

FLEXIBLE PAVEMENT DESIGN MANUAL



PUBLISHED BY
FLORIDA DEPARTMENT OF TRANSPORTATION
PAVEMENT MANAGEMENT OFFICE
605 SUWANNEE STREET, M.S. 70
TALLAHASSEE, FLORIDA 32399-0450

DOCUMENT NO. 625-010-002-e

JANUARY 2002

UPDATES TO THIS MANUAL WILL BE ANNOUNCED ON PAVEMENT
MANAGEMENT WEB SITE.

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Approved:

Pavement Management Office
Topic Number: 625-010-002-e
Effective: January 1, 2002

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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 rehabilitation project. This design manual addresses methods to properly develop a rehabilitation project, pavement milling, and the computations necessary for the pavement design process.

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

1.2 AUTHORITY

Section 334.044(2), 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. Under Section 334.044, the Code 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 (ie. 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 BACKGROUND

The manual (Topic No.625-010-002-e) is published as a revision, using English and Metric values.

1.5.2 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 Council on Highway Research Projects (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.

1.5.3 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.

1.5.4 APPENDICES

Included with this manual are 4 appendices:

<u>Appendix</u>	<u>Contents</u>
A	Design Tables.
B	Flexible Pavement Design Quality Control Plan.
C	Flexible Pavement Design Analysis Computer Program.
D	Estimating Design 18-kip(80-kiloNewton)Equivalent Single Axle Loads (ESAL _p).

1.6 DISTRIBUTION

This document is available through the Maps and Publications Section.

Manuals may be purchased from:

Florida Department of Transportation
Map and Publication Sales
Mail Station 12
605 Suwannee Street
Tallahassee, FL 32399-0450

Telephone (850) 414-4050
SUN COM 994-4050
FAX Number (850) 414-4915
<http://www11.myflorida.com/mapsandpublications>

Contact the above office for latest price information. Authorized Florida Department Of Transportation personnel may obtain the manual from the above office at no charge with the appropriate cost center information.

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 Office
605 Suwannee Street, M.S. 70
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, District Consultant Pavement Management Engineers and posted on, F.D.O.T. website. <http://www11.myflorida.com/pavementmanagement>. 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 Organization, Forms and Procedures Office prior to implementation to ensure conformance with and incorporation into the Department's standard operating system.

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.

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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" (0.1 m) 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 Course FC-12.5{FC-6} is a dense graded mix and is placed approximately 1 1/2" thick or 160 lb/yd² (40 mm thick or 88 kg/m²).
- Friction Course FC-9.5 is a dense graded mix and is placed approximately 1.0" thick or 110 lb/yd² (30 mm thick or 66 kg/m²).
- Friction Course or FC-5 is an open graded mix and is placed approximately 3/4" thick or 80 lb/yd² (20 mm thick or 44 kg/m²).

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"(9.5 mm) nominal maximum size aggregate.
- Structural Course Type SP-12.5 uses a 1/2"(12.5 mm) nominal maximum size aggregate.
- Structural Course Type SP-19.0 uses a 3/4"(19.0 mm) nominal maximum size aggregate.

Old Mixes

Type S-I, S-II, S-III, FC-1, FC-2, FC-3, FC-4, Type I, II and III Asphaltic Concrete, Binder, and Asphaltic Concrete base mixes will be encountered on rehabilitation projects but are not currently designed by the Department.

