Application of Road Test Formulas in Structural Design of Pavement

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• The analysis of data obtained in the AASHO Road Test controlled traffic studies has resulted in a set of equations that explains the performance of the test pavements in terms of pavement design, axle load and configuration, and number of axle load applications. These equations apply directly to the pavement designs, axle loadings, and traffic of the Road Test, and to the conditions of embankment soil, pavement materials, and physical environment that existed for the test. It has been expected that the equations must be modified to be applicable where either external or internal influences differ appreciably from those which existed during the Road Test.

Assuming that the Road Test performance equations will require modification for practical application, it is necessary that evidence of the effects of variations in the factors that influence pavement performance be established before the modifications can be made. This evidence may be obtained by additional experimentation through the establishment of satellite research projects, and by analysis of the behavior of existing pavements in regular service.

Obviously, a considerable savings of time and expense can be realized if data already available or easily obtained for existing pavements can be used in providing suitable modifications for practical application of the Road Test equations.

This paper discusses work that is being done by the Illinois Division of Highways in examining the Road Test performance equations by comparing the performance of Illinois pavements of various designs serving under varying traffic conditions for variable periods of time with the performance predicted by the equations.

The pavements selected for the study are on the rural primary system in areas where the roadbed soils are similar to those of the Road Test. These pavements are located mostly in the northern half of the State where climatic and environmental conditions are generally the same as in the immediate area of the Road Test at Ottawa. Many of the pavements were being or recently had been retired from service. It was anticipated that the study would provide data for modifying the Road Test equations to represent the performance that the Road Test pavements would have given had they been subjected to a normal life span of service under regular mixed traffic. It was also presumed that studies conducted on pavements in this area would be advantageous in the early stages of exploration of the equations by lessening the number of probable significant variables so that the individual effects of the remaining variables could be better assessed.

The results of the Illinois study encourage the belief that the Road Test performance equations can be modified suitably for practical application to rural highway pavements serving under normal environmental conditions by applying data from existing pavements. It also appears evident that the equations can not be applied to regular rural highway pavements without modification, at least under conditions typical of much of the Midwest. Definite trends now appear to have been established between actual performance of Illinois pavements and the performance as predicted by the Road Test equations when suitably modified. The study suggests relatively simple procedures for developing factors to modify the equations so that they can be applied directly to the design and evaluation of highway pavements.

AASHO ROAD TEST EQUATIONS

Essential to the development of the Road Test equations was the establishment of a definition of, and a system for measuring, pavement performance. The definition that was evolved was founded on the basic principle that the prime function of a pavement is to serve for the comfort and convenience of the traveling public. The system of measurement that was developed established the degree to which the public considers itself to be served. This system has come to be known as the Pavement Serviceability-Performance System.

The system generated on the AASHO Road Test is one of the most powerful tools ever to be placed in the hands of highway engineers. It offers, for the first time, a standardized rational means for measuring on a nationwide basis the performance of pavements of any design.

Under the new system, the term "present serviceability" was chosen to represent the ability of a highway pavement to serve high-volume, high-speed, mixed truck and passenger vehicle traffic at the moment it is rated. Performance is then determined by summarizing the serviceability records over a period of time or number of axle-load applications. The system was derived through the use of the subjective serviceability ratings of a great number of typical pavements rated by a panel of men selected to represent many important groups of highway users. A mathematical index (Present Serviceability Index) was developed and validated through which the subjective serviceability ratings could be estimated from objective measurements taken on the pavement. This latter development was fundamental to the work described in this paper.

Details regarding the development of the Pavement Serviceability-Performance System and the Road Test pavement performance equations have been stated in HRB Special Report 61E.

For the convenience of the reader in following the subsequent discussion, the Road Test equations are repeated here.

Rigid pavement equations:

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

in which

p = present serviceability index;
$\overline{SV}$ = mean slope variance in the two wheelpaths as measured by the AASHO profilometer;
C = the lineal feet of cracking per 1,000 sq ft of pavement area (this includes the lengths taken parallel or perpendicular to the pavement, whichever is greater, of all cracks that are sealed and all cracks that are opened or spalled at the surface for a width of one-fourth inch or more for at least half of their length); and
P = square feet of bituminous patching per 1,000 sq ft of pavement area.

$$\log W = \log \rho + \frac{\log\left(\frac{4.5 - p}{3}\right)}{\beta} \quad (2)$$

in which

W = the number of axle load applications required to reduce the serviceability level from 4.5 to p, and
ρ and β = both positive functions of the design and load variables. ρ is the estimate applications at which p = 1.5 and β determines the shape of the serviceability trend with time.

$$\log \rho = 5.85 + 7.35 \log (D_2 + 1) + 3.28 \log L_2 - 4.62 \log (L_1 + L_2) \quad (3)$$

in which

D_2 = concrete pavement slab thickness, in inches;
L_1 = nominal axle load (single or tandem), in kips; and
L_2 = two-value constant, with value of 1 for single axles and 2 for tandem axles.

$$\log (\beta - 1) = 0.56 + 5.20 \log (L_1 + L_2) - 8.46 \log (D_2 + 1) - 3.52 \log L_2 \quad (4)$$

All terms are as previously defined.

Flexible pavement equations:

$$p = 5.03 - 1.91 \log (1 + \overline{SV}) - 0.01 \sqrt{C + P} - 1.38 (\overline{RD})^2 \quad (5)$$

in which

C = square feet of cracking per 1,000 sq ft of pavement area (this includes only cracking that has progressed to the stage where cracks have connected together to form a grid-type pattern or where the surfacing segments have become loosened); and
$\overline{RD}$ = mean depth of rutting in both wheelpaths measured in inches under a 4-ft straightedge.

All remaining terms are as previously defined.

$$\log W = \log \rho + \frac{\log\left(\frac{4.2 - p}{2.7}\right)}{\beta} \quad (6)$$

All terms are as previously defined except W is the number of applications required to reduce the serviceability level from 4.2 to p.

$$\log \rho = 5.93 + 9.36 \log (D + 1) + 4.33 \log L_2 - 4.79 \log (L_1 + L_2) \quad (7)$$

in which

D = thickness index = $0.44D_1 + 0.14D_2 + 0.11D_3$ (D_1, D_2, and D_3 are thicknesses in inches of surfacing, base, and subbase, respectively).

All other terms are as previously defined.

$$\log (\beta - 0.4) = 3.23 \log (L_1 + L_2) - 5.19 \log (D + 1) - 3.23 \log L_2 - 1.09 \quad (8)$$

All terms are as previously defined.

FACTORS OF INFLUENCE

The pavement performance equations include terms for pavement design, axle loading and axle configuration, number of axle load applications, and serviceability level. Each of these factors can be determined independently for any existing pavement with available data on pavement design and traffic, and with relatively simple measurements of pavement surface smoothness and structural condition.

Pavement Design

The AASHO Road Test pavement performance equations relate specifically to portland cement concrete pavement and to bituminous concrete on granular-material pavement of the thicknesses, materials, and physical properties of the pavements on the project. The Illinois pavements which have been used in examining the applicability of the performance equations to pavements in regular service are of the types and within the range of thicknesses employed on the Road Test project. In the preliminary analysis, the pavement materials and the physical properties of the completed structures have been considered to not be variables of consequence. This simplifying assumption appears to be reasonable in the preliminary stage of analysis, particularly when it is considered that no great differences with respect to materials and physical properties existed in most instances between the Road Test pavements and normal Illinois pavements.

