State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

THICKNESS DESIGN PROCEDURE FOR BITUMINOUS RESURFACING OF PORTLAND CEMENT CONCRETE PAVEMENTS

by
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Research Project IHR-28
AASHO Road Test

A Research Study
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ABSTRACT

The performances of 89 resurfaced PCC pavements were analyzed relative to the performance expected from new rigid and flexible pavements. The analysis has led to a resurfacing design procedure based on a modification of the currently used Illinois rigid pavement design procedure. This new procedure allows the designer to evaluate the anticipated future traffic, the existing subgrade support, and the thickness of the existing pavement components to select the required resurfacing thickness. In addition, a maximum realistic design life of 15 years was established from an analysis of the actual service lives of 64 resurfaced pavements.

SUMMARY

Performance data were collected from 89 resurfaced PCC pavements and were studied relative to the performance predicted for new pavements by the Illinois rigid and flexible design procedures. This analysis revealed that the performance of a resurfaced pavement resembles the performance of a rigid pavement more closely than it does the performance of a flexible pavement. Based on this finding a resurfacing design procedure for both first and second resurfacings was developed by modifying the currently used rigid pavement procedure. It was subsequently demonstrated that adoption of this procedure would result in a significant improvement in the Division's resurfacing design capability.

Being developed by modifying the existing procedure, the resurfacing procedure utilizes the same format as the existing procedures and considers the same design parameters - traffic, soil support, and material thicknesses. Traffic is evaluated in terms of equivalent 18-kip single axle load applications based on the AASHO Road Test performance equation for rigid pavements. Material thicknesses are included in a linear, structural number relationship similar to that employed in the Illinois and AASHO Interim Guide procedures for flexible pavements. The design analysis is presented in the form of nomographs which include the three design parameters.

In addition, an analysis of the actual service lives of 64 resurfaced sections showed that a service life of about 15 years is the maximum that reasonably can be assumed in design computations.

INTRODUCTION

Following the completion of the AASHO Road Test, the Illinois Division of Highways initiated research directed toward developing pavement design procedures based on the findings of the test. Subsequently, interim design procedures for both flexible and rigid pavements were developed and put into practice (1,2). Continuation of this work has since progressed into the design of bituminous resurfacings for existing PCC pavements. The current paper is presented to discuss the findings of this portion of the studies and to display the bituminous resurfacing thickness design procedure developed therefrom.

The developed procedure enables the designer to evaluate the predicted future traffic along with the existing subgrade support and pavement thickness in order to determine, on the average, the resurfacing thickness required to retain the serviceability above a given level for the desired design period. As in the previously developed procedures, traffic is evaluated in terms of equivalent 18-kip single axle load applications with the relationship between traffic, subgrade support, and pavement design being expressed in the form of a design nomograph. The pavement design is represented by a thickness index called a structural number which is a linear function of portland cement concrete thickness and resurfacing thickness.

BACKGROUND INFORMATION

An initial assumption in this study was that the previously developed design procedures could be successfully modified and adapted for use in resurfacing design. Thus, to fully understand this study, it is necessary to know certain details of the development of the existing design procedures. These procedures are based on the AASHO Road Test performance equations for flexible and rigid pavements which were developed empirically from the Road Test data to provide a mathematical relationship between pavement design, axle load, and performance.

Since the equations consider only one magnitude of load at a time, the first step necessary before utilizing them in pavement design was the establishment of a method for converting mixed traffic axle loadings to an equivalent number of applications of a single axle load. This was accomplished by developing axle load equivalency factors based on the numbers of applications of the various axle loads predicted to have equivalent effects on the pavement's level of service. Using the 18-kip single axle load as a base, the equivalency factors were defined as:

$$E.F.(x) = \frac{W_{18}}{W_x} \qquad (1)$$

where

$E.F.(x)$ = 18-kip single axle load equivalency factor for axle load "x"

W_{18} = predicted number of 18-kip single axle load applications a pavement will carry before its serviceability level is p

W_x = predicted number of "x" axle load applications a pavement will carry before its serviceability level is p.

These axle load equivalency factors were used in conjunction with Illinois statewide loadometer and classification count data to establish vehicle type equivalency factors for passenger cars, single unit commercial vehicles, and multiple unit commercial vehicles for rigid and flexible pavements in each of the four classifications of Illinois highways (Table 1). These vehicle factors, along with the predicted volumes of the various vehicle types, thus, provided a method for evaluating traffic in terms of equivalent applications of a single axle loading that can be utilized with the performance equations.

Having established a method of traffic evaluation, the next step was to compare the actual performance of in-service Illinois pavements with the performance predicted by the performance equations. This comparison, which established

TABLE 1

EQUIVALENT 18-KIP SINGLE AXLE LOAD APPLICATIONS PER VEHICLE CLASSIFICATION

Road or Street Class	Highway System	Equivalent 18-Kip Single Loads Per Vehicle		
		Passenger Car	Single Unit Commercial	Multiple Unit Commercial
		Rigid Pavements		
I	Primary	0.0004	0.123	1.155
II	Primary	0.0004	0.123	1.134
III	Secondary	0.0004	0.123	1.134
IV	Local	0.0004	0.123	1.134
		Flexible Pavements		
I	Primary	0.0004	0.117	0.947
II	Primary	0.0004	0.109	0.924
III	Secondary	0.0004	0.098	0.794
IV	Local	0.0004	0.027	0.216

the applicability of the equations and provided information necessary to adjust the equations to the actual Illinois conditions, utilized the ratios of actual pavement thickness indices to the thickness indices predicted by the equations for equivalent performance. For rigid pavement, this thickness index was the thickness of the concrete slab, in inches. For flexible pavement, the index was defined by the equation:

$$D_T = a_1D_1 + a_2D_2 + a_3D_3 \tag{2}$$

in which

D_T = structural number
a_1, a_2, a_3 = material strength coefficients based on the strength of the surface, base, and subbase materials respectively
D_1, D_2, D_3 = thickness of the surface, base, and subbase respectively.

The comparison indicated that, while the equations predicted levels of performance greater than those that were actually experienced, a simple modification of the thickness term could be utilized to provide a realistic performance prediction. Figures 1 and 2 show plots of the thickness index ratios versus pavement age for the pavements studied. The average values of these ratios for each pavement type were called the time-traffic exposure factors. These factors were used to modify the performance equations in order to utilize them for design. Thus, the design thickness relationship became:

$$D_T = T \times D \tag{3}$$

where

D_T = Illinois PCC pavement thickness or flexible structural number
T = time-traffic exposure factor
1.1 for flexible pavement
1.3 for PCC pavement
D = PCC pavement thickness or flexible structural number predicted by the AASHO performance equation.

