FLEXIBLE PAVEMENT DESIGN MANUAL

JANUARY 2026

OFFICE OF DESIGN, PAVEMENT DESIGN SECTION
TALLAHASSEE, FLORIDA
Topic #625-010-002

FLEXIBLE PAVEMENT DESIGN MANUAL

CHAPTER 1
INTRODUCTION

1.1 PURPOSE

The objective of this manual is to provide a Pavement Design Engineer with sufficient information so that the necessary input data can be developed and proper engineering principles applied to design a new flexible pavement, or develop a properly engineered pavement rehabilitation project. This design manual addresses methods to properly develop a pavement rehabilitation project, pavement milling, and the computations necessary for the pavement design process.

It is the responsibility of the Pavement Design Engineer to ensure that the designs produced conform to Department policies, procedures, standards, guidelines, and sound engineering practices.

1.2 AUTHORITY

Sections 20.23(3) (a) and 334.048(3), Florida Statutes

1.3 GENERAL

Chapter 334 of the Florida Statutes, known as the Florida Transportation Code, establishes the responsibilities of the state, counties, and municipalities for the planning and development of the transportation systems serving the people of the State of Florida, with the objective of assuring development of an integrated, balanced statewide system.

The Code's purpose is to protect the safety and general welfare of the people of the State and to preserve and improve all transportation facilities in Florida. Section 334.148(3), Florida Statutes, sets forth the powers and duties of the Department of Transportation to develop and adopt uniform minimum standards and criteria for the design, construction, maintenance, and operation of public roads.

The standards in this manual represent minimum requirements, which must be met for flexible pavement design for new construction and pavement rehabilitation of Florida Department of Transportation projects. Any variances should be documented in project files.

Pavement design is primarily a matter of sound application of acceptable engineering criteria and standards. While the standards contained in this manual provide a basis for uniform design practice for typical pavement design situations, precise rules which would apply to all possible situations are impossible to give.

1.4 SCOPE

The principal users of this manual are the District Pavement Design Engineers and their agents (i.e. Consultants). Additional users include other department offices such as Construction, Maintenance, Traffic Operations, etc., and city and county offices.

1.5 FLEXIBLE PAVEMENT DESIGN MANUAL ORGANIZATION AND REVISIONS

1.5.1 REFERENCES

The design procedures incorporated in this document are based on the American Association of State Highway and Transportation Officials (AASHTO) Guide for Design of Pavement Structures plus numerous National Cooperative Highway Research Program (NCHRP), Transportation Research Board (TRB), and Federal Highway Administration (FHWA) publications.

The specifics addressed in this manual have been tailored to Florida conditions, materials, and policy.

1.5.2 FLORIDA CONDITIONS

A number of coefficients and variables are specified in this manual. They should be considered as standard values for typical Florida projects. There may be instances where a variance from the values would be appropriate. In these instances, the Pavement Design Engineer will stay within the bounds established by the basic AASHTO Design Guide, justify the variance, and document the actions in the Pavement Design File.

1.5.3 APPENDICES

Included with this manual are 4 appendices:

Appendix	Contents
A	Design Tables
B	Flexible Pavement Design Quality Control Plan
C	Mechanistic-Empirical Pavement Design Guide
D	Estimating Design 18-kip Equivalent Single Axle Loads ($ESAL_D$)

1.6 DISTRIBUTION

This document is available through the Maps and Publications Section. Manuals may be downloaded from:

Florida Department of Transportation

Maps and Publications

http://www.fdot.gov/publications/publications.shtm

1.7 PROCEDURE FOR REVISIONS AND UPDATES

Flexible Pavement Design Manual holders are solicited for comments and suggestions for changes to the manual by writing to the address below:

Florida Department Of Transportation
Pavement Management Section
605 Suwannee Street, M.S.32
Tallahassee, Florida
32399-0450

Each idea or suggestion received will be reviewed by appropriate pavement design staff in a timely manner. Items warranting immediate change will be made with the approval of the State Pavement Design Engineer in the form of a Pavement Design Bulletin.

Pavement Design Bulletins for the Flexible Pavement Design Manual are distributed to the District Design Engineers, District Pavement Design Engineers, and District

Consultant Pavement Design Engineers, Federal Highway Administration (FHWA) and posted on the FDOT website.

http://www.fdot.gov/roadway/PM/publications.shtm

Pavement Design Bulletins will be in effect until the official manual revision.

Statewide meetings of District Roadway Design Engineers will be held quarterly and a statewide meeting of designers may be held annually. A major agenda item at these meetings will be the review of Design Bulletins, planned revisions, and suggestions and comments that may warrant revisions. Based on input from these meetings, official revisions are developed and distributed to the District Design Engineers, District Pavement Design Engineers, Consultant Project Managers, Roadway Design Office, State Materials Office, Federal Highway Administration, industry and other appropriate offices as necessary.

All revisions and updates will be coordinated with the Forms and Procedures Office prior to implementation to ensure conformance with and incorporation into the Department's Standard Operating System, Procedure No. 025-020-002.

The final revisions and addenda will be distributed to District Pavement Design Engineers and copies provided to Maps and Publications. The date of the latest revision will be posted on the Pavement Management Section and the Maps and Publications Internet Web Pages.

http://www.fdot.gov/publications/publications.shtm

1.8 TRAINING

No mandatory training is required by this procedure. Classes on the manual are available on request by the District Pavement Design Engineer.

1.9 FORMS

No forms are required by this procedure.

CHAPTER 2
DEFINITIONS

2.1 PAVEMENT SYSTEM

The following define the general pavement layers in a flexible pavement system. Some of the most important layers are shown in ***Figure 2.1***. The definitions are presented "top-down" through the pavement structure with the stronger layers on top of the weaker layers.

The concept of stronger layers on top of weaker layers, as load stresses are spread out and down through the pavement, is further supported by the horizontal extension of weaker layers beyond stronger layers in a pyramidal effect (see ***Figure 2.1***). Standard Department practice is to extend the base 4 inches beyond the edge of the structural course. This is very important when dealing with granular materials. Without this support, vehicle loads would cause failure along the pavement edge.

The pavement structure or system as it is sometimes referred to, is the pavement layers designed to support traffic loads and distribute them to the roadbed soil or select embankment material.

Friction Course

The friction course is the uppermost pavement layer and is designed to provide a skid resistant surface. The following friction courses are used by the Department:

- Friction Courses FC-9.5 and FC-12.5 are dense-graded mixes
- Friction Courses FC-5 and FC-7 are open-graded mixes
- High Friction Surface Treatment (HFST) is a safety treatment used to restore and provide additional pavement friction

Additional details on friction courses are included in ***Chapter 4***.

Structural Course

The structural course is designed to distribute the traffic loadings to the base course. The following structural courses are used by the Department:

- Structural Course Type SP-9.5 uses a 3/8-inch nominal maximum size aggregate.

- Structural Course Type SP-12.5 uses a 1/2-inch nominal maximum size aggregate.
- Structural Course Type SP-19.0 uses a 3/4-inch nominal maximum size aggregate.

Old Mixes

Types S-I, S-II, S-III, FC-1, FC-2, FC-3, FC-4, FC-6, Type I, II and III Asphaltic Concrete, Binder, and Asphaltic Concrete base mixes will occasionally be encountered on rehabilitation projects but are no longer designed by the Department.

Overbuild Course

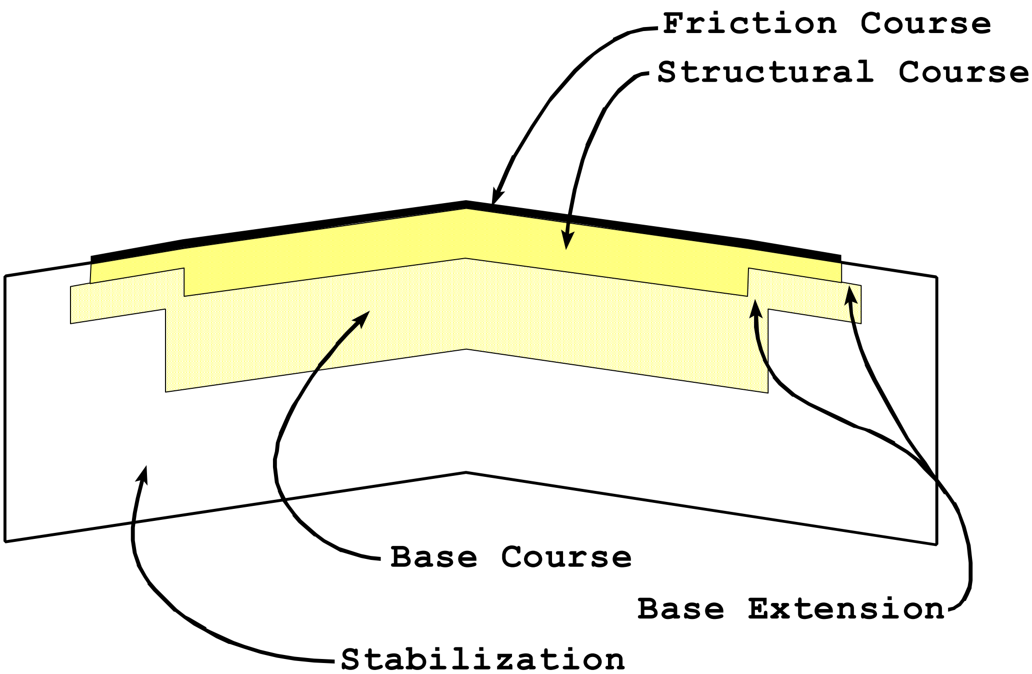
The Overbuild Courses are used for longitudinal profile and cross-slope correction.

Base Course

The base course is a course (or courses) of specified material and design thickness, which supports the structural course and distributes the traffic loads to the subbase or subgrade.

Different base course materials that may have different thickness, but are structurally equivalent, are grouped together to form an optional base group. More detailed information can be found in ***Chapter 5*** of this manual (***Tables 5.6*** and ***5.7***), or in the Specifications.

FIGURE 2.1
ROADWAY TYPICAL SECTION



Composite Base

The composite base is a combined granular subbase and asphalt Type B-12.5 that together are bid as an Optional Base Material.

Subbase

The subbase is a layer of specified material and design thickness that supports the base. This generally is limited to use with a Composite Base.

Stabilized Subgrade

The stabilized subgrade is a structural layer that is 12 inches thick. This structural layer serves as a working platform to permit the efficient construction of the base material. It is generally bid as Type B Stabilization (LBR-40) with the contractor selecting the approved materials necessary to achieve the LBR 40 value.

Roadbed Soil

The roadbed soil is the natural (in-situ) materials or embankment upon which the Pavement Structure is constructed.

2.2 AASHTO DESIGN EQUATION

The following definitions relate to the AASHTO Design Equation used for calculating pavement thickness.

2.2.1 VARIABLES

Accumulated 18-kip Equivalent Single Axle Loads ESAL or $ESAL_D$

The Accumulated 18-kip Equivalent Single Axle Loads (ESAL) is the traffic load information used for pavement thickness design. The accumulation of the damage caused by mixed truck traffic during a design period is referred to as the $ESAL_D$.

Traffic Levels

The following are the Traffic Levels for the Design Equivalent Single Axle Loads ($ESAL_D$) ranges for Superpave Asphalt Concrete Structural Courses. It should be noted that previous versions of this Manual included traffic levels A and D. Based on experience, it was determined that the following traffic levels could be combined: Traffic Level A is now combined with B, and Traffic Level D is now combined with E.

AASHTO DESIGN $ESAL_D$ RANGE (MILLION)	TRAFFIC LEVEL
0 to < 3	B
3 to < 10	C
≥ 10	E

Resilient Modulus (M_R)

The Resilient Modulus (M_R) is a measurement of the stiffness of the roadbed soil.

Reliability (%R)

The use of Reliability (%R) permits the Pavement Design Engineer to tailor the design to more closely match the needs of the project. It is the probability of achieving the design life that the Department desires for that facility. The reliability value replaces the safety factor that was previously imbedded in the Soil Support Value. As such, a single Reliability (%R) should be selected for an entire project, even if the project includes both widening and resurfacing. There may be project-specific cases where two different Reliabilities (%R) are necessary within the same project (e.g., different facility types within a single project). These cases should be justified and documented in the Pavement Design Package.

The Pavement Design Engineer is cautioned, however, that a high reliability value may increase the asphalt thickness substantially. The models are based on serviceability and not a specific failure mechanism, such as rutting.

Recommended values range from 75% to 99% and can be found in ***Table 5.2***. It is important to note that this is not a direct input into the AASHTO Design Equation. The use of a converted value known as the Standard Normal Deviate (Z_R) is input into the equation.

Standard Normal Deviate (Z_R)

The Standard Normal Deviate (Z_R) is the corresponding Reliability (%R) value that has been converted into logarithmic form for calculation purposes.

2.2.2 CONSTANTS

Standard Deviation (S_O)

The Standard Deviation (S_O) of 0.45 is used in the design calculations to account for variability in traffic load predictions and construction.

Present Serviceability Index (PSI)

The Present Serviceability Index (PSI) is the ability of a roadway to serve the traffic which uses the facility. A rating of 0 to 5 is used with 5 being the best and 0 being the worst. As road condition decreases due to deterioration, the PSI decreases.

Initial Serviceability (P_I)

The Initial Serviceability (P_I) is the condition of a newly constructed roadway. A value of 4.2 is assumed.

Terminal Serviceability (P_T)

The Terminal Serviceability (P_T) is the condition of a road that reaches a point where some type of rehabilitation or reconstruction is warranted. A value of 2.5 is generally assumed.

Change In Serviceability (ΔPSI)

The Change in Serviceability (ΔPSI) is the difference between the Initial Serviceability (P_I) and Terminal Serviceability (P_T). The Department uses a value of 1.7.

2.2.3 UNKNOWNS

Required Structural Number (SN_R)

The Required Structural Number (SN_R) is a weighted thickness in inches calculated from traffic load information and roadbed soil stiffness, representing the required strength of the pavement structure.

2.3 TERMS

The following terms will be used to describe the Department's design options.

New Construction

New construction is the complete development of a pavement system on a new alignment.

Reconstruction

Reconstruction is the complete removal of the friction course, structural course, and base layers along the existing alignment. Some lane additions or alignment changes may occur resulting in the design of additional subgrade.

Resurfacing

Entails improvement to the structural condition of existing pavement.

Milling

Milling is the controlled removal of existing asphalt pavement by using a rotating drum with teeth which removes the existing material to the desired depth or cross slope.

Pavement Only Projects

Pavement Only Projects (POP) are resurfacing projects that are not on the high crash list and that have been determined not to need an increase in structural capacity to achieve the required minimum pavement design life. See ***Section 7.8.5*** for additional information on POPs. POPs are also known as “Maintenance Resurfacing Projects,” and they are completely state-funded. Refer to ***Part III, Chapter 26, Resurfacing***, of the ***FDOT Work Program Instructions*** for further information on funding of resurfacing projects.

Operational Type Projects

Operational Type Projects are projects approximately 1000 feet or less that are relatively small such as turn lanes, radius improvements, culvert, replacement, skid hazard, etc.

Overlay

Overlay is the placement of additional layers of asphalt pavement to remedy functional or structural deficiencies of existing pavement, and may or may not include milling.

Widening

Widening includes trench widening, lane addition, and operational type projects. This type of design does not require thickness design calculations, unless there are special design considerations as directed by the District Pavement Design Engineer.

Asphalt Membrane Interlayer (AMI)

A reflective crack treatment using a modified asphalt spray application and cover aggregate. Cover aggregate normally consists of No.6 stone, slag or gravel, so a layer thickness of 0.5-inch may be used. No prime or tack coat is required over the cover aggregate prior to overlaying with initial asphalt lift. AMI is placed beneath the overlay to resist the stress/strain of reflective cracks and delay the propagation of the cracks through the new overlay. An AMI layer has no structural value.

Shared Use Path

A paved facility physically separated from motorized vehicular traffic by an open space or barrier. May be within the highway right of way or an independent right of way, with minimal cross flow by motor vehicles. Users are non-motorized and may include: pedestrians, bicyclists, skaters, people with disabilities, and others.

CHAPTER 3
PAVEMENT THICKNESS DESIGN PROCESS

3.1 DESIGN SOURCE

The American Association of State Highway Officials (AASHO) Road Test at Ottawa, Illinois provided the basis for calculating the required pavement thickness. Models were developed that related pavement performance, vehicle loadings, strength of roadbed soils, and the pavement structure. ***Figure 3.1*** is the AASHTO Equation used by the Department for design purposes.

The purpose of the AASHTO model in the pavement thickness design process is to calculate the Required Structural Number (SN_R). This is the strength of the pavement that must be constructed to carry the mixed vehicle loads over the roadbed soil, while providing satisfactory serviceability during the design period. Knowing the SN_R, the pavement layer thickness or overlay thickness can be calculated. ***Figure 3.2*** illustrates the processes.

Vehicle loads are expressed in 18-kip Equivalent Single Axle Loads (ESAL's). This information is normally generated by the District Planning Office and is found in the Project Traffic Forecasting Procedure (Topic No. 525-030-120) using the Project Traffic Forecasting Handbook. A simple procedure for estimating 18-kip ESAL's is given in ***Appendix D***. The summation of the 18-kip ESAL's during the design period is referred to as $ESAL_D$.

FIGURE 3.1
AASHTO DESIGN EQUATION FOR FLEXIBLE PAVEMENT

$$\log_{10} W_{18} = Z_R * S_O + 9.36 * \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 * \log_{10}(M_R) - 8.07$$

FIGURE 3.2
AASHTO DESIGN EQUATION INPUT FOR FLEXIBLE PAVEMENT

The unknown to be determined is:

SN_R = Structural Number Required (inches)

The input includes the variables:

W_{18} = Accumulated 18-kip Equivalent Single Axle Loads over the life of the project (18-kip) ESAL.

Z_R = Standard Normal Deviate

M_R = Resilient Modulus (psi)

The input includes the constants:

S_O = Standard Deviation

ΔPSI = Change In Serviceability (1.7 is the Department value used)

FIGURE 3.3
FLEXIBLE PAVEMENT DESIGN VARIABLES

SN_R = ($ESAL_D$, M_R, %R)

<u>For New Construction:</u>

$SN_C = SN_R$

<u>Overlay With and Without Milling:</u>

$SN_O = SN_R - SN_E$

Where:

$ESAL_D$ = Accumulated 18-kip Equivalent Single Axle Loads over the life of the project (18-kip ESAL)

SN_R = Structural number determined as a function of $ESAL_D$, Resilient Modulus (M_R) and the Reliability (%R)

SN_C = Structural number of the proposed structural layers in a newly constructed pavement

SN_O = Structural number of the structural layers needed in the overlay

SN_E = Structural number of the existing pavement structure after any milling

3.2 DESIGN PERIODS

The design periods that will be used for flexible pavement design vary from 8 years to 20 years based on the type of construction proposed. The Pavement Design Engineer can adjust the design period within guidelines based on project-specific conditions and constraints. These Design Period guidelines are summarized in ***Table 3.1***.

3.3 DISTRICT COORDINATION

Early in the design process, the Pavement Design Engineer should closely coordinate with the following offices:

District Design

The District Design Office should be involved in providing the proposed roadway typical section sheets for such information as: pavement widening, design speed, expected posted speed, a change in design speed occurring within project limits, side street work, and other related information required for the typical section package according to the ***FDOT Design Manual***.

District Drainage

The District Drainage Office (DDO) should be involved to determine the Design High Water (DHW) applicable to each new construction and reconstruction project for base clearance considerations. The DDO should determine if there are any special drainage considerations, such as a high water table condition that is affecting pavement performance and needs correcting. Another example would be the impact that additional asphalt overlay thickness would have on the drainage performance of the curb and gutter.

District Construction

The District Construction Office should be involved to determine if there is any specific information that needs to be included in the plans, such as special construction details, or issues that need to be addressed with regard to constructability and construction time. Some of these items may include base type, stabilization, temporary traffic control plans, construction time, etc.

District Materials

The District Materials Office should be involved to determine the availability of suitable materials in the construction area and any other special conditions that may exist. The District Materials Office can also provide recommendations with respect to stabilizing, milling, cross slope correction, and existing pavement condition.

Additional coordination of project field reviews and data collection might be needed. The latest Pavement Evaluation Coring and Condition Data (Form No. 675-030-09) can be obtained from the District Materials Office.

3.4 QUALITY

The Quality Control of a pavement's design is the District’s responsibility. A written Pavement Design Quality Control Plan should be maintained by the district. Upon completion of the design process, an independent design review needs to be performed by a responsible Professional Engineer other than the original pavement design engineer. A suggested Pavement Design Quality Control Plan is provided in ***Appendix B***.

3.5 GUIDELINES FOR DESIGN-BUILD PROJECTS

The complete pavement design package as part of the design criteria for Design-Build projects may be provided by the Department if sufficient data is available. If the pavement design is not provided by the Department, project-specific pavement design criteria should be provided as part of the Request for Proposal/Design Criteria Package to assure a reasonable pavement design is provided by all competing Design-Build teams.

The project-specific pavement design criteria may include the minimum ESALs, minimum design reliability, roadbed resilient modulus, minimum structural asphalt thickness and whether or not modified asphalt binder should be used in the structural layer(s). For resurfacing designs, a minimum milling depth and whether a crack relief layer is required may be included in the criteria. The Pavement Evaluation Coring and Condition Data will normally be provided with the criteria. In addition to project-specific criteria, all standard requirements of the Department's pavement design manuals are to be followed.

TABLE 3.1
DESIGN PERIODS

Use The Following Design Periods For Flexible Pavement Designs:

New Construction or Reconstruction	20 Years
Pavement Overlay without Milling	15 to 20 Years
Pavement Overlay with Milling	
Limited Access	15 to 20 Years*
Non-Limited Access	15 to 20 Years*
Pavement Overlay of Rigid Pavement	8 to 12 Years

Notes

* Shorter design periods can be used if there are constraints such as curb and gutter or scheduled future capacity projects that justify limiting overlay thickness. These reasons should be documented in the pavement design package.

CHAPTER 4
FRICTION COURSE POLICY

4.1 FRICTION COURSE TYPES

The standard types of friction courses used by the Department are dense-graded friction courses, DGFCs (FC-9.5 & FC-12.5), and open-graded friction courses, OGFCs (FC-5 & FC-7). Their thickness is shown in the plans on the Typical Section Sheets and are quantified by the ton.

The individual layer thickness (lift thickness) are typically within the following ranges:

Type Mix	Minimum	Maximum
FC-9.5 [1]	1”	1.5”
FC-12.5	1.5”	2”
FC-5 & FC-7	0.75”	1” [2]

Notes:
1. Do not place FC-9.5 less than 1.5” thick for Traffic Level E applications.
2. FC-5 may be placed at 1” thickness for FC-5 Only Resurfacing Projects.

For friction course thicknesses outside the ranges noted above, coordinate with the District Pavement Design Engineer. Consideration of desirable smoothness is the primary factor in this decision. Thicker lifts of asphalt are more challenging to achieve a high degree of smoothness during construction. It is desirable for the surface layer (friction course) to be as smooth as possible, and this is why the above thicknesses are recommended for designing the friction course.

Place a friction course on all roads and ramps with a design speed of 35 mph or higher, except for low volume two lane roads having a five-year projected AADT from the opening year of 3,000 vehicles per day or less.

4.2 FRICTION COURSE POLICY

Use FC-5 on all Limited Access mainline roadways, regardless of design speed.

Use an OGFC (FC-5 or FC-7) on multi-lane flush shoulder arterials and collectors with a design speed of 55 mph or greater.

Use a DGFC (FC-12.5 or FC-9.5) on all other flush shoulder or curbed roadways. However, if there is a history of wet-weather crashes on a multilane curbed roadway with design speeds ≥ 55 mph, an OGFC should be considered. ***Table 4.1*** summarizes these requirements.

TABLE 4.1
FRICTION COURSE POLICY

<table>
<tr><th>Design Speed (mph)</th><th>Two Lane</th><th>Multilane</th></tr>
<tr><th colspan="3">Limited Access Mainline Roadways</th></tr>
<tr><td>All</td><td>FC-5</td><td>FC-5</td></tr>
<tr><th colspan="3">Arterial and Collector Flush Shoulder Roadways</th></tr>
<tr><td>≤ 50</td><td rowspan="2">FC-12.5 or FC-9.5</td><td>FC-12.5 or FC-9.5</td></tr>
<tr><td>≥ 55</td><td>FC-5 or FC-7</td></tr>
<tr><th colspan="3">Arterial and Collector Curbed Roadways</th></tr>
<tr><td>All</td><td>FC-12.5 or FC-9.5</td><td>FC-12.5 or FC-9.5</td></tr>
<tr><td colspan="3">NOTES:
1. Include a friction course on all roads and ramps with a design speed ≥ 35 mph, except for two lane roads having a five-year projected AADT (from the opening year) of 3,000 vehicles per day or less.
2. An OGFC should be considered for multilane curbed roadways with design speeds ≥ 55 mph when there is a history of wet weather crashes.
3. Coordinate with the District Pavement Design Engineer to determine the appropriate friction course to use on limited access ramps. See Section 4.3 for additional information.</td></tr>
</table>

4.3 FRICTION COURSE ON RAMPS

Coordinate with the District Pavement Design Engineer to determine the appropriate friction course to use on limited access ramps. The type of friction course used must be evaluated for long term maintenance, surface drainage, existing crash patterns, and pavement structural value.

- DGFC is typically used on ramps with heavy volumes of truck traffic and/or turning and stopping movements.

- FC-5 is typically only used on high speed ramps with long tangent sections and/or large radii (e.g., a ramp connecting two limited access facilities).

4.4 DENSE-GRADED FRICTION COURSES

FC-12.5 and FC-9.5 provide smooth riding surfaces with good pavement friction. They are considered as both a structural and friction course.

FC-9.5 will allow a 1-inch lift of friction course. On some projects, this thinner lift may allow room for an additional structural or overbuild lift, as in some curb and gutter sections, without milling into the base or overlaying friction course into the gutter.

4.5 OPEN-GRADED FRICTION COURSES

FC-5 and FC-7 provide a skid resistant surface that allows for the rapid removal of water from between the tire and the pavement, reducing the potential for hydroplaning at higher speeds.

The main difference between FC-5 and FC-7 is the aggregate size and gradation used in the mix. FC-5 uses slightly larger aggregate with more of a coarse gradation, which provides a high amount of drainability and permeability, with adequate durability. FC-7 uses a slightly smaller aggregate, and a finer gradation, which results in adequate drainability and permeability, and higher durability.

Both OGFC mixes provide good drainability and permeability for wet conditions. Based on their different aggregate sizes and gradations, FC-5 will provide slightly better drainability and permeability, while FC-7 will provide slightly better durability.

FC-7 may be an ideal friction course type for higher-speed flush shoulder arterials that require an OGFC and have multiple and/or closely spaced intersections. The additional durability of the mix should have better long-term performance in areas of stopping and turning movements than FC-5.

The following are some of the limitations on the use of OGFC:

- **<u>On all roads that require an OGFC:</u>**
  - OGFCs should not be overlaid (due to its potential to allow water into the pavement system) except when approved by the District Materials Engineer.

- OGFCs should not sit after construction for more than four (4) months before being opened to traffic. If necessary, the OGFC may need to be let under a separate contract.
- OGFCs may be placed directly on the milled surface provided the underlying layers are in good structural shape.

- **On multi-lane non-limited access facilities:**
  - OGFC typically covers the deceleration areas of turn lanes. This is illustrated in ***Figure 4.1***.
  - OGFC is not to be placed in median openings, turn outs, or gore areas on these facilities. This is illustrated in ***Figures 4.1*** and ***4.2***.
  - OGFC is to be placed over the entire paved shoulder.
  - OGFC should not be placed in the turning area of signalized intersections, as shown in ***Figure 4.3***. An exception to this is where both of the intersecting roads qualify for OGFC, then the entire intersection should use OGFC.

- **On limited access facilities:**
  - FC-5 is to extend 8-inches beyond the edge of the travel lane, onto the paved shoulder.
  - FC-5 is not to be placed in median crossovers or gore areas.
  - To minimize raveling/deterioration due to pavement sawcuts, FC-5 is not required on flexible pavement within proposed Toll facilities that utilize electronic data collection requiring loop installation in the pavement surface. ***Chapter 221*** (in ***Part 2***) of the Florida's Turnpike Enterprise's ***General Tolling Requirements*** (***GTR***) provides additional details for pavement design requirements near Toll facilities.

FIGURE 4.1
TYPICAL LIMITS OF OGFC
FOR MULTI-LANE NON-LIMITED ACCESS FACILITIES
NON-SIGNALIZED INTERSECTION/MEDIAN OPENING

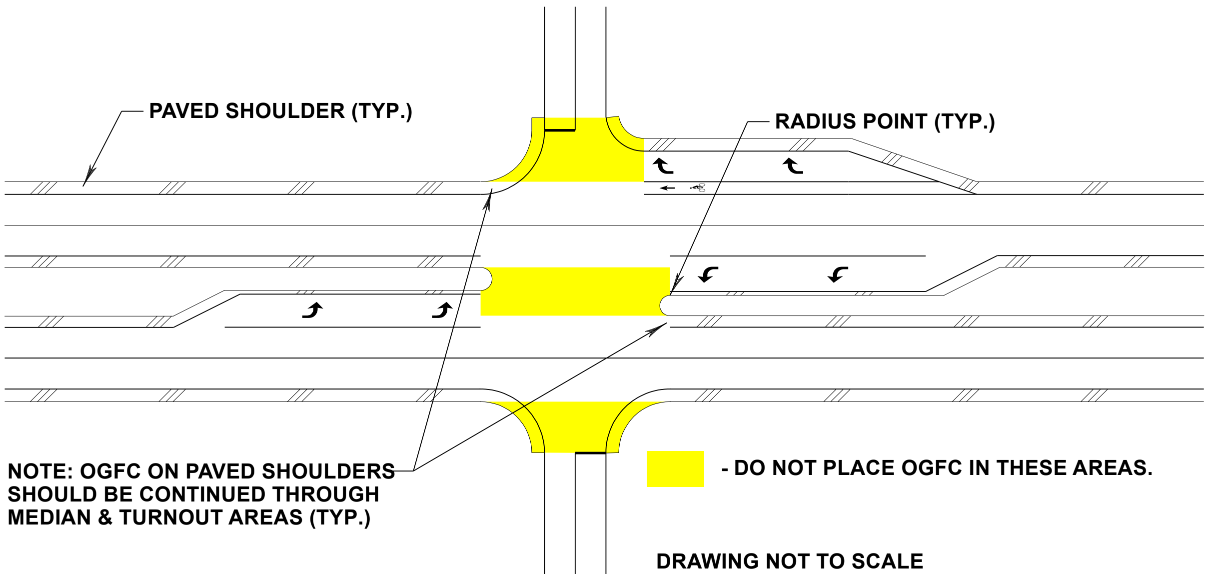


FIGURE 4.2
TYPICAL LIMITS OF OGFC
FOR MULTI-LANE NON-LIMITED ACCESS FACILITIES
MEDIAN OPENING (NO TURN LANES)

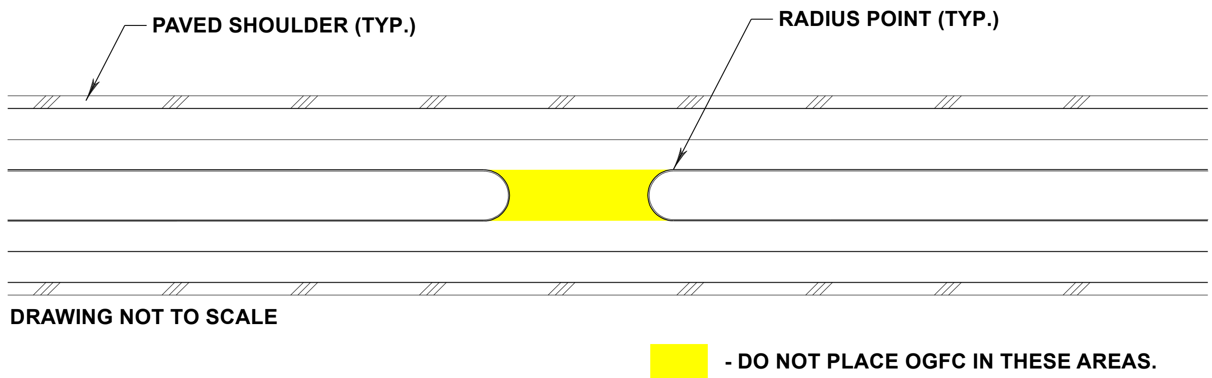
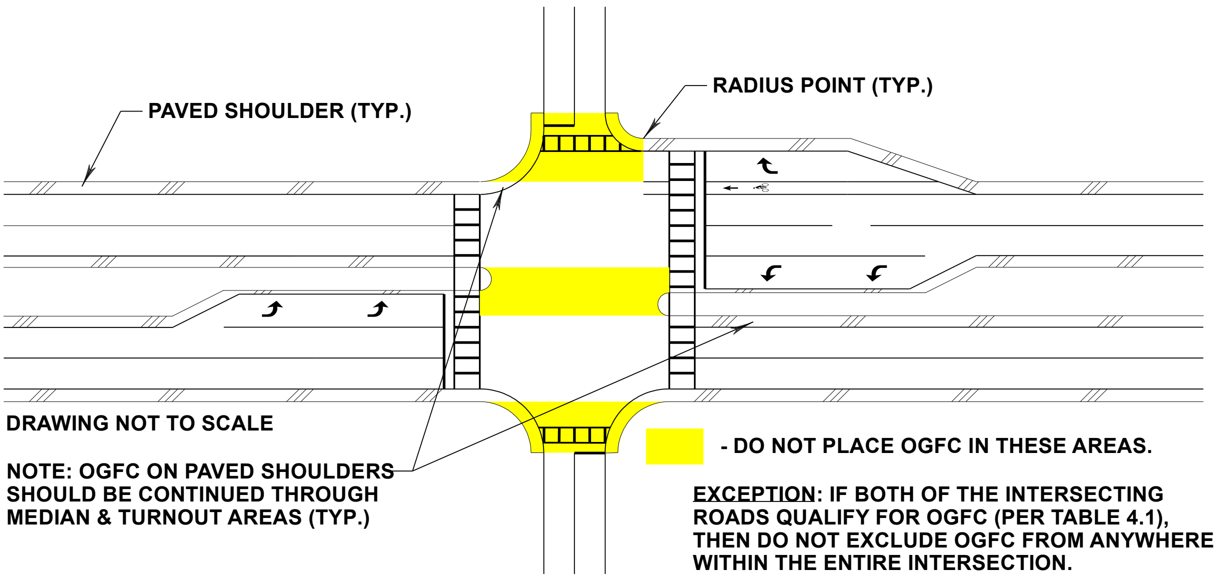


FIGURE 4.3
TYPICAL LIMITS OF OGFC
FOR MULTI-LANE NON-LIMITED ACCESS FACILITIES
SIGNALIZED INTERSECTION



4.6 HIGH FRICTION SURFACE TREATMENT

High Friction Surface Treatment (HFST) is a safety treatment used to restore and provide additional pavement friction to reduce crashes. It is a thin layer of high-quality polish-resistant aggregate bonded to the pavement surface with polymer resin binder, specified in ***FDOT Developmental Specification, Section 333 (Dev333HFST)***.

HFST is only used as a mitigation strategy for identified safety issues specific to pavement friction on existing facilities. Its use must be coordinated with the State Pavement Materials Engineer at the State Materials Office.

When a location requires mitigation, the priority should be to correct the substandard condition to meet applicable design criteria. If there are justifiable reasons why the correction cannot be made and other mitigation strategies have been ruled out, then HFST could be considered.

Additional guidance on site selection, materials, and construction of HFST can be found in the ***High Friction Surface Treatment Guidelines***, published by the State Materials Office, and also on the ***FHWA HFST website***.

CHAPTER 5
PAVEMENT THICKNESS DESIGN PROCESS FOR NEW CONSTRUCTION OR RECONSTRUCTION

5.1 OVERVIEW

This process is applicable to new construction or total reconstruction projects in Florida where the Pavement Design Engineer must calculate the pavement layer thickness using the AASHTO Procedure.

For new lane additions, short pavement sections (approximately 1,000 feet or less) such as bridge replacement, crossroads, short turnouts, etc., the principles provided in ***Chapter 6*** of this manual shall apply.

5.2 REQUIRED STRUCTURAL NUMBER (SN_R) CALCULATIONS USING THE AASHTO DESIGN GUIDE

The following is a summary of the steps to be taken to solve for the Required Structural Number (SN_R):

- The 18-kip Equivalent Single Axle Loads 18-kip ESAL's are obtained from the District Planning Office. This process can be found in the Project Traffic Forecasting Handbook Procedure (Topic No. 525-030-120) using the Project Traffic Forecasting Handbook. ***Appendix D*** provides a simple procedure for calculating the accumulated 18-kip ESAL's or $ESAL_D$ for the appropriate design period.
- The Resilient Modulus (M_R) used to characterize the strength of the roadbed soil is obtained from the State Materials Office, through the District Materials Office using direct resilient modulus laboratory testing. As an alternative for low volume roads, the Design Limerock Bearing Ratio (LBR) value which is based on 90% of the anticipated LBR's exceeding the Design LBR is discussed in ***Section 5.2.4***. The relationship between the Design LBR and Resilient Modulus (M_R) sample values are shown in ***Table 5.1***.
- A safety factor is applied using a Reliability (%R) value from ***Table 5.2***. Recommended values range from 75% to 99%. A Standard Deviation (S_O) of 0.45 is used in the calculation. The Standard Normal Deviate (Z_R) is dependent on the Reliability (%R).

Using these values, the Pavement Design Engineer will calculate the Structural Number Required (SN_R) using the design tables in ***Appendix A***.

Each design table uses a different Reliability (%R) and relates Design 18-kip Equivalent Single Axle Loads ($ESAL_D$) to the Structural Number Required (SN_R) for multiple Resilient Modulus (M_R) values. ***Table 5.3*** provides an example of an FDOT design table.