Leveling and Overbuild Course

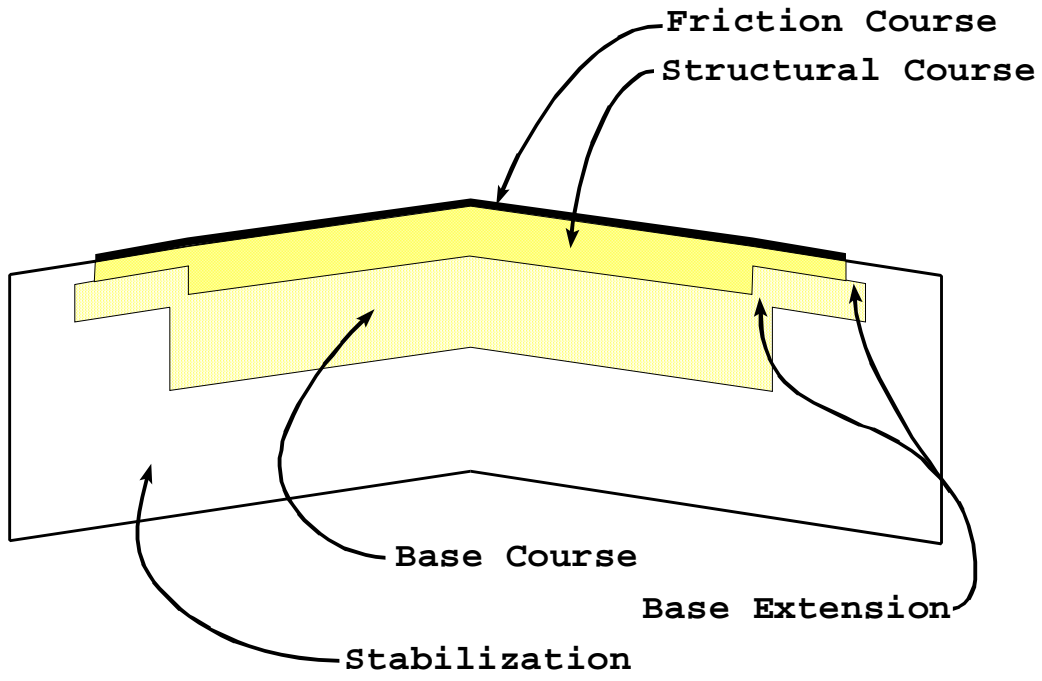
The Leveling and Overbuild Courses are used for surface leveling, longitudinal profile and cross-slope correction.

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, that are structurally equivalent, are grouped together to form an optional base group. More detailed information can be found in Section 5 of this manual or Standard Index 514.

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"(300 mm) thick. This structural layer serves as a working platform to permit the efficient construction of the base material. It is 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 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 (80-kiloNewton) Equivalent Single Axle Loads ESAL or ESAL_p

The Accumulated 18-kip (80-kiloNewton) 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_p.

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

<u>AASHTO REVISED</u> <u>DESIGN ESAL_D RANGE</u> <u>(MILLION)</u>	<u>TRAFFIC LEVEL</u>	<u>PREVIOUS</u> <u>TRAFFIC LEVEL</u>
< 0.3	A	1
0.3 to < 3	B	2,3
3 to < 10	C	4
10 to < 30	D	5
>= 30	E	6,7

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 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. The reliability value replaces the safety factor that was previously imbedded in the Soil Support Value.

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 calculations 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 UNKNOWNNS

Required Structural Number (SN_R)

The Required Structural Number (SN_R) is a weighted thickness in inches (millimeters) 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.

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.

Operational Type Projects

Operational Type Projects are projects approximately 1000' (300 m) 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. This is sometimes referred to as resurfacing.

Widening

Widening includes trench widening, lane addition, and operational type projects. This type of design does not require thickness design calculations.

Asphalt Rubber Membrane Interlayer (ARMI)

A reflective crack treatment using an asphalt rubber spray application and cover aggregate. Cover aggregate normally uses No. 6 stone, slag or gravel, so a layer thickness of ½" (10 mm) may be used. No prime nor tack coat is required over the cover aggregate prior to overlaying with initial asphalt lift. ARMI is placed beneath the overlay to resist the stress/strain of reflective cracks and delay the propagation of the crack through the new overlay.

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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 (80-kiloNewton) Equivalent Single Axle Loads 18-kip (80-kN) ESAL. 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 (80-kN) ESAL's is given in Appendix D. The summation of the 18-kip (80-kN) ESAL's during the design period is referred to as $ESAL_p$.

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 (mm).

The input includes the variables:

W_{18} = Accumulated 18-kip(80-kN) Equivalent Single Axle Loads over the life of the project (18-kip(80-kN) ESAL).

