

MBTC 1070

Development of Comprehensive Low-Volume Pavement Design Procedures

FINAL REPORT

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ABSTRACT

Historically, “low-volume” pavements (<500 ADT) in Arkansas were typically constructed using a “standard” section, i.e., a double surface treatment over a specified thickness of granular base. Subsequent analysis indicated these sections were structurally inadequate in many cases. In response, the Arkansas State Highway and Transportation Department (AHTD) moved to designing low-volume pavements by normal methods, such as the *AASHTO Guide for Design of Pavement Structures*. Other state highway agencies have developed or adopted other design methods for lower-volume pavements. In many cases, “normal” design methods often provide substantial, and perhaps unwarranted, structural sections for low-volume pavements, resulting in fewer miles of low-volume pavements constructed annually. This project compiled efforts by pavement agencies to develop specific low-volume design methods, and suggests potential method(s) for designing low-volume pavements for a variety of traffic, materials, soils, and environmental conditions in Arkansas. The recommendations provide a framework for field investigations of low-volume pavement performance to validate a comprehensive procedure for designing low-volume pavements in Arkansas and the surrounding region.

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INTRODUCTION

The overall objective of this research was to develop a comprehensive low-volume road (LVR) pavement design procedure suitable for use by the Arkansas State Highway and Transportation Department (AHTD) and other local pavement agencies. This report primarily documents the result of an exhaustive literature review of the methods used by the forty eight continental State Highway Agencies (SHA) and additional selected agencies, and will provide engineers with a reference manual on the current state-of-the-practice in the area of LVR pavement design. Preliminary recommendations regarding potential methods for designing low-volume pavements in Arkansas are given at the end of the report.

In a rural state such as Arkansas, there are generally a large number of miles of low volume roads. Trucking, agriculture, and logging industries put heavy pressure on some of these roads, highlighting the need for a solid pavement design procedure. Currently, there are more than 2.6 million miles of LVRs throughout the United States.*(1)*

Low-volume roads typically carry less than 500 vehicles per day *(1)*, but this definition varies with the responsible agency and the location. Historically LVRs were not a primary focus of the transportation industry; public and official scrutiny (along with expenditures) was concentrated on the higher volume, higher classification of roads such as the interstate highways and primary state highways. Local low-volume roads were typically constructed using a

‘standard’ section, such as a double surface treatment over a specified thickness of granular base material. As the low-volume roads began to deteriorate, it was apparent that these ‘standard’ sections were often inadequately designed. In response, the American Association of State Highway and Transportation Officials (AASHTO) developed a pavement design procedure for LVRs which is similar to their design procedure for higher volume roads, as detailed in the “AASHTO Guide for Design of Pavement Structures” (2). A survey conducted as part of this research revealed that 37 of the 48 states in the continental United States design their LVRs using the AASHTO design method. Eleven SHAs in the continental United States have developed their own pavement design procedures for low-volume roads. Table 1 lists each state with the LVR pavement design procedure currently used.

OTHER AVAILABLE DESIGN PROCEDURES

Before the eleven non-AASHTO state procedures are discussed and analyzed, there are other LVR pavement design procedures deserving mention. The following is a listing of those methods found from the literature review:

- American Association of State Highway and Transportation Officials (AASHTO)
- United States Army Corps of Engineers (USACE)
- National Crushed Stone Association (NCSA)
- Asphalt Institute (AI)
- Portland Cement Association (PCA)

A brief discussion of each of these procedures follows.

AASHTO DESIGN PROCEDURE

The LVR procedure used by AASHTO (2) is essentially the same as the corresponding procedure for high volume pavements. However, methods are provided to estimate some input values required for design. The basic AASHTO procedure requires information on the subgrade soil (in terms of resilient modulus), reliability (in terms of desired design reliability), traffic (in terms of 18-kip Equivalent Single Axle Loads, ESALs), and material properties for each layer (in terms of AASHTO structural layer coefficients, a_i). The procedure is relatively complex and includes many input variables. For low-volume roads, design charts for flexible pavements are similar to those for highway pavement design, but the input requirements have been simplified to allow local agencies the option of using “standard” inputs for design.

UNITED STATES ARMY CORPS OF ENGINEERS PROCEDURE

The U.S. Army Corps of Engineers (USACE) design method for flexible pavements is an abbreviated method of the detailed procedure developed for airport pavements. The two major input factors for this method are traffic load (in terms of 18-kip ESALs) and soil strength (in terms of California Bearing Ratio, CBR). This procedure is relatively simple to use, but is limited in some respects. With only two input factors, varying environmental effects and other uncertainties may not be adequately covered. This procedure is based on equations that give required thicknesses for material that is to be placed over underlying material of a given strength (in terms of CBR), provided that the placed material has greater CBR strength than the underlying material. (3)

NATIONAL CRUSHED STONE ASSOCIATION PROCEDURE

The National Crushed Stone Association (NCSA) procedure (4) is basically an adaptation of the CBR-based USACE procedure previously discussed. This procedure considers only bituminous surfaced roads on a good crushed stone base. This is a relatively simple four-step procedure. First, probable soil support must be evaluated according to soil classification (AASHTO or Unified methods) and approximate CBR strength. The soil is given a support category of excellent, good, fair, or poor. Next, the probable traffic intensity must be evaluated. A Design Index (DI) category is assigned to the road in question. Most local, rural roads serve only light traffic corresponding to the DI-1 or DI-2 categories, but with heavy truck traffic being carried by many low-volume roads today, other Design Index categories may need to be considered. The third step of the design procedure is to select a basic design thickness from a Flexible Pavement Design Table, which is CBR-based. The thickness shown in the Design Table is the total combined thickness of the crushed stone base and either a bituminous surface treatment or a bituminous concrete surface. The decision to use a surface treatment or bituminous concrete is typically based on local experience and cost factors. The surface treatment has a lower initial cost, but must be rehabilitated or overlaid more frequently; the bituminous concrete surface has a higher initial cost, but the need for rehabilitation is less frequent than that of the surface treatment. The final step in this procedure is to check the basic design thickness for severe conditions such as frost damage and drainage problems. A subgrade soil frost group is determined and a 'new' thickness is chosen from another Flexible Pavement Design Table based on this frost group. The thicker section of step 3 or step 4 is used in the construction of the pavement.