5.2.1 DESIGN EXAMPLE

The following is an example illustrating the mechanics of this procedure. Using the following input for New Construction of an Urban Arterial:

$ESAL_D$ = 4,900,000 (from the Planning Office)

Use 5,000,000

M_R = 14,000 psi (from the State Materials Office)

%R = 80 to 90 (choose %R = 90 from ***Table 5.2***)

Design 18-kip Equivalent Single Axle Loads ($ESAL_D$) and Resilient Modulus (M_R) values can generally be rounded up or down to the nearest table values. Final thickness designs are to the nearest 0.5-inch of structural course for new construction. If desired, an interpolated SN_R value can be used. The solution is:

SN_R = 3.57-inch (from ***Table 5.3***)

5.2.2 DESIGN BASE HIGHWATER CLEARANCE

Base clearance above high water is critical for good pavement performance and to achieve the required compaction and stability during construction operations. (Dr. Ping - "Design Highwater Clearances for Highway Pavements" research report BD543-13).

The laboratory Design Resilient Modulus obtained from the State Materials Office is based on optimum moisture content conditions which correspond to a 3-feet base clearance.

In addition to thicker pavement structure for 1-foot base clearance, significant construction problems are also likely and additional costs such as dewatering may be required to achieve compaction.

When the base clearance is less than 3-feet, the pavement designer must reduce the Design Resilient Modulus as follows:

For 2-feet Base Clearance, a 25% modulus reduction

For 1-foot Base Clearance, a 50% modulus reduction

These reductions are not to be misconstrued as having a linear relationship with the base clearance itself. Findings of FDOT Project Number BDX86 "Methods to Predict Seasonal High Ground Water Table (SHGWT) have confirmed that there is not enough confidence in reducing Resilient Modulus at any closer intervals than 1-foot. To do so would be outside the accuracy of any estimated value of SHGWT.

The pavement design engineer has the discretion to attempt refinement beyond these limits by using monitoring wells, and performing a more comprehensive soil analysis than is currently standard, where assurance can be reached that the particular soil types in the project limits are homogenous.

It is recommended that in high ground water situations, the District Geotechnical Engineer, the District Drainage Engineer, and the State Geotechnical Materials Engineer (at the State Materials Office (SMO)) be consulted.

Note: Refer to ***Section 5.6.2*** for further guidance on high-water clearance and base design considerations.

5.2.3 LABORATORY RESILIENT MODULUS (M_R)

The Design Resilient Modulus (M_R) is determined by the SMO directly from laboratory testing (AASHTO T 307) for new construction and reconstruction projects based on instructions in ***FDOT Soils and Foundation Handbook***.

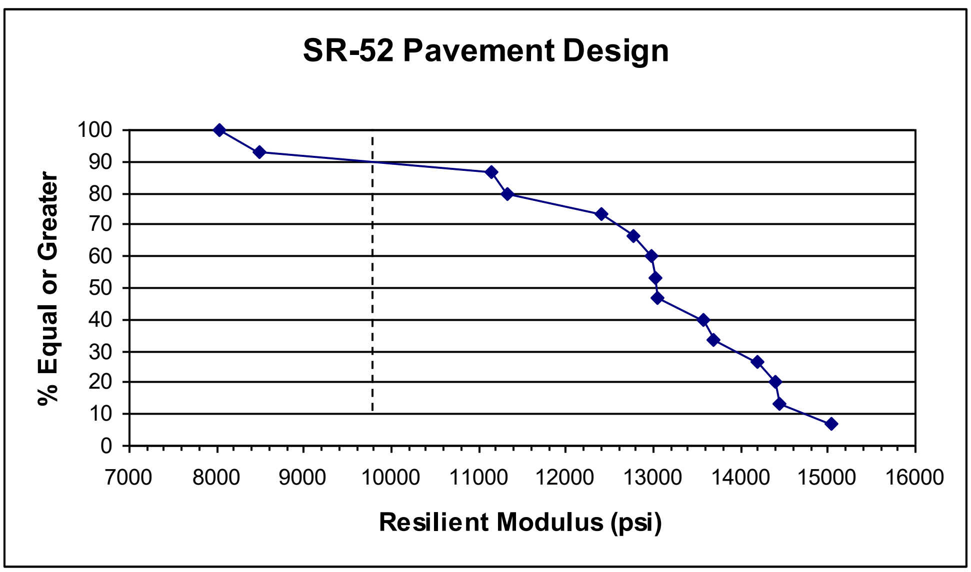
For new construction with substantial fill sections in excess of 3-feet, samples should be obtained from potential borrow areas to estimate the roadway embankment resilient modulus.

The following method (illustrated in ***Figure 5.1***) is generally applied by the SMO to the M_R test data to account for variability in materials and to provide for an optimum pavement design:

90% M_R Method - Resilient modulus values using AASHTO T 307 at 11 psi bulk stress are sorted into descending order. For each value, the percentage of values, which are equal to or greater than that value, is calculated. These percentages are plotted versus the M_R values. The M_R value corresponding to 90% is used as the design value. Thus, 90% of the individual tests results are equal to or greater than the design value.

Figure 5.1 – 90% M_R Method Illustration
Ranked M_R Test Results for 90% Method

Rank	Sample Location	≥%	M_R (psi)
1	337+98	100	8,030
2	254+90	93	8,477
3	289+80	87	11,148
4	56+07	80	11,335
5	41+98	73	12,399
6	242+00	67	12,765
7	321+92	60	12,976
8	600+00	53	13,025
9	225+00	47	13,039
10	272+99	40	13,565
11	615+43	33	13,682
12	211+98	27	14,190
13	307+04	20	14,398
14	584+66	13	14,449
15	273+99	7	15,031



Based on the results shown, the resilient modulus corresponding to a 90th percentile is 9,800 psi.

5.2.4 RESILIENT MODULUS (M_R) FROM LBR

The roadbed soil resilient modulus, M_R can be estimated from the Limerock Bearing Ratio (LBR) value by the following equation.

$$\boldsymbol{M_R(PSI) = 10^{[0.7365*\log(LBR)]} * 809}$$

This equation combines equation SSV = 4.596 * Log (LBR) - 0.576 developed by Dr. Robert Ho of the State Materials Office (2/2/93 memo to Lofroos) that relates LBR to soil support value (SSV) and equation FF.3: SSV= 6.24 * Log (M_R) – 18.72 from the Appendix FF, Volume 2 of the AASHTO Guide for Design of Pavement Structures, that relates M_R to SSV.

Due to the approximate relationship of LBR to M_R, a Design LBR greater than 40 should not be recommended or used to estimate the Design M_R.

If a Design LBR or M_R Value is not available from the District Materials Office, and a series of LBR values are provided, the Pavement Design Engineer may select a Design LBR Value (not to exceed a maximum of 40 LBR) based on the 90th percentile methodology. The following simple analysis is provided as an example.

GIVEN:

The following illustrates the mechanics of calculating the Resilient Modulus (M_R) obtained from a set of LBR data.

DATA:

The following field data has been provided:

Sample Number	LBR Values In Ascending Order
1	22
2	22
3	23
4	24
5	24
6	24
7	25
8	25
9	25
10	26
11	26
12	27
13	27
14	40

SOLUTION:

Sample No. 14 is considered an outlier by inspection and should be eliminated. It is satisfactory to drop a high number as in this example, but care should be taken before dropping a low number, because it may indicate a localized weak spot, that may require special treatment.

This results in 13 good samples.

13 x 90% = 11.7 (Use 12)

Count back 12 samples starting with Sample Number 13 to Sample Number 1:

Use LBR = 22.

CONCLUSION:

90% meet or exceed the Design LBR = 22.

The Pavement Design Engineer can now convert the Design LBR Value to a Resilient Modulus (M_R) using ***Table 5.1***. Therefore: M_R = 8,000 psi

TABLE 5.1

RELATIONSHIP BETWEEN RESILIENT MODULUS (M_R) AND LIMEROCK BEARING RATIO (LBR) SAMPLE VALUES

The following are some Limerock Bearing Ratio (LBR) input values that were input into these equations to obtain Resilient Modulus (M_R) values.

Limerock Bearing Ratio (LBR)	Resilient Modulus (PSI)
10	4,500
12	5,000
14	5,500
16	6,000
18	7,000
20	7,500
22	8,000
24	8,500
26	9,000
28	9,500
30	10,000
32	10,500
34	11,000
36	11,500
38	12,000
40	12,000

TABLE 5.2

RELIABILITY (%R) FOR DIFFERENT ROADWAY FACILITIES

Facility	New	Rehabilitation
Limited Access	80 – 95	95 – 99
Urban Arterials	80 – 90	90 – 97
Rural Arterials	75 – 90	90 – 95
Collectors	75 – 80	90 – 95

Notes

- The type of roadway is determined by the Transportation Statistics Office and can be obtained from the Roadway Characteristics Inventory (RCI).
- The designer has some flexibility in selecting values that best fit the project when choosing the Reliability (%R).
- Considerations for selecting a reliability level include projected traffic volumes and the consequences involved with early rehabilitation, if actual traffic loadings are greater than anticipated. A detailed discussion of reliability concepts can be found in the AASHTO Guide For Design Of Pavement Structures.

TABLE 5.3 - Example Design Table (From Appendix A, Table A.4A)

REQUIRED STRUCTURAL NUMBER (SN_R)
90% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	3.02	2.77	2.59	2.44	2.31	2.21	2.12	2.04	1.97	1.91	1.86	1.81	1.76	1.72	1.68
150,000	3.23	2.97	2.77	2.61	2.47	2.36	2.27	2.19	2.11	2.05	1.99	1.94	1.89	1.84	1.80
200,000	3.39	3.11	2.90	2.73	2.60	2.48	2.38	2.30	2.22	2.15	2.09	2.03	1.98	1.94	1.89
250,000	3.52	3.23	3.01	2.84	2.69	2.57	2.47	2.38	2.30	2.23	2.17	2.11	2.06	2.01	1.97
300,000	3.62	3.33	3.10	2.92	2.78	2.65	2.55	2.46	2.37	2.30	2.24	2.18	2.12	2.07	2.03
350,000	3.71	3.41	3.18	3.00	2.85	2.72	2.61	2.52	2.44	2.36	2.30	2.23	2.18	2.13	2.08
400,000	3.79	3.49	3.25	3.07	2.91	2.78	2.67	2.58	2.49	2.42	2.35	2.29	2.23	2.18	2.13
450,000	3.87	3.56	3.32	3.13	2.97	2.84	2.73	2.63	2.54	2.46	2.39	2.33	2.27	2.22	2.17
500,000	3.93	3.62	3.38	3.18	3.02	2.89	2.77	2.67	2.59	2.51	2.44	2.37	2.31	2.26	2.21
600,000	4.05	3.73	3.48	3.28	3.12	2.98	2.86	2.76	2.67	2.58	2.51	2.45	2.39	2.33	2.28
700,000	4.14	3.82	3.57	3.36	3.20	3.05	2.93	2.83	2.73	2.65	2.58	2.51	2.45	2.39	2.34
800,000	4.23	3.90	3.64	3.44	3.27	3.12	3.00	2.89	2.80	2.71	2.63	2.57	2.50	2.44	2.39
900,000	4.31	3.97	3.71	3.51	3.33	3.18	3.06	2.95	2.85	2.76	2.69	2.62	2.55	2.49	2.44
1,000,000	4.38	4.04	3.78	3.57	3.39	3.24	3.11	3.00	2.90	2.81	2.73	2.66	2.60	2.54	2.48
1,500,000	4.65	4.30	4.03	3.81	3.62	3.46	3.33	3.21	3.10	3.01	2.92	2.85	2.78	2.71	2.65
2,000,000	4.85	4.50	4.21	3.99	3.79	3.63	3.49	3.36	3.25	3.16	3.07	2.99	2.91	2.85	2.78
2,500,000	5.01	4.65	4.36	4.13	3.93	3.76	3.62	3.49	3.38	3.27	3.18	3.10	3.02	2.95	2.89
3,000,000	5.14	4.77	4.48	4.25	4.05	3.88	3.73	3.60	3.48	3.37	3.28	3.19	3.12	3.04	2.98
3,500,000	5.25	4.88	4.59	4.35	4.14	3.97	3.82	3.69	3.57	3.46	3.36	3.28	3.20	3.12	3.06
4,000,000	5.35	4.98	4.68	4.44	4.23	4.06	3.90	3.77	3.65	3.54	3.44	3.35	3.27	3.19	3.12
4,500,000	5.44	5.06	4.76	4.52	4.31	4.13	3.98	3.84	3.72	3.61	3.51	3.42	3.33	3.26	3.19
5,000,000	5.52	5.14	4.83	4.59	4.38	4.20	4.04	3.90	3.78	3.67	3.57	3.47	3.39	3.31	3.24
6,000,000	5.66	5.27	4.96	4.71	4.50	4.32	4.16	4.02	3.89	3.78	3.67	3.58	3.49	3.41	3.34
7,000,000	5.78	5.38	5.07	4.82	4.61	4.42	4.26	4.12	3.99	3.87	3.77	3.67	3.58	3.50	3.43
8,000,000	5.88	5.48	5.17	4.91	4.70	4.51	4.35	4.20	4.07	3.95	3.85	3.75	3.66	3.58	3.50
9,000,000	5.97	5.57	5.26	5.00	4.78	4.59	4.43	4.28	4.15	4.03	3.92	3.82	3.73	3.65	3.57
10,000,000	6.06	5.65	5.33	5.07	4.85	4.66	4.50	4.35	4.22	4.10	3.99	3.89	3.79	3.71	3.63
15,000,000	6.39	5.97	5.64	5.37	5.14	4.95	4.77	4.62	4.48	4.36	4.25	4.14	4.05	3.96	3.88
20,000,000	6.63	6.20	5.86	5.59	5.35	5.15	4.98	4.82	4.68	4.55	4.44	4.33	4.23	4.14	4.06
25,000,000	6.82	6.38	6.04	5.76	5.52	5.32	5.14	4.98	4.84	4.71	4.59	4.48	4.38	4.29	4.20
30,000,000	6.98	6.53	6.18	5.90	5.66	5.45	5.27	5.11	4.96	4.83	4.71	4.60	4.50	4.41	4.32
35,000,000	7.12	6.66	6.31	6.02	5.78	5.57	5.38	5.22	5.07	4.94	4.82	4.71	4.61	4.51	4.42
40,000,000	7.24	6.78	6.42	6.13	5.88	5.67	5.48	5.32	5.17	5.04	4.91	4.80	4.70	4.60	4.51
45,000,000	7.34	6.88	6.52	6.22	5.97	5.76	5.57	5.41	5.26	5.12	5.00	4.88	4.78	4.68	4.59
50,000,000	7.44	6.97	6.61	6.31	6.06	5.84	5.65	5.49	5.34	5.20	5.07	4.96	4.85	4.76	4.66
60,000,000	7.61	7.13	6.76	6.46	6.21	5.99	5.79	5.62	5.47	5.33	5.21	5.09	4.98	4.88	4.79
70,000,000	7.76	7.27	6.90	6.59	6.33	6.11	5.91	5.74	5.59	5.45	5.32	5.20	5.09	4.99	4.90
80,000,000	7.88	7.40	7.01	6.70	6.44	6.22	6.02	5.85	5.69	5.55	5.42	5.30	5.19	5.09	4.99
90,000,000	8.00	7.51	7.12	6.80	6.54	6.31	6.11	5.94	5.78	5.64	5.51	5.39	5.28	5.17	5.08
100,000,000	8.10	7.60	7.21	6.90	6.63	6.40	6.20	6.02	5.86	5.72	5.59	5.47	5.35	5.25	5.15

5.3 LAYER THICKNESS CALCULATIONS FOR NEW CONSTRUCTION

Once the Required Structural Number (SN_R) has been determined, the individual pavement layer thickness can be calculated using the following equation:

$$SN_C = (a_1 \text{ x } D_1) + (a_2 \text{ x } D_2) + (a_3 \text{ x } D_3) + ...+ (a_N \text{ x } D_N)$$

where:

SN_C = The total calculated strength of the pavement layers and has units of inches.

a_1 = Layer coefficient of the 1st layer.

D_1 = Layer thickness in inches of the 1st layer.

Layer 1 is generally the friction course.

Layer 2 is generally the structural course.

Layer 3 is generally the base course.

Layer 4 is generally the stabilized subgrade.

a_N = Layer coefficient of the Nth layer.

D_N = Layer thickness in inches of the Nth layer.

Layer coefficients have been developed which represent the relative strength of different pavement materials in Florida. The values for these materials are given in ***Table 5.4***. The coefficients presented in this table are based on the best available data. Future adjustments will be made to these values by manual revisions should research or other information dictate.

Always design to the nearest 0.5-inch of structural course for new construction.

Optional Bases, which are combinations of material type, thickness, and equivalent strength, have been developed as shown in ***Tables 5.6*** and ***5.7*** (Notes provided in ***Table 5.8***). This permits the Department to bid Optional Base with the contractor selecting from the base materials shown on the Typical Section Sheet or from the ***Standard Specifications***. If only the Base Group Number is shown in the plans then Sheet 1 of 2 (***Table 5.6*** General Use Bases) is applicable. The Base Group Numbers (1 thru 15) are shown on the left of the sheet.

Each set of bases within a base group have equivalent strength. As an example, reading across Optional Base Group 6, 8-inches of Limerock (LBR 100) is equivalent to 5-inches of Asphalt Base in total structural number. Either Optional Base could be constructed to provide a base Structural Number within the structural range of 1.35 – 1.50 of this base group.

Note that there are restrictions placed on certain materials. For new construction, certain minimum thicknesses have been established. These minimums are based on the type of road and are shown in ***Table 5.5***.

Granular subbases are used as a component of a Composite Base. Subbase layer coefficients are set at 90% of the base coefficient.

To determine how much each layer (D_2 and D_3) will contribute, a balanced approach has been provided with the use of ***Table 5.9***. ***Table 5.9*** relates all optional bases with practical structural course thickness in 0.5-inch increments and provides a band of recommended base and structural course thickness. Note that the structural value provided by the stabilization is not included in the Combined Structural Number shown in ***Table 5.9***.

5.4 BINDER SELECTION ON THE BASIS OF TRAFFIC SPEED AND TRAFFIC LEVEL

By specification, the standard asphalt binder grade is a PG 67-22, which means the binder should be rut resistant up to temperatures of 67°C and crack resistant down to temperatures of -22°C.

When High Polymer binder is being considered for a project, coordinate this decision with the State Bituminous Materials Engineer's office at the SMO.

For open-graded friction course mixtures (FC-5 and FC-7), use PG 76-22 unless the underlying structural layer contains High Polymer. Use High Polymer in the open-graded friction course if the underlying structural layer contains High Polymer.

The Resilient Modulus (M_R) of asphalt concrete is less under a slow-moving load than under a more dynamic, high speed load. As a result of this effect, slow moving or stopped trucks have a greater potential to cause rutting. For situations with slow-moving or standing truck traffic, and particularly those sections with a history of rutting, use a PG 76-22 binder or use a High Polymer binder when recommended by the SMO.

High Polymer should only be used in travel lanes and turn lanes with slow-moving or standing truck traffic or a history of raveling, rutting, or severe cracking. When High Polymer is specified on a project, use PG 76-22 for median openings, side streets, turnouts, overbuild, turn lanes not meeting the above criteria, and other areas where High Polymer is not needed.

Examples:

For toll booths, intersections with slow truck traffic, pavement sections with history of rutting or severe cracking and existing weigh stations with standing traffic, use a PG 76-22 or High Polymer binder. A minimum of 1,000 tons of modified structural mix is generally recommended per project or group of projects to make the most efficient use of the material.

For traffic level E, use PG 76-22 or High Polymer binder as follows:

- 10 million to < 30 million ESALs: use, at a minimum, in the top 1.5” of the structural layer
- ≥ 30 million ESALs: use, at a minimum, in the top 3” of the structural layer
- Note: the structural layer may include SP courses, FC-9.5, or FC-12.5

The PG 76-22 or High Polymer layer thickness should be shown separately on the typical section and a separate pay item used.

The appropriate Traffic Level is to be shown for structural friction courses FC-9.5 and FC-12.5. For Traffic Levels B, and C, PG 76-22 should be called for in the friction course. For Traffic Level E, PG 76-22 or High Polymer should be called for in the friction course.

High Polymer binder may be used for Traffic Level C friction course applications in special situations. As with any use of High Polymer binder, coordinate these situations with the State Bituminous Materials Engineer.

TABLE 5.4

STRUCTURAL COEFFICIENTS FOR DIFFERENT PAVEMENT LAYERS
(New Construction or Reconstruction)

Layer Type	Layer Coeff. (a_x) per inch	Specification Section
FC-5, FC-7	0.00	337
FC-12.5, FC-9.5	0.44	337
Superpave Type SP (SP-9.5, SP-12.5, SP-19.0)	0.44	334
Limerock (LBR 100)	0.18	200
Cemented Coquina (LBR 100)	0.18	911
Shell Rock (LBR 100)	0.18	200
Bank Run Shell (LBR 100)	0.18	200
Calcarenite (LBR 100)	0.18	911
Graded Aggregate (LBR 100)	0.15	204
Recycled Concrete Aggregate (LBR 150)	0.18	911
Type B-12.5	0.30	234
Limerock Stab. (LBR 70)	0.12	230
Shell Stab. (LBR 70)	0.10	
Sand Clay (LBR 75)	0.12	
Soil Cement (500 psi)	0.20	
Soil Cement (300 psi)	0.15	
Type B Stab. (LBR 40)	0.08	
Type B Stab. (LBR 30)	0.06	
Type C Stab.	0.06	
Cement Treated (300 psi)	0.12	
Lime Treated	0.08	

TABLE 5.5

REQUIRED MINIMUM THICKNESS FOR NEW CONSTRUCTION OR RECONSTRUCTION

In order to avoid the possibility of producing an impractical design, the following minimum thicknesses are required for New Construction. It is assumed that a 12-inch stabilized subgrade (LBR 40) is to be constructed in order to establish a satisfactory working platform.

18-kip ESAL’s 20-year period	Minimum Structural Course	Minimum Base Group
Limited Access	4”	9
Greater than 3,500,000	3”	9
Ramp less than 3,500,000	2”	9
300,000 to 3,500,000	2”	6
Less than 300,000	1.5”	3
Limited Access Shoulder	1.5”	1
Residential Streets, Parking Areas, Shoulder Pavement, Bike Paths	1”	1
Shared Use Paths	1.5”	1

FC-12.5 and FC-9.5 can be considered as structural courses and are sufficient for single layer shoulder pavement.

FC-5 and FC-7 have no structural value and are typically shown as 0.75-inches thick.

See *Chapter 8* for Shoulder Design Guidance.

TABLE 5.6

GENERAL USE OPTIONAL BASE GROUPS AND STRUCTURAL NUMBERS (inches)

			BASE THICKNESS AND OPTION CODES									
Base Group	Structural Range	Base Group Pay Item Number	Base Options									
			Limerock, LBR 100	Cemented Coquina, LBR 100	Shell Rock, LBR 100	Bank Run Shell, LBR 100	Calcarenite, LBR 100	Recycled Concrete Aggregate, LBR 150 **	Graded Aggregate Base, LBR 100	Type B-12.5	B-12.5 And 4” Granular Subbase, LBR 100 *	RAP Base
				Structural Number (Per in.)								
			(0.18)	(0.18)	(0.18)	(0.18)	(0.18)	(0.18)	(0.15)	(0.30)	(0.30 & 0.15)	(N/A)
1	0.65–0.75	701	4”	4”	4”	4”	4”	4”	4½”	Δ 4”		□ 5”
2	0.80–0.90	702	5”	5”	5”	5”	5”	5”	5½”	Δ 4”		
3	0.95–1.05	703	5½”	5½”	5½”	5½”	5½”	5½”	6½”	Δ 4”		
4	1.05–1.15	704	6”	6”	6”	6”	6”	6”	7½”	Δ 4”		
5	1.25–1.35	705	7”	7”	7”	7”	7”	7”	8½”	4½”		
6	1.35–1.50	706	8”	8”	8”	8”	8”	8”	9”	5”		
7	1.50–1.65	707	8½”	8½”	8½”	8½”	8½”	8½”	10”	5½”		
8	1.65–1.75	708	9½”	9½”	9½”	9½”	9½”	9½”	11”	5½”		
9	1.75–1.85	709	10”	10”	10”	10”	10”	10”	12”	6”		
10	1.90–2.00	710	11”	11”	11”	11”	11”	11”	13”	6½”	4½”	
11	2.05–2.15	711	12”	12”	12”	12”	12”	12”	14”	7”	5”	
12	2.20–2.30	712	12½”	12½”	12½”	12½”	12½”	12½”		7½”	5½”	
13	2.35–2.45	713	Φ13½”	Φ13½”	Φ13½”	Φ13½”	Φ13½”	Φ13½”		8”	6”	
14	2.45–2.55	714	Φ14”	Φ14”	Φ14”	Φ14”	Φ14”	Φ14”		8½”	6½”	
15	2.60–2.70	715								9”	7”	

* For granular subbase, the construction of both the subbase and Type B-12.5 will be bid and used as Optional Base. Granular subbases include Limerock, Cemented Coquina, Shell Rock, Bank Run Shell, Calcarenite, Recycled Concrete Aggregate and Graded Aggregate Base. The base thickness shown is Type B-12.5. All subbase thicknesses are 4" minimum.

** For restrictions on the use of Recycled Concrete Aggregate, see Specifications.

Φ To be used for widening, three feet or less.

Δ Based on minimum practical thicknesses.

□ For restrictions on the use of RAP Base, see ***Standard Specifications***.

TABLE 5.7

LIMITED USE OPTIONAL BASE GROUPS AND STRUCTURAL NUMBERS (inches)

Base Group	Structural Range	Base Group Pay Item Number	Base Options: Limerock Stabilized, LBR 70	Shell LBR 70	Shell Stabilized LBR 70	Sand-Clay, LBR 75	Soil Cement (300 psi) (Plant Mixed)	Soil Cement (300 psi) (Road Mixed)	Soil Cement (500 psi) (Plant Mixed)
			Structural Number (Per in.)						
			(0.12)	(0.12)	(0.10)	(0.12)	(0.15)	(0.115)	(0.20)
1	0.65 – 0.75	701	5”	5”	7”	5”	5”	5”	∆ 4”
2	0.80 – 0.90	702	6½”	6½”	8½”	6½”	5½”	5½”	4”
3	0.95 – 1.05	703	8”	8”	9½”	8”	6½”	6½”	5”
4	1.05 – 1.15	704	9”	9”	10½”	9”	7½”	7½”	5½”
5	1.25 – 1.35	705	10”	10”	12”	10”	8½”	8½”	6”
6	1.35 – 1.50	706	11”	11”		11”	9”		7”
7	1.50 – 1.65	707	12½”	12½”		12½”	10”		7½”
8	1.65 – 1.75	708					11”		8½”

Not Recommended for 20-year Design Accumulated 18-kip Equivalent Single Axle Loads (ESAL) Greater Than 1,000,000

Note: These base materials may be used on FDOT projects when approved in writing by the District Materials Engineer and shown in the plans.

∆ Based On Minimum Practical Thicknesses.

TABLE 5.8

GENERAL INFORMATION FOR OPTIONAL BASE GROUPS AND STRUCTURAL NUMBERS

(1) On new construction and complete reconstruction projects, when an entirely new base is to be built, the design engineer may specify the Base Group and any unrestricted General Use Optional Base shown in that base group. Note, however, that some thick granular bases are limited to widening which prevents their general use.

(2) Where base options are specified in the plans, only those options may be bid and used.

(3) The designer may require the use of a single base option, for instance Type B-12.5 in a high water condition. This single base option will be bid and used as Optional Base.

5.5 NEW CONSTRUCTION DESIGN SAMPLE PROBLEMS

This process is applicable for new construction. The following steps will take place in approximately the order shown, with the understanding that some activities can take place concurrently.

5.5.1 EXAMPLE 1: RURAL ARTERIAL WIDENING

GIVEN:

This project will widen an existing 2-lane flush shoulder arterial to a 4-lane divided flush shoulder arterial with a Design Speed of 50 mph. The design traffic obtained from the District Planning Office is $ESAL_D$ = 12,000,000. The subgrade resilient modulus (M_R) value provided by the State Materials Office is M_R = 11,500 psi.

FIND:

The design pavement thickness from the information provided for a 20-year design.

DATA:

- %R = 90% (selected from ***Table 5.2***; 90% was chosen by the designer because of the high traffic volume)
- SN_R = 4.39 (interpolated from the design tables in ***Appendix A*** for the appropriate reliability, %R)

SOLUTION:

With the SN_R known, the required pavement structure can be determined using the following equation:

$$SN_R = SN_C = 4.39$$

$$SN_C = (a_1 \times D_1) + (a_2 \times D_2) + (a_3 \times D_3) + (a_4 \times D_4)$$

First, assume that a 12-inch Stabilized Subgrade (LBR 40) is to be used in order to establish a satisfactory working platform. Recall that Structural Coefficients for new pavement layers (a_x) are found in ***Table 5.4***. So, for 12-inch Stabilized Subgrade (also called Type B Stabilization (LBR 40)), the Structural Coefficient is equal to 0.08 per inch.

The equation becomes:

$$4.39 = (a_1 \text{ x } D_1) + (a_2 \text{ x } D_2) + (a_3 \text{ x } D_3) + (0.08 \text{ x } 12")$$

$$4.39 = (a_1 \text{ x } D_1) + (a_2 \text{ x } D_2) + (a_3 \text{ x } D_3) + (0.96)$$

Next, review ***Table 5.5***, which provides the required minimum thicknesses for new structural course and Base Groups. Based on the $ESAL_D$ of 10,000,000, this road requires a minimum of 3" of structural course with a minimum Base Group of 9.

For the Base Group, ***Table 5.6*** provides several combinations of structural coefficients and thicknesses, depending on the base material type. Each of the various combinations of structural coefficients and thickness in Optional Base Group (OBG) 9 yields a structural value of 1.8, as shown here:

Using ***Table 5.6***, for OBG 9:

- Limerock, LBR 100: $a_3 = 0.18$, $D_3 = 10"$; $a_3 \text{ x } D_3 = 1.8$
- Cemented Coquina, LBR 100: $a_3 = 0.18$, $D_3 = 10"$; $a_3 \text{ x } D_3 = 1.8$
- Shell Rock, LBR 100: $a_3 = 0.18$, $D_3 = 10"$; $a_3 \text{ x } D_3 = 1.8$
- Bank Run Shell, LBR 100: $a_3 = 0.18$, $D_3 = 10"$; $a_3 \text{ x } D_3 = 1.8$
- Recycled Concrete Aggregate, LBR 150: $a_3 = 0.18$, $D_3 = 10"$; $a_3 \text{ x } D_3 = 1.8$
- Graded Aggregate Base, LBR 100: $a_3 = 0.15$, $D_3 = 12"$; $a_3 \text{ x } D_3 = 1.8$
- Type B-12.5: $a_3 = 0.30$, $D_3 = 6"$; $a_3 \text{ x } D_3 = 1.8$

The structural coefficient for a new structural course (SP-9.5, SP-12.5, or SP-19.0) is 0.44, as noted in ***Table 5.4***. With a minimum required thickness of 3" (per ***Table 5.5***), the minimum structural value of the structural course is:

$$a_2 \text{ x } D_2 = 0.44 \text{ x } 3" = 1.32$$

The remaining pavement layer to determine is the friction course, which will be a dense-graded friction course (FC-9.5 or FC-12.5) since the road is an arterial with a Design Speed of 50 mph. The structural coefficient for a new dense-graded friction course (found in ***Table 5.4***) is 0.44, which is the same coefficient as the structural course. Thus, the only remaining value to calculate is the thickness of the friction course:

$$a_1 \text{ x } D_1 = 0.44 \text{ x } D_1$$

The equation is now:

$SN_C = (a_1 \times D_1) + (a_2 \times D_2) + (a_3 \times D_3) + (a_4 \times D_4)$

$4.39 = (0.44 \times D_1) + 1.32 + 1.8 + 0.96$

Solving for D_1:

$D_1 = 0.70”$

Rounding up to the nearest 0.5”, $D_1 = 1.0”$

The minimum lift thickness of friction course is 1.0” (for FC-9.5). However, ***Table 5.5*** notes that FC-12.5 and FC-9.5 can be considered as structural courses. Additionally, the structural coefficient for FC-12.5 and FC-9.5 (0.44) is identical to that of SP-9.5, SP-12.5, or SP-19.0. So, knowing that the SN_R can be met with 3” of structural course and 1.0” of friction course, and they have identical structural coefficients, the total structural asphalt thickness can be easily adjusted for practicality and constructability:

$SN_C = (a_1 \times D_1) + (a_2 \times D_2) + (a_3 \times D_3) + (a_4 \times D_4)$

$SN_C = (0.44 \times \underline{1.0}) + (0.44 \times \underline{3.0}) + 1.8 + 0.96$

$SN_C = 4.52$

$SN_C \geq SN_R$

$4.52 > 4.39$ ✓

OR

$SN_C = (a_1 \times D_1) + (a_2 \times D_2) + (a_3 \times D_3) + (a_4 \times D_4)$

$SN_C = (0.44 \times \underline{1.5}) + (0.44 \times \underline{2.5}) + 1.8 + 0.96$

$SN_C = 4.52$

$SN_C \geq SN_R$

$4.52 > 4.39$ ✓

OR

$SN_C = (a_1 \times D_1) + (a_2 \times D_2) + (a_3 \times D_3) + (a_4 \times D_4)$

$SN_C = (0.44 \times \underline{2.0}) + (0.44 \times \underline{2.0}) + 1.8 + 0.96$

$SN_C = 4.52$

$SN_C \geq SN_R$

$4.52 > 4.39$ ✓

CONCLUSION:

A theoretical over-design using the minimums is not uncommon when a stabilized subgrade is constructed. The construction of at least the minimum thicknesses is required to provide practical designs that stay within the empirical limits of the AASHO Road Test. If a stabilized subgrade is not constructed due to unusual conditions, the base and structural asphalt courses (FC & SP) would have to provide a structural number of 4.39".

The pavement description in the plans (depending on which scenario from above is selected) should read:

NEW CONSTRUCTION
OPTIONAL BASE GROUP 9
TYPE SP STRUCTURAL COURSE (TRAFFIC E) (1.5")
TYPE SP STRUCTURAL COURSE (TRAFFIC E) (1.5") (PG76-22)
FRICTION COURSE FC-9.5 (TRAFFIC E) (1") (PG76-22)

OR

NEW CONSTRUCTION
OPTIONAL BASE GROUP 9
TYPE SP STRUCTURAL COURSE (TRAFFIC E) (2.5")
FRICTION COURSE FC-12.5 (TRAFFIC E) (1.5") (PG76-22)

OR

NEW CONSTRUCTION
OPTIONAL BASE GROUP 9
TYPE SP STRUCTURAL COURSE (TRAFFIC E) (2")
FRICTION COURSE FC-12.5 (TRAFFIC E) (2") (PG76-22)

Note that the first pavement description shown above includes 2 individual thicknesses of SP, with the top layer including PG76-22. This is to meet the requirements of binder use in the top 1.5” of the structural layer, as noted in ***Section 5.4***, since the $ESAL_D$ for this example was 12,000,000.

Additionally, the Type B Stabilization is not included in any of the descriptions shown above. This becomes a part of the plan detail, shown on the typical section.

5.5.2 EXAMPLE 2: LIMITED ACCESS RECONSTRUCTION

GIVEN:

This project will reconstruct an existing Limited Access (LA) facility from 4-lanes to 6-lanes. The design traffic obtained from the District Planning Office is $ESAL_D$ = 20,000,000. The subgrade resilient modulus (M_R) value provided by the State Materials Office is M_R = 18,000 psi.

FIND:

The design pavement thickness from the information provided for a 20-year design.

DATA:

- %R = 95% (selected from ***Table 5.2***; 95% was chosen by the designer because of the facility type and the high traffic volume)
- SN_R = 4.30 (per ***Appendix A***)
- Minimum Structural Course = 4” & Minimum Base Group = 9 (per ***Table 5.5***)
- 12-inch Stabilized Subgrade (LBR 40) is to be used
- Open-graded friction course (FC-5) to be used

SOLUTION:

The required layer thicknesses can be determined using the following equation:

$SN_R = SN_C = 4.30$

$SN_C = (a_1 \times D_1) + (a_2 \times D_2) + (a_3 \times D_3) + (a_4 \times D_4)$

As shown in Example 1 above, the structural values provided by the OBG 9 and the 12-inch Stabilized Subgrade (LBR 40) are 1.8 and 0.96, respectively. Additionally, FC-5 has no structural value and is always shown as 0.75" thick. The in-place thickness will average 0.75" with edge rolling down to approximately 0.25". The equation can be updated with this information as follows:

$$SN_C = (0 \times 0.75") + (a_2 \times D_2) + (1.8) + (0.96)$$

Finally, using the minimum structural course of 4", the calculated structural number can be checked against the required structural number:

$$SN_C = (0.00 \times 0.75") + (0.44 \times 4") + (1.8) + (0.96)$$

$$SN_C = 4.52$$

$$SN_C \geq SN_R$$

$$4.52 > 4.30 \checkmark$$

CONCLUSION:

The pavement description in the plans should read:

NEW CONSTRUCTION
OPTIONAL BASE GROUP 9
TYPE SP STRUCTURAL COURSE (TRAFFIC E) (2")
TYPE SP STRUCTURAL COURSE (TRAFFIC E) (2") (PG76-22)
FRICTION COURSE FC-5 (¾") (PG76-22)

Similar to Example 1, the pavement description includes 2 individual thicknesses of SP, with the top layer including PG76-22 to meet the requirements of binder use in ***Section 5.4***. Additionally, it is not necessary to identify the traffic level for FC-5.

And just as in Example 1, the Type B Stabilization is not included in any of the descriptions shown above. This becomes a part of the plan detail, shown on the typical section.

