Asphalt Overlay Design

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A predicted $120 million annual cost for highway pavement and shoulder maintenance in the United States by 1975 points out the need for asphalt concrete overlays to be structurally designed with as much precision as possible in order to make the most efficient use of the tax dollar. For this purpose, The Asphalt Institute has prepared a design manual entitled "Asphalt Overlays and Pavement Rehabilitation." The manual describes two methods for determining the thickness requirements of an asphalt concrete overlay. The component analysis method requires an evaluation of the existing pavement to compare with a new full-depth asphalt pavement design. The second method requires an analysis of pavement deflection and is partially based on elastic-layered theory. Both methods provide thicknesses of asphalt concrete directly and are based on field observations and engineering experience. This report describes the new technology related to each method.

•MAINTENANCE expenditures for highways in the United States are predicted to increase greatly so that by 1975 there will be an annual maintenance budget of $261,000,000, of which 45 percent, or $120,000,000, will be for pavement and shoulder maintenance (1). These figures emphasize the necessity of structurally designing asphalt overlays with as much precision as possible in order to make the most efficient use of the tax dollar.

Asphalt overlays are required for restoring pavement smoothness and for strengthening existing pavements. Where the pavement is sufficiently strong, a thin overlay of $\frac{1}{2}$ to $\frac{3}{4}$ in. is all that is required. However, where strengthening is required, more substantial thicknesses of overlay may be needed. The scope of this paper is limited to the structural design of asphalt overlays that increase pavement strength.

The Asphalt Institute's new design manual (2) contains two methods for the determination of an asphalt overlay thickness. The first, component analysis, is applicable to both asphalt concrete and portland cement concrete pavements. The second method, the deflection method, is applicable where the original design is asphalt. The choice between the methods depends on the experience of the designer and the equipment that he has at his disposal. Both methods can be expected to give realistic and reliable thicknesses of asphalt concrete directly.

The purpose of this report is to describe the new technology related to each method. Where a previsously published procedure is mentioned, reference is given to the appropriate publication. As both overlay design methods are a mix of old and new technology, this paper does not attempt to give the overlay designer all the tools necessary to determine the required thickness of asphalt overlays.

COMPONENT-ANALYSIS METHOD

The first step in the component analysis is an evaluation of the existing pavement. An existing pavement may be converted to an effective thickness of asphalt concrete by

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TABLE 1

FACTORS FOR CONVERTING THICKNESS OF EXISTING PAVEMENT COMPONENTS TO EFFECTIVE THICKNESS (T_E)

Classification	Description of Material	Conversion Factors[a]
I	Native subgrade in all cases.	0.0
II	(a) Improved subgrade constructed with predominantly granular materials that may contain some silt and clay but have PI of 10 or less. Improved subgrade is any course or courses of improved material between the native subgrade soil and the pavement structure.	0.0 to 0.2
	(b) Lime-modified subgrade constructed from high-plasticity soils having a PI greater than 10. Lime-modified subgrade is a prepared and mechanically compacted unhardened or semihardened intimate mixture of lime, water, and soil below the pavement system.[c]	
III	(a) Granular subbase or base constructed with reasonably well-graded, hard aggregates having some plastic fines and CBR not less than 20. Upper part of range is used if PI is 6 or less; lower lower part of range is used if PI is more than 6.	0.2 to 0.3
	(b) Cement-modified subbases and bases constructed from low plasticity soils that have a PI of 10 or less. Cement-modified subbase is an unhardened or semihardened intimate mixture of pulverized soil, portland cement, and water used as a layer in a pavement system between the subgrade and the base course. Cement-modified base is an unhardened or semihardened intimate mixture of pulverized soil, portland cement, and water and is used as a layer in the pavement system to reinforce and prtect the subgrade or subbase.[c]	
IV	(a) Granular base constructed with a nonplastic granular material complying with established standards for high-quality aggregate base. Upper part of range is used.	0.3 to 0.5
	(b) Asphalt surface mixtures that have large, well-defined crack patterns, spalling along the cracks, and appreciable deformation in the wheel paths showing some evidence of instability.	
	(c) Portland cement concrete pavement that has been broken into small pieces, 2 ft or less in maximum dimension, prior to overlay construction. Upper part of range is used when subbase is present; lower part of range is used when slab is on subgrade.	
	(d) Soil-cement bases that have developed extensive crack patterns as shown by reflected surface cracks, and may exhibit pumping; pavement shows minor evidence of instability. Soil-cement base is a hardened material formed by curing a mechanically compacted intimate mixture of pulverized soil, portland cement, and water and is used as a layer in a pavement system to reinforce and protect the subgrade or subbase.[c]	
V	(a) Asphalt surfaces and underlying asphalt bases[b] that exhibit appreciable cracking and crack patterns, have little or no spalling along the cracks, and remain essentially stable even though exhibiting some wheel path deformation.	0.5 to 0.7
	(b) Appreciably cracked and faulted portland cement concrete pavement that cannot be effectively undersealed. Slab fragments, ranging in size from approximately 1 to 4 sq yd, are well seated on the subgrade by heavy pneumatic rolling.	
	(c) Soil-cement bases that exhibit little cracking, as shown by reflected surface crack patterns, and that are under stable surfaces. (See definition of soil-cement base under IV-d of this table.)	
VI	(a) Asphalt concrete surfaces that exhibit some fine cracking, small intermittent cracking patterns, and slight deformation in the wheel paths though they remain stable.	0.7 to 0.9
	(b) Liquid asphalt mixtures that are stable, generally uncracked, show no bleeding, and exhibit little deformation in the wheel paths.	
	(c) Asphalt treated base, other than asphalt concrete.[b]	
	(d) Portland cement concrete pavement that is stable and undersealed, has some cracking, but contains no pieces smaller than about 1 sq yd.	
VII	(a) Asphalt concrete, including asphalt concrete base, that is generally uncracked and has little deformation in the wheel paths.	0.9 to 1.0
	(b) Portland cement concrete pavement that is stable, undersealed, and generally uncracked.	
	(c) Portland cement concrete base, under asphalt surface, that is stable, nonpumping, and exhibits little reflected surface cracking.	