THE ASPHALT INSTITUTE PROCEDURE

The Asphalt Institute design procedure is a mechanistic-empirical design procedure based on elastic layer analysis. (5) The two input requirements include the design subgrade resilient modulus and traffic, in terms of 18-kip ESALs. It considers full depth asphalt pavements, asphalt over emulsified asphalt stabilized base pavements, and asphalt over granular base pavements. Simplified methods to calculate the number of 18-kip ESALs and the resilient modulus are provided. This procedure is relatively simple to use, but it is limited by not allowing use of other stabilized layers or subbase layers.

PORTLAND CEMENT ASSOCIATION PROCEDURE

The Portland Cement Association (PCA) has a design procedure for cement treated bases. (6) Due to the limited scope of this procedure it will not be discussed in detail for this report.

STATE PROCEDURES

Various state low-volume road pavement design procedures (non-AASHTO) that have been developed is a primary focus of this report. It is reasonable to review such procedures to identify common inputs and methods for considering the factors involved in low-volume pavement design. Future developments regarding low-volume pavement design could draw from the methods successfully employed by state highway agencies. A general discussion and analysis of each of the eleven non-AASHTO state procedures follows.

CALIFORNIA PROCEDURE

The California low-volume pavement design procedure (7) was developed in January of 1979 and is based on studies, and tests from various agencies. Despite its length, it is a relatively simple procedure, requiring three major input parameters. These include the Traffic Index (TI, based on 18-kip ESALs), the Resistance value (R-value) of the supporting layer (usually found by a stabilometer test), and the strength of the pavement structure, or Gravel Factor (GF), which can be obtained from a table derived from previous design experiences.

The first step in this design procedure is to obtain the Traffic Index (TI). There are three different methods of accomplishing this; however, the first of the three methods is considered the standard and should be used whenever possible. The “standard” method requires inputs including truck constants, a truck traffic count, and factors to estimate an increase or decrease if traffic volume and the design life warrants. The method itself is rather involved, requiring the use of a number of graphs, charts, and equations. Because of this, the mechanics of the procedure will not be discussed in detail here. Another method of obtaining the TI uses the average daily two-way traffic (ADT) and the percentage of trucks over a ten-year design life, with a table of “typical” TI values generated from historic data. This method is less sophisticated and less accurate than the preferred standard method. The third method of obtaining the TI is to simply estimate the value based on the type of road; TI values are listed in a given table for various road types.

The next element of the California procedure involves the quality of the subgrade support, in terms of a Resistance Value (R-value). The resistance refers to the ability of a material to resist lateral deformation when acted upon by a vertical load. The R-value, measured using a stabilometer test, ranges from 0 (water) to 100 (steel). Typically, soil and

aggregates range from less than 5 up to 85. Specimens are compacted to conditions that approximate those in the field and then they are tested at full moisture saturation as to represent the worst case the soil can be in at any given time. The expansive tendency of the soil is also taken into consideration and estimated at various water contents. Design charts and graphs are used to determine the R-value once the stabilometer tests have been performed. If the stabilometer test is not performed on the soil, the R-value may be estimated by using some simple soil classification tests in conjunction with the sand equivalent (SE) test.

After the R-value of the subgrade has been found, the final input for the design procedure is the strength of the structural layer, or the “gravel equivalent factor” (G_f). This is an empirical factor developed through research and field experience, which relates the relative strength of a unit thickness of the particular material in terms of an equivalent thickness of gravel. The G_f is easily taken from a chart included in the design procedure.

Once these three major input values are obtained, a design chart is used to determine the required thickness of each layer of the pavement structure.

ANALYSIS OF CALIFORNIA PROCEDURE

Figure 1 shows a comparison of a design performed using the California procedure (7) and the AASHTO procedure. The results of the comparison suggest the California procedure yields a more ‘conservative’ design than that using AASHTO. The traffic is dealt with in an efficient and effective manner, but the R-value appears to be the biggest factor in determining layer thicknesses. Since the R-value is always presented as the worst case scenario, the procedure will yield a conservative design. The gravel equivalent factor seems to be

appropriate and logical for this type of pavement design. Overall, this is a thorough, yet conservative, LVR pavement design procedure.

ILLINOIS PROCEDURE

The Illinois pavement design procedure (8) was developed in 1995 and is based on University of Illinois research documents. This procedure characterizes a road with less than 400 ADT as a low-volume facility. The first basic design element for the Illinois procedure involves the class of the roads or streets. A low-volume road would be classified a Class IV road in this procedure.

A design period is the next item that is taken into account. The design period is the length of time in years that the pavement is being designed to serve the structural design traffic. The tables used in designing the Class IV roads are satisfactory for a design period of 15 or 20 years.

The next item to be considered is the Structural Design Traffic, estimated using the ADT for the year representing one-half of the design period. Traffic Factors are typically calculated for the various classes of roads, but the Class IV road does not take include the Traffic Factor. This Traffic Factor weighs the effects of different types of vehicles such as passenger cars, single unit trucks and multiple-unit trucks.

Staged construction is typically considered in the Illinois design process, but is rarely used on a Class IV, low-volume road. Asphalt cement viscosity grades and base / subbase materials and thicknesses are recommended for the various classes of roads. A Subgrade Support Rating is a very important input for the Illinois LVR design procedure. For the

conventional flexible pavement, this subgrade rating is presented in the form of a critical subgrade modulus (E_{Ri}). The procedure for estimating E_{Ri} is very simple for Class IV roads.