Axle Loadings

The Road Test axle loadings cover not only the range of loadings now being used in regular service, but extend beyond the ordinary range into heavier loadings than are now permitted to travel regularly on the highway system. Both single- and tandem-axle loadings as used in regular service were used on the test pavements.

The Road Test traffic differed from regular traffic in that vehicles traveling any one test section had identical axle loads and arrangements. However, the experimental design permits the use of the resultant data in the reduction of regular mixed traffic loadings to a number of equivalent fixed axle loads for analysis.

The axle loadings on the Road Test project covered a range varying from 2,000- to 30,000-lb single-axle loads and 12,000- to 48,000-lb tandem-axle loads. As indicated previously, the performance equations suggest a means by which normal mixed axle loadings can be reduced to some equivalent axle loading for comparison with the Road Test axle loadings. For example, this can be done by expressing axle loadings of any weight in terms of 18,000-lb (18-kip) single-axle equivalencies as follows:

$$\text{18-kip S equiv.} = \frac{\text{No. 18-kip S appl. to } p = 1.5 \ (\rho\ 18S)}{\text{No. } x\text{-kip appl. to } p = 1.5 \ (\rho\ x)}$$

For rigid pavement:

$$R_{18S} = \frac{(L_1 + L_2)^{4.62}}{808{,}800\,(L_2)^{3.28}} \qquad (9)$$

in which

R_{18S} = Number of 18-kip single-axle loads equivalent to one axle load (L_1) in question;

L_1 = Nominal axle load (single or tandem), in kips; and

L_2 = 1 for single axles, 2 for tandem axles.

For flexible pavement:

$$R_{18S} = \frac{(L_1 + L_2)^{4.79}}{1{,}334{,}000\,(L_2)^{4.33}} \qquad (10)$$

Eqs. 9 and 10 are developed on the basis of equivalent loadings at a present serviceability index of 1.5. The choice of this value was made because the Road Test equations are such that its use considerably simplifies the computations. Although the equivalencies vary somewhat with variations in the present serviceability index and with pavement design, these variations have not been taken into consideration in preparing the illustrations used in this paper. It is assumed that this has not appreciably affected the result used for illustration.

To assess the applicability of the Road Test equations to existing pavements, it is necessary first to estimate the number and weight of axle loadings that have been applied to these pavements. To do this for the Illinois pavements, use was made of vehicle count information and loadometer survey data gathered through the years beginning in 1936.

Traffic data available in Illinois permit fairly close estimates of the number and type of vehicles, and of the number, type and configuration of axle loadings, to which any pavement of the rural primary highway system has been subjected in any year since 1936. Vehicle volume data available for the secondary and local systems are less reliable but still useful when applied to such pavements. Only isolated data are available on vehicle types, and on axle volume, type and configuration, on secondary and urban rural highways.

Distribution of commercial vehicles by type is shown in Figure 1. Dash lines have been used to indicate projections beyond the year 1959, the last year for which data were available at the time the study began.

Loadometer axle-weight surveys, in combination with classified vehicle and axle counts, have been made with regularity since 1956 at 19 locations on Illinois primary highways. Most of these locations are on primary truck routes. The loadometer data, as a consequence, are considered to be less accurate for estimating the weight of axle loadings than is the axle

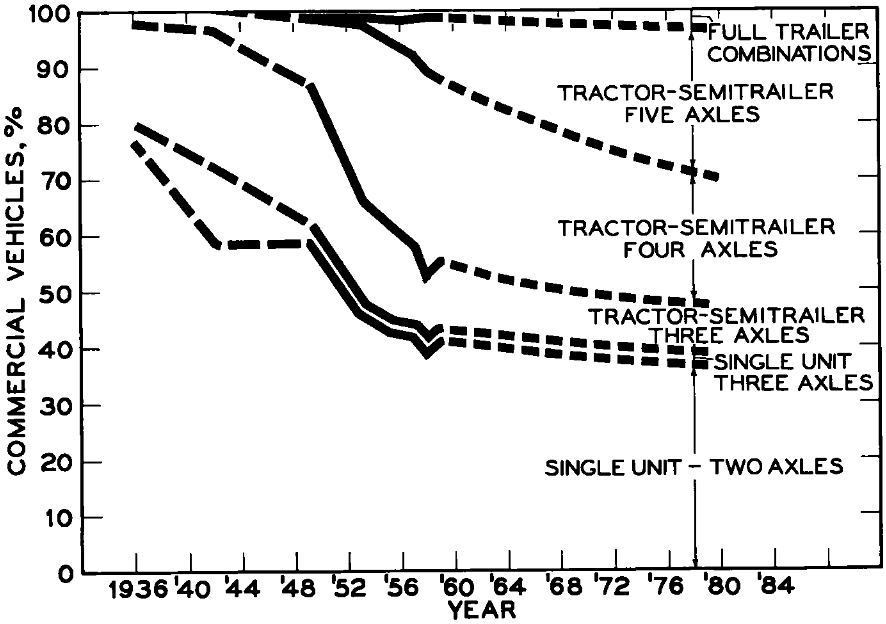

Figure 1. Distribution of commercial vehicle types at loadometer stations in Illinois.

count data for estimating number of applications. The loadometer data are probably not suitable for application to light traffic rural primary pavements and rural secondary and local pavements.

The loadometer data for the 19 stations were combined to provide a single statewide average commercial axle-load distribution which is considered to be applicable to any pavement of the rural primary system. Actually, this can be expected to result in substantial overestimates in some instances and underestimates in others. Nevertheless, it is believed that the assumption is reasonable at the pilot stage of the work described in the paper. However, additional refinement is desirable in this area, and work in this direction should be undertaken.

Average distributions of single axle and of individual axles of tandem pairs by weight in the truck traffic stream on Illinois pavements, as determined from loadometer studies and classified vehicle counts, are shown in Figures 2 and 3. Dash lines are used to indicate projections beyond the year 1959, the last year for which actual data were available.

Passenger-vehicle axle loadings were considered separate from the commercial axle loadings and were assumed to be 2,000 lb each. This, of course, is not entirely consistent with observed conditions. However, additional refinement does not appear to be warranted as even a considerable change in axle-load distribution of passenger vehicles would have very little effect on the total 18-kip equivalent axle loads for any pavement.

A trend through the years toward the use of commercial vehicles with increased numbers of axles is evident in Figure 1. A trend through the years toward the use of heavier commercial axle loadings is evident in Figures 2 and 3.

By substitution of the appropriate axle-weight and distribution data in Eqs. 9 and 10, the loadings of mixed traffic can be represented by equivalent 18-kip single-axle loads. Axle loadings were grouped in 2-kip increments of weight up to 20 kips, the highest weight recorded in the field studies. Percentage distributions taken from Figures 2 and 3 were applied to the weight groups in computing the over-all distributions.

Using a base of 100 commercial axles, 18-kip single-axle load equivalents were computed for all years for which loadometer data were available between 1936 and 1959, and also for the years 1968 and 1975. The results are shown in Figure 4 for rigid pavements and in Figure 5 for flexible pavements. A pronounced upward trend through the years toward heavier axle loadings is evident.

In the work described in this paper, the total 18-kip equivalent single-axle loads representative of the axle loadings applied through the years to any pavement of the primary system is estimated by determining the number of axle loadings using the recorded passenger and commercial vehicle counts and data on commercial axle distribution from Figure 1, together with the equivalence indicated in either Figures 4 or 5 depending on the pavement type.