[a] Values and ranges of conversion factors are multiplying factors for conversion of thickness of existing structural layers to equivalent thickness of asphalt concrete. These conversion factors apply only to pavement evaluation for overlay design. In no case are they applicable to original thickness design.

[b] Asphalt concrete base, asphalt macadam base, plant-mixed base, and asphalt mixed-in-place base.

[c] Terms follow the definitions prepared by the Committee on Soil-Portland Cement Stabilization (*11*, pp. 20-29).

using conversion factors. Factors for different materials (including portland cement concrete) and different pavement conditions are given in Table 1. They are based on experience and field tests. To determine the equivalent thickness of asphalt concrete for the existing pavement, one selects the appropriate conversion factor for each pavement layer and multiplies the thickness of the pavement layer by the conversion factor.

Adding the results for each layer gives the effective full-depth asphalt pavement thickness, T_E. Step two of the component-analysis method is to determine the required thickness, T_A, of a new full-depth asphalt pavement for the subgrade and predicted traffic loadings. This is done by using the current thickness-design method of The Asphalt Institute's Manual Series 1 (3).

Required as input to the method are evaluations of the subgrade strength (CBR or R value) and traffic. The traffic factor is the design traffic number (DTN) defined as the daily number of equivalent 18-kip axle loads on one lane averaged over the design life of the overlay.

The overlay thickness in inches of asphalt concrete is then determined by subtraction as follows:

$$T = T_A - T_E$$

where

T_A = asphalt concrete thickness for a new full-depth asphalt pavement, and
T_E = the total effective thickness of the existing pavement in inches of asphalt concrete.

For portland cement concrete pavements, a minimum thickness of 4½ in. is recommended to minimize reflection cracking.

An example of the component-analysis procedure follows. An existing pavement consists of 3 in. of asphalt concrete surface and 8 in. of crushed stone base. The pavement is in good condition, but evaluation indicates need for strengthening to handle increasing traffic. Procedures for subgrade and traffic evaluation described elsewhere (3) were used in determining the subgrade CBR and design traffic number to be 5 and 134 respectively. The overlay thickness required for a 20-year life is computed as follows:

1. New full-depth asphalt pavement $T_A = 9.5$ in.
2. Effective thickness T_E = thickness of pavement layers × conversion factor (from Table 1), or $(3.0 \times 0.8) + (8.0 \times 0.4) = 5.6$ in.
3. Thickness of asphalt concrete overlay = $T_A - T_E$, or $9.5 - 5.6 = 4.0$ in.

PAVEMENT-DEFLECTION METHOD

This method for determining the thickness of asphalt concrete overlay requires evaluation of the strength of the existing pavement. The pavement strength indicator used in the method is the representative rebound deflection. This deflection and the design chart are discussed in the following.

