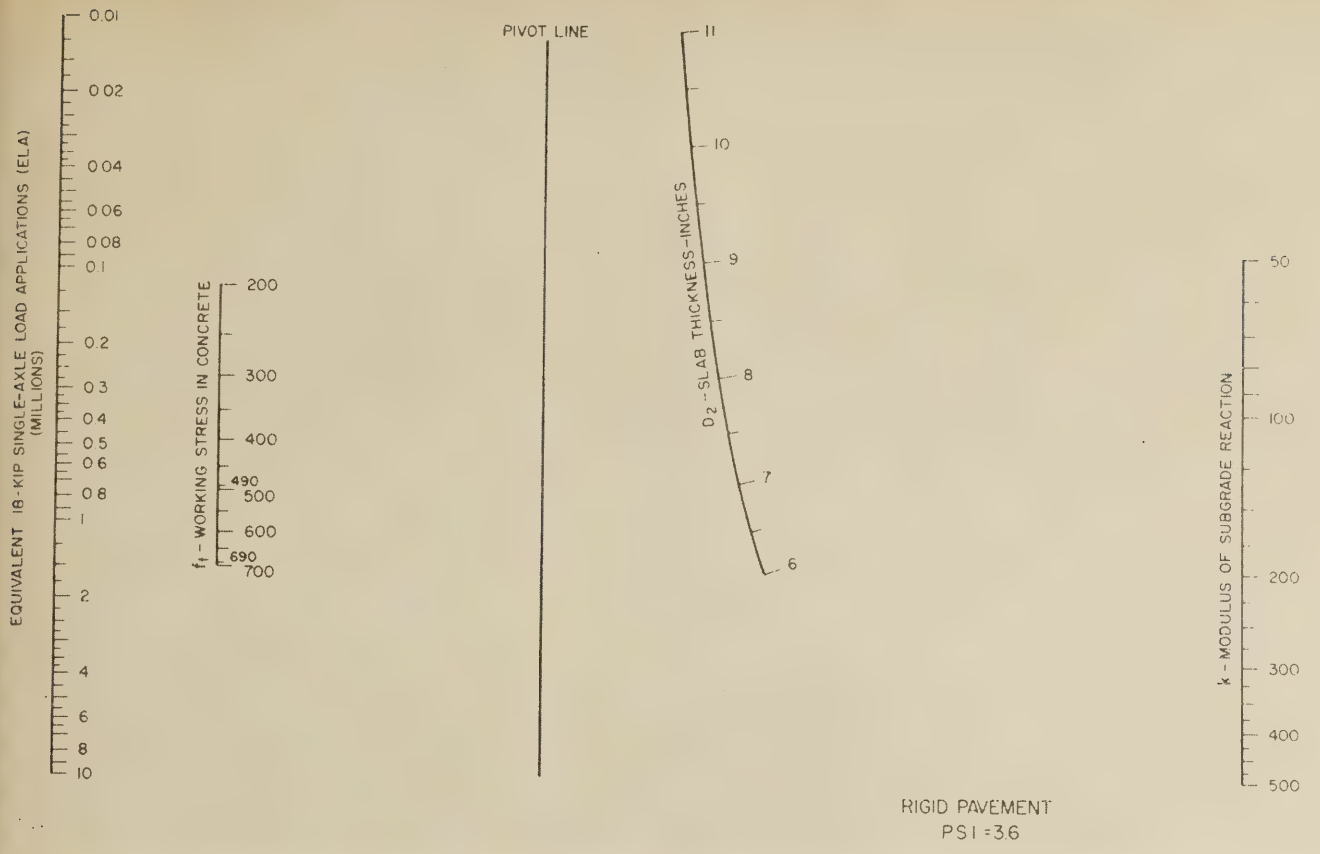
SERVICE LIFE NOMOGRAPH



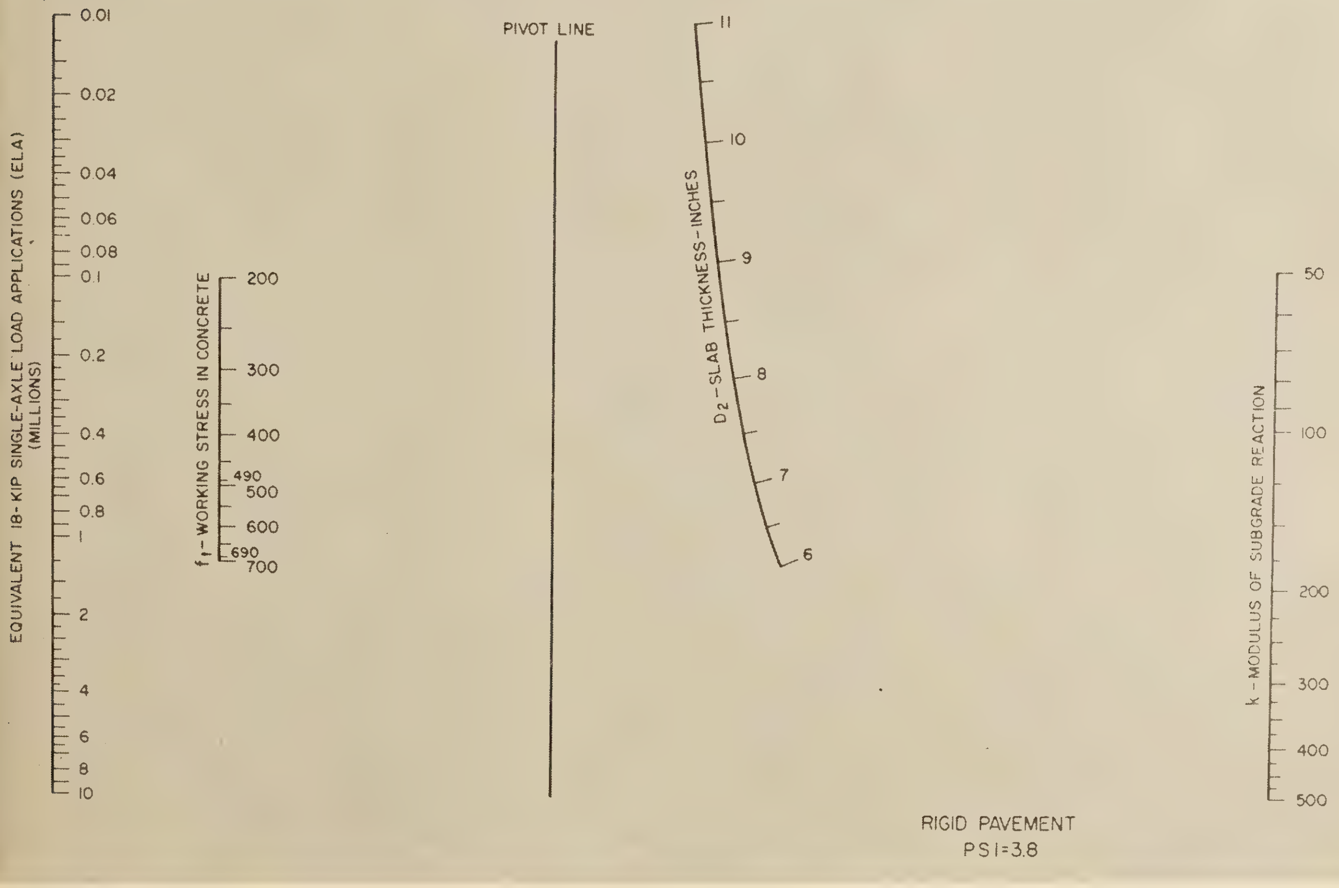
SERVICE LIFE NOMOGRAPH



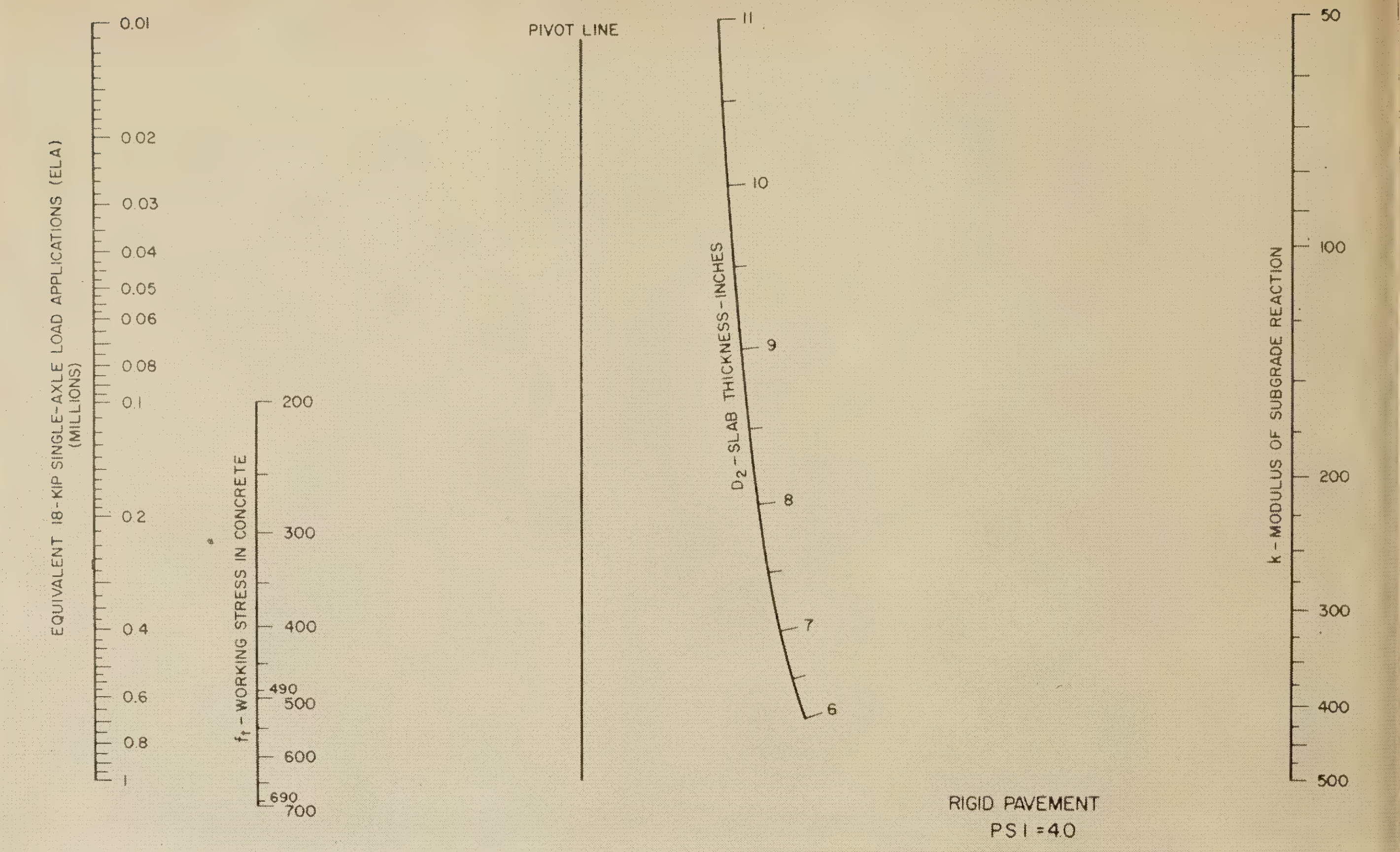
SERVICE LIFE NOMOGRAPH



SERVICE LIFE NOMOGRAPH



SERVICE LIFE NOMOGRAPH



Highway Research and Development Reports Available From National Technical Information Service

The following highway research and devel- ment reports are available from the National echnical Information Service (formerly the learinghouse for Federal Scientific and Tech- ical Information), Sills Building, 5285 Port oyal Road, Springfield, Va. 22151. Paper pies are priced at $3 each and microfiche copies 65 cents each. To order, send the stock number each report desired and a check or money order the National Technical Information Service. repayment is required.