Pavement Serviceability

The remaining factor to be considered in applying the Road Test equations to existing pavements is the serviceability level. As stated

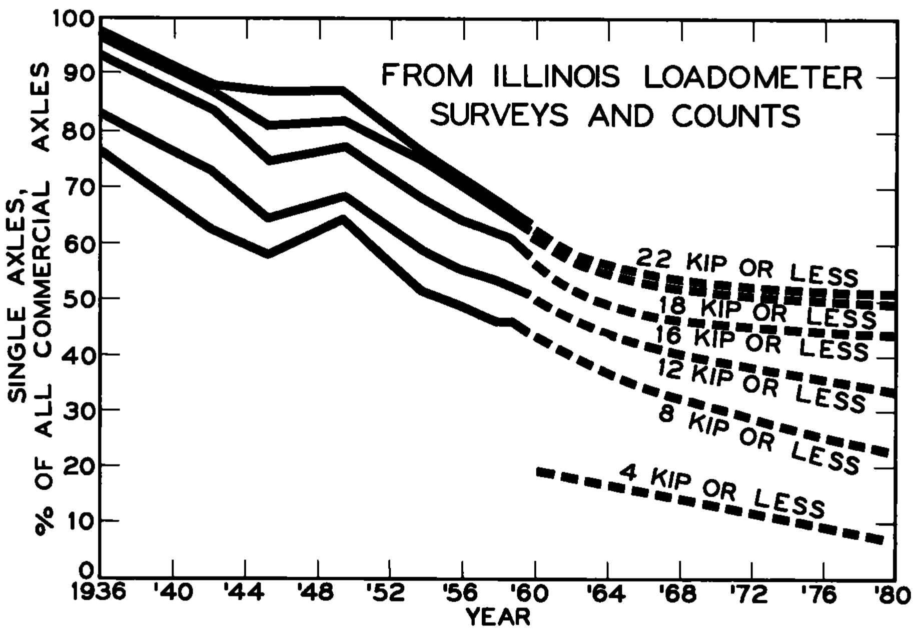

Figure 2. Proportion and distribution of single axles in commercial traffic axle stream.

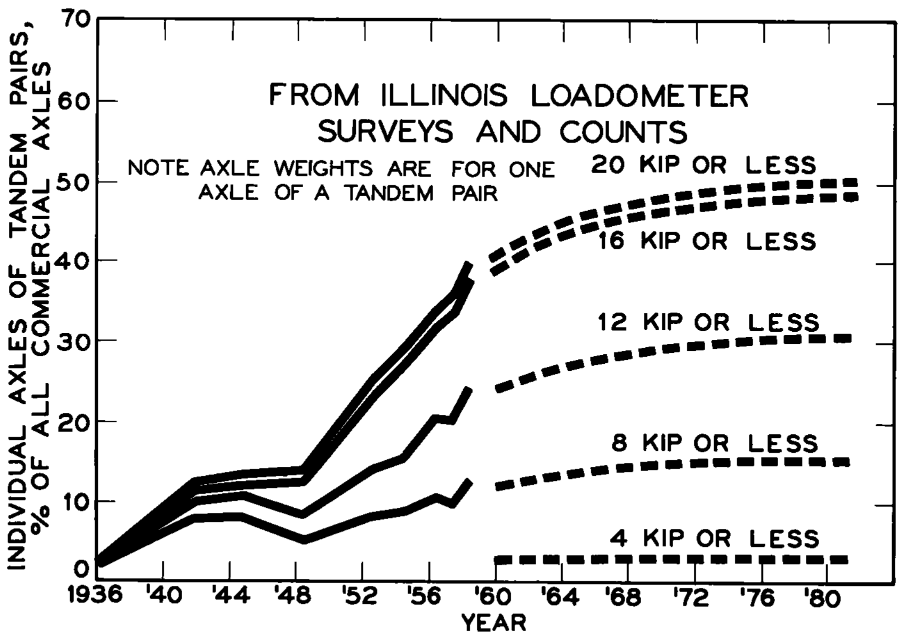

Figure 3. Proportion and distribution of individual axles of tandem pairs in commercial traffic axle stream.

previously, the serviceability level of a pavement at the time of rating can be expressed by a mathematical index that is determined by a series of objective measurements made on the pavement. The mathematical index is termed the "Present Serviceability Index" (PSI).

The PSI of a pavement, as used in the Road Test equations, is determined by its observed structural condition and surface smoothness. The observed structural condition, which is expressed in terms of the amount of patching and cracking, together with the amount of rutting in the case of flexible pavements, can be determined by relatively simple pavement condition surveys. Surface smoothness can be measured with any of several available devices. All that is necessary for comparisons with Road Test results on a country-wide basis is that the output of the particular device be correlated with the output of the device used on the Road

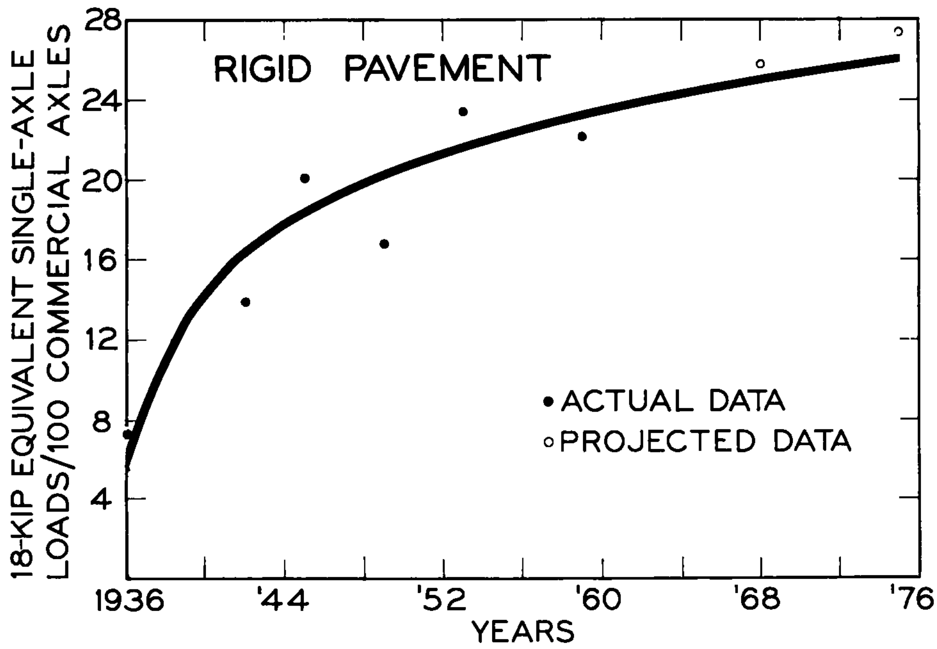

Figure 4. Equivalent loading vs time, rigid pavement.