The only required inputs for the Class IV road pavement thickness design include traffic information (in terms of % heavy vehicles) and the critical subgrade modulus (E_{Ri}). Once these two variables are known (or estimated), the minimum thicknesses for the surface, base and subbase layers are obtained from design tables. The procedure does give some 'basic' minimums regardless of road class, which are a 3-inch asphalt surface and an 8-inch base layer.

ANALYSIS OF ILLINOIS PROCEDURE

The critical factors for the Illinois LVR procedure are the traffic and the subgrade modulus. Expressing the traffic in terms of heavy commercial vehicles is a good concept, because the vehicles found on a LVR that cause significant structural damage are typically these heavy commercial vehicles or trucks. The design tables take into account the various amount of heavy commercial vehicles which can be on a road on any given day. The critical subgrade modulus is a little vague in its definition and the designer must go to another publication to determine how to find this input for the design procedure. However, this procedure is not as conservative as the AASHTO procedure, as demonstrated in the comparison shown in Figure 2.

KENTUCKY PROCEDURE

The Kentucky procedure (9) was developed in June of 1995 and based on research and experience. The design consists of inputting the Average Daily Traffic (ADT) and the Aggregate (DGA) into a design table provided. There is only one row of values in the design

table applicable to low-volume roads, comprising 500 ADT or less. The aggregate thickness (DGA) is estimated by considering local practices and economics, along with a design chart relating to total pavement structure thickness.

ANALYSIS OF KENTUCKY PROCEDURE

A direct comparison between the Kentucky procedure and AASHTO procedure is not particularly valid; the Kentucky procedure deals only with an asphalt-stabilized base course. The soil strength, which is a major factor in almost every other low-volume road pavement design procedure, is buried somewhere in the Aggregate DGA concept. This value is left up to the discretion or engineering judgment of the designer. The ADT does not consider the percent trucks or heavy vehicles being carried by the road being designed. There is a note included in the procedures that if the Equivalent Single Axle Loads exceed 275,000, then this procedure should not be used for the design. The procedure is very simple, but it does not account for various aspects that can greatly influence the structural needs of a pavement.

MINNESOTA PROCEDURE

Minnesota gives local agencies a choice between two LVR pavement design procedures, both developed in December of 1992 and based on research performed by the Department of Transportation. The procedure most commonly used by local agencies is the Gravel Equivalency (GE) method found in Minnesota's State Aid Manual. (10) The standard input variables of soil strength and traffic load are used in this procedure. The local agencies

prefer this method to the R-value method found in the Road Design Manual (*II*) because it is less conservative.

In the GE method, the designer simply has to know the soil classification and the ADT for the road in question. Using a provided design table, the designer obtains a Soil Factor and an assumed R-value for the soil. This information is then combined with the ADT to obtain a Minimum Bituminous GE and a Total GE for the design. The Minimum Bituminous GE is the amount of bituminous base and surface, in inches, which must be part of the Total GE.

The first consideration in the R-value method is the traffic load, which is expressed as Sigma N-18. This is a convenient identification of the cumulative damage effect of heavy vehicles during the design life of a flexible pavement. Sigma N-18 is the equivalent to one passage of a standard 18,000-pound single axle load (18-kip ESAL). Design tables illustrate the process of combining data to calculate the total Sigma N-18 value, which is subsequently adjusted by a seasonal adjustment factor and growth factors. The R-value for the soil is then determined for the design. This is a critical step in the pavement design; structural requirements are considerably influenced by a small change in R-value. Given tables establish sampling frequency guidelines for Stabilometer R-values as a function of major soil texture, and illustrate typical R-values associated with AASHTO Soil Types. Once the R-value and Sigma N-18 values are known, the designer then uses a design table to obtain the appropriate Granular Equivalency Factor and a design figure to estimate the structural layer thicknesses. In general, the more detailed R-value method yields a thicker, more conservative design than the shorter GE method used by most of the local agencies.

ANALYSIS OF MINNESOTA PROCEDURE

Both of the Minnesota procedures (*10,11*) offer designs that are more conservative than the AASHTO procedure, as illustrated in Figure 3. The seasonal factor for the Sigma N-18 traffic value is a good idea for this cold part of the country. The most often used GE method is very simple to use and straight forward in its philosophy. Overall, both of the Minnesota procedures appear well thought out and applicable to that region of the country.

MISSISSIPPI PROCEDURE

The Mississippi LVR pavement design procedure (*12*) was recently updated to account for changes in Mississippi state law. Research begun in 1976 and concluded in September of 1983, influenced the design procedure. In the 1994 Session of the Mississippi State Legislature, Senate Bill No. 2476 was passed which increased the allowable load on all roads except the Federal Interstate System. Effective July 1, 1994, the maximum allowable weight was changed to 84,000 pounds, a significant increase from the previous maximum allowable weight of 57,650 pounds. Given this change, the existing LVR pavement design procedure in Mississippi was updated to accommodate this increase in loads.

The updated Mississippi procedure includes many of the basic design inputs that have been discussed previously. Soil strength (in terms of a Soil Support Value (SSV), found from using CBR), design life (in terms of number of years), traffic loads (in terms of percent 18-kip loads), and an average 18-kip daily load (ADL) are all input variables used in this design procedure. Once these design inputs are determined, the designer uses the appropriate design chart provided and obtains the required thicknesses of each layer.

The Soil Support Value (SSV) is determined by correlating a known CBR value, whether estimated by testing or some other method, to the SSV. The equation used is shown:

$$SSV = 30289 \log \text{ base } 10 * (CBR) + 1.421$$

This equation was developed through research performed for Mississippi soils.

