This study was undertaken to provide the LA DOTD with an implementation package to facilitate adoption of the new AASHTO Guide for Design of Pavement Structures. The study included evaluation of design parameters for rigid and flexible pavements, including several new parameters such as design reliability, resilient modulus, drainage, and use of tied concrete shoulders and widened lanes. Recommendations were made for design values which best represent Louisiana conditions, materials, and construction procedures. An automated procedure was developed to estimate roadbed resilient modulus by using soils engineering and classification data as an interim design measure. Traffic equivalence factors were updated using Weigh-in-Motion data for selected vehicle types. Layer structural coefficients were updated for flexible design to reflect new materials and construction procedures. A computer program was developed for DOTD use which is tailored to its design reporting format and which has storage capabilities for pavement management purposes. The program is designed to calculate layer thicknesses for a variety of available materials to satisfy the flexible design structural number while maintaining a uniform final pavement elevation. Recommendations are provided for a high stability wearing course layer which is designed to resist rutting and early surface failure, and for permeable asphalt base drainage for rigid and flexible pavement designs.

# IMPLEMENTATION OF THE

# NEW AASHTO PAVEMENT DESIGN PROCEDURE

# IN LOUISIANA

FINAL REPORT

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ABSTRACT

This study was undertaken to provide the LA DOTD with an implementation package to facilitate adoption of the new AASHTO Guide for Design of Pavement Structures. The study included evaluation of design parameters for rigid and flexible pavements, including several new parameters such as design reliability, resilient modulus, drainage, and use of tied concrete shoulders and widened lanes. Recommendations were made for design values which best represent Louisiana conditions, materials, and construction procedures. An automated procedure was developed to estimate roadbed resilient modulus by using soils engineering and classification data as an interim design measure. Traffic equivalence factors were updated using Weigh-in-Motion data for selected vehicle types. Layer structural coefficients were updated for flexible design to reflect new materials and construction procedures. A computer program was developed for DOTD use which is tailored to its design reporting format and which has storage capabilities for pavement management purposes. The program is designed to calculate layer thicknesses for a variety of available materials to satisfy the flexible design structural number while maintaining a uniform final pavement elevation. Recommendations are provided for a high stability wearing course layer which is designed to resist rutting and early surface failure, and for permeable asphalt base drainage for rigid and flexible pavement designs.

# IMPLEMENTATION STATEMENT

The new AASHTO Guide for Design of Pavement Structures will be implemented by Louisiana DOTD as a part of its Pavement Management Information System (PMIS). The computer software developed under this study (LA PAVE) has been designed to accomplish data storage of project design information for PMIS.

The portion of the new guide which will be implemented by this study is specific to section design of new pavements and does not include overlay, rehabilitation, staged construction, or calculation of life costs.

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# INTRODUCTION

The design of pavements requires the prediction of the interrelation of several influencing factors. To help define these interrelationships, the AASHO Road Test was performed. In 1961 and 1962 the results of the AASHO Road Test were published in the Interim Design Guides.[1,2] Louisiana adopted the Interim Design Guides as its pavement design procedure in that same year and participated in subsequent revisions is 1972 [3] and again in 1981.[4]

In 1986, AASHTO released a new revision of the pavement design guide entitled AASHTO Guide for Design of Pavement Structures, 1986, henceforth referred to as the AASHTO Design Guide.[5] With this revision several new factors were considered and defined in terms of their influence on pavement thickness selection. Among these are:

Reliability of the Pavement Structure
Resilient Modulus for Soil Support
Drainage
Tied Concrete Shoulders or Widened Lanes

Each of these factors served to add to or modify a computational term in the flexible and/or rigid design equations. To facilitate implementation by DOTD, these new design factors were incorporated into computer software which was tailored to the needs of flexible and rigid pavement design in Louisiana. One of the goals in the software development was to include a subroutine which calculates several flexible section designs using alternate base course materials.

The report describes the factors used in both the rigid and flexible design equations with recommendations on which values or range of input variables best apply to design of pavements in this state. Several changes are recommended to improve the design and performance of flexible pavements constructed with cement-treated bases. The flexible pavement structural design coefficients were updated to reflect new materials and constructions practices. These include the new, high-stability, high friction, asphaltic concrete surface mix, crushed portland cement concrete used as an aggregate layer, a synthetic aggregate, and plant mixing of materials stabilized with portland cement.

# SCOPE

The study and software development are specific to the design of new pavements for a single design period, and therefore, do not address overlay, design of staged construction, determination of life cycle costing, or pavement rehabilitation. The study includes an update of design factors which reflect new materials and new construction practices. The study does not address new methods for estimating future traffic loading for design, but does include updated vehicle equivalency factors.

