Overlay Design Based on AASHO Road Test Data

N. K. Vaswani, Virginia Highway and Transportation Research Council, Charlottesville

The raw data on the 99 overlays tested at the American Association of State Highway Officials Road Test were evaluated. In the process, the raw data on the pavements that were overlaid were also evaluated. The relationship between the serviceability index of the pavement, the accumulated traffic in terms of 80-kN [18 000-lbf/in² (18-kip)] equivalent loads, and the thickness index of the pavement before the overlay was determined. This relationship was found to apply to the overlaid pavements also. Based on this relationship, the strength coefficient of the overlay was determined and a method of designing the thickness of an overlay was developed. This design method does not require the use of pavement-deflection data.

Since 1962, the American Association of State Highway Officials (AASHO) Road Test results (1) have provided the fundamental guidance for the design of pavements in this country. However, although the Road Test included studies on 99 overlays, these failed to produce conclusive results and, thus, the test results provide no guidance for the design of overlays. The conclusions from the study of overlays stated in part that "Attempts at mathematical analysis designed to establish a specific relationship between performance and overlay design were unsuccessful." But recently, the need for suitable methods of designing overlay thicknesses and of predicting their performance has been recognized, and it has become imperative that the AASHO results be further investigated to provide suitable guidance for the design of overlays.

OBJECTIVE AND SCOPE

The objective of this investigation was to use the raw data from the AASHO Road Test for the determination of the strength coefficient of overlays and the design of overlay thicknesses. The objective was met by accomplishing the following three tasks:

1. The development of a relationship between the serviceability of a pavement, the accumulated traffic, and the structural strength of the pavement before and after an overlay,
2. The determination of the strength coefficient of the overlay, and
3. The development of a method for designing the thickness of overlays.

VARIABLES

The extent and type of distress that a pavement undergoes depends on the traffic it carries and its structural strength. These three variables are discussed below.

Distress, in the AASHO Road Test, is defined by the serviceability index (SI). The SI of a new pavement decreases as the accumulation of traffic increases. The rate of decrease depends on the structural strength of the pavement; the higher the structural strength, the lower the rate of decrease. Traffic is defined in terms of the number of accumulated 80-kN [18 000 lbf (18-kip)] equivalent single-axle loads. The structural strength is defined in terms of the design thickness index (D), which is defined as

$$D = a_1 h_1 + a_2 h_2 + a_3 h_3 \quad (1)$$

where

h_1, h_2, and h_3 = thicknesses of the surface layer, the base layer, and the subbase layer, respectively, and
a_1, a_2, and a_3 = strength coefficients of the layers h_1, h_2, and h_3, respectively.

The SI is measured by pavement roughness, cracking, patching, and rutting.

RELATIONSHIP BETWEEN ACCUMULATED TRAFFIC AND D

Before Overlay

The AASHO Road Test report gives raw data—including the cross section, total traffic, and axle loads—on 270 pavements for five values of the SI (3.5, 3.0, 2.5, 2.0, and 1.5). These raw data were used to determine the value of D for each pavement and its accumulated traffic as discussed below.

Thickness Index

The AASHO Road Test results give the strength coefficients of the materials used in the pavement sections as 0.44 for an asphalt concrete surface layer, 0.14 for an untreated stone base, and 0.11 for an untreated material in the subbase. Because all of the 270 pavements tested in the AASHO Road Test consisted of these three materials only, in this investigation, Equation 1 can be written as

$$D = (0.44h_1 + 0.14h_2 + 0.11h_3)/2.5 \quad (1a)$$

(when h_1, h_2, and h_3 are measured in centimeters).

Accumulated Traffic

The axle-load equivalency factors given by the AASHO Road Test results were used to determine the 80-kN equivalent load for a given axle load. The accumulated number of 80-kN equivalent loads for each of the five SIs on each project were then determined by multiplying the accumulated number of axle-load repetitions by the axle load in terms of the 80-kN equivalent load.

Linear multiregression analyses of the D-values and the accumulated traffic for each of the five SIs were carried out separately by using Equation 2.

$$\text{log no. of 80-kN equivalent loads} = C + E\,(\text{thickness index}) \quad (2)$$

where

C = intercept of the D-axis for a given SI and
E = slope of the linear portion of the curve of the accumulated traffic versus D for a given SI.

Figure 1. Relationship between serviceability index and cumulative traffic at different values of thickness index.

