Research Report
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COMPARISON OF THREE METHODS OF PAVEMENT DESIGN FOR LEXINGTON-FAYETTE COUNTY

by

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INTRODUCTION

It is imperative in an era of limited budgets for construction and maintenance of streets and highways that a rational approach be followed for managing these funds. One of the first steps of this management process is the adequate and proper design of new streets and roads. In the interest of having a more rational system of design, representatives of the Lexington-Fayette Urban County Government requested the Kentucky Transportation Center to assist in the development of a new pavement design system that more clearly reflects differences in soils, traffic streams, enviromental conditions, and materials. In fulfillment of that request, this brief report compares three available methods of pavement design for flexible pavement and one method of design for rigid pavement. Comments and recommendations based upon pavement design experience and field performance of pavements are also included.

The three flexible pavement design methods are the 1981 Edition of the Kentucky thickness design curves (1), the 1986 American Association of State Highway and Transportation Officials (AASHTO) Pavement Design Guide (2), and the 1981 Asphalt Institute design methods (3). There are two basic systems of pavement design presently in use in this country. These are mechanistic systems and empirical systems. A mechanistic system employs the theories of engineering mechanics and mathematics to analyze the pavement structure. An empirical system largely uses observed behavior of in-service pavements to develop mathematical equations describing this behavior. These equations are then used in design of new pavements.

The Kentucky method is entirely mechanistic. The Asphalt Institute method is largely mechanistic with some empirical analysis included. These two methods use a "limiting strain" criterion as a basis of design. Figure 1 illustrates this criterion. The two important numbers are the tensile strain at the bottom of the asphalt layers, and the vertical compressive strain at the top of the subgrade. The thicker the asphalt layers and granular base (DGA) become, the less strain will occur at these two locations under traffic loads. Therefore, it necessarily follows that larger numbers of expected traffic and larger traffic loads require thicker pavements. If the tensile strain at the bottom of the asphalt layer becomes too large, the asphalt layers will begin to crack at the bottom. These cracks will eventually work their way to the surface and will appear as fatigue cracks. If the vertical compressive strain at the top of the subgrade exceeds the maximum permissible, the pavement will fail from excessive deflection.

The AASHTO design method is an empirical method. The design equations were developed from observation of damage on the test loops of the AASHO Road Test conducted in Ottawa, Illinois in the late 1950's and early 1960's. These equations are concerned with limiting overall fatigue and rutting damage. In 1986, major revisions were made to this method. Unlike the two previously discussed mechanistic methods, the AASHTO method includes such

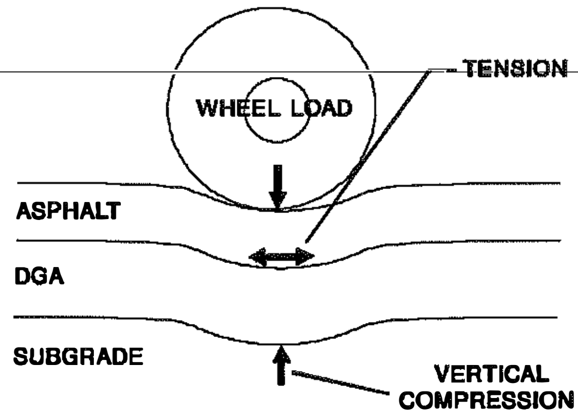

Figure 1. Location of Critical Strains

enviromental and material factors as freeze-thaw, moisture, drainage, and soil erodibility.

The design charts presented in this report are divided according to three general classes of roads and streets. these are as follows:

1. Local Roads and Residential Streets,
2. Collector Roads and Streets, and
3. Arterial Streets and Industrial Drives.

The first two classes are further divided into three volume groups. The last class is subdivided into only two volume groups. The difference in pavement thickness between the highest volume group and the lowest volume group did not warrant a third volume group in the last class.