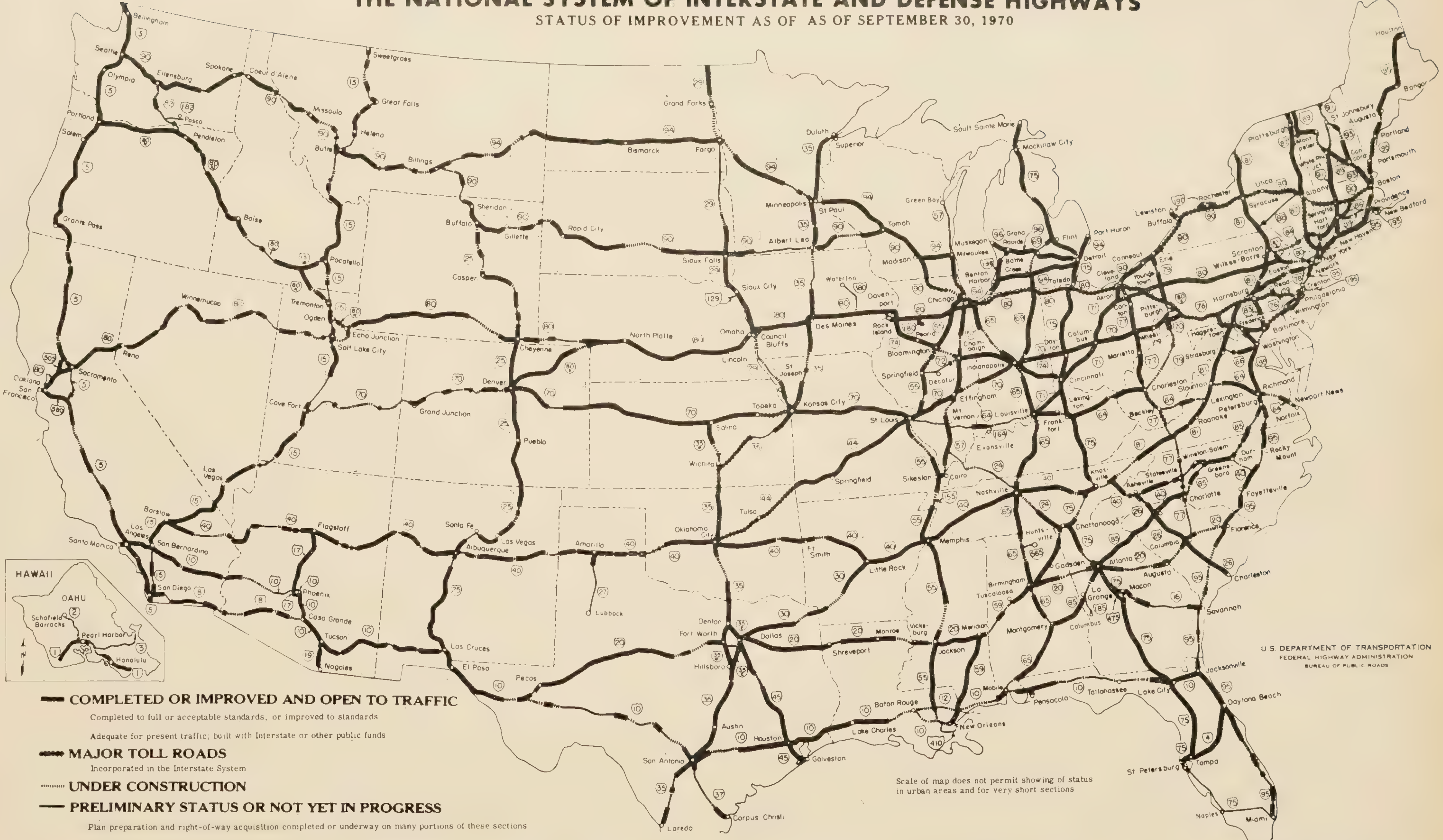
Highway research and development reports vailable from the National Technical Informa- on Service are also listed by subject in Public oads annual publication Highway Research nd Development Studies (see inside back cover) ccording to the goals and projects of the national rogram of highway research and development.