The design life for the structure is estimated using guidelines based on the amount of DHVs or Design Heavy Vehicles. Typical design life estimates range from 5 to 8 years for flexible pavements. A 4-inch minimum subbase is required on all full depth asphalt construction. A standard 6-inch base was determined to be adequate for all flexible pavements according to the percentage of 18-kip loads corresponding to the new 80,000-lb load limit.

The final aspect of the design procedure is the ADT (Average Daily Traffic) for the road in question. The ADT is used in the design charts to help determine the design thicknesses of the subbase, base and surface combined.

ANALYSIS OF MISSISSIPPI PROCEDURE

The Mississippi LVR design procedure is relatively simple to use. The minimum values for the subbase and base seem to be consistent with the other LVR procedures. It yields design thicknesses which are more conservative than those obtained using the AASHTO procedure with similar input parameters, as shown in Figure 4.

NEW YORK PROCEDURE

The New York design procedure (*I3*) was developed in October of 1994 and is based on the AASHTO procedure for determining pavement thickness, as well as using a treated

open-graded permeable base layer with continuous edge drains in the pavement structure to provide for positive drainage. This procedure takes into account various frost susceptible soils which can be encountered in the upper Northeast section of the United States. The major input variables for this procedure are those used in the AASHTO procedure. The only variance from the AASHTO method is that the frost susceptibility of the soil is taken into consideration in the determination of the Structural Layer Coefficients (a_i) and the Drainage Coefficient (m_i). The effects of frost susceptible soils are incorporated into design charts used for determining subgrade modulus. The mechanics of performing a given design match those for the AASHTO procedure.

ANALYSIS OF THE NEW YORK PROCEDURE

For a state in the upper Northeast section of the United States that wishes to use the AASHTO procedure for low-volume roads, but wants the frost susceptibility of the soils to be considered, the New York procedure appears to be ideal. However, due to the incorporation of frost-susceptibility considerations for subgrade soils, the procedure is not universally applicable. The New York procedure is more conservative than the “unmodified” AASHTO procedure for a given set of input values, as shown in Figure 5.

OKLAHOMA PROCEDURE

The low-volume road pavement design procedure that was developed by Oklahoma is known as the Oklahoma Subgrade Index (OSI) method. (14) This design procedure was originally developed in June of 1991 in English units and updated to metric in May of 1996; it is

primarily based on research done by the DOT. The input parameters are basically similar to most other procedures previously discussed (soil strength, traffic information, design life, etc.) with a few exceptions. The OSI method is described in detail in “Oklahoma Department of Highways Office of Design Policies and Procedures”, but the publication sent to County Commissioners and engineers is a simplified nomograph method from the more detailed procedure. The detailed procedure offers explanations of equations and derivations of the graphs and tables that are used in the nomograph procedure.

One of the exceptions noted for the Oklahoma procedure regards the idea of a design wheel load. The selection of the design wheel load is made based upon actual traffic counts with a clear breakdown that includes numbers of trucks and overloads. The OSI method provides the designer with recommendations regarding the design wheel load and the thickness of the base material. For average daily traffic (ADT) values greater than 400, the minimum design wheel load used is 3175 kg. For ADT values less than 400, where traffic counts have been certified by the consultant to justify less than a 3175 kg design wheel load and the county has requested by official resolution the use of less than 3175 kg design wheel load, an equivalent based thickness (EBT) of 50 mm less than that for a 3175 kg design wheel load may be used. In no case shall the EBT be less than 150 mm.

Another exception to the basic design rule is the idea or concept of overloaded axles. The Oklahoma procedure is the only one of those surveyed which actually takes into account the fact that some trucks will be “overloaded” or heavier than the normal weight for a particular type of truck. The overloaded axles, along with the heavy commercial traffic percent, are used to come up with what the OSI method calls the Traffic Factor. This Traffic Factor is used as

part of the input for one of the nomographs in this procedure. The types and/or the existence of a shoulder for the roadway also effects the design in the form of a Shoulder Factor. The climate of the area is also taken into account with the Climatic Factor.

The three major input factors (Shoulder, Traffic, and Climatic) are used in a design nomograph to determine the “STC Factor” for the road in question. Once the STC Factor has been determined, a design table is used to determine the adjustment factor for the Equivalent Base Thickness (EBT). This adjustment factor is then applied to the unadjusted EBT. The unadjusted EBT is based on the Oklahoma Subgrade Index (OSI), which is determined using sieve analysis information for the subgrade soil. The final “design” EBT is the “adjusted” EBT – a combination of the OSI-based EBT and the STC-based adjustment factor.

The minimum design for flexible pavements is an equivalent of 150 mm of base thickness. The Oklahoma design charts are based on EBT. In using materials of different quality, the following conversions are used:

25 mm of Asphalt Concrete = 38 mm of EBT

25 mm of Aggregate Base = 25 mm of EBT

25 mm of Soil Asphalt Base = 25 mm of EBT

25 mm of Cement Treated Base = 25 mm of EBT

25 mm of Subbase (Type I, II or III) = 13 mm of EBT

25 mm of Subbase (Type IV) = 19 mm of EBT

25 mm of Lime Treated Subgrade (150 mm Treatment) = 13 mm – 19 mm
of EBT

25 mm of Fly Ash Treated Subgrade (150 mm Treatment) = 13 mm – 19
mm of EBT

ANALYSIS OF OKLAHOMA PROCEDURE

The Oklahoma design procedure (*14*) appears relatively complicated with all of the tables, graphs and the number of input variables. Closer inspection of the procedure, however, proves this false; indeed, the procedure is actually quite simple to use. All of the input parameters are handled in an efficient manner. The provision for the “overloaded truck” is a very good idea. Soil strength and traffic are the two major deciding factors in the final design, but other aspects are also considered. Compared with the AASHTO method (see Figure 6), the Oklahoma procedure is not as conservative and therefore a less substantial pavement structure is usually recommended.

