9. Austin Research Engineers, Inc. Asphalt Concrete Overlays of Flexible Pavements: Volume 1—Development of New Design Criteria. Federal Highway Administration, Rept. FHWA-RD-75-75, June 1975. NTIS: PB 263 432/7SL.
10. J. P. Zaniewski. Design Procedure for Asphalt Concrete Overlays of Flexible Pavements. Univ. of Texas at Austin, Dissertation, Dec. 1977.
11. R. K. Kher, W. R. Hudson, and B. F. McCullough. A Systems Analysis of Rigid Pavement Design. Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 123-5, Jan. 1971.

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Overlay Design Based on Visible Pavement Distress

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Data collected on 111 Interstate highway projects in Virginia were analyzed by using a multiregression procedure, and the rating coefficient for each type of distress was determined. From these coefficients, the total distress and the resultant maintenance rating for each pavement were calculated. The types of distress that were found to affect the maintenance rating are longitudinal cracking, alligator cracking, rutting, pushing, raveling, and patching. A method for designing the required thickness of an overlay was developed based on taking the thickness equivalency of an asphalt concrete overlay in Virginia as equal to 0.5 and the overlay thickness as a function of the ratio of the traffic, in terms of the number of 80-kN [18 000-lbf (18-kip)] equivalent loads, carried by the pavement before the overlay to the traffic it would carry after the overlay, depending on the durability of the asphalt mix. This design method does not require the use of a deflection-measuring device.

In Virginia, the decision to provide an overlay over a flexible pavement conventionally is based on a visual inspection that does not make reference to any defined criterion for pavement evaluation. However, to comply with the Reconstruction, Rehabilitation, and Resurfacing Program of the Federal Highway Administration, the states now need procedures by which the necessity for an overlay can be validated and its required thickness can be estimated so as to obtain federal participating funds.

In Virginia and some other states, mechanistic methods for determining the required thicknesses for overlays have been developed. However, these methods are based on deflection data (1, 2) and their use would require that all districts have deflection equipment such as the Dynaflect available, along with a technician, for the collection of data. Similarly, the methods for quantifying total pavement distress based on rating systems require the use of some technique for measuring distress by mechanical means. Consequently, there is a need for a method by which to establish a relationship between the total pavement distress, the accumulated traffic and the structural strength of the pavement that can be used to design overlays without the necessity of using pavement-deflection (or any other) measuring devices.

OBJECTIVE AND SCOPE

The objective of the investigation reported here was the development of a method for designing the thickness of overlays for flexible pavements that would be based on maintenance ratings of the pavements as determined by visual observations and sound engineering judgment. These overlays would be designed for the sole purpose of improving the structural strength of the pavement. Defects in the pavement surface that did not affect its strength would not be considered.

As outlined in the working plan (3), the study was designed to accomplish the following tasks:

1. To develop a pavement-maintenance-rating system based on the total observed pavement distress;
2. To develop a relationship between the maintenance rating, the accumulated traffic {in terms of 80-kN [18 000 lbf (18-kip)] equivalents}, and the structural strength of the pavement (in terms of its thickness index) that could be used to evaluate the performance of the pavement before and after the overlay;
3. To determine the thickness equivalency of the overlay; and
4. To develop a method for determining the required thickness of the overlay.

PAVEMENT-MAINTENANCE-RATING SYSTEM

The pavement-maintenance-rating technique that was developed is based on the same principle as the serviceability index (SI) included in the American Association of State Highway and Officials (AASHO) Road Test results. The SIs of the new pavements at the AASHO Road Test varied from 3.9 to 4.5, with an average value of 4.2. For the design of overlays in Virginia, it is proposed that a maintenance-rating factor (MR) of 100 for a new pavement be adopted. Thus, an AASHO SI of 4.2 would equal an MR of 100, and an SI of 0 would equal an MR of 0. As distress to the pavement increases, factors assigned to various types and degrees of distress are subtracted and the MR decreases. The MR for a new pavement will decrease from 100 as the accumulated traffic, and hence the distress, increases.

Although the pavement distress over the first few years that a road is open to traffic is so small that it is not discernible to the naked eye, it can be measured by a Dynaflect or a roughometer. However, measurement of this indiscernible distress is not necessary for the design of overlays. In the rating system developed, an SI of 3.9 or an MR of 93 [i.e., $(3.9/4.2) \times 100 = 93$] is

Table 1. Interstate flexible pavement distress ratings and overlay data.