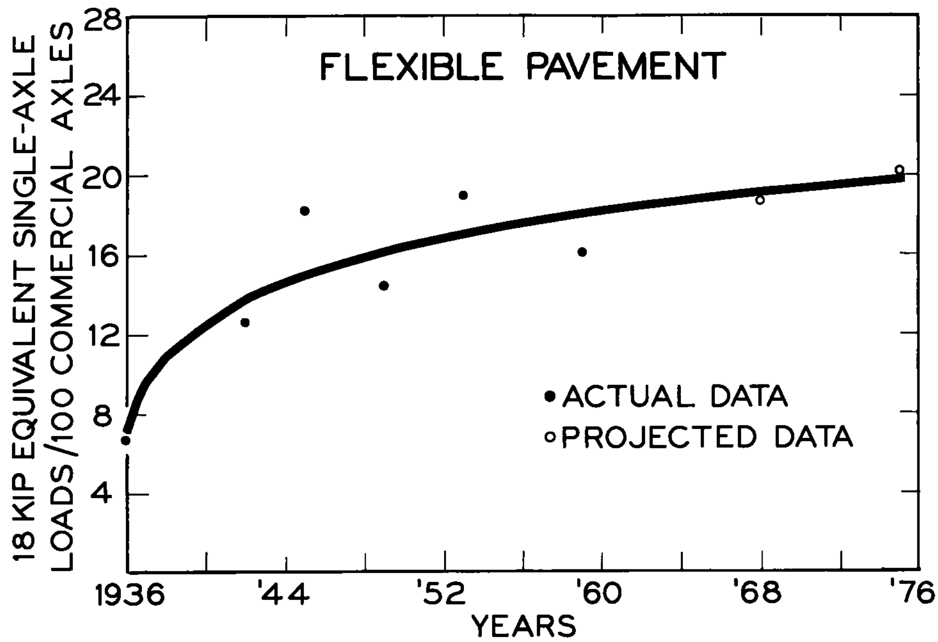

Figure 5. Equivalent loading vs time, flexible pavement.

Test, either directly or indirectly through correlation with a previously correlated device.

The surface smoothness of Illinois pavements is being measured with a BPR-type roadometer (Fig. 6). The roadometer is basically a single-wheel trailer that is towed over the pavement at a speed of 20 mph. The wheel is linked to the trailer by two single-leaf springs. Two damping units help control the movement of the wheel with respect to the chassis. The device operates on the fundamental principle that vertical oscillations of the wheel with reference to the chassis are indicative of the riding quality of a pavement. The output of the machine is vertical movement in inches over a measured distance of travel. The resultant inches of vertical movement per mile of travel is termed the "roughness index." The roadometer proper is housed within the outrigger trailer hitched to the towing vehicle.

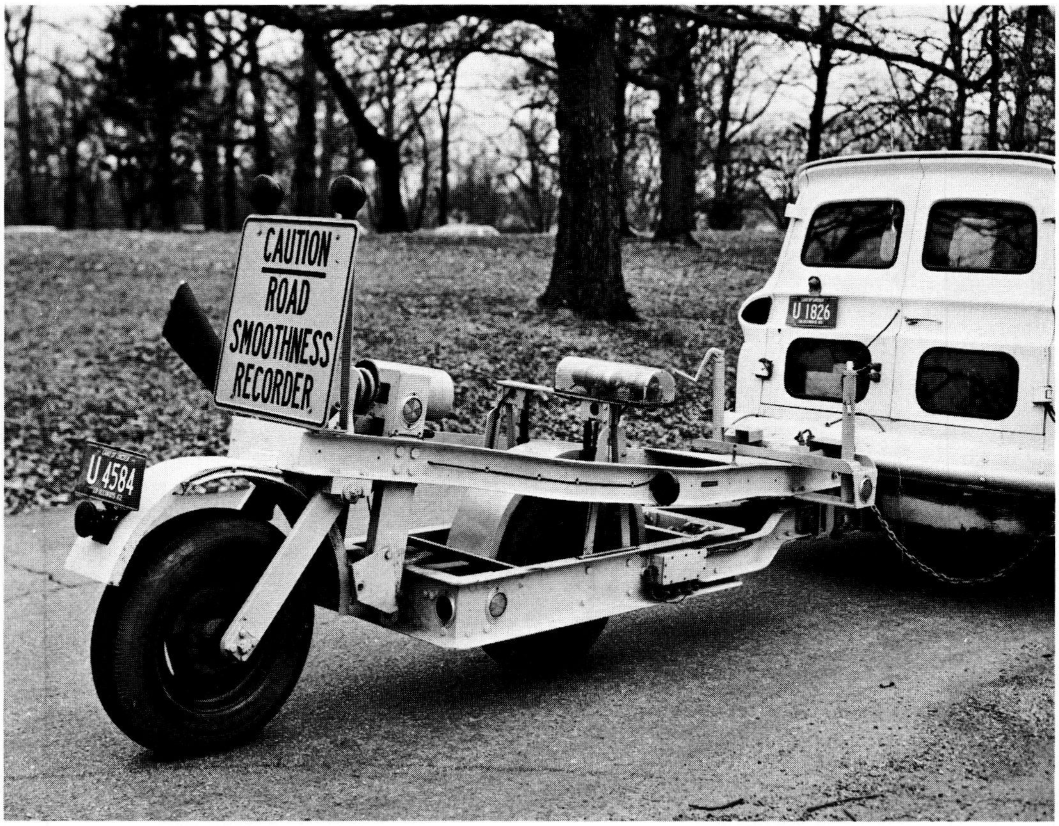

Figure 6. BPR-type roadometer used by Illinois.

Correlation of the Illinois roadometer with the Road Test profilometer has furnished the following equations for determining the PSI.

Portland cement concrete pavement:

$$p = 12.0 - 4.27 \log \overline{RI} - 0.09 \sqrt{C + P} \quad (11)$$

in which the terms are as previously defined except $\overline{RI}$ is the roughness index, in inches per mile as measured by the Illinois Roadometer.

Bituminous concrete (on granular base) pavement:

$$p = 10.91 - 3.90 \log \overline{RI} - 0.01 \sqrt{C+P} - 1.38 \overline{RD}^2 \quad (12)$$

All terms are as previously defined.

Other agencies, even those using the BPR-type roadometer, will need to develop correlation equations for their own pieces of equipment. This need is illustrated in Table 1 where it will be seen that rather wide variations exist

TABLE 1

Variations in Present Serviceability Index Formula for Different BPR-Type Roadometers

State	Rigid Pavement	Flexible Pavement
Ill.	$p = 12.00 - 4.27 \log \overline{RI} - 0.09 \sqrt{C + P}$	$p = 10.91 - 3.90 \log \overline{RI} - 0.01 \sqrt{C + P} - 1.38 \overline{RD}^2$
Ind.	$p = 15.53 - 5.83 \log \overline{RI} - 0.09 \sqrt{C + P}$	$p = 12.54 - 4.49 \log \overline{RI} - 0.01 \sqrt{C + P} - 1.38 \overline{RD}^2$
Mich.	$p = 14.10 - 4.73 \log \overline{RI} - 0.09 \sqrt{C + P}$	$p = 13.82 - 4.83 \log \overline{RI} - 0.01 \sqrt{C + P} - 1.38 \overline{RD}^2$
Mo.	$p = 13.73 - 5.00 \log \overline{RI} - 0.09 \sqrt{C + P}$	$p = 16.53 - 6.82 \log \overline{RI} - 0.01 \sqrt{C + P} - 1.38 \overline{RD}^2$
Va.	$p = 14.30 - 5.15 \log \overline{RI} - 0.09 \sqrt{C + P}$	$p = 12.71 - 4.64 \log \overline{RI} - 0.01 \sqrt{C + P} - 1.38 \overline{RD}^2$

Note: p = Present Serviceability Index; $\overline{RI}$ = roughness index; C = amount of cracking; P = amount of patching; and $\overline{RD}$ = rut depth.

in formulas that have been developed for several pieces of equipment, all of which in this case were BPR-type roadometers constructed to the same standard plans furnished by the U.S. Bureau of Public Roads. It is also desirable that the various devices be correlated with an acceptable standard so that the results obtained by different agencies can be compared.

APPLYING ROAD TEST EQUATIONS TO EXISTING PAVEMENTS

As previously stated, the Illinois pavements selected for use in developing a method for applying the Road Test equations to pavements in regular service are on the primary highway system in the northern part of the State where foundation conditions, on the average, and other physical environmental conditions, are very similar to those at the site of the Road Test. Hence, these conditions were considered in the analysis as being the same as existed on the Road Test.