Stock No.	
B 191157	Final Report Projections of Socioeconomic Data to 1967, 1975, 1990.
B 191196	Transportation in Connecticut—2020.
B 191272	Highway Research and Development Studies in Progress as of July 1, 1969.
B 191774	Twenty-Eighth Short Course on Roadside Development.
B 191839	A General Traffic Flow Simulation Model for Freeway Operation.
B 191877	Effects of Chemical and Mineralogical Properties on the Engineering Characteristics of Arkansas Soils.
B 191878	Bridge Deck Deterioration Study, Part 2—Effectiveness of Various Bituminous Covers in Preventing Bridge Deck Deterioration.
B 191880	Performance of Concrete Bridges Reinforced With Hing-Strength Steel, First Interim Report.
B 191881	Asphalt Cement Viscosity and Penetration.
B 191882	Experimental Paved Shoulders on Frost Susceptible Soils.
B 191883	Load Distribution for a Drilled Shaft in Clay Shale.
B 191978	A Discrete-Element Method of Multiple-Loading Analysis for Two-Way Bridge Floor Slabs.
B 191979	Stresses and Displacements in Viscoelastic Pavement Systems Under a Moving Load.
B 191980	Behavior and Performance of Flexible Pavements Evaluated in the University of Illinois Pavement Test Track.
B 191981	Stability of Slender Prestressed Concrete Piling Phase II.
B 191982	Fill Placement Rates for Highway Embankments.
B 192005	Concrete Probe-Strength Study.
B 192006	Commuter Parking at Highway Interchanges.
B 192012	Air-Rights Potentials in Major Highway Criteria for Joint-Development.
B 192013	Ambient Vibration Survey of New Port Bridge.
B 192014	Ambient Vibration Survey of Chesapeake Bay Bridge.
B 192018	Development and Validation of a Digital Simulation Model for Research in Geometric Design and Control of Diamond Interchanges.
B 192019	Bituminous Mixture Analysis by Process Control.
B 192040	Traffic Systems Reviews and Abstracts: April 1970 Issue.
B 192109	State of the Art Study of Tubular Member in Highway Structures.
B 192169	Benefit Measurements on Highway Electronic Route Guidance.
PB 192470	Bridge Deck Deterioration Study, Part 9—Epoxy Seal Coats and Epoxy Mortar Patching for Bridge Decks.
PB 192471	Oxidation Cracking of Asphalt Pavement Report No. 4.
PB 192472	Effect of Synthetic Aggregate Thermal Transformation on Performance of Concrete.
PB 192473	Fundamental Factors Involved in the Use of Synthetic Aggregate Portland Cement Concrete.
PB 192474	Fired-Clay Aggregates for Use in Flexible Bases.
PB 192475	Predicting Performance of Pavements by Deflection Measurements.
PB 192476	1969 Annual Report Vegetation Control on Roadsides and Similar Areas.
PB 192477	Judgment of Vehicle Speed and Traffic Problems Phase I.
PB 192479	Development of a Hydraulic-Plastic Barrier for Impact-Energy Absorption.
PB 192480	Penn Avenue Interchange Study.
PB 192481	Soil Resilience Test for Virginia Flexible Pavement Design Method.
PB 192482	Bridge Deck Deterioration Study, Part 5—Effectiveness of Bituminous Seals in Preventing Deterioration of New Concrete Bridge Decks.
PB 192483	A Study of Coatings Based on Water Soluble Linseed Oil to be Used as a Concrete Curing Membrane.
PB 192541	The Statistical Approach to Quality Control in Highway Construction, Phase II, Developing Acceptance Sampling Plans and Phase III—Trial Use of Acceptance Sampling Plans Part B Asphalt Construction.
PB 192565	Use of Synthetic Rubber-in-Asphalt Pavement to Determine Mixture Behavior, Pavement Performance.
PB 192566	Thermoheologic Properties.
PB 192889	A Study of Winter Maintenance of Bituminous Pavements in Texas.
PB 192899	Composite Bridge Stringers.
PB 192900	Louisiana Slabjacking Study.
PB 192901	Flange Buckling Studies.
PB 192902	Skid Resistance of Polished Aggregates, Field and Laboratory Investigation.
PB 192912	Ultimate Strength of Plate Girders Under Shear—1937.