Z_R = Standard Normal Deviate.

M_R = Resilient Modulus psi(MPa).

The input includes the constants:

S_o = Standard Deviation.

ΔPSI = Change In Serviceability.

FIGURE 3.3

FLEXIBLE PAVEMENT DESIGN VARIABLES

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

For New Construction

$$SN_C = SN_R$$

Overlay With and Without Milling

$$SN_O = SN_R - SN_E$$

Where:

$ESAL_D$ = Accumulated 18-kip (80-kN) Equivalent Single Axle Loads over the life of the project (18-kip(80-kN) ESAL).

SN_R = Structural number determined as a function of the Design Equivalent Single Axle Loadings (DESAL), 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 Engineer office should be involved for 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 Department Roadway Plans Preparation Manual.

District Drainage

The District Drainage Office should be involved to determine if there are any special drainage considerations. An example would be 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 are any special construction details that need to be included in the plans or issues that need to be addressed. Some of these items may include Base Type, Stabilization, Traffic Control Plans (TCP), 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 Coring and Evaluations Procedures (Topic No. 675-030-005) can be obtained from the District Materials Office or through the Intranet and DOTNET document library.

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. 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 may be provided as part of the 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(PG 76-22) should be used in the final structural layer. For resurfacing designs, a minimum milling depth and whether an ARMI layer is required may be included in the criteria. The Pavement Coring and Evaluation report 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

The Following Design Periods Will Be Used For Flexible Pavement Designs.

New Construction or Reconstruction	20 Years
Pavement Overlay Without Milling	8 to 20 Years
Pavement Overlay With Milling	
Limited Access	12 to 20 Years*
Non-Limited Access	14 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.

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CHAPTER 4

FRICITION COURSE POLICY

4.1 FRICITION COURSE OPTIONS

There are two general types of friction courses currently in use by the Department, dense graded and open graded. Their thickness is controlled by specification through the minimum and maximum spread rate and paid for by the ton.

	<u>Minimum Spread rate</u>	<u>Maximum Spread rate</u>
FC-9.5	105 lb/yd ² (54 kg/m ²)	110 lb/yd ² (66 kg/m ²)
FC-12.5(FC-6)	150 lb/yd ² (80 kg/m ²)	160 lb/yd ² (88 kg/m ²)
FC-5	70 lb/yd ² (38 kg/m ²)	80 lb/yd ² (44 kg/m ²)

The nomenclature for FC-6 has been changed to FC-12.5. Friction Course, FC-12.5 (FC-6) and FC-9.5 are dense graded mixes which are placed 1 1/2"(40 mm) and 1"(30mm) thick respectively. The maximum spread rates of 160 lb/yd² (88 kg/m²) and 110 lb/yd² (66 kg/m²) are shown on the typical section. These Friction Courses provide smooth riding surfaces with adequate friction numbers for skid resistance.

The FC-9.5 fine graded mix will allow a one-inch lift of friction course. On some projects this may allow for an additional structural or overbuild lift, as in some curb and gutter sections, without milling into the base or filling up the gutter.

The other friction course, FC-5, consists of an open graded material.

FC-5 is placed approximately 3/4" (20 mm) thick. The maximum spread rate for this mix is shown as 80 lb/yd² (44 kg/m²) on the typical section. FC-5 provides a skid resistant surface. The open graded texture of the mix provides for the rapid removal of water from between the tire and the pavement to reduce the potential for hydroplaning at higher speeds.

A friction course will be placed on all roads with a design speed of 35 mph (60 km/h) or higher, except for low volume two lane roads having a five year projected AADT from the opening year of 3000 vehicles per day or less. On multi lane roadways with a design speed of 50 mph(80 km/h) or greater, FC-5 will be used. On all other roadways FC-12.5 (FC-6) or FC-9.5 will normally be used. Table 4.1 summarizes these requirements.

TABLE 4.1

ASPHALT CONCRETE FRICTION COURSE SELECTION

The Following Asphalt Concrete Friction Course Selection Chart Is Required For Design Speed Of 35 mph (60 km/h) Or Greater.