Serial No.	Pavement Distress: 1974-1975 LC	AC	Ru	Pu	Ra	MR	Year Constructed	First Overlay Year	No. of 80-kN Equivalent Loads (000 000s)	D
1	2	1	0	1	0	88	1961	1971	1.55	12.3
2	1	3	1	1	0	78	1960	1971	2.00	12.3
3	3	2	2	0	0	83	1963	1977	2.72	14.0
4	3	2	2	0	1	83	1963	1975	2.24	13.8
5	1	0	0	0	0	93	1962	1975	2.43	13.8
6	3	3	0	0	3	78	1963	1976	2.44	13.8
7	0	0	0	0	0	93	1963	1974	2.02	13.6
8	2	0	0	0	0	93	1963	1974	1.97	13.6
9	2	0	0	0	0	93	1963	1969	1.09	13.8
10	1	0	0	0	2	91	1963	1969	1.16	13.8
11	1	0	0	0	2	91	1963	1970	1.27	13.8
12	3	3	3	0	0	78	1963	1976	2.27	13.8
13	0	0	0	0	0	93	1964	1974	1.77	13.8
14	0	0	0	0	0	93	1964	1973	1.57	13.8
15	0	0	0	0	0	93	1964	1973	1.55	13.8
16	0	0	0	2	0	91	1964	1972	1.42	13.8
17	3	3	3	0	0	78	1965	1975	1.61	13.8
18	1	0	0	0	0	93	1968			15.2
19	1	0	0	0	0	93	1961	1969	1.36	13.4
20	0	0	0	0	0	93	1962	1970	1.39	13.4

Note: 1 kN = 225 lbf.

considered as the maximum value of incipient visible distress for the following reasons:

1. The minimum value of the AASHO SI for a new pavement was 3.9, which is equal to an MR of 93;
2. The rate of decrease of the MR as the traffic increases is constant to an MR of approximately 93 and, below that value, accelerates (i.e., at an MR of 93, the deterioration of the pavement begins to accelerate);
3. Statistical analysis gives higher values of correlation coefficients when pavements that do not have visible distress are assigned an MR of 93—in the present investigation, all pavements that did not have visible distress were assigned an MR of 93, irrespective of their age, because pavements that have MRs of 93 or higher are never considered for overlays.

The types of distress that contribute to pavement deterioration are longitudinal cracking (LC), alligator cracking (AC), rutting (Ru), pushing (Pu), raveling (Ra), and patching (Pa). For these types, it is recommended that the ratings given below be adopted.

Distress	Not Severe	Severe	Very Severe
None observed	0	0	0
Rarely observed	1	2	3
Occasionally observed	2	4	6
Frequently observed	3	6	9

On Interstate highways, overlays are applied while the distress is still not severe but, on low-traffic primary roads, the distress may be rated severe or very severe before overlays are placed. The amount and severity of distress considered indicative of a need for an overlay will require clear specification before the rating system can be used by field engineers.

In 1974-1975, McGhee carried out a survey of 111 flexible-pavement projects on 886 km (521 miles) of the Interstate highway system and visually determined the MRs (4) shown in Table 1. A multiregression analysis based on Equation 1 of these data, in which it is assumed that none of the distress recorded was rated as being severe,

$$MR = a_0 + a_1(\text{LC rating}) + a_2(\text{AC rating}) + a_3(\text{Ru rating}) + a_4(\text{Pu rating}) + a_5(\text{Ra rating}) + a_6(\text{Pa rating}) \quad (1)$$

gives Equation 1a which has a correlation coefficient of 0.96 and standard error of 0.39.

$$MR = 92.6 - 2.4LC - 2.3AC - 1.0Ru - 1.0Pu - 0.9Ra \quad (1a)$$

Because none of the projects on the Interstate highways considered had any patched areas, no coefficient for patching was included in Equation 1a. Patching is usually provided to cover severe or very severe distress, generally in the form of alligator cracking. If patching were considered in Equation 1a, the coefficient for it would be 2.3, the same as that for alligator cracking. However, patching is here classified as not severe and is rated only by the amount observed.