DESIGN PARAMETERS AND ASSUMPTIONS

1. The average daily traffic (ADT) is assumed to be in both directions of travel (two-way).

2. Traffic is assumed to be equally distributed in each direction (50 percent each direction). Therefore, the equivalent single axle loads (ESAL) are calculated for one direction (one-way). An ESAL is defined as the passage of one vehicle axle carrying an 18,000-pound load.

3. It should be noted that Kentucky ESAL's are not the same as AASHTO ESAL's because load equivalencies for each class of vehicle are calculated differently. The Asphalt Institute method uses the same ESAL's as AASHTO.

4. All trucks were assumed to be combination 5-axles with a total load of 80,000 pounds. Local roads and residential streets were assumed to carry one

percent trucks. Collector roads and streets were assumed to have three percent trucks. Arterial streets and industrial drives were assumed to have seven percent trucks.

5. The ESAL's are calculated on the basis of the highest volume in a particular volume group.

6. The thicknesses of all asphalt layers are rounded to the nearest 0.5 inch. The thicknesses of the aggregate bases are rounded to the nearest 1.0 inch. The thickness of the Portland cement concrete pavement is rounded to the nearest 0.5 inch.

7. As much as possible, when calculating the thicknesses using the Kentucky and AASHTO methods, a ratio of 1/3 between the thickness of the asphalt layers and total thickness (the thickness of the asphalt and the aggregate base layer) was maintained. Usually this was not possible when using the Asphalt Institute method because the design charts are developed for only a few specified thicknesses of aggregate bases.

8. All designs are assumed to have a 20-year design life.

9. The AASHTO method for rigid pavement design was used to calculate the thickness of the Portland cement concrete pavement.

10. The following parameters were used in the flexible pavement design:

Kentucky Method
Resilient Modulus = CBR x 1,500

AASHTO Method
Resilient Modulus = CBR x 1,500
Overall Deviation = 0.50
Initial Serviceability = 4.0
Terminal Serviceability = 2.5
Layer Coefficient - Asphalt = 0.44
Layer Coefficient - Aggregate Base = 0.14

Asphalt Institute Method
Resilient Modulus = CBR x 1,500

11. The following parameters were used in the rigid pavement design (AASHTO Method only):

Reliability = 85 percent
Overall Deviation = 0.40
Modulus of Rupture = 630 psi
Modulus of Elasticity = 3,600,000 psi
Load Transfer = 3.2
Drainage Coefficient = 1.0
Initial Serviceability = 4.0

Terminal Serveceability = 2.5

12. In the AASHTO Method of design, the minimum thickness of flexible pavement reported is 3.0 inches of asphalt on 6.0 inches of aggregate base. However, The AASHTO Method predicted some thinner pavements at low volumes and high CBR values.

RECOMMENDATIONS AND DISCUSSION

The minimum pavement designs reported herein are 3.0 inches of AC on 6.0 inches of aggregrate base (AASHTO), 3.0 inches of AC on 7.0 inches of aggregate base (Kentucky), and 4.0 inches of AC on 8.0 inches of aggregate base (AI). It is recommended that the minimim design for any street be no less than 4.0 inches of AC on 8.0 inches of aggregate base. The present minimum design in Fayette County is 3.0 inches of AC on 9.0 inches of aggregate base. However, it is probable that in many of the resdential streets that are presently being constructed, construction traffic is failing some of the pavements before all of the residences on the street are completed. A brief analysis (AASHTO Method) shows that 4.0 inches on 8.0 inches (Design A) is considerably better than 3.0 inches on 9.0 inches (Design B). Design A has a capacity of 100,000 ESAL, whereas Design B has a capacity of only 53,000 ESAL. Estimated pavement costs for a 1,000-foot section of these two designs are $23,600 (Design A) and $22,300 (Design B). If it is assumed that a 1,000-foot section of a residential street is bordered by 28 houses (lots assumed to be 70 feet wide), requiring Design A as a minimum would add less than $50 to the cost of each lot. However, the design life of the pavement would be almost doubled.