# OBJECTIVES

The objectives of the study included:

1. Familiarization with the new AASHTO pavement design procedure and software.

2. Development of a modified computer program for DOTD which is tailored to its design reporting format, which has storage capabilities for pavement management purposes, and which incorporates internal policies governing materials and mix type useage.

3. Development of a subroutine which predicts soil resilient modulus from soil engineering classification using test data developed in Louisiana.

4. Updating the structural design coefficients used in flexible pavement design to reflect new materials and construction practices.

5. Recommendation of values for the new design input parameters which best represent Louisiana conditions, materials and construction procedures.

6. Updating vehicle equivalency factors where appropriate.

7. Providing recommendations regarding where internal drainage would most likely benefit flexible pavement performance in Louisiana.

# INPUT VARIABLES USED IN THE PAVEMENT DESIGN EQUATIONS

In the chapters which follow, the discussion of input variables for pavement design has been divided into those variables which are to be used in both flexible and rigid pavement designs, and those which are unique to the design of one pavement type. These variables are listed as follows:

## Variables Common to Flexible and Rigid Design

Change in Present Serviceability Index (PSI)
Traffic Loading (Cumulative 18-kip Equivalent Single Axles)
Design Reliability of the Pavement Structure

## Variables Unique to Flexible Design

Roadbed Soil Resilient Modulus
Structural Design Coefficients

## Variables Unique to Rigid Design

Modulus of Subgrade Reaction (Composite K-value)
Modulus of Concrete Rupture (Flexural Strength)
Concrete Elastic Modulus
Drainage Coefficient
Load Transfer Coefficient

## DISCUSSION OF COMMON INPUT VARIABLES

### Change in Present Serviceability Index

The serviceability of a pavement is defined as its ability to serve the automobiles and trucks which use the facility. The primary measure of serviceability is the Present Serviceability Index (PSI), which ranges from 0 (impassable road) to 5 (perfect road). The AASHTO design philosophy is based upon the performance concept, by which the designed pavement will carry the estimated traffic loading over the performance period while maintaining at least a minimum level of serviceability.

The constructed serviceability of a pavement decreases with time and traffic. To find change in PSI two values are needed, the initial serviceability index ($P_i$) and the terminal serviceability index ($P_t$).

$P_i$ is an estimate of the value of PSI for the pavement structure immediately after construction. Typical values encountered in Louisiana on construction of major highways are 4.2 - 4.6 for flexible pavements and 4.0 - 4.3 for rigid pavements. These typical PSI values reflect surface tolerances specified and tested using the 10-foot rolling straightedge. Minimum acceptable values of 4.3 are being targeted for major highways as DOTD implements the rolling profilograph for construction control and acceptance. This level of PSI is attainable on jointed concrete pavements, although some degree of ride correction may be required. Recent evaluations of new asphaltic concrete construction indicate that this level of PSI should be routinely attainable, therefore 4.3 is viewed as the minimum level allowed for this type of construction before corrective action is required. Target values necessary to obtain a PSI of 4.3 have recently been determined by LTRC using a California style (Ames) profilograph (0.2-inch blanking band). The values to be specified are 5-inches per mile for jointed concrete paving and 2-inches per mile for asphaltic concrete paving.

$P_t$ is defined as the value of PSI which is the lowest acceptable level before resurfacing or reconstruction becomes necessary. It is usually represented by values of 3.0 or 2.5 for major highways, and 2.0 for lower classed highways and 1.5 for relatively minor highways.

One of the changes in the AASHTO Design Guide is that the designer can now address change in PSI as design input. In the past, $P_t$ was used in the design process based upon the functional classification of the highway (major, minor, etc.) and pavements were assumed to have high $P_i$ values. The new guide allows for the input of a value for the change in PSI over the life of the pavement structure. This permits the designer to account for multiple factors affecting the change in PSI. Among the most influential factors affecting this change are the traffic and the environmental conditions.

In an effort to recognize the importance of route class, the change in PSI was evaluated on the basis of the class of highway under design such as interstate, primary, collectors, and local routes. This resulted in levels of design serviceability loss ( PSI), indicated in Table 1, based on the expected initial serviceability index and the minimum desirable terminal serviceability index for each route class.

TABLE 1

SERVICEABILITY INDEX -- DESIGN LOSS, INITIAL, AND TERMINAL

| | PS | Pi | Pt |
|---|---|---|---|
| Interstate | 1.5 | 4.3 | 2.8 |
| Primary | 1.8 | 4.3 | 2.5 |
| Collectors | 2.0 | 4.0 | 2.0 |
| Local | 2.0 | 3.5 | 1.5 |

Prediction of Total Traffic Loading

Pavement are designed, regardless of the type of materials, to withstand repeated applications of traffic load. This load is expressed in terms of the total 18-kip equivalent single axle loads generated over the design life of the project.