It was anticipated that the degree to which the performance equations are applicable to highway pavements in regular service could be investigated by comparing the actual performance of the selected pavements with the performance as predicted by the equations. The actual performance was estimated from the measured present serviceability level of the pavement and the estimated number of 18-kip equivalent single-axle loads estimated to represent the loads actually applied.

The total number of 18-kip equivalent single-axle loadings representative of the loadings applied during the life of each of the pavements was estimated in accordance with the principles established in the previous section of this report. PSI's were determined from surface smoothness measurements and pavement condition surveys as outlined previously.

Performance data for the Illinois pavements were plotted against the Road Test equations to indicate the degree to which the equations are applicable to these highway pavements in regular service. Typical plots for uniform 10-in. portland cement concrete pavement, 9-6-9 in. thickened-edge sections, and bituminous concrete (on granular base) pavement with a thickness index of 4.5 are shown in Figures 7, 8 and 9, respectively. PSI's are plotted as a function of the log of the number of 18-kip single-axle load equivalents.

These plots demonstrate that the equations can not be applied directly, as they predict a higher level of performance than was actually obtained in regular service. However, definite trends exist which appear to indicate that the performance of the regular highway pavements agrees closely with the performance of pavements on the Road Test that are of a lesser thickness. This suggests the hypothesis that the general form of the performance equations is applicable, at least within a range of PSI of about 1.5 to 3, and that the equations can be suitably modified to represent actual conditions by developing a factor for adjusting the design thickness represented in the equations for ρ and β. Early indications are that the factor is not

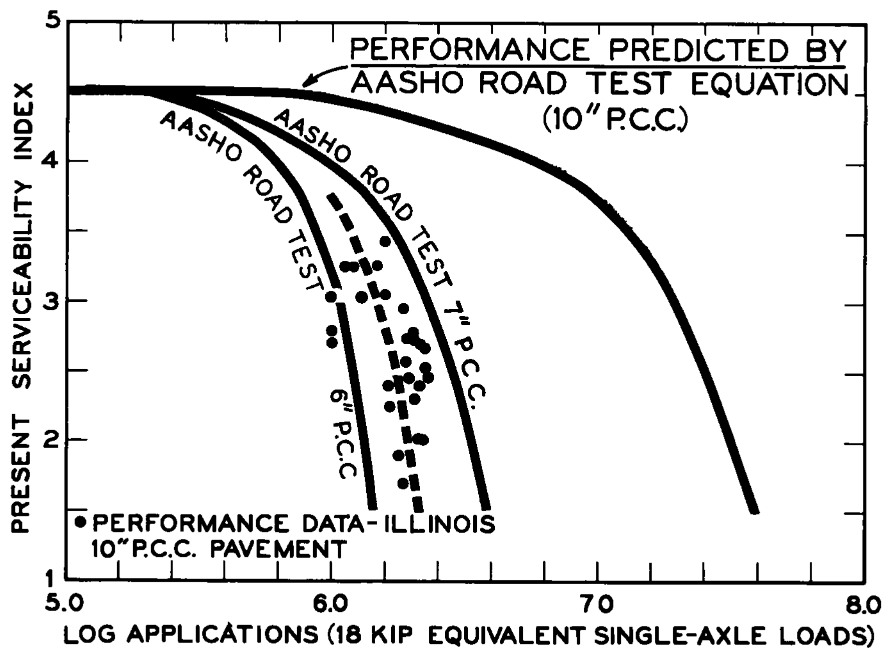

Figure 7. Performance of Illinois 10-in. PCC pavement vs predicted performance by AASHO Road Test equations.

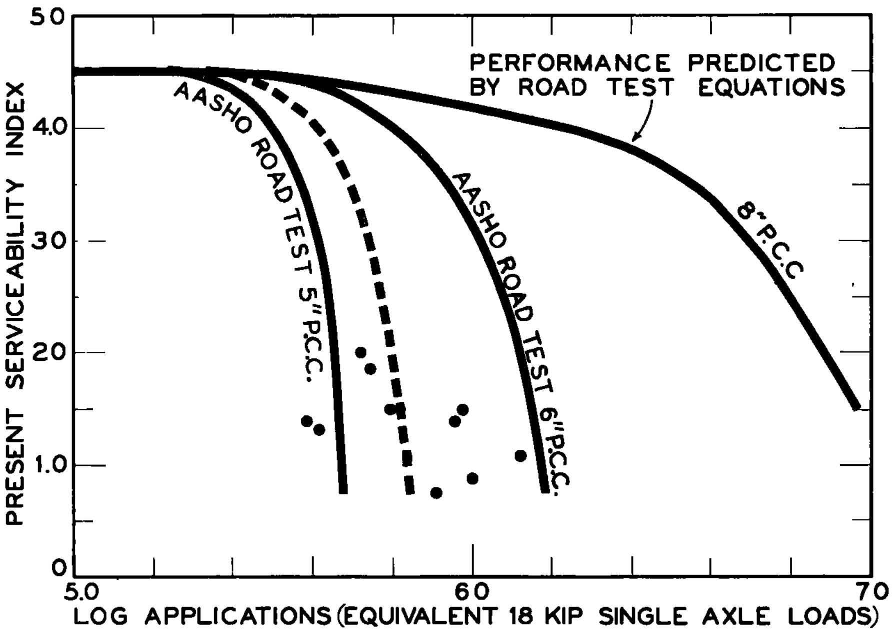

Figure 8. Performance of Illinois 9-6-9 in. pavement vs predicted performance by AASHO Road Test equations.

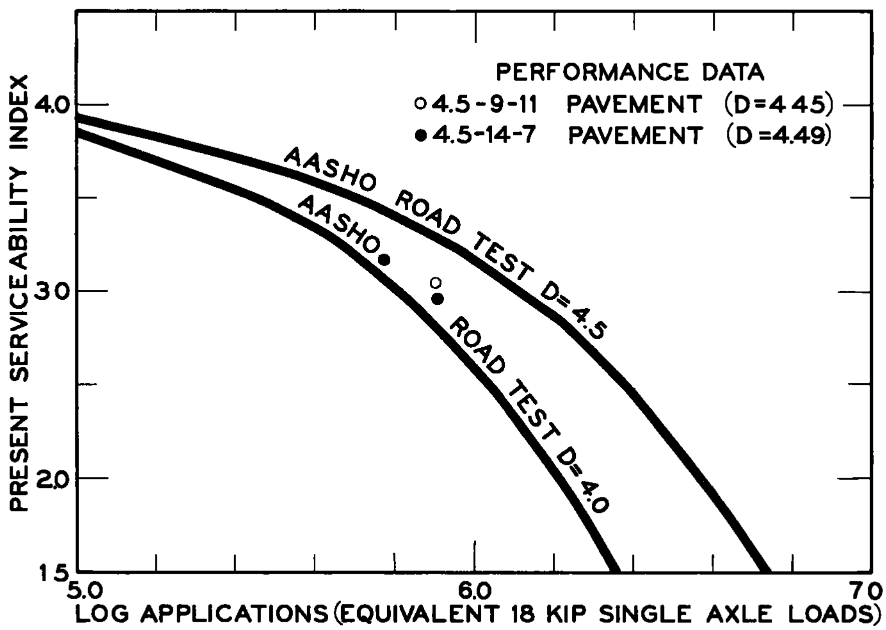

Figure 9. Performance of Illinois bituminous-concrete flexible pavement vs predicted performance by Road Test equations.

constant, but is different for the two different types of pavement, and may be a variable within types. The reasons that are believed to be responsible for the necessity for applying the factor will be discussed in the next section. This factor, for the present, is being termed a "time-traffic exposure" factor.