The data given below, taken from serial no. 4 in Table 1, can be used to illustrate the method for determining the MR of a pavement.

Type of Distress	Amount	Severity	Rating
LC	Frequent	Not severe	3
AC	Occasional	Not severe	2
Ru	Occasional	Not severe	2
Pu	None		0
Ra	Rare	Not severe	1
Pa	None		0

By using these data and Equation 1a, $MR = 92.6 - (2.4 \times 3) - (2.3 \times 2) - (1.0 \times 2) - (1.0 \times 0) - (0.9 \times 1) - (2.3 \times 0) = 77.9$. None of the MRs of the 111 Interstate projects cited above were lower than 78.

The MRs for the 111 projects were determined in June 1975. Pavements that had values between 78 and 83 were overlaid in 1975 or 1976, except for a few that were overlaid in 1977. Thus, there is an indication that the rating system determined in the investigation is in line with field practice. However, the establishment of priorities based on the system might lead to improvements in the utilization of funds. As shown in Table 1, (a) one project that had an MR of 83 in 1975 was overlaid in 1977; (b) two projects that had MRs of 78 in 1975 were overlaid in 1976; and (c) three projects that had MRs of 78, 83, and 93, respectively, were overlaid in 1975. If priorities had been established by using the rating system, the pavements that had the

Figure 1. Determination of number of 80-kN equivalent loads from traffic counts.

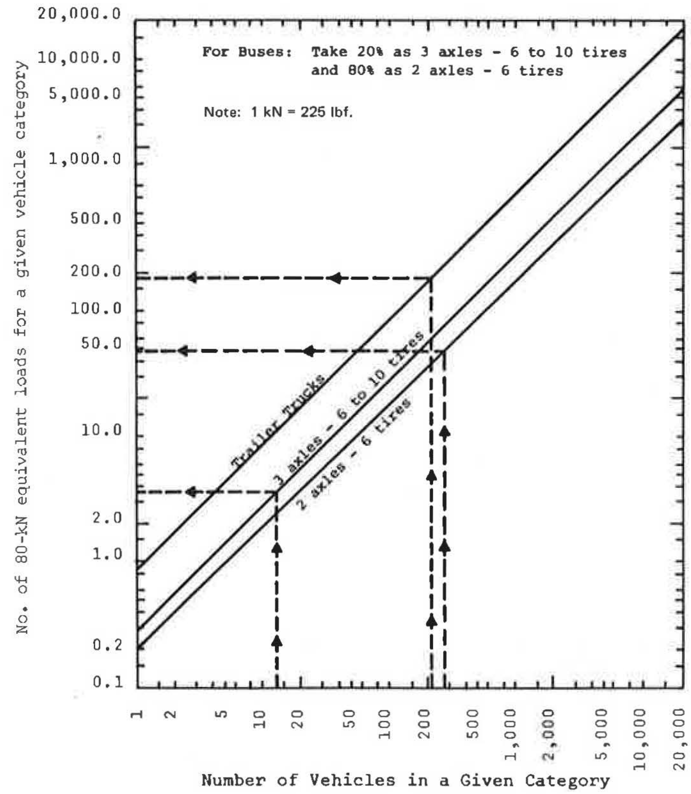


Table 2. Thickness equivalencies of materials used in Virginia for Interstate, arterial, and primary roads.

Location	Material	Thickness Equivalent
a_1	Asphalt concrete	1.0
a_2	Asphalt concrete	1.0
	Untreated aggregate base material (crushed or uncrushed, specification numbers 20, 21, and 22)	0.35
	Type 1 select material directly under asphalt concrete mat and over good quality subbase	0.35
a_3	Types 1, 2, and 3 select material	
	In Piedmont area	0.0
	In Valley and Ridge area and coastal plain	0.2
	Soil cement or soil lime	0.4
	Cement-treated aggregate base directly over subgrade	0.6

lower MRs would have been overlaid first.

The SI limits recommended by the AASHO committee (5) for use in decisions as to when overlays should be applied were correlated with the MR system as shown below.