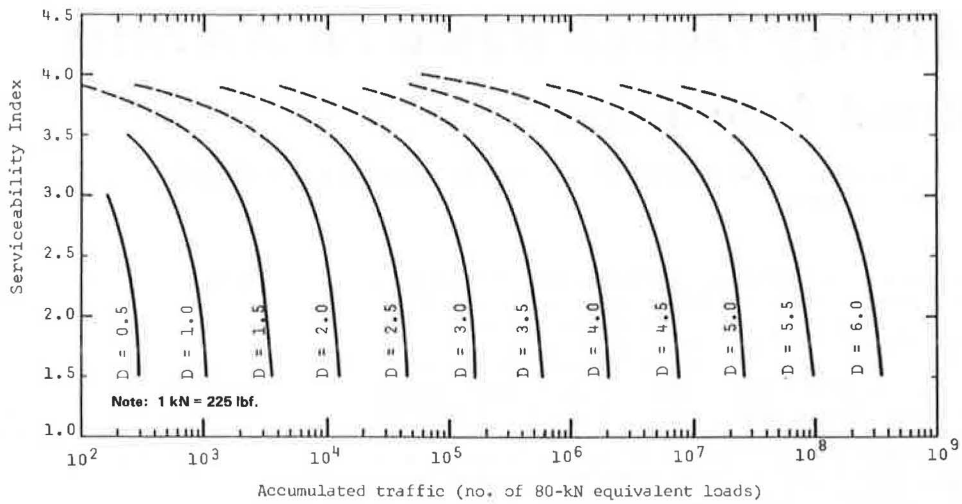
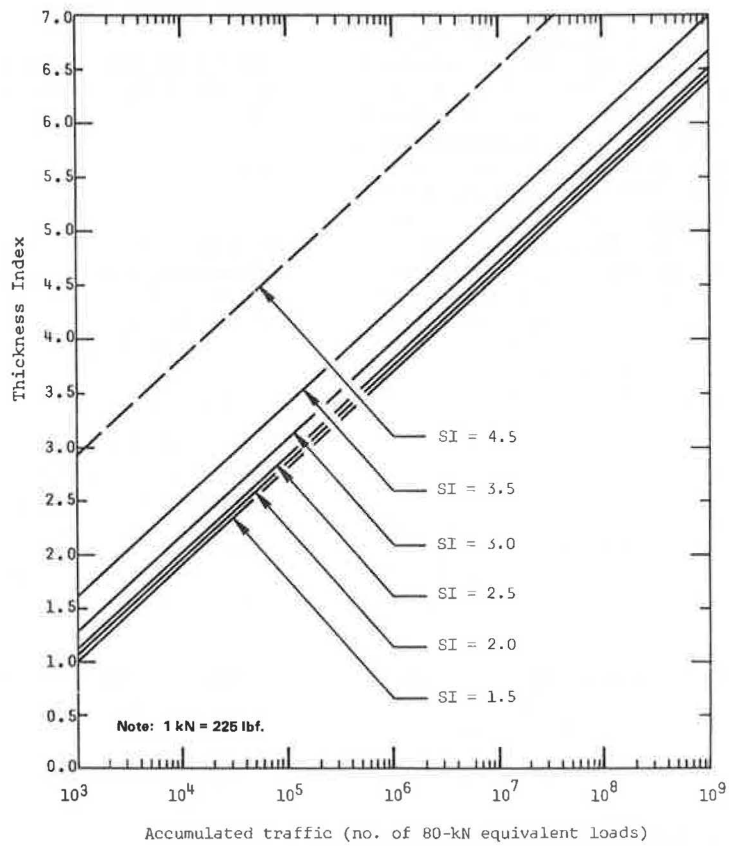


Figure 2. Relationship between thickness index and cumulative traffic at different values of serviceability index.



The values of C and E in the equations so developed and the correlation coefficients (Rs) of these equations are given below.

SI	C	E	R
3.5 (N = 270)	1.140	1.128	0.88
3.0 (N = 258)	1.702	1.063	0.93
2.5 (N = 239)	1.810	1.080	0.95
2.0 (N = 230)	1.814	1.106	0.95
1.5 (N = 216)	1.834	1.116	0.95

Thus, the values of E in Equation 2 for the five SIs are almost identical. Therefore, its value was taken as its average (i.e., 1.1) and the values of C in Equation 2 were redetermined.