Referring to Eqs. 2 and 6 for log W and substituting 18-kip single-axle loading for the load terms, the equations become:

For portland cement concrete pavement:

$$\log W = 7.35 \log (DT) - 0.06 + \frac{(DT)^{8.46} \log \left(\frac{4.5 - p}{3} \right)}{(DT)^{8.46} + 16{,}197{,}060} \quad (13)$$

in which, (DT) is the design term which for the Road Test pavements $= D_2 + 1$; and W and p are as previously defined.

For bituminous concrete (on granular base) pavement:

$$\log W = 9.36 \log (DT) - 0.20 + \frac{(DT)^{5.19} \log\left(\frac{4.2 - p}{2.7}\right)}{0.4\,(DT)^{5.19} + 1{,}093.6} \quad (14)$$

in which, (DT) is the design term which for the Road Test pavements $= D + 1$; and W and p are as previously defined.

From the presumption that the performance equations would have to be modified to take into consideration changes in climate, soil, and pavement materials, together with what has been learned in Illinois regarding the difference in behavior of pavements serving over a long period of time as compared with the two years for the Road Test pavements, it is assumed that the design term (DT) for pavements in regular service will take the following form:

For portland cement concrete pavement:

$$(DT) = D_0 + A_0 + A_1 + A_2 + A_3 + \ldots + 1 \quad (15)$$

in which

- (DT) = design term;
- D_0 = regular service pavement slab thickness, in inches;
- A_0 = a term relating to climatic conditions or (regional factor);
- A_1 = a term relating to foundation soil strength characteristics or (soil factor);
- A_2 = a term relating to the concrete strength characteristics or (pavement strength factor);
- A_3 = a term relating to the behavior of pavements serving over long periods of time as compared to the Road Test pavements which is herein called the time-traffic exposure factor; and
- $\ldots$ = other pertinent factor influencing pavement performance.

For bituminous concrete (on granular base) pavement:

$$(DT) = a_1 D_1 + a_2 D_2 + a_3 D_3 + A_0 + A_1 + A_3 + \ldots + 1 \quad (16)$$

in which

- (DT) = the design term;
- D_1, D_2, and D_3 = thicknesses in inches of the surfacing, base, and subbase, respectively; and
- a_1, a_2, and a_3 = coefficients relating to the performance and strength characteristics of the surfacing, base and subbase.

A_0, A_1, A_3 and $\ldots$ are as defined in Eq. 15.

As previously stated, the pavements in Illinois that have been studied in connection with the equations were selected on the basis that the soil, pavement materials, and climatic conditions be, insofar as possible, the same as they were on the Road Test. Therefore, in modifying the Road Test equations, the terms relating to these conditions are considered as being the same as on the Road Test and can be disregarded in the analysis. Eq. 15 for portland cement concrete pavement can then be modified by dropping the terms A_0, A_1 and A_2 since they are now considered constants. Similarly, Eq. 16 can be modified by dropping the terms A_0 and A_1, and the coefficients a_1, a_2, and a_3 are considered the same as for the Road Test; *i.e.*, $a_1 = 0.44$, $a_2 = 0.14$, and $a_3 = 0.11$.

Modification of the equations to fit the performance of the pavements in the study suggests the following:

For the portland cement concrete pavements:

$$(DT) = D_0 + A_3 + 1$$

From the hypothesis that the equations can be modified by a factor for adjusting the design thickness represented in the equations for ρ and β, it is believed that the A_3 can be expressed as follows:

$$A_3 = \frac{D_0}{T_1} - D_0$$

in which T_1 is the time-traffic exposure factor for portland cement concrete pavement.

Then, by substituting this expression for A_3 for (DT):

$$(DT) = \frac{D_0}{T_1} + 1 \quad (17)$$

Further, by substituting Eq. 17 into Eq. 13, the performance equation becomes:

$$\log W = 7.35 \log\left(\frac{D_0}{T_1} + 1\right) - 0.06 + \frac{\left(\frac{D_0}{T_1} + 1\right)^{8.46} \log\left(\frac{4.5 - p}{3}\right)}{\left(\frac{D_0}{T_1} + 1\right)^{8.46} + 16{,}197{,}060} \quad (18)$$

For the bituminous concrete (on granular base) pavements:

$$(DT) = 0.44D_1 + 0.14D_2 + 0.11D_3 + A_3 + 1$$

$$A_3 = \frac{0.44D_1 + 0.14D_2 + 0.11D_3}{T_2} - (0.44D_1 + 0.14D_2 + 0.11D_3)$$

in which T_2 is the time-traffic exposure factor for bituminous concrete (on granular base) pavement.

And, by substitution:

$$(DT) = \frac{0.44D_1 + 0.14D_2 + 0.11D_3}{T_2} + 1 \qquad (19)$$

By substituting Eq. 19 into Eq. 14 the modified equation becomes:

$$\log W = 9.36 \log \left(\frac{0.44D_1 + 0.14D_2 + 0.11D_3}{T_2} + 1\right) - 0.20 + \frac{\left(\frac{0.44D_1 + 0.14D_2 + 0.11D_3}{T_2} + 1\right)^{5.19} \log\left(\frac{4.2 - p}{2.7}\right)}{0.4\left(\frac{0.44D_1 + 0.14D_2 + 0.11D_3}{T_2} + 1\right)^{5.19} + 1093.6} \qquad (20)$$

It should be noted that the time-traffic exposure factors T_1 and T_2 modify the Road Test performance equations only to the extent that they would represent behavior of the Road Test pavements had they been tested over a long period of time.

The study thus far has indicated that the value of T_1 is about 1.5 for portland cement concrete pavements when 12 to 15 years of age at resurfacing, and that the value of T_2 is about 1.15 for bituminous concrete pavements on granular bases and subbases when 6 to 10 years of age. These values are tentative and are subject to further modification when additional data and refinements in procedures are developed.

Complete modification of the performance equations suitable for application to the design and evaluation of highway pavements in regular service will require the development of additional design term modifying factors, as indicated by Eqs. 15 and 16, to account for differences in climate (regional factor); differences in soil foundation support (soils factor); differences in the strength characteristics of the pavement materials (pavement strength factors); and other pertinent factors that express their effects on pavement performance.

ELABORATION

The foregoing is a presentation of one of several possible procedures for adjusting the Road Test equations to represent the conditions that would have existed had the pavements been tested over a time period approximating the life expectancy of pavements in regular service. The preliminary work done in Illinois, in areas where physical environment and foundation conditions vary from Road Test conditions probably less than anywhere else, indicates that many, and perhaps all agencies using the Road Test equations will find that modifications are necessary before the equations will represent performance under conditions of regular service.

The modifications that appear to be necessary based on the Illinois study are believed to be brought about by differences of behavior of pavements subjected to long-time traffic while undergoing gradual deterioration from climatic exposure and exposure to the generally acknowledged adverse effects of the winter maintenance procedures that are commonly used to keep roads open to the regular flow of traffic, as compared with the behavior of the Road Test pavements subjected to a 2-yr period of testing and little winter maintenance. It seems reasonable to assume that, as deterioration from these causes progresses, the deleterious influences of traffic on pavement behavior are accelerated.

The modifying factors that Illinois is in the process of developing to adjust for the conditions that have been cited appear appropriate for application in the thickness terms in the Road Test equations. For the present, this factor is being termed a time-traffic exposure factor. It must be realized that this factor does not adjust for the climatic variable, the foundation variable, and variations in the strength properties of the paving materials from conditions at the Road Test project. Further modifications are necessary to adjust for these and other pertinent factors.