TABLE 5.9

COMBINED STRUCTURAL NUMBER (INCHES)

COMBINED STRUCTURAL NUMBER (INCHES)											
Optional Base Group	Structural Course – Inches										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
1	1.12	1.38									
2	1.34	1.56									
3	1.43	1.65	1.87								
4	1.52	1.74	1.96	2.18							
5	1.70	1.92	2.14	2.36	2.58						
6	1.88	2.10	2.32	2.54	2.76	2.98					
7		2.16	2.41	2.63	2.85	3.04					
8		2.37	2.59	2.81	3.03	3.25	3.47	3.69			
9				2.90	3.12	3.34	3.56	3.78			
10					3.30	3.52	3.74	3.96	4.18		
11					3.48	3.70	3.92	4.14	4.36	4.58	
12						3.79	4.01	4.23	4.45	4.67	4.89
13							4.19	4.41	4.63	4.85	5.07
14							4.28	4.50	4.72	4.94	5.16
15							4.46	4.68	4.90	5.12	5.34

Stabilization Structural Numbers Not Included.

5.6 DESIGN CONSIDERATIONS

The following special areas need to be addressed by the Pavement Design Engineer as the project develops.

5.6.1 STABILIZED SUBGRADE

Since stabilized subgrade has a history of good performance and provides strength to the pavement system at a low cost, it is highly recommended that a stabilized subgrade element be included in a pavement design as shown in the FDOT Design Manual. On rural highways, stabilized subgrade should extend to the shoulder point in order to provide a stable shoulder condition. On urban projects, stabilized subgrade is usually necessary to support curb and gutter.

In some situations, project conditions may dictate elimination of a stabilized subgrade during design and achieving the Required Structural Number (SN_R) with base course and asphalt structural course. These conditions might include:

- Limited working areas at intersections or in medians.
- Shallow existing utilities that are impractical to relocate.
- Areas of urban projects where it is essential to accelerate construction to limit restriction of access to adjacent businesses.

Stabilized subgrade should not normally be eliminated over extensive areas, because it is necessary to provide a working platform for base construction operations. This is an especially important consideration with asphalt base course, because of the difficulty in achieving compaction of the first course placed on an unstable subgrade. The decision to eliminate or substitute stabilization materials must be coordinated with the District Pavement Design Engineer, District Geotechnical Engineer, and District Construction Engineer. If elimination of stabilized subgrade in limited or constrained areas is desired and an asphalt base course will be used, the in-situ strength of the native subgrade and ability to compact the asphalt must be approved by the Pavement Design Engineer of Record in concurrence with the District Geotechnical Engineer. The in-situ subgrade must have an LBR value of 40. *(Note: Granular Subbase substitution for stabilization (meeting **Standard Specifications**, Section 290 as discussed below) does not require evaluation of the in-situ subgrade.)* The reasons for eliminating or substituting stabilized subgrade must be documented in the project file. If an asphalt base course is used, refer to ***Section 5.6.2*** for additional information.

In situations where construction time is critical, the following alternates to in-situ sampling and testing to determine the Limerock Bearing Ratio (LBR) value of a stabilized subgrade include:

- Mixing of soil and stabilized material and testing off site.
- Use of a natural occurring material that meets the Limerock Bearing Ratio (LBR) value requirement that has been tested at the source.
- Use of a Predesigned Stabilized Subgrade per a Special Provision specification covering this concept.

These alternatives should be discussed with the District Construction Engineer and the District Materials Engineer and appropriate Special Provisions included in the Project Specifications.

The ***Standard Specifications*** also provide that when 12-inches of Type B Stabilization requiring an LBR value of 40 is called for, the Engineer may allow, at no additional compensation, the substitution of 6-inches of Granular Subbase meeting the requirements of ***Standard Specifications***, Section 290.

The Specifications provide for use of the No Soak LBR Test Method to expedite LBR testing under certain conditions. Use of this test method is at the option of the Contractor if approved by the District Materials Engineer.

5.6.2 BASE

Except as limited by ***Table 5.6*** or as may be justified by special project conditions, the options for base material should not be restricted. Allowing the contractor the full range of base materials will permit him to select the least costly material, thus resulting in the lowest bid price.

Unbound granular base materials are generally the least expensive. However, project conditions may dictate restricting the base course to Asphalt Base Course. The following conditions may warrant restricting the base course to Asphalt Base Course (designated as Type B-12.5) if the additional cost can be justified:

- In an urban area, maintenance of access to adjacent business is critical to the extent that it is desirable to accelerate base construction.
- The maintenance of traffic scheme requires acceleration of base construction in certain areas of the project.

- High ground water and back of sidewalk grade restrictions make it difficult to obtain adequate design high water clearance from the bottom of a thicker limerock base. The thinner asphalt base can help increase the clearance. Note that asphalt base requires a well compacted subgrade, just as limerock base. It is usually necessary to have two feet of clearance above ground water to get adequate compaction in the top foot of subgrade. In areas where this cannot be obtained, the District Drainage Engineer should be consulted for an underdrain design or other methods to lower the ground water. Refer to ***Section 5.2.2*** for guidance on Design Base Highwater Clearance.

- The configuration of base widening and subgrade soil conditions are such that accumulation of rainfall in excavated areas will significantly delay construction.

The Pavement Design Engineer should become familiar with the material properties, construction techniques, testing procedures, and maintenance of traffic techniques that may enter into the decision to restrict the type of base material to be used. Consultation with the District Construction Engineer and the District Materials Engineer should be done prior to making any decision.

A decision to restrict base course material to an Asphalt Base Course throughout a project must be documented and approved by the District Design Engineer. A copy of the documentation shall be furnished to the State Pavement Design Engineer.

Base courses are normally set up under Optional Base Group (OBG) bid item.

On projects where the Pavement Design Engineer would like to use Asphalt Base (Type B-12.5) on a part of a project and allow multiple base options on other parts of the projects, the Pavement Design Engineer should change the OBG Number by one and specify Asphalt Base only for the area where it is required.

An example of a project where this may occur would be on a project where OBG 6 is recommended, and the Pavement Design Engineer encounters an area of high water. The option would be to use Type B-12.5 from OBG 7. Another option would be to use Type B-12.5 from OBG 5. In both cases the structural asphalt thickness can be adjusted to meet the structural number requirements and allow for separate unit prices.

The Optional Base Group should not exceed OBG 12 for unbound granular base materials, except for trench widening where up to OBG 14 may be used.

5.6.3 ASPHALT BASE CURB PAD

When asphalt base only is decided on for a curb and gutter project, it is generally advisable to show, on the typical section, an asphalt Type B-12.5 pad under the curb (see ***FDOT Design Manual*** (***FDM***) ***Exhibit 913-4*** for example). The thickness of the asphalt pad should be shown in a constructability sketch and shown in the plans, so that the bottom of the curb pad matches the bottom of the initial lift of asphalt base. This will allow the initial lift of the asphalt base to include the curb pad and to be placed prior to the curb placement. This will protect the subgrade from rain earlier and potentially speed up construction. Since the thickness of the asphalt curb pad will be less than the asphalt base, the Base Group may need to be increased to provide for a minimum of 1.5-inches of asphalt curb pad.

5.6.4 STRUCTURAL COURSE

Individual asphalt layers are not shown on the Plans Typical Section, only the overall asphalt thickness. ***Table 5.11*** provides several examples of combinations of individual layer thicknesses for asphalt structural courses.

Variations can occur when recommended in advance by the District Pavement Materials Engineer and concurred with by the District Pavement Design Engineer. For unusual situations, the State Pavement Design Section and the State Materials Office should be consulted.

The Pavement Design Engineer shall sketch out the construction sequence of the Typical Section to ensure constructability. This sketch is to be included in the pavement design package. Emphasis should be placed on allowing the final structural layer to be placed on the mainline and shoulder at the same time. This makes construction easier for the contractor and improves the final product by avoiding a construction joint at the shoulder.

Type SP mixes are designated in the plans by Traffic Level, based on the design $ESAL_D$ and shoulders per ***Table 5.10***. The same Traffic Level as the roadway should be used for paved shoulders less than or equal to 5-feet wide, where the final layer for the upper pavement structural layer and shoulder must be the same and paved in a single pass. For shoulders wider than 5-feet, refer to ***Chapter 8*** of this manual.

As a practical matter, Superpave mixes for crossroads and other small sections with quantities less than 1,000 tons can be designed with the same mix (i.e., Traffic Level) as the mainline. This should be discussed on a project-by-project basis with the District Pavement Materials Engineer.

5.6.5 TRAFFIC LEVELS

TRAFFIC LEVELS FOR DESIGN EQUIVALENT SINGLE AXLE LOADS ($ESAL_D$) RANGE FOR SUPERPAVE ASPHALT CONCRETE STRUCTURAL COURSES

The following are the Traffic Levels for the Design Equivalent Single Axle Loads ($ESAL_D$) ranges for Superpave Asphalt Concrete Structural Courses. It should be noted that previous versions of this Manual included traffic levels A and D. Based on experience, it was determined that the following traffic levels could be combined: Traffic Level A was combined with B, and Traffic Level D was combined with E.

AASHTO DESIGN $ESAL_D$ RANGE (MILLION)	TRAFFIC LEVEL
0 to < 3	B
3 to < 10	C
≥ 10	E

5.6.6 LAYER THICKNESS

SPECIFICATION REQUIREMENTS ON LAYER THICKNESS FOR TYPE SP STRUCTURAL COURSES

The layer thickness must be consistent with the following thickness ranges:

Type Mix	Minimum	Maximum
SP-9.5	1”	1.5”
SP-12.5	1.5”	3”
SP-19.0	2”	4”

Note: These thicknesses correspond to the requirements in ***Standard Specifications, Section 334***.

In addition to the minimum and maximum thickness requirements, the following restrictions are placed on the respective material when used as a structural course:

SP-9.5 Limited to the top two structural layers, two layers maximum.

SP-9.5 Do not place less than 1.5 inches thick for Traffic Level E applications.

Overbuild requirements are discussed in ***Section 7.8.2*** and ***Standard Specifications, Section 334***.

Structural and Friction Courses are shown by thickness in plans, but bid as tonnage items. Bid quantities are estimated using a maximum spread rate of 110 lbs per square yard-inch (110 lbs/yd^2-in).

Actual spread rates to construct the plan thickness are determined by specification formula for the mix selected by the contractor.

When construction includes the paving of adjacent shoulders ≤ 5-feet wide, the traffic level and layer thickness for the upper structural pavement layer and shoulder must be the same and paved in a single pass, unless otherwise specified in plans.

A minimum of 1.5-inches initial lift of Type SP structural course is required over an Asphalt Membrane Interlayer (AMI).

Superpave mixes are classified as fine and mixture gradation requirements are defined in ***Standard Specifications***, ***Section 334-3.2.2***.

The equivalent AASHTO nominal maximum aggregate size Superpave mixes are as follows:

SP-9.5 …………………………………….. 9.5 mm

SP-12.5……………………………………..12.5 mm

SP-19.0……………………………………..19.0 mm

For construction purposes, plan thickness and individual layer thickness will be converted to spread rate based on the maximum specific gravity of the asphalt mix being used, as well as the minimum density level as in the following equation:

$$\text{Spread rate } (lbs/yd^2) = t \times G_{mm} \times 43.3$$

Where:

t = Thickness (in) (Plan thickness or individual layer thickness)

G_{mm} = Maximum Specific Gravity from the verified mix design

Plan quantities are based on a G_{mm} of 2.540, corresponding to a spread rate of 110 lbs/yd^2-in. Pay quantities will be based on the actual Maximum Specific Gravity of the mix used.

TABLE 5.10

LAYER THICKNESS FOR ASPHALT CONCRETE SHOULDER STRUCTURAL COURSES

For projects requiring FC-5 or FC-7, the top structural layer of the roadway overlay and a narrow adjacent shoulder course (≤ 5-feet wide) must be constructed in one pass. The following apply when a 5-feet-wide or less shoulder is to be constructed in conjunction with an overlay of the road.

Roadway Course Thickness	Shoulder Structural Course Thickness
1.0”	1.0” *
1.5”	1.5”
2.0”	1.0” *
2.5”	1.0” *
3.0”	1.0” *
3.5”	1.0” *

For projects requiring FC-12.5 or FC-9.5, a single lift may be sufficient structural thickness for the shoulder pavement.

*Note: Do not place SP-9.5 less than 1.5 inches thick for Traffic Level E applications.

TABLE 5.11
EXAMPLE LAYER THICKNESS FOR ASPHALTIC CONCRETE STRUCTURAL COURSES

(Layers Are Listed In Sequence Of Construction)																				
Course Thickness (in)	LAYER THICKNESS (inches)																			
	SP-19.0 with SP-12.5 Top Layer			SP-19.0 with SP-9.5 Top Layer			SP-12.5			SP-12.5 with SP-9.5 Top Layer			SP-9.5		SP-19.0 1st Layer with SP-12.5 2nd Layer and Top Layer			SP-12.5 1st Layer with SP-9.5 2nd Layer and Top Layer		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	1	2	3	1	2	3
1													1							
1½							1½						1½							
2							2						1	1						
2½							2½			1½	1		1½	1						
													1¼	1¼						
3				2	1		1½	1½		2	1		1½	1½						
							3			1½	1½									
3½	2	1½		2½	1		2	1½		2	1½							1½	1	1
				2	1½					2½	1									
4	2½	1½		3	1		2	2		2½	1½							1½	1½	1
	2	2		2½	1½		2½	1½		1½	1½	1						2	1	1
										3	1									
4½	2½	2		3	1½		2½	2		3	1½							2	1½	1
	3	1½		3½	1		1½	1½	1½	2	1½	1						1½	1½	1½
							3	1½		1½	1½	1½						2½	1	1
5	3	2		2	2	1	2½	2½		2	1½	1½			2	1½	1½	2	1½	1½
	2½	2½		3½	1½		2	1½	1½	2	2	1						2½	1½	1
	3½	1½		4	1		3	2										3	1	1
5½	2	2	1½	2½	2	1	2½	1½	1½	2	2	1½			2½	1½	1½	2½	1½	1½
	3	2½		2	2	1½	2	2	1½	2½	2	1			2	2	1½	3	1½	1
	3½	2		4	1½		3	2½		3	1½	1								
	4	1½																		
6	2½	2	1½	2½	2½	1	2	2	2	2½	2½	1			2½	2	1½	3	1½	1½
	2	2	2	3	2	1	2½	2	1½	2½	2	1½			2	2	2			
	3	3		2½	2	1½	3	3		3	2	1			3	1½	1½			
	3½	2½					3	1½	1½											
	4	2																		

Notes:

(1) Values shown in this table are not intended to convey all possible layer thickness combinations. This table provides several options as an aide to designers. Allowable layer thicknesses are identified in ***Standard Specifications, Section 334***.

(2) Do not place SP-9.5 less than 1.5 inches thick for Traffic Level E applications.

(3) SP-9.5 limited to the top two structural layers, two layers maximum.

5.6.7 RAMP DESIGN

On new construction of limited access ramps, where future traffic is very uncertain, the structural number can be reduced by 25% from the mainline structural number in rural areas, and 15% in urban areas.

The reduction in structural number will be made in the thickness of the structural layer (SP or FC-9.5 or FC-12.5). A minimum Base Group 9 and 2-inches of structural pavement will be provided. The transition from mainline thickness to ramp thickness will occur just beyond the gore. (See ***Standard Plans*, Index 000-525**, Ramp Terminals).

The design assumptions used for the above guidelines were based on 25% of the mainline traffic using the ramp in rural areas and 50% of the mainline traffic using the ramp in urban areas. The Pavement Design Engineer must verify that these assumptions are appropriate for each project.

A situation where the designer would not want to reduce the design would be a case where reliable traffic data has been provided and the design thickness is greater than the reduced thickness.

From the prior Design Example given in ***Section 5.5.2*** with a mainline structural course thickness of 4-inches and, for the purposes of this example, assume it is in an urban area, reduce 4" x 0.85 = 3.4" (use 3.5").

Also, note that the friction course used on the ramp must be determined in coordination with the District Pavement Design Engineer, as discussed in ***Chapter 4, Section 4.3***.

If using FC-9.5 on the ramp, the ramp design could be as follows:

Layer/Material	Coefficient		Thickness		SN_C
Friction Course, FC-9.5	0.44	x	1.5”	=	0.66
Structural Course	0.44	x	2.0”	=	0.88
Optional Base Group 9				=	1.80
Type B Stabilization (LBR 40)	0.08	x	12.0”	=	0.96
				=	4.30

If using FC-5 on the ramp, the ramp design would be as follows:

Layer/Material	Coefficient		Thickness		SN_C
Friction Course, FC-5	0.00	x	0.75”	=	0.00
Structural Course	0.44	x	3.5”	=	1.54
Optional Base Group 9				=	1.80
Type B Stabilization (LBR 40)	0.08	x	12.0”	=	0.96
				=	4.30

CHAPTER 6
PAVEMENT WIDENING

6.1 REQUIREMENTS

Pavement widening, which includes trench widening, lane addition, and operational type projects, do not require thickness design calculations. The Pavement Design Engineer needs to determine what the existing pavement structure consists of, including any designed overlays. The widening section will be designed and constructed to match the existing plus overlay pavement. The total structural number of the widened section must equal or exceed the total mainline structural number.

The pavement designer should take special care to avoid designing pavement alignments which results in a widening longitudinal joint in the wheel path. Extensive research has shown joints in the wheel path invariably lead to a higher rate of joint deterioration. If possible, the joint line should be shifted further into the existing pavement to reduce or eliminate this condition.

The following guidelines will assist in providing a well-engineered design.

6.2 STRUCTURAL COURSE

To provide for future milling, the asphalt thickness of the structural course of the widening should match or exceed the existing mainline asphalt plus any overlays planned as a part of the project.

It may be impractical to match the existing pavement of an old road that has had numerous overlays. It is essential that the Pavement Design Engineer evaluate what will be left if there is a future milling operation that for some reason removes a substantial amount of asphalt. A 4-in to 5-in thickness of structural asphalt is a reasonable limit depending on truck volumes, for inside traffic lanes which have less truck use.

Industry representatives and the Department's Construction Office indicate that the following procedure could be used to permit the construction of trench widening without requiring the use of a barricade:

DAY ONE

- Cut a trench for that day's run.
- Place the first layer of granular base in the trench.
- Compact and finish.
- Check the density.
- Place the second layer of granular base in the trench.
- Compact and grade to comply with ***Standard Plans*, *Index 102-600***.

DAY TWO

- Compact and finish second layer.
- Construct Structural Layers.

Standard Plans*, *Index 102-600 provides several optional treatments that could be utilized during the construction of a granular base.

The Pavement Design Engineer must also consider the constructability of the design. It is highly recommended that widening projects be kept as simple as possible.

If a granular base is to be used, it should be designed flush with the existing granular base. Asphalt structural layers will then be brought up to the top of the existing asphalt layers. Subsequent asphalt layers can then be constructed full width over the existing roadway and the widening. The purpose is to minimize the possibility of a longitudinal crack at this joint.

On complicated projects, it is highly recommended that the District Construction Engineer and the Resident Construction Engineer be contacted and the project reviewed in detail.

6.3 BASE AND SUBGRADE

The strength of the widened section base material, as measured by its layer coefficient multiplied by its thickness, must match or exceed the existing base strength.

The Pavement Design Engineer must visualize what is left when future milling occurs to ensure that the remaining structural numbers are compatible. Normally the top of the new base and the top of the old base should match to facilitate future milling. From the top of the existing base down, the widening structural number must be equal to or greater than the existing structural number (including any stabilized subgrade).

On any type of widening project, the base options to be used may be specified by the Pavement Design Engineer and shown in the plans to ensure layer coefficients equal or greater than the existing base.

On selected projects, it may be necessary to justify and use an Asphalt Base (Type B-12.5) for widening. However, with proper design it may be possible to take advantage of the potential economics of a granular base material and bid an Optional Base. Refer to ***Section 5.6.2*** for additional information on asphalt base course.

6.4 STABILIZATION

Stabilization should be considered when adding lanes or shoulders, extending turn lanes, and on some operational type projects. The use of stabilization in trench widening strips is generally not recommended due to constructability issues and constrained space to compact the stabilization soil. Stabilization construction equipment requires a wide area to operate, so the limited area within trench widening strips makes preparing the subgrade to achieve an LBR of 40 challenging.

The decision to eliminate or substitute stabilization materials must be coordinated with the District Pavement Design Engineer, District Geotechnical Engineer, and District Construction Engineer. When stabilization is eliminated, the reasons must be documented in the project file. When stabilization is not provided, single course base layers should not be used. Refer to ***Section 5.6.1*** for additional guidance on elimination or substitution of stabilization material.

6.5 LABORATORY RESILIENT MODULUS (M_R)

For widening projects, such as the addition of a new truck lane with substantial fill areas in excess of three feet (3-ft), samples should be obtained from potential borrow areas.

6.6 WIDENING DESIGN SAMPLE PROBLEM

The following is a sample problem on widening that is commonly found.

GIVEN:

An existing two lane rural roadway, Traffic Level C, with a design speed of 65 mph is to be milled 2.5" and resurfaced with 1.5" Type SP and 1.5" FC-12.5 with PG76-22. The existing lanes are 11-ft wide. The road needs to be brought up to current standards by widening the lane to 12-ft and adding a 5-ft paved shoulder.

FIND:

The pavement design for widening is to match the existing pavement plus resurfacing. List any assumptions. Sketch a possible layer construction sequence of the design, including resurfacing, widening, and shoulders, to insure constructability.

DATA:

Field data from the existing pavement as evaluated by the District Pavement Materials Engineer includes the following information:

Material	Thickness	Condition
Type S + FC	3.5”	poor
Limerock	10”	good
Stabilization	12”	good

SOLUTION:

The original plans and field inspection indicate that the area beyond the edge of pavement was stabilized to the shoulder point.

The pavement design for the widening includes:

SN_E (Limerock) = (0.18 x 10") = 1.8" or Optional Base Group 9

Use 1.5" Structural Course and 1.5" Friction Course over 6" Type B-12.5 base to match the total asphalt thickness after milling plus resurfacing

= 1.5" FC-12.5 (PG 76-22) (new)

1.5" Type SP (new)

6" Type B -12.5 Base

Existing stabilization is assumed.

A construction sketch of the design is provided (See ***Figure 6.1***) showing the widening structural layers.

The pavement description in the plans should read:

<u>WIDENING</u>

OPTIONAL BASE GROUP 9 (TYPE B-12.5 ONLY)
TYPE SP STRUCTURAL COURSE (TRAFFIC C) (1½")
FRICTION COURSE FC-12.5 (TRAFFIC C)(1½")(PG 76-22)

Selection of optional base should result in material meeting or exceeding the structural strength of the existing material.

<u>The pavement design for the shoulder includes:</u>

Existing shoulder stabilization is adequate and traffic loadings are moderate. Therefore, the following minimums for design found in ***Table 5.5*** could be used:

1" Structural Course

Optional Base Group 1

However, for constructability, the widening pavement design should also be used for the shoulder. It would be impractical to construct a 1-foot-wide strip of widening with one pavement thickness immediately adjacent to a 5-foot-wide shoulder with a different pavement thickness.

Therefore, the shoulder should be designed as follows:

1.5” FC-12.5 (PG 76-22) (new)

1.5" Type SP (new)

6” Type B-12.5 Base

In summary, the resurfacing, widening, and shoulder designs each include 1.5" structural course overlain by 1.5” friction course. Note that the total structural course on the resurfacing will be 2.5” thick (this includes 1" of remaining Type S). A construction sketch of the shoulder design is provided (See ***Figure 6.1***) showing the shoulder structural layers.

The pavement description in the plans should read:

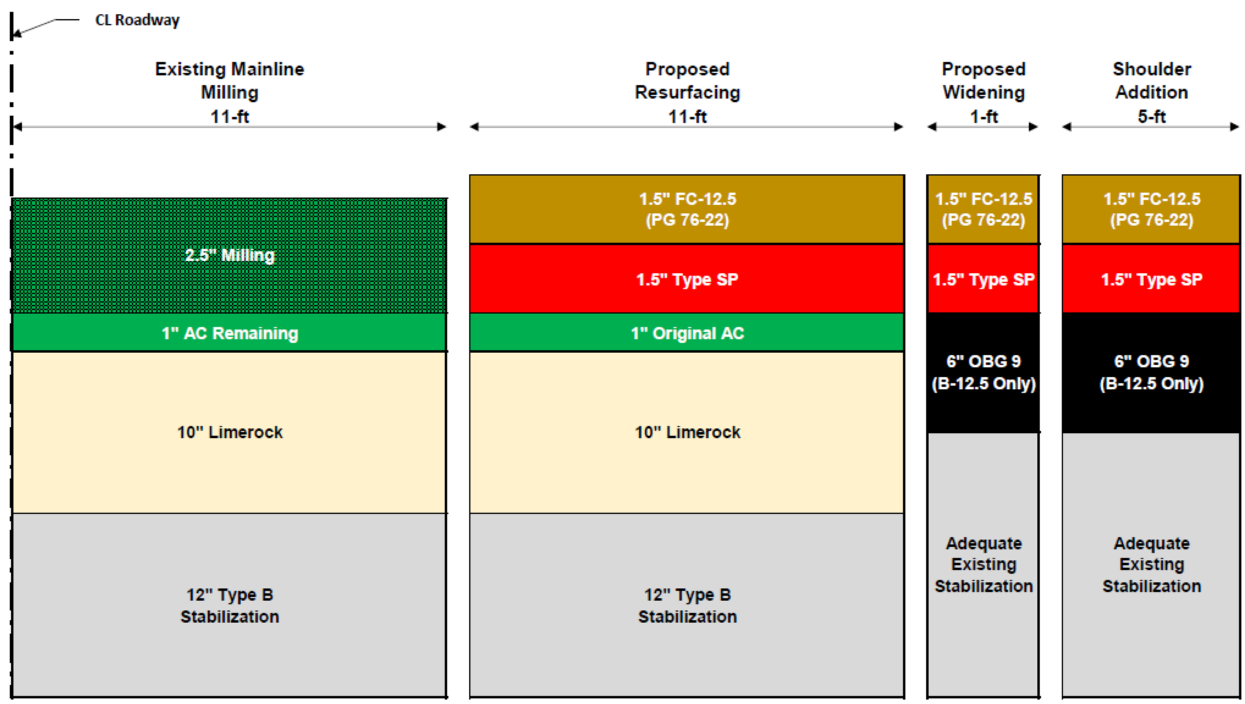
SHOULDER

OPTIONAL BASE GROUP 9 (TYPE B-12.5 ONLY)
TYPE SP STRUCTURAL COURSE (TRAFFIC C) (1 ½")
FRICTION COURSE FC-12.5 (1.5")(PG 76-22)

Note that the 12" Type B Stabilization is not included in the description since the existing stabilization is adequate.

FIGURE 6.1
WIDENING DETAIL FOR SAMPLE PROBLEM

The following is an example of a detail sketch, showing what needs to be done when designing a widening project.



CHAPTER 7
PAVEMENT THICKNESS DESIGN PROCESS FOR REHABILITATION PROJECTS
(Section 5.6.4, 5.6.5, and 5.6.6 Requirements Apply)

7.1 OVERVIEW

This process is applicable to all rehabilitation projects in Florida where the Pavement Design Engineer must calculate a structural overlay thickness using the AASHTO procedure.

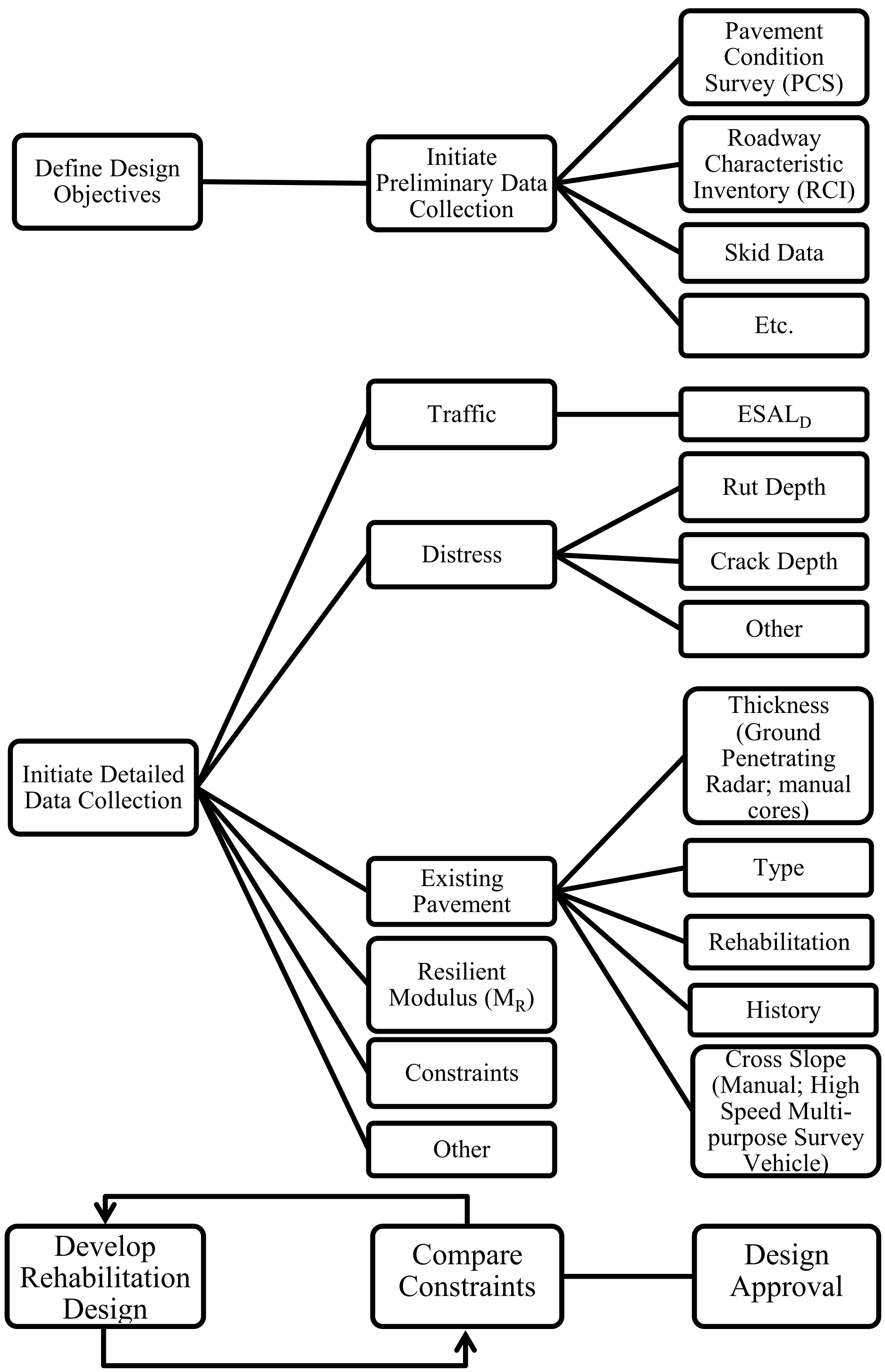
The following steps will take place in approximately the order shown with the understanding that some activities can take place concurrently. A schematic of the process is shown in ***Figure 7.1***.

7.2 REQUIRED STRUCTURAL NUMBER (SN_R) CALCULATIONS USING THE AASHTO DESIGN GUIDE

The procedure for calculating the Required Structural Number (SN_R) is the same method detailed under New Construction (Refer to ***Section 5.2***).

FIGURE 7.1

FLEXIBLE PAVEMENT REHABILITATION PROCESS



7.3 RESILIENT MODULUS (M_R) VARIATIONS

Rehabilitation projects use the existing subgrade soils. This material may be variable within a project for several reasons. One reason for subgrade variability may be that different parts of the project were constructed under several earlier projects. Other variability may be due to factors such as soil strata, compaction, and moisture content. Three methods of obtaining the Resilient Modulus (M_R) values are available to the Pavement Design Engineer. These are non-destructive testing using the Deflection Equipment, historic Deflection Testing data, and Soil Test Data. This information needs to be obtained as early as possible in the design process.

It is important to understand the difference between the M_R value obtained from laboratory testing (Lab M_R) and the M_R value obtained through Deflection Testing in the field (Field M_R). The Field M_R is typically a higher value than the Lab M_R due to these tests being performed under different conditions, as well as from additional compaction resulting from the construction of the road and the traffic loading applied through its life. Therefore, Lab M_R Values should only be used for new construction or widening projects. Rehabilitation projects should use Field M_R data in order to avoid over-designing the pavement.

7.3.1 RESILIENT MODULUS (M_R) FROM NONDESTRUCTIVE TESTING

Nondestructive Deflection testing is the preferred method for obtaining the Resilient Modulus (M_R) for a rehabilitation project. The deflection values obtained represents the deflection of the embankment or natural subgrade material. More test data can be collected and used to statistically calculate the Resilient Modulus (M_R). A plot of the actual deflection data permits the Pavement Design Engineer to evaluate the uniformity of the material under the existing roadway.

The State Materials Office will provide an evaluation of the deflections and will provide one or more recommended Resilient Modulus (M_R) values for the project. The design Resilient Modulus (M_R) represents the weakest area within the design limits that it is practical to design for. It is based on the mean deflection plus two standard deviations and represents an optimum tradeoff between future isolated maintenance costs and increased overlay costs. This analysis is different than the Reliability factor (%R) which is used to account for traffic forecasting and construction variability.

Significant variances that show up on the plots should warrant further investigation to determine if special attention must be paid to these areas or if the designs must be modified accordingly.

Example plots are given in ***Figures 7.2***, ***7.3***, and ***7.4***. Note that in ***Figure 7.2*** the plot is constant compared to ***Figures 7.3*** and ***7.4***. In ***Figure 7.3***, a significant change takes place in the Pavement Structure. In ***Figure 7.4***, a "Blip" occurs in the plot warranting a field check.

7.3.2 RESILIENT MODULUS (M_R) FROM HISTORIC DATA

The State Materials Office maintains the ***Falling Weight Deflectometer (FWD) Dashboard***, which is an online GIS tool that is a collection of all FWD data (i.e., Field M_R Values) throughout the state.

This tool may be used to find Field M_R values previously determined from a roadway that is on or within close proximity to the current project need. This tool should be used in combination with review of existing pavement thickness (from pavement cores) and its performance (historic knowledge and Pavement Condition Survey data).

7.3.3 RESILIENT MODULUS (M_R) FROM LABORATORY DATA

This method is typically only used for off-system roads. If it is not practical to obtain Deflection data through field testing or through the historic database, and a Design M_R or LBR Value is available, the Pavement Design Engineer should coordinate with the State Pavement Office. Department staff can assist with the conversion of the Design M_R or LBR Value to a Field M_R value, which is necessary for rehabilitation design, as described in ***Section 7.3***.

It should be noted that ***Table 5.1*** is not applicable for rehabilitation design.

FIGURE 7.2
DEFLECTION PLOT EXAMPLE

State of Florida
Department of Transportation
State Materials Office
Pavement Deflections

Example of normal pavement deflections

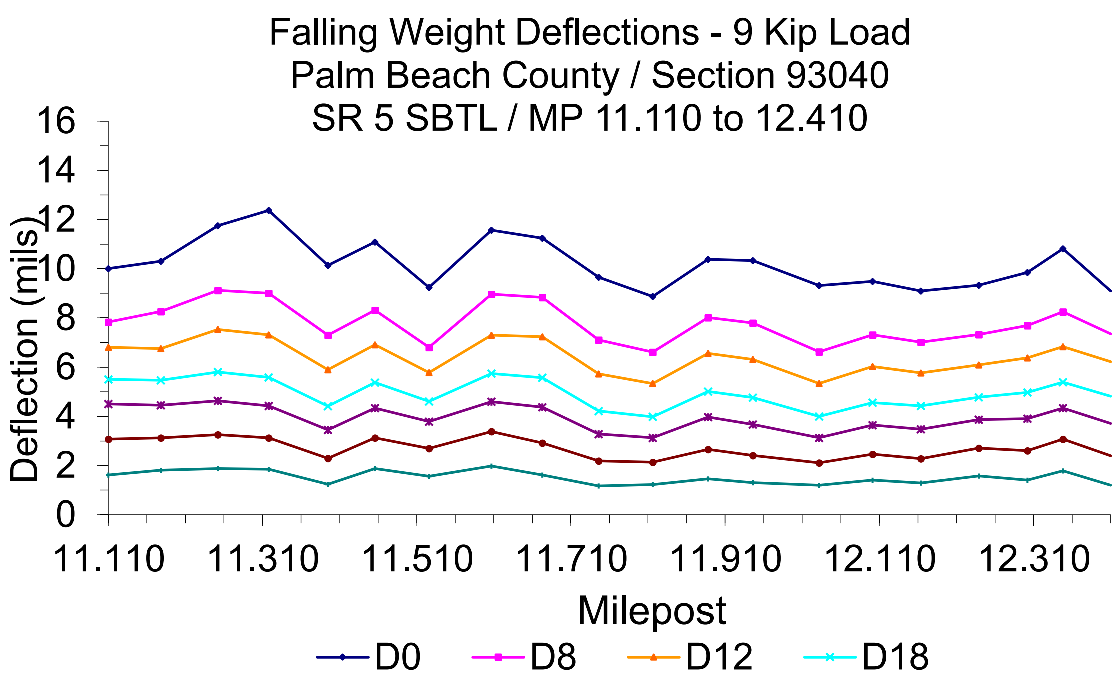


FIGURE 7.3
DEFLECTION PLOT EXAMPLE

State of Florida
Department of Transportation
State Materials Office
Pavement Deflections

Example of a pavement change.