Road Classification	SI	MR
Interstate	≤3.5	≤83
Arterial	≤3.0	≤71
Primary	≤2.5	≤60
Low primary or secondary	≤1.5	≤36

Thus, it is seen that, for the Interstate highway pavements in Virginia that had MRs of 83 or less, overlays are justified. Pennsylvania has used the same approach to pavement-maintenance rating (6).

RELATIONSHIP BETWEEN MAINTENANCE RATING, ACCUMULATED TRAFFIC, AND STRUCTURAL STRENGTH

The rate and amount of pavement deterioration are a function of the pavement strength and the accumulated traffic (in terms of the number of 80-kN equivalent loads) and can be determined by using Equation 2 (7).

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

where

A = f(MR), a function of the maintenance rating and constant for a given MR value, and
B = a constant for any given MR value.

The number of 80-kN equivalent loads can be determined from a traffic count by using Figure 1 (8). The annual traffic counts are prepared by the Traffic and Safety Division of the Virginia Department of Highways and Transportation (9).

The thickness index (D) is a number that shows the intrinsic strength of the pavement (i.e., without the subgrade support). It is a nondimensional quantity and is obtained by using Equation 3.

$$D = a_1h_1 + a_2h_2 + a_3h_3 + \ldots \quad (3)$$

where

h_1, h_2, and h_3 = thicknesses of asphalt concrete surface layer, base layer, and 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 values of a_1, a_2, and a_3 are given in Table 2.

Because there were no MR data for pavements in

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

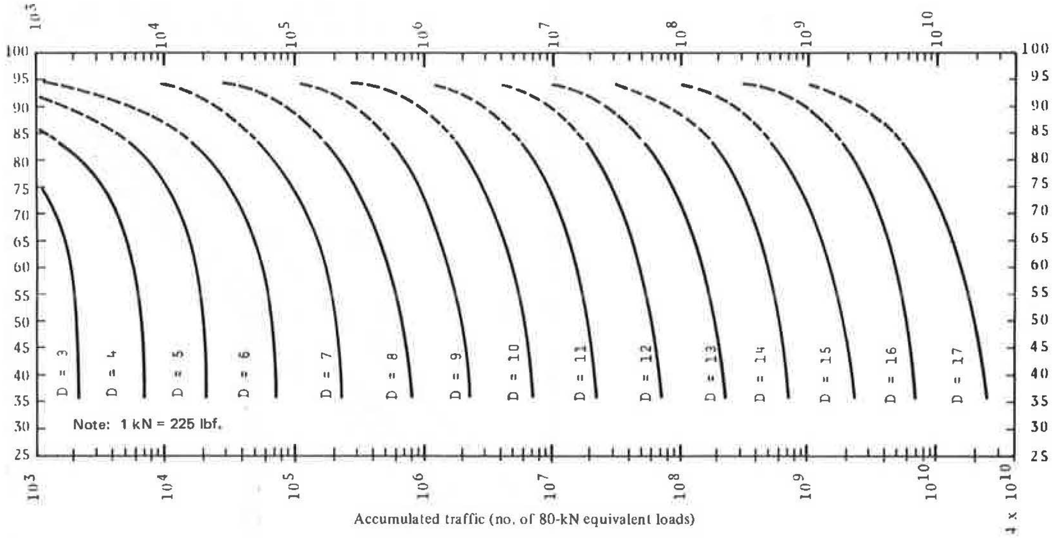
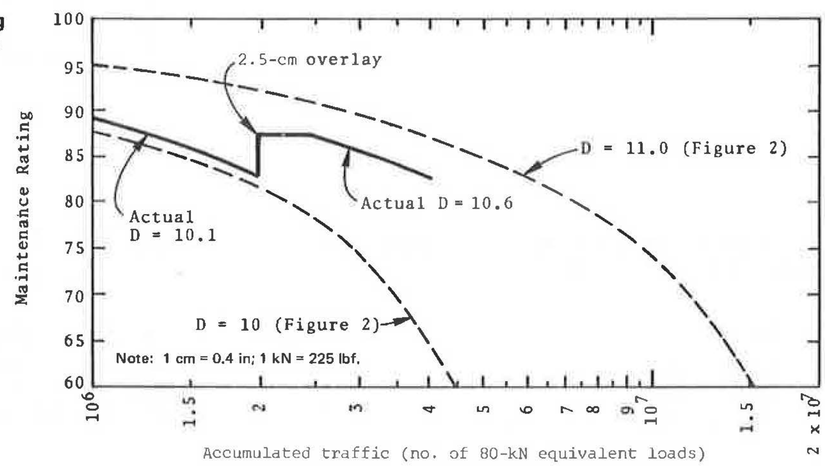


Figure 3. Relationship between maintenance rating and cumulative traffic of an Interstate pavement in Virginia before and after an overlay.