The AASHO Road Test experiment produced equivalency factors which can be used to convert the relative damage associated with a single or tandem axle of known weight, to an equivalent unit of damage associated with an 18-kip single axle load. As a result, any vehicle of known axle loading can be converted to an equivalent single axle loading (ESAL, 18-kip). In an effort to best estimate total expected loading, pavement designers use a design factor (Vehicle Equivalency Factor) which is characteristic of a particular vehicle type. In the case of trucks, which are the most damaging to pavements, the factors take into consideration the fact that not all trucks in the traffic stream are always loaded. These design factors are produced by periodically conducting loadometer studies in which trucks are sampled for weighing without bias to a load or no-load condition. The information published for use in pavement design is entitled the "W-4" Table, which is specific to three criteria:

1. Terminal PSI of the pavement structure.

2. Initial assumption of thickness for rigid pavement or structural number for flexible pavement.

3. Number of axles of the vehicle for which the 18-kip equivalence factor is desired.

The vehicle equivalency factors currently used in Louisiana are listed in Appendix A. Several of these factors were determined from Weigh-in-Motion studies[6] used to supplement data not collected in the most recent loadometer study data. The design software developed in this study includes a data file with these factors for rigid and flexible pavements so the designer need only enter the projected 24-hour vehicle classification (design lane) distribution for the median design year, and the length of the design period in years. The program will then compute the total design load and the average daily load for the median design year.

Reliability of the Pavement Structure

Although the flexible and rigid pavement design equations have several unique computational terms representing the various influencing factors, there is a term in the equations which is shared by both. This term represents the design reliability of the pavement structure.

According to the AASHTO Design Guide, the reliability level of a pavement structure is defined as "the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period." Naturally, all state agencies desire 100 percent reliability in their pavement structures, as this would mean that no future costs for maintenance and/or repair of the pavement structure would be required during its design life. In the theoretical world this is possible, but in reality the cost of producing a 100 percent reliable pavement structure is not economically feasible.

It can be demonstrated graphically that as reliability increases, so does the initial cost of construction of the pavement structure. This is shown in Figure 1 on page 13. In addition, there is a line on the graph that demonstrates how future costs (projected back to present value) decrease with increased reliability. The key to selecting an appropriate value of pavement structure reliability is to look at the total of the future and the initial cost curves. There will be a point in the graph of total costs versus reliability where total costs will be at a minimum. The corresponding reliability level will be the desired level of pavement structure reliability.

The selection of a reliability levels for the current study was based upon the functional classification of each pavement facility and whether the facility is located in a urban or rural location. The suggested values included in the AASHTO Design Guide and the levels recommended for incorporation into the Louisiana Pavement Design System are included in Table 2 on page 14. The values recommended typically represent the upper range of AASHTO recommended values for interstate and primary routes and the median to upper range of recommended values for collector and local routes.

TABLE 2

AASHTO SUGGESTED RELIABILITY LEVELS

| Location | Functional Class | AASHTO Suggested Reliability Levels | Louisiana Recommended Reliability Levels |
|---|---|---|---|
| Urban | Interstate | 85 - 99.99 | 99 |
| | Principal | 80 - 99 | 97 |
| | Collectors | 80 - 95 | 90 |
| | Local | 50 - 80 | 75 |
| Rural | Interstate | 80 - 99.99 | 97 |
| | Principal | 75 - 95 | 95 |
| | Collectors | 75 - 95 | 85 |
| | Local | 50 - 80 | 70 |

These default values are automatically selected by the computer software after the user identifies the location and functional class of the pavement structure.

Higher levels of reliability are recommended for urban construction due to the increased difficulty in interrupting traffic for maintenance or rehabilitation in these areas. A sensitivity analysis of the effect of change in reliability level on pavement thickness is illustrated in Figures 2 and 3 on pages 15 and 16 for an example rigid and flexible pavement, respectively.

Reliability Design Factor

The reliability concept is intended to provide the designer with a mechanism for applying a factor of safety in design as a safeguard against incorrect traffic predictions and overloads, unfavorable environmental effects, and variations in material strengths which cannot be controlled by construction and specification requirements. The new AASHTO design procedure accomplishes this by calculating a reliability design factor using the selected reliability level (previously discussed) and the expected overall standard deviation associated with the type of pavement under design (described below). These two values are combined by the following equation.

$$\log R_f = -Z_r * S_o$$

where:

$R_f$ = Reliability Design Factor

$Z_r$ = Standard Normal Value Corresponding to the selected Reliability Level

$S_o$ = Overall Standard Deviation of Pavement Structure

The $Z_r$ term, standard normal value, corresponds statistically to the level of reliability selected in design. Refer to the new AASHTO Guide for Design of Pavement Structures for additional discussion.