PENNSYLVANIA PROCEDURE

The Pennsylvania design procedure (*15*) for low-volume roads is similar to that used for most other roadways. The major difference is that traffic data regarding each type of truck is not necessary for the LVR design procedure. The input variables for this method are the traffic (in terms of 18-kip ESALs), the soil strength (in terms of CBR), and the effects of freeze-thaw action (in terms of a Design Freezing Index, DFI). This, like other procedures, uses several predetermined tables and nomographs to determine design thicknesses for each structural layer of pavement.

For the local or low-volume roads (<400 ADT), the Frost Factor is not to be used explicitly because the appropriate adjustments have already been made and incorporated into the table of minimum depths. This leaves the input parameters relating to traffic and soil strength. The soil strength is determined by performing tests to determine the CBR value for the

soil. The traffic (in terms of 18-kip ESALs) and CBR value are used in a design nomograph to determine a Structural Number (SN). The designer must then determine the combinations of surface, base and subbase depths that will provide a total Construction Number (CN) equal to or slightly greater than the required SN using structural coefficients given.

ANALYSIS OF PENNSYLVANIA PROCEDURE

The Frost Factor, or Design Freezing Index, appears to govern the design of Pennsylvania's low-volume roads. The freezing effect is accounted for in the design table for the Frost Factor. It is obvious that the traffic does not have as great an impact as the freeze-thaw effect in this procedure. The minimum values in the design thickness table are more conservative than would be determined using the AASHTO procedure.

TEXAS PROCEDURE

The flexible pavement design process used by Texas for low-volume roads, developed in 1972 from the AASHO Road Test of 1962, is totally computer based. (16) The Texas procedure basically requires the two main inputs used by most other states: traffic and soil strength.

The current ADT and the projected 20-year ADT are required for design. A traffic equation built in to the computer program uses this information to estimate the distribution of 18-kip ESALs over time. The program also estimates a traffic delay cost during overlay construction. Additional inputs include the one-direction cumulative 18-kip ESALs at the end

of 20 years and the percent trucks. The program uses this information to select the appropriate built-in cost and capacity tables.

There is an Environment and Subgrade section of inputs for the procedure that includes information regarding varying temperatures and soil types across the State of Texas. A temperature constant and the probability that a certain percentage of the project will experience swelling is entered in this section. Layer moduli values are used as a measure of the material strength. These moduli values represent *in-situ* values, back-calculated from deflection data collected from Falling Weight Deflectometer (FWD) measurements. These are the essential inputs for finding the layer thickness' of the pavement structure. There are additional input variables for this procedure -- the program calculates much more than just the structural thicknesses. Cost of maintenance, frequency of overlays, user costs, construction costs, and other values are also estimated. An explanation of how all of the inputs are used to determine the output values is given elsewhere. (17)

There is also a procedure called the "Modified Triaxial Design Procedure For Use With The Flexible Pavement Design System (FPS)" (18) which is recommended to check designs generated by the computer program. This procedure will not be discussed in detail here.

ANALYSIS OF TEXAS PROCEDURE

The Texas procedure (16) requires a large amount of input for the computer program to perform its analysis. At first, this seems a bit overwhelming, but it is largely a matter of entering "known" values into the program. This procedure offers much more information than just structural layer thicknesses. This procedure appears to offer a good tool for a county or other

local agency that wanted to know all of the costs involved for rehabilitation of existing roads, as well as the predicted time frame for rehabilitation and overlay procedures. Overall, this is a very comprehensive and thorough LVR pavement design procedure.

VERMONT PROCEDURE

The Vermont Agency of Transportation procedure for the design of low volume pavement structures, developed in March of 1996, is based on the 1986 AASHTO Guide for Design of Pavement Structures. In fact, if the frost depth is not taken into account, (which is left to the designer's discretion), the procedure is exactly that used by AASHTO, only presented in a "table" format.

The frost depth is the one input that differs from AASHTO. The maximum frost penetration is found by looking at a map provided in the procedure. Interpolations can be made if the area is directly between two values and the designer feels it is necessary to do so. Design tables give layer coefficients for various pavement, base and subbase courses. Once the maximum frost depth is determined, a factor is applied to estimate the amount of frost protection needed. This value is then checked against the thicknesses resulting from the remainder of the procedure. If the selected pavement structure is substantial enough to provide adequate strength and frost protection, no adjustment to the design is necessary. If the frost protection needed extends below the surface and base of the selected pavement structure, the design thicknesses must be increased to provide the needed frost protection.

ANALYSIS OF VERMONT PROCEDURE

This procedure is more conservative than the AASHTO procedure, as shown in Figure 7. It is a thorough procedure, but it tends to be conservative and could prove to be “not” cost-effective when the responsible agency is a county or a small town with limited resources and funds. The frost protection is a good idea for that part of the country and this procedure could be recommended for the Northeast portion of the United States or anywhere the climate tends to be cold and wet.

VIRGINIA PROCEDURE

The Virginia LVR pavement design procedure (20) differs from the previously discussed procedures. Virginia’s procedure, originally developed in October of 1973 by Dr. N. K. Vaswani and then revised in January of 1996, is based on the original AASHO Road Test results of 1962 and Virginia’s design experiences. Standard traffic and soil strength data are used, but with some notable differences.

The design ADT is determined by taking the present ADT and applying a Growth Factor (GF), found from historical traffic data or from estimates made by a traffic engineer. There is also a method for estimating the Design ADT when the percent of heavy vehicles exceeds 5 percent of the current ADT.

The soil strength is estimated using a Design CBR value and a Resiliency Factor (RF), which determines a Soil Support Value (SSV). The Design CBR is taken to be two-thirds of the average CBR value of the soil. The RF is a relative value that reflects a soil’s elastic deformation characteristics and its ability to withstand repeated loading. The RF is typically found by determining the soil classification obtaining the RF from a given table. The SSV is the

design CBR multiplied by the RF. Averages of all three of these values are shown in design tables for each county in the State of Virginia.