Virginia available for evaluation, the raw data from the AASHO Road Test pavements were used. The AASHO results give data on 270 projects that had different pavement cross sections. On each of the projects, traffic in terms of 80-kN equivalent loads is given for MRs of 83, 71, 60, 48, and 36 (SI values of 3.5, 3.0, 2.5, 2.0, and 1.5), respectively. The D-value index of each project was obtained by using the strength coefficients given in Table 2.

$$D = (1.00h_1 + 0.35h_2 + 0.20h_3)/2.50 \quad (3a)$$

(h_1, h_2, and h_3 are measured in centimeters), and an equation based on Equation 2 had the form

$$\text{log no. of 80-kN equivalent loads} = A + 0.5(\text{thickness index}) \quad (2a)$$

The values of A so obtained and the correlation coefficients (Rs) and standard errors (SEs) are summarized below.

MR	A	R	SE
83	1.213	0.87	0.71
71	1.582	0.92	0.49
60	1.742	0.94	0.41
48	1.823	0.94	0.39
36	1.871	0.94	0.39

These correlation coefficients show that an excellent relationship exists between the MR, the traffic, and the structural strength (see Figure 2).

STRENGTH COEFFICIENT

No MR data are available for overlaid pavements in Virginia; however, the AASHO Road Test gives basic data on 99 overlaid projects. These data have been evaluated and the results reported elsewhere (7). The evaluation showed that the strength coefficient of an overlay should be taken as one-half that of the asphalt concrete for new construction. In Virginia, the thickness equivalency of asphalt concrete for new construction is equal to 1 (as shown in Table 2). The strength coefficient of asphalt concrete for an overlay in Virginia is, therefore, 0.5.

Of the 111 projects analyzed in the investigation, 8 were overlaid in 1975. The average MR of these 8 projects was 83, and the average traffic on them before the overlay was about 2 million 80-kN equivalent loads. The average thickness of the overlays on these 8 projects was 2.5 cm (1 in). A 2.5-cm overlay on a new pavement in Virginia usually lasts as long as did the pavement before the overlay. Hence, it is assumed that these 8 pavements will be able to carry an additional 2 million 80-kN equivalent loads before a second overlay

Figure 4. Relationship between traffic-carrying capacity and overlay thickness.

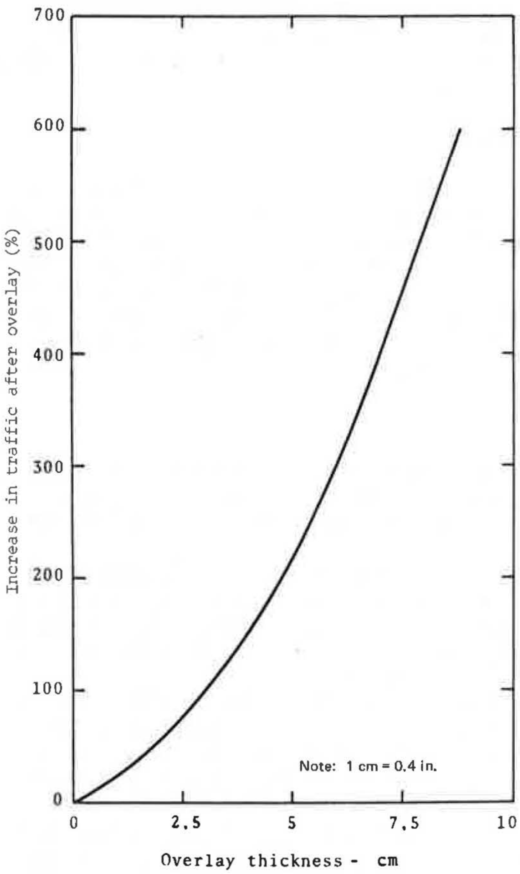


Table 3. Traffic growth rate and accumulated traffic (assuming 5 percent growth/year).