The $S_o$ term, the overall standard deviation, is included to account for expected variation in the prediction of pavement performance for a given traffic loading. Values for the overall standard deviation are selected by the type of pavement structure being designed. The AASHTO Design Guide recommends the following range of values:

0.33 - 0.39 for rigid pavements and

0.44 - 0.49 for flexible pavements

The lower end of each range corresponds roughly to the estimated variances associated with the AASHO Road Test pavements. Since it is reasonable to expect that on any given construction project the variation in material components, density of asphaltic concrete, strength of portland cement concrete, etc. would typically exceed the variation expected in a controlled experiment like the Road Test, the midpoint values have been recommended for general design practice in Louisiana.

The values of $S_o$ recommended are:

0.37 for rigid pavements and

0.47 for flexible pavements

A sensitivity analysis for a particular set of parameters was conducted to determine the effect of a change in $S_o$ on pavement thickness, as illustrated in Figures 4 and 5, pages 19 and 20.
The effect of $S_o$ on design thickness is so slight that additional study of this variable would not appear to be cost effective.

Since the reliability design factor, $R_f$, is applied in the design process as a factor of safety on the predicted traffic load for each pavement type, the factors of safety previously used in pavement design are no longer necessary. This would include the factor of safety applied to concrete flexural strength and the regional factor used in flexible pavement design. It is, therefore, the intent of the design procedure that design input values reflect the normally expected or statistical mean level of material strengths.

DISCUSSION OF FLEXIBLE PAVEMENT DESIGN INPUT VARIABLES

As previously stated, the two input factors unique to flexible pavement design are the roadbed soil resilient modulus ($M_r$), which replaces the Soil Support Value, and the flexible pavement structural design coefficients, which have been updated for this study. Discussion is also provided on an automated layer thickness selection subroutine developed to facilitate design of alternate base materials.

Roadbed Soil Resilient Modulus

Resilient Modulus ($M_r$) is the definitive materials property used by the AASHTO Guide to characterize roadbed soils. It is a measure of the elastic property of soil which recognizes certain nonlinear characteristics.

In Louisiana, resilient modulus is neither a standard soils test, nor is the equipment for such testing currently owned by DOTD. Extensive soil modulus testing as a part of a recent research study "Louisiana Experimental Base Study"[(7)], LTRC, 1987, has provided the relationships necessary to generally verify the soil R-value -- $M_r$ conversion relationships suggested in the AASHTO Design Guide for use by agencies as an interim procedure.

Louisiana currently uses a relationship (developed by the Research Section in 1963[(8)]) to estimate soil support values which converts soil class/engineering properties to R-values. This procedure has been used successfully for over 20 years in pavement design in the state. The referenced R-value -- $M_r$ relationship will permit the designer to convert from soil class/engineering properties to $M_r$. These relationships are depicted in Figures 6 and 7 pages 22 and 23 for the following general soil types: sand, sandy loam, sandy-clay loam, silt, silty clay, and heavy clay. The procedure is believed to be adequate in defining the variation in support afforded by the various, indicated soil types and is therefore usable as an interim design tool.

Values of measured roadbed resilient moduli (determined by the Asphalt Institute) were generally confirmed in the referenced "Experimental Base Study" using two independent methods: (1) laboratory R-values with the indicated correlations and (2) Dynaflect defection data, used in conjunction with a computer program which estimates layer moduli using deflection basin fitting techniques.[7]

A subroutine has been programmed for the design software which will provide the designer with soil resilient modulus by inputing the following soil characteristics:

1. Soil classification
2. Liquid, plastic limits
3. Percent retained on #4, 10, 40, 200 sieves
4. Percent silt, percent clay

In the future comparisons will be made of resilient modulus values determined by this method and laboratory developed materials properties.

<u>Structural Design Coefficients</u>

As a part of the updating of the Louisiana pavement design process for flexible pavements, structural coefficients (listed in Appendix B) used to determine layer thickness necessary to satisfy the required structural number (SN) have been revised predicated on the following:

1) Providing interim design values for new materials, for new combinations of existing materials, and for changes in materials strengths.

2) Providing for the use of central plant mixing of cement stabilized base course materials for higher traffic loadings (ADL 250). A higher structural coefficient has been provided for bases which are plant-mixed.

These revised values are reflective of the anticipated, improved stiffness and the anticipated improved performance of these bases.

3) Requiring design of total asphaltic concrete thickness which is greater than or equal to the thickness of the cement stabilized base, where ADL  250. This requirement is not generally implementable for lower traffic loadings since the thickness of base course might fall below a six-inch layer thickness.

Several research studies have indicated that improved construction practices are needed to improve the long term performance of asphaltic concrete pavements placed on cement treated bases in Louisiana.(7)(9)(10) Improved blending of cement and soil or aggregate is needed to provide uniform cement distribution and ultimately to improve the cracking characteristics and load carrying capabilities of the bases. The concept of plant mixing and of increasing the relative portion of the pavement section which consists of asphalt concrete were recently endorsed by the "Louisiana Asphaltic Concrete Forum", (11) a group comprised of paving contractors, consultants, and engineers from DOTD.