All Projects

	<u>Two Lane</u>	<u>Multi Lane</u>
35 thru 45 mph (60 thru 70 km/h)	FC-12.5(FC-6) or FC-9.5	FC-12.5(FC-6) or FC-9.5
50 mph(80 km/h) or Greater	FC-12.5(FC-6) or FC-9.5	FC-5

Low Volume Two Lane Roads

- Type SP Structural Course without a friction course may be used if the five years projected AADT from the opening year is less than 3000 vehicles per day.

4.2 FRICTION COURSE 12.5(FC-6) AND FC-9.5

The following are some of the features of the use of FC-12.5(FC-6) and FC-9.5:

- FC-12.5(FC-6) and FC-9.5 are allowed directly on top of any structural course mix.
- FC-12.5(FC-6) and FC-9.5 are considered part of the structural layer and may be considered as both a structural and friction course.

4.3 FRICTION COURSE 5 (FC-5)

The following are some of the limitations on the use of FC-5:

- Open graded friction courses such as FC-2 and FC-5 normally should not be overlaid (due to its potential to allow water into the pavement system) except when recommended by the District Materials Engineer.
- FC-5 should not sit after construction for more than four(4) months before being opened to traffic. If necessary, the FC-5 may need to be let under a separate contract.
- FC-5 can be used safely in all areas. If the majority of a project is FC-5 and the quantity of FC-12.5(FC-6)or FC-9.5 would be less than 1000 tons, FC-5 can be used throughout the project.
- On multi lane non-limited access facilities, the District Bituminous Engineer may recommend to place FC-5 at intermediate median crossovers (see Figure 4.1 and 4.2) or in median areas of low volume intersections (see Figure 4.3) having a five year projected AADT from the opening year of 3000 or less.

FC-5 is not required in these areas and can be difficult to construct, and may ravel over time due to low traffic volumes. However, complaints have been received that projects have an unfinished look and about the drop-off when FC-5 is left off.

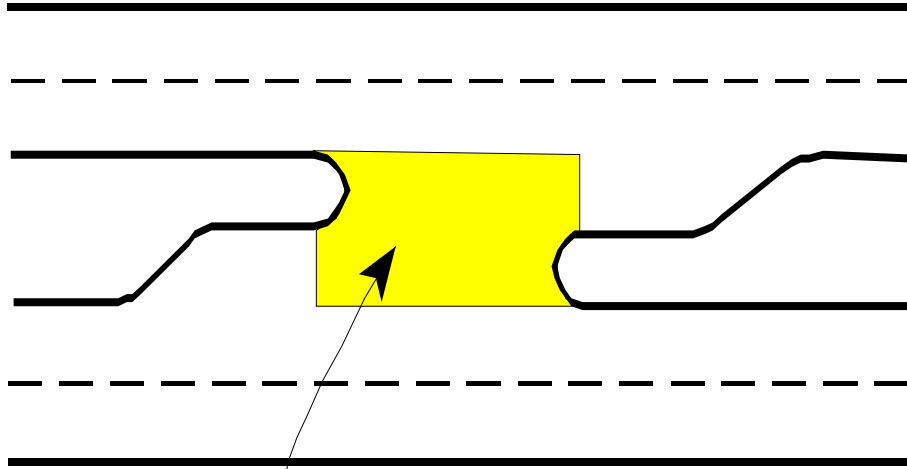
The FC-5 will cover the deceleration areas of turn lanes and shoulder pavement of non-limited access facilities.

FC-5 can also be placed directly on the milled surface provided the underlying layers are in good structural shape.

- On non-limited access facilities, the friction course is to be placed over the entire paved shoulder. On limited access facilities, the friction course is to extend 0.7' (0.2 m) beyond the edge of the travel lane, onto the paved shoulder.