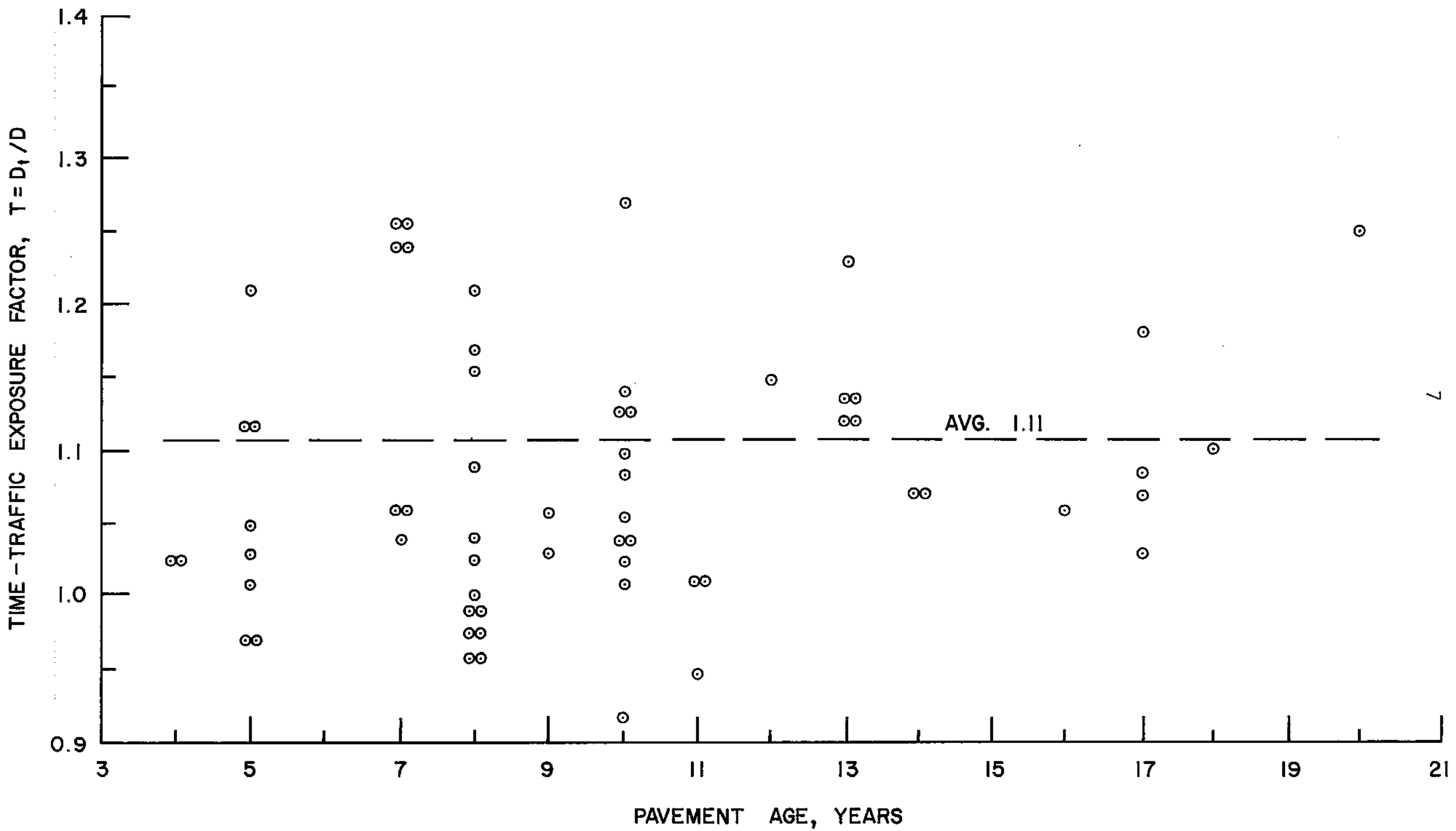

FIGURE 1. FLEXIBLE PAVEMENT TIME - TRAFFIC EXPOSURE FACTORS VERSUS PAVEMENT AGE

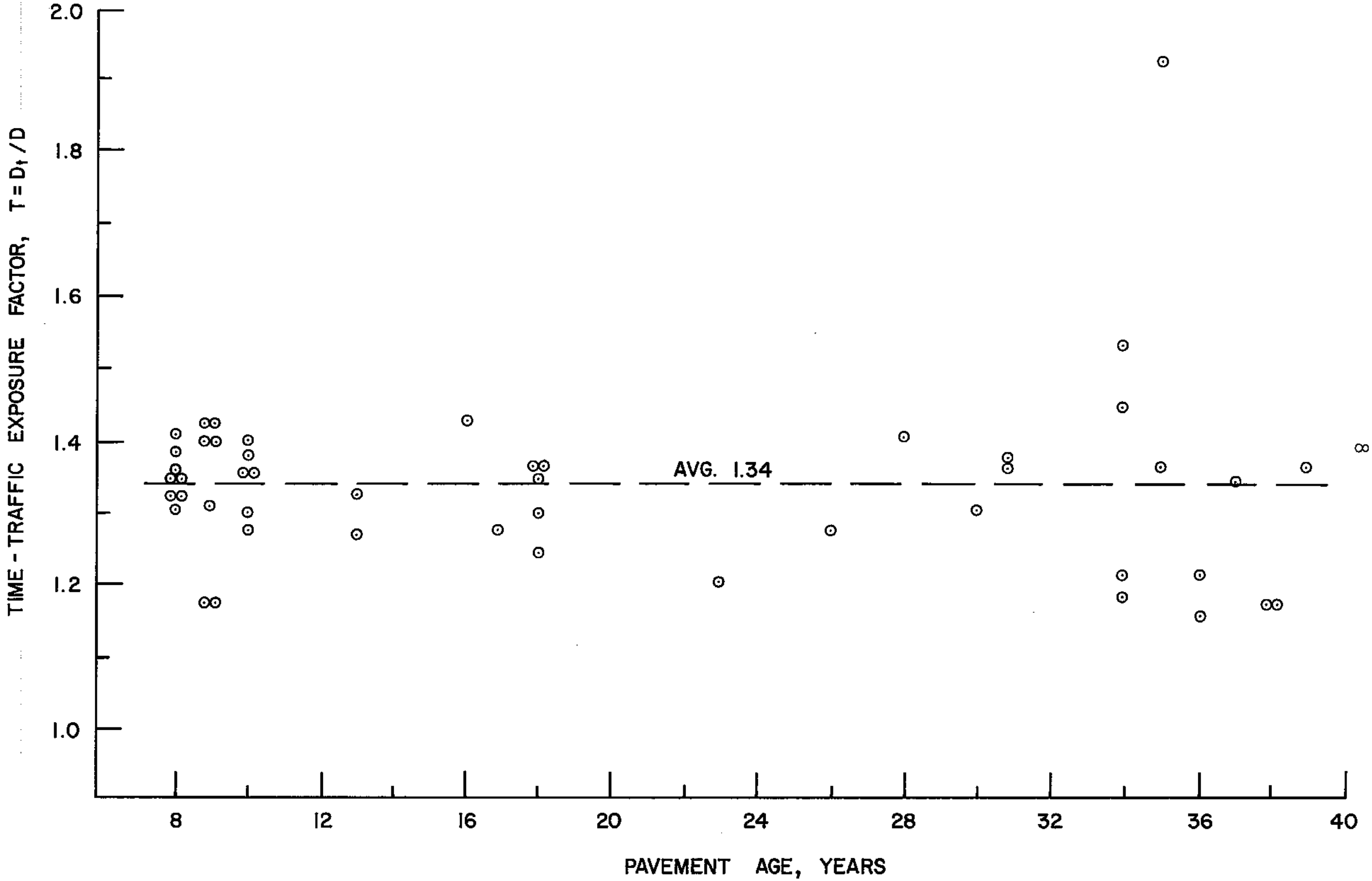

FIGURE 2. RIGID PAVEMENT TIME – TRAFFIC EXPOSURE FACTORS VERSUS PAVEMENT AGE

The results of these modifications were subsequently put in the form of the nomographs which are used for pavement design. Two of these nomographs are shown in Figures 3 and 4. By knowing the traffic conditions predicted for a roadway and the subgrade conditions anticipated, the design engineer is able to select the required pavement thickness.

RESURFACING DESIGN PROCEDURE STUDY

Following development and implementation of the design procedures for rigid and flexible pavements, a study aimed toward establishing a resurfacing design procedure was initiated. Because bituminous concrete surfacing in combination with a portland cement concrete base was not included in the AASHO Road Test, it was necessary to arrive at a design procedure for resurfacings by indirect means. It was hoped that a design procedure for both first and second resurfacings could be developed which utilized information generated while developing the two initial procedures. Thus, it was hoped that a modification of either the flexible or rigid nomograph could be used for resurfacing design. However, it appeared probable that the soil support scale and the traffic evaluation of the rigid pavement procedure might provide the more realistic means of predicting the performance of a resurfaced pavement since the existing underlying portland cement concrete pavement should continue to provide a slab action. Nevertheless, both procedures were investigated to determine their suitabilities for modification.