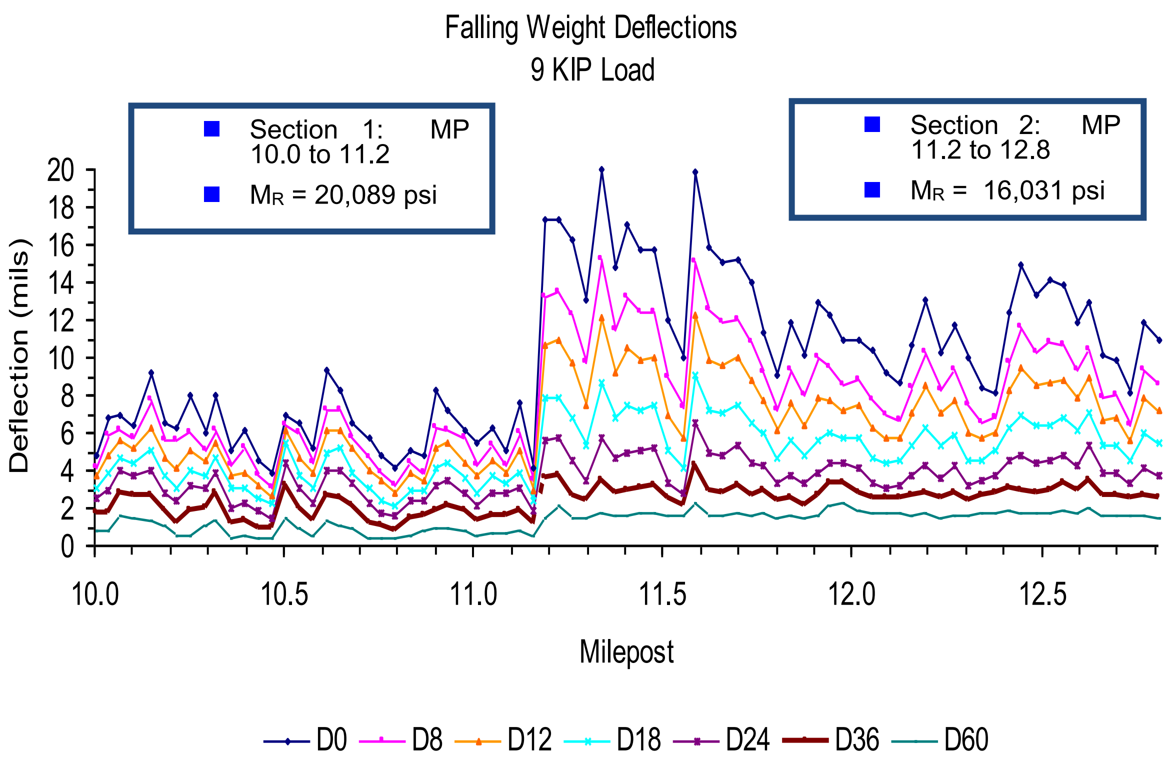
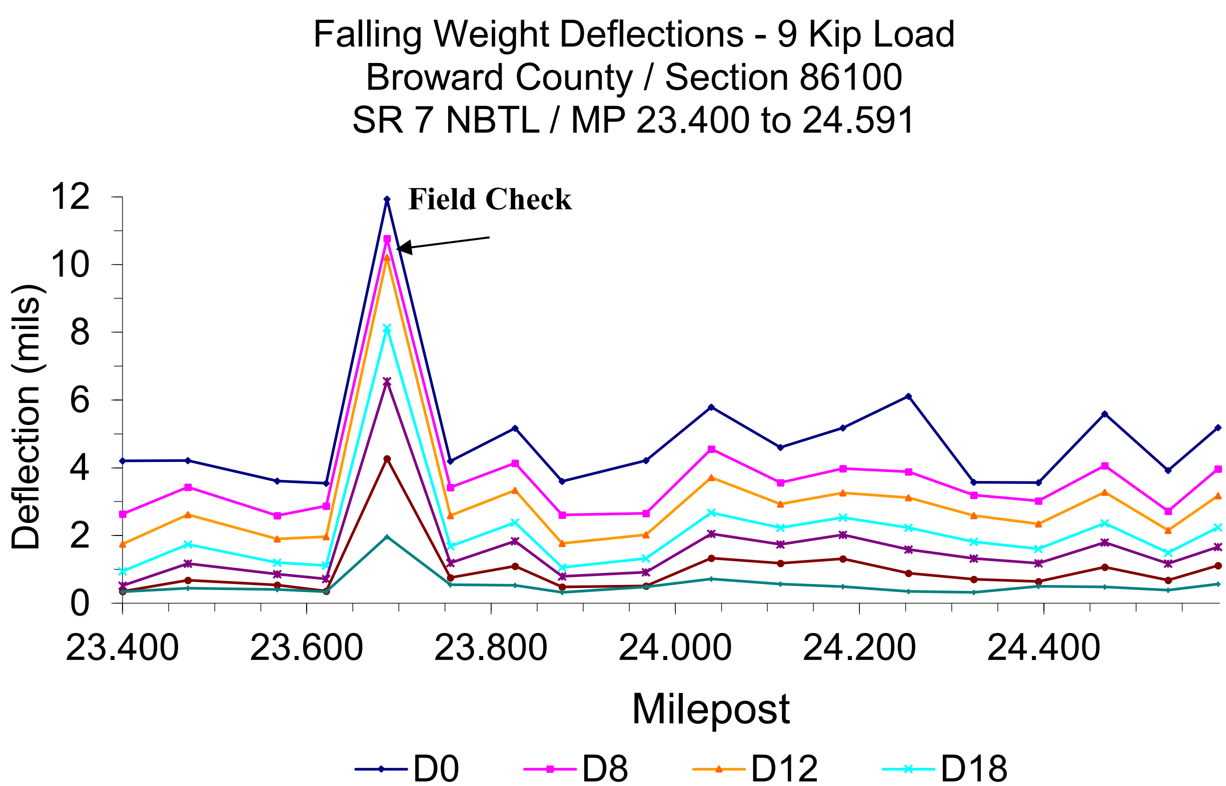


FIGURE 7.4
DEFLECTION PLOT EXAMPLE

State of Florida
Department of Transportation
State Materials Office
Pavement Deflections

Example of a 'Blip' that occurred that warrants a field investigation.



7.4 EVALUATING THE EXISTING STRUCTURAL NUMBER (SN_E)

Many items must be examined before the proper rehabilitation strategy can be initiated. After these items are reviewed, action by the Pavement Design Engineer is important to meet production schedules.

7.4.1 FIELD TESTING

The Pavement Design Engineer must determine what the project is to accomplish. Some jobs, such as skid hazard, widening, or operational type projects, are not designed structurally. They do not require a standard pavement thickness design and normally do not require deflection testing unless an evaluation of the underlying materials is needed.

Testing is not feasible for extremely short projects due to the reduction in the normal testing frequency, testing confidence limits, and logistical issues in the field (e.g., setting up Temporary Traffic Control (TTC) for very limited data collection, inconvenience to the public due to limited access/egress points).

Deflection testing requests should <u>not</u> be made for:

- Two lane roadway projects less than 1 mile long.
- Three lanes or more roadway projects less than 0.5 miles long.
- Ramps or frontage roads.

Example projects where Deflection testing should not be required include bridge or culvert replacement, intersection improvement, etc. Ramps present a unique challenge for field data collection due to their typically curved alignment and relatively short lengths. Frontage roads present similar data collection challenges because they are relatively short lengths and are typically one-way roads. Both facility types have logistical and safety challenges, and alternative ways to collect deflection data are available. Therefore, deflection data is not usually collected for either ramps or frontage roads. The mainline M_R data can typically be used for the adjacent ramp or frontage road pavement design.

Scheduling the Temporary Traffic Control (TTC) in order to accomplish this field testing requires close coordination between the State Materials Office and the District Maintenance Offices. It is highly recommended that the longest possible lead time be allowed to accomplish this field work.

It is preferable to give the State Materials Office a year or more advance notice so that they can schedule their work throughout the state. A good time to do this is after the work program is updated and project schedules are set. Coordinated requests for multiple jobs within a district are preferred.

7.4.2 DATA COLLECTION

The goal of a Pavement Design Engineer is to provide a pavement structure that will maintain the desired serviceability over the design period at optimum cost. The design period will be between 8 and 20 years depending on the type of project the Pavement Design Engineer ultimately develops.

The Pavement Design Engineer will need to initiate a preliminary data collection effort. Sources of information include the present and historical Pavement Condition Survey (PCS).

Additional information can be obtained from the Roadway Characteristics Inventory (RCI), Straight Line Diagrams (SLD), and old plans.

The Design Survey Information should be obtained so that existing pavement cross slope can be checked.

Documentation is also available from the District Materials, Drainage, Maintenance, and Construction personnel who have knowledge of, and are interested in the project. A field review of the project is recommended to verify the project information and ensure that the design objectives have been properly defined.

The year of last rehabilitation, condition of the pavement before the last rehabilitation, and the type of rehabilitation performed should be documented in the pavement design package.

7.4.3 PAVEMENT EVALUATION

The pavement evaluation information should be used by the designer to carefully evaluate the possible causes of the current distress, so that the distresses are not simply repaired, but are also prevented from rapidly recurring.

The designer should not be satisfied with simply providing an adequate Structural Number, but should also consider other factors. An example would be an unstable lower layer that has repeatedly contributed to rutting in the past. By studying the pavement history, this problem could be identified and evaluated and a deeper milling depth set. A concrete overlay or reconstruction to concrete are other alternatives to consider.

The District Materials Office should be requested to perform an evaluation of the project. Deflection data should be reviewed to see if special areas of investigation are warranted. Pavement Coring and Evaluation Procedure per the Materials Manual can be obtained from the State Materials Office or through the departments INTERNET and INFONET sites. Specific pavement data required includes the existing material type and thickness, the quality and condition of the materials, and the cross slope.

Research on the existing pavement should also include researching old plans for existing stabilization. If the existing plans are not available, additional testing to determine the need for stabilization on widening and/or shoulder pavement may be needed.

Specific detailed distress data needed at this time includes, type and extent of cracking, crack depths, cross slope, and rut depth. The District Materials Office will provide recommendations on milling, overbuild, use of automatic screed control, and an Asphalt Membrane Interlayer (AMI) when required.

7.4.4 REDUCED LAYER COEFFECIENTS

When a pavement has been in service for some time, it can be demonstrated that the asphaltic materials will have lost some of their load carrying ability. To represent this in the Existing Structural Number (SN_E) calculations, a set of reduced layer coefficients reflecting the current pavement condition to be used for rehabilitation projects have been tabulated. These values are given in ***Table 7.1***.

Granular base, subbase, and stabilizing, if present in the pavement structure, are assumed to remain at full strength and are not reduced in the Existing Structural Number (SN_E) calculations. If substandard materials are suspected, the State Materials Office should be requested to do an evaluation and possibly recommend a lower value.

The Existing Structural Number (SN_E) can be calculated using the following formula:

$$SN_E = (a_1 \times D_1) + (a_2 \times D_2) + (a_3 \times D_3) + ... + (a_N \times D_N)$$

where:

SN_E = Total strength of the existing pavement layers.

a_1 = Reduced layer coefficient of the 1st layer.

D_1 = Layer thickness in inches of the 1st layer.

a_2 = etc.

D_2 = etc.

a_N = Layer coefficient of the Nth layer.

D_N = Layer thickness in inches of the Nth layer.

If a pavement is to be milled, the thickness of the uppermost layers affected by the milling operation will be eliminated. The layer coefficients for asphaltic materials are reduced as shown in ***Table 7.1***, based on the condition of the pavement. Pavement Condition should be based on the surface appearance of the pavement (cracking, patching, rutting, etc.) and may be supplemented by additional testing.

TABLE 7.1
REDUCED STRUCTURAL COEFFICIENTS OF ASPHALT MATERIALS PER INCH

Recommended Criteria
(based on the Pavement Condition Survey ratings)

Good - Crack Rated 9.0 or higher, minor rutting/distortion

Fair - Crack Rated 7.1 to 8.9, minor rutting and / or distortion

Poor - Cracking or Rutting rated 7.0 or less

Layer coefficients for granular base, subbase, and stabilization are not reduced. Use the values shown in ***Table 5.4***.

		Pavement Condition		
Layer	**Original Design**	**Good**	**Fair**	**Poor**
FC-2, FC-5, FC-7	0			
FC-1 or FC-4	0.20	0.17	0.15	0.12
FC-3	0.22	0.20	0.17	0.15
FC-6	0.44	0.34	0.25	0.15
FC-12.5 or FC-9.5	0.44	0.34	0.25	0.15
Type S or SP	0.44	0.34	0.25	0.15
Type I	0.37	0.30	0.23	0.15
Type II	0.20	0.17	0.15	0.12
Type III	0.30	0.25	0.20	0.15
Binder	0.30	0.25	0.20	0.15
ABC-1	0.20	0.17	0.14	0.10
ABC-2	0.25	0.20	0.16	0.12
ABC-3	0.30	0.25	0.20	0.15
Type B-12.5	0.30	0.25	0.20	0.15
Sand Asphalt Hot Mix (SAHM)	0.15	0.13	0.11	0.08
Sand Bituminous Road Mix (SBRM)	0.15	0.13	0.11	0.08

TABLE 7.2
AASHTO SUGGESTED LAYER COEFFICIENT
FOR FRACTURED SLAB PAVEMENT

MATERIAL	SLAB CONDITION	COEFFICIENT
Crack/Seat JPCP	Pieces one to three feet	0.20 – 0.35
Rubblized PCC	Completely fractured slab pieces less than one foot	0.14 – 0.30
Base/Subbase granular and stabilized	No evidence of degradation or intrusion of fines	0.10 – 0.14
	Some evidence of degradation or intrusion of fines	0.00 – 0.10

NOTE: The experience to date is to use the middle values for the AASHTO suggested layer coefficient for fractured slab pavements for asphalt overlay. However, complete evaluation of the existing PCC pavement must be made prior to selection of an appropriate layer coefficient per project.

7.5 MILLING

The need to mill all or part of the existing pavement should be evaluated for every project. A decision to mill should be based on sound economic and engineering principles. Consideration should also be given to the time between coring and evaluation of the project, and the construction phase of the project. If the project is cored and evaluated but not constructed for several years, the pavement conditions in the Pavement Evaluation may change significantly.

7.5.1 CANDIDATE PROJECTS

Milling may be appropriate for the following reasons:

- Remove cracked asphalt.
- To correct cross-slope.
- Avoid raising the grade excessively (i.e. curb and gutter sections, bridges, underpasses, etc.).
- To remove rut susceptible mixes.

- Minimize the need to perform construction work outside the mainline pavement area, (an example would be requiring a structurally unnecessary overlay of paved shoulders plus safety work and earthwork).
- Elimination of an existing mix problem that should be removed rather than be overlaid.
- For removal of FC-2, FC-5, or FC-7 when overlaying.
- If the overall project cost would be less with milling than without.

Cracked pavement should be milled out to avoid reflective cracking in the overlay. It is usually desirable to leave at least 0.75-inch of asphalt over the base throughout the project to protect it from traffic and rain. However, the entire asphalt structure can be milled out as long as contract provisions provide for maintenance of traffic and protection of the base, such as placement of the first lift of structural asphalt no later than the day after the surface was milled.

Consideration should also be given to underlying layers that may consist of potentially unstable materials that could cause problems if exposed by milling (such as some old low asphalt content binder courses or low Marshall Stability mixes). If these situations exist, they should be carefully discussed with the District Pavement Materials Engineer and the Roadway Design Engineer.

Special Provisions may be needed to limit the exposure of these layers to traffic until adequate structural thickness is placed.

Distress in an overlay due to reflective cracking is not fully modeled in the Structural Number calculations. Research is being done to better evaluate reflective cracking potential using computer modeling.

If it is not practical to mill out most of the cracked pavement, a crack relief layer and/or additional overlay thickness should be considered. Generally, it is not practical to mill to a depth greater than 5 inches. Use of crack relief layers is discussed further in ***Section 7.8.6***.

Milling is not the solution when the base or subgrade is the problem. An evaluation of the base or subgrade should be made to determine if reconstruction is necessary to correct the poor condition of the base or remove poor base materials.

7.5.2 PAVEMENT CORING AND SAMPLING

Where milling on a project will exceed 5000 tons of RAP material, 6-inch diameter core specimens representative of the mix to be milled, will be taken in accordance with the coring and sampling requirements of the Materials Manual (Topic No. 675-000-000).

The condition of the pavement at each core location will be observed by District Materials Office and a Pavement Evaluation coring and Condition Data Form (No. 675-030-09) will be prepared and entered into the Pavement Coring and Reporting (PCR) System, per the Materials Manual.

7.5.3 VARIABLE DEPTH MILLING

Under some conditions, variable depth milling may be appropriate. As an example, cracks in a truck lane may be significantly deeper than cracks in the passing lane. This must be coordinated closely with district Construction.

Crack depth is recorded in the Pavement Evaluation and Condition Data Form (No. 675-030-09). The milling depth should be uniform within a lane except when the milling slope has been set to correct a cross slope problem.

7.5.4 CROSS SLOPE

Proper pavement cross-slope is essential to provide adequate drainage, especially if minor rutting occurs on the pavement. The Pavement Design Engineer should work closely with the District Pavement Materials Engineer to ensure cross-slope is addressed in design.

Existing cross-slope should be field verified from the Design Survey, a roadway cross-slope measurement from a multi-purpose survey vehicle (MPSV), or from the cross-slope measurements shown on the Pavement Evaluation Coring and Condition Data Form. (It should be noted that cross slope data collection using a MPSV is not recommended for ramps or frontage roads unless there is a concern for safety during field data collection.) If a Design Survey has not been performed and cross-slope problems are suspected, then a survey should be requested according to Survey Guidelines for RRR Projects (***FDOT Design Manual (FDM) 114.2.2***).

If the existing cross-slope is out of tolerance (see criteria provided in ***FDM 210.2.4.1*** for arterials and collectors, or ***FDM 211.2.2.1*** for Limited Access facilities), sufficient overbuild material must be provided by the Roadway Designer in the quantity estimate to correct the deficiency. The District Pavement Materials Engineer will provide recommendations with regard to specifying the use of transverse screed control for the pavers. Milling to a specified cross slope should also be considered.

If correction to the cross-slope is needed, the pavement designer should discuss possible corrective actions with the District Pavement Materials Engineer and the Roadway Design Engineer to ensure constructability. Special milling and layering details shall be shown in the plans when cross-slope correction is needed. (See examples in the ***FDM 913*** Exhibits).

If the longitudinal profile is also to be corrected, sufficient overbuild materials must be provided in the estimate.

7.5.5 RUTTED PAVEMENT

The rehabilitation technique to be applied to a rutted pavement must be carefully evaluated.

If the pavement is relatively young and rutting is a major form of distress, there may be a materials or mix problem. Milling of the substandard material may be essential. The history of the pavement should be studied to see if unstable mixes previously existed and need to be removed.

For a pavement that is rutted and not cracked, a special evaluation should be made prior to a decision on the depth of milling. The State Materials Office should be contacted and their assistance requested to determine if milling would be prudent and if special testing is needed. Special tests on various layers and cross sectional coring or trenching may be warranted to identify problem layers in the top 5inches of pavement

7.5.6 MILLING DEPTH

The District Pavement Materials Engineer and the District Pavement Design Engineer will set the milling depth based on field data that is collected using the Pavement Coring and Evaluation Guidelines.

Laboratory testing of the project field cores cannot be completed until the milling depths have been set. The cores are then cut and tested to provide a coring report for the Recycled Asphalt Pavement (RAP). This must be taken into consideration with the timing of these various operations. A Coring and Condition Data Form (No. 675-030-09) should be prepared by the State Materials Office and placed on the web for any project with milled material quantities over 5000 tons from the same general pavement structure.

7.5.7 CONSTRUCTION CONSIDERATIONS

Certain elements should be considered during Design to improve construction efficiency, long-term durability, performance, and smoothness of pavement. The following are items for the Pavement Engineer to consider during the Design process. These are not requirements but are considered to be best practices:

Number of Mainline Milling Depths:

It is generally advisable to limit the number of different milling depths used for the mainline travel lanes on a project. When mill depths are close in depth and quantities are relatively small, it could make sense to combine them into a single mill depth for overall project simplicity and construction efficiency. While there will be site-specific conditions that can require different milling depths, the pavement design engineer should look for opportunities to reduce the overall number of different milling depths on a project when practical.

Additionally, it is understood that turn lanes, shoulders, and ramps may have different milling depths from the mainline travel lanes.

Different Milling Depths within the Same Travel Lane (longitudinal direction):

When a project requires multiple different milling depths within the same travel lane, consideration should be given to providing a full lift thickness between adjacent mill depths. An illustration of this concept is shown in ***Figure 7.5***. A mill thickness difference of 1.5-inches is ideal. Providing a full lift thickness between adjacent mill depths within a lane is beneficial for the following reasons:

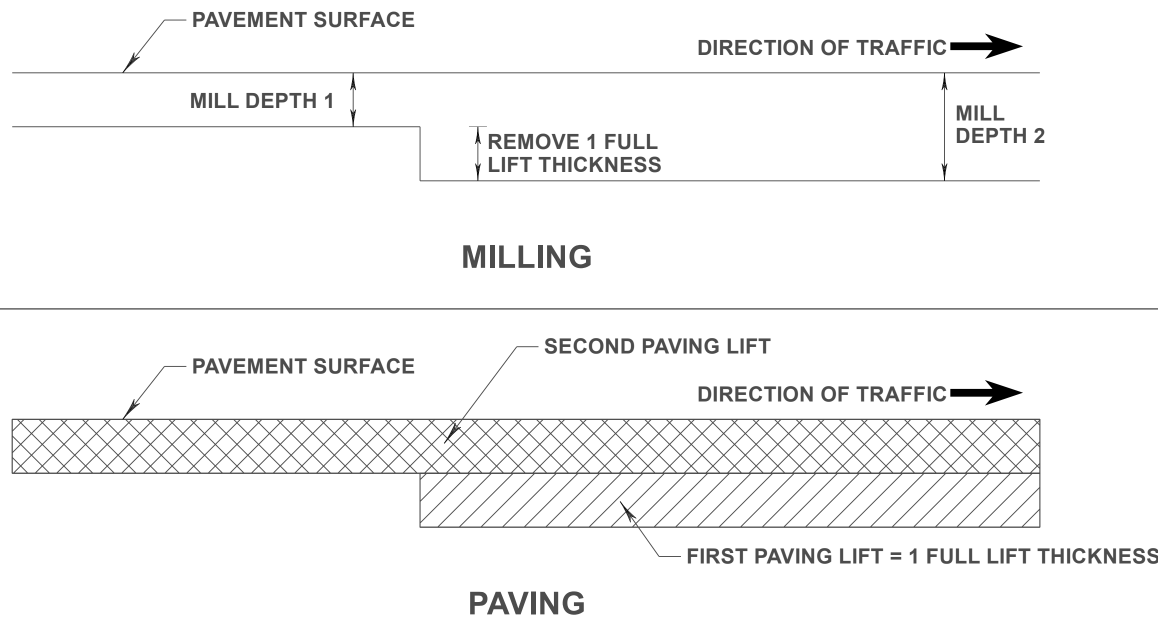
- With an even lift thickness, the deeper milled area can be paved and compacted in one effort, and then the next layer can be paved in another continuous lift and compaction effort for the entire length of the two different milling depths.

- In areas with different mill depths that are not a full lift thickness, the thicker mill depths (and therefore thicker lifts) will compact differently, which could potentially result in smoothness and density issues.

- Multiple lift thicknesses within a lane can potentially create challenges with avoiding scabbing (very thin layers left after milling that can result in potholes or other pavement performance issues) and often result in additional construction costs (e.g., the contractor may be requested to back up and mill the area deeper).

- Providing a full lift thickness can avoid the potential of creating "bumps" in the final pavement surface in these locations due to differences in compaction.

FIGURE 7.5
MILLING AND LIFT THICKNESSES ILLUSTRATION



7.6 CALCULATING THE STRUCTURAL OVERLAY NUMBER (SN_O)

The Overlay Structural Number (SN_O) as a minimum will provide the difference between the Required Structural Number (SN_R) and the Existing Pavement Strength (SN_E) after milling. This can be used to solve for the overlay thickness D_S as follows:

$$SN_O = SN_R - SN_E$$

$$a_S \times D_S = SN_R - SN_E$$

$$D_S = (SN_R - SN_E) / a_S$$

Where:

D_S = The required overlay thickness of the new structural course in inches (in).

a_S = Layer coefficient of structural course. This value is 0.44.

SN_R = The Required Structural Number determined from $ESAL_D$ and M_R.

SN_E = The Existing Structural Number of the pavement at the time of the overlay including any deductions for milling.

SN_O = The Overlay Structural Number needed to bring the pavement up to the needed design requirements.

Once D_S has been determined, round to the nearest 0.5-inch increment (for exceptions to this, see ***Section 7.8***). This process works well when designing an open-graded friction course (OGFC). For a dense-graded friction course, use the following:

$SN_O = SN_R - SN_E - SN_{FC\text{-}12.5}$

$a_S \times D_S = SN_R - SN_E - SN_{FC\text{-}12.5}$

$D_S = (SN_R - SN_E - SN_{FC\text{-}12.5}) / a_S$

Where: $SN_{FC\text{-}}$ = Structural strength of the 1.5-inch FC-12.5 or 1-inch FC-9.5 thick with structural coefficient of 0.44 per inch.

7.7 OVERLAY DESIGN SAMPLE PROBLEM

This process is applicable for overlay projects. The following steps will take place in approximately the order shown with the understanding that some activities can take place concurrently.

GIVEN:

This project will mill and resurface an existing 6-lane Limited Access (LA) facility. The design traffic obtained from the District Planning Office is $ESAL_D$ = 30,000,000. The subgrade resilient modulus (M_R) value, obtained from non-destructive testing (Falling Weight Deflectometer) by the State Materials Office, is M_R = 18,000 psi.

FIND:

The design pavement thickness from the information provided for a 20-year design.

DATA:

- %R = 99% (selected from ***Table 5.2***; 99% was selected based on the high traffic volume of this LA facility)
- Minimum Structural Course = 4 inches & Minimum Base Group = 9 (per ***Table 5.5***)
- 12-inch Stabilized Subgrade (LBR 40) is to be used
- OGFC (FC-5) to be used

The following field data has been collected. The layers are rated in poor condition. Determine the SN_E.

Material[1]	Thickness[1]	Coefficient	SN_E
FC-5	0.75 inch	0.00	0.00
Type SP	3.0 inches	0.15[2]	0.45
Type S	7.0 inches	0.15[2]	1.05
Limerock (LBR 100)	10.0 inches	0.18[3]	1.80
Type B Stab. (LBR 40)	12.0 inches	0.08[3]	0.96
			4.26

(1) From Coring and Condition Data form
(2) From ***Table 7.1***
(3) From ***Table 5.4***

Based on observed crack depths throughout the project limits, the recommendation provided by the District Materials Office is to mill 3.75 inches from the existing pavement structure.

SOLUTION:

SN_R can be determined from the design tables in ***Appendix A*** for the appropriate reliability.

From ***Table A.10A***:

SN_R = 5.07 inches

Recall that the SN_E is the existing structural number of the pavement at the time of the overlay including any deductions for milling. Thus, SN_E can be determined based on the existing pavement structure, its condition, and the proposed milling depth as follows:

The recommended milling depth of 3.75 inches will remove the existing FC-5 (0.75 inches) and Type SP (3.0 inches) layers. Therefore, the SN_E (after milling) is calculated as follows:

SN_E = 4.26" – [(0.75" x 0.00) + (3.0" x 0.15)] = 3.81"

Once the SN_R and the SN_E are determined, the thickness of the overlay (D_S), (in this case, with an OGFC, FC-5), can be calculated using the following equation and a new Type SP structural coefficient of 0.44:

$$SN_O = SN_R - SN_E$$

$$a_S \times D_S = SN_R - SN_E$$

$$D_S = (SN_R - SN_E) / a_S$$

D_S = (5.07" – 3.81") / 0.44

D_S = 2.86 inches

Knowing that the asphalt layer thickness is normally rounded to the nearest 0.5-inch, use D_S = 3.0 inches

CONCLUSION:

This sample problem is a Limited Access facility, therefore, FC-5 is required according to the friction course policy in ***Chapter 4***. FC-5 has no structural value and is shown as 0.75-inch thick.

Layer/Material	Coefficient		Asphalt Thickness		SN_O
Friction Course, FC-5	0.00	x	0.75"	=	0.00
Structural Course, Type SP	0.44	x	3"	=	1.32
			3.75"		1.32

To check:

$$SN_R = SN_O + SN_E$$

$SN_R = 1.32 + 3.81 = 5.13$

$5.13 > 5.07$ ✓

So, this meets or exceeds SN_R.

Note: See ***Section 5.4*** for binder selection guidance.

The milling and resurfacing description in the plans should read:

TRAVEL LANES

MILL EXISTING ASPHALT PAVEMENT (3¾" DEPTH)
TYPE SP STRUCTURAL COURSE (TRAFFIC E)(3")(PG 76-22)
FRICTION COURSE FC-5 (¾")(PG 76-22)

7.8 SPECIAL CONSIDERATIONS FOR REHABILITATION PROJECTS

It is essential that the Pavement Design Engineer coordinates very closely with all of the offices that will be affected by the work. It is highly recommended that field reviews of projects be made in a timely fashion. If appropriate, the State Pavement Design Section is available to assist on complex projects where statewide experience may be of value.

There are instances where, for constructability purposes, paving to 0.25-inch increments makes practical sense and is therefore allowed at the discretion of the District Pavement Design Engineer. For example, FC-5 and FC-7 are typically shown paved at 0.75-inch, therefore mill depths set at 0.5-inch increments require a paving operation at a 0.25-inch increment to match existing grades when normal feathering is difficult to achieve.

In locations where there have been constructability concerns with 1.0-inch lifts, 1.25- inch lifts of Type SP-9.5 or FC-9.5 should be called for in the plans in lieu of 1.0-inch lifts, however, ensure that the pavement design does not result in additional structure being added when it is not warranted by the SN_R or the recommendation from the Materials Office.

In all cases, the SN_R must be achieved, and the engineer should be familiar with construction and materials Standard Specifications (i.e., Sections 327, 330, and 334) to compensate for construction tolerance issues.

7.8.1 PAYMENT OF STRUCTURAL COURSE

It is the Department's policy to pay for all structural and friction course asphalt items by the ton. One of the reasons that this is done is due to the amount of material that may be needed for irregular shaped areas (i.e. transitions, driveways, intersections, etc.) in which the quantities are hard to determine.

7.8.2 OVERBUILD

The District Materials Office should be consulted for recommendations with respect to overbuild, taking into consideration existing pavement condition and cross slope. The following minimum values recommended by the State Materials Office are:

- Overbuild by specification is placed by a paving machine and is used to provide proper cross-slope and longitudinal profile.
- For SP-9.5 overbuild, minimum average uniform thickness with or without a structural course is 1-inch.
- For overbuild greater than 1.5-inches, Type SP-12.5 may be used.
- Use the minimum and maximum layer thickness as noted in ***Section 5.6.6*** for uniform thickness overbuild layers.
- As good practice, a structural layer is placed on top of overbuild when plans call for an OGFC.
- All overbuild layers shall be Type SP Asphalt Concrete designed at the traffic level as stated in the Contract Documents. On variable thickness overbuild layers, the minimum and maximum allowable thicknesses will be as specified below, unless called for differently in the Contract Documents.

  Type SP-9.5 .... 3/8 to 2 inches

  Type SP-12.5 .... 0.5 to 3 inches

  Type SP-19.0 .... 1.5 to 4 inches

- Variable thickness overbuild layers constructed using a Type SP-9.5 or SP-12.5 mixtures may be tapered to zero thickness provided the Contract Documents require a minimum of 1.5 inches of dense-graded mix placed over the variable thickness overbuild layer.

7.8.3 OPERATIONAL PROJECTS

On resurfacing projects such as skid hazard, intersection improvements, etc., where only a minimum amount of overbuild and an OGFC (FC-5 or FC-7), are required, and no structural course is provided, the plans should specify:

TYPE SP 9.5 (TRAFFIC C) OVERBUILD 1" Average

The District Pavement Design Engineer can make the determination to place an OGFC directly on the overbuild or directly on the milled surface provided the underlying layers are in good structural shape.

Projects using an OGFC without a structural course (such as Skid Hazard projects) where the existing roadway structural course is in good condition might include projects:

- With little or no cracking.
- No structural improvement is required.
- Minimum distortion and rutting are observed.

Friction course selection should continue to be in accordance with current Friction Course Policy located in ***Chapter 4***.

7.8.4 FUNCTIONAL OVERLAYS

On an older road that has been resurfaced several times, the computations may indicate that no added structural course is required. In this case the Pavement Design Engineer should remedy the problem by using the minimum amount of material appropriate for the distress. This should include a subjective consideration of reflective cracking potential that is not accounted for by Structural Number calculations.

If the ride of the existing pavement is poor, it may be desirable to provide sufficient structural asphalt to restore a smooth ride. Milling, prior to overlay can also help improve the ride. The District Pavement Materials Engineer should be consulted for a recommendation in these cases.

Document the basis for the overlay thickness regardless of exceeding the theoretical Structural Number requirements.

7.8.5 PAVEMENT ONLY PROJECTS

Pavement Only Projects (POP) are resurfacing projects that are not on the high crash list and that have been determined not to need an increase in structural capacity to achieve the required minimum pavement design life. POPs are also known as "Maintenance Resurfacing Projects," and they are completely state-funded. Refer to ***Part III, Chapter 26, Resurfacing***, of the ***FDOT Work Program Instructions*** for further information on funding of resurfacing projects.

To qualify for this category, pavement designs will still need to meet a minimum design life of 15 years, and the required Structural Number for the design period must be met without increasing the structural thickness of the pavement. In other words, mill out and replace the same pavement thickness (e.g., mill 2.5" and resurface 2.5"). The pavement design package for a POP must document that additional structural capacity is not needed to achieve the design life.

In order to reduce lane mile costs, POPs are only required to meet Americans with Disabilities Act (ADA) requirements for curb ramps and detectable warnings; all other RRR requirements in ***FDOT Design Manual*** (***FDM***) ***Chapter 114*** (e.g., adding/improving paved shoulders, upgrading roadside barriers) are exempt for POPs.

7.8.6 CRACK RELIEF LAYERS

The use of a crack relief layer and/or additional overlay thickness may be necessary if insufficient material, cross slope, or other problems limit milling to remove cracked pavement.

Cracks left in underlying layers will reflect up through overlays due to stress concentrations at the cracks from temperature movement and load deflections. This can cause the overlay to deteriorate faster than would be indicated strictly by Structural Number calculations.

To provide sufficient design life for an overlay over cracked pavement, it is often necessary to use a crack relief layer with at least a minimum structural overlay thickness based on the type of vehicle loadings. The crack relief layer helps to reduce the stress concentrations while the structural thickness will reduce deflections and help insulate the cracked pavement to reduce temperature movements.

The crack relief layer must be covered prior to being opened to traffic or other action should be taken to prevent windshield breakage from loose cover material.

The review of the performance history of the pavement and similar projects in the area can provide useful information on reflective crack propagation potential for a specific project.

Research is underway to evaluate the effectiveness of alternative methods of preventing or delaying reflective cracking, including additional structural thickness, ARMI, 0.5-inch overbuild, and a 1-inch open-graded crack relief layer (OGCR).

It is recommended that the State Materials Office or the State Pavement Design Engineer be contacted if the Pavement Design Engineer is considering the use of a crack relief layer and has not had recent experience in the District in the use of these materials.

Asphalt Membrane Interlayer

An Asphalt Membrane Interlayer (AMI) should normally be used over cracked and reseated concrete pavement.

An AMI may also be useful as a moisture barrier if subgrade moisture is entering the pavement system through capillary action and causing a rippling of the asphalt surface. The District Pavement Materials Engineer should be consulted for a recommendation on when an AMI layer is needed.

AMI should be placed on top of overbuild when the overbuild is being used for cross-slope correction.

The State Materials Office recommends that an AMI should not be used under a relatively thin overlay due to its cost and the need for sufficient heat in the overlay to properly bond the AMI with the overlay.

A 1.5-inch minimum initial structural asphalt lift is required over the AMI to provide this heat, with a 2-inch lift preferred. This will require that the initial lift thickness be specified on the plans. Special consideration should be given to construction sequencing if paved shoulders are being added.

Do not mill an existing AMI layer during rehabilitation unless the AMI is contributing to the pavement distress (ex. bleeding).

7.8.7 OVERWEIGHT AND DIVISIBLE LOADS

There are routes on the State Highway System that experience overweight and/or divisible loads. The State Maintenance Office issues permits to allow overweight vehicles to exceed the statutory maximum load by a certain amount. For overweight permit requests, coordinate with the State Maintenance Office, Structures Operations Division.

Divisible loads are loads that can be divided into multiple shipments (e.g., produce, timber), and are typically found in areas with paper mills, mines, landfills, citrus, sugar cane, produce, etc. Conversely, non-divisible loads are loads that cannot physically be divided (e.g., a large boat).

ESALs are a function of (among other things) the Equivalency Factor (E_{18}). The E_{18} values currently used by the Department (see ***Table D.3*** in ***Appendix D***) are based on a specific number of weigh-in-motion sites around the state and are averaged by road classification (rural & urban interstates, and rural & urban arterials/collectors). Thus, ESALs are a good tool to predict pavement deterioration, however, they may not necessarily capture the full effects of overweight or divisible loads since they are based on *average* trucks.

Understanding project-specific truck traffic is essential to pavement design. Review the project area to determine if it is a route that is commonly used as a divisible load route. Review the past pavement performance in these areas to identify accelerated deterioration. The pavement design should be based on the surrounding area and traffic, past pavement performance, and structural number requirements.

As of January 2022, there is ongoing research to develop a design methodology to account for divisible loads. Therefore, coordinate with the State Pavement Design Office for assistance on these projects.

CHAPTER 8
SHOULDER DESIGN

8.1 DESIGN GUIDANCE

On low volume roadways, or where $ESAL_D$ < 10 million, shoulders can be designed using the minimum values shown in ***Table 5.5***. A typical minimum design would be 1½-in of FC-12.5 or 1-in of FC-9.5 and Optional Base Group 1.

These minimums were established assuming a stabilized subgrade in conjunction with Optional Base Group 1. The pavement evaluation process will often indicate the shoulder was stabilized during original construction and additional stabilization is not needed.

If stabilization is not used under the shoulder, the Pavement Design Engineer must determine the type of materials in the embankment and evaluate the need for increasing the shoulder base and structural course.

On higher volume type roadways ($ESAL_D$ = 10 million or more), a shoulder thickness design should be performed using 3% of the $ESAL_D$ to calculate the required SN. This is an estimate of the number of trucks that will be riding or parking on the shoulder during the life of the pavement.