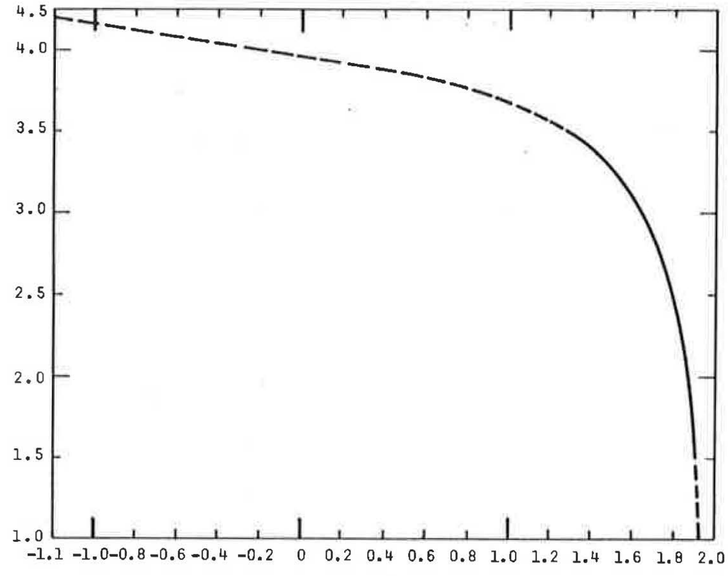
$$\text{log no. of 80-kN equivalent loads} = C + 1.1(\text{thickness index}) \qquad (2a)$$

The values of C and the Rs and standard errors of estimate (SEs) of the equations so developed are given below.

SI	C	R	SE
3.5	1.27	0.88	0.69
3.0	1.63	0.93	0.47
2.5	1.79	0.95	0.38
2.0	1.87	0.95	0.36
1.5	1.92	0.95	0.36

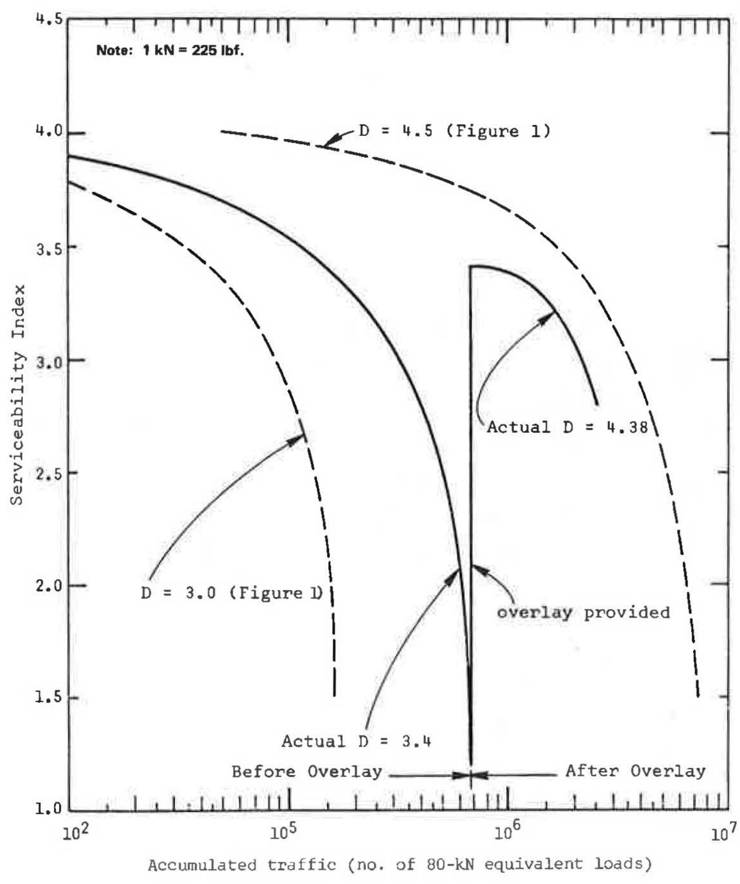
Figures 1 and 2 show the relationship between the SI, the accumulated traffic, and D throughout the life of a

Figure 3. Relationship between serviceability index and C.