Resurfacing Performance

Since performance was to be the guiding criterion of the study, the establishment of a means for measuring performance was a necessary initial consideration. At the Road Test, performance was defined as the change in the pavement's ability to serve traffic with increasing numbers of load applications. To measure the pavement's "ability to serve," mathematical relationships (one each

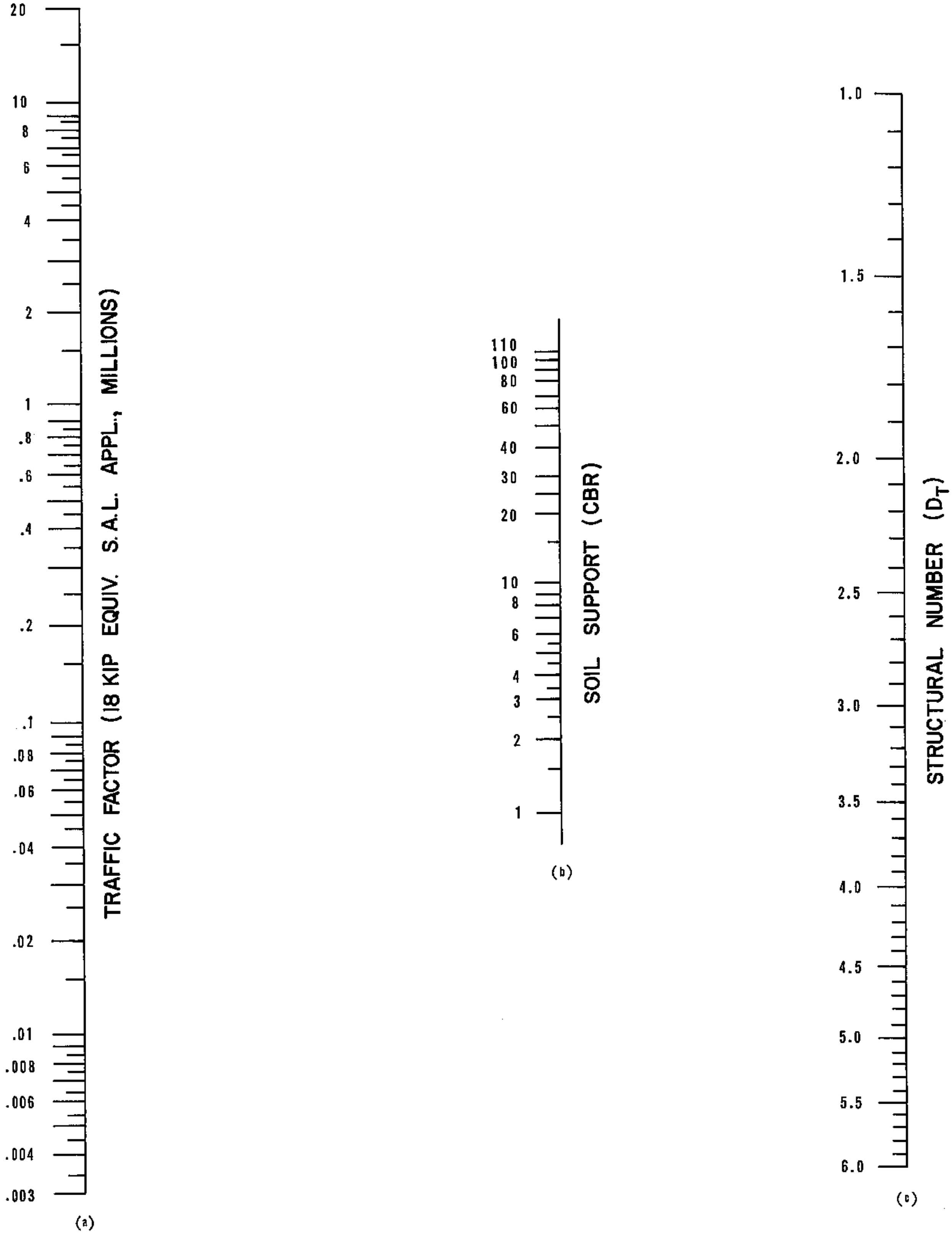

FIGURE 3. DESIGN NOMOGRAPH FOR FLEXIBLE PAVEMENTS ON CLASSES II, III, AND IV ROADS, USING A TERMINAL PSI OF 2.0

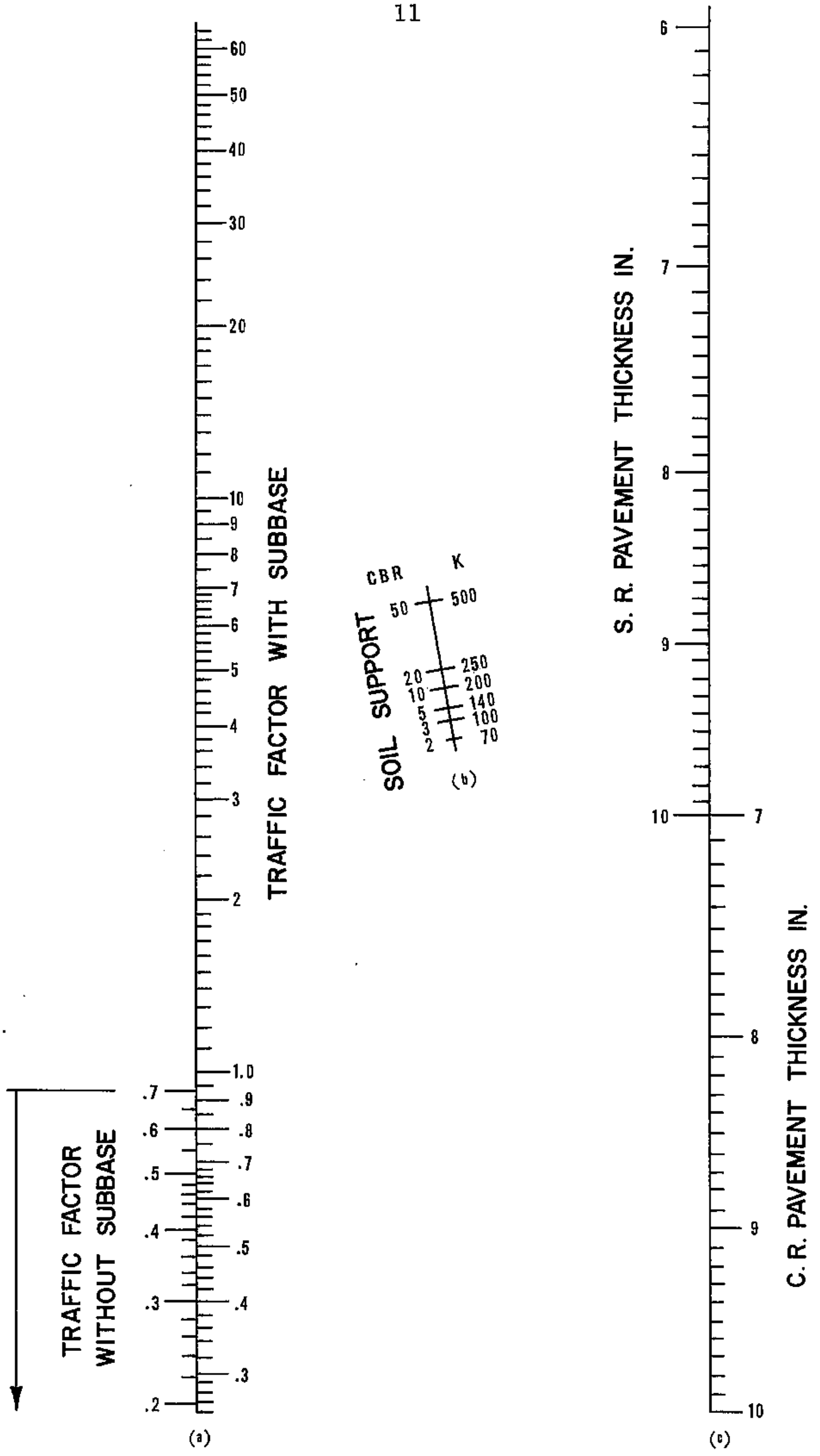

FIGURE 4. DESIGN NOMOGRAPH FOR RIGID PAVEMENTS ON CLASSES II, III, AND IV ROADS, USING A TERMINAL PSI OF 2.0

for flexible and rigid pavements) were established between measurable pavement surface properties and opinion ratings obtained from a panel of highway users. These relationships, known as the Present Serviceability Index (PSI) equations, were later modified slightly for use in Illinois by replacing the roughness term used at the Road Test by a similar, correlated roughness term that could be measured by the Illinois Roadometer. However, because the combination of a bituminous concrete surface and portland cement concrete base was not included in the Road Test, neither equation could be applied directly to measure the performance of a resurfaced pavement.