It is recommended for all designs other than the minimum proposed in the previous paragraph, that the 1981 Kentucky method be used to determine pavement thicknesses. The Kentucky method is easier to use, requires fewer inputs, and is based upon subgrade CBR. (Most designers and engineering consultants are familiar with the CBR test.) The 1986 AASHTO method is relatively difficult to learn and to use. Some of the input variables are not clearly understood by the average designer. The method requires a resilient modulus test, which cannot be performed by most engineering laboratories. In addition, standardized procedures for this test are presently under review and probably will change. The Asphalt Institute method requires significantly thicker pavements at higher ESAL's. The thicker designs result from the fact that the method assumes very little strength for the aggregate base. This method would add considerable cost to construction.

All subgrades with CBR values less than 6.0 should be considered for stabilization. However, the stabilized layer should not be considered as a structural member of the pavement.It should be considered only as a working platform against which to compact the aggregate base. Experience in Kentucky presently is not sufficient to definitively say what is the long-term behavior of the stabilized layer.

When using full-depth asphalt pavements (no aggregate base), stabilization should be required for all subgrades with CBR values less than 6.0. Experience has shown that it is very difficult to compact the first layer of asphalt against a soft subgrade.

Drainage is a very important aspect of pavement design. Until recent years, very little attention was paid to subsurface drainage. It is now a recognized fact that pavement subdrains are very important in helping to remove subsurface water. For many years, dense-graded aggregate (DGA) has been the primary material used for unbound base courses. However, it is well known that when DGA becomes saturated it tends to remain saturated. This weakens the pavement and permits greater deflections which causes premature fatigue cracking. Today's trend in pavement design is toward more open-graded aggregate bases that permit better drainage. This is used in conjunction with longitudinal and transverse pavement underdrains that carry the subsurface water away from the pavement structure. Pavement subdrains add significant cost to road and street construction. However, it is recommended that studies be initiated on various designs of subdrain systems, and on the cost analysis of such systems, with the idea of possibly implementing subdrains systems in the future.

REFERENCES

1. Havens, J. H.; Deen, R. C.; and Southgate, H. F.; "Design Guide for Bituminous Concrete Pavement Structures", UKTRP 81-17, Transportation Research Program, College of Engineering, University of Kentucky, August 1981.

2. AASHTO Guide for Design of Pavement Structures; AASHTO, 444 North Capitol Street N.W., Suite 225, Washington D.C. 20001.

3. Thickness Design--Asphalt Pavements for Highways and Streets (MS-1); The Asphalt Institute, Asphalt Institute Building, College Park, Maryland 20740.