SI	C
1.0-	1.92
1	1.92
1.25	1.91
1.50	1.90
1.70	1.89
1.80	1.88
2.0	1.87
2.1	1.85
2.2	1.84
2.3	1.83
2.4	1.81
2.5	1.78
2.6	1.76
2.7	1.74
2.8	1.71
2.9	1.68
3.0	1.64
3.1	1.59
3.2	1.54
3.3	1.47
3.4	1.39
3.5	1.27
3.6	1.14
3.7	0.97
3.8	0.70
3.9	0.32
4.0	-0.2

Figure 4. Example of pavement and overlay behavior (loop 5: AASHO Road Test).



flexible pavement. In these two figures, the values of the SIs were extrapolated by plotting C versus the SI as given in Equation 2a and shown in Figure 3. By using Figure 3, the value of C can be obtained for any value of the SI.

After Overlay

The AASHO Road Test results give raw data on 99 overlay projects. From these data, the following were obtained: (a) the values of the SI before the overlay, immediately after the overlay, and at the end of the overlay service and (b) the accumulated traffic before the overlay and at the end of the service life of the overlay. The accumulated traffic immediately after the overlay is equal to the accumulated traffic immediately before the overlay. The three data points so obtained for each project can be plotted in Figure 1 and extrapolated parallel to the curves given there and, thus, the values of the SI, the accumulated traffic, and D for the pavement

Table 1. Data on AASHO overlay projects.

Loop	AASHO Design D	Overlay Thickness (cm)	Before Overlay: Accumulated Traffic [80-kN equivalent loads (000s)]	Before Overlay: SI	Before Overlay: Actual D	After Overlay: SI	After Overlay, At End of Service: Accumulated Traffic [80-kN equivalent loads (000s)]	After Overlay, At End of Service: SI	After Overlay, At End of Service: Actual D	Mean Strength Coefficient of Overlay
5	3.04	7.5	214	0.6	3.07	3.23	2894	3.65	5.15	0.693
	3.04	7.5	183	1.4	3.03	2.97	2413	2.85	4.30	0.423
	3.06	7.5	281	1.2	3.18	3.20	2894	2.35	4.26	0.360
	3.06	7.5	341	1.6	3.30	3.27	2297	2.85	4.30	0.333
	3.04	7.5	147	0.9	2.94	3.83	292	2.00	3.43	0.163
	3.04	7.5	132	1.4	2.94	3.10	271	2.00	3.40	0.153
	3.50	7.5	375	0.4	3.32	3.80	2798	2.60	4.31	0.330
	3.50	7.5	385	1.5	3.36	3.80	2208	3.65	5.08	0.573
	3.48	7.5	362	0.9	3.28	3.00	2849	2.00	4.21	0.310
	3.48	7.5	337	1.7	3.31	3.17	2297	2.54	4.22	0.303
	3.92	7.5	1667	0.1	3.88	3.40	1224	2.45	4.24	0.120
	3.92	7.5	975	1.4	3.68	3.10	1053	2.85	4.20	0.173
	3.06	7.5	161	1.5	2.98	3.60	330	2.00	3.48	0.167
	3.06	7.5	170	1.1	2.96	3.75	167	1.55	3.31	0.117
	3.46	7.5	364	1.4	3.30	3.50	2848	3.60	5.02	0.573
	3.46	7.5	334	1.7	3.31	2.90	240	2.00	3.54	0.077
	3.90	7.5	1654	1.4	3.87	3.50	735	3.60	4.95	0.360
	3.50	7.5	378	1.6	3.35	3.63	2797	3.85	5.72	0.790
	3.50	7.5	304	1.7	3.26	3.30	2296	2.55	4.23	0.323
	3.48	7.5	370	1.3	3.30	4.07	2798	3.95	5.93	0.877
	3.48	7.5	942	1.1	3.66	3.55	1053	2.50	4.10	0.147
	3.48	7.5	378	1.5	3.33	4.00	2798	3.10	4.50	0.390
	3.92	7.5	2001	0.9	3.95	3.53	895	2.15	4.20	0.083
	3.46	7.5	231	1.0	3.11	3.00	2894	2.55	4.27	0.387
	3.46	7.5	319	1.6	3.28	3.37	2257	2.20	4.16	0.293
	3.90	7.5	1852	0.8	3.93	3.30	1192	3.30	4.61	0.227
	3.90	7.5	1544	0.6	3.85	2.97	882	2.95	4.30	0.150
	3.90	8.8	1492	1.5	3.88	3.30	1283	3.15	4.50	0.207
	3.90	7.5	1334	1.2	3.80	3.33	946	3.45	4.60	0.267
	3.48	7.5	994	1.0	3.68	3.67	1005	3.60	4.85	0.390
Mean	3.48	7.5	674	1.2	3.40	3.40	1696	2.79	4.38	0.325[a]
Mean of 99 projects	3.35	7.5	760	1.2	2.93	3.26	2338	2.82	3.79	0.30[b]

Note: 1 cm = 0.4 in; 1 kN = 225 lbf.
[a]SD = 0.203. [b]SD = 0.30.

before and after the overlay can be determined. An example of this is shown in Figure 4.