The designer determines the required Thickness Index (D_R) by using a design nomograph, in which the SSV and Design ADT values are input. The pavement structure is derived from a design figure based on the D_R value.

ANALYSIS OF VIRGINIA PROCEDURE

This design procedure does not appear as conservative as the AASHTO procedure, but they yield fairly similar design values, as shown in Figure 8. The Growth Rate and the alternate method when the heavy vehicles constitute a larger than 5 percent of the ADT are both appealing ideas. Since the SSV, CBR and Resiliency Factors have been determined for every county in Virginia, this method is very easy to use. However, it is noted that should another state wish to use this procedure, those values would have to be generated for local conditions. Overall, this procedure is appears sound and could be recommended to almost any state in the country.

DISCUSSION

From the review of design procedures, it is apparent that traffic loads and soil strength are considered to be the two most important factors in designing low-volume road pavement structures. Some methods have many additional inputs and some methods only have these two, but it is clear that these two parameters are key.

It is also apparent that states that have developed specific design procedures (as opposed to using the procedures recommended by AASHTO) did so in an effort to “tailor” specific variables or design parameters to their particular needs. This general observation is applicable to any future efforts to develop a comprehensive LVR design procedure – just as with procedures for designing high-volume roadways, “one-size” does not fit all.

CONCLUSION

Several different states deal very effectively with the different input variables required for the low-volume road pavement design. When considering how design inputs should be considered for developing a new comprehensive procedure, it is useful to identify those existing methodologies that seem to provide a reasonable, effective approach to the parameter.

The method of considering an “overloaded truck” in the Oklahoma procedure (*14*) seems to be a reasonable approach. It is particularly attractive for a rural state such as Arkansas, which has a large proportion of hauling trucks on its low-volume roads. Another potentially effective method for considering the effect of heavy traffic is given by Virginia (*20*), which incorporates a consideration of heavy vehicles (greater than 5 percent of ADT) into its design traffic calculation. Ideally, a combination of the Oklahoma and Virginia methods for estimating design traffic could be very effective in considering the traffic input in a design procedure.

Oklahoma (*14*) also includes an effective procedure for considering the effects of soil on an LVR pavement design. The percent passing the 0.75 sieve, the liquid limit, and the plasticity index of a soil are used to estimate the Oklahoma Subgrade Index (OSI). This OSI number governs the remaining design process. In addition, Oklahoma includes a procedure to consider

the effects of climate on the subgrade soil through the use of a Climate Factor. If it is necessary or desired to include the amount and effects of frost penetration in the design, the Pennsylvania (15) procedure offers a reasonable process. From the depth of frost penetration, a frost factor is determined, which is then be used in the design of the pavement structure.

In addition to these design inputs, it might be beneficial for the paving agency to get an idea of the costs as well as the predicted time frame for rehabilitation and the overlay procedures. Such capabilities are included in the Texas procedure (16).

As stated previously, even a comprehensive LVR design procedure will not be a “one-size fits all” solution – various regions have specific local conditions that must be considered in design. However, this report identifies those design parameters deemed most important by various pavement agencies, and details methods for considering those parameters in the design process. Should an agency desire to develop specific procedures for LVR design, the processes listed here represent a good starting point from which to tailor a design methodology for local conditions.

REFERENCES

1. *Local Low-Volume Roads and Streets*, Publication No. FHWA-SA-93-006, Federal Highway Administration, U. S. Department of Transportation, Washington D.C., Nov 1992.
2. *AASHTO Guide for Design of Pavement Structures, 1986*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.
3. *Flexible Pavements for Roads, Streets, Walks, and Open Storage Areas*, TM 5-822-5, Department of the Army, Washington, D.C., 1980.
4. *NCSA Design Guide for Low Volume Rural Roads*, National Crushed Stone Association, Washington, D.C., Feb 1973.
5. *Thickness Design – Asphalt Pavements for Highways and Streets*, Manual Series No. 1, The Asphalt Institute, Lexington, KY, 1991.
6. *Thickness Design for Soil-Cement Pavements*, Portland Cement Association, Skokie, IL.
7. *Flexible Pavement Structural Section Design Guide For California Cities and Counties*, Third Edition, California Department of Transportation, Sacramento, CA, Jan 1979.
8. *Pavement Design Procedures*, Illinois Department of Transportation, Springfield, IL, Aug 1995.
9. Kentucky Transportation Cabinet, Frankfort, KY, June 1995.
10. *State Aid Manual*, Minnesota Department of Transportation, St. Paul, MN, Dec 1992.
11. *Road Design Manual*, Minnesota Department of Transportation, St. Paul, MN, Jan 1982.
12. *Pavement Design Review for State Aid Division*, Mississippi State Highway Department, Jackson, MS, June 1994.
13. *The New York State Thickness Design Manual For New and Reconstructed Pavements*, New York State Department of Transportation, Albany, NY, Oct 1994.

14. *State of Oklahoma County Roads Metric Design Guidelines Manual*, Oklahoma Department of Transportation and the Association of County Commissioners of Oklahoma, Oklahoma City, OK, May 1996.
15. *Pavement Policy Manual*, Publication 242, Commonwealth of Pennsylvania Department of Transportation, Harrisburg, PA, 1995.
16. *Flexible Pavement Designer's Manual*, Third Revision, Texas State Department of Highways and Public Transportation, Austin, TX.
17. *Modified Triaxial Design Procedure for use with the Flexible Pavement Design System (FPS)*, Texas State Department of Highways and Public Transportation, Austin, TX.
18. *Flexible Pavement System Computer Program Documentation*, Research Report No. 123-15, Texas State Department of Highways and Public Transportation, Austin, TX, Oct 1972.
19. *Low Volume Pavement Design Procedure*, Vermont Agency of Transportation, Montpelier, VT, March 1996.
20. *Pavement Design Guide for Subdivision and Secondary Roads in Virginia*, Virginia Department of Transportation, Richmond, VA, Jan 1996.