Period of Traffic (years)	Growth Rate	Accumulated Traffic	Period of Traffic (years)	Growth Rate	Accumulated Traffic
1	1	365	11	1.62	5 169
2	1.05	748	12	1.70	5 789
3	1.10	1 149	13	1.78	6 438
4	1.16	1 572	14	1.87	7 120
5	1.22	2 017	15	1.97	7 839
6	1.27	2 480	16	2.07	8 595
7	1.34	2 969	17	2.17	9 387
8	1.40	3 480	18	2.28	10 219
9	1.47	4 016	19	2.39	11 091
10	1.54	4 578	20	2.51	12 007

is needed. The relationship of the MRs to the traffic history of the average of these 8 pavements is shown on an exaggerated scale in Figure 3, which shows that the averages of the thickness indices of these 8 pavements before and after the overlays were 10.1 and 10.6, respectively. Thus, a 2.5-cm overlay gives a strength coefficient of 10.6 - 10.1 (or 0.5). Hence, it appears that the conclusion reached in the evaluation of the overlay strength coefficient for AASHO road projects (7) could also be applied to overlays in Virginia.

THICKNESS OF AN OVERLAY

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

$$\text{Traffic} = \text{antilog}(Aa + 0.5Da) - \text{antilog}(Ab + 0.5Db) \quad (4)$$

where

Ab and Aa = constants for the MR before the overlay and at the end of the overlay service and
Da and Db = thickness indices of the pavement before and after the overlay.

As described above, for a given type of highway, the MRs before the overlay and at the end of the overlay service are the same; that is, Aa = Ab. In such a case, Equation 4 reduces to

$$\text{Traffic after overlay} = \text{traffic before overlay} \times \{\text{antilog}\,[0.5\,(\text{overlay thickness}/2.5) \times \text{thickness equivalency of overlay}] - 1\} \quad (4a)$$

(when overlay thickness is measured in centimeters) or

$$\text{Traffic after overlay/traffic before overlay} = [\text{antilog}\,(0.1 \times \text{overlay thickness}) - 1] \quad (4b)$$

or

$$\text{Percentage increase in traffic after overlay} = [\text{antilog}(\text{overlay thickness}/10) - 1] \times 100 \quad (4c)$$

Figure 4, which is based on Equation 4c, shows the percentage increase in the number of 80-kN equivalent loads versus the overlay thickness in centimeters and 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.

Deflection studies carried out before and after the application of asphalt concrete overlays have shown that overlay thicknesses of 2.5 cm or more do contribute to an increase in the structural strength of the pavement. It is therefore recommended that the overlays provided for increasing the structural strength of pavements be a minimum of 2.5 cm thick. The following method is recommended for designing the thickness of an overlay.

The design for the thickness of an overlay is dependent on the durability of the asphalt concrete mix used and the way it is affected by such factors as age, hardening, and stripping of the asphalt. An overlay made from a properly placed, well-designed mix can perform satisfactorily for 10-15 years without surface rejuvenation. For determining the required thickness of an overlay, the use of a 12-year service life for the mix is recommended. The procedure for determining the overlay thickness is as follows:

1. Determine the accumulated traffic in terms of the number of 80-kN equivalent loads that the pavement has carried from the date of construction to the date of the proposed overlay, irrespective of any previous overlays. If necessary, use Figure 1 to convert the traffic count into 80-kN equivalent loads.
2. Determine the accumulated traffic in terms of the number of 80-kN equivalent loads the pavement will carry in the 12 years following the overlay.
3. From Figure 4, determine the thickness of the overlay for a given percentage increase in traffic after the overlay, taking the percentage increase as (number of 80-kN equivalent loads after the overlay ÷ number of 80-kN equivalent loads before the overlay) × 100.

For an Interstate highway pavement that had been built in 1967 and had a maintenance rating of 76.5 in

1977, an overlay probably would be justified. The thickness of the overlay can be calculated as outlined below.

1. (a) Determine the daily traffic in 80-kN equivalent loads. From the average daily traffic (ADT) volume records published annually, obtain the ADT for 1976 and use these data and Figure 1 to calculate the number of 80-kN equivalent loads as shown below.