The high stability, high friction, "Type 8" wearing course mix is designed to have a minimum stability of 1700 pounds; however, test records indicate that the mix is typically providing a stability closer to 2100 pounds. This is a result of increased strength provided by the angular aggregate currently required to add skid resistance. Accordingly this mix has been assigned a design coefficient of 0.44 as indicated in Appendix B. The wearing course mix is currently required by DOTD where traffic volume (ADT) is equal to or greater than 3500. The software developed in this study will automatically select this wearing course mix at the appropriate levels of traffic volume.

The material strength values for asphaltic concrete in Appendix B reflect minimum specified Marshall stabilities and actual mean values obtained for all mix placed from 1986-1988 in Louisiana. The design coefficients listed reflect the mean material strengths in accordance with the intent of the 1986 AASHTO Design Guide. The layer moduli values listed were based on relationships provided in the guide.

Automated Layer Thickness Selection

One of the primary benefits in computer aided pavement design is the rapid calculation of alternative designs for layered pavement systems. This is particularly helpful where several alternate materials which vary in strength are to be allowed.

A subroutine has been included in the pavement design software to accomplish this, and to generate a table of layer thickness for inclusion in project plans. A sample of the programming logic used for the flexible pavement design is contained in Appendix C. The automated thickness selection procedure contains the following features:

(1) Layer thicknesses are calculated considering a variety of available base course materials.

(2) All alternate flexible designs begin and end at the same roadway elevation. This is accomplished by calculating the thickest total pavement section and specifying the additional inches of subbase required in thinner sections to make final elevations equal.

(3) The thickness of all layers are automatically rounded off to values which are reasonable to construct with consideration given to each unique material type and layer thickness requirements.

(4) The designer has the option of deleting a base or subbase material due to considerations which affect availability of materials. If by chance the material deleted represented the thickest design then the program will recalculate the additional inches of subbase required for each alternate based on the next thickest design.

(5) The designer has the option of selecting an asphaltic concrete base for full-depth design or a

non-asphaltic base as the principal load carrying base course.

(6) The designer also has the choice of selecting a "subbase treatment" where the designed layer contributes to the SN, or of selecting a "subbase treatment" where the layer does not contribute to the SN. In the latter case the layer is considered a working table only. This decision is a consideration which reflects design policy, and may vary as policies change.

Minimum and/or maximum layer thickness have been included for the wearing and binder course layers, as well as for the asphaltic concrete, cement stabilized, and granular base layers. These limiting values are necessary to develop the programming logic and to provide realistic design thickness. The upper and lower limits are listed in Table 3.

TABLE 3

PROGRAMMED LAYER THICKNESS LIMITS (inches)

| LAYER | SN 5 | SN 5 |
|---|---|---|
| Wearing Course | 1.5 | 3.0 |
| Binder Course | 1.5 - 5.0 | 1.5 - 6.0 |
| Asphaltic Concrete Base | 3.0 min. | 3.0 min. |
| Cement Treated Base | | |
| Mixed in Place | 8.5 | 8.5 |
| Plant Mixed | 6.0 - 8.5 | 6.0 - 8.5 |
| Granular Base | 8.5 | 8.5 |

The thickness of high stability wearing mix has been set at 1.5- inches or 3.0-inches depending on the relative level of designed

SN; whether below or above SN=5. This is intended to provide increased upper pavement strength (stability), specifically to resist rutting and to improve upper layer performance where repeated heavy loads and repeated high tire pressures are expected, such as on Interstate routes and other major facilities. It is not intended that special non-polishing aggregate be required in the lower 1.5-inches of a 3.0-inch wearing course; however, the mix stability should be in the 1800-2000 pound range. In this instance, the computer program will select the 2100-pound Marshall Stability "Type 8" wearing course mix for the top 1.5-inch and the 1800-pound Marshall stability "Type 3" mix for the lower 1.5-inch layer for the condition SN 5.

Drainage of Flexible Pavements

Drainage of flexible pavement sections is encouraged in the AASHTO design guide and a mechanism is included in the design to account for the effects of drainage. The design provides for layer thickness adjustment for a drainable layer by increasing the design coefficient of the material in that layer. This process effectively reduces the total required thickness of the flexible pavement. This procedure has not been included in the software developed for this study since DOTD does not currently utilize drainable layers within flexible pavement sections.

Based on observations of the performance of flexible pavements with cement-treated bases, it is believed that DOTD should consider adding through the shoulder drainage (such as a drainable asphaltic concrete layer) where the following conditions exist:

1) A cement-treated base is the principle load carrying component other than the pavement surfacing.

2) The roadbed soil $M_r$ 12,000 psi. This will provide for drainage in the flat, poorly drained areas of the state.