PAVEMENT THICKNESS DESIGNS FOR LOCAL ROADS AND RESIDENTIAL STREETS

Two-Way ADT (vpd)	One-Way ESAL		CBR	AASHTO			Kentucky			Asphalt Institute			AASHTO
	KY.	AASHTO		Full Depth	AC-Agg. Base		Full Depth	AC-Agg. Base		Full Depth	AC-Agg. Base		PCC
				(in.)	AC (in.)	Base (in.)	(in.)	AC (in.)	Base (in.)	(in.)	AC (in.)	Base (in.)	
<400	3.7×10^4	4.5×10^4	3	6.0	3.0	7.0	7.0	5.5	10.0	6.5	4.5	8.0	4.5
			4	5.5	3.5	6.0	6.5	5.0	9.0	5.5	4.0	8.0	4.5
			5	5.0	3.0	6.0	6.5	4.0	9.0	5.5	4.0	8.0	4.5
			6	4.5	3.0	6.0	5.5	4.0	8.0	5.0	4.0	8.0	4.5
			7	4.0	3.0	6.0	5.5	3.5	8.0	4.5	4.0	8.0	4.5
			8	4.0	3.0	6.0	5.0	3.5	7.0	4.5	4.0	8.0	4.5
			9	4.0	3.0	6.0	5.0	3.0	7.0	4.0	4.0	8.0	4.5
			10	4.0	3.0	6.0	4.5	3.0	7.0	4.0	4.0	8.0	4.5
400 to 700	6.4×10^4	7.9×10^4	3	6.5	4.0	7.0	7.5	5.0	11.0	7.0	5.0	8.0	5.0
			4	6.0	3.5	7.0	7.0	5.0	10.0	6.5	4.0	8.0	5.0
			5	5.5	3.5	6.0	6.5	5.0	10.0	6.0	4.0	8.0	5.0
			6	5.0	3.0	6.0	6.5	4.5	9.0	5.5	4.0	8.0	5.0
			7	4.5	3.0	6.0	6.0	4.5	8.0	5.0	4.0	8.0	5.0
			8	4.5	3.0	6.0	6.0	4.0	8.0	5.0	4.0	8.0	5.0
			9	4.0	3.0	6.0	5.5	3.5	8.0	5.0	4.0	8.0	5.0
			10	4.0	3.0	6.0	4.5	3.0	7.0	4.5	4.0	8.0	5.0
701 to 1,000	9.1×10^4	1.1×10^5	3	7.0	4.0	8.0	8.0	5.5	12.0	7.5	5.5	8.0	5.5
			4	6.0	4.0	7.0	7.5	5.5	11.0	6.5	4.5	8.0	5.5
			5	5.5	3.5	7.0	7.0	5.5	10.0	6.5	4.0	8.0	5.5
			6	5.5	3.0	7.0	6.5	5.0	9.0	6.0	4.0	8.0	5.5
			7	5.0	3.0	6.0	6.5	4.5	9.0	5.5	4.0	8.0	5.5
			8	4.5	3.0	6.0	6.5	4.0	9.0	5.5	4.0	8.0	5.5
			9	4.5	3.0	6.0	6.0	4.0	8.0	5.5	4.0	8.0	5.5
			10	4.5	3.0	6.0	6.0	4.0	7.0	4.5	4.0	8.0	5.5

PAVEMENT THICKNESS DESIGNS FOR COLLECTOR ROADS AND STREETS

Two-Way ADT (vpd)	One-Way ESAL KY.	One-Way ESAL AASHTO	CBR	AASHTO Full Depth (in.)	AASHTO AC-Agg. Base AC (in.)	AASHTO AC-Agg. Base Base (in.)	Kentucky Full Depth (in.)	Kentucky AC-Agg. Base AC (in.)	Kentucky AC-Agg. Base Base (in.)	Asphalt Institute Full Depth (in.)	Asphalt Institute AC-Agg. Base AC (in.)	Asphalt Institute AC-Agg. Base Base (in.)	AASHTO PCC (in.)
1,001 to 4,000	$1.0x10^6$	$1.3x10^6$	3	10.0	6.5	12.0	11.0	8.0	15.0	10.5	8.5	12.0	8.0
			4	9.0	5.5	11.0	10.5	7.5	14.0	9.5	7.5	12.0	8.0
			5	8.5	5.0	10.0	10.0	7.5	13.0	9.5	7.0	12.0	8.0
			6	8.0	5.0	9.0	10.0	6.5	13.0	9.0	6.5	12.0	8.0
			7	7.5	4.5	9.0	9.5	6.0	13.0	8.5	6.0	12.0	8.0
			8	7.0	4.0	9.0	9.5	6.0	12.0	8.5	6.0	12.0	8.0
			9	6.5	4.0	8.0	9.0	5.5	12.0	8.0	5.5	12.0	8.0
			10	6.5	4.0	8.0	9.0	5.5	11.0	7.5	5.0	12.0	8.0
4,001 to 6,000	$1.5x10^6$	$1.9x10^6$	3	11.0	6.0	13.0	12.0	8.0	16.0	11.5	8.5	18.0	9.0
			4	10.0	6.0	12.0	11.5	7.5	15.0	10.5	8.0	18.0	9.0
			5	9.0	5.5	11.0	11.0	7.5	14.0	10.0	7.5	18.0	9.0
			6	8.5	5.0	10.0	10.5	6.5	14.0	10.0	7.5	12.0	9.0
			7	8.0	5.0	9.0	10.0	6.5	13.0	9.5	7.0	12.0	9.0
			8	7.5	4.5	9.0	10.0	6.5	12.0	9.5	7.0	12.0	9.0
			9	7.0	4.5	8.0	9.5	6.0	12.0	9.0	6.5	12.0	9.0
			10	7.0	4.5	8.0	9.5	5.5	12.0	8.5	6.0	12.0	9.0
6,001 to 8,000	$2.0x10^6$	$2.5x10^6$	3	11.5	7.0	14.0	13.0	8.0	17.0	11.5	9.0	18.0	9.0
			4	10.5	6.5	12.0	12.0	8.0	16.0	11.0	8.5	18.0	9.0
			5	9.5	5.5	12.0	11.5	7.5	15.0	10.5	8.5	18.0	9.0
			6	9.0	5.5	11.0	11.0	7.0	14.0	10.5	8.0	18.0	9.0
			7	8.5	5.0	10.0	10.5	6.5	14.0	10.0	8.0	12.0	9.0
			8	8.0	5.0	9.0	10.5	6.5	13.0	10.0	8.0	12.0	9.0
			9	7.5	4.5	9.0	10.0	6.0	12.0	9.5	7.5	12.0	9.0
			10	7.5	4.5	9.0	10.0	6.0	12.0	9.0	7.0	12.0	9.0