Type of Vehicle	ADT	No. of 80-kN Equivalent Loads
Two axle, 6 tire	320	58
Three axle, 10 tire	50	14
Trailer trucks	2850	2500
Buses (assume 20 percent three-axle and 80 percent two-axle vehicles)	40	6
Total		2578

(In these calculations, automobiles and two-axle, four-tire vehicles are not considered because their damaging effect on the pavement is almost negligible.) Thus, for a four-lane highway, the design traffic = 2578 × 0.5 × 0.8 = one thousand thirty-one 80-kN equivalent loads, where the reported traffic counts include both directions of travel, one-half the reported traffic is assumed to travel in each direction, and 80 percent of the truck traffic is assumed to use the outside (design) lane.
(b) Determine the accumulated traffic before the overlay. These data can be determined from the traffic records or estimated on the assumption that the traffic has increased as the rate of 5 percent/year (a widely accepted standard) by using Table 3, which gives the growth rate for each year for a 20-year period (e.g., the ADT after 9 years = 1.47 × ADT during the first year) and the accumulated traffic for each year for a 20-year period (the accumulated traffic after 9 years = 4016 × ADT during the first year). Thus, in the above example, the accumulated traffic on the road in 1977 (i.e., at the end of 11 years of service and before the overlay) = design daily traffic in 1977 × accumulated traffic rate ÷ growth rate = 1031 × 5169 ÷ 1.62 = 3.29 million 80-kN equivalent loads.

2. Determine the accumulated traffic after the overlay. From the daily traffic just before the overlay (i.e., 2578 equivalent loads), the traffic to be carried by the overlay is 2578 × accumulated traffic rate (12 years) ÷ growth rate (12 years) = 2578 × 5789 ÷ 1.70 = 8.78 million 80-kN equivalent loads.

3. Determine the overlay thickness. The required overlay thickness can be determined by using Figure 4. The percentage increase in daily traffic to be sustained by the overlay is (8.78 million ÷ 3.29 million) × 100 = 267 percent and the required overlay thickness is approximately 130 mm (5.1 in).

CONCLUSIONS

1. A simplified method based on visual inspections can provide uniformity in decisions regarding the stages at which pavements would be overlaid in an economical manner.

2. In Virginia, the thickness equivalency for an asphalt concrete overlay is 0.5.

3. A method for designing the thickness of overlays has been developed.

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REFERENCES

1. Pavement Rehabilitation: Proceedings of a Workshop. Federal Highway Administration, Rept. FHWA-RD-74-60, June 1974. NTIS: PB 246 801/5ST.
2. Austin Research Engineers, Inc. Asphalt Concrete Overlays of Flexible Pavements: Volume 1—Development of New Design Criteria. Federal Highway Administration, Rept. FHWA-RD-75-75, June 1975. NTIS: PB 263 432/7SL.
3. N. K. Vaswani. Working Plan: Design of Overlays Based on Pavement Condition, Roughness, and Deflections. Virginia Highway and Transportation Research Council, Charlottesville, Rept. VHTRC 77-WP20, April 1977.
4. K. H. McGhee. A Review of Pavement Performance on Virginia's Interstate System. Virginia Highway and Transportation Research Council, Charlottesville, Rept. VHTRC 77-R24, Nov. 1976.
5. AASHO Committee on Design. Interim Guide for the Design of Flexible Pavement Structures. AASHO, Oct. 12, 1961.
6. A. C. Bhajandas and others. A Practical Approach to Flexible Pavement Evaluation and Rehabilitation. Proc., 4th International Conference on Structural Design of Asphalt Pavements, Univ. of Michigan, Ann Arbor, Vol. 1, 1977, pp. 665-673.
7. N. K. Vaswani. Design of Overlays for Flexible Pavements Based on AASHO Road Test Results. Virginia Highway and Transportation Research Council, Charlottesville, Rept. VHTRC 78-R37, Feb. 1978.
8. N. K. Vaswani. Estimation of 18-Kip Equivalent on Primary and Interstate Road Systems in Virginia. HRB, Highway Research Record 466, 1973, pp. 82-95.
9. Average Daily Traffic Volumes on Interstate, Arterial, and Primary Roads. Virginia Department of Highways and Transportation, 1976.

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