If the shoulders are to be used to carry substantial amounts of traffic as a part of a Maintenance of Traffic (MOT) scheme, the Pavement Design Engineer may need to design the shoulder in the same manner as a roadway. Under severe conditions, full depth shoulders matching the thickness of the travel lane pavement may be warranted.

When paved shoulders less than or equal to 5-ft wide are to be constructed in conjunction with an overlay of the roadway, the top layer of structural course of the roadway overlay and the adjacent shoulder structural course must be constructed in one pass and with the same traffic level mix unless called for differently in the Contract Documents.

For new or reconstructed curb and gutter sections in urban areas, with pavement shoulders less than or equal to 5-ft, full depth shoulders may be considered to accommodate future widening.

8.1.1 FRICTION COURSE

On non-limited access asphalt facilities, a friction course is to be placed over the entire paved shoulder. On limited access asphalt facilities, FC-5 is to extend 8-in beyond the edge of the travel lane, onto the paved shoulder.

For very low volume two lane roads (see ***Table 4.1***) a friction course may not be required.

Roads with a concrete pavement mainline and asphalt shoulders may use either a friction course or a structural course for the asphalt shoulders.

APPENDIX A
DESIGN TABLES

A.1 INSTRUCTIONS

The following are Required Structural Number (SN_R) Design Tables for 75%, 80%, 85%, 90%, 92%, 94%, 95%, 96%, 97% and 99% Reliability (%R).

Selected values of the 18-kip Equivalent Single Axle Loads ($ESAL_D$) and the Resilient Modulus (M_R) are provided.

The Change In Serviceability (ΔPSI) and the Standard Deviation (S_O) is the same for all the design tables.

The Standard Normal Deviate (Z_R) is dependent on the Reliability (%R) and is shown below:

Reliability (%R)	Standard Normal Deviation (Z_R)
75%	-0.674
80%	-0.841
85%	-1.037
90%	-1.282
92%	-1.405
94%	-1.555
95%	-1.645
96%	-1.751
97%	-1.881
99%	-2.327

To find the Required Structural Number (SN_R), use the following method:

- Determine the appropriate Reliability (%R).
- Using the known Resilient Modulus (M_R) value, select the table with the proper range. Ranges provided include the Resilient Modulus (M_R) between 4,000 psi to 18,000 psi and 18,000 psi to 32,000 psi. Overlap is provided between tables for ease of use.
- Select the design Resilient Modulus (M_R) value at the top of the table.
- Select the design Accumulated 18-kip Equivalent Single Axle Loads ($ESAL_D$) value at the left of the table.
- Read down the column of the selected Resilient Modulus (M_R) value and read across the row of the selected Accumulated 18-kipEquivalent Single Axle Loads ($ESAL_D$) value.
- The value intersected is the Structural Number Required (SN_R) in inches of the pavement system.

If the Resilient Modulus (M_R) value and/or the 18-kip Equivalent Single Axle Loads ($ESAL_D$) value is not listed in the design tables provided, the Structural Number Required (SN_R) of the flexible pavement can be interpolated.

TABLE A.1A

REQUIRED STRUCTURAL NUMBER (SN_R)
75% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

RESILIENT MODULUS (M_R), (PSI x 1000)															
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	2.72	2.50	2.33	2.19	2.08	1.99	1.91	1.83	1.77	1.71	1.66	1.62	1.57	1.53	1.50
150,000	2.91	2.67	2.49	2.35	2.23	2.13	2.04	1.97	1.90	1.84	1.79	1.74	1.69	1.65	1.61
200,000	3.05	2.80	2.61	2.46	2.34	2.23	2.14	2.07	2.00	1.93	1.88	1.83	1.78	1.74	1.70
250,000	3.17	2.91	2.71	2.55	2.43	2.32	2.23	2.14	2.07	2.01	1.95	1.90	1.85	1.81	1.76
300,000	3.27	3.00	2.79	2.63	2.50	2.39	2.29	2.21	2.14	2.07	2.01	1.96	1.91	1.86	1.82
350,000	3.35	3.08	2.87	2.70	2.57	2.45	2.35	2.27	2.19	2.13	2.07	2.01	1.96	1.91	1.87
400,000	3.42	3.14	2.93	2.76	2.62	2.51	2.41	2.32	2.24	2.17	2.11	2.06	2.00	1.96	1.91
450,000	3.49	3.21	2.99	2.82	2.68	2.56	2.46	2.37	2.29	2.22	2.15	2.10	2.04	2.00	1.95
500,000	3.55	3.26	3.04	2.87	2.72	2.60	2.50	2.41	2.33	2.26	2.19	2.13	2.08	2.03	1.99
600,000	3.66	3.36	3.14	2.95	2.81	2.68	2.58	2.48	2.40	2.33	2.26	2.20	2.15	2.10	2.05
700,000	3.75	3.45	3.22	3.03	2.88	2.75	2.64	2.55	2.46	2.39	2.32	2.26	2.20	2.15	2.10
800,000	3.83	3.52	3.29	3.10	2.94	2.81	2.70	2.60	2.52	2.44	2.37	2.31	2.25	2.20	2.15
900,000	3.91	3.59	3.35	3.16	3.00	2.87	2.75	2.66	2.57	2.49	2.42	2.36	2.30	2.24	2.19
1,000,000	3.97	3.65	3.41	3.22	3.06	2.92	2.80	2.70	2.61	2.53	2.46	2.40	2.34	2.28	2.23
1,500,000	4.23	3.90	3.64	3.44	3.27	3.12	3.00	2.89	2.80	2.71	2.63	2.57	2.50	2.44	2.39
2,000,000	4.42	4.08	3.82	3.60	3.43	3.27	3.15	3.03	2.93	2.84	2.76	2.69	2.62	2.56	2.51
2,500,000	4.57	4.23	3.96	3.74	3.55	3.40	3.26	3.15	3.04	2.95	2.87	2.79	2.72	2.66	2.60
3,000,000	4.70	4.35	4.07	3.85	3.66	3.50	3.36	3.24	3.14	3.04	2.96	2.88	2.81	2.74	2.68
3,500,000	4.80	4.45	4.17	3.94	3.75	3.59	3.45	3.33	3.22	3.12	3.03	2.95	2.88	2.81	2.75
4,000,000	4.90	4.54	4.26	4.03	3.83	3.67	3.53	3.40	3.29	3.19	3.10	3.02	2.94	2.88	2.81
4,500,000	4.98	4.62	4.33	4.10	3.91	3.74	3.59	3.47	3.35	3.25	3.16	3.08	3.00	2.93	2.87
5,000,000	5.06	4.69	4.40	4.17	3.97	3.80	3.66	3.53	3.41	3.31	3.22	3.13	3.06	2.99	2.92
6,000,000	5.19	4.82	4.53	4.29	4.09	3.91	3.76	3.63	3.52	3.41	3.31	3.23	3.15	3.08	3.01
7,000,000	5.30	4.93	4.63	4.39	4.19	4.01	3.86	3.72	3.60	3.50	3.40	3.31	3.23	3.16	3.09
8,000,000	5.40	5.02	4.72	4.48	4.27	4.10	3.94	3.81	3.68	3.57	3.48	3.39	3.30	3.23	3.16
9,000,000	5.49	5.11	4.81	4.56	4.35	4.17	4.02	3.88	3.75	3.64	3.54	3.45	3.37	3.29	3.22
10,000,000	5.57	5.18	4.88	4.63	4.42	4.24	4.08	3.94	3.82	3.71	3.60	3.51	3.43	3.35	3.28
15,000,000	5.88	5.48	5.17	4.91	4.70	4.51	4.35	4.20	4.07	3.95	3.85	3.75	3.66	3.58	3.50
20,000,000	6.11	5.70	5.38	5.12	4.90	4.71	4.54	4.39	4.26	4.14	4.03	3.93	3.83	3.75	3.67
25,000,000	6.29	5.88	5.55	5.28	5.06	4.86	4.69	4.54	4.40	4.28	4.17	4.07	3.97	3.88	3.80
30,000,000	6.44	6.02	5.69	5.42	5.19	4.99	4.82	4.67	4.53	4.40	4.29	4.18	4.09	4.00	3.92
35,000,000	6.57	6.14	5.81	5.53	5.30	5.10	4.93	4.77	4.63	4.51	4.39	4.28	4.19	4.10	4.01
40,000,000	6.68	6.25	5.91	5.63	5.40	5.20	5.02	4.87	4.72	4.60	4.48	4.37	4.27	4.18	4.10
45,000,000	6.78	6.35	6.01	5.73	5.49	5.29	5.11	4.95	4.81	4.68	4.56	4.45	4.35	4.26	4.17
50,000,000	6.88	6.43	6.09	5.81	5.57	5.36	5.18	5.02	4.88	4.75	4.63	4.52	4.42	4.33	4.24
60,000,000	7.04	6.59	6.24	5.95	5.71	5.50	5.32	5.16	5.01	4.88	4.76	4.65	4.55	4.45	4.36
70,000,000	7.17	6.72	6.36	6.07	5.83	5.62	5.43	5.27	5.12	4.99	4.87	4.75	4.65	4.55	4.46
80,000,000	7.29	6.83	6.47	6.18	5.93	5.72	5.53	5.37	5.22	5.08	4.96	4.85	4.74	4.65	4.55
90,000,000	7.40	6.94	6.57	6.28	6.03	5.81	5.62	5.45	5.30	5.17	5.04	4.93	4.82	4.73	4.64
100,000,000	7.50	7.03	6.66	6.36	6.11	5.89	5.70	5.53	5.38	5.25	5.12	5.01	4.90	4.80	4.71

TABLE A.1B

REQUIRED STRUCTURAL NUMBER (SN_R)
75% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 18,000 PSI TO 32,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
100,000	1.50	1.46	1.43	1.40	1.37	1.35	1.32	1.30	1.28	1.25	1.23	1.21	1.20	1.18	1.16
150,000	1.61	1.58	1.54	1.51	1.48	1.45	1.43	1.40	1.38	1.36	1.33	1.31	1.29	1.28	1.26
200,000	1.70	1.66	1.62	1.59	1.56	1.53	1.51	1.48	1.45	1.43	1.41	1.39	1.37	1.35	1.33
250,000	1.76	1.73	1.69	1.66	1.63	1.60	1.57	1.54	1.52	1.49	1.47	1.45	1.43	1.41	1.39
300,000	1.82	1.78	1.74	1.71	1.68	1.65	1.62	1.59	1.57	1.54	1.52	1.50	1.47	1.45	1.43
350,000	1.87	1.83	1.79	1.76	1.72	1.69	1.66	1.64	1.61	1.59	1.56	1.54	1.52	1.50	1.48
400,000	1.91	1.87	1.83	1.80	1.77	1.73	1.70	1.68	1.65	1.62	1.60	1.58	1.55	1.53	1.51
450,000	1.95	1.91	1.87	1.84	1.80	1.77	1.74	1.71	1.68	1.66	1.63	1.61	1.59	1.57	1.54
500,000	1.99	1.95	1.91	1.87	1.84	1.80	1.77	1.74	1.72	1.69	1.66	1.64	1.62	1.60	1.57
600,000	2.05	2.01	1.97	1.93	1.89	1.86	1.83	1.80	1.77	1.74	1.72	1.69	1.67	1.65	1.63
700,000	2.10	2.06	2.02	1.98	1.94	1.91	1.88	1.85	1.82	1.79	1.77	1.74	1.72	1.69	1.67
800,000	2.15	2.11	2.07	2.03	1.99	1.95	1.92	1.89	1.86	1.83	1.81	1.78	1.76	1.73	1.71
900,000	2.19	2.15	2.11	2.07	2.03	1.99	1.96	1.93	1.90	1.87	1.84	1.82	1.79	1.77	1.75
1,000,000	2.23	2.19	2.14	2.10	2.07	2.03	2.00	1.96	1.93	1.91	1.88	1.85	1.83	1.80	1.78
1,500,000	2.39	2.34	2.30	2.25	2.21	2.17	2.14	2.10	2.07	2.04	2.01	1.98	1.96	1.93	1.91
2,000,000	2.51	2.46	2.41	2.36	2.32	2.28	2.24	2.21	2.17	2.14	2.11	2.08	2.06	2.03	2.00
2,500,000	2.60	2.55	2.50	2.45	2.41	2.37	2.33	2.29	2.26	2.22	2.19	2.16	2.14	2.11	2.08
3,000,000	2.68	2.63	2.58	2.53	2.48	2.44	2.40	2.36	2.33	2.29	2.26	2.23	2.20	2.17	2.15
3,500,000	2.75	2.70	2.64	2.59	2.55	2.50	2.46	2.42	2.39	2.35	2.32	2.29	2.26	2.23	2.20
4,000,000	2.81	2.76	2.70	2.65	2.60	2.56	2.52	2.48	2.44	2.41	2.37	2.34	2.31	2.28	2.25
4,500,000	2.87	2.81	2.76	2.70	2.66	2.61	2.57	2.53	2.49	2.45	2.42	2.39	2.36	2.33	2.30
5,000,000	2.92	2.86	2.80	2.75	2.70	2.66	2.61	2.57	2.53	2.50	2.46	2.43	2.40	2.37	2.34
6,000,000	3.01	2.95	2.89	2.84	2.79	2.74	2.69	2.65	2.61	2.57	2.54	2.50	2.47	2.44	2.41
7,000,000	3.09	3.02	2.97	2.91	2.86	2.81	2.76	2.72	2.68	2.64	2.60	2.57	2.54	2.50	2.47
8,000,000	3.16	3.09	3.03	2.98	2.92	2.87	2.83	2.78	2.74	2.70	2.66	2.63	2.59	2.56	2.53
9,000,000	3.22	3.15	3.09	3.03	2.98	2.93	2.88	2.84	2.79	2.75	2.72	2.68	2.64	2.61	2.58
10,000,000	3.28	3.21	3.15	3.09	3.03	2.98	2.93	2.89	2.84	2.80	2.76	2.73	2.69	2.66	2.63
15,000,000	3.50	3.43	3.36	3.30	3.24	3.19	3.14	3.09	3.04	3.00	2.96	2.92	2.88	2.84	2.81
20,000,000	3.67	3.60	3.53	3.46	3.40	3.34	3.29	3.24	3.19	3.14	3.10	3.06	3.02	2.98	2.95
25,000,000	3.80	3.73	3.66	3.59	3.53	3.47	3.41	3.36	3.31	3.26	3.22	3.17	3.13	3.09	3.06
30,000,000	3.92	3.84	3.77	3.70	3.63	3.57	3.52	3.46	3.41	3.36	3.32	3.27	3.23	3.19	3.15
35,000,000	4.01	3.93	3.86	3.79	3.73	3.66	3.61	3.55	3.50	3.45	3.40	3.36	3.31	3.27	3.23
40,000,000	4.10	4.02	3.94	3.87	3.81	3.74	3.68	3.63	3.58	3.52	3.48	3.43	3.39	3.34	3.30
45,000,000	4.17	4.09	4.02	3.95	3.88	3.82	3.76	3.70	3.64	3.59	3.54	3.50	3.45	3.41	3.37
50,000,000	4.24	4.16	4.08	4.01	3.94	3.88	3.82	3.76	3.71	3.65	3.60	3.56	3.51	3.47	3.43
60,000,000	4.36	4.28	4.20	4.13	4.06	3.99	3.93	3.87	3.82	3.76	3.71	3.66	3.62	3.57	3.53
70,000,000	4.46	4.38	4.30	4.23	4.16	4.09	4.03	3.97	3.91	3.86	3.81	3.76	3.71	3.66	3.62
80,000,000	4.55	4.47	4.39	4.32	4.24	4.18	4.11	4.05	4.00	3.94	3.89	3.84	3.79	3.74	3.70
90,000,000	4.64	4.55	4.47	4.39	4.32	4.25	4.19	4.13	4.07	4.01	3.96	3.91	3.86	3.82	3.77
100,000,000	4.71	4.62	4.54	4.46	4.39	4.32	4.26	4.20	4.14	4.08	4.03	3.98	3.93	3.88	3.83

TABLE A.2A

REQUIRED STRUCTURAL NUMBER (SN_R)
80% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	2.80	2.57	2.40	2.26	2.14	2.05	1.96	1.89	1.83	1.77	1.72	1.67	1.62	1.58	1.55
150,000	3.00	2.75	2.56	2.42	2.29	2.19	2.10	2.03	1.96	1.90	1.84	1.79	1.74	1.70	1.66
200,000	3.14	2.88	2.69	2.53	2.41	2.30	2.21	2.13	2.06	1.99	1.93	1.88	1.83	1.79	1.75
250,000	3.26	2.99	2.79	2.63	2.50	2.39	2.29	2.21	2.13	2.07	2.01	1.95	1.91	1.86	1.82
300,000	3.36	3.09	2.88	2.71	2.57	2.46	2.36	2.28	2.20	2.13	2.07	2.02	1.97	1.92	1.88
350,000	3.45	3.17	2.95	2.78	2.64	2.52	2.42	2.34	2.26	2.19	2.13	2.07	2.02	1.97	1.93
400,000	3.52	3.24	3.02	2.84	2.70	2.58	2.48	2.39	2.31	2.24	2.17	2.12	2.06	2.02	1.97
450,000	3.59	3.30	3.08	2.90	2.75	2.63	2.53	2.44	2.35	2.28	2.22	2.16	2.11	2.06	2.01
500,000	3.65	3.36	3.13	2.95	2.80	2.68	2.57	2.48	2.40	2.32	2.26	2.20	2.14	2.09	2.05
600,000	3.76	3.46	3.23	3.04	2.89	2.76	2.65	2.55	2.47	2.40	2.33	2.27	2.21	2.16	2.11
700,000	3.86	3.55	3.31	3.12	2.96	2.83	2.72	2.62	2.53	2.46	2.39	2.33	2.27	2.22	2.17
800,000	3.94	3.63	3.38	3.19	3.03	2.90	2.78	2.68	2.59	2.51	2.44	2.38	2.32	2.27	2.22
900,000	4.01	3.70	3.45	3.25	3.09	2.95	2.84	2.73	2.64	2.56	2.49	2.42	2.37	2.31	2.26
1,000,000	4.08	3.76	3.51	3.31	3.14	3.00	2.89	2.78	2.69	2.61	2.53	2.47	2.41	2.35	2.30
1,500,000	4.34	4.01	3.75	3.54	3.36	3.21	3.09	2.98	2.88	2.79	2.71	2.64	2.58	2.52	2.46
2,000,000	4.54	4.19	3.92	3.71	3.52	3.37	3.24	3.12	3.02	2.93	2.84	2.77	2.70	2.64	2.58
2,500,000	4.69	4.34	4.06	3.84	3.65	3.50	3.36	3.24	3.13	3.04	2.95	2.87	2.80	2.74	2.68
3,000,000	4.82	4.46	4.18	3.95	3.76	3.60	3.46	3.34	3.23	3.13	3.04	2.96	2.89	2.82	2.76
3,500,000	4.93	4.57	4.28	4.05	3.86	3.69	3.55	3.42	3.31	3.21	3.12	3.04	2.96	2.90	2.83
4,000,000	5.02	4.66	4.37	4.14	3.94	3.77	3.63	3.50	3.38	3.28	3.19	3.11	3.03	2.96	2.90
4,500,000	5.10	4.74	4.45	4.21	4.01	3.84	3.70	3.57	3.45	3.35	3.25	3.17	3.09	3.02	2.95
5,000,000	5.18	4.81	4.52	4.28	4.08	3.91	3.76	3.63	3.51	3.40	3.31	3.22	3.14	3.07	3.01
6,000,000	5.32	4.94	4.64	4.40	4.20	4.02	3.87	3.74	3.62	3.51	3.41	3.32	3.24	3.17	3.10
7,000,000	5.43	5.05	4.75	4.51	4.30	4.12	3.97	3.83	3.71	3.60	3.50	3.41	3.32	3.25	3.18
8,000,000	5.53	5.15	4.84	4.60	4.39	4.21	4.05	3.91	3.79	3.68	3.57	3.48	3.40	3.32	3.25
9,000,000	5.62	5.23	4.93	4.68	4.47	4.28	4.13	3.99	3.86	3.75	3.64	3.55	3.46	3.39	3.31
10,000,000	5.70	5.31	5.00	4.75	4.54	4.35	4.19	4.05	3.93	3.81	3.71	3.61	3.52	3.44	3.37
15,000,000	6.02	5.61	5.30	5.04	4.82	4.63	4.46	4.31	4.18	4.06	3.96	3.86	3.76	3.68	3.60
20,000,000	6.25	5.84	5.51	5.25	5.02	4.83	4.66	4.51	4.37	4.25	4.14	4.04	3.94	3.85	3.77
25,000,000	6.43	6.01	5.68	5.41	5.18	4.99	4.81	4.66	4.52	4.40	4.28	4.18	4.08	3.99	3.91
30,000,000	6.59	6.16	5.82	5.55	5.32	5.12	4.94	4.79	4.65	4.52	4.40	4.30	4.20	4.11	4.02
35,000,000	6.72	6.28	5.94	5.67	5.43	5.23	5.05	4.89	4.75	4.62	4.51	4.40	4.30	4.21	4.12
40,000,000	6.83	6.39	6.05	5.77	5.53	5.33	5.15	4.99	4.85	4.72	4.60	4.49	4.39	4.30	4.21
45,000,000	6.93	6.49	6.14	5.86	5.62	5.41	5.23	5.07	4.93	4.80	4.68	4.57	4.47	4.37	4.29
50,000,000	7.03	6.58	6.23	5.94	5.70	5.49	5.31	5.15	5.00	4.87	4.75	4.64	4.54	4.44	4.36
60,000,000	7.19	6.74	6.38	6.09	5.84	5.63	5.45	5.28	5.13	5.00	4.88	4.77	4.66	4.57	4.48
70,000,000	7.33	6.87	6.51	6.21	5.96	5.75	5.56	5.40	5.25	5.11	4.99	4.88	4.77	4.67	4.58
80,000,000	7.45	6.99	6.62	6.32	6.07	5.85	5.66	5.50	5.35	5.21	5.08	4.97	4.86	4.77	4.67
90,000,000	7.56	7.09	6.72	6.42	6.16	5.95	5.76	5.59	5.43	5.30	5.17	5.05	4.95	4.85	4.75
100,000,000	7.66	7.18	6.81	6.51	6.25	6.03	5.84	5.67	5.51	5.37	5.25	5.13	5.02	4.92	4.83

TABLE A.2B

REQUIRED STRUCTURAL NUMBER (SN_R)
80% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 18,000 PSI TO 32,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
100,000	1.55	1.51	1.48	1.45	1.42	1.39	1.37	1.34	1.32	1.30	1.28	1.26	1.24	1.22	1.20
150,000	1.66	1.63	1.59	1.56	1.53	1.50	1.47	1.45	1.42	1.40	1.38	1.36	1.34	1.32	1.30
200,000	1.75	1.71	1.68	1.64	1.61	1.58	1.55	1.53	1.50	1.48	1.46	1.43	1.41	1.39	1.37
250,000	1.82	1.78	1.74	1.71	1.68	1.65	1.62	1.59	1.56	1.54	1.52	1.49	1.47	1.45	1.43
300,000	1.88	1.84	1.80	1.76	1.73	1.70	1.67	1.64	1.62	1.59	1.57	1.54	1.52	1.50	1.48
350,000	1.93	1.89	1.85	1.81	1.78	1.75	1.72	1.69	1.66	1.64	1.61	1.59	1.57	1.54	1.52
400,000	1.97	1.93	1.89	1.85	1.82	1.79	1.76	1.73	1.70	1.67	1.65	1.63	1.60	1.58	1.56
450,000	2.01	1.97	1.93	1.89	1.86	1.82	1.79	1.76	1.74	1.71	1.68	1.66	1.64	1.62	1.59
500,000	2.05	2.00	1.96	1.93	1.89	1.86	1.83	1.80	1.77	1.74	1.72	1.69	1.67	1.65	1.62
600,000	2.11	2.07	2.03	1.99	1.95	1.92	1.88	1.85	1.82	1.80	1.77	1.75	1.72	1.70	1.68
700,000	2.17	2.12	2.08	2.04	2.00	1.97	1.93	1.90	1.87	1.85	1.82	1.79	1.77	1.75	1.72
800,000	2.22	2.17	2.13	2.09	2.05	2.01	1.98	1.95	1.92	1.89	1.86	1.84	1.81	1.79	1.76
900,000	2.26	2.21	2.17	2.13	2.09	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.85	1.82	1.80
1,000,000	2.30	2.25	2.21	2.17	2.13	2.09	2.06	2.02	1.99	1.96	1.93	1.91	1.88	1.86	1.83
1,500,000	2.46	2.41	2.36	2.32	2.28	2.24	2.20	2.17	2.13	2.10	2.07	2.04	2.02	1.99	1.97
2,000,000	2.58	2.53	2.48	2.43	2.39	2.35	2.31	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06
2,500,000	2.68	2.62	2.57	2.52	2.48	2.44	2.40	2.36	2.32	2.29	2.26	2.23	2.20	2.17	2.14
3,000,000	2.76	2.70	2.65	2.60	2.56	2.51	2.47	2.43	2.40	2.36	2.33	2.30	2.27	2.24	2.21
3,500,000	2.83	2.77	2.72	2.67	2.62	2.58	2.54	2.50	2.46	2.42	2.39	2.36	2.33	2.30	2.27
4,000,000	2.90	2.84	2.78	2.73	2.68	2.64	2.59	2.55	2.51	2.48	2.44	2.41	2.38	2.35	2.32
4,500,000	2.95	2.89	2.84	2.78	2.73	2.69	2.64	2.60	2.56	2.53	2.49	2.46	2.43	2.39	2.37
5,000,000	3.01	2.94	2.89	2.83	2.78	2.73	2.69	2.65	2.61	2.57	2.53	2.50	2.47	2.44	2.41
6,000,000	3.10	3.03	2.97	2.92	2.87	2.82	2.77	2.73	2.69	2.65	2.61	2.58	2.54	2.51	2.48
7,000,000	3.18	3.11	3.05	2.99	2.94	2.89	2.84	2.80	2.76	2.72	2.68	2.64	2.61	2.58	2.55
8,000,000	3.25	3.18	3.12	3.06	3.01	2.96	2.91	2.86	2.82	2.78	2.74	2.70	2.67	2.64	2.60
9,000,000	3.31	3.24	3.18	3.12	3.07	3.02	2.97	2.92	2.88	2.83	2.80	2.76	2.72	2.69	2.65
10,000,000	3.37	3.30	3.24	3.18	3.12	3.07	3.02	2.97	2.93	2.88	2.84	2.81	2.77	2.73	2.70
15,000,000	3.60	3.53	3.46	3.40	3.34	3.28	3.23	3.18	3.13	3.09	3.04	3.00	2.96	2.93	2.89
20,000,000	3.77	3.70	3.63	3.56	3.50	3.44	3.38	3.33	3.28	3.24	3.19	3.15	3.11	3.07	3.03
25,000,000	3.91	3.83	3.76	3.69	3.63	3.57	3.51	3.46	3.41	3.36	3.31	3.27	3.22	3.18	3.15
30,000,000	4.02	3.95	3.87	3.80	3.74	3.67	3.62	3.56	3.51	3.46	3.41	3.37	3.32	3.28	3.24
35,000,000	4.12	4.04	3.97	3.90	3.83	3.77	3.71	3.65	3.60	3.55	3.50	3.45	3.41	3.37	3.33
40,000,000	4.21	4.13	4.05	3.98	3.91	3.85	3.79	3.73	3.68	3.63	3.58	3.53	3.48	3.44	3.40
45,000,000	4.29	4.20	4.13	4.05	3.99	3.92	3.86	3.80	3.75	3.70	3.64	3.60	3.55	3.51	3.47
50,000,000	4.36	4.27	4.19	4.12	4.05	3.99	3.93	3.87	3.81	3.76	3.71	3.66	3.61	3.57	3.53
60,000,000	4.48	4.39	4.31	4.24	4.17	4.10	4.04	3.98	3.92	3.87	3.82	3.77	3.72	3.68	3.63
70,000,000	4.58	4.50	4.42	4.34	4.27	4.20	4.14	4.08	4.02	3.97	3.91	3.86	3.81	3.77	3.72
80,000,000	4.67	4.59	4.51	4.43	4.36	4.29	4.23	4.16	4.11	4.05	4.00	3.95	3.90	3.85	3.80
90,000,000	4.75	4.67	4.59	4.51	4.44	4.37	4.30	4.24	4.18	4.12	4.07	4.02	3.97	3.92	3.88
100,000,000	4.83	4.74	4.66	4.58	4.51	4.44	4.37	4.31	4.25	4.19	4.14	4.09	4.04	3.99	3.94

TABLE A.3A

REQUIRED STRUCTURAL NUMBER (SN_R)
85% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	2.90	2.66	2.48	2.33	2.22	2.12	2.03	1.96	1.89	1.83	1.78	1.73	1.68	1.64	1.60
150,000	3.10	2.84	2.65	2.50	2.37	2.27	2.18	2.10	2.03	1.96	1.91	1.85	1.81	1.76	1.72
200,000	3.25	2.98	2.78	2.62	2.49	2.38	2.28	2.20	2.13	2.06	2.00	1.95	1.90	1.85	1.81
250,000	3.37	3.10	2.89	2.72	2.58	2.47	2.37	2.28	2.21	2.14	2.08	2.02	1.97	1.93	1.88
300,000	3.47	3.19	2.97	2.80	2.66	2.54	2.44	2.35	2.28	2.21	2.14	2.09	2.03	1.99	1.94
350,000	3.56	3.27	3.05	2.88	2.73	2.61	2.51	2.42	2.34	2.26	2.20	2.14	2.09	2.04	1.99
400,000	3.64	3.35	3.12	2.94	2.79	2.67	2.56	2.47	2.39	2.32	2.25	2.19	2.14	2.09	2.04
450,000	3.71	3.41	3.18	3.00	2.85	2.72	2.61	2.52	2.44	2.36	2.29	2.23	2.18	2.13	2.08
500,000	3.77	3.47	3.24	3.05	2.90	2.77	2.66	2.56	2.48	2.40	2.34	2.27	2.22	2.17	2.12
600,000	3.89	3.58	3.34	3.14	2.99	2.85	2.74	2.64	2.55	2.48	2.41	2.34	2.29	2.23	2.18
700,000	3.98	3.67	3.42	3.23	3.06	2.93	2.81	2.71	2.62	2.54	2.47	2.40	2.35	2.29	2.24
800,000	4.07	3.75	3.50	3.30	3.13	2.99	2.88	2.77	2.68	2.60	2.53	2.46	2.40	2.34	2.29
900,000	4.14	3.82	3.56	3.36	3.19	3.05	2.93	2.83	2.73	2.65	2.58	2.51	2.45	2.39	2.34
1,000,000	4.21	3.88	3.63	3.42	3.25	3.11	2.98	2.88	2.78	2.70	2.62	2.55	2.49	2.43	2.38
1,500,000	4.48	4.14	3.87	3.65	3.47	3.32	3.19	3.08	2.98	2.88	2.80	2.73	2.66	2.60	2.54
2,000,000	4.68	4.33	4.05	3.83	3.64	3.48	3.35	3.23	3.12	3.03	2.94	2.86	2.79	2.73	2.67
2,500,000	4.83	4.47	4.19	3.97	3.78	3.61	3.47	3.35	3.24	3.14	3.05	2.97	2.90	2.83	2.77
3,000,000	4.96	4.60	4.31	4.08	3.89	3.72	3.58	3.45	3.34	3.24	3.15	3.06	2.99	2.92	2.86
3,500,000	5.07	4.70	4.42	4.18	3.98	3.81	3.67	3.54	3.42	3.32	3.23	3.14	3.07	2.99	2.93
4,000,000	5.17	4.80	4.51	4.27	4.07	3.90	3.75	3.61	3.50	3.39	3.30	3.21	3.13	3.06	2.99
4,500,000	5.25	4.88	4.59	4.35	4.14	3.97	3.82	3.68	3.57	3.46	3.36	3.28	3.20	3.12	3.05
5,000,000	5.33	4.95	4.66	4.42	4.21	4.04	3.88	3.75	3.63	3.52	3.42	3.33	3.25	3.18	3.11
6,000,000	5.47	5.08	4.78	4.54	4.33	4.15	4.00	3.86	3.74	3.63	3.53	3.43	3.35	3.27	3.20
7,000,000	5.58	5.20	4.89	4.64	4.43	4.25	4.09	3.95	3.83	3.72	3.61	3.52	3.44	3.36	3.29
8,000,000	5.68	5.29	4.99	4.74	4.52	4.34	4.18	4.04	3.91	3.80	3.69	3.60	3.51	3.43	3.36
9,000,000	5.77	5.38	5.07	4.82	4.60	4.42	4.26	4.11	3.99	3.87	3.76	3.67	3.58	3.50	3.42
10,000,000	5.86	5.46	5.15	4.89	4.68	4.49	4.33	4.18	4.05	3.94	3.83	3.73	3.64	3.56	3.48
15,000,000	6.18	5.77	5.45	5.18	4.96	4.77	4.60	4.45	4.31	4.19	4.08	3.98	3.89	3.80	3.72
20,000,000	6.42	5.99	5.67	5.39	5.17	4.97	4.80	4.64	4.51	4.38	4.27	4.16	4.07	3.98	3.90
25,000,000	6.60	6.17	5.84	5.56	5.33	5.13	4.96	4.80	4.66	4.53	4.42	4.31	4.21	4.12	4.04
30,000,000	6.76	6.32	5.98	5.70	5.47	5.26	5.09	4.93	4.79	4.66	4.54	4.43	4.33	4.24	4.15
35,000,000	6.89	6.45	6.10	5.82	5.58	5.38	5.20	5.04	4.89	4.76	4.64	4.54	4.43	4.34	4.25
40,000,000	7.01	6.56	6.21	5.93	5.68	5.48	5.30	5.13	4.99	4.86	4.74	4.63	4.52	4.43	4.34
45,000,000	7.11	6.66	6.31	6.02	5.78	5.57	5.38	5.22	5.07	4.94	4.82	4.71	4.60	4.51	4.42
50,000,000	7.21	6.75	6.39	6.10	5.86	5.65	5.46	5.30	5.15	5.02	4.89	4.78	4.68	4.58	4.49
60,000,000	7.37	6.91	6.55	6.25	6.00	5.79	5.60	5.43	5.28	5.15	5.02	4.91	4.80	4.71	4.61
70,000,000	7.52	7.05	6.68	6.38	6.12	5.91	5.72	5.55	5.40	5.26	5.13	5.02	4.91	4.81	4.72
80,000,000	7.64	7.17	6.79	6.49	6.23	6.01	5.82	5.65	5.50	5.36	5.23	5.11	5.01	4.91	4.81
90,000,000	7.75	7.27	6.89	6.59	6.33	6.11	5.91	5.74	5.59	5.45	5.32	5.20	5.09	4.99	4.90
100,000,000	7.86	7.37	6.99	6.68	6.42	6.19	6.00	5.82	5.67	5.52	5.40	5.28	5.17	5.07	4.97