Alabama	AASHTO	Nebraska	AASHTO
Arizona	AASHTO	Nevada	AASHTO
Arkansas	AASHTO	New Hampshire	AASHTO
California	Other	New Jersey	AASHTO
Colorado	AASHTO	New Mexico	AASHTO
Connecticut	AASHTO	New York	Other
Delaware	AASHTO	North Carolina	AASHTO
Florida	AASHTO	North Dakota	AASHTO
Georgia	AASHTO	Ohio	AASHTO
Idaho	AASHTO	Oklahoma	Other
Illinois	Other	Oregon	AASHTO
Indiana	AASHTO	Pennsylvania	Other
Iowa	AASHTO	Rhode Island	AASHTO
Kansas	AASHTO	South Carolina	AASHTO
Kentucky	Other	South Dakota	AASHTO
Louisiana	AASHTO	Tennessee	AASHTO
Maine	AASHTO	Texas	AASHTO
Maryland	AASHTO	Utah	AASHTO
Massachusetts	AASHTO	Vermont	Other
Michigan	AASHTO	Virginia	Other
Minnesota	Other	Washington	AASHTO
Mississippi	Other	West Virginia	AASHTO
Missouri	AASHTO	Wisconsin	AASHTO
Montana	AASHTO	Wyoming	AASHTO

Table 1. LVR Procedures Used by States

EXAMPLE: Illinois vs. AASHTO

Given input data: 100,000 ESAL's
5 ksi Resilient Modulus (M_R)
PSI = 2.5
50% Reliability

Illinois:

Class IV roads are low volume in Ill. procedure (<400 ADT).

100,000 ESAL's correlates to almost 30 HCV's/year.

5 ksi is fair/good relative quality of subgrade for lower Illinois in the AASHTO procedure.

Going into Table 4 of the Illin. proc., with HCV 20-40 and Eri >3, the design yields:

3" of Asphalt Concrete
8" of Aggregate Base
(No Subbase is addressed for Class IV roads.)

When 4 inches or more of Class I bituminous concrete are used, 8 inches of Type A aggregate base material is satisfactory for all combinations of soil types and traffic levels in all districts.

Using this statement, the largest section that should be built for low volume roads in Illinois is this:

4" Asphalt Concrete
8" Aggregate Base

Total Structural Thickness is 12".

AASHTO:

Plugging into the nomograph, the SN is 2.4.

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

2" minimum AC
4" minimum Base

$$a_1 = 0.44, a_2 = 0.14 \\ a_3 = 0.11$$

$$2.4 = .44(2) + .14(4) + .11 D_3 \\ D_3 = 8.7''$$

2" Asphalt Concrete
4" Aggregate Base
8.7" Aggregate Subbase

Total Structural Thickness is 14.7".

Figure 2. Comparison of Illinois and AASHTO Procedures

EXAMPLE: Minnesota vs. AASHTO

Given input data: 100,000 ESAL's
5 ksi Resilient Modulus (M_R)
PSI = 2.5
50% Reliability

Minnesota:

With a Resilient Modulus of 5,000 psi, The R-value can be approximated by the following equation provided by the Asphalt Institute in "Thickness Design - Asphalt Pavements for Highways and Streets, Manual Series No. 1":

$$M_R = 115 + 555(R\text{-value})$$

This yields an approximate R-value = 8.

100,000 ESAL's correlates with the 9-ton, less than 150 heavy commercial average daily traffic (HCADT) provided in the design chart.

The R-value of 8 corresponds to a Soil Factor (S.F.) of 130.

Going into the design chart with S.F.=130 in the appropriate box:

$$\begin{aligned} \text{Min. Bituminous G.E.} &= 7.0 \\ \text{Total G.E.} &= 22.0 \end{aligned}$$

Multiplying these with their respective layer G.E. factors yields:

$$\begin{aligned} \text{Asphalt Concrete (in.)} &= (7.0)(1.5) = 10.5'' \\ \text{Aggregate Base (in.)} &= (22-7)(1.0) = 15'' \end{aligned}$$

Total Structural Thickness is 25.5''.

AASHTO:

Plugging into the nomograph, the SN is 2.4.

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

2" minimum AC
4" minimum Base

$$\begin{aligned} a_1 &= 0.44, a_2 = 0.14 \\ a_3 &= 0.11 \end{aligned}$$

$$\begin{aligned} 2.4 &= .44(2) + .14(4) + .11 D_3 \\ D_3 &= 8.7'' \end{aligned}$$

2" Asphalt Concrete
4" Aggregate Base
8.7" Aggregate Subbase

Total Structural Thickness is 14.7''.

Figure 3. Comparison of Minnesota and AASHTO Procedures

EXAMPLE: Mississippi vs. AASHTO

Given input data: 100,000 ESAL's
5 ksi Resilient Modulus (M_R)
PSI = 2.5
50% Reliability

Mississippi:

The inputs needed are Average Daily Traffic (ADT) and soil strength in terms of CBR.