Of the two existing PSI equations, the one for flexible pavements appeared to be most nearly applicable for resurfaced pavements since the surfacing materials and the response of the Illinois Roadometer to the surface are similar to those of flexible pavements. However, the cracking term of this equation was inappropriate. Only alligator cracking, which predominates in flexible pavements, was considered. The transverse and longitudinal reflective cracking which predominates in resurfaced concrete pavements could not be considered. Since this type of cracking generates from and is very similar to rigid pavement cracking, the cracking term of the rigid pavement PSI equation seemed to apply. Therefore, the following equation, which combines the rigid pavement cracking term with the flexible pavement equation, was used along with traffic histories to measure the performance of the resurfaced pavements:

$$PSI = 10.91 - 3.90 \log \overline{RI} - 0.01(C+P)^{1/2} - 1.38\,\overline{RD}^{2} - 0.09(C')^{1/2} \quad (4)$$

where

$\overline{RI}$ = roughness index measured by the Illinois roadometer
C = a measure of alligator cracking
P = a measure of patching
C' = a measure of reflective cracking
$\overline{RD}$ = a measure of rut depth

A subsequent check of the values obtained from the equation revealed that it produced realistic estimates of the pavement's serviceability ratings.

First Resurfacing

Data were collected from 53 pavement sections that had been resurfaced once and were nearing the end of their service lives. These data included pavements having resurfacing thicknesses ranging from 1 1/2 inches to 3 inches and effective slab thicknesses ranging from 7 inches to 10 inches. Many of the slabs had thickened edge designs. In these cases, an effective thickness (Table 2) based on Westergaard's equation for corner loading (3) was used for analysis purposes. Using the performance data of these sections (traffic histories since resurfacing and current PSI ratings) in conjunction with the AASHO performance equations and the time-traffic exposure factors (Equation 3), performance indices based on both the flexible and rigid design procedures were determined. For the flexible procedure basis, the performance index was defined as the structural number of an Illinois flexible pavement that would be expected to provide an equivalent performance. For the rigid procedure basis, the performance index was defined as one-half the thickness of an equivalently performing standard reinforced slab. An analysis of the Road Test data indicated that, in general, for equivalent service lives the ratio of flexible pavement structural number to rigid slab thickness is 0.5. Thus, the use of one-half the rigid pavement thickness made the rigid and flexible performance indices comparable.

Having determined the performance indices for all of the study sections, the next step was to relate them to the pavement component thicknesses in order to determine whether a modification of either the Illinois flexible or rigid design formulas could produce a reasonable fit and, if so, which procedure - flexible or rigid - provided the better fit. This was done using multiple regression analysis procedures in conjunction with the linear relationship:

$$D_P = a_0 + a_1 D_F + a_2 D_C \quad (5)$$

where

D_P = the performance index
D_F = thickness of the first resurfacing
D_C = thickness of the PCC pavement
a_0, a_1, and a_2 = regression coefficients.

The results of these analyses along with pertinent statistical data are shown in Table 3. It will be seen that both procedures could be modified to produce reasonable results but that the rigid pavement procedure provides a slightly better fit. Thus, it was decided that the resurfacing design procedure would be developed using a modification of the existing rigid pavement procedure.

For the first resurfacing portion of the procedure, the data generated in the regression analysis could be used. However, it was hoped that as an added refinement the condition of the existing pavement prior to being resurfaced could be included in the procedure. Undoubtedly this factor has an influence on the performance of the resurfaced pavements and should eventually be considered. However, such condition data were not available, and the inclusion of this factor could only be made by evaluating some current, but related condition. Of the data available, reflective cracking was the only factor that might have been sufficiently related to the earlier pavement conditions to provide a realistic measure of those conditions. Thus, an attempt was made to relate the amount of reflective cracking to the regression coefficient of the existing slab (a_2).

An accurate measure of reflective cracking was available for 26 of the 53 data sections. For each of these sections a value for a_2 in equation (5) was obtained by solving the equation:

$$a_2 = \frac{D_P - a_0 - a_1 D_F}{D_C} \quad (6)$$

TABLE 2

EFFECTIVE UNIFORM THICKNESES OF THICKENED EDGE SLABS

Slab Thickness (in.)	Effective Thickness (in.)
9-6-9	7.06
9-7-9	7.71
9-9-7-9-9	8.75

TABLE 3

REGRESSION ANALYSIS OF FIRST RESURFACING DATA

Regression Model - $D_P = a_0 + a_1 D_F + a_2 D_C$

	Rigid Pavement Basis			Flexible Pavement Basis		
	a_0	a_1	a_2	a_0	a_1	a_2
Regression Coefficient	-1.124	0.63	0.41	0.03	0.51	0.35
Std. Error of Coefficient		0.110	0.055		0.111	0.056
Regression Equation	$D_P = -1.12 + 0.63 D_F + 0.41 D_C$			$D_P = 0.03 + 0.51 D_F + 0.35 D_C$		
Multiple Correlation Coefficient (R)		0.816			0.758	
Std. Error of Est. of D_P		0.435			0.441	

using the regression coefficients for a_0 and a_1 and the section's values for D_P, D_F, and D_C. These values plotted against the amount of reflective cracking are shown in Figure 5. For the range of reflective cracking included in the study, this plot indicates that the concrete coefficient is relatively constant. Although the evidence is obviously meager, and this matter needs further exploration, it is being accepted for the time being that, within the usual limits of pavement condition when resurfacing is scheduled in Illinois, a single strength coefficient can be applied to existing concrete pavements that will serve as bases for resurfacings with a reasonable expectation that service-life predictions will be of acceptable accuracy. This appears reasonable since the practice in Illinois is to repair all deteriorated areas in an existing concrete pavement before resurfacing.

The presence or absence of a subbase beneath the existing concrete pavement was another factor which could not be taken into account in developing the resurfacing design procedure. At the Road Test, the presence of three to nine inches of granular subbase was found to increase the traffic carrying capability of a pavement by about one-third. This was taken into account when the Illinois rigid pavement design procedure was developed. Of the 53 data sections included in the present study, only 12 were constructed with a subbase beneath the existing slab. The performance of these 12 sections was not appreciably different from that of the other 41 sections, and resurfacing performance could not be related to the presence or absence of a subbase.

At this point some concern developed over the lack of performance data for sections resurfaced with more than three inches of bituminous concrete. If a design procedure was developed solely from the available data, its use