TABLE A.3B

REQUIRED STRUCTURAL NUMBER (SN_R)
85% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 18,000 PSI TO 32,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
100,000	1.60	1.57	1.53	1.50	1.47	1.45	1.42	1.39	1.37	1.35	1.33	1.31	1.29	1.27	1.25
150,000	1.72	1.68	1.65	1.62	1.59	1.56	1.53	1.50	1.48	1.45	1.43	1.41	1.39	1.37	1.35
200,000	1.81	1.77	1.74	1.70	1.67	1.64	1.61	1.58	1.56	1.53	1.51	1.49	1.47	1.45	1.43
250,000	1.88	1.84	1.80	1.77	1.74	1.71	1.68	1.65	1.62	1.60	1.57	1.55	1.53	1.51	1.49
300,000	1.94	1.90	1.86	1.83	1.79	1.76	1.73	1.70	1.67	1.65	1.62	1.60	1.58	1.56	1.54
350,000	1.99	1.95	1.91	1.88	1.84	1.81	1.78	1.75	1.72	1.69	1.67	1.65	1.62	1.60	1.58
400,000	2.04	2.00	1.96	1.92	1.88	1.85	1.82	1.79	1.76	1.73	1.71	1.68	1.66	1.64	1.62
450,000	2.08	2.04	2.00	1.96	1.92	1.89	1.86	1.83	1.80	1.77	1.74	1.72	1.70	1.67	1.65
500,000	2.12	2.07	2.03	1.99	1.96	1.92	1.89	1.86	1.83	1.80	1.78	1.75	1.73	1.71	1.68
600,000	2.18	2.14	2.10	2.06	2.02	1.98	1.95	1.92	1.89	1.86	1.83	1.81	1.78	1.76	1.74
700,000	2.24	2.19	2.15	2.11	2.07	2.04	2.00	1.97	1.94	1.91	1.88	1.86	1.83	1.81	1.79
800,000	2.29	2.24	2.20	2.16	2.12	2.08	2.05	2.02	1.98	1.96	1.93	1.90	1.88	1.85	1.83
900,000	2.34	2.29	2.24	2.20	2.16	2.12	2.09	2.06	2.02	2.00	1.97	1.94	1.91	1.89	1.86
1,000,000	2.38	2.33	2.28	2.24	2.20	2.16	2.13	2.09	2.06	2.03	2.00	1.97	1.95	1.92	1.90
1,500,000	2.54	2.49	2.44	2.40	2.35	2.31	2.28	2.24	2.21	2.17	2.14	2.12	2.09	2.06	2.03
2,000,000	2.67	2.61	2.56	2.52	2.47	2.43	2.39	2.35	2.32	2.28	2.25	2.22	2.19	2.16	2.14
2,500,000	2.77	2.71	2.66	2.61	2.56	2.52	2.48	2.44	2.40	2.37	2.34	2.30	2.27	2.25	2.22
3,000,000	2.86	2.80	2.74	2.69	2.64	2.60	2.56	2.52	2.48	2.44	2.41	2.38	2.34	2.31	2.29
3,500,000	2.93	2.87	2.81	2.76	2.71	2.67	2.62	2.58	2.54	2.51	2.47	2.44	2.41	2.38	2.35
4,000,000	2.99	2.93	2.88	2.82	2.77	2.73	2.68	2.64	2.60	2.56	2.53	2.49	2.46	2.43	2.40
4,500,000	3.05	2.99	2.93	2.88	2.83	2.78	2.73	2.69	2.65	2.61	2.58	2.54	2.51	2.48	2.45
5,000,000	3.11	3.04	2.98	2.93	2.88	2.83	2.78	2.74	2.70	2.66	2.62	2.59	2.55	2.52	2.49
6,000,000	3.20	3.14	3.08	3.02	2.97	2.91	2.87	2.82	2.78	2.74	2.70	2.67	2.63	2.60	2.57
7,000,000	3.29	3.22	3.16	3.10	3.04	2.99	2.94	2.90	2.85	2.81	2.77	2.73	2.70	2.67	2.63
8,000,000	3.36	3.29	3.23	3.17	3.11	3.06	3.01	2.96	2.92	2.87	2.83	2.80	2.76	2.73	2.69
9,000,000	3.42	3.35	3.29	3.23	3.17	3.12	3.07	3.02	2.97	2.93	2.89	2.85	2.81	2.78	2.75
10,000,000	3.48	3.41	3.35	3.29	3.23	3.17	3.12	3.07	3.03	2.98	2.94	2.90	2.86	2.83	2.79
15,000,000	3.72	3.65	3.58	3.51	3.45	3.39	3.34	3.29	3.24	3.19	3.15	3.10	3.06	3.03	2.99
20,000,000	3.90	3.82	3.75	3.68	3.62	3.56	3.50	3.44	3.39	3.35	3.30	3.25	3.21	3.17	3.13
25,000,000	4.04	3.96	3.88	3.81	3.75	3.69	3.63	3.57	3.52	3.47	3.42	3.38	3.33	3.29	3.25
30,000,000	4.15	4.07	4.00	3.93	3.86	3.80	3.74	3.68	3.63	3.57	3.53	3.48	3.43	3.39	3.35
35,000,000	4.25	4.17	4.10	4.02	3.96	3.89	3.83	3.77	3.72	3.67	3.62	3.57	3.52	3.48	3.44
40,000,000	4.34	4.26	4.18	4.11	4.04	3.97	3.91	3.85	3.80	3.75	3.69	3.65	3.60	3.56	3.51
45,000,000	4.42	4.34	4.26	4.18	4.11	4.05	3.99	3.93	3.87	3.82	3.77	3.72	3.67	3.62	3.58
50,000,000	4.49	4.41	4.33	4.25	4.18	4.12	4.05	3.99	3.94	3.88	3.83	3.78	3.73	3.69	3.64
60,000,000	4.61	4.53	4.45	4.37	4.30	4.23	4.17	4.11	4.05	4.00	3.94	3.89	3.84	3.80	3.75
70,000,000	4.72	4.63	4.55	4.48	4.40	4.34	4.27	4.21	4.15	4.09	4.04	3.99	3.94	3.89	3.85
80,000,000	4.81	4.73	4.64	4.57	4.49	4.42	4.36	4.30	4.24	4.18	4.12	4.07	4.02	3.97	3.93
90,000,000	4.90	4.81	4.73	4.65	4.57	4.50	4.44	4.37	4.31	4.26	4.20	4.15	4.10	4.05	4.00
100,000,000	4.97	4.88	4.80	4.72	4.65	4.57	4.51	4.44	4.38	4.33	4.27	4.22	4.17	4.12	4.07

TABLE A.4A

REQUIRED STRUCTURAL NUMBER (SN_R)
90% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	3.02	2.77	2.59	2.44	2.31	2.21	2.12	2.04	1.97	1.91	1.86	1.81	1.76	1.72	1.68
150,000	3.23	2.97	2.77	2.61	2.47	2.36	2.27	2.19	2.11	2.05	1.99	1.94	1.89	1.84	1.80
200,000	3.39	3.11	2.90	2.73	2.60	2.48	2.38	2.30	2.22	2.15	2.09	2.03	1.98	1.94	1.89
250,000	3.52	3.23	3.01	2.84	2.69	2.57	2.47	2.38	2.30	2.23	2.17	2.11	2.06	2.01	1.97
300,000	3.62	3.33	3.10	2.92	2.78	2.65	2.55	2.46	2.37	2.30	2.24	2.18	2.12	2.07	2.03
350,000	3.71	3.41	3.18	3.00	2.85	2.72	2.61	2.52	2.44	2.36	2.30	2.23	2.18	2.13	2.08
400,000	3.79	3.49	3.25	3.07	2.91	2.78	2.67	2.58	2.49	2.42	2.35	2.29	2.23	2.18	2.13
450,000	3.87	3.56	3.32	3.13	2.97	2.84	2.73	2.63	2.54	2.46	2.39	2.33	2.27	2.22	2.17
500,000	3.93	3.62	3.38	3.18	3.02	2.89	2.77	2.67	2.59	2.51	2.44	2.37	2.31	2.26	2.21
600,000	4.05	3.73	3.48	3.28	3.12	2.98	2.86	2.76	2.67	2.58	2.51	2.45	2.39	2.33	2.28
700,000	4.14	3.82	3.57	3.36	3.20	3.05	2.93	2.83	2.73	2.65	2.58	2.51	2.45	2.39	2.34
800,000	4.23	3.90	3.64	3.44	3.27	3.12	3.00	2.89	2.80	2.71	2.63	2.57	2.50	2.44	2.39
900,000	4.31	3.97	3.71	3.51	3.33	3.18	3.06	2.95	2.85	2.76	2.69	2.62	2.55	2.49	2.44
1,000,000	4.38	4.04	3.78	3.57	3.39	3.24	3.11	3.00	2.90	2.81	2.73	2.66	2.60	2.54	2.48
1,500,000	4.65	4.30	4.03	3.81	3.62	3.46	3.33	3.21	3.10	3.01	2.92	2.85	2.78	2.71	2.65
2,000,000	4.85	4.50	4.21	3.99	3.79	3.63	3.49	3.36	3.25	3.16	3.07	2.99	2.91	2.85	2.78
2,500,000	5.01	4.65	4.36	4.13	3.93	3.76	3.62	3.49	3.38	3.27	3.18	3.10	3.02	2.95	2.89
3,000,000	5.14	4.77	4.48	4.25	4.05	3.88	3.73	3.60	3.48	3.37	3.28	3.19	3.12	3.04	2.98
3,500,000	5.25	4.88	4.59	4.35	4.14	3.97	3.82	3.69	3.57	3.46	3.36	3.28	3.20	3.12	3.06
4,000,000	5.35	4.98	4.68	4.44	4.23	4.06	3.90	3.77	3.65	3.54	3.44	3.35	3.27	3.19	3.12
4,500,000	5.44	5.06	4.76	4.52	4.31	4.13	3.98	3.84	3.72	3.61	3.51	3.42	3.33	3.26	3.19
5,000,000	5.52	5.14	4.83	4.59	4.38	4.20	4.04	3.90	3.78	3.67	3.57	3.47	3.39	3.31	3.24
6,000,000	5.66	5.27	4.96	4.71	4.50	4.32	4.16	4.02	3.89	3.78	3.67	3.58	3.49	3.41	3.34
7,000,000	5.78	5.38	5.07	4.82	4.61	4.42	4.26	4.12	3.99	3.87	3.77	3.67	3.58	3.50	3.43
8,000,000	5.88	5.48	5.17	4.91	4.70	4.51	4.35	4.20	4.07	3.95	3.85	3.75	3.66	3.58	3.50
9,000,000	5.97	5.57	5.26	5.00	4.78	4.59	4.43	4.28	4.15	4.03	3.92	3.82	3.73	3.65	3.57
10,000,000	6.06	5.65	5.33	5.07	4.85	4.66	4.50	4.35	4.22	4.10	3.99	3.89	3.79	3.71	3.63
15,000,000	6.39	5.97	5.64	5.37	5.14	4.95	4.77	4.62	4.48	4.36	4.25	4.14	4.05	3.96	3.88
20,000,000	6.63	6.20	5.86	5.59	5.35	5.15	4.98	4.82	4.68	4.55	4.44	4.33	4.23	4.14	4.06
25,000,000	6.82	6.38	6.04	5.76	5.52	5.32	5.14	4.98	4.84	4.71	4.59	4.48	4.38	4.29	4.20
30,000,000	6.98	6.53	6.18	5.90	5.66	5.45	5.27	5.11	4.96	4.83	4.71	4.60	4.50	4.41	4.32
35,000,000	7.12	6.66	6.31	6.02	5.78	5.57	5.38	5.22	5.07	4.94	4.82	4.71	4.61	4.51	4.42
40,000,000	7.24	6.78	6.42	6.13	5.88	5.67	5.48	5.32	5.17	5.04	4.91	4.80	4.70	4.60	4.51
45,000,000	7.34	6.88	6.52	6.22	5.97	5.76	5.57	5.41	5.26	5.12	5.00	4.88	4.78	4.68	4.59
50,000,000	7.44	6.97	6.61	6.31	6.06	5.84	5.65	5.49	5.34	5.20	5.07	4.96	4.85	4.76	4.66
60,000,000	7.61	7.13	6.76	6.46	6.21	5.99	5.79	5.62	5.47	5.33	5.21	5.09	4.98	4.88	4.79
70,000,000	7.76	7.27	6.90	6.59	6.33	6.11	5.91	5.74	5.59	5.45	5.32	5.20	5.09	4.99	4.90
80,000,000	7.88	7.40	7.01	6.70	6.44	6.22	6.02	5.85	5.69	5.55	5.42	5.30	5.19	5.09	4.99
90,000,000	8.00	7.51	7.12	6.80	6.54	6.31	6.11	5.94	5.78	5.64	5.51	5.39	5.28	5.17	5.08
100,000,000	8.10	7.60	7.21	6.90	6.63	6.40	6.20	6.02	5.86	5.72	5.59	5.47	5.35	5.25	5.15

TABLE A.4B

REQUIRED STRUCTURAL NUMBER (SN_R)
90% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 18,000 PSI TO 32,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
100,000	1.68	1.64	1.61	1.57	1.54	1.51	1.49	1.46	1.44	1.41	1.39	1.37	1.35	1.33	1.31
150,000	1.80	1.76	1.73	1.69	1.66	1.63	1.60	1.57	1.55	1.52	1.50	1.48	1.46	1.44	1.42
200,000	1.89	1.85	1.81	1.78	1.75	1.71	1.68	1.66	1.63	1.61	1.58	1.56	1.54	1.51	1.49
250,000	1.97	1.92	1.89	1.85	1.81	1.78	1.75	1.72	1.70	1.67	1.65	1.62	1.60	1.58	1.56
300,000	2.03	1.99	1.95	1.91	1.87	1.84	1.81	1.78	1.75	1.72	1.70	1.67	1.65	1.63	1.61
350,000	2.08	2.04	2.00	1.96	1.92	1.89	1.86	1.83	1.80	1.77	1.75	1.72	1.70	1.67	1.65
400,000	2.13	2.08	2.04	2.00	1.97	1.93	1.90	1.87	1.84	1.81	1.79	1.76	1.74	1.71	1.69
450,000	2.17	2.13	2.08	2.04	2.01	1.97	1.94	1.91	1.88	1.85	1.82	1.80	1.77	1.75	1.73
500,000	2.21	2.16	2.12	2.08	2.04	2.01	1.97	1.94	1.91	1.88	1.86	1.83	1.81	1.78	1.76
600,000	2.28	2.23	2.19	2.15	2.11	2.07	2.04	2.00	1.97	1.94	1.92	1.89	1.86	1.84	1.82
700,000	2.34	2.29	2.24	2.20	2.16	2.13	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.89	1.87
800,000	2.39	2.34	2.30	2.25	2.21	2.17	2.14	2.10	2.07	2.04	2.01	1.99	1.96	1.93	1.91
900,000	2.44	2.39	2.34	2.30	2.26	2.22	2.18	2.15	2.11	2.08	2.05	2.03	2.00	1.97	1.95
1,000,000	2.48	2.43	2.38	2.34	2.30	2.26	2.22	2.18	2.15	2.12	2.09	2.06	2.03	2.01	1.98
1,500,000	2.65	2.60	2.55	2.50	2.46	2.41	2.38	2.34	2.30	2.27	2.24	2.21	2.18	2.15	2.12
2,000,000	2.78	2.73	2.67	2.62	2.58	2.53	2.49	2.45	2.42	2.38	2.35	2.32	2.29	2.26	2.23
2,500,000	2.89	2.83	2.77	2.72	2.67	2.63	2.59	2.55	2.51	2.47	2.44	2.40	2.37	2.34	2.31
3,000,000	2.98	2.92	2.86	2.81	2.76	2.71	2.67	2.62	2.58	2.55	2.51	2.48	2.45	2.42	2.39
3,500,000	3.06	2.99	2.93	2.88	2.83	2.78	2.73	2.69	2.65	2.61	2.58	2.54	2.51	2.48	2.45
4,000,000	3.12	3.06	3.00	2.94	2.89	2.84	2.80	2.75	2.71	2.67	2.63	2.60	2.57	2.53	2.50
4,500,000	3.19	3.12	3.06	3.00	2.95	2.90	2.85	2.81	2.76	2.72	2.69	2.65	2.62	2.58	2.55
5,000,000	3.24	3.17	3.11	3.05	3.00	2.95	2.90	2.86	2.81	2.77	2.73	2.70	2.66	2.63	2.60
6,000,000	3.34	3.27	3.21	3.15	3.09	3.04	2.99	2.94	2.90	2.86	2.82	2.78	2.74	2.71	2.68
7,000,000	3.43	3.36	3.29	3.23	3.17	3.12	3.07	3.02	2.98	2.93	2.89	2.85	2.82	2.78	2.75
8,000,000	3.50	3.43	3.36	3.30	3.24	3.19	3.14	3.09	3.04	3.00	2.96	2.92	2.88	2.84	2.81
9,000,000	3.57	3.50	3.43	3.37	3.31	3.25	3.20	3.15	3.10	3.06	3.01	2.97	2.94	2.90	2.86
10,000,000	3.63	3.56	3.49	3.43	3.37	3.31	3.25	3.20	3.16	3.11	3.07	3.03	2.99	2.95	2.91
15,000,000	3.88	3.80	3.73	3.66	3.60	3.54	3.48	3.43	3.37	3.33	3.28	3.24	3.20	3.16	3.12
20,000,000	4.06	3.98	3.90	3.83	3.77	3.71	3.65	3.59	3.54	3.49	3.44	3.39	3.35	3.31	3.27
25,000,000	4.20	4.12	4.04	3.97	3.90	3.84	3.78	3.72	3.67	3.62	3.57	3.52	3.48	3.43	3.39
30,000,000	4.32	4.24	4.16	4.09	4.02	3.95	3.89	3.83	3.78	3.73	3.67	3.63	3.58	3.54	3.49
35,000,000	4.42	4.34	4.26	4.19	4.12	4.05	3.99	3.93	3.87	3.82	3.77	3.72	3.67	3.63	3.58
40,000,000	4.51	4.43	4.35	4.27	4.20	4.14	4.07	4.01	3.96	3.90	3.85	3.80	3.75	3.71	3.66
45,000,000	4.59	4.51	4.43	4.35	4.28	4.21	4.15	4.09	4.03	3.97	3.92	3.87	3.82	3.78	3.73
50,000,000	4.66	4.58	4.50	4.42	4.35	4.28	4.22	4.15	4.10	4.04	3.99	3.94	3.89	3.84	3.80
60,000,000	4.79	4.70	4.62	4.54	4.47	4.40	4.34	4.27	4.21	4.16	4.10	4.05	4.00	3.95	3.91
70,000,000	4.90	4.81	4.73	4.65	4.58	4.51	4.44	4.38	4.32	4.26	4.20	4.15	4.10	4.05	4.00
80,000,000	4.99	4.90	4.82	4.74	4.67	4.60	4.53	4.46	4.40	4.35	4.29	4.24	4.19	4.14	4.09
90,000,000	5.08	4.99	4.90	4.82	4.75	4.68	4.61	4.54	4.48	4.42	4.37	4.31	4.26	4.21	4.16
100,000,000	5.15	5.06	4.98	4.90	4.82	4.75	4.68	4.62	4.55	4.49	4.44	4.38	4.33	4.28	4.23

TABLE A.5A

REQUIRED STRUCTURAL NUMBER (SN_R)
92% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	3.09	2.83	2.64	2.49	2.36	2.26	2.17	2.09	2.02	1.95	1.90	1.85	1.80	1.76	1.72
150,000	3.30	3.03	2.82	2.66	2.53	2.42	2.32	2.23	2.16	2.09	2.03	1.98	1.93	1.88	1.84
200,000	3.46	3.18	2.96	2.79	2.65	2.53	2.43	2.35	2.27	2.20	2.14	2.08	2.03	1.98	1.93
250,000	3.59	3.30	3.07	2.90	2.75	2.63	2.53	2.43	2.35	2.28	2.22	2.16	2.10	2.05	2.01
300,000	3.70	3.40	3.17	2.99	2.84	2.71	2.60	2.51	2.43	2.35	2.29	2.23	2.17	2.12	2.07
350,000	3.79	3.48	3.25	3.06	2.91	2.78	2.67	2.57	2.49	2.41	2.35	2.28	2.23	2.17	2.13
400,000	3.87	3.56	3.32	3.13	2.98	2.84	2.73	2.63	2.55	2.47	2.40	2.33	2.28	2.22	2.18
450,000	3.94	3.63	3.39	3.19	3.03	2.90	2.78	2.68	2.60	2.52	2.45	2.38	2.32	2.27	2.22
500,000	4.01	3.69	3.45	3.25	3.09	2.95	2.83	2.73	2.64	2.56	2.49	2.42	2.36	2.31	2.26
600,000	4.13	3.80	3.55	3.35	3.18	3.04	2.92	2.82	2.72	2.64	2.57	2.50	2.44	2.38	2.33
700,000	4.23	3.90	3.64	3.44	3.26	3.12	3.00	2.89	2.79	2.71	2.63	2.56	2.50	2.44	2.39
800,000	4.31	3.98	3.72	3.51	3.34	3.19	3.06	2.95	2.86	2.77	2.69	2.62	2.56	2.50	2.44
900,000	4.39	4.06	3.79	3.58	3.40	3.25	3.12	3.01	2.91	2.82	2.74	2.67	2.61	2.55	2.49
1,000,000	4.46	4.12	3.86	3.64	3.46	3.31	3.18	3.06	2.96	2.87	2.79	2.72	2.65	2.59	2.53
1,500,000	4.74	4.39	4.11	3.89	3.70	3.54	3.40	3.28	3.17	3.07	2.99	2.91	2.84	2.77	2.71
2,000,000	4.94	4.58	4.30	4.07	3.87	3.71	3.56	3.44	3.32	3.22	3.13	3.05	2.98	2.91	2.84
2,500,000	5.10	4.74	4.45	4.21	4.01	3.84	3.69	3.56	3.45	3.34	3.25	3.17	3.09	3.02	2.95
3,000,000	5.23	4.86	4.57	4.33	4.13	3.95	3.80	3.67	3.55	3.45	3.35	3.26	3.18	3.11	3.04
3,500,000	5.35	4.97	4.68	4.43	4.23	4.05	3.90	3.76	3.64	3.53	3.44	3.35	3.27	3.19	3.12
4,000,000	5.45	5.07	4.77	4.52	4.32	4.14	3.98	3.84	3.72	3.61	3.51	3.42	3.34	3.26	3.19
4,500,000	5.54	5.15	4.85	4.60	4.39	4.21	4.06	3.92	3.79	3.68	3.58	3.49	3.40	3.33	3.25
5,000,000	5.62	5.23	4.92	4.67	4.46	4.28	4.12	3.98	3.86	3.74	3.64	3.55	3.46	3.38	3.31
6,000,000	5.76	5.36	5.06	4.80	4.59	4.40	4.24	4.10	3.97	3.86	3.75	3.65	3.57	3.49	3.41
7,000,000	5.88	5.48	5.17	4.91	4.69	4.51	4.34	4.20	4.07	3.95	3.84	3.75	3.66	3.57	3.50
8,000,000	5.98	5.58	5.26	5.00	4.79	4.60	4.43	4.29	4.15	4.03	3.93	3.83	3.74	3.65	3.58
9,000,000	6.08	5.67	5.35	5.09	4.87	4.68	4.51	4.36	4.23	4.11	4.00	3.90	3.81	3.72	3.64
10,000,000	6.16	5.75	5.43	5.17	4.94	4.75	4.58	4.43	4.30	4.18	4.07	3.97	3.87	3.79	3.71
15,000,000	6.49	6.07	5.74	5.47	5.24	5.04	4.86	4.71	4.57	4.45	4.33	4.23	4.13	4.04	3.96
20,000,000	6.74	6.30	5.96	5.68	5.45	5.25	5.07	4.91	4.77	4.64	4.52	4.42	4.32	4.22	4.14
25,000,000	6.93	6.49	6.14	5.86	5.62	5.41	5.23	5.07	4.93	4.80	4.68	4.57	4.46	4.37	4.28
30,000,000	7.09	6.64	6.29	6.00	5.76	5.55	5.37	5.20	5.06	4.92	4.80	4.69	4.59	4.49	4.40
35,000,000	7.23	6.77	6.42	6.12	5.88	5.67	5.48	5.32	5.17	5.03	4.91	4.80	4.69	4.60	4.51
40,000,000	7.35	6.89	6.53	6.23	5.98	5.77	5.58	5.41	5.27	5.13	5.01	4.89	4.79	4.69	4.60
45,000,000	7.46	6.99	6.63	6.33	6.08	5.86	5.67	5.50	5.35	5.22	5.09	4.98	4.87	4.77	4.68
50,000,000	7.56	7.09	6.72	6.41	6.16	5.94	5.75	5.58	5.43	5.29	5.17	5.05	4.94	4.84	4.75
60,000,000	7.73	7.25	6.87	6.57	6.31	6.09	5.89	5.72	5.57	5.43	5.30	5.18	5.07	4.97	4.88
70,000,000	7.88	7.39	7.01	6.70	6.44	6.21	6.02	5.84	5.69	5.54	5.41	5.30	5.19	5.08	4.99
80,000,000	8.01	7.51	7.13	6.81	6.55	6.32	6.12	5.95	5.79	5.65	5.51	5.39	5.28	5.18	5.08
90,000,000	8.13	7.63	7.23	6.92	6.65	6.42	6.22	6.04	5.88	5.74	5.60	5.48	5.37	5.27	5.17
100,000,000	8.23	7.73	7.33	7.01	6.74	6.51	6.30	6.12	5.96	5.82	5.68	5.56	5.45	5.34	5.25

TABLE A.5B

REQUIRED STRUCTURAL NUMBER (SN_R)
92% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 18,000 PSI TO 32,000 PSI

RESILIENT MODULUS (M_R), (PSI x 1000)															
$ESAL_D$	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
100,000	1.72	1.68	1.64	1.61	1.58	1.55	1.52	1.50	1.47	1.45	1.43	1.40	1.38	1.36	1.35
150,000	1.84	1.80	1.76	1.73	1.70	1.67	1.64	1.61	1.58	1.56	1.54	1.51	1.49	1.47	1.45
200,000	1.93	1.89	1.85	1.82	1.79	1.75	1.72	1.69	1.67	1.64	1.62	1.59	1.57	1.55	1.53
250,000	2.01	1.97	1.93	1.89	1.86	1.82	1.79	1.76	1.73	1.71	1.68	1.66	1.64	1.61	1.59
300,000	2.07	2.03	1.99	1.95	1.91	1.88	1.85	1.82	1.79	1.76	1.74	1.71	1.69	1.67	1.65
350,000	2.13	2.08	2.04	2.00	1.97	1.93	1.90	1.87	1.84	1.81	1.79	1.76	1.74	1.71	1.69
400,000	2.18	2.13	2.09	2.05	2.01	1.98	1.94	1.91	1.88	1.85	1.83	1.80	1.78	1.75	1.73
450,000	2.22	2.17	2.13	2.09	2.05	2.02	1.98	1.95	1.92	1.89	1.86	1.84	1.81	1.79	1.77
500,000	2.26	2.21	2.17	2.13	2.09	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.85	1.82	1.80
600,000	2.33	2.28	2.23	2.19	2.15	2.12	2.08	2.05	2.02	1.99	1.96	1.93	1.91	1.88	1.86
700,000	2.39	2.34	2.29	2.25	2.21	2.17	2.14	2.10	2.07	2.04	2.01	1.98	1.96	1.93	1.91
800,000	2.44	2.39	2.34	2.30	2.26	2.22	2.18	2.15	2.12	2.09	2.06	2.03	2.00	1.98	1.95
900,000	2.49	2.44	2.39	2.35	2.30	2.27	2.23	2.19	2.16	2.13	2.10	2.07	2.04	2.02	1.99
1,000,000	2.53	2.48	2.43	2.39	2.35	2.31	2.27	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.03
1,500,000	2.71	2.66	2.60	2.55	2.51	2.47	2.43	2.39	2.35	2.32	2.29	2.26	2.23	2.20	2.17
2,000,000	2.84	2.79	2.73	2.68	2.63	2.59	2.55	2.51	2.47	2.43	2.40	2.37	2.34	2.31	2.28
2,500,000	2.95	2.89	2.83	2.78	2.73	2.69	2.64	2.60	2.56	2.52	2.49	2.46	2.42	2.39	2.36
3,000,000	3.04	2.98	2.92	2.87	2.82	2.77	2.72	2.68	2.64	2.60	2.57	2.53	2.50	2.47	2.44
3,500,000	3.12	3.06	3.00	2.94	2.89	2.84	2.79	2.75	2.71	2.67	2.63	2.60	2.56	2.53	2.50
4,000,000	3.19	3.13	3.06	3.01	2.95	2.90	2.86	2.81	2.77	2.73	2.69	2.66	2.62	2.59	2.56
4,500,000	3.25	3.19	3.12	3.07	3.01	2.96	2.91	2.87	2.82	2.78	2.74	2.71	2.67	2.64	2.61
5,000,000	3.31	3.24	3.18	3.12	3.07	3.01	2.96	2.92	2.87	2.83	2.79	2.76	2.72	2.69	2.65
6,000,000	3.41	3.34	3.28	3.22	3.16	3.11	3.06	3.01	2.96	2.92	2.88	2.84	2.80	2.77	2.73
7,000,000	3.50	3.43	3.36	3.30	3.24	3.19	3.13	3.09	3.04	3.00	2.95	2.91	2.88	2.84	2.81
8,000,000	3.58	3.50	3.44	3.37	3.31	3.26	3.20	3.15	3.11	3.06	3.02	2.98	2.94	2.90	2.87
9,000,000	3.64	3.57	3.50	3.44	3.38	3.32	3.27	3.22	3.17	3.12	3.08	3.04	3.00	2.96	2.93
10,000,000	3.71	3.63	3.56	3.50	3.44	3.38	3.32	3.27	3.22	3.18	3.13	3.09	3.05	3.01	2.98
15,000,000	3.96	3.88	3.80	3.74	3.67	3.61	3.55	3.50	3.45	3.40	3.35	3.31	3.26	3.22	3.18
20,000,000	4.14	4.06	3.98	3.91	3.85	3.78	3.72	3.67	3.61	3.56	3.51	3.47	3.42	3.38	3.34
25,000,000	4.28	4.20	4.12	4.05	3.98	3.92	3.86	3.80	3.75	3.69	3.64	3.59	3.55	3.51	3.46
30,000,000	4.40	4.32	4.24	4.17	4.10	4.03	3.97	3.91	3.86	3.80	3.75	3.70	3.66	3.61	3.57
35,000,000	4.51	4.42	4.34	4.27	4.20	4.13	4.07	4.01	3.95	3.90	3.85	3.80	3.75	3.70	3.66
40,000,000	4.60	4.51	4.43	4.36	4.29	4.22	4.15	4.09	4.04	3.98	3.93	3.88	3.83	3.78	3.74
45,000,000	4.75	4.67	4.58	4.51	4.43	4.37	4.30	4.24	4.18	4.12	4.07	4.02	3.97	3.92	3.87
50,000,000	4.88	4.79	4.71	4.63	4.56	4.49	4.42	4.36	4.30	4.24	4.19	4.13	4.08	4.03	3.99
60,000,000	4.99	4.90	4.82	4.74	4.66	4.59	4.52	4.46	4.40	4.34	4.29	4.23	4.18	4.13	4.09
70,000,000	5.08	4.99	4.91	4.83	4.76	4.68	4.62	4.55	4.49	4.43	4.37	4.32	4.27	4.22	4.17
80,000,000	5.17	5.08	4.99	4.91	4.84	4.77	4.70	4.63	4.57	4.51	4.45	4.40	4.35	4.30	4.25
90,000,000	5.25	5.16	5.07	4.99	4.91	4.84	4.77	4.70	4.64	4.58	4.52	4.47	4.42	4.37	4.32
100,000,000	5.32	5.23	5.14	5.06	4.98	4.91	4.84	4.77	4.71	4.65	4.59	4.53	4.48	4.43	4.38

TABLE A.6A

REQUIRED STRUCTURAL NUMBER (SN_R)
94% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	3.17	2.91	2.71	2.55	2.42	2.32	2.22	2.14	2.07	2.01	1.95	1.90	1.85	1.80	1.76
150,000	3.39	3.11	2.90	2.73	2.59	2.48	2.38	2.29	2.22	2.15	2.09	2.03	1.98	1.93	1.89
200,000	3.55	3.26	3.04	2.86	2.72	2.60	2.50	2.41	2.33	2.26	2.19	2.13	2.08	2.03	1.99
250,000	3.68	3.38	3.15	2.97	2.82	2.70	2.59	2.50	2.42	2.34	2.28	2.21	2.16	2.11	2.06
300,000	3.79	3.49	3.25	3.06	2.91	2.78	2.67	2.57	2.49	2.41	2.35	2.28	2.23	2.18	2.13
350,000	3.88	3.57	3.33	3.14	2.99	2.85	2.74	2.64	2.55	2.48	2.41	2.34	2.29	2.23	2.18
400,000	3.97	3.65	3.41	3.21	3.05	2.92	2.80	2.70	2.61	2.53	2.46	2.40	2.34	2.28	2.23
450,000	4.04	3.72	3.48	3.28	3.11	2.98	2.86	2.75	2.66	2.58	2.51	2.44	2.38	2.33	2.28
500,000	4.11	3.79	3.54	3.33	3.17	3.03	2.91	2.80	2.71	2.63	2.55	2.49	2.43	2.37	2.32
600,000	4.23	3.90	3.64	3.44	3.26	3.12	3.00	2.89	2.79	2.71	2.63	2.56	2.50	2.44	2.39
700,000	4.33	3.99	3.73	3.52	3.35	3.20	3.07	2.96	2.87	2.78	2.70	2.63	2.57	2.51	2.45
800,000	4.42	4.08	3.81	3.60	3.42	3.27	3.14	3.03	2.93	2.84	2.76	2.69	2.62	2.56	2.51
900,000	4.50	4.15	3.89	3.67	3.49	3.34	3.20	3.09	2.99	2.90	2.82	2.74	2.67	2.61	2.56
1,000,000	4.57	4.22	3.95	3.73	3.55	3.40	3.26	3.14	3.04	2.95	2.87	2.79	2.72	2.66	2.60
1,500,000	4.85	4.49	4.21	3.98	3.79	3.63	3.49	3.36	3.25	3.15	3.06	2.98	2.91	2.84	2.78
2,000,000	5.05	4.69	4.40	4.17	3.97	3.80	3.65	3.52	3.41	3.31	3.21	3.13	3.05	2.98	2.92
2,500,000	5.21	4.84	4.55	4.31	4.11	3.94	3.79	3.65	3.54	3.43	3.33	3.25	3.17	3.10	3.03
3,000,000	5.35	4.97	4.68	4.43	4.23	4.05	3.90	3.76	3.64	3.53	3.44	3.35	3.27	3.19	3.12
3,500,000	5.46	5.08	4.78	4.54	4.33	4.15	4.00	3.86	3.73	3.62	3.52	3.43	3.35	3.27	3.20
4,000,000	5.56	5.18	4.88	4.63	4.42	4.24	4.08	3.94	3.82	3.70	3.60	3.51	3.42	3.35	3.27
4,500,000	5.65	5.27	4.96	4.71	4.50	4.32	4.16	4.01	3.89	3.77	3.67	3.58	3.49	3.41	3.34
5,000,000	5.74	5.34	5.04	4.78	4.57	4.38	4.22	4.08	3.95	3.84	3.73	3.64	3.55	3.47	3.40
6,000,000	5.88	5.48	5.17	4.91	4.69	4.51	4.34	4.20	4.07	3.95	3.85	3.75	3.66	3.58	3.50
7,000,000	6.00	5.60	5.28	5.02	4.80	4.61	4.45	4.30	4.17	4.05	3.94	3.84	3.75	3.67	3.59
8,000,000	6.11	5.70	5.38	5.12	4.90	4.70	4.54	4.39	4.25	4.13	4.02	3.92	3.83	3.75	3.67
9,000,000	6.20	5.79	5.47	5.20	4.98	4.79	4.62	4.47	4.33	4.21	4.10	4.00	3.90	3.82	3.74
10,000,000	6.29	5.87	5.55	5.28	5.05	4.86	4.69	4.54	4.40	4.28	4.17	4.06	3.97	3.88	3.80
15,000,000	6.62	6.19	5.86	5.58	5.35	5.15	4.97	4.82	4.68	4.55	4.43	4.33	4.23	4.14	4.05
20,000,000	6.87	6.43	6.09	5.80	5.57	5.36	5.18	5.02	4.88	4.75	4.63	4.52	4.42	4.33	4.24
25,000,000	7.07	6.62	6.27	5.98	5.74	5.53	5.34	5.18	5.04	4.90	4.78	4.67	4.57	4.47	4.39
30,000,000	7.23	6.77	6.42	6.12	5.88	5.67	5.48	5.32	5.17	5.03	4.91	4.80	4.69	4.60	4.51
35,000,000	7.37	6.91	6.55	6.25	6.00	5.79	5.60	5.43	5.28	5.15	5.02	4.91	4.80	4.70	4.61
40,000,000	7.50	7.03	6.66	6.36	6.11	5.89	5.70	5.53	5.38	5.24	5.12	5.00	4.90	4.80	4.70
45,000,000	7.61	7.13	6.76	6.46	6.20	5.98	5.79	5.62	5.47	5.33	5.20	5.09	4.98	4.88	4.79
50,000,000	7.71	7.23	6.85	6.54	6.29	6.07	5.87	5.70	5.55	5.41	5.28	5.16	5.05	4.95	4.86
60,000,000	7.88	7.39	7.01	6.70	6.44	6.21	6.02	5.84	5.69	5.54	5.42	5.30	5.19	5.08	4.99
70,000,000	8.03	7.53	7.15	6.83	6.57	6.34	6.14	5.96	5.81	5.66	5.53	5.41	5.30	5.20	5.10
80,000,000	8.16	7.66	7.27	6.95	6.68	6.45	6.25	6.07	5.91	5.76	5.63	5.51	5.40	5.29	5.20
90,000,000	8.28	7.77	7.38	7.05	6.78	6.55	6.35	6.16	6.00	5.86	5.72	5.60	5.49	5.38	5.28
100,000,000	8.39	7.87	7.47	7.15	6.87	6.64	6.43	6.25	6.09	5.94	5.80	5.68	5.57	5.46	5.36

TABLE A.6B

REQUIRED STRUCTURAL NUMBER (SN_R)
94% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 18,000 PSI TO 32,000 PSI