PB 192917	Studies of the Thermal Transformation of Synthetic Aggregates Produced in a Rotary Kiln.
PB 192919	Ultimate Strength of Transversely and Logitudinally Stiffened Plate Girders.
PB 192920	South Dakota Interstate Routes.
PB 192923	Supplementary Studies in Highway Illumination.
PB 192924	A Recommended Texas Highway Department Pavement Design System User's Manual.
PB 192927	Mini-Computers and Traffic Control.
PB 192929	Traffic Systems Reviews and Abstracts: June 1970 Issue.
PB 192937	A Systems Approach Applied to Pavement Design and Research.
PB 192966	A Direct Computer Solution for Plane Frames.
PB 192978	Molecular Size Distribution of Asphalt as Determined by Gel Permeation Chromatography.
PB 192980	Freeze-and-Thaw Phenomena in Concretes and Aggregates.
PB 192984	An Energy Absorbing Reusable Highway Protective System.
PB 193099	Bridge Stress Range History and Diaphragm Stiffening Investigation.
PB 193100	Evaluation of an Emergency Call Box System.
PB 193101	Basic Mechanics Study for Computer Evaluation of Automobile Barrier Systems.
PB 193104	Traffic Sensor Program.
PB 193105	Static and Fatigue Behavior of Continuous Composite Beams With High-Strength Bolts as Shear Connectors.
PB 193106	Static Behavior in the Negative-Moment Region of Composite Beams Using Bolts as Shear Connectors.
PB 193107	Traffic Simulation for the Design of Uniform Service Roads in Mountainous Terrain: Volume I—Experimental Program.
PB 193108	Volume II—Description and Validation of the Simulation.
PB 193109	Volume III—Simulation Results and Design Criteria.
PB 193110	Volume IV—User's Manual for the Simulation.
PB 193111	Subgrade Moisture Variations Evaluation of Collected Data 1966 1969.
PB 193112	Investigation of Soil-Structure Interaction: Flexible Culvert Pipes.
PB 193114	Study of a Proposed Precast-Prestressed Composite Bridge System.
PB 193115	Benkelman Beam Deflection Test Parameter Investigation on Arkansas Highways.
PB 193119	Forecasting of Heavy Loading Patterns on Highway Bridges.
PB 193130	Highway Sign Study.
PB 193481	Incremental Costs of Bridges.
PB 193781	Development of a Methodology for Evaluating Road Signs.
PB 193825	Experimental Verification of Descrete-Element Solutions for Plates and Pavement Slabs.
PB 193826	Dynamic Overturning Loads on Drilled Shaft Footings Used for Minor Service Structures.
PB 193831	Investigation of Paints and Glass Beads Used in Traffic Delineation Markings, Phase I.
PB 193832	Final Performance Report on Experimental Use of Thermoplastic Pavement—Striping Materials.
PB 193860	Investigating Sources of Variances in Bituminous Concrete Testing: Part I, 1967—1968 Study.
PB 193861	Part II, 1968—1969 Study.
PB 193863	Experimental Lime Stabilization in Nebraska.
PB 193864	Analysis of Accident Data Reporting and Use of Accident Records.
PB 193865	Judgment of Vehicle Speed and Traffic Patterns, Phase II.
PB 193866	Economic Survey of Anthony, New Mexico-Texas.
PB 193867	Application of Instrumental Methods for Evaluating Highway Materials.
PB 193868	Freeway Surveillance Studies, 1969 Annual Report.
PB 193875	Evaluation of the Use of Antistripping Additives in Asphaltic Concrete Mixtures.
PB 193876	Determination of Cement Content of Hardened Slag Concrete.
PB 193877	Truck Equivalency.
PB 193878	Equipment for the Establishment and Maintenance of Roadside Cover.
PB 193879	Development and Evaluation of Second Generation Analog Merging Controllers.
PB 193888	Finishability of Gap-Graded Versus Continuously-Graded Concrete—Report No. 8.
PB 193889	Optimum Mix Design for Gap-Graded Concrete—Report No. 9.
PB 193901	Gap Acceptance and Traffic Interaction in the Freeway Merging Process, Phase II.
PB 193902	Workability of Gap-Graded Versus Continuously-Graded Concrete and the Correlation Between Slump and Vebe Time—Report No. 3.