Representative Rebound Deflection

Pavement deflection is measured with the Benkelman beam by using a rebound test procedure and an 18-kip single axle load. To determine the measurement locations, engineering judgment is necessary for subdividing the section under study where deflections will obviously be of different magnitude. Poorly drained areas and broken-up areas are cases in point. These areas are tested separately, as it is likely that a change in overlay thickness or other special treatment will be required. Pavement deflections are obtained for the section or subsections by testing the outer wheel path at a minimum of 20 locations per mile, selected with the aid of a random numbers procedure. The procedure details for data collection and summary are beyond the scope of this paper but may be found elsewhere (2, part 2). The measured rebound deflections are reduced to a representative rebound deflection value that is the mean of adjusted measured rebound deflections plus two standard deviations. Measured rebound deflections should be adjusted for temperature and the most critical period of the year for pavement performance.

Also considered for special treatment should be test locations that have adjusted deflections greater than the adjusted mean of measured rebound deflections plus two

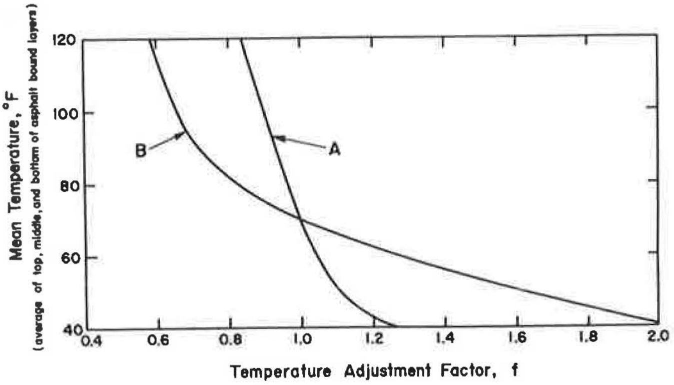

Figure 1.

standard deviations. Additional deflection measurements should be made to determine the extent of such weak areas. These locations may require patching or local increases in thickness to provide uniform support for the entire length of the section. Deflection measurements representing these special-treatment locations are omitted from calculations to obtain the representative deflection.

As it has been shown that the weakest area of the pavement is more closely associated with the critical performance of the pavement, the representative rebound deflection value includes the standard deviation (4). A rebound deflection of the mean plus 2 standard deviations ($\bar{x} + 2s$) represents a deflection level that would be exceeded in only 2 percent of the length of the pavement.

The adjustments to the mean of the measured rebound deflection plus 2 standard deviations are necessary because of temperature and seasonal effects. The rebound deflection has been shown to correlate with the mean temperature of the asphalt layers of a pavement (5). Mean temperatures may be estimated from air and pavement surface temperatures by procedures described elsewhere (6, 7). Temperature adjustment factors derived from many correlations are shown in Figure 1. Curve A, derived mostly from granular base pavements, has the greatest data support and should be used for all but a few special situations. The special situations that would call for the use of curve B are those pavements with 4 in. or more of total asphalt thickness on a weak foundation, i.e., the support to the asphalt layers contributed by all materials directly underneath at the time of deflection measurement.

An adjustment for seasonal effects is necessary because, in some climatic environments, certain periods of the year are more critical for pavement performance than others. It is extremely important that the representative rebound deflection reflect the most critical period. For this purpose, the following three methods for adjustment are given.

1. Make the rebound measurements during the most critical period.
2. Make the rebound measurements at any time and adjust to the critical-period deflection using a continuous record of measured rebound values for a similar pavement in a similar environment and on a similar subgrade. The ratio of critical-period deflection to the deflection for the date of test provides a multiplying factor for adjusting the deflection.
3. Make the rebound measurements at any time and adjust according to engineering judgment.

Design Chart

In addition to the representative rebound deflection, the design chart requires a traffic evaluation. The design traffic number (DTN) described in the component-analysis

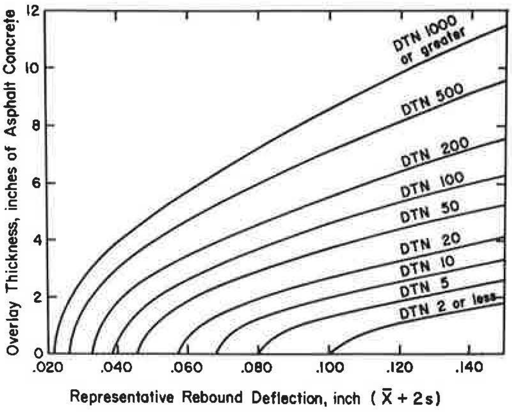

Figure 2.