RESILIENT MODULUS (M_R), (PSI x 1000)															
$ESAL_D$	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
100,000	1.76	1.72	1.69	1.66	1.62	1.59	1.57	1.54	1.51	1.49	1.47	1.45	1.42	1.40	1.39
150,000	1.89	1.85	1.81	1.78	1.74	1.71	1.68	1.66	1.63	1.60	1.58	1.56	1.53	1.51	1.49
200,000	1.99	1.94	1.90	1.87	1.83	1.80	1.77	1.74	1.71	1.69	1.66	1.64	1.62	1.59	1.57
250,000	2.06	2.02	1.98	1.94	1.91	1.87	1.84	1.81	1.78	1.76	1.73	1.70	1.68	1.66	1.64
300,000	2.13	2.08	2.04	2.00	1.97	1.93	1.90	1.87	1.84	1.81	1.79	1.76	1.74	1.71	1.69
350,000	2.18	2.14	2.10	2.06	2.02	1.98	1.95	1.92	1.89	1.86	1.83	1.81	1.78	1.76	1.74
400,000	2.23	2.19	2.14	2.10	2.06	2.03	1.99	1.96	1.93	1.90	1.88	1.85	1.83	1.80	1.78
450,000	2.28	2.23	2.19	2.14	2.11	2.07	2.04	2.00	1.97	1.94	1.91	1.89	1.86	1.84	1.82
500,000	2.32	2.27	2.22	2.18	2.14	2.11	2.07	2.04	2.01	1.98	1.95	1.92	1.90	1.87	1.85
600,000	2.39	2.34	2.29	2.25	2.21	2.17	2.14	2.10	2.07	2.04	2.01	1.98	1.96	1.93	1.91
700,000	2.45	2.40	2.35	2.31	2.27	2.23	2.19	2.16	2.13	2.09	2.06	2.04	2.01	1.98	1.96
800,000	2.51	2.45	2.41	2.36	2.32	2.28	2.24	2.21	2.17	2.14	2.11	2.08	2.06	2.03	2.00
900,000	2.56	2.50	2.45	2.41	2.37	2.32	2.29	2.25	2.22	2.18	2.15	2.12	2.10	2.07	2.04
1,000,000	2.60	2.55	2.50	2.45	2.41	2.37	2.33	2.29	2.26	2.22	2.19	2.16	2.13	2.11	2.08
1,500,000	2.78	2.72	2.67	2.62	2.58	2.53	2.49	2.45	2.41	2.38	2.35	2.31	2.28	2.26	2.23
2,000,000	2.92	2.86	2.80	2.75	2.70	2.66	2.61	2.57	2.53	2.50	2.46	2.43	2.40	2.37	2.34
2,500,000	3.03	2.97	2.91	2.85	2.80	2.76	2.71	2.67	2.63	2.59	2.55	2.52	2.49	2.46	2.43
3,000,000	3.12	3.06	3.00	2.94	2.89	2.84	2.79	2.75	2.71	2.67	2.63	2.60	2.56	2.53	2.50
3,500,000	3.20	3.14	3.07	3.02	2.96	2.91	2.87	2.82	2.78	2.74	2.70	2.66	2.63	2.60	2.57
4,000,000	3.27	3.21	3.14	3.09	3.03	2.98	2.93	2.89	2.84	2.80	2.76	2.72	2.69	2.66	2.62
4,500,000	3.34	3.27	3.21	3.15	3.09	3.04	2.99	2.94	2.90	2.86	2.82	2.78	2.74	2.71	2.68
5,000,000	3.40	3.33	3.26	3.20	3.14	3.09	3.04	2.99	2.95	2.91	2.87	2.83	2.79	2.76	2.72
6,000,000	3.50	3.43	3.36	3.30	3.24	3.19	3.13	3.09	3.04	3.00	2.95	2.91	2.88	2.84	2.81
7,000,000	3.59	3.52	3.45	3.38	3.32	3.27	3.22	3.17	3.12	3.07	3.03	2.99	2.95	2.91	2.88
8,000,000	3.67	3.59	3.52	3.46	3.40	3.34	3.29	3.24	3.19	3.14	3.10	3.06	3.02	2.98	2.94
9,000,000	3.74	3.66	3.59	3.53	3.46	3.41	3.35	3.30	3.25	3.20	3.16	3.12	3.08	3.04	3.00
10,000,000	3.80	3.73	3.65	3.59	3.52	3.47	3.41	3.36	3.31	3.26	3.22	3.17	3.13	3.09	3.05
15,000,000	4.05	3.97	3.90	3.83	3.76	3.70	3.64	3.59	3.54	3.48	3.44	3.39	3.35	3.31	3.27
20,000,000	4.24	4.16	4.08	4.01	3.94	3.88	3.82	3.76	3.70	3.65	3.60	3.56	3.51	3.47	3.42
25,000,000	4.39	4.30	4.22	4.15	4.08	4.02	3.95	3.90	3.84	3.79	3.74	3.69	3.64	3.59	3.55
30,000,000	4.51	4.42	4.34	4.27	4.20	4.13	4.07	4.01	3.95	3.90	3.85	3.80	3.75	3.70	3.66
35,000,000	4.61	4.53	4.45	4.37	4.30	4.23	4.17	4.11	4.05	3.99	3.94	3.89	3.84	3.80	3.75
40,000,000	4.70	4.62	4.54	4.46	4.39	4.32	4.26	4.19	4.13	4.08	4.03	3.97	3.92	3.88	3.83
45,000,000	4.79	4.70	4.62	4.54	4.47	4.40	4.33	4.27	4.21	4.15	4.10	4.05	4.00	3.95	3.90
50,000,000	4.86	4.77	4.69	4.61	4.54	4.47	4.40	4.34	4.28	4.22	4.17	4.12	4.07	4.02	3.97
60,000,000	4.99	4.90	4.82	4.74	4.66	4.59	4.53	4.46	4.40	4.34	4.29	4.23	4.18	4.13	4.09
70,000,000	5.10	5.01	4.93	4.85	4.77	4.70	4.63	4.57	4.50	4.45	4.39	4.33	4.28	4.23	4.19
80,000,000	5.20	5.11	5.02	4.94	4.86	4.79	4.72	4.66	4.60	4.54	4.48	4.42	4.37	4.32	4.27
90,000,000	5.28	5.19	5.11	5.02	4.95	4.87	4.80	4.74	4.68	4.62	4.56	4.50	4.45	4.40	4.35
100,000,000	5.36	5.27	5.18	5.10	5.02	4.95	4.88	4.81	4.75	4.69	4.63	4.57	4.52	4.47	4.42

TABLE A.7A

REQUIRED STRUCTURAL NUMBER (SN_R)
95% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	3.22	2.95	2.75	2.59	2.46	2.35	2.26	2.18	2.10	2.04	1.98	1.93	1.88	1.83	1.79
150,000	3.44	3.16	2.94	2.77	2.63	2.52	2.42	2.33	2.25	2.18	2.12	2.06	2.01	1.97	1.92
200,000	3.60	3.31	3.09	2.91	2.76	2.64	2.54	2.44	2.36	2.29	2.23	2.17	2.11	2.06	2.02
250,000	3.74	3.43	3.20	3.02	2.87	2.74	2.63	2.54	2.45	2.38	2.31	2.25	2.19	2.14	2.10
300,000	3.85	3.54	3.30	3.11	2.96	2.83	2.71	2.61	2.53	2.45	2.38	2.32	2.26	2.21	2.16
350,000	3.94	3.63	3.39	3.19	3.03	2.90	2.78	2.68	2.59	2.52	2.44	2.38	2.32	2.27	2.22
400,000	4.03	3.71	3.46	3.26	3.10	2.96	2.85	2.74	2.65	2.57	2.50	2.43	2.37	2.32	2.27
450,000	4.10	3.78	3.53	3.33	3.16	3.02	2.90	2.80	2.70	2.62	2.55	2.48	2.42	2.36	2.31
500,000	4.17	3.84	3.59	3.39	3.22	3.07	2.95	2.85	2.75	2.67	2.59	2.53	2.46	2.41	2.35
600,000	4.29	3.96	3.70	3.49	3.32	3.17	3.04	2.93	2.84	2.75	2.67	2.60	2.54	2.48	2.43
700,000	4.39	4.05	3.79	3.58	3.40	3.25	3.12	3.01	2.91	2.82	2.74	2.67	2.61	2.55	2.49
800,000	4.48	4.14	3.87	3.66	3.48	3.32	3.19	3.08	2.98	2.89	2.80	2.73	2.66	2.60	2.55
900,000	4.56	4.22	3.95	3.73	3.54	3.39	3.25	3.14	3.03	2.94	2.86	2.78	2.72	2.65	2.60
1,000,000	4.63	4.28	4.01	3.79	3.60	3.45	3.31	3.19	3.09	2.99	2.91	2.83	2.76	2.70	2.64
1,500,000	4.91	4.56	4.27	4.04	3.85	3.68	3.54	3.41	3.30	3.20	3.11	3.03	2.96	2.89	2.83
2,000,000	5.12	4.75	4.46	4.23	4.03	3.86	3.71	3.58	3.46	3.36	3.26	3.18	3.10	3.03	2.96
2,500,000	5.28	4.91	4.62	4.37	4.17	4.00	3.84	3.71	3.59	3.48	3.39	3.30	3.22	3.14	3.08
3,000,000	5.42	5.04	4.74	4.50	4.29	4.11	3.96	3.82	3.70	3.59	3.49	3.40	3.32	3.24	3.17
3,500,000	5.53	5.15	4.85	4.60	4.39	4.21	4.05	3.92	3.79	3.68	3.58	3.49	3.40	3.32	3.25
4,000,000	5.64	5.25	4.94	4.69	4.48	4.30	4.14	4.00	3.87	3.76	3.66	3.56	3.48	3.40	3.32
4,500,000	5.73	5.33	5.03	4.77	4.56	4.38	4.22	4.07	3.95	3.83	3.73	3.63	3.54	3.46	3.39
5,000,000	5.81	5.41	5.10	4.85	4.63	4.45	4.28	4.14	4.01	3.90	3.79	3.69	3.61	3.52	3.45
6,000,000	5.95	5.55	5.24	4.98	4.76	4.57	4.41	4.26	4.13	4.01	3.90	3.80	3.71	3.63	3.55
7,000,000	6.07	5.67	5.35	5.09	4.87	4.68	4.51	4.36	4.23	4.11	4.00	3.90	3.81	3.72	3.64
8,000,000	6.18	5.77	5.45	5.18	4.96	4.77	4.60	4.45	4.32	4.19	4.08	3.98	3.89	3.80	3.72
9,000,000	6.28	5.86	5.54	5.27	5.05	4.85	4.68	4.53	4.39	4.27	4.16	4.06	3.96	3.87	3.79
10,000,000	6.36	5.95	5.62	5.35	5.12	4.93	4.75	4.60	4.46	4.34	4.23	4.12	4.03	3.94	3.86
15,000,000	6.70	6.27	5.93	5.65	5.42	5.22	5.04	4.88	4.74	4.61	4.50	4.39	4.29	4.20	4.11
20,000,000	6.95	6.51	6.16	5.88	5.64	5.43	5.25	5.09	4.94	4.81	4.69	4.58	4.48	4.39	4.30
25,000,000	7.15	6.70	6.34	6.05	5.81	5.60	5.41	5.25	5.10	4.97	4.85	4.74	4.63	4.54	4.45
30,000,000	7.32	6.86	6.49	6.20	5.95	5.74	5.55	5.39	5.24	5.10	4.98	4.86	4.76	4.66	4.57
35,000,000	7.46	6.99	6.62	6.33	6.07	5.86	5.67	5.50	5.35	5.21	5.09	4.97	4.87	4.77	4.68
40,000,000	7.58	7.11	6.74	6.44	6.18	5.96	5.77	5.60	5.45	5.31	5.19	5.07	4.96	4.86	4.77
45,000,000	7.69	7.21	6.84	6.53	6.28	6.06	5.86	5.69	5.54	5.40	5.27	5.15	5.05	4.95	4.85
50,000,000	7.79	7.31	6.93	6.62	6.36	6.14	5.95	5.77	5.62	5.48	5.35	5.23	5.12	5.02	4.93
60,000,000	7.97	7.48	7.09	6.78	6.52	6.29	6.09	5.92	5.76	5.62	5.49	5.37	5.26	5.15	5.06
70,000,000	8.12	7.62	7.23	6.91	6.65	6.42	6.22	6.04	5.88	5.73	5.60	5.48	5.37	5.27	5.17
80,000,000	8.26	7.75	7.35	7.03	6.76	6.53	6.32	6.14	5.98	5.84	5.70	5.58	5.47	5.36	5.27
90,000,000	8.38	7.86	7.46	7.14	6.86	6.63	6.42	6.24	6.08	5.93	5.80	5.67	5.56	5.45	5.35
100,000,000	8.48	7.96	7.56	7.23	6.95	6.72	6.51	6.33	6.16	6.01	5.88	5.75	5.64	5.53	5.43

TABLE A.7B

REQUIRED STRUCTURAL NUMBER (SN_R)
95% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 18,000 PSI TO 32,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
100,000	1.79	1.75	1.72	1.68	1.65	1.62	1.59	1.57	1.54	1.52	1.49	1.47	1.45	1.43	1.41
150,000	1.92	1.88	1.84	1.81	1.77	1.74	1.71	1.68	1.66	1.63	1.61	1.58	1.56	1.54	1.52
200,000	2.02	1.98	1.94	1.90	1.86	1.83	1.80	1.77	1.74	1.72	1.69	1.67	1.64	1.62	1.60
250,000	2.10	2.05	2.01	1.97	1.94	1.90	1.87	1.84	1.81	1.78	1.76	1.73	1.71	1.69	1.66
300,000	2.16	2.12	2.07	2.03	2.00	1.96	1.93	1.90	1.87	1.84	1.81	1.79	1.76	1.74	1.72
350,000	2.22	2.17	2.13	2.09	2.05	2.01	1.98	1.95	1.92	1.89	1.86	1.84	1.81	1.79	1.77
400,000	2.27	2.22	2.18	2.14	2.10	2.06	2.03	1.99	1.96	1.93	1.91	1.88	1.86	1.83	1.81
450,000	2.31	2.26	2.22	2.18	2.14	2.10	2.07	2.03	2.00	1.97	1.95	1.92	1.89	1.87	1.84
500,000	2.35	2.30	2.26	2.22	2.18	2.14	2.10	2.07	2.04	2.01	1.98	1.95	1.93	1.90	1.88
600,000	2.43	2.38	2.33	2.29	2.24	2.21	2.17	2.14	2.10	2.07	2.04	2.02	1.99	1.96	1.94
700,000	2.49	2.44	2.39	2.35	2.30	2.26	2.23	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.99
800,000	2.55	2.49	2.44	2.40	2.36	2.32	2.28	2.24	2.21	2.18	2.14	2.12	2.09	2.06	2.04
900,000	2.60	2.54	2.49	2.45	2.40	2.36	2.32	2.29	2.25	2.22	2.19	2.16	2.13	2.10	2.08
1,000,000	2.64	2.59	2.54	2.49	2.44	2.40	2.36	2.33	2.29	2.26	2.23	2.20	2.17	2.14	2.11
1,500,000	2.83	2.77	2.71	2.66	2.62	2.57	2.53	2.49	2.45	2.42	2.38	2.35	2.32	2.29	2.26
2,000,000	2.96	2.90	2.85	2.79	2.74	2.70	2.65	2.61	2.57	2.54	2.50	2.47	2.43	2.40	2.37
2,500,000	3.08	3.01	2.95	2.90	2.85	2.80	2.75	2.71	2.67	2.63	2.59	2.56	2.53	2.49	2.46
3,000,000	3.17	3.10	3.04	2.99	2.93	2.88	2.84	2.79	2.75	2.71	2.67	2.64	2.60	2.57	2.54
3,500,000	3.25	3.19	3.12	3.06	3.01	2.96	2.91	2.87	2.82	2.78	2.74	2.71	2.67	2.64	2.61
4,000,000	3.32	3.26	3.19	3.13	3.08	3.03	2.98	2.93	2.89	2.84	2.80	2.77	2.73	2.70	2.66
4,500,000	3.39	3.32	3.26	3.20	3.14	3.09	3.04	2.99	2.94	2.90	2.86	2.82	2.79	2.75	2.72
5,000,000	3.45	3.38	3.31	3.25	3.19	3.14	3.09	3.04	3.00	2.95	2.91	2.87	2.83	2.80	2.76
6,000,000	3.55	3.48	3.41	3.35	3.29	3.24	3.18	3.13	3.09	3.04	3.00	2.96	2.92	2.88	2.85
7,000,000	3.64	3.57	3.50	3.44	3.38	3.32	3.27	3.21	3.17	3.12	3.08	3.04	3.00	2.96	2.92
8,000,000	3.72	3.65	3.58	3.51	3.45	3.39	3.34	3.29	3.24	3.19	3.15	3.10	3.06	3.03	2.99
9,000,000	3.79	3.72	3.65	3.58	3.52	3.46	3.40	3.35	3.30	3.25	3.21	3.17	3.12	3.09	3.05
10,000,000	3.86	3.78	3.71	3.64	3.58	3.52	3.46	3.41	3.36	3.31	3.27	3.22	3.18	3.14	3.10
15,000,000	4.11	4.03	3.96	3.89	3.82	3.76	3.70	3.64	3.59	3.54	3.49	3.44	3.40	3.36	3.32
20,000,000	4.30	4.22	4.14	4.07	4.00	3.94	3.87	3.82	3.76	3.71	3.66	3.61	3.56	3.52	3.48
25,000,000	4.45	4.36	4.29	4.21	4.14	4.08	4.01	3.95	3.90	3.84	3.79	3.74	3.70	3.65	3.61
30,000,000	4.57	4.49	4.41	4.33	4.26	4.19	4.13	4.07	4.01	3.96	3.90	3.85	3.81	3.76	3.71
35,000,000	4.68	4.59	4.51	4.43	4.36	4.29	4.23	4.17	4.11	4.05	4.00	3.95	3.90	3.85	3.81
40,000,000	4.77	4.68	4.60	4.52	4.45	4.38	4.32	4.25	4.20	4.14	4.08	4.03	3.98	3.94	3.89
45,000,000	4.85	4.76	4.68	4.60	4.53	4.46	4.39	4.33	4.27	4.21	4.16	4.11	4.06	4.01	3.96
50,000,000	4.93	4.84	4.75	4.68	4.60	4.53	4.47	4.40	4.34	4.28	4.23	4.18	4.12	4.08	4.03
60,000,000	5.06	4.97	4.88	4.80	4.73	4.66	4.59	4.52	4.46	4.40	4.35	4.29	4.24	4.19	4.15
70,000,000	5.17	5.08	4.99	4.91	4.84	4.76	4.69	4.63	4.57	4.51	4.45	4.40	4.34	4.29	4.25
80,000,000	5.27	5.17	5.09	5.01	4.93	4.86	4.79	4.72	4.66	4.60	4.54	4.49	4.43	4.38	4.33
90,000,000	5.35	5.26	5.17	5.09	5.01	4.94	4.87	4.80	4.74	4.68	4.62	4.57	4.51	4.46	4.41
100,000,000	5.43	5.34	5.25	5.17	5.09	5.02	4.94	4.88	4.81	4.75	4.69	4.64	4.58	4.53	4.48

TABLE A.8A

REQUIRED STRUCTURAL NUMBER (SN_R)
96% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	3.28	3.01	2.80	2.64	2.51	2.40	2.30	2.22	2.14	2.08	2.02	1.96	1.91	1.87	1.83
150,000	3.50	3.22	3.00	2.82	2.68	2.56	2.46	2.37	2.29	2.22	2.16	2.10	2.05	2.00	1.96
200,000	3.67	3.37	3.14	2.96	2.81	2.69	2.58	2.49	2.41	2.33	2.27	2.21	2.15	2.10	2.06
250,000	3.80	3.50	3.26	3.07	2.92	2.79	2.68	2.58	2.50	2.42	2.35	2.29	2.23	2.18	2.13
300,000	3.92	3.60	3.36	3.17	3.01	2.88	2.76	2.66	2.57	2.50	2.43	2.36	2.30	2.25	2.20
350,000	4.01	3.69	3.45	3.25	3.09	2.95	2.83	2.73	2.64	2.56	2.49	2.42	2.36	2.31	2.26
400,000	4.10	3.77	3.52	3.32	3.16	3.02	2.90	2.79	2.70	2.62	2.55	2.48	2.42	2.36	2.31
450,000	4.17	3.85	3.59	3.39	3.22	3.08	2.95	2.85	2.75	2.67	2.60	2.53	2.47	2.41	2.36
500,000	4.24	3.91	3.65	3.45	3.28	3.13	3.01	2.90	2.80	2.72	2.64	2.57	2.51	2.45	2.40
600,000	4.36	4.03	3.76	3.55	3.38	3.23	3.10	2.99	2.89	2.80	2.72	2.65	2.59	2.53	2.47
700,000	4.46	4.12	3.86	3.64	3.46	3.31	3.18	3.07	2.96	2.87	2.79	2.72	2.65	2.59	2.54
800,000	4.55	4.21	3.94	3.72	3.54	3.38	3.25	3.13	3.03	2.94	2.86	2.78	2.71	2.65	2.59
900,000	4.63	4.29	4.01	3.79	3.61	3.45	3.31	3.20	3.09	3.00	2.91	2.84	2.77	2.70	2.64
1,000,000	4.71	4.36	4.08	3.86	3.67	3.51	3.37	3.25	3.14	3.05	2.96	2.89	2.82	2.75	2.69
1,500,000	4.99	4.63	4.34	4.11	3.92	3.75	3.60	3.48	3.36	3.26	3.17	3.09	3.01	2.94	2.88
2,000,000	5.20	4.83	4.54	4.30	4.10	3.93	3.77	3.64	3.52	3.42	3.32	3.24	3.16	3.09	3.02
2,500,000	5.36	4.99	4.69	4.45	4.24	4.07	3.91	3.78	3.66	3.55	3.45	3.36	3.28	3.20	3.13
3,000,000	5.50	5.12	4.82	4.57	4.36	4.18	4.03	3.89	3.76	3.65	3.55	3.46	3.38	3.30	3.23
3,500,000	5.62	5.23	4.93	4.68	4.47	4.28	4.12	3.98	3.86	3.75	3.64	3.55	3.46	3.38	3.31
4,000,000	5.72	5.33	5.02	4.77	4.56	4.37	4.21	4.07	3.94	3.83	3.72	3.63	3.54	3.46	3.38
4,500,000	5.81	5.42	5.11	4.85	4.64	4.45	4.29	4.14	4.02	3.90	3.79	3.70	3.61	3.53	3.45
5,000,000	5.89	5.50	5.18	4.93	4.71	4.52	4.36	4.21	4.08	3.96	3.86	3.76	3.67	3.59	3.51
6,000,000	6.04	5.63	5.32	5.06	4.84	4.65	4.48	4.33	4.20	4.08	3.97	3.87	3.78	3.70	3.62
7,000,000	6.16	5.75	5.43	5.17	4.94	4.75	4.58	4.43	4.30	4.18	4.07	3.97	3.87	3.79	3.71
8,000,000	6.27	5.86	5.53	5.26	5.04	4.85	4.68	4.52	4.39	4.27	4.15	4.05	3.96	3.87	3.79
9,000,000	6.37	5.95	5.62	5.35	5.12	4.93	4.76	4.60	4.47	4.34	4.23	4.13	4.03	3.94	3.86
10,000,000	6.45	6.03	5.70	5.43	5.20	5.00	4.83	4.68	4.54	4.41	4.30	4.19	4.10	4.01	3.93
15,000,000	6.80	6.36	6.02	5.74	5.50	5.30	5.12	4.96	4.82	4.69	4.57	4.46	4.36	4.27	4.18
20,000,000	7.05	6.60	6.25	5.96	5.72	5.51	5.33	5.17	5.02	4.89	4.77	4.66	4.56	4.46	4.37
25,000,000	7.25	6.79	6.43	6.14	5.89	5.68	5.50	5.33	5.18	5.05	4.93	4.81	4.71	4.61	4.52
30,000,000	7.42	6.95	6.59	6.29	6.04	5.82	5.63	5.47	5.32	5.18	5.06	4.94	4.84	4.74	4.65
35,000,000	7.56	7.09	6.72	6.42	6.16	5.94	5.75	5.58	5.43	5.29	5.17	5.05	4.95	4.85	4.75
40,000,000	7.69	7.21	6.83	6.53	6.27	6.05	5.86	5.69	5.53	5.39	5.27	5.15	5.04	4.94	4.85
45,000,000	7.80	7.31	6.94	6.63	6.37	6.14	5.95	5.78	5.62	5.48	5.35	5.23	5.13	5.02	4.93
50,000,000	7.90	7.41	7.03	6.72	6.46	6.23	6.03	5.86	5.70	5.56	5.43	5.31	5.20	5.10	5.00
60,000,000	8.08	7.58	7.19	6.87	6.61	6.38	6.18	6.00	5.84	5.70	5.57	5.45	5.34	5.23	5.14
70,000,000	8.23	7.73	7.33	7.01	6.74	6.51	6.31	6.13	5.96	5.82	5.69	5.56	5.45	5.35	5.25
80,000,000	8.37	7.85	7.45	7.13	6.86	6.62	6.42	6.23	6.07	5.92	5.79	5.67	5.55	5.45	5.35
90,000,000	8.49	7.97	7.56	7.23	6.96	6.72	6.51	6.33	6.17	6.02	5.88	5.76	5.64	5.53	5.43
100,000,000	8.60	8.07	7.66	7.33	7.05	6.81	6.60	6.42	6.25	6.10	5.96	5.84	5.72	5.61	5.51

TABLE A.8B

REQUIRED STRUCTURAL NUMBER (SN_R)
96% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 18,000 PSI TO 32,000 PSI

RESILIENT MODULUS (M_R), (PSI x 1000)															
$ESAL_D$	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
100,000	1.83	1.79	1.75	1.72	1.68	1.65	1.62	1.60	1.57	1.55	1.52	1.50	1.48	1.46	1.44
150,000	1.96	1.92	1.88	1.84	1.81	1.77	1.74	1.72	1.69	1.66	1.64	1.61	1.59	1.57	1.55
200,000	2.06	2.01	1.97	1.93	1.90	1.87	1.83	1.80	1.78	1.75	1.72	1.70	1.68	1.65	1.63
250,000	2.13	2.09	2.05	2.01	1.97	1.94	1.91	1.88	1.85	1.82	1.79	1.77	1.74	1.72	1.70
300,000	2.20	2.16	2.11	2.07	2.03	2.00	1.97	1.93	1.90	1.88	1.85	1.82	1.80	1.78	1.75
350,000	2.26	2.21	2.17	2.13	2.09	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.85	1.82	1.80
400,000	2.31	2.26	2.22	2.18	2.14	2.10	2.06	2.03	2.00	1.97	1.94	1.92	1.89	1.87	1.84
450,000	2.36	2.31	2.26	2.22	2.18	2.14	2.11	2.07	2.04	2.01	1.98	1.96	1.93	1.90	1.88
500,000	2.40	2.35	2.30	2.26	2.22	2.18	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.94	1.91
600,000	2.47	2.42	2.37	2.33	2.29	2.25	2.21	2.18	2.14	2.11	2.08	2.05	2.03	2.00	1.97
700,000	2.54	2.48	2.43	2.39	2.35	2.31	2.27	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.03
800,000	2.59	2.54	2.49	2.44	2.40	2.36	2.32	2.28	2.25	2.22	2.18	2.16	2.13	2.10	2.07
900,000	2.64	2.59	2.54	2.49	2.45	2.40	2.37	2.33	2.29	2.26	2.23	2.20	2.17	2.14	2.12
1,000,000	2.69	2.63	2.58	2.53	2.49	2.45	2.41	2.37	2.33	2.30	2.27	2.24	2.21	2.18	2.15
1,500,000	2.88	2.82	2.76	2.71	2.66	2.62	2.58	2.54	2.50	2.46	2.43	2.39	2.36	2.33	2.30
2,000,000	3.02	2.96	2.90	2.84	2.79	2.75	2.70	2.66	2.62	2.58	2.55	2.51	2.48	2.45	2.42
2,500,000	3.13	3.07	3.01	2.95	2.90	2.85	2.80	2.76	2.72	2.68	2.64	2.61	2.57	2.54	2.51
3,000,000	3.23	3.16	3.10	3.04	2.99	2.94	2.89	2.84	2.80	2.76	2.72	2.69	2.65	2.62	2.59
3,500,000	3.31	3.24	3.18	3.12	3.07	3.01	2.96	2.92	2.87	2.83	2.79	2.76	2.72	2.69	2.65
4,000,000	3.38	3.32	3.25	3.19	3.13	3.08	3.03	2.98	2.94	2.90	2.86	2.82	2.78	2.75	2.71
4,500,000	3.45	3.38	3.31	3.25	3.20	3.14	3.09	3.04	3.00	2.95	2.91	2.87	2.84	2.80	2.77
5,000,000	3.51	3.44	3.37	3.31	3.25	3.20	3.15	3.10	3.05	3.01	2.96	2.92	2.89	2.85	2.82
6,000,000	3.62	3.54	3.48	3.41	3.35	3.29	3.24	3.19	3.14	3.10	3.06	3.01	2.98	2.94	2.90
7,000,000	3.71	3.63	3.56	3.50	3.44	3.38	3.33	3.27	3.22	3.18	3.13	3.09	3.05	3.01	2.98
8,000,000	3.79	3.71	3.64	3.58	3.51	3.45	3.40	3.35	3.30	3.25	3.20	3.16	3.12	3.08	3.04
9,000,000	3.86	3.78	3.71	3.64	3.58	3.52	3.47	3.41	3.36	3.31	3.27	3.22	3.18	3.14	3.10
10,000,000	3.93	3.85	3.78	3.71	3.64	3.58	3.53	3.47	3.42	3.37	3.32	3.28	3.24	3.20	3.16
15,000,000	4.18	4.10	4.03	3.96	3.89	3.83	3.77	3.71	3.65	3.60	3.55	3.51	3.46	3.42	3.38
20,000,000	4.37	4.29	4.21	4.14	4.07	4.00	3.94	3.88	3.83	3.77	3.72	3.67	3.63	3.58	3.54
25,000,000	4.52	4.44	4.36	4.28	4.21	4.15	4.08	4.02	3.97	3.91	3.86	3.81	3.76	3.72	3.67
30,000,000	4.65	4.56	4.48	4.40	4.33	4.26	4.20	4.14	4.08	4.02	3.97	3.92	3.87	3.83	3.78
35,000,000	4.75	4.67	4.58	4.51	4.44	4.37	4.30	4.24	4.18	4.12	4.07	4.02	3.97	3.92	3.88
40,000,000	4.85	4.76	4.68	4.60	4.53	4.46	4.39	4.33	4.27	4.21	4.15	4.10	4.05	4.00	3.96
45,000,000	4.93	4.84	4.76	4.68	4.61	4.54	4.47	4.40	4.34	4.29	4.23	4.18	4.13	4.08	4.03
50,000,000	5.00	4.92	4.83	4.75	4.68	4.61	4.54	4.48	4.41	4.36	4.30	4.25	4.20	4.15	4.10
60,000,000	5.14	5.05	4.96	4.88	4.80	4.73	4.66	4.60	4.54	4.48	4.42	4.37	4.32	4.27	4.22
70,000,000	5.25	5.16	5.07	4.99	4.91	4.84	4.77	4.71	4.64	4.58	4.53	4.47	4.42	4.37	4.32
80,000,000	5.35	5.25	5.17	5.09	5.01	4.93	4.86	4.80	4.73	4.67	4.62	4.56	4.51	4.46	4.41
90,000,000	5.43	5.34	5.25	5.17	5.09	5.02	4.95	4.88	4.82	4.76	4.70	4.64	4.59	4.54	4.49
100,000,000	5.51	5.42	5.33	5.25	5.17	5.09	5.02	4.96	4.89	4.83	4.77	4.71	4.66	4.61	4.56

TABLE A.9A

REQUIRED STRUCTURAL NUMBER (SN_R)
97% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

RESILIENT MODULUS (M_R), (PSI x 1000)															
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	3.35	3.07	2.87	2.70	2.57	2.45	2.35	2.27	2.19	2.13	2.06	2.01	1.96	1.91	1.87
150,000	3.58	3.29	3.07	2.89	2.74	2.62	2.52	2.43	2.35	2.27	2.21	2.15	2.10	2.05	2.00
200,000	3.75	3.45	3.21	3.03	2.88	2.75	2.64	2.55	2.46	2.39	2.32	2.26	2.20	2.15	2.10
250,000	3.89	3.57	3.34	3.14	2.99	2.85	2.74	2.64	2.55	2.48	2.41	2.34	2.29	2.23	2.18
300,000	4.00	3.68	3.44	3.24	3.08	2.94	2.83	2.72	2.63	2.55	2.48	2.42	2.36	2.30	2.25
350,000	4.10	3.77	3.52	3.32	3.16	3.02	2.90	2.79	2.70	2.62	2.55	2.48	2.42	2.36	2.31
400,000	4.18	3.86	3.60	3.40	3.23	3.09	2.96	2.86	2.76	2.68	2.60	2.53	2.47	2.41	2.36
450,000	4.26	3.93	3.67	3.46	3.29	3.15	3.02	2.91	2.82	2.73	2.65	2.58	2.52	2.46	2.41
500,000	4.33	4.00	3.73	3.52	3.35	3.20	3.07	2.96	2.87	2.78	2.70	2.63	2.57	2.51	2.45
600,000	4.45	4.11	3.85	3.63	3.45	3.30	3.17	3.06	2.95	2.86	2.78	2.71	2.64	2.58	2.53
700,000	4.56	4.21	3.94	3.72	3.54	3.38	3.25	3.13	3.03	2.94	2.86	2.78	2.71	2.65	2.59
800,000	4.65	4.30	4.02	3.80	3.62	3.46	3.32	3.20	3.10	3.01	2.92	2.84	2.77	2.71	2.65
900,000	4.73	4.38	4.10	3.88	3.69	3.53	3.39	3.27	3.16	3.06	2.98	2.90	2.83	2.76	2.70
1,000,000	4.80	4.45	4.17	3.94	3.75	3.59	3.45	3.32	3.22	3.12	3.03	2.95	2.88	2.81	2.75
1,500,000	5.09	4.72	4.43	4.20	4.00	3.83	3.68	3.55	3.44	3.33	3.24	3.16	3.08	3.01	2.94
2,000,000	5.30	4.92	4.63	4.39	4.18	4.01	3.86	3.72	3.60	3.50	3.40	3.31	3.23	3.16	3.09
2,500,000	5.46	5.08	4.78	4.54	4.33	4.15	4.00	3.86	3.74	3.63	3.52	3.43	3.35	3.27	3.20
3,000,000	5.60	5.22	4.91	4.66	4.45	4.27	4.11	3.97	3.85	3.73	3.63	3.54	3.45	3.37	3.30
3,500,000	5.72	5.33	5.02	4.77	4.56	4.37	4.21	4.07	3.94	3.83	3.72	3.63	3.54	3.46	3.39
4,000,000	5.82	5.43	5.12	4.86	4.65	4.46	4.30	4.15	4.03	3.91	3.80	3.71	3.62	3.54	3.46
4,500,000	5.92	5.52	5.20	4.95	4.73	4.54	4.38	4.23	4.10	3.98	3.88	3.78	3.69	3.60	3.53
5,000,000	6.00	5.60	5.28	5.02	4.80	4.61	4.45	4.30	4.17	4.05	3.94	3.84	3.75	3.67	3.59
6,000,000	6.15	5.74	5.42	5.15	4.93	4.74	4.57	4.42	4.29	4.17	4.06	3.96	3.86	3.78	3.70
7,000,000	6.27	5.86	5.53	5.27	5.04	4.85	4.68	4.53	4.39	4.27	4.15	4.05	3.96	3.87	3.79
8,000,000	6.38	5.96	5.63	5.36	5.14	4.94	4.77	4.62	4.48	4.35	4.24	4.14	4.04	3.95	3.87
9,000,000	6.48	6.06	5.72	5.45	5.22	5.02	4.85	4.70	4.56	4.43	4.32	4.21	4.12	4.03	3.94
10,000,000	6.57	6.14	5.81	5.53	5.30	5.10	4.93	4.77	4.63	4.50	4.39	4.28	4.19	4.09	4.01
15,000,000	6.92	6.47	6.13	5.84	5.60	5.40	5.22	5.06	4.91	4.78	4.66	4.55	4.45	4.36	4.27
20,000,000	7.17	6.72	6.36	6.07	5.83	5.61	5.43	5.27	5.12	4.99	4.86	4.75	4.65	4.55	4.46
25,000,000	7.37	6.91	6.55	6.25	6.00	5.79	5.60	5.43	5.28	5.15	5.02	4.91	4.80	4.71	4.61
30,000,000	7.54	7.07	6.70	6.40	6.15	5.93	5.74	5.57	5.42	5.28	5.15	5.04	4.93	4.83	4.74
35,000,000	7.69	7.21	6.83	6.53	6.27	6.05	5.86	5.69	5.53	5.39	5.27	5.15	5.04	4.94	4.85
40,000,000	7.82	7.33	6.95	6.64	6.38	6.16	5.96	5.79	5.63	5.49	5.37	5.25	5.14	5.04	4.94
45,000,000	7.93	7.44	7.05	6.74	6.48	6.25	6.06	5.88	5.72	5.58	5.45	5.33	5.22	5.12	5.03
50,000,000	8.03	7.54	7.15	6.83	6.57	6.34	6.14	5.96	5.81	5.66	5.53	5.41	5.30	5.20	5.10
60,000,000	8.21	7.71	7.31	6.99	6.72	6.49	6.29	6.11	5.95	5.80	5.67	5.55	5.44	5.33	5.23
70,000,000	8.37	7.86	7.46	7.13	6.86	6.62	6.42	6.23	6.07	5.92	5.79	5.67	5.55	5.45	5.35
80,000,000	8.51	7.99	7.58	7.25	6.97	6.74	6.53	6.34	6.18	6.03	5.89	5.77	5.65	5.55	5.45
90,000,000	8.63	8.10	7.69	7.36	7.08	6.84	6.63	6.44	6.28	6.12	5.99	5.86	5.74	5.64	5.54
100,000,000	8.74	8.21	7.79	7.45	7.17	6.93	6.72	6.53	6.36	6.21	6.07	5.94	5.83	5.72	5.62