Other highway research and development reports available from the National Technical Information Service will be announced in future issues.

THE NATIONAL SYSTEM OF INTERSTATE AND DEFENSE HIGHWAYS

STATUS OF IMPROVEMENT AS OF AS OF SEPTEMBER 30, 1970



COMPLETED OR IMPROVED AND OPEN TO TRAFFIC

Completed to full or acceptable standards, or improved to standards

Adequate for present traffic; built with Interstate or other public funds

MAJOR TOLL ROADS

Incorporated in the Interstate System

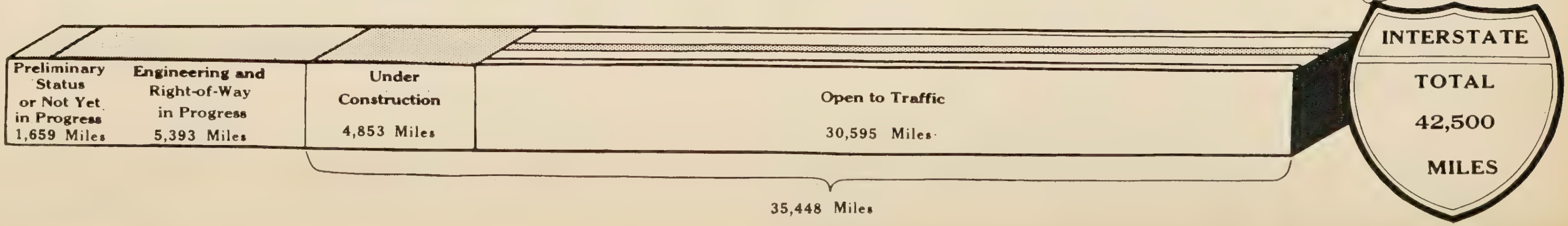
UNDER CONSTRUCTION

PRELIMINARY STATUS OR NOT YET IN PROGRESS

Plan preparation and right-of-way acquisition completed or underway on many portions of these sections

Scale of map does not permit showing of status in urban areas and for very short sections