M_R is related to CBR by the following equation provided by the Asphalt Institute in "Thickness Design - Asphalt Pavements for Highways and Streets, Manual Series No. 1":

$$M_R = 1500(\text{CBR})$$

With $M_R = 5$, $\text{CBR} = 3.333$:

This information is entered into tables already provided from previous experience and research. From the tables (since $\text{CBR}=3.33$, use $\text{CBR}=4$):

2" Asphalt Concrete (standard)
6" Clay Gravel Base (standard)
13.25" Clay Gravel Subbase

Total Structural Thickness is 21.25"

AASHTO:

Plugging into the nomograph, the SN is 2.4.

$$\text{SN} = a_1 D_1 + a_2 D_2 + a_3 D_3$$

2" minimum AC
4" minimum Base

$$a_1 = 0.44, a_2 = 0.14 \\ a_3 = 0.11$$

$$2.4 = .44(2) + .14(4) + .11 D_3 \\ D_3 = 8.7"$$

2" Asphalt Concrete
4" Aggregate Base
8.7" Aggregate Subbase

Total Structural Thickness is 14.7"

Figure 4. Comparison of Mississippi and AASHTO Procedures

EXAMPLE: New York vs. AASHTO

Given input data: 100,000 ESAL's
5 ksi Resilient Modulus (M_R)
PSI = 2.5
90% Reliability (Reliability is 90% in the N.Y. design)

New York:

The inputs for this procedure are in metric units:
MPa for M_R and 80 kN ESAL's for traffic.

A 5,000 psi MR equals 34 Mpa and there are
less than 4 million 80 kN ESAL's over the design
life of 15 years.

With this information, the appropriate design 'box'
is chosen and the following apply:

(150mm) or 6" Asphalt Concrete
(100mm) or 4" Asphalt Stabilized Base
(300mm) or 12" Subbase

Total Structural Thickness is 22"

(All designs include 100mm (4") Dia. perforated 2" Asphalt Concrete
plastic edge drains.)

AASHTO:

Plugging into the
nomograph, the SN
is 2.8.

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

2" minimum AC
4" minimum Base

$$a_1 = 0.44, a_2 = 0.14$$
$$a_3 = 0.11$$

$$2.8 = .44(2) + .14(4) + .11 D_3$$
$$D_3 = 12.4"$$

4" Aggregate Base
12.4" Aggregate Subbase

**Total Structural Thickness
is 18.4" .**

Figure 5. Comparison of New York and AASHTO Procedures

EXAMPLE: Oklahoma vs. AASHTO

Given input data: 100,000 ESAL's
5 ksi Resilient Modulus (MR)
PSI = 2.5
50% Reliability

Oklahoma:

Using design charts and graphs, a MR of 5 ksi correlates to an OSI number of approx. 12.

There are several factors that must be estimated in this Oklahoma procedure because the traffic breakdown is more involved than just ESAL's.

Estimated values:

Shoulder Factor = 2
Climate Factor = 30
Traffic Factor = 11.25
ADT = 500 (low volume)
15% trucks, 15% overloaded
Yields STC Factor of 2.86

From OSI of 12, EBT = 230.

From STC of 2.86, EBT adjustment factor = 75 mm.

Design EBT = 230+75 = 305 mm.
(Minimum of 150 mm base)

50mm(2") Asphalt Concrete = 76mm EBT
150mm(6") Aggregate Base = 150mm EBT
150mm(6") Subbase = 79mm EBT
Total EBT=305mm

Total Structural Thickness is 14".

AASHTO:

Plugging into the nomograph, the SN is 2.4.

$$SN = a_1D_1+a_2D_2+a_3D_3$$

2" minimum AC
4" minimum Base

$$a_1 = 0.44, a_2 = 0.14$$
$$a_3 = 0.11$$

$$2.4 = .44(2)+.14(4)+.11 D_3$$
$$D_3 = 8.7"$$

2" Asphalt Concrete
4" Aggregate Base
8.7" Aggregate Subbase

Total Structural Thickness is 14.7" .

Figure 6. Comparison of Oklahoma and AASHTO Procedures

EXAMPLE: Vermont vs. AASHTO

Given input data: 100,000 ESAL's
5 ksi Resilient Modulus (M_R)
PSI = 2.5
50% Reliability

Vermont:

This procedure is based on the AASHTO procedure:

The following are minimum thickness' based on 100,000 ESAL's:

2" Asphalt Concrete (3" suggested)
12" Subbase
12" Sand

Total Structural Thickness is 26"

(The large thickness of the sand layer takes into account the fact that there will be a frost layer that must have adequate cover)

This procedure just hands you the information, no 'designing' required.

AASHTO:

Plugging into the nomograph, the SN is 2.4.

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

2" minimum AC
4" minimum Base

$$a_1 = 0.44, a_2 = 0.14 \\ a_3 = 0.11$$

$$2.4 = .44(2) + .14(4) + .11 D_3 \\ D_3 = 8.7"$$

2" Asphalt Concrete
4" Aggregate Base
8.7" Aggregate Subbase

Total Structural Thickness is 14.7".

Figure 7. Comparison of Vermont and AASHTO Procedures

EXAMPLE: Virginia vs. AASHTO

Given input data: 100,000 ESAL's
5 ksi Resilient Modulus (M_R)
PSI = 2.5
50% Reliability

Virginia:

A M_R of 5 ksi correlates to a 3.33 CBR and a Resistance Factor (RF) of 1.5.

$$\text{Design CBR} = 2/3 * (3.33) = 2.22$$

This information yields a Soil Support Value (SSV) of 6.

Go into nomograph with ADT = 500; DR = 12.0. 4" minimum Base

Using the equivalency values given, the following $a_1 = 0.44$, $a_2 = 0.14$ layer thickness' were found:

1.5" Asphalt Concrete
5" Aggregate Base
8" Subbase

Total Structural Thickness is 14.5".

AASHTO:

Plugging into the nomograph, the SN is 2.4.

$$SN = a_1 D_1 + a_2 D_2 + a_3 D_3$$

2" minimum AC

$$2.4 = 0.44(2) + 0.14(4) + 0.11 D_3$$

$$D_3 = 8.7"$$

2" Asphalt Concrete
4" Aggregate Base
8.7" Aggregate Subbase

Total Structural Thickness is 14.7".

Figure 8. Comparison of Virginia and AASHTO Procedures