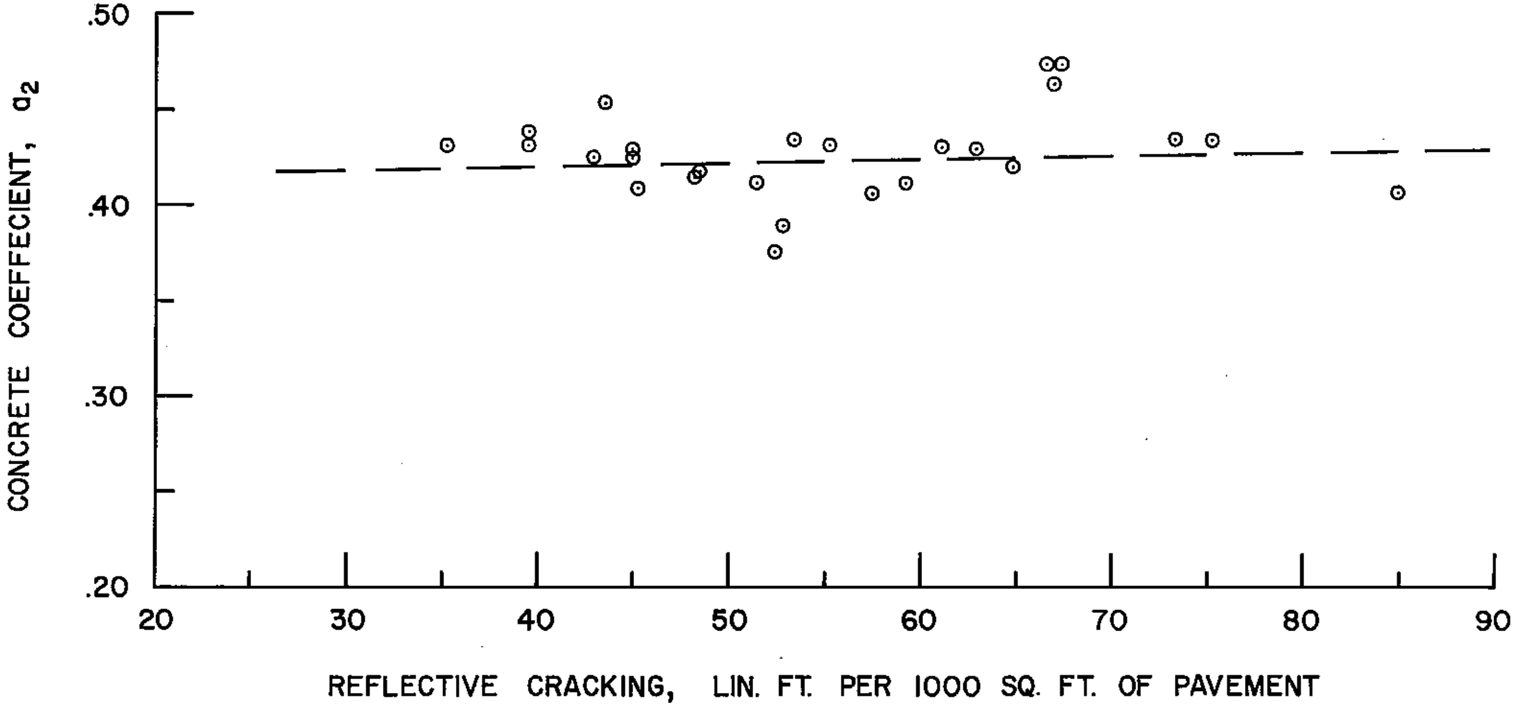

FIGURE 5. CONCRETE COEFFECIENT, a_2, VERSUS THE AMOUNT OF REFLECTIVE CRACKING FOR INDIVIDUAL SECTIONS

would often require extrapolation beyond the original data limits. Yet data for greater thicknesses were not available. This concern, however, was tempered by two facts. First, the regression analysis had produced a reasonable correlation. This indicated that a thickness-performance relationship similar to that discovered at the Road Test existed for the resurfaced pavements. Secondly, the development of design procedures from the Road Test data had itself required extrapolation beyond the original data. This was particularly true in the case of rigid pavements. Since in actual usage these extrapolations had proved to be reasonable, an assumption that a parallel situation existed in the resurfacing design appeared to be realistic.

A first resurfacing design procedure was developed, therefore, based on a regression analysis of the data from the 53 sections using the relationship given in equation (5). This resulted in the following equation:

$$D_P = -1.124 + .63\ D_F + .41\ D_C \qquad (7)$$

However, for ease of usage it appeared desirable to keep the format of the procedure and the material coefficients consistent with the present flexible design procedure. In that procedure the material coefficient for a high quality, bituminous concrete surfacing (Illinois Subclass I) is 0.40. In order to adjust the regression equation to addommodate this value, equation (7) was multiplied by 0.635(0.40 ÷ 0.63):

$$0.635\ D_P = -0.71 + 0.40\ D_F + 0.26\ D_C \qquad (8)$$

By definition the performance index was:

$$D_P = 0.5\ t\ (PCC) \qquad (9)$$

where

t (PCC) - thickness of a standard reinforced Illinois PCC pavement that would be required for equivalent performance.

By substituting equation (9) into equation (8) and moving the constant 0.71 to the left hand side of the equation, the following was obtained:

$$0.32\ t\ (\mathrm{PCC}) + 0.71 = 0.40\ D_F + 0.26\ D_C \qquad (10)$$

From this equation the resurfacing structural number was defined as:

$$SN_R = 0.32\ t\ (\mathrm{PCC}) + 0.71 \qquad (11)$$

and the thickness design relationship as:

$$SN_R = 0.40\ D_F + 0.26\ D_C \qquad (12)$$

The rigid pavement design nomographs were subsequently modified in accordance with equation (11) (Figures 6 and 7). This completed the first resurfacing portion of the design procedure. Traffic would be evaluated in accordance with the rigid pavement traffic factor equations and the resurfacing thickness could be determined using Figure 6 or 7 with equation (12). The next step was to determine how much improvement the adoption of this procedure would make in the Division's first resurfacing design capability.

By applying both the current design policy and the newly developed procedure to the data from the 53 study sections, it was possible to compare statistically the actual resurfacing thicknesses with the predicted thickness requirements. This comparison, shown in Table 4, indicated that with the new procedure the error in the predicted thickness requirement would be less than 1/2 inch 53 percent of the time as compared to only 35 percent of the time with the policy currently in use. Thus, a substantial improvement in design capability can be realized by adopting the new procedure.

Second Resurfacing

It was hoped that the same approach could be used to develop a design procedure for second resurfacings. Thus, performance data were collected from pavement sections that had received second resurfacings which were nearing their