A study of these data for each project showed that all pavements behave in the manner shown by the solid line in Figure 4 (which is an example of the mean values of pavements on loop 5 as given in Table 1).

In this example, the pavement had deteriorated to an SI of 1.2 before the overlay. Because the overlay covered all the observed types of distress, the SIs increased without a change in traffic. When an overlaid pavement is first opened to traffic, the rate of decrease in the SI as the traffic increases is constant but the duration of this situation depends on the thickness of the overlay. After some time, the reduction in the SI accelerates in the same manner as for a new pavement, and the curve of the SI versus the traffic follows the general trend shown for new pavements before the overlay. This behavior of the overlaid pavement is shown in Figure 4.

In practice, the SI of the pavement and the accumulated traffic carried by the pavement before the overlay are known. If the additional value of D contributed by the overlay could be determined, the pavement behavior in terms of the SI versus the traffic after the overlay could be predicted, as shown in Figure 4. The D-value of the overlay can be determined if its strength coefficient is known.

DETERMINATION OF STRENGTH COEFFICIENT OF AN OVERLAY

To determine the strength coefficient of an overlay, the raw data on the 99 AASHO overlay projects were used. The data on each of the 99 projects needed for this investigation were used in their original form or after conversion. The data showed the following:

1. The pavements overlaid had a minimum D-value of 1.28, a maximum of 4.82, and an average of 3.35. The actual thicknesses of the pavements ranged from 12.7 to 53 cm (5 to 21 in). Thus, the strength-coefficient values used in this investigation covered a broad range of pavement strengths.
2. All of the pavements had reached an SI of about 1.5 or lower, with an average of 1.2, before they were overlaid. Usually, pavements—especially those that are heavily trafficked—are overlaid at an SI of 2.5 or higher. The overlay data based on low terminal SIs will not affect the results of this investigation and could be applied to pavements that have high terminal SIs because, as shown in Figure 1, the traffic carried at an SI of 2.5 is not a great deal more than the traffic carried at an SI of 1.5 or lower.
3. Except for one case of an overlay that was 10 cm (4 in) thick, the overlay thickness varied from 5 to 8.9 cm (2 to 3.5 in) and averaged 7.6 cm (3 in). The results of this study must therefore be assumed to be applicable for overlay thicknesses greater than 5 cm until further data are available for verification.

The strength coefficient of an overlay can be obtained by using Equation 3.