PAVEMENT THICKNESS DESIGNS FOR ARTERIAL STREETS AND INDUSTRIAL DRIVES

Two-Way ADT (vpd)	One-Way ESAL		CBR	AASHTO			Kentucky			Asphalt Institute			AASHTO
	KY.	AASHTO		Full Depth	AC-Agg. Base		Full Depth	AC-Agg. Base		Full Depth	AC-Agg. Base		
				(in.)	AC (in.)	Base (in.)	(in.)	AC (in.)	Base (in.)	(in.)	AC (in.)	Base (in.)	PCC (in.)
8,001 to 11,000	$6.3X10^6$	$8.0x10^6$	3	13.5	8.5	15.0	14.5	9.5	19.0	14.5	12.0	18.0	11.0
			4	12.0	7.5	14.0	14.0	9.0	18.0	14.0	11.5	18.0	11.0
			5	11.5	7.0	13.0	13.5	8.5	17.0	14.0	11.0	18.0	11.0
			6	10.5	6.5	13.0	13.0	8.0	16.0	13.5	11.0	18.0	11.0
			7	10.0	6.0	13.0	12.5	8.0	15.0	13.0	10.5	18.0	11.0
			8	9.5	6.0	12.0	12.5	7.5	15.0	13.0	10.5	18.0	11.0
			9	9.0	5.5	11.0	12.0	7.5	14.0	12.5	10.5	18.0	11.0
			10	9.0	5.5	10.0	11.5	7.0	14.0	12.0	10.0	18.0	11.0
11,001 to 15,000	$8.6x10^6$	$1.1x10^7$	3	14.0	9.0	16.0	15.0	10.0	19.0	15.0	13.0	18.0	11.5
			4	12.5	8.0	15.0	14.5	9.5	19.0	14.5	12.5	18.0	11.5
			5	12.0	7.5	14.0	14.0	9.0	18.0	14.5	12.5	18.0	11.5
			6	11.0	6.5	14.0	13.5	8.0	17.0	13.5	11.5	18.0	11.5
			7	10.5	6.5	13.0	13.0	8.0	16.0	13.5	11.5	18.0	11.5
			8	10.0	6.0	13.0	13.0	7.5	16.0	13.0	11.0	18.0	11.5
			9	9.5	6.5	12.0	12.5	7.5	15.0	13.0	11.0	18.0	11.5
			10	9.5	5.5	12.0	12.0	7.0	15.0	12.5	10.5	18.0	11.5