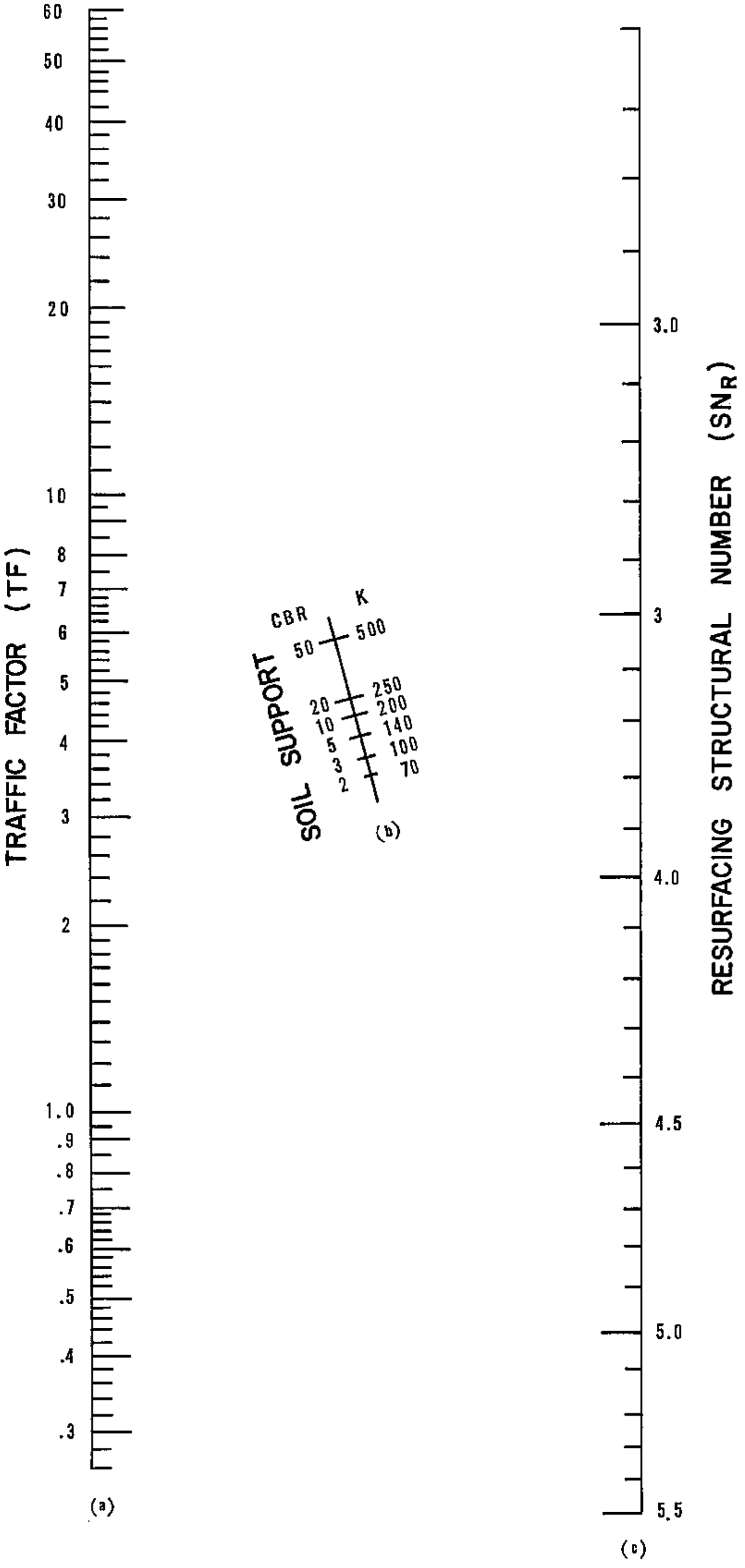

FIGURE 6. DESIGN NOMOGRAPH FOR RESURFACING OF PCC PAVEMENTS ON CLASS I ROADS, USING A TERMINAL PSI OF 2.5

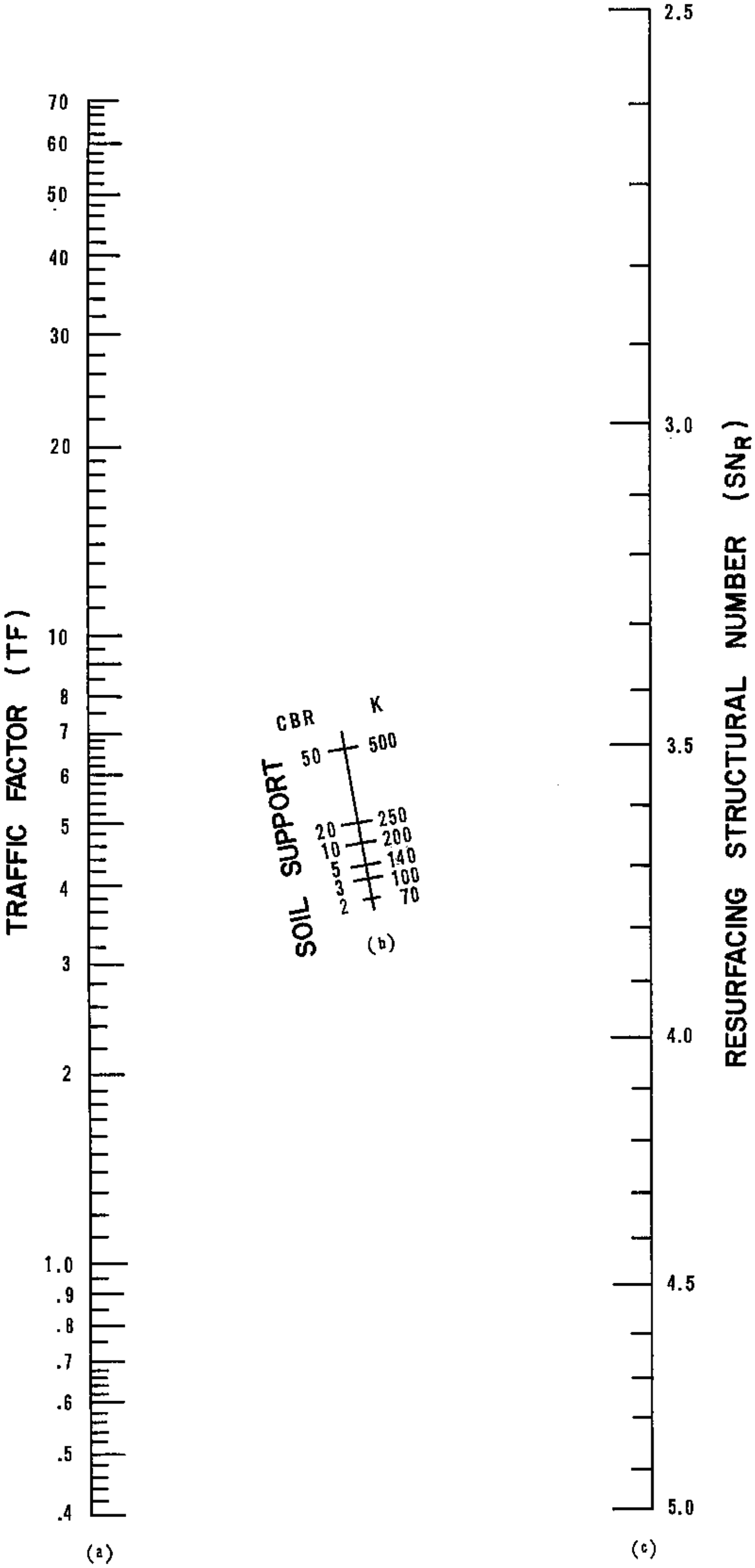

FIGURE 7. DESIGN NOMOGRAPH FOR RESURFACING OF PCC PAVEMENTS ON CLASSES II, III, AND IV ROADS, USING A TERMINAL PSI OF 2.0

terminal PSI levels, and performance indices based on the rigid design procedure were determined. Through a regression analysis, it was hoped that material coefficients and a structural number relationship could be established.

While the initial data included only 14 sections, the regression analysis of these data provided added encouragement to this portion of the study since the values obtained followed a trend similar to that obtained with the first resurfacing data. However, it was obvious that additional data were necessary to establish confidence in the results and to provide greater variation in the data. Thus, a search was initiated for additional highway sections that met the necessary criteria of having been resurfaced twice with the second resurfacing approaching the end of its serviceable life.

The search produced only 22 additional sections. While this number was disappointingly low, it was felt that, if the analysis using all 36 sections produced results similar to those obtained initially, a usable design procedure could be established.

This, however, proved not to be the case. The results of this analysis differed so sharply from both the initial analysis results and the first resurfacing results that the absence of some important factor of influence was apparent. An investigation of the data revealed that they were lacking in both quantity and quality. A mathematical analysis revealed that, for the results of the second resurfacing study to be statistically comparable with the first resurfacing results, data from 459 sections would be required. Two factors made this number so large: (1) this portion of the study involved evaluation of three structural components (two resurfacing thicknesses and a concrete thickness) while the first resurfacing portion involved only two components; (2) the performance of pavements having a second resurfacing was found to be more

TABLE 4

STATISTICAL COMPARISON OF THE DESIGN CAPABILITIES OF THE PRESENT AND PROPOSED FIRST RESURFACING DESIGN PROCEDURES

Design Procedure	Standard Error of Estimate	Estimated Percent of Pavement Whose Design Error Will Be Less Than		
		1/2"	1"	2"
Present Policy	1.08"	35	64	93
Proposed Procedure	0.69"	53	85	100

TABLE 5

STATISTICAL COMPARISON OF THE DESIGN CAPABILITIES OF THE PRESENT AND PROPOSED SECOND RESURFACING DESIGN PROCEDURES

Design Procedure	Standard Error of Estimate	Estimated Percent of Pavement Whose Design Error Will Be Less Than		
		1/2"	1"	2"
Present Policy	1.52"	26	49	81
Proposed Procedure	1.11"	35	63	93

variable than the performance of first resurfaced pavements.

A quality missing from the data was adequate variation of pavement component thickness. Ideally, the data should have a factorial representation of high, low, and medium thicknesses of each component. The real data possessed virtually only one thickness of concrete since 33 of the 36 sections had thicknesses between 7 and 8 inches. Of the first resurfacing thickness, 16 were 1.5 inches and 19 were 3 inches with one section being 2 inches thick. While the second resurfacing thicknesses showed a little more variation, 27 sections were either 1.5 or 2 inches thick with only 2 sections being thicker than 4 inches.

Thus, it was obvious that either a great deal additional data would have to be obtained or a different approach had to be employed to analyze the available data. Since the previous searches for data already had been exhaustive, the only acceptable alternative was to approach the analysis of the present data in a different manner. For this analysis, the following assumptions were made:

(1) The performance-structural number relationship for second resurfacings is the same as that found in the first resurfacing study.

(2) The new resurfacing material coefficient is 0.40 whether the new resurfacing is a first resurfacing or a second resurfacing.

(3) The structural number contribution of the existing concrete slab and resurfacing is some percentage of the pavement's original structural number following its initial resurfacing.

These assumptions seemed reasonable and realistic and, at the same time, offered assurance that the analysis results would be compatible with the first resurfacing results. The new analysis utilized the equations:

$$SN_R = 0.32\ t\ (PCC) + 0.71 \qquad (11)$$

$$SN_R = 0.40\ D_S + C\ (0.40\ D_F + 0.26\ D_C) \qquad (13)$$

where SN_R, D_T and D_C are as defined previously and

D_S = thickness of the second resurfacing
C = coefficient of remaining structural value of the existing pavement.

The object of the analysis was to determine a realistic value for C.