FIGURE 4.1

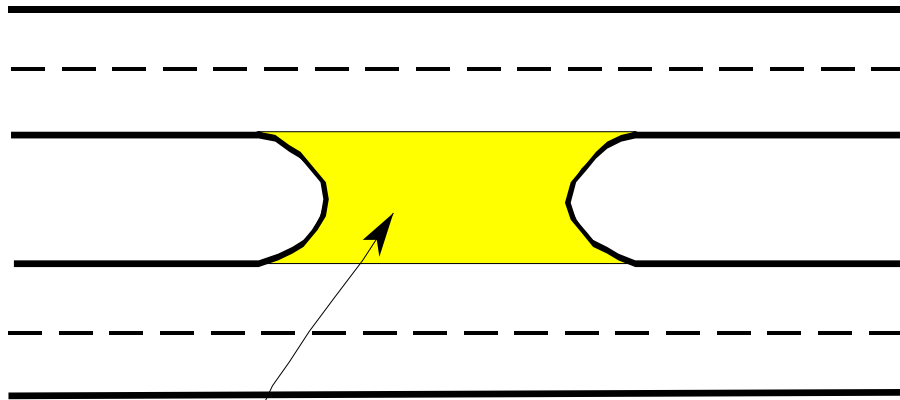
ILLUSTRATION SHOWING OPTIONAL LIMITS OF FRICTION COURSE
FC-5 AT INTERMEDIATE MEDIAN CROSSOVER



District Bituminous
Engineer may recommend
to place FC-5 within
these limits

FIGURE 4.2

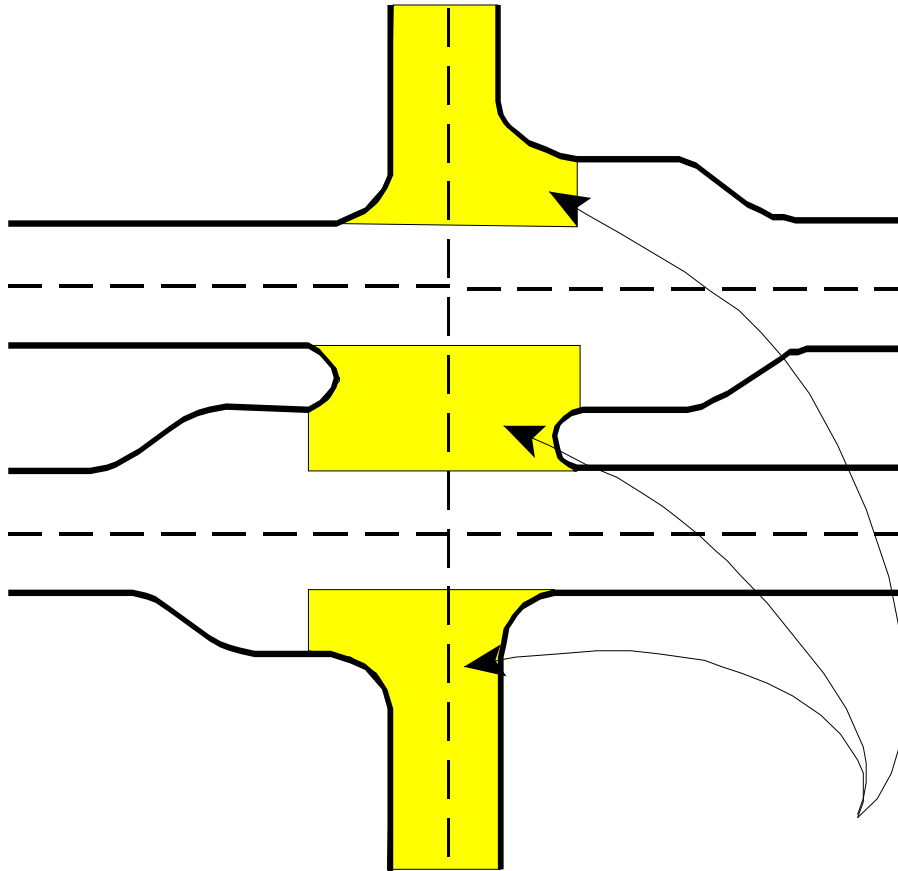
ILLUSTRATION SHOWING OPTIONAL LIMITS OF FRICTION COURSE
FC-5 AT INTERMEDIATE MEDIAN CROSSOVER