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BUREAU OF PUBLIC ROADS



Preliminary Status or Not Yet in Progress	Engineering and Right-of-Way in Progress	Under Construction	Open to Traffic	INTERSTATE TOTAL
1,659 Miles	5,393 Miles	4,853 Miles	30,595 Miles	42,500 MILES

35,448 Miles

U.S. GOVERNMENT PRINTING OFFICE: 1970

PUBLICATIONS of the Federal Highway Administration

A list of articles in past issues of Public Roads *and title sheets or volumes 24–35 are available upon request from the Federal ighway Administration, U.S. Department of Transportation, ashington, D.C. 20591.*

The following publications are sold by the Superintendent of ocuments, Government Printing Office, Washington, D.C. 20402. rders should be sent direct to the Superintendent of Documents. repayment is required.

ccidents on Main Rural Highways—Related to Speed, Driver, and Vehicle (1964). 35 cents.

ggregate Gradation for Highways: Simplification, Standardization, and Uniform Application, and A New Graphical Evaluation Chart (1962). 25 cents.

merica's Lifelines—Federal Aid for Highways (1969). 35 cents.

nalysis and Modeling of Relationships between Accidents and the Geometric and Traffic Characteristics of the Interstate System (1969). $1.00.

Book About Space (1968). 75 cents.

ridge Inspector's Training Manual (1970). $2.50.

he Bridge to Your Success (1969). 45 cents.

alibrating & Testing a Gravity Model for Any Size Urban Area (1968). $1.00.

apacity Analysis Techniques for Design of Signalized Intersections (Reprint of August and October 1967 issues of PUBLIC ROADS, a Journal of Highway Research). 45 cents.

onstruction Safety Requirements, Federal Highway Projects (1967). 50 cents.

orrugated Metal Pipe (1970). 35 cents.

reating, Organizing, & Reporting Highway Needs Studies (Highway Planning Technical Report No. 1) (1963). 15 cents.

atal and Injury Accident Rates on Federal-Aid and Other Highway Systems, 1968. 45 cents.

ederal-Aid Highway Map (42x65 inches) (1970). $1.50.

ederal Laws, Regulations, and Other Material Relating to Highways (1970). $2.50.

ederal Role in Highway Safety, House Document No. 93, 86th Cong., 1st sess. (1959). 60 cents.

he Freeway in the City (1968). $3.00.

reeways to Urban Development, A new concept for joint development (1966). 15 cents.

uidelines for Trip Generation Analysis (1967). 65 cents.

andbook on Highway Safety Design and Operating Practices (1968). 40 cents.
  Supplement No. 1 (Nov. 1968). 35 cents.
  Supplement No. 2 (Nov. 1969). 40 cents.

ighway Beautification Program. Senate Document No. 6, 90th Cong., 1st sess. (1967). 25 cents.

ighway Condemnation Law and Litigation in the United States (1968):
  Vol. 1—A Survey and Critique. 70 cents.
  Vol. 2—State by State Statistical Summary of Reported Highway Condemnation Cases from 1946 through 1961. $1.75.

ighway Cost Allocation Study: Supplementary Report, House Document No. 124, 89th Cong., 1st sess. (1965). $1.00.

ighway Finance 1921–62 (a statistical review by the Office of Planning, Highway Statistics Division) (1964). 15 cents.

ighway Planning Map Manual (1963). $1.00.

ighway Research and Development Studies Using Federal-Aid Research and Planning Funds (1969). $1.50.

ighway Statistics (published annually since 1945):
  1966, $1.25; 1967, $1.75; 1968, $1.75.
  (Other years out of print.)

ighway Statistics, Summary to 1965 (1967). $1.25.

ighway Transportation Criteria in Zoning Law *and* Police Power and Planning Controls for Arterial Streets (1960). 35 cents.

Highways and Human Values (Annual Report for Bureau of Public Roads) (1966). 75 cents.
  Supplement (1966). 25 cents.

Highways to Beauty (1966). 20 cents.

Highways and Economic and Social Changes (1964). $1.25.

Hydraulic Engineering Circulars:
  No. 5—Hydraulic Charts for the Selection of Highway Culverts (1965). 55 cents.
  No. 10—Capacity Charts for the Hydraulic Design of Highway Culverts (1965). 65 cents.
  No. 11—Use of Riprap for Bank Protection (1967). 40 cents.
  No. 12—Drainage of Highway Pavements (1969). $1.00.