For each data section, SN_R was determined from the section's performance. Using the section's pavement component thicknesses, equation (13) was solved for C. These C-values ranged from 0.29 to 0.95 and averaged 0.64. Since it was felt that C could be a function of various pavement parameters, the C-values were studied relative to different details of the data sections. While this study revealed some general trends (Figure 8), no relationship was found which was sufficiently strong to be included in a design procedure at the present time, and the average value (C = 0.64) was taken as the most realistic for present use. This provided a design equation:

$$SN_R = 0.40\ D_S + 0.25\ D_F + 0.17\ D_C \qquad (14)$$

To compare the design capabilities of the present design policy and a procedure based on equation (14), estimated resurfacing thickness requirements were computed for each of the 36 data sections using both methods. Then, the estimated and actual second resurfacing thicknesses were compared statistically. This comparison, presented in Table 5, demonstrated that a design procedure based on equations (11) and (14) would provide a significant improvement in the second resurfacing thickness design capability.

DESIGN LIFE ANALYSIS

As a secondary feature, a small investigation was made to gain knowledge on what average life expectancy would be the maximum practicable to be assumed as the design life for pavement resurfacings. The actual service lives of 64 sections were available for this investigation. The resurfacing thicknesses

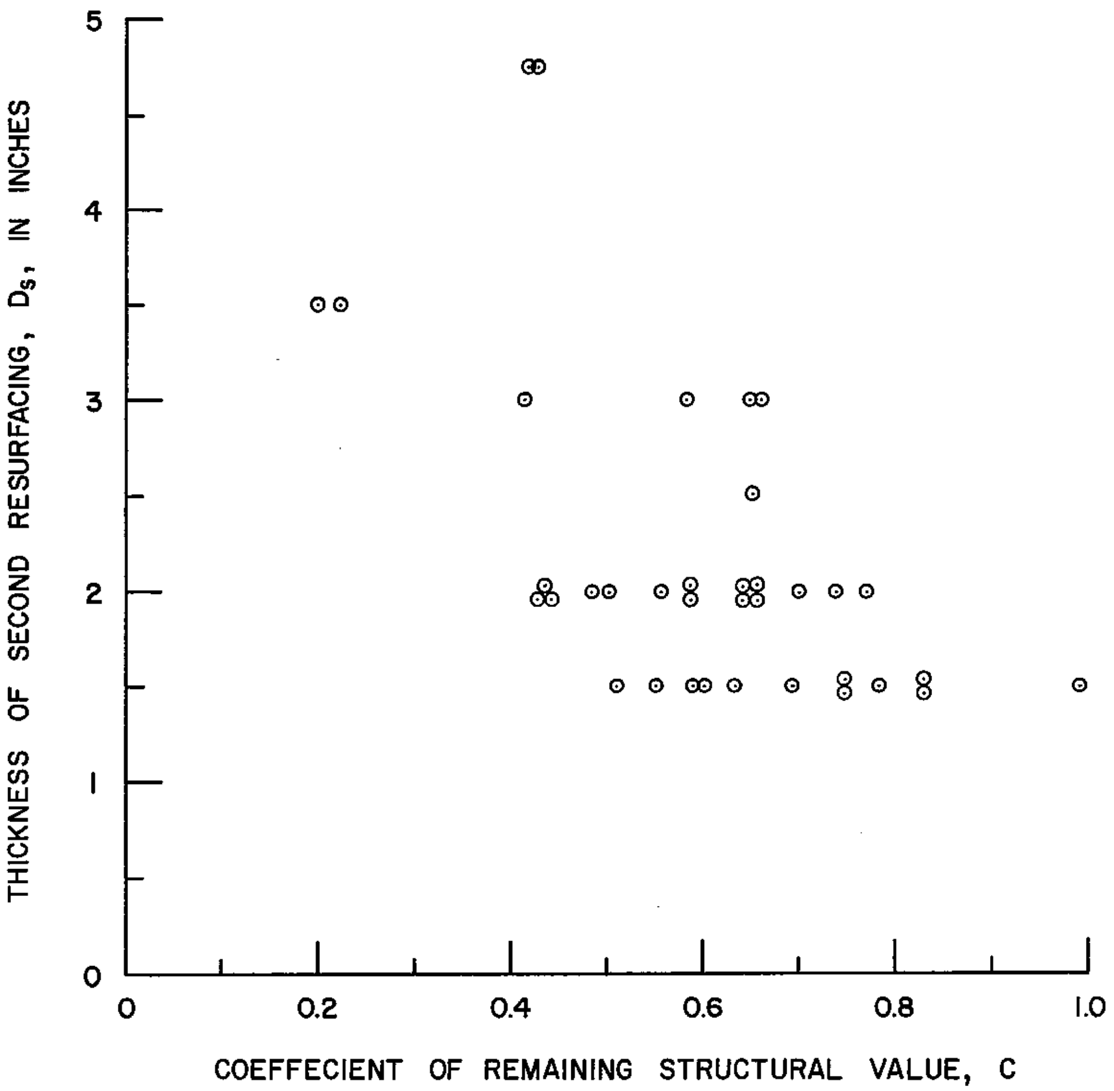

FIGURE 8. THICKNESS OF THE SECOND RESURFACING VERSUS THE COEFFECIENT OF REMAINING STRUCTURAL VALUE OF THE EXISTING PAVEMENT

of these sections ranged from 1 1/2 inches to 3 inches. An initial investigation of these data revealed a significantly shorter average service life for the sections having 2 inches or less of resurfacing when compared with the average life of the thicker sections. Since the concern was to establish a maximum design-life period, the sections resurfaced with less than 2 1/2 inches were excluded from further analyses.

The distribution of service lives of the remaining 35 sections is displayed on Figure 9. The average service life was found to be 14 years with none surviving beyond 24 years and only 2 of the 35 sections still surviving at 20 years. A check of the thickness designs and traffic histories of the 35 sections revealed that the data included both overdesigned and underdesigned sections. Since so few of these pavements survived 20 years, a 20-year anticipated service life as used for concrete pavement design was considered to be unrealistic. On the other hand, because of the inclusion of some underdesigned sections in the data, the average service life of 14 years for the pavements under consideration seemed slightly low for adequately designed resurfacings. A 15-year design period appeared to represent a tolerable maximum average life expectation for resurfacing design analyses and was selected for use in the resurfacing thickness design procedures.

MINIMUM THICKNESS

The two primary reasons for resurfacing a PCC pavement with bituminous concrete are to increase or reestablish the load carrying capability of the pavement and to improve the riding quality of the surface. The proposed thickness design procedure, as outlined thus far, is intended to cover the first of these. However, because experience has shown that resurfacing can be too thin