TABLE A.9B

REQUIRED STRUCTURAL NUMBER (SN_R)
97% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 18,000 PSI TO 32,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
100,000	1.87	1.83	1.79	1.76	1.72	1.69	1.66	1.64	1.61	1.58	1.56	1.54	1.52	1.50	1.48
150,000	2.00	1.96	1.92	1.88	1.85	1.82	1.79	1.76	1.73	1.70	1.68	1.65	1.63	1.61	1.59
200,000	2.10	2.06	2.02	1.98	1.94	1.91	1.88	1.85	1.82	1.79	1.76	1.74	1.72	1.69	1.67
250,000	2.18	2.14	2.10	2.06	2.02	1.98	1.95	1.92	1.89	1.86	1.83	1.81	1.78	1.76	1.74
300,000	2.25	2.20	2.16	2.12	2.08	2.05	2.01	1.98	1.95	1.92	1.89	1.87	1.84	1.82	1.79
350,000	2.31	2.26	2.22	2.18	2.14	2.10	2.07	2.03	2.00	1.97	1.94	1.92	1.89	1.87	1.84
400,000	2.36	2.31	2.27	2.23	2.19	2.15	2.11	2.08	2.05	2.02	1.99	1.96	1.93	1.91	1.89
450,000	2.41	2.36	2.31	2.27	2.23	2.19	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.95	1.92
500,000	2.45	2.40	2.35	2.31	2.27	2.23	2.19	2.16	2.13	2.09	2.06	2.04	2.01	1.98	1.96
600,000	2.53	2.47	2.43	2.38	2.34	2.30	2.26	2.23	2.19	2.16	2.13	2.10	2.07	2.05	2.02
700,000	2.59	2.54	2.49	2.44	2.40	2.36	2.32	2.28	2.25	2.22	2.19	2.16	2.13	2.10	2.07
800,000	2.65	2.60	2.55	2.50	2.45	2.41	2.37	2.34	2.30	2.27	2.23	2.20	2.18	2.15	2.12
900,000	2.70	2.65	2.60	2.55	2.50	2.46	2.42	2.38	2.35	2.31	2.28	2.25	2.22	2.19	2.16
1,000,000	2.75	2.69	2.64	2.59	2.55	2.50	2.46	2.42	2.39	2.35	2.32	2.29	2.26	2.23	2.20
1,500,000	2.94	2.88	2.83	2.77	2.72	2.68	2.63	2.59	2.55	2.52	2.48	2.45	2.42	2.39	2.36
2,000,000	3.09	3.02	2.96	2.91	2.86	2.81	2.76	2.72	2.68	2.64	2.60	2.57	2.54	2.50	2.47
2,500,000	3.20	3.14	3.08	3.02	2.96	2.91	2.87	2.82	2.78	2.74	2.70	2.67	2.63	2.60	2.57
3,000,000	3.30	3.23	3.17	3.11	3.06	3.00	2.96	2.91	2.87	2.82	2.78	2.75	2.71	2.68	2.65
3,500,000	3.39	3.32	3.25	3.19	3.13	3.08	3.03	2.98	2.94	2.90	2.86	2.82	2.78	2.75	2.71
4,000,000	3.46	3.39	3.32	3.26	3.21	3.15	3.10	3.05	3.01	2.96	2.92	2.88	2.84	2.81	2.77
4,500,000	3.53	3.46	3.39	3.33	3.27	3.21	3.16	3.11	3.07	3.02	2.98	2.94	2.90	2.86	2.83
5,000,000	3.59	3.52	3.45	3.38	3.33	3.27	3.22	3.17	3.12	3.07	3.03	2.99	2.95	2.91	2.88
6,000,000	3.70	3.62	3.55	3.49	3.43	3.37	3.31	3.26	3.21	3.17	3.12	3.08	3.04	3.00	2.97
7,000,000	3.79	3.71	3.64	3.58	3.51	3.46	3.40	3.35	3.30	3.25	3.21	3.16	3.12	3.08	3.04
8,000,000	3.87	3.79	3.72	3.65	3.59	3.53	3.47	3.42	3.37	3.32	3.28	3.23	3.19	3.15	3.11
9,000,000	3.94	3.87	3.79	3.73	3.66	3.60	3.54	3.49	3.44	3.39	3.34	3.30	3.25	3.21	3.17
10,000,000	4.01	3.93	3.86	3.79	3.72	3.66	3.60	3.55	3.50	3.45	3.40	3.35	3.31	3.27	3.23
15,000,000	4.27	4.19	4.11	4.04	3.97	3.91	3.85	3.79	3.73	3.68	3.63	3.58	3.54	3.49	3.45
20,000,000	4.46	4.38	4.30	4.23	4.16	4.09	4.03	3.97	3.91	3.86	3.80	3.76	3.71	3.66	3.62
25,000,000	4.61	4.53	4.45	4.37	4.30	4.23	4.17	4.11	4.05	4.00	3.94	3.89	3.84	3.80	3.75
30,000,000	4.74	4.65	4.57	4.49	4.42	4.35	4.29	4.23	4.17	4.11	4.06	4.01	3.96	3.91	3.86
35,000,000	4.85	4.76	4.68	4.60	4.53	4.46	4.39	4.33	4.27	4.21	4.16	4.10	4.05	4.01	3.96
40,000,000	4.94	4.85	4.77	4.69	4.62	4.55	4.48	4.42	4.36	4.30	4.24	4.19	4.14	4.09	4.04
45,000,000	5.03	4.94	4.85	4.77	4.70	4.63	4.56	4.50	4.43	4.38	4.32	4.27	4.21	4.17	4.12
50,000,000	5.10	5.01	4.93	4.85	4.77	4.70	4.63	4.57	4.51	4.45	4.39	4.34	4.28	4.23	4.19
60,000,000	5.23	5.14	5.06	4.98	4.90	4.83	4.76	4.69	4.63	4.57	4.51	4.46	4.40	4.35	4.31
70,000,000	5.35	5.26	5.17	5.09	5.01	4.94	4.87	4.80	4.74	4.68	4.62	4.56	4.51	4.46	4.41
80,000,000	5.45	5.35	5.27	5.18	5.10	5.03	4.96	4.89	4.83	4.77	4.71	4.65	4.60	4.55	4.50
90,000,000	5.54	5.44	5.35	5.27	5.19	5.12	5.04	4.98	4.91	4.85	4.79	4.73	4.68	4.63	4.58
100,000,000	5.62	5.52	5.43	5.35	5.27	5.19	5.12	5.05	4.99	4.92	4.86	4.81	4.75	4.70	4.65

TABLE A.10A

REQUIRED STRUCTURAL NUMBER (SN_R)
99% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 4,000 PSI TO 18,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100,000	3.61	3.32	3.09	2.92	2.77	2.65	2.54	2.45	2.37	2.30	2.23	2.17	2.12	2.07	2.02
150,000	3.86	3.55	3.31	3.12	2.96	2.83	2.72	2.62	2.53	2.46	2.39	2.32	2.27	2.21	2.17
200,000	4.04	3.72	3.47	3.27	3.11	2.97	2.85	2.75	2.66	2.58	2.50	2.44	2.38	2.32	2.27
250,000	4.18	3.85	3.60	3.39	3.22	3.08	2.96	2.85	2.76	2.67	2.60	2.53	2.47	2.41	2.36
300,000	4.30	3.96	3.71	3.50	3.32	3.18	3.05	2.94	2.84	2.76	2.68	2.61	2.54	2.49	2.43
350,000	4.40	4.06	3.80	3.59	3.41	3.26	3.13	3.02	2.92	2.83	2.75	2.68	2.61	2.55	2.49
400,000	4.49	4.15	3.88	3.66	3.48	3.33	3.20	3.08	2.98	2.89	2.81	2.74	2.67	2.61	2.55
450,000	4.57	4.22	3.95	3.73	3.55	3.40	3.26	3.14	3.04	2.95	2.87	2.79	2.72	2.66	2.60
500,000	4.64	4.29	4.02	3.80	3.61	3.45	3.32	3.20	3.09	3.00	2.92	2.84	2.77	2.71	2.65
600,000	4.77	4.41	4.14	3.91	3.72	3.56	3.42	3.30	3.19	3.09	3.01	2.93	2.86	2.79	2.73
700,000	4.87	4.52	4.24	4.01	3.81	3.65	3.51	3.38	3.27	3.17	3.08	3.00	2.93	2.86	2.80
800,000	4.97	4.61	4.32	4.09	3.90	3.73	3.58	3.46	3.34	3.24	3.15	3.07	3.00	2.93	2.86
900,000	5.05	4.69	4.40	4.17	3.97	3.80	3.65	3.52	3.41	3.31	3.21	3.13	3.05	2.98	2.92
1,000,000	5.13	4.76	4.47	4.24	4.04	3.87	3.72	3.59	3.47	3.37	3.27	3.19	3.11	3.04	2.97
1,500,000	5.43	5.05	4.75	4.50	4.30	4.12	3.97	3.83	3.71	3.60	3.50	3.41	3.32	3.25	3.18
2,000,000	5.65	5.26	4.95	4.70	4.49	4.31	4.15	4.01	3.88	3.77	3.66	3.57	3.48	3.40	3.33
2,500,000	5.82	5.42	5.11	4.86	4.64	4.46	4.29	4.15	4.02	3.90	3.80	3.70	3.61	3.53	3.46
3,000,000	5.96	5.56	5.24	4.99	4.77	4.58	4.41	4.27	4.14	4.02	3.91	3.81	3.72	3.64	3.56
3,500,000	6.08	5.68	5.36	5.10	4.88	4.69	4.52	4.37	4.24	4.12	4.01	3.91	3.81	3.73	3.65
4,000,000	6.19	5.78	5.46	5.19	4.97	4.78	4.61	4.46	4.32	4.20	4.09	3.99	3.90	3.81	3.73
4,500,000	6.29	5.87	5.55	5.28	5.05	4.86	4.69	4.54	4.40	4.28	4.17	4.07	3.97	3.88	3.80
5,000,000	6.37	5.96	5.63	5.36	5.13	4.93	4.76	4.61	4.47	4.35	4.24	4.13	4.04	3.95	3.87
6,000,000	6.53	6.10	5.77	5.49	5.26	5.07	4.89	4.74	4.60	4.47	4.36	4.25	4.15	4.06	3.98
7,000,000	6.66	6.23	5.89	5.61	5.38	5.18	5.00	4.84	4.70	4.58	4.46	4.35	4.25	4.16	4.08
8,000,000	6.77	6.33	5.99	5.71	5.48	5.27	5.10	4.94	4.80	4.67	4.55	4.44	4.34	4.25	4.16
9,000,000	6.87	6.43	6.09	5.80	5.57	5.36	5.18	5.02	4.88	4.75	4.63	4.52	4.42	4.33	4.24
10,000,000	6.96	6.52	6.17	5.89	5.65	5.44	5.26	5.10	4.95	4.82	4.70	4.59	4.49	4.40	4.31
15,000,000	7.33	6.87	6.51	6.21	5.96	5.75	5.56	5.40	5.25	5.11	4.99	4.87	4.77	4.67	4.58
20,000,000	7.60	7.12	6.75	6.45	6.19	5.97	5.78	5.61	5.46	5.32	5.19	5.08	4.97	4.87	4.78
25,000,000	7.81	7.32	6.94	6.63	6.37	6.15	5.96	5.78	5.63	5.49	5.36	5.24	5.13	5.03	4.94
30,000,000	7.98	7.49	7.10	6.79	6.53	6.30	6.10	5.93	5.77	5.63	5.50	5.38	5.26	5.16	5.07
35,000,000	8.14	7.63	7.24	6.92	6.66	6.43	6.23	6.05	5.89	5.74	5.61	5.49	5.38	5.27	5.18
40,000,000	8.27	7.76	7.37	7.04	6.77	6.54	6.34	6.16	5.99	5.85	5.71	5.59	5.48	5.37	5.28
45,000,000	8.39	7.87	7.47	7.15	6.87	6.64	6.43	6.25	6.09	5.94	5.81	5.68	5.57	5.46	5.36
50,000,000	8.50	7.98	7.57	7.24	6.97	6.73	6.52	6.34	6.17	6.02	5.89	5.76	5.65	5.54	5.44
60,000,000	8.69	8.16	7.74	7.41	7.13	6.89	6.68	6.49	6.32	6.17	6.03	5.91	5.79	5.68	5.58
70,000,000	8.85	8.31	7.89	7.55	7.27	7.02	6.81	6.62	6.45	6.30	6.16	6.03	5.91	5.80	5.70
80,000,000	8.99	8.45	8.02	7.68	7.39	7.14	6.92	6.73	6.56	6.41	6.26	6.13	6.01	5.90	5.80
90,000,000	9.12	8.57	8.14	7.79	7.50	7.25	7.03	6.83	6.66	6.50	6.36	6.23	6.11	6.00	5.89
100,000,000	9.24	8.68	8.24	7.89	7.60	7.34	7.12	6.93	6.75	6.59	6.45	6.32	6.19	6.08	5.97

TABLE A.10B

REQUIRED STRUCTURAL NUMBER (SN_R)
99% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 18,000 PSI TO 32,000 PSI

	RESILIENT MODULUS (M_R), (PSI x 1000)														
$ESAL_D$	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
100,000	2.02	1.98	1.94	1.90	1.87	1.83	1.80	1.77	1.75	1.72	1.69	1.67	1.65	1.62	1.60
150,000	2.17	2.12	2.08	2.04	2.00	1.97	1.93	1.90	1.87	1.85	1.82	1.79	1.77	1.75	1.72
200,000	2.27	2.23	2.18	2.14	2.10	2.07	2.03	2.00	1.97	1.94	1.91	1.88	1.86	1.83	1.81
250,000	2.36	2.31	2.26	2.22	2.18	2.14	2.11	2.08	2.04	2.01	1.99	1.96	1.93	1.91	1.88
300,000	2.43	2.38	2.33	2.29	2.25	2.21	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.97	1.94
350,000	2.49	2.44	2.40	2.35	2.31	2.27	2.23	2.20	2.16	2.13	2.10	2.07	2.05	2.02	1.99
400,000	2.55	2.50	2.45	2.40	2.36	2.32	2.28	2.25	2.21	2.18	2.15	2.12	2.09	2.07	2.04
450,000	2.60	2.55	2.50	2.45	2.41	2.37	2.33	2.29	2.26	2.22	2.19	2.16	2.13	2.11	2.08
500,000	2.65	2.59	2.54	2.49	2.45	2.41	2.37	2.33	2.30	2.26	2.23	2.20	2.17	2.14	2.12
600,000	2.73	2.67	2.62	2.57	2.53	2.48	2.44	2.40	2.37	2.33	2.30	2.27	2.24	2.21	2.18
700,000	2.80	2.74	2.69	2.64	2.59	2.55	2.51	2.47	2.43	2.39	2.36	2.33	2.30	2.27	2.24
800,000	2.86	2.80	2.75	2.70	2.65	2.60	2.56	2.52	2.48	2.45	2.41	2.38	2.35	2.32	2.29
900,000	2.92	2.86	2.80	2.75	2.70	2.66	2.61	2.57	2.53	2.50	2.46	2.43	2.40	2.37	2.34
1,000,000	2.97	2.91	2.85	2.80	2.75	2.70	2.66	2.62	2.58	2.54	2.51	2.47	2.44	2.41	2.38
1,500,000	3.18	3.11	3.05	2.99	2.94	2.89	2.84	2.80	2.76	2.72	2.68	2.64	2.61	2.58	2.55
2,000,000	3.33	3.26	3.20	3.14	3.08	3.03	2.98	2.94	2.89	2.85	2.81	2.77	2.74	2.70	2.67
2,500,000	3.46	3.39	3.32	3.26	3.20	3.15	3.10	3.05	3.00	2.96	2.92	2.88	2.84	2.80	2.77
3,000,000	3.56	3.49	3.42	3.36	3.30	3.24	3.19	3.14	3.09	3.05	3.01	2.97	2.93	2.89	2.86
3,500,000	3.65	3.58	3.51	3.44	3.38	3.33	3.27	3.22	3.17	3.13	3.08	3.04	3.00	2.97	2.93
4,000,000	3.73	3.66	3.59	3.52	3.46	3.40	3.35	3.29	3.24	3.20	3.15	3.11	3.07	3.03	3.00
4,500,000	3.80	3.73	3.65	3.59	3.53	3.47	3.41	3.36	3.31	3.26	3.22	3.17	3.13	3.09	3.05
5,000,000	3.87	3.79	3.72	3.65	3.59	3.53	3.47	3.42	3.37	3.32	3.27	3.23	3.19	3.15	3.11
6,000,000	3.98	3.90	3.83	3.76	3.69	3.63	3.58	3.52	3.47	3.42	3.37	3.33	3.28	3.24	3.20
7,000,000	4.08	4.00	3.92	3.85	3.79	3.72	3.67	3.61	3.56	3.51	3.46	3.41	3.37	3.33	3.29
8,000,000	4.16	4.08	4.01	3.94	3.87	3.81	3.75	3.69	3.63	3.58	3.53	3.49	3.44	3.40	3.36
9,000,000	4.24	4.16	4.08	4.01	3.94	3.88	3.82	3.76	3.70	3.65	3.60	3.56	3.51	3.47	3.43
10,000,000	4.31	4.23	4.15	4.08	4.01	3.94	3.88	3.82	3.77	3.72	3.67	3.62	3.57	3.53	3.48
15,000,000	4.58	4.50	4.42	4.34	4.27	4.20	4.14	4.08	4.02	3.96	3.91	3.86	3.81	3.77	3.72
20,000,000	4.78	4.69	4.61	4.53	4.46	4.39	4.33	4.26	4.20	4.15	4.09	4.04	3.99	3.94	3.90
25,000,000	4.94	4.85	4.76	4.69	4.61	4.54	4.47	4.41	4.35	4.29	4.24	4.18	4.13	4.08	4.04
30,000,000	5.07	4.98	4.89	4.81	4.74	4.67	4.60	4.53	4.47	4.41	4.36	4.30	4.25	4.20	4.15
35,000,000	5.18	5.09	5.00	4.92	4.84	4.77	4.70	4.64	4.58	4.52	4.46	4.41	4.35	4.30	4.25
40,000,000	5.28	5.18	5.10	5.02	4.94	4.87	4.80	4.73	4.67	4.61	4.55	4.50	4.44	4.39	4.34
45,000,000	5.36	5.27	5.18	5.10	5.02	4.95	4.88	4.81	4.75	4.69	4.63	4.58	4.52	4.47	4.42
50,000,000	5.44	5.35	5.26	5.18	5.10	5.02	4.95	4.89	4.82	4.76	4.70	4.65	4.59	4.54	4.49
60,000,000	5.58	5.48	5.39	5.31	5.23	5.16	5.08	5.02	4.95	4.89	4.83	4.77	4.72	4.67	4.62
70,000,000	5.70	5.60	5.51	5.43	5.34	5.27	5.20	5.13	5.06	5.00	4.94	4.88	4.83	4.77	4.72
80,000,000	5.80	5.70	5.61	5.53	5.44	5.37	5.29	5.22	5.16	5.09	5.03	4.98	4.92	4.87	4.81
90,000,000	5.89	5.79	5.70	5.61	5.53	5.46	5.38	5.31	5.24	5.18	5.12	5.06	5.00	4.95	4.90
100,000,000	5.97	5.88	5.78	5.70	5.61	5.53	5.46	5.39	5.32	5.26	5.20	5.14	5.08	5.02	4.97

APPENDIX B
FLEXIBLE PAVEMENT DESIGN
QUALITY CONTROL PLAN

B.1 QUALITY CONTROL PLAN

All flexible pavement designs will be reviewed independently by a responsible Professional Engineer other than the original pavement design engineer for accuracy and correctness. The following quality control plan is provided as a guideline.

B.2 DEFINITIONS

The following definitions are used throughout this section.

Quality

Conformance to policies, procedures, standards, guidelines and above all, good engineering practice.

Quality Assurance (QA)

QA consists of all planned and systematic actions necessary to provide adequate confidence that a design, structure, system, or component will perform satisfactorily and conform to project requirements. QA involves establishing project related policies, procedures, standards, training, guidelines, and systems necessary to produce quality.

Quality Control (QC)

QC is the checking and review of designs and plans for compliance with policies, procedures, standards, guidelines and good engineering practice.

B.3 RESPONSIBILITY

The district offices and turnpike consultants are responsible for Quality Control. Quality Assurance is the role of the Central Office.

B.4 FLEXIBLE PAVEMENT DESIGNS

Pavement designs will be developed in accordance with the ***Flexible Pavement Design Manual*** (Topic No. 625-010-002). The approved pavement design and the supporting data will be included in the District Project Design File.

B.4.1 MINIMUM REQUIREMENTS

The Pavement Design Package, at a minimum, will include the following items:

- The Pavement Design Summary Sheet will show the approved pavement design, and each Pavement Design Summary Sheet will be signed and sealed by the District Pavement Design Engineer or the designated responsible Pavement Design Engineer. The District Design Engineer will sign for concurrence with the design. The file copy will show Federal Highway Administration (FHWA) approval, if required, for Federal Aid Projects or Certification Acceptance as appropriate.
- Project location and description of the type of work, if not clearly stated on the summary sheet.
- The basis for the pavement design, signed and sealed where required, including if applicable for:

New Construction

  - Resilient Modulus (M_R).
  - Material properties used if different than those in the design manual.
  - Subgrade stabilization requirements.

Rehabilitation and Lane Widening

  - Existing pavement layer information (layer types, thickness, and condition).
  - A copy of the Pavement Coring and Evaluation Report.
  - Subgrade stabilization requirements.
  - Overbuild recommendations.
  - A copy of the signed and sealed Nondestructive Testing Report from the State Materials Office.

- A Pavement Evaluation Coring and Condition Data report must be requested based on the milling recommendations for all projects involving milling greater than 5,000 tons.
- Existing cross-slope from design survey and method of correction if required.
- The $ESAL_D$ calculations, signed and certified. This may be either a copy of the report prepared by the Planning Office or calculations using the design computer program. The basis for the input data used for these calculations must be stated.

- Design calculations (including pavement layer thickness).
- Documentation addressing any special features such as feathering details, cross slope, coordination with adjacent projects, stage construction, drainage considerations, etc.
- Sketch of a possible layer construction sequence, including any widening and shoulders, to ensure constructability.
- A drawing of the final pavement design typical section or an adequate narrative description.

B.4.2 DISTRIBUTION

Central Office approval of the pavement design is not required. Designs will be monitored and periodically reviewed, in detail, for quality assurance and for purposes of identifying and improving deficiencies in design policies, procedures, standards, and guidelines.

For Federal Aid Projects which are for oversight in design, two copies of the approved Pavement Design Summary Sheet and one copy of the supporting documentation, will be forwarded directly to the appropriate Federal Highway Administration (FHWA) Engineer for FHWA concurrence.

Only mainline or major elements of a project need formal FHWA pavement design approval. Details such as cross roads and shoulders will be handled as a part of the plans approval process. Do not send these copies to the Central Office for transmittal to FHWA.

The District will deal directly with the FHWA to resolve any questions. Central Office Pavement Management will be available for assistance if requested by the District or

FHWA. The FHWA will return directly to the District one copy of the summary sheet with signature denoting concurrence. This copy will be filed in the District Project Design file.

B.4.3 REVISIONS

Changes made subsequent to formal distribution will require that a revised summary sheet be prepared, a copy of which shall be signed and sealed, distributed, and filed for permanent record in the Project Design File. Minor changes may be noted in type or ink on the original Pavement Design Summary Sheet with the responsible Professional Engineer's initials and the date of change. A copy of the revised original should then be signed, dated, sealed and filed for permanent record.

Major changes may require that a complete new Pavement Design Summary Sheet be prepared and processed, in which case it shall note that it supersedes a previous design. Copies of revised pavement designs including backup data documenting why the change is being made will be transmitted to the State Pavement Design Engineer and redistributed as appropriate.

For skid hazard, intersection improvement, short roadway connectors on bridge replacement projects, and roadway widening projects, the Resilient Modulus, $ESAL_D$, and computation of Required Structural Number, SN_R, are normally not required. However, in all cases, a document describing how the pavement design was developed should be prepared, signed and sealed.

B.4.4 DOCUMENTATION

The one area of pavement design involving perhaps the greatest liability to the Department is friction course selection. It is highly recommended that the Pavement Design Engineer become thoroughly familiar with the Department's Friction Course Policy. On projects where the policy is not adhered to, the reasons should be clearly documented in the Pavement Design Package. Small projects are not exempt.

Every attempt should be made to follow written procedures. Situations will occur where following the pavement design procedure will result in a SN_R which cannot be met. This could occur when an overlay is required in a curb and gutter section, or, when an existing cracked or distressed pavement requires rehabilitation, but the Existing Structural Number (SN_E) exceeds the Structural Required (SN_R).

The Pavement Design Engineer will have to exercise engineering judgment on what should be done in these cases. When this occurs, the Pavement Design Engineer is advised to document the project, make special note of the problem, and provide additional explanation as to how the recommended design was developed. Consultation with other engineers (Construction, Drainage, Materials, etc.) is highly recommended and should be noted in the design file.

B.5 DISTRICT QUALITY CONTROL

The quality control process will include three activities:

- The checking and review of pavement designs for compliance with policies, procedures, standards, guidelines, and good engineering practice.
- The checking and review of plans to ensure that the approved pavement designs are correctly incorporated.
- Documentation of the Quality Control Process.

The Quality Control Process will be carried out by an independent responsible Professional Engineer other than the original pavement design engineer. As a minimum, the documentation will consist of a copy of the QC Checklist filed with the Pavement Design Package, or a Pavement Design Quality Control File identified by State Project Number consisting of:

- A copy of the signed and sealed Pavement Design Summary Sheet.
- A copy of the QC Checklist signed by the QC Engineer.
- A sample checklist is attached.

B.6 QUALITY ASSURANCE REVIEWS

The State Pavement Design Engineer will be responsible for conducting and/or coordinating all pavement related QA activities within each District and the Turnpike. A QA review of District Pavement Design activities will generally be conducted semi-annually.

B.7 PAVEMENT DESIGN UPDATES

A pavement design review activity by an experienced pavement designer should be scheduled in the project scheduling system on all pavement projects approximately three months prior to letting. This final review will allow for updating pavement designs and plans for new technologies and pay items that may have been implemented since the original pavement design was prepared.

If the pavement evaluation report is over two years old, another field review of the pavement should be conducted to see if the pavement condition has significantly changed. If there is a significant change, a few additional cores may be needed to evaluate crack depths for milling and the pavement design and quantities may need updating to reflect the latest pavement condition.

PAGE ____ OF ____

FLEXIBLE PAVEMENT DESIGN
QUALITY CONTROL CHECKLIST

State Proj. No. __________ Federal Aid No. __________

FP ID No. __________ County__________

Flexible Pavement Design Review	**Satisfactory Yes/No/NA**
Pavement Design Summary Sheet……………………………………………..	______
Project Location and Description………………………………………………	______
Traffic Data and $ESAL_D$ Calculations……………………………………......	______
Resilient Modulus (M_R)………………………………………………………..	______
Reduced Resilient Modulus (M_R) for base high-water clearance less than 3 ft………..…………………………………..	______
Required Structural Number (SN_R) Calculations…………………………......	______
Calculated Structural Number (SN_C) Calculations……………………………	______
Base Material Selection...…………………………………………………......	______
Friction Course Selection………………………………………………………..	______
Stabilized Subgrade Evaluation…………………………………………….......	______
Shoulder Design…………………………………………………………………	______
Coordination with Other Offices…………………………………………….......	______
Other Special Details……………………………………………………………	______
Final Pavement Design Drawing or Narrative…………………………………	______

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Rehabilitation

Field Evaluation of Project………..…………………………………………….. _______

Pavement Coring and Evaluation Complete…..……………………………… _______

Distress Evaluation…………………..……………………………………....... _______

Existing Cross Slope and Correction Method…...…………………………….. _______

Milling Depth and Purpose……………………………………………………. _______

Overlay Structural Number (SNO) Calculations…...………………………….. _______

Overbuild Recommendation…………………….……………………………. _______

Pavement Evaluation Coring and Condition Data Report……………..…...... _______

Projects That Do Not Require Design Calculations

Existing Pavement Evaluation…….………………………………………….. _______

Existing Cross Slope and Correction Method…...…………………………….. _______

Asphalt Thickness……………………………………………………………… _______

Base Type and Thickness…………………………………………………….. _______

Future Milling Considerations……………………………………………… _______

Structural Evaluation……………………………………………………….... _______

Plans Review

Plans Conform to Pavement Design…..……………………………………….. _______

Cross Slope Correction Addressed……………...…………………………….. _______

Design Details Adequately Covered……………………………………… _______

PAGE ____ OF ____

____

Standard Plans Indexes Properly Referenced…..…………………………….. _______

Project is Constructible with Current Technology…...………………………… _______

Comments

QA by ______________________________ Date _____________________

FLORIDA DEPARTMENT OF TRANSPORTATION
FLEXIBLE PAVEMENT DESIGN SUMMARY SHEET

Prepared by ____________________	Date Prep ____________________
FP ID # ________________________	US # _________ SR # _________
State Proj. # ____________________	From ________________________
FAP # _________________________	To __________________________
County ________________________	Begin MP ____________________
Project Length _________________	End MP ______________________
Type of Work __________________	%R _________________________
Opening Year __________________	M_R _________________________
Design Year ___________________	Design Speed ________________
$ESAL_D$ ________________________	Design Seq. # ________________
SN_R __________________________	Proj. Name ___________________

Existing Pavement

Proposed Design

Approved By Res. Engineer	Concurrence By Dist. Des. Engineer	Concurrence By FHWA (If Needed)
____________________	______________________	______________________
Date ______________	Date ______________	Date ______________

APPENDIX C
MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE: A MANUAL OF PRACTICE

C.1 MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE: A MANUAL OF PRACTICE

The Mechanistic-Empirical Pavement Design Guide: A Manual of Practice, commonly referred to as the MOP, was developed as part of the National Cooperative Highway Research Program (NCHRP). It includes software (AASHTOWare's Pavement ME Design) with mechanistic-empirical models to predict pavement performance for a given climatic location.

The FDOT has not adopted the MOP for flexible pavement design.

APPENDIX D
ESTIMATING DESIGN 18-KIP EQUIVALENT SINGLE AXLE LOADS ($ESAL_D$)

D.1 BACKGROUND

One of the products of the AASHO (American Association of State Highway Officials) Road Test conducted in Ottawa, Illinois from 1958 to 1960 was a method for relating the relative damage caused by different axle loadings. This evolved into a procedure that permitted the calculation of the accumulated damage caused by mixed vehicle loadings over a pavement design period. The four tires, single axle, carrying 18,000 lb (18-kip Equivalent Single Axle Load or $ESAL_D$) was accepted as the base for these calculations. ***Table D.1*** illustrates the relationship of axle weight to damage.

A detailed write-up, including tabulated damage factors for single, tandem, and triple axles, is given in Appendix D of the 1993 AASHTO (American Association of State Highway and Transportation Officials) Guide for Design of Pavement Structures.

A procedure for calculating a more precise estimate on the Department's projects can be obtained from the Office of Planning Project Traffic Forecasting Procedure (Topic No. 525-030-120) using the ***Project Traffic Forecasting Handbook***. Calculations on Department projects must be signed and certified by the Department's planning section.

The following is a simple procedure for estimating $ESAL_D$ in the design lane. Design periods used in these calculations can be found in the manual. The design lane is the lane where the majority of the trucks can be found. A common example would be a four-lane divided highway where most of the trucks would be found in the outside lanes. The basic equation is presented and the variables are defined. Simple input coefficients are tabulated. Several computer programs that perform the necessary computations are available from the Department.

TABLE D.1
RELATIONSHIP OF AXLE WEIGHT TO DAMAGE
SN=5

	Total Axle Load in KIP	Equivalent Damage in ESAL's
Single Axle	14	0.36
	18	**1.00**
	22	2.18
Tandem Axle	30	0.66
	34	1.09
	38	1.70
	44	3.00

D.2 BASIC EQUATION

The $ESAL_D$ required for pavement design purposes can be computed using the following equation:

$$ESAL_D = \sum_{y=1}^{y=x} (AADT \times T_{24} \times D_F \times L_F \times E_{18} \times 365)$$

Where:

$ESAL_D$ = Number of accumulated 18-kip Equivalent Single Axle Loads in the design lane for the design period.

y = The year that the calculation is made for. When y=1, all the variables apply to year 1. Most of the variables are constant except AADT which may change from year to year. Others may change when changes in the system occur. Such changes include parallel roads, shopping centers, truck terminals, etc.

x = The Design Year.

AADT = Average Annual Daily Traffic.

T_{24} = Percent Heavy Trucks during a 24-hour period. Trucks with 6 tires or more are considered in the calculations.

D_F = Directional Distribution Factor. Use 1.0 if one-way traffic is counted or 0.5 for two-way traffic. This value is not to be confused with the Directional Factor use for planning capacity computations.

L_F = Lane Factor converts directional trucks to the design lane trucks. Lane factors can be adjusted to account for unique features known to the designer such as roadways with designated truck lanes. L_F values can be determined from ***Table D.2***.

E_{18} = Equivalency factor which is the damage caused by one average heavy truck measured in 18-kip Equivalent Single Axle Loads. These factors will be periodically updated based on Weigh-In-Motion (WIM) data. E_{18}values can be determined from ***Table D.3***.

TABLE D.2
LANE FACTORS (L_F) FOR DIFFERENT TYPES OF FACILITIES

	Number of Lands in One Direction	
Total AADT	**Two Lanes L_F**	**Three Lanes L_F**
4,000	0.94	0.82
8,000	0.88	0.76
12,000	0.85	0.72
16,000	0.82	0.70
20,000	0.81	0.68
30,000	0.77	0.65
40,000	0.75	0.63
50,000	0.73	0.61
60,000	0.72	0.59
70,000	0.70	0.58
80,000	0.69	0.57
100,000	0.67	0.55
120,000	0.66	0.53
140,000	- -	0.52
160,000	- -	0.51
200,000	- -	0.49

The equation that best defines this Lane Factor (L_F) information is:

$$L_F = (1.567 - 0.0826 \times \text{Ln(One Way AADT)} - 0.12368 \times LV)$$

Where:

L_F = Proportion of all one directional trucks in the design lane.

LV = 0 if the number of lanes in one direction is 2. LV = 1 if the number of lanes in one direction is 3 or more.

Ln = Natural Logarithm.

Source – National Cooperative Highway Research Program Report 277, Portland Cement Concrete Pavement Evaluation System (COPES), Transportation Research Board, September 1986

TABLE D.3
EQUIVALENCY FACTORS E_{18} FOR DIFFERENT TYPES OF FACILITIES

	Flexible Pavement	Rigid Pavement
Freeways		
Rural	1.05	1.60
Urban	0.90	1.27
Arterials and Collectors		
Rural	0.96	1.35
Urban	0.89	1.22

D.3 SAMPLE PROBLEMS

Several sample problems have been provided that illustrates this process.

D.3.1 SAMPLE PROBLEM #1

The District Planning Engineer has provided the following information about a high volume, urban arterial; four lanes divided two-way projects that will open in the year 2005. The Pavement Type Selection Process indicates that the best alternative is flexible pavement.

GIVEN:

The following input is provided. Note that changes occur to other facilities within the urban area in the year 2013 which cause the AADT to increase while the percent truck traffic (T_{24}) decreases.

T_{24} = 12%

2005 Estimated AADT = 12,000

2013 Estimated AADT = 16,000

T_{24} = 8%

2014 Estimated AADT = 34,000

2025 Estimated AADT = 56,000

DATA:

The following data can be determined from information and tables provided.

D_F = 0.50 (for two-way traffic)

E_{18} = 0.89 (from ***Table D.3***)

L_F = Determined using the equation from ***Table D.2***

FIND:

The $ESAL_D$ for 20 years design period beginning in 2005.

SOLUTION:

Using the following equations:

For the years 2005 to 2013:

$$\mathbf{ESAL_D} = \sum_{y=2005}^{y=2013} (\mathbf{AADT \times T_{24} \times D_F \times L_F \times E_{18} \times 365})$$

$$\mathbf{ESAL_D} = \sum_{y=2005}^{y=2013} (\mathbf{AADT \times 0.12 \times 0.50 \times L_F \times 0.89 \times 365})$$

For the years 2014 to 2025:

$$\mathbf{ESAL_D} = \sum_{y=2014}^{y=2025} (\mathbf{AADT \times T_{24} \times D_F \times L_F \times E_{18} \times 365})$$

$$\mathbf{ESAL_D} = \sum_{y=2014}^{y=2025} (\mathbf{AADT \times 0.08 \times 0.50 \times L_F \times 0.89 \times 365})$$

Calculating:

Year	AADT	L_F	Annual ESAL *	Accumulated ESAL
2005	12,000	0.85	198,800	198,800
2006	12,500	0.84	204,700	403,500
2007	13,000	0.84	212,800	616,300
2008	13,500	0.84	221,000	837,300
2009	14,000	0.84	229,200	1,066,500
2010	14,500	0.83	234,600	1,301,100
2011	15,000	0.83	242,700	1,543,800
2012	15,500	0.83	250,800	1,794,600
2013	16,000	0.82	255,700	2,050,300
2014	34,000	0.76	335,800	2,386,100
2015	36,000	0.76	355,500	2,741,600
2016	38,000	0.75	370,300	3,111,900
2017	40,000	0.75	389,800	3,501,700
2018	42,000	0.75	409,300	3,911,000
2019	44,000	0.74	423,100	4,334,100
2020	46,000	0.74	442,300	4,776,400
2021	48,000	0.73	455,300	5,231,700
2022	50,000	0.73	474,300	5,706,000
2023	52,000	0.73	493,300	6,199,300
2024	54,000	0.72	505,200	6,704,500
2025	56,000	0.72	523,900	7,228,400
* Values are rounded for simplicity.				

CONCLUSION:

Note that the 20 years accumulated value ($ESAL_D$) is 6,704,500 ESALs or 7,000,000 ESALs.

D.3.2 SAMPLE PROBLEM #2

The District Planning Engineer has provided the following information about a moderate volume, rural arterial four lanes divided two way projects that will open in the year 1990. The Pavement Type Selection Process indicates that the best alternative is flexible pavement.

GIVEN:

The following input is provided.

T_{24} = 10%

1990 Estimated AADT = 17,000

2006 Estimated AADT = 25,000

DATA:

The following data can be determined from information and tables provided.

D_F = 0.50 (for two-way traffic)

E_{18} = 0.96 (from ***Table D.3***)

L_F = Determined using the equation from ***Table D.2***

FIND:

The $ESAL_D$ for 14 years design period beginning in 1990.

SOLUTION:

Using the following equations:

For the years 1990 to 2003:

$$\mathbf{ESAL_D = \sum_{y=1990}^{y=2003} (AADT \times T_{24} \times D_F \times L_F \times E_{18} \times 365)}$$

$$\mathbf{ESAL_D = \sum_{y=1990}^{y=2003} (AADT \times 0.10 \times 0.50 \times L_F \times 0.96 \times 365)}$$

Calculating:

Year	AADT	L_F	Annual ESAL *	Accumulated ESAL
1990	17,000	0.82	244,300	244,300
1991	17,500	0.82	251,400	495,700
1992	18,000	0.82	258,600	754,300
1993	18,500	0.81	262,500	1,016,800
1994	19,000	0.81	269,600	1,286,400
1995	19,500	0.81	276,700	1,563,100
1996	20,000	0.81	283,800	1,846,900
1997	20,500	0.80	287,300	2,134,200
1998	21,000	0.80	294,300	2,428,500
1999	21,500	0.80	301,300	2,729,800
2000	22,000	0.80	308,400	3,038,200
2001	22,500	0.79	315,400	3,353,600
2002	23,000	0.79	318,300	3,671,900
2003	23,500	0.79	325,300	3,997,200
2004	24,000	0.79	332,200	4,329,400
2005	24,500	0.79	339,100	4,668,500
2006	25,000	0.79	346,000	5,014,500
* Values are rounded for simplicity.				

CONCLUSION:

Note that the 14 year (2003) accumulated value is 3,997,200 ESALs (rounding $ESAL_D$ = 4,000,000). If the project was delayed one year, the new $ESAL_D$ would be:

4,329,400 - 244,300 = 4,085,100 ESALs

It is important to note that even though ESAL information is needed for only a 14-year period, additional ESAL information beyond that period is sometimes needed for project delays or increased design periods due to different rehabilitation strategies (i.e., resurfacing verses milling and resurfacing). This gives the designer flexibility in design and programming of this project.