3) The pavement is subjected to repeated heavy loads, ADL 250.

Differential settlement of cracked bases under layers of asphaltic concrete is more prevalent in moderate to low soil support conditions. Once cracks in the base occur, the bases tend to exhibit characteristics similar to an overlaid concrete pavement, but with no mechanism for load transfer across the cracks. It is believed that a well-drained roadbed would reduce the rate of differential settlement of the cement-treated bases under repeated heavy loads and thereby reduce the rate of serviceability decline.

Louisiana DOTD is considering incorporating a permeable asphalt base course in construction of full-depth asphalt concrete pavements. Inclusion of a permeable base will remove the "bathtub" effect created by the use of full-depth asphaltic concrete shoulders on flexible pavements.

## DISCUSSION OF RIGID PAVEMENT DESIGN INPUT VARIABLES

There are five data input variables unique to the design of rigid pavements. These variables include:

1. Modulus of Subgrade Reaction
2. Modulus of Concrete Rupture (Flexural Strength)
3. Modulus of Elasticity
4. Drainage Coefficient
5. Load Transfer Coefficient

Modulus of Subgrade Reaction

The modulus of subgrade reaction, K-value, has traditionally been defined as the vertical deflection (penetration) of a 30-inch diameter plate into a layer loaded to 10 psi according to the formula:

$D = 1.5\ pa / E_s$ ; where

D = deflection or penetration of plate into subgrade

p = 10 psi

a = radius of plate (15 inches)

$E_s$ = subgrade modulus ($M_r$);

therefore the expression;

$$K = \frac{\text{pressure}}{\text{deflection}} = \frac{10\ \text{psi}}{D} = \frac{E_s}{22.5}$$

provides the relationship between K-value and subgrade (roadbed) resilient modulus, as indicated in Figure 8, page 32.

The chart for determination of the combined support of a subgrade and subbase layer (composite K-value) is the same as is currently used in Louisiana. The actual determination of the composite K-value was not included in the software package and therefore remains a manual procedure.  In addition to simplifying the program, this enables the designer to include or not included the contribution of a working table to the concrete slab support computations, as prescribed by design policy.

Modulus of Concrete Rupture

The modulus of concrete rupture or flexural strength of portland cement concrete is determined though the use of a mean value of third point loading failure (AASHTO T97, ASTM C78). AASHTO suggests that the normal construction specification for flexural strength not be used as the design input value. A more representative design input value is the mean value of the actual test results. The suggested value for Louisiana rigid pavement design is 550 psi. This value assumes the substitution of 20% fly ash for cement and the use of gravel aggregate, and is therefore conservative when alternative materials are used.

Concrete Elastic Modulus

The elastic modulus of concrete is determined through the procedure described in ASTM C459. The value recommended to represent Louisiana rigid pavement design is $4.2 \times 10^6$ psi.

Load Transfer Coefficient

The load transfer coefficient, J, is used to account for the ability of a rigid pavement to transfer load across joints and/or cracks in the pavement. The design procedure is programmed to require thicker concrete pavements where a lower level of load transfer is designed. Lower values of J indicate higher levels of load transfer. The addition of load transfer devices, tied concrete shoulders, and widened lanes all serve all serve to lower the J values selected thereby reducing the final concrete thickness.

Table 4 contains the AASHTO Design Guide recommended values of load transfer coefficient, J.

TABLE 4

AASHTO RECOMMENDED LOAD TRANSFER COEFFICIENTS

| | ASPHALT SHOULDERS | | TIED PCC SHOULDERS | |
|---|---|---|---|---|
| | Load Transfer Device? | | Load Transfer Device? | |
| | YES | NO | YES | NO |
| Jointed | 3.2 | 3.8 - 4.4 | 2.5 - 3.1 | 3.6 - 4.2 |
| CRC | 2.9 - 3.2 | N/A | 2.3 - 2.9 | N/A |

Current policy for Louisiana DOTD rigid pavement design includes 20-foot transverse joint spacing with steel dowels placed on 12-inch centers. Interstate designs may contain tied concrete shoulders and an outside lane which is 15-feet wide, a combination which is not addressed in the AASHTO Design Guide. The recommended values for load transfer coefficient, J, follow the AASHTO recommended values and are as follows for jointed concrete pavement:

TABLE 5

LOAD TRANSFER COEFFICIENTS RECOMMENDED FOR LOUISIANA

| | |
|---|---|
| Asphalt Shoulder and 12 ft. Truck Lane | 3.2 |
| Asphalt Shoulder and 15 ft. Truck Lane or Concrete Shoulder | 2.5 |

Performance studies of jointed, doweled pavements in Louisiana have indicated that joint faulting is not a contributor to loss of serviceability. In fact, in many cases Interstate pavements of this type have carried more than their design loads without joint faulting exceeding 0.15 inch and this is without the benefit of tied concrete shoulders or widened lanes. (10) For this reason, it is felt that a value of J of 2.5 is appropriate.