District Bituminous
Engineer may
recommend to place
FC-5 within these
limits

FIGURE 4.3

ILLUSTRATION SHOWING OPTIONAL LIMITS OF FRICTION COURSE
FC-5 AT MEDIAN AREAS OF LOW VOLUME INTERSECTION



District Bituminous Engineer
may recommend to place FC-5
within these limits

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CHAPTER 5

PAVEMENT THICKNESS DESIGN PROCESS FOR NEW CONSTRUCTION

5.1 OVERVIEW

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

For short pavement sections (approximately 1000' (300 m) or less) such as bridge replacement, cross roads, short turnouts, etc., the principles provided in Chapter 7 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(80-kilonewton) Equivalent Single Axle Loads 18-kip(80-kN) 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(80-kN) ESAL's or $ESAL_b$ 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, or from the District Materials Office using either actual laboratory testing or the Design Limerock Bearing Ratio (LBR) value which is based on 90% of the anticipated LBR's exceeding the Design LBR. This process is discussed in the next section. The relationship between the Design Limerock Bearing Ratio (LBR) and Resilient Modulus (M_R) is shown in Figure 5.1 with example values 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., or AASHTOWare DARWin Pavement Design and Analysis System computer program.

Each design table uses a different Reliability (%R) and relates Design 18-kip(80-kilonewton) Equivalent Single Axle Loads ($ESAL_d$) to the Structural Number Required (SN_r) for multiple Resilient Modulus (M_r) values. A design table example is provided using Table 5.3.

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 (95 MPa) (from the State Materials Office)

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

Design 18-kip(80-kilonewton) 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 1/2"(10 mm) of structural course. If desired, an interpolated SN_r value can be used. The solution is:

$SN_r = 3.57$ "(91 mm) (from Table 5.3)

5.2.2 RESILIENT MODULUS (M_R) FROM LBR

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. 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;

<u>Sample Number</u>	<u>LBR Values In Ascending Order</u>
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.

$$13 \times 90\% = 11.7 \text{ (Use 12)}$$

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

$$\text{Use LBR} = 22.$$

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: $M_r = 8,000 \text{ psi (54 Mpa)}$

FIGURE 5.1

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

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

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

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 .

Equation #3 - The following equation converts the Resilient Modulus (M_r) from the English System (pounds per square inch or psi) to the metric system (MegaPascals or MPa).

$$M_R (MPa) = (0.007 \frac{MPa}{psi}) * M_R (psi)$$

$$M_R (PSI) = \frac{M_R (MPa)}{0.007 \frac{MPa}{psi}}$$

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.

<u>Limerock Bearing</u>	<u>Resilient Modulus</u>	
<u>Ratio (LBR)</u>	<u>PSI</u>	<u>MPa</u>
10	4500	30
12	5000	35
14	5500	39
16	6000	43
18	7000	47
20	7500	51
22	8000	54
24	8500	58
26	9000	61
28	9500	65
30	10000	68
32	10500	72
34	11000	75
36	11500	78
38	12000	81
40	12000	84

TABLE 5.2

RELIABILITY (%R) FOR DIFFERENT ROADWAY FACILITIES

<u>Facility</u>	<u>New</u>	<u>Rehabilitation</u>
Limited Access	80 - 95	95 - 99
Urban Arterials	80 - 90	90 - 97
Rural Arterials	75 - 90	90 - 95
Collectors	75 - 85	90 - 95

Notes

The type of roadway is determined by the Office of Planning and can be obtained from the Roadway Characteristics Inventory (RCI).

The designer has some flexibility in selecting values that best fits 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.

For traffic volume ranges, refer to Chapter 2, Design Geometrics and Criteria, of the Plans Preparation Manual - Topic No. 625-000-007(625-000-005).