$$D_a = D_b + ha_o \quad (3)$$

where

D_b and D_a = actual D-values before and after the overlay,

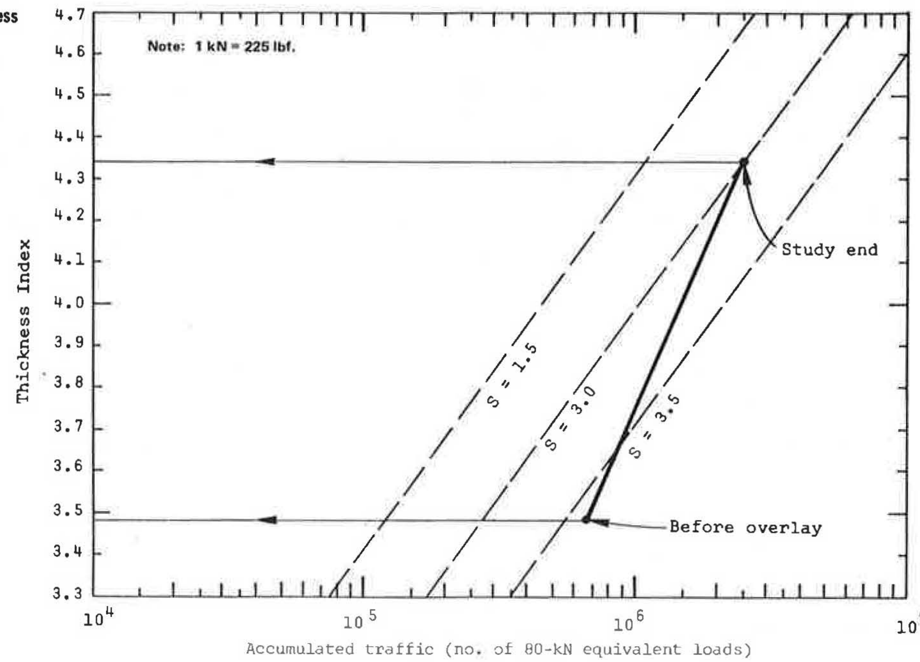
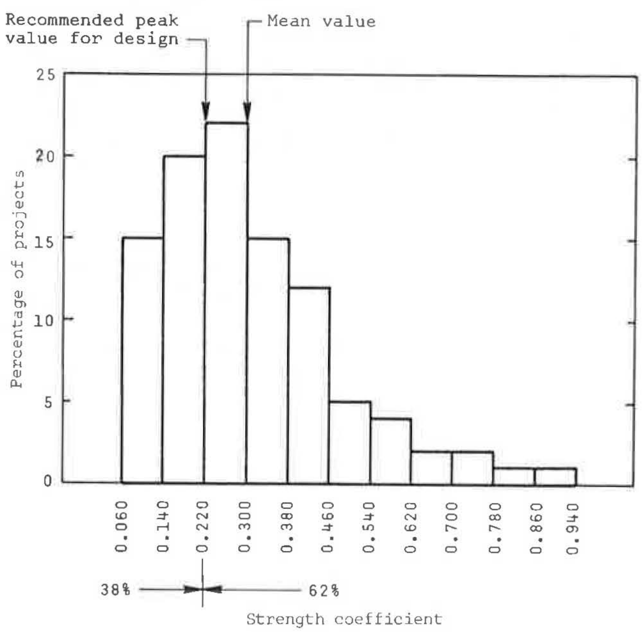


Figure 5. Method for determining thickness index from accumulated traffic and serviceability index (example: loop 5–AASHO Road Test).

Figure 6. Histogram of thickness equivalency values of overlays on AASHO overlay test pavements.



h = thickness of the overlay, and

a_o = strength coefficient for one unit thickness of the overlay.

The value of D_b before the overlay may not be exactly the same as the design value obtained by using Equation 1a. This difference may be due to various factors such as subgrade support, material variations, and construction techniques. Thus, in the example shown in Figure 4 for the mean of values of pavements on loop 5, the mean design D-value of the pavements obtained by using Equation 1a was 3.48. When plotted, the data of the SI versus the traffic showed that the actual value of D_b was 3.40. It is therefore necessary that the actual value of D_b be determined for the design of overlays.

The actual value of D_b can be obtained by using the data on the SI and the accumulated traffic as given by (a) Equation 2a and Figure 3, or (b) Figure 1, or (c) Figure 2. The use of these three methods can be shown by taking as an example the mean of the values on loop 5 wherein the mean values of the SI and the accumulated traffic before the overlay are 1.2 and 674 thousand 80-kN equivalent loads. From Figure 3, the value of C for an SI of 1.2 is 1.92. Hence, D_b in Equation 2a = (log 674 000 - 1.92)/1.1 = 3.6. From Figure 1, the value of D_b (as shown on an enlarged scale in Figure 4) is 3.4. From Figure 2, the value of D_b (as shown on an enlarged scale in Figure 5) is 3.48.

In a similar way, the value of D_a in Equation 3 can be determined by using Figures 1 or 2. This can be shown by the example of the mean of the values on loop 5, wherein the mean values of the SI and of the accumulated traffic after the service life of the overlay are 2.79 and 2.370 million 80-kN equivalent loads. The value of D_a from Figure 1 (as shown on an enlarged scale in Figure 4) is 4.38 and that from Figure 2 (as shown on an enlarged scale in Figure 5) is 4.34.

By using the average values of D_b and D_a obtained from Figures 4 and 5, we obtain D_b = 3.44 and D_a = 4.36. The mean thickness of an overlay on loop 5 is 7.5 cm (3 in). Thus, the strength coefficient of the overlay is (4.36 - 3.44)/3 = 0.31.