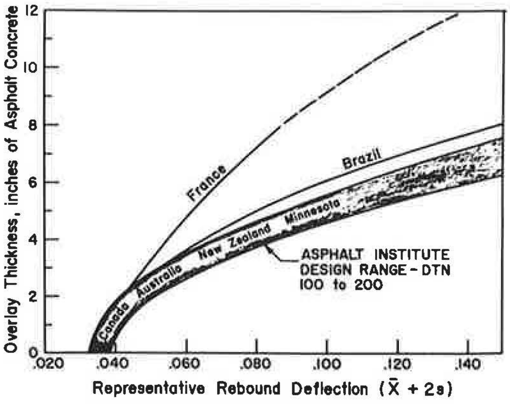

Figure 3.

method is also used here. Once the representative rebound deflection and the DTN are known, it is then a simple matter to determine the asphalt concrete overlay thickness from Figure 2. One first reads the deflection on the abscissa and proceeds to the desired DTN curve. The intersection provides the overlay thickness that is read on the ordinate. For a representative rebound deflection of 0.066 in. and a DTN of 100, the asphalt concrete overlay thickness required is 2.8 in. or, rounded off, 3 in.

Comparison With Other Deflection Methods

The design curves for The Asphalt Institute, for a state, and for five countries are shown for comparison purposes in Figure 3. The California method was also studied, but it could not be reduced to the form in Figure 3 because of California practice that requires, in some design situations, the use of "sandwich" layers of untreated granular material or cement-treated base. The shaded area is the area between The Asphalt Institute design curves for DTN 100 and DTN 1,000. The design curves for the five countries have been taken for a moderately heavy traffic defined as follows: Canada (8), Australia (9), and New Zealand (10)—AADT equal to approximately 1,000 and equivalent to 100 18-kip axle loads per day in one lane; Brazil (11)—moderately heavy; and France (12, 13)—3,700 vehicles per day, which is the middle of design traffic range. Where necessary, design curves giving thicknesses of granular material have been converted to asphalt concrete thicknesses using the layer equivalency of two to one. The coefficient of variation for purposes of estimating the $\bar{x} + 2\sigma$ deflection was assumed to be 0.2. A seasonal factor of 1.8 applicable to Ontario pavements was used for the Canadian curve.

Curves in Figure 3 for all but one country fall close to or within the DTN 100 to DTN 1,000 range. The exception, France, probably arises because of the 28,000 lb legal, single axle load. The general agreement of The Asphalt Institute's design curves with those of other agencies gives credence to the theory and experience on which they are based.

REFERENCES

1. Bertram D. Tallamy Associates. Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index. NCHRP Rept. 42, 1967.
2. Asphalt Overlays and Pavement Rehabilitation, 1st Ed. The Asphalt Institute, Manual Series 17, 1969.
3. Thickness Design—Asphalt Pavement Structures for Highways and Streets, 8th Ed. The Asphalt Institute, Manual Series 1, 1969.
4. Canadian Good Roads Association, Pavement Evaluation Studies in Canada. Proc. First Internat. Conf. on the Structural Design of Ann Arbor, Mich., 1962, p. 210.

5. Kingham, R. I. A New Temperature Correction Procedure for Benkelman Beam Rebound Deflections. The Asphalt Institute, Research Rept. 69-1, Feb. 1969.
6. Kingham, R. I. Development of The Asphalt Institute's Deflection Method for Designing Asphalt Concrete Overlays for Asphalt Pavements. The Asphalt Institute, Research Rept. 69-3, 1969.
7. Southgate, H. F., and Deen, R. C. Temperature Distribution Within Asphalt Pavements and Its Relationship to Pavement Deflection. Highway Research Record 291, 1969, pp. 116-131.
8. A Guide to the Structural Design of Flexible and Rigid Pavements in Canada. Canadian Good Roads Association, 1965.
9. Gawith, A. H., and Perrin, C. C. Development in the Design and Construction of Bituminous Surfaced Pavements in the State of Victoria, Australia. Proc. First Internat. Conf. on the Structural Design of Asphalt Pavements, Ann Arbor, Mich., 1962, p. 908.
10. Trial Sections Used to Determine Overlay Thickness. New Zealand Road Research Unit Newsletter No. 9, Oct. 1965.
11. Carneiro, F. B. L. Benkelman Beam—Auxiliary Instrument of the Maintenance Engineer. Highway Research Record 129, 1966, pp. 28-59.
12. La Salle, J., and Langumier, S. A Method for Strengthening Flexible Pavements. Proc. Second Internat. Conf. on the Structural Design of Asphalt Pavements, Ann Arbor, Mich., 1967, p. 89.
13. Prandi, E. The La Croix L. C. P. C. Reflectograph. Preprints, Second Internat. Conf. on the Structural Design of Asphalt Pavements, Ann Arbor, Mich., 1967, p. 903.
14. Definition of Terms Relating to Soil-Portland Cement Stabilization. Highway Research Abstracts, Vol. 29, No. 6, June 1959.