TABLE 5.3

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 5.3

REQUIRED STRUCTURAL NUMBER (SN_R) (METRIC)

90% RELIABILITY (%R)

RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

ESAL _D	Resilient Modulus (M_R), MPa														
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100 000	74	70	67	64	61	59	57	55	54	52	51	50	49	47	47
150 000	79	75	71	68	65	63	61	59	57	56	54	53	52	51	50
200 000	83	79	75	71	68	66	64	62	60	59	57	56	55	53	52
250 000	86	82	77	74	71	69	66	64	62	61	59	58	57	55	54
300 000	89	84	80	76	73	71	68	66	64	63	61	60	58	57	56
350 000	91	86	82	78	75	72	70	68	66	64	63	61	60	59	58
400 000	93	88	84	80	77	74	72	69	68	66	64	63	61	60	59
450 000	95	90	85	82	78	76	73	71	69	67	65	64	62	61	60
500 000	97	91	87	83	80	77	74	72	70	68	67	65	64	62	61
600 000	100	94	89	86	82	79	77	74	72	70	69	67	66	64	63
700 000	102	96	92	88	84	81	79	76	74	72	70	69	67	66	65
800 000	104	99	94	90	86	83	80	78	76	74	72	70	69	67	66
900 000	106	100	96	91	88	85	82	79	77	75	73	72	70	69	67
1 000 000	108	102	97	93	89	86	83	81	79	77	75	73	71	70	69
1 500 000	115	109	104	99	95	92	89	86	84	82	80	78	76	75	73
2 000 000	120	114	108	104	100	96	93	91	88	86	84	82	80	78	77
2 500 000	124	117	112	108	104	100	97	94	91	89	87	85	83	81	80
3 000 000	127	121	115	111	106	103	100	97	94	92	89	87	86	84	82
3 500 000	130	123	118	113	109	105	102	99	96	94	92	90	88	86	84
4 000 000	132	126	120	115	111	108	104	101	99	96	94	92	90	88	86
4 500 000	135	128	122	118	113	110	106	103	100	98	96	93	91	90	88
5 000 000	136	130	124	119	115	111	108	105	102	100	97	95	93	91	89
6 000 000	140	133	127	123	118	114	111	108	105	102	100	98	96	94	92
7 000 000	143	136	130	125	121	117	114	110	108	105	103	100	98	96	94
8 000 000	146	139	133	128	123	119	116	113	110	107	105	102	100	98	96
9 000 000	148	141	135	130	125	122	118	115	112	109	107	104	102	100	98
10 000 000	150	143	137	132	127	123	120	117	114	111	108	106	104	102	100
15 000 000	158	151	145	139	135	131	127	124	121	118	115	113	111	108	107
20 000 000	164	157	150	145	140	136	132	129	126	123	120	118	115	113	111
25 000 000	169	161	155	149	145	140	137	133	130	127	124	122	119	117	115
30 000 000	173	165	159	153	148	144	140	136	133	130	128	125	123	120	118
35 000 000	176	169	162	156	151	147	143	139	136	133	130	128	125	123	121
40 000 000	179	171	165	159	154	150	146	142	139	136	133	130	128	126	123
45 000 000	182	174	167	161	156	152	148	144	141	138	135	132	130	128	125
50 000 000	184	176	170	164	159	154	150	146	143	140	137	134	132	130	127
60 000 000	189	180	174	168	162	158	154	150	146	143	140	138	135	133	131
70 000 000	192	184	177	171	166	161	157	153	150	146	143	141	138	136	134
80 000 000	196	187	180	174	168	164	160	156	152	149	146	143	141	138	136
90 000 000	198	190	183	176	171	166	162	158	155	151	148	146	143	141	138
100 000 000	201	192	185	179	173	169	164	160	157	153	150	148	145	143	140

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;

$$SN_C = (a_1 \times D_1) + (a_2 \times D_2) + (a_3 \times D_3) + \dots \\ + (a_N \times D_N)$$

where:

SN_C = The total calculated strength of the pavement layers and has units of inches or (millimeters).

a_1 = Layer coefficient of the 1st layer.

D_1 = Layer thickness in inches (millimeters) 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 Stabilization.

a_N = Layer coefficient of the Nth layer.

D_N = Layer thickness in inches (millimeters) of the Nth layer.