The time-traffic exposure factors, once they have been established, should modify the equations to the form they would have taken had the Road Test pavements been subjected to traffic over a period of time equaling the life of a normal highway pavement.

The equations as modified should be of advantage to other highway agencies. Through their use in conjunction with studies of pavements where soil foundation conditions and pavement materials are similar to those on the AASHO Road Test project, it should be possible to isolate and observe the effect on performance of the climatic variable or regional factor and to develop appropriate modification factors to adjust for this variable. Further studies where the foundation conditions or pavement strength characteristics vary from those on the Road Test should then lead to the development of suitable adjustment factors for these variables also.

Over-all, this study strongly suggests the practicability of modifying the Road Test equations for direct application in the evaluation and design of highway pavements through a study of the behavior of existing pavements. Tentative design and evaluation policies can be established. Data obtained from future experimental projects (primarily, the so-called satellite studies) should provide the basis for verification and refinement of the design and evaluation procedures.

It should be emphasized that this paper suggests only a possible procedure. The relationships between PSI and 18-kip axle-load equivalency for the Illinois pavements are subject to further investigation as refinements in the procedure are developed.

FUTURE STUDIES

Data obtained thus far on the behavior of existing pavements encourage the belief that usable factors can be developed for modifying the Road Test rigid and flexible pavement performance equations for use in the evaluation of existing pavements and in the development of thickness design policies for new pavement designs.

Sufficient data are available to indicate performance trends for regular pavements in the general area of the Road Test; however, additional data for pavements of the area spread over a wider range of present serviceabilities and axle-load applications must be obtained before modification factors of the desired precision can be established for these pavements. The Illinois Division of Highways is in the process of acquiring this additional information. Information on the time-traffic exposure factors, once they are developed on the basis of the behavior of regular pavements in the area of the Road Test, can be of especial value to highway departments in other climatic areas in isolating the climatic effect (regional factors) when studies along the foregoing lines are pursued.

The collection and use of traffic volume, classification, and loadometer data for estimating 18-kip axle-load equivalencies to represent loadings applied to rural primary, secondary, and tertiary highway pavements will be the subject of continued and likely accelerated investigation in Illinois. It is believed that further improvement can be made in the use of this information.

The Illinois Division of Highways is extending its studies to other areas of the State where the influences of different foundation soils and soil conditions can be assessed. Whether or not climatic variation within the State is of significance with respect to pavement performance also will be subject to observation.

Illinois and other States, must undertake studies to determine the adjustments in the Road Test equations that are necessary for differences in the strength properties of the pavements themselves. Procedures similar to those outlined probably can be followed in determining the nature and degree of these adjustments. The establishment of satellite projects should be of particular value in determining these factors.

The Illinois Division of Highways is engaged in developing tentative design procedures and procedures for evaluating remaining life of existing pavements by applying the Road Test equations. Modifications will be made in these procedures as additional information is accumulated on the application of the Road Test equations to pavements in regular service.

An important type of pavement not covered in the AASHO Road Test is the composite pavement, including bituminous overlays of old portland cement concrete pavements. Studies of these pavements have begun in Illinois, but have not progressed to the extent that real trends have been indicated. Results, thus far, are shown in Figures 10 and 11 where estimated 18-kip equivalent axle loadings are shown for a number of resurfaced pavements at retirement. Information on PSI's was not available for these particular pavements, and the assumption was made that they were retired at PSI = 2.0. This value is close to the nationwide averages for the retirements of both rigid and flexible pavements as indicated by recent tests conducted by the Bureau of Public Roads in cooperation with representative State highway departments in compliance with a request of the Highway Transport Committee of AASHO late in 1961. Figure 10 was prepared considering the composite pavement as a flexible type. Figure 11 was prepared considering the composite pavement as a rigid type.

From the preliminary study, it appears that the general form of the flexible pavement equations can be applied to composite pavement and that the actual equations can be modified through the design term as follows:

$$DT = (a_1 D_1 + a_2 D_0) + A_0 + A_1 + A_3 + \ldots +1) \quad (21)$$

in which

DT = the design term (for the Road Test flexible pavement $DT = (0.44D_1 + 0.14D_2 + 0.11D_3) + 1)$;

D_1 and D_0 = bituminous surfacing and concrete pavement slab thickness, in inches; and

a_1 and a_2 = coefficients relating to the strength characteristics of the bituminous surfacing and concrete pavement.

A_0, A_1, A_3 and . . . are as previously defined.

The study, thus far, has indicated that the value of a_2 is about 0.4 for Illinois composite pavements. Further study may determine that this coefficient is not a constant, and may vary in accordance with the observed structural condition of the existing concrete pavement serving as a base.

Another type of pavement not considered on the AASHO Road Test is the continuously-reinforced concrete pavement. Illinois now has one experimental project which includes 7-in.

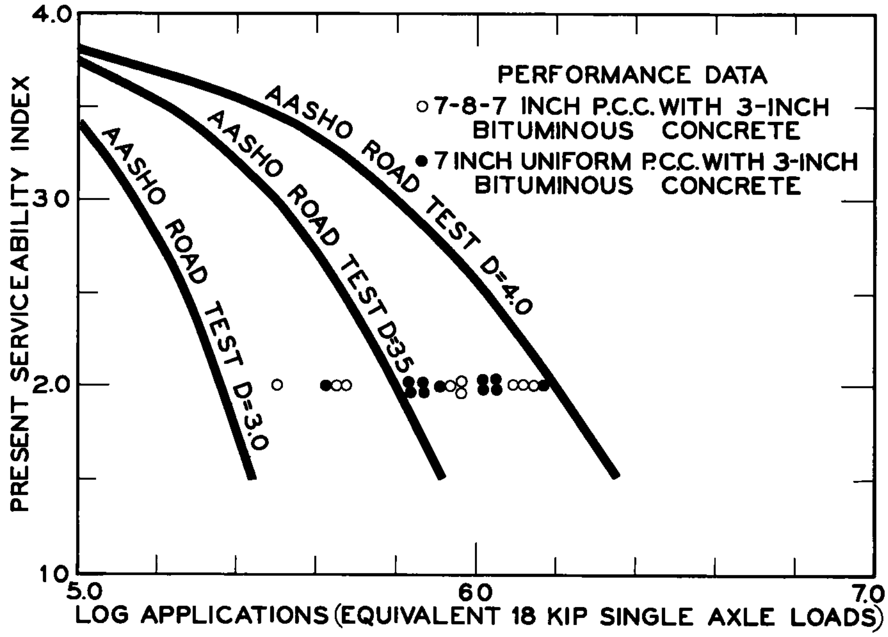

Figure 10. Performance of Illinois resurfaced PCC pavements vs Road Test flexible pavement equations.