A sensitivity analysis depicting change in concrete thickness with change in J is illustrated in Figure

9, page 35.

Drainage Coefficient

The drainage coefficient ($C_d$) is used to account for the expected level of drainage a rigid pavement is to encounter over its life. Values of $C_d$ are dependent upon the quality of drainage and the percent of time during the year the pavement structure is normally exposed to moisture levels approaching saturation. Descriptions of the quality of drainage and are listed in Table 6, and the AASHTO Design Guide recommended values for $C_d$ are provided in Table 7 below.

TABLE 6

QUALITY OF DRAINAGE DESCRIPTIONS

| Quality of Drainage | Water Removed Within |
|---|---|
| Excellent | 2 Hours |
| Good | 1 Day |
| Fair | 1 Week |
| Poor | 1 Month |
| Very Poor | No Drainage |

TABLE 7

AASHTO RECOMMENDED VALUES FOR DRAINAGE COEFFICIENT

| Quality of Drainage | Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation | | | |
|---|---|---|---|---|
| | 1% | 1 - 5% | 5 - 25% | 25% |
| Excellent | 1.25 - 1.20 | 1.20 - 1.15 | 1.15 - 1.10 | 1.10 |
| Good | 1.20 - 1.25 | 1.15 - 1.10 | 1.10 - 1.00 | 1.00 |
| Fair | 1.15 - 1.10 | 1.10 - 1.00 | 1.00 - 0.90 | 0.90 |

| | | | | |
|---|---|---|---|---|
| Poor | 1.10 - 1.00 | 1.00 - 0.90 | 0.90 - 0.80 | 0.80 |
| Very Poor | 1.00 - 0.90 | 0.90 - 0.80 | 0.80 - 0.70 | 0.70 |

The effect of $C_d$ on slab thickness is similar to that of the load transfer coefficient J; that is, better drainage will decrease the slab thickness required. A sensitivity analysis of how the change in $C_d$ will affect the change in slab thickness is presented in Figure 10 on page 38.

The choice of drainage characteristics for rigid pavements in Louisiana is based on a presumption that greater than 25% of the time pavements will be exposed to moisture levels approaching saturation. The quality of drainage where a drainage layer is included in the shoulder section (through-the-shoulder-drainage) is considered excellent, since drainage is provided immediately adjacent to the outside lane. Accordingly, when through-the-shoulder-drainage features are designed, the value for $C_d$ is recommended to be 1.10. Where longitudinal edge drains are added to drain a concrete shoulder (outside edge of shoulder), a $C_d$ value of 1.05 is recommended. A lower value is recommended because although a drainage mechanism is provided, it is not immediately adjacent to the travel lane. A preferred drainage design would incorporate a permeable asphalt base for the full width of concrete pavements and shoulders, whether the shoulder section is asphaltic or portland cement concrete. In rigid pavement designs where no drainage features are incorporated, it is believed that a value of 0.90 for $C_d$ should be selected. This value of $C_d$ will effectively thicken a concrete slab to overcome the negative effects that not providing internal drainage has been observed to have on pavement performance. The pavement design software will automatically apply these values of $C_d$, depending on whether or not the designer indicates which drainage feature is planned or whether no drainage feature is planned.

## RECOMMENDATIONS

The following is a summary of the recommendations included in the report:

1. Design serviceability loss ( PSI) factors are recommended as follows:
   InterstatePSI = 1.5
   Primary PSI = 1.8
   Secondary, Local PSI = 2.0

2. An expanded table of vehicle equivalency factors is recommended with updated factors determined from evaluation of Weigh-In-Motion data for the 3-S-3 and Double Trailer carriers.

3. Reliability Levels for urban and rural routes for Interstate, Primary, Collector, and Local roads are recommended as follows:

| | URBAN | RURAL |
|---|---|---|
| Interstate | 99 | 97 |
| Primary | 97 | 95 |
| Collector | 90 | 85 |
| Local | 75 | 70 |

4. Overall standard deviation, $S_o$, values by pavement types are recommended as follows:

| | $S_o$ |
|---|---|
| Rigid | 0.37 |
| Flexible | 0.47 |

5. An automated procedure for estimating the road bed resilient from soils engineering and

classification data was developed and is recommended.

6. A table of updated structural coefficients for flexible pavement design is recommended, which includes:

(a) Interim design values for several new materials and revised values for asphaltic concrete which reflect mean field stabilities.

(b) A provision for plant mixing of cement-treated base materials with an associated higher design value.

7. A design guideline for selecting the relative thickness of asphaltic concrete surfacing and cement - treated base has been automated in the design software and is recommended to improve the performance of this type of pavement.