The strength coefficients for the 99 overlay projects are given in Table 1. The average value is 0.30. A histogram of the strength coefficients of the overlays (see Figure 6) indicates that the population is not normally distributed. If the mean value of 0.30 is adopted as the strength coefficient for overlays, 50 percent of the design projects will be satisfied. To cover a greater percentage of projects, a value of 0.22 is recommended. This value will cover 62 percent of the design projects for AASHO pavements that had been reduced to a terminal SI of 2.5 or lower before an overlay was provided. For roads and highways for which overlays are provided at higher terminal indices, a strength coefficient of 0.22 should satisfy a much larger percentage of the design projects. The value of 0.22 is exactly half the value of the strength coefficient of asphalt concrete for new pavements. It is, therefore, recommended that, for design purposes, the strength coefficient for an overlay be taken as half the strength coefficient of asphalt concrete.

Taking the strength coefficient of an asphalt concrete overlay as half the value for new construction can be justified as follows. As a pavement ages and is trafficked, it becomes fatigued and weak. When an underlying layer becomes weaker than the overlying one, the thickness equivalency of the overlying layer decreases. This is illustrated by the practice in Virginia of taking the thickness equivalency of a cement-treated aggregate placed directly over a raw subgrade as 0.6 times its thickness equivalency when placed over a strong subbase or a base course.

THICKNESS OF AN OVERLAY

By using Equation 2a, the traffic carried by an overlaid pavement can be calculated as

$$\text{Traffic} = \text{antilog}(C_a + 1.1D_a) - \text{antilog}(C_b - 1.1D_b) \quad (4)$$

where C_b and C_a = values of C in Equation 2a before the overlay and at the end of the overlay service period, respectively.

In the AASHO Road Test, the SIs before the overlay and at the end of the service period of the overlay were not the same. In practice, these values are the same, depending on the road classification; i.e., $C_a = C_b$, and Equation 3 reduces to

$$\text{Traffic after overlay} = \text{traffic before overlay} \times \{\text{antilog}[0.11 \times (\text{overlay thickness}/2.5) \times \text{strength coefficient of overlay}] - 1\} \quad (5a)$$

(when overlay thickness is measured in centimeters) or

$$\text{Traffic after overlay/traffic before overlay} = \{\text{antilog}[0.11 \times 0.22 \times (\text{overlay thickness}/2.5)] - 1\} = [\text{antilog}(0.01 \times \text{overlay thickness}) - 1] \quad (5b)$$

or

$$\text{Percentage increase in traffic after overlay} = \text{antilog}(0.01 \times \text{overlay thickness}) - 1 \times 100 \quad (5c)$$

As shown by Vaswani in Figure 4 of the previous paper in this Record, the relationship between the percentage increase in the accumulated traffic and the overlay thickness can be used to determine the required thickness of an overlay. This figure shows that the traffic capacities for overlay thicknesses of 2.5, 5.1, and 7.6 cm (1, 2, and 3 in) are, respectively, 78, 217, and 464 percent of the traffic before the overlay.

If these percentage increases in traffic are examined carefully, it is seen that the percentage increase in traffic would be the same if the overlay were applied in several thin layers rather than in one thick layer. Thus, one 7.6-cm-thick layer would carry the same traffic as three 2.5-cm-thick layers.

CONCLUSIONS

1. The strength coefficient of an asphalt overlay is less than the strength coefficient of asphalt concrete for new pavements. It is recommended that, in the design of overlays, the strength coefficient for an asphalt overlay should be taken as half (0.22) the strength coefficient of asphalt concrete for new pavements (0.44).
2. The method for designing an overlay developed in this investigation could be used to determine the thickness of an overlay.

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Analytical Study of Minimization of Reflection Cracking in Asphalt Concrete Overlays by Use of a Rubber-Asphalt Interlayer

N. F. Coetzee and C. L. Monismith, Department of Civil Engineering and Institute of Transportation Studies, University of California, Berkeley

The problem of the reflection cracking that is associated with the rehabilitation of existing cracked pavements by the application of an overlay is considered. A general-purpose finite-element program was used to determine the stresses in the overlay at the discontinuities in the underlying pavement, focusing on the effect of a rubber-asphalt stress-absorbing-membrane interlayer on these stresses. A number of variables—the thickness and stiffness of the overlay, interlayer, cracked layer, and subgrade as well as the crack width—were investigated for a specific load condition.