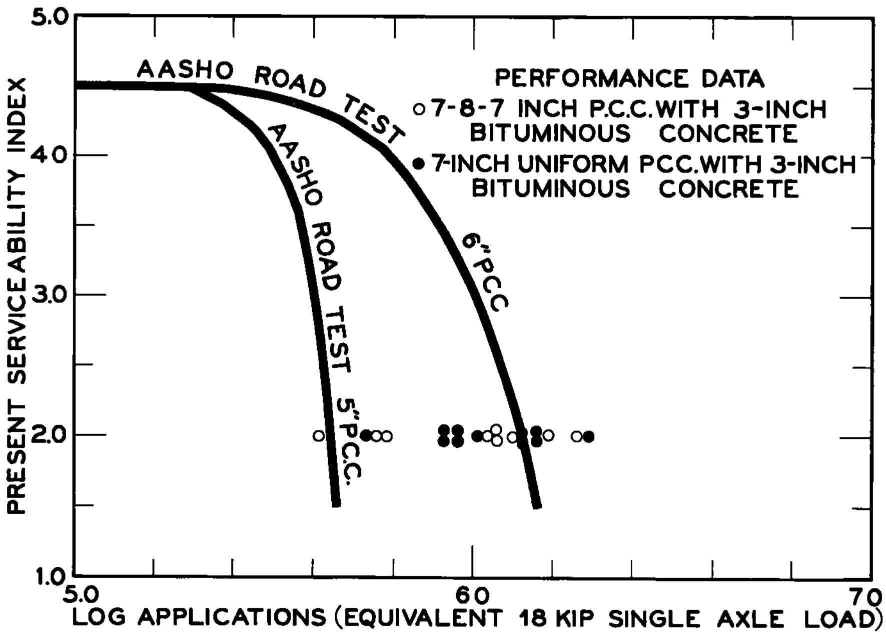

Figure 11. Performance of Illinois resurfaced PCC pavements vs Road Test rigid pavement equations.

and 8-in. pavement reinforced with various percentages of steel. Not enough data have been obtained to develop trends with respect to the performance equations. However, comparison of the plots shown in Figures 12 and 13 for the 7-in. and 8-in. pavements with similar plots shown in Figure 7 for 10-in. standard reinforced pavement suggests that the performance of the continuously-reinforced pavement is superior to that of standard reinforced pavement in Illinois.

Illinois is now engaged in a research program involving the construction of ten projects of continuously-reinforced concrete pavement. Nine of these are primarily for gaining experience in constructing and developing equipment and procedures for reducing construction costs. The tenth will be highly instrumented for intensive study.

Satellite studies have been mentioned as a

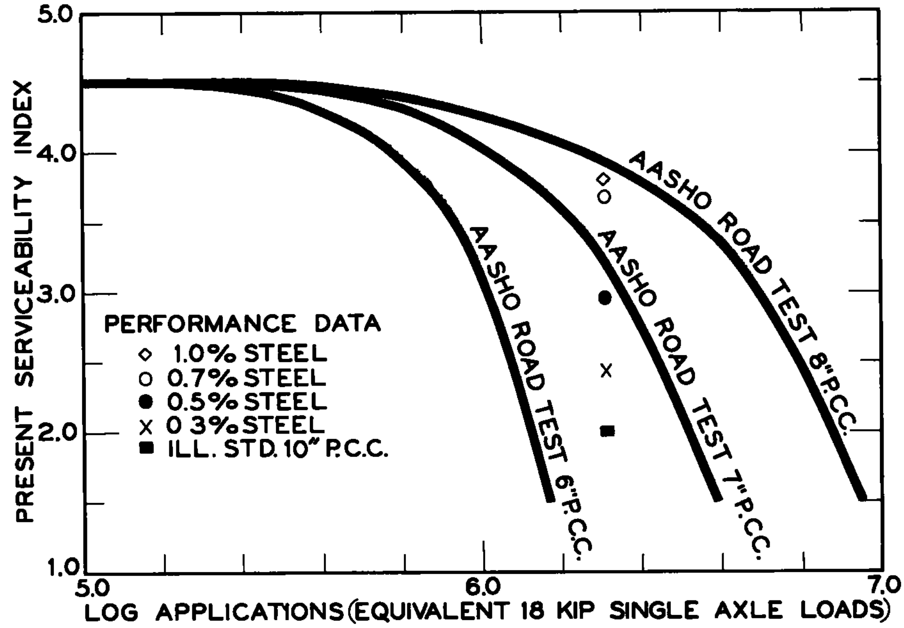

Figure 12. Performance of Illinois 7-in. continuously-reinforced PCC pavement vs Road Test equations.

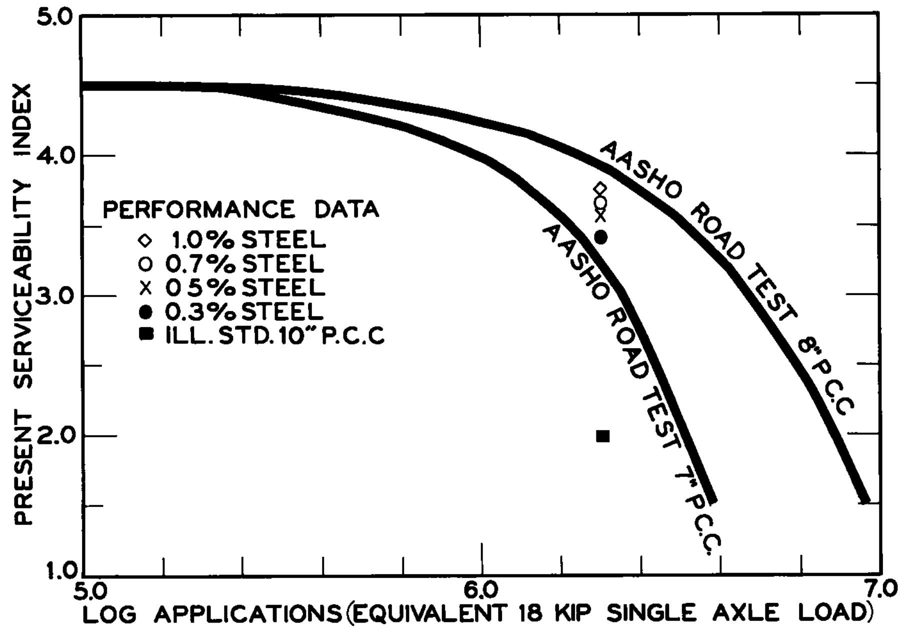

Figure 13. Performance of Illinois 8-in. continuously-reinforced PCC pavement vs Road Test equations.

source of information for a better understanding and correlation of performance as predicted by the Road Test equations with performance in regular service. A satellite study which potentially may be of particular significance is that which the Illinois Division of Highways has undertaken at the site of the Road Test. Construction work at the site is now in progress where as many as possible of the original test sections and a number of new test sections will be included in the pavement that will serve regular traffic as part of Interstate 80 due to be opened in November 1962.

For the purpose of continuing the study of pavements at the Road Test site under mixed traffic conditions the following is being done:

1. Original portland cement concrete test sections 8 in. and more in thickness and not seriously damaged by test traffic have been retained.

2. Comparable bituminous-concrete flexible test sections have been re-established.

3. New test sections of portland cement concrete on cement-stabilized and bituminous-stabilized granular subbase courses, and on high-type gravel and crushed stone subbase courses (from very thick to relatively thin), have been added.

4. New test sections of bituminous concrete on portland cement-stabilized and bituminous-stabilized granular base courses, and on crushed-stone base courses of thicknesses greater than those used in the original tests, have been added.

5. New test sections of composite pavements consisting of bituminous concrete on portland cement concrete base course have been added.

6. Sections of bituminous concrete have been added in which hydrated lime, kaolin clay, and short-fiber asbestos fiber have been introduced as the variable in a special filler study.

Surface smoothness and pavement condition studies of the nature of those used in the original Road Test project are scheduled to continue on the satellite project. Climatic studies initiated during the original tests are also scheduled to continue. For making the traffic studies that are essential to the continuing research, electronic scales are being installed in both the eastbound and westbound pavements for weighing vehicles while in motion, thereby acquiring data on the complete range of individual axle loadings these new and old test sections will have carried.