Hydraulic Design Series:
  No. 1—Hydraulics of Bridge Waterways, 2d ed. (1970). $1.25.
  No. 2—Peak Rates of Runoff From Small Watersheds (1961). 30 cents.
  No. 3—Design Charts for Open-Channel Flow (1961). $1.50.
  No. 4—Design of Roadside Drainage Channels (1965). 65 cents.

Identification of Rock Types (1960). 20 cents.

Increasing the Traffic-Carrying Capability of Urban Arterial Streets: The Wisconsin Avenue Study (1962). Out of print—(Request from Federal Highway Administration).

The 1965 Interstate System Cost Estimate, House Document No. 42, 89th Cong., 1st sess. (1965). 20 cents.

Interstate System Route and Log Finder List (1963). 10 cents.

Joint Development and Multiple Use (1970). $1.50.

Labor Compliance Manual for Direct Federal and Federal-Aid Construction, 3d ed. (1970). $3.75.

Landslide Investigations (1961). 30 cents.

Manual for Highway Severance Damage Studies (1961). $1.00.

Manual on Uniform Traffic Control Devices for Streets and Highways (1961). $2.00.
  Part V only of above—Traffic Controls for Highway Construction and Maintenance Operations (1962). 25 cents.

Maximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-Aid Systems, House Document No. 354, 88th Cong. 2d sess. (1964). 45 cents.

Maximum Safe Speed for Motor Vehicles (1969). $1.00.

Modal Split—Documentation of Nine Methods for Estimating Transit Usage (1966). 70 cents.

Motor Carrier Safety Regulations (1968). 45 cents.

National Driver Register. A State Driver Records Exchange Service (1967). 25 cents.

National Highway Needs Report, H. Comm. Print 90–22 90th Cong. 2d sess. (1968). 25 cents. Supplement 10 cents.

The National System of Interstate and Defense Highways (1969). 15 cents.

Overtaking and Passing on Two-Lane Rural Highways—a Literature Review (1967). 20 cents.

Presplitting. A Controlled Blasting Technique for Rock Cuts (1966). 30 cents.

Proposed Program for Scenic Roads & Parkways (prepared for the President's Council on Recreation and Natural Beauty), 1966. $2.75.

Quality Assurance in Highway Construction. (Reprinted from PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH, vol. 35, Nos. 6–11, 1969). 50 cents.

Reinforced Concrete Bridge Members—Ultimate Design (1969). 45 cents.

Reinforced Concrete Pipe Culverts—Criteria for Structural Design and Installation (1963). 30 cents.

Road-User and Personal Property Taxes on Selected Motor Vehicles (1970). 65 cents.

(Continued on reverse side)

UNITED STATES
GOVERNMENT PRINTING OFFICE
DIVISION OF PUBLIC DOCUMENTS
WASHINGTON, D.C. 20402

OFFICIAL BUSINESS

If you do not desire to continue to receive this publication, please CHECK HERE ☐: tear off this label and return it to the above address. Your name will then be removed promptly from the appropriate mailing list.

Publications of the Federal Highway Administration—Continued

Role of Economic Studies in Urban Transportation Planning (1965). 65 cents.

The Role of Third Structure Taxes in the Highway User Tax Family (1968). $2.25.

Second Annual Highway Beauty Awards Competition (1969). 50 cents.

Specifications for Aerial Surveys and Mapping by Photogrammetrical Methods for Highways (1968). $1.25.

Standard Alphabets for Highway Signs (1966). 30 cents.

Standard Land Use Coding Manual (1965). 50 cents.

Standard Plans for Highway Bridges:
  Vol. I—Concrete Superstructures (1968). $1.25.
  Vol. II—Structural Steel Superstructures (1968). $1.00.
  Vol. III—Timber Bridges (1969). 75 cents.
  Vol. IV—Typical Continuous Bridges (1969). $1.50.
  Vol. V—Typical Pedestrian Bridges (1962). $1.75.

Standard Specifications for Construction of Roads and Bridge on Federal Highway Projects (1969). $3.50.

Standard Traffic Control Signs Chart (as defined in the Manua on Uniform Traffic Control Devices for Streets and Highways) 22 x 34, 20 cents—100 for $15.00. 11 x 17, 10 cents—100 fo $5.00.

Study of Airspace Utilization (1968). 75 cents.

Traffic Safety Services, Directory of National Organization (1963). 15 cents.

Transition Curves for Highways (1940). $2.50.

Ultrasonic Testing Inspection for Butt Welds in Highway an Railway Bridges (1968). 40 cents.