8. Design values reflecting expected strengths of portland cement concrete are recommended as follows:

Flexural Strength = 550 psi

Modulus of Elasticity = $4.2 \times 10^6$ psi

9. Design Load Transfer coefficients, J, are recommended for the following situations in concrete paving:

| | J |
|---|---|
| Asphalt Shoulder and 12 ft. Truck Lane | 3.2 |
| Asphalt Shoulder and 15 ft. Truck Lane or Concrete Shoulder | 2.5 |

10. Design Drainage Coefficient, $C_d$, values are recommended for the following situations

in concrete paving:

| | $C_d$ |
|---|---|
| Drainable Layer Through the Shoulder | 1.10 |
| Longitudinal Edge Drain Outside Shoulder | 1.05 |
| No Drainage Feature | 0.90 |

A permeable asphalt base is recommended full width through the shoulder for both rigid and flexible pavement.

11. Drainage of flexible pavements which utilize cement treated bases constructed on roadbeds with $M_r$ 12,000 psi and with design average daily traffic values (ADL) greater than 250 ESAL should contain through-the-shoulder drainage. An asphaltic concrete drainage layer in the shoulder at a depth equal to the bottom of the pavement base is recommended.

REFERENCES


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4. "AASHTO Interim Guide for Design of Pavement Structures," AASHTO, 1981.

5. "AASHTO Guide for Design of Pavement Structures, 1986," AASHTO, 1986.

6. Broussard, David T., "Weigh-in-Motion for Planning Applications in Louisiana", Report No. FHWA/LA-87/196, Louisiana Transportation Research Center, April, 1988.

7. Temple, W. H., Shah, S. C., "Louisiana Experimental Base Project", Report No. FHWA/LA-87/192, Louisiana Transportation Research Center, December 1987.

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9. Shah, S. C., Melancon, J. L., "Soil Cement Study", Report No. FHWA/LA-73/72, Research and Development Section, Louisiana Department of Highways, 1973.

10. Temple, W. H., Cumbaa, Steven L., Boleware, Deborah, "Life Cycle, Cost and Loading Characteristics of AASHTO Designed Rigid and Flexible Pavements in Louisiana (1965 - 1989)", Report No. FHWA/LA-88/214, Louisiana Transportation Research Center, February, 1989.

## STRUCTURAL COEFFICIENTS FOR FLEXIBLE SECTION DESIGN
## (MAY 1989)

### MATERIAL STRENGTH VALUES

| | | SPECIFIED MINIMUM | ACTUAL MEAN | LAYER MODULI PSIx$10^3$ (MEAN) | DESIGN COEFFICIENT |
|---|---|---|---|---|---|
| SURFACE COURSE | | | | | |
| Asphaltic | Type 8 | 1700 MS | 2100 MS | 450 | 0.44 |
| Concrete | Type 3 WC | 1500 MS | 1800 MS | 400 | 0.42 |
| | Type 3 BC | 1400 MS | 1600 MS | 400 | 0.42 |
| | Type 1, WC, BC | 1200 MS | 1600 MS | 350 | 0.38 |
| BASE COURSE | | | | | |
| Untreated | Sand Clay Gravel | 3.5 TxTr | | 17 | 0.07 |
| | Sand/Shell, Sand | 2.2 TxTr | | 30 | 0.10 |
| | Crushed Stone | 2.0 TxTr | | 30 | 0.14 |
| | Crushed PCC | | | 30 | 0.14 |
| Cement | Soil Cement | | | 550 | 0.14 |
| Treated | Sand Clay Gravel | | | 550 | 0.14 |
| (Mixed in | Sand/Shell, Shell (4%) | | | 600 | 0.15 |
| Place) | Sand/Shell, Shell (5%) | | | 650 | 0.18 |
| Cement | Soil Cement | | | 650 | 0.18 |
| Stabilized | Sand Clay Gravel | | | 650 | 0.18 |
| (Plant Mixed) | Sand/Shell, Shell (6%) | | | 725 | 0.20 |
| ~~Asphalt~~ | Hot Mix Base Course (5A) | 1200 MS | 1500 MS | 320 | 0.28 |
| SUBBASE COURSE | | | | | |
| | Lime Treated Sand Clay Gravel | | | 20 | 0.14 |
| | Crushed Stone | | | 20 | 0.14 |
| | Sand/Shell, Shell | | | 20 | 0.14 |
| | Sand Clay Gravel | | | 15 | 0.11 |
| | Sand | | | 15 | 0.11 |
| | Old Gravel, Shell Roadbed (8") | | | 15 | 0.11 |
| | Lime Treated Soil | | | 10 | 0.07 |
| | Suitable Material (Soil) | | | 8 | 0.04 |

MS - Marshall Stability
TxTr - Texas Triaxial
Layer Moduli related from design coefficients unless otherwise indicated

# APPENDIX E

## Example of Hardcopy of Rigid and Flexible Designs