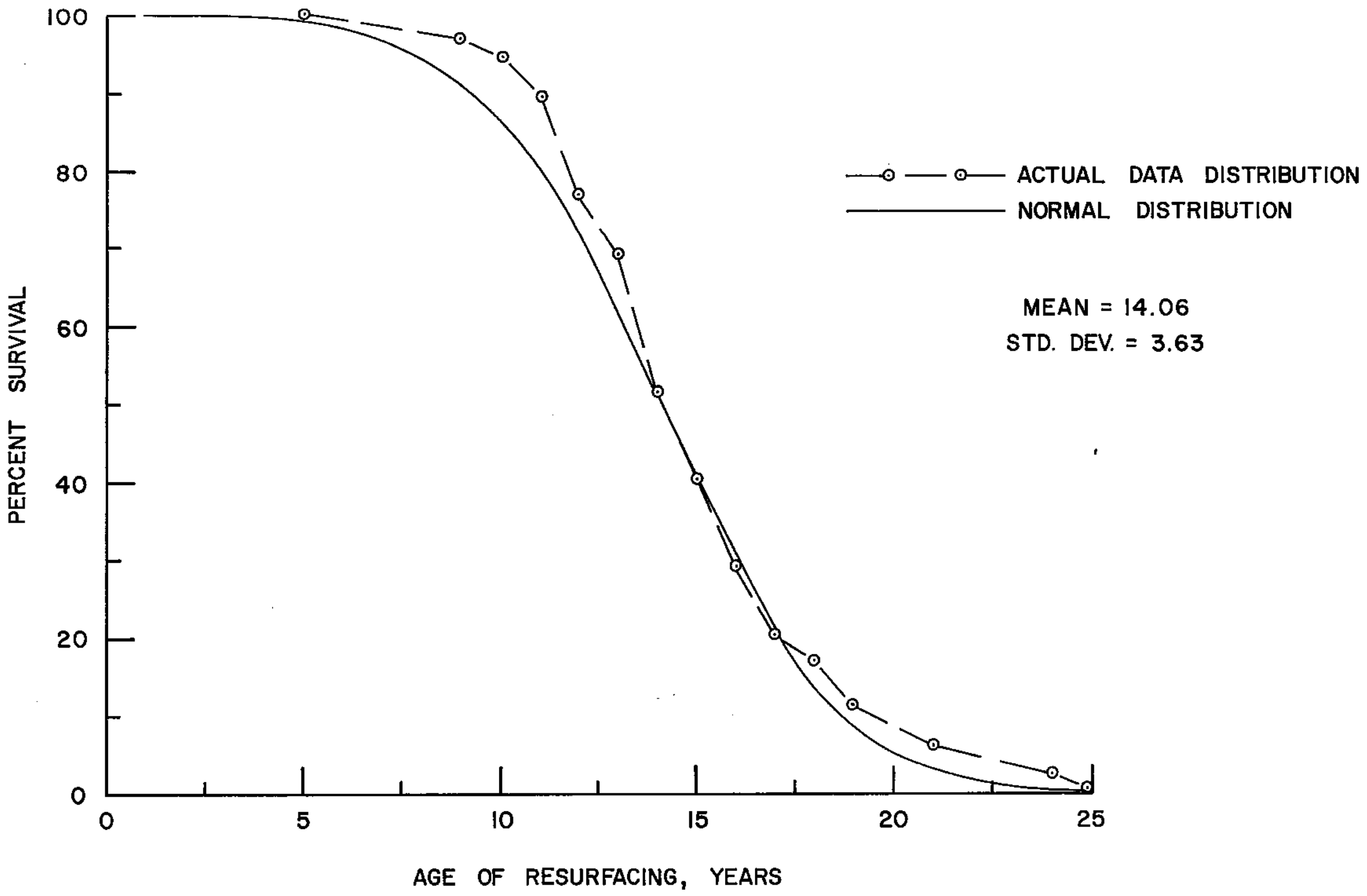

FIGURE 9. PERCENT OF RESURFACED PAVEMENTS REMAINING IN SERVICE VERSUS AGE OF THE RESURFACING

or contain too few layers to produce and maintain adequate riding quality, it was considered necessary to establish minimum thickness and placement standards for the design procedure to be complete.

The riding quality desired for interstate and primary routes has been found in the past very difficult and often impossible to achieve with less than three inches of resurfacing and two layers of placement. Thus, a minimum of three inches and two layers was selected for Class I and Class II roads. However, with the realization that a lower quality ride can be acceptable for local and secondary pavements, minimum thicknesses of 2 1/4 inches and 1 1/2 inches were selected for Class III and Class IV roads, respectively, with the Class III roads still requiring the minimum two-course construction.

USE OF THE DESIGN PROCEDURE

The design procedure developed and presented in this paper enables the design engineer to select the thickness of resurfacing needed to prolong the useful life of an existing rigid pavement for up to 15 years while improving its riding quality. The designer is able to consider the anticipated future traffic, the thickness of the existing slab, the support provided by the subgrade, and, in the case of a previously resurfaced pavement, the thickness of an existing resurfacing.

Use of the procedure follows the same format employed in the previously adopted flexible and rigid pavement design procedures. Traffic factors are determined using the appropriate equation from Table 6, a selected design period not exceeding 15 years, and the estimated average daily traffic for the middle year of the design period. Roadway classifications, which determine the traffic factor equation and the nomograph that apply in a given case, are defined in

Table 6. The soil support CBR value can be determined in any logical fashion including use of the estimated values shown in Table 7. However, in many cases this value can be obtained from original soil surveys or from construction or design records.

Having secured the traffic factor and soil support values, a straight line is constructed on the appropriate nomograph (Figures 6 or 7) connecting these two values on their respective scales and intersecting the structural number scale. The value of this point of intersection is the required resurfacing structural number. The required thickness of resurfacing can then be determined using the thickness of the existing pavement components. If the resurfacing is to be the first for the pavement, the thickness is determined by the equation:

$$D_F = \frac{SN_R - 0.26\ D_C}{0.40} \qquad (15)$$

For second resurfacings the thickness is determined by the equation:

$$D_S = \frac{SN_R - (0.25\ D_F + 0.17\ D_C)}{0.40} \qquad (16)$$

However, in no case should the thickness be less than three inches for Class I and Class II roads, 2 1/4 inches for Class III roads and 1 1/2 inches for Class IV roads. In addition to the thickness determined by this procedure, consideration should be given to using a leveling course of nominal thickness to correct the more severe existing surface irregularities. The thickness of such a course should not be included as a part of the required thickness.

PROCEDURE LIMITATIONS

This procedure has been developed to provide a means for determining the resurfacing thickness required to upgrade the structural capabilities and restore the riding qualities of properly repaired existing concrete pavements and resurfaced concrete pavements that have already served their original lives. It is not intended for use in selecting thicknesses for structurally sound pavements that require resurfacing simply to restore riding qualities lost due to scaling, raveling, or inadequate skid resistance. Also, since the procedure was developed with the assumption that the existing pavement will be properly repaired prior to placement of the resurfacing, the selected thickness will not be adequate to bridge highly distressed or failed areas in the existing pavement. However, when used properly, the procedure will, on the average, determine the thickness needed for sufficient structural capacity to prolong the pavement's service life and maintain the desired level of service for the design period.

IMPLEMENTATION

The design procedure developed and presented in this paper should not be construed to be a final answer to the resurfacing design problem. The influence of many factors, such as the condition of the existing pavement, has not been sufficiently defined to be included in the procedure. Indeed the great variability in performance of seemingly identical designs clearly indicates that many unknown factors still need to be considered. However, as demonstrated by Tables 3 and 4, the use of this procedure should greatly improve the resurfacing design capability of Illinois Division of Highways.

TABLE 6

DEFINITIONS OF ROAD CLASSES AND TRAFFIC FACTOR EQUATIONS

DEFINITIONS

Class I Roads and Streets

Trunk, major, area service, and collector roads and streets designed as four-lane or more facilities, and one-way streets with structural design traffic greater than 3,500 ADT.

Class II Roads and Streets

Major and area service roads and streets designed as two-lane facilities, one-way streets with structural design traffic less than 3,500 ADT and collector routes designed as two-lane facilities with structural design traffic greater than 2,000 ADT.

Class III Roads and Streets

Collector routes designed as two-lane facilities with structural design traffic between 750 and 2,000 ADT.

Class IV Roads and Streets

Collector and land access routes with structural design traffic less than 750 ADT.

TRAFFIC FACTOR EQUATIONS

Class I Roads and Streets

$$TF = \frac{DP(0.146 \times U_P \times PC + 44.895 \times U_S \times SU + 421.575 \times U_M \times MU)}{1,000,000}$$

Class II, III, and IV Roads and Streets

$$TF = \frac{DP(0.146 \times U_P \times PC + 44.895 \times U_S \times SU + 413.910 \times U_M \times MU)}{1,000,000}$$

where:

TF = equivalent 18-kip single axle load applications in millions
DP = design period, not to exceed 15 years
PC = average daily passenger car traffic
SU = average daily single unit traffic
MU = average daily multiple unit traffic
U_P = percent passenger cars in design lane
U_S = percent single units in design lane
U_M = percent multiple units in design lane

TABLE 7

ESTIMATED SOAKED CBR VALUES FOR VARIOUS SOIL CLASSIFICATIONS

Soil Classification	CBR Value
A-1	20
A-2-4, A-2-5	15
A-2-6, A-2-7	12
A-3	10
A-4, A-5, A-6	3
A-7-5, A-7-6	2

REFERENCES

1. Chastain, Sr., W. E., et. al., "AASHO Road Test Equations Applied to the Design of Portland Cement Concrete Pavements in Illinois," Highway Research Record 90, 1965.

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3. "Concrete Pavement Design," Portland Cement Association, 1946.