Layer coefficients have been developed which represent the relative strength of different pavement in 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 1/2" (10 mm) of structural course.

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 Standard Index 514. 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" (200 mm) of Limerock (LBR 100) is equivalent to 5" (120 mm) 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 thickness has 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.

TABLE 5.4

STRUCTURAL COEFFICIENTS FOR DIFFERENT PAVEMENT LAYERS

<u>Group</u>	<u>Layer Type</u>	<u>Layer Coef. Per unit Thickness</u>	<u>Spec. Sect.</u>
Friction Courses	FC-5	0.00	337
	FC-12.5, FC-9.5	0.44	337
Structural Courses	Superpave Type SP (SP-9.5, SP-12.5, SP-19.0)	0.44	334
Base Courses (General use)	Limerock (LBR 100)	0.18	200
	Cemented Coquina (LBR 100)	0.18	250
	Shell Rock (LBR 100)	0.18	250
	Bank Run Shell (LBR 100)	0.18	250
	Graded Aggregate (LBR 100)	0.15	204
	Type B-12.5	0.30	280
Base Courses (Limited use)	Limerock Stab. (LBR 70)	0.12	230
	Shell Stab. (LBR 70)	0.10	260
	Sand Clay (LBR 75)	0.12	240
	Soil Cement (500 psi)	0.20	270
	Soil Cement (300 psi)	0.15	270
Stabilization	Type B Stab. (LBR 40)	0.08	160-2
	Type B Stab. (LBR 30)	0.06	160-2
	Type C Stab.	0.06	160-2
Subgrade	Cement Treated (300 psi)	0.12	170
	Lime Treated	0.08	165

TABLE 5.5

RECOMMENDED MINIMUM THICKNESS FOR NEW CONSTRUCTION

In order to avoid the possibility of producing an impractical design, the following minimum thickness are recommended for New Construction. It is assumed that a 12"(300 mm) stabilized subgrade is to be constructed.

<u>18-kip(80-kN) ESAL's 20 year period</u>	<u>Minimum Structural Course</u>	<u>Minimum Base Group</u>
Limited Access	4"(100 mm)	9
Greater than 3 500 000	3"(80 mm)	9
300 000 to 3 500 000	2"(50 mm)	6
Less than 300 000	1 ½"(40 mm)	3
Limited Access Shoulder	1 ½"(40 mm)	1
Residential Streets, Parking Areas, Shoulder Pavement, Bike Paths	1"(30 mm)	1

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

FC-5 has no structural value and is always shown as 80 lb/y², ¾" (44 kg/m²)(20 mm) thick. Also assume that a 12"(300 mm) Stabilized Subgrade (LBR-40) is to be used in order to establish a satisfactory working platform.

TABLE 5.6
GENERAL USE OPTIONAL BASE GROUPS AND STRUCTURAL NUMBERS
(STANDARD INDEX 514) (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	Graded Aggregate Base LBR 100	Type B-12.5	B-12.5 And 4" Granular Subbase, LBR 100*	RAP Base
			Structural Number (Per.in)							
			(.18)	(.18)	(.18)	(.18)	(.15)	(.30)	(.30&.15)	(NA)
1	.65- .75	701	4"	4"	4"	4"	4½"	4" [△]		5" [□]
2	.80- .90	702	5"	5"	5"	5"	5½"	4" [△]		
3	.95-1.05	703	5½"	5½"	5½"	5½"	6½"	4" [△]		
4	1.05-1.15	704	6"	6"	6"	6"	7½"	4" [△]		
5	1.25-1.35	705	7"	7"	7"	7"	8½"	4½"		
6	1.35-1.50	706	8"	8"	8"	8"	9"	5"		
7	1.50-1.65	707	8½"	8½"	8½"	8½"	10"	5½"		
8	1.65-1.75	708	9½"	9½"	9½"	9½"	11"	5½"		
9	1.75-1.85	709	10"	10"	10"	10"	12"	6"	4"	
10	1.90-2.00	710	11"	11"	11"	11"	13" [⊙]	6½"	4½"	
11	2.05-2.15	711	12"	12"	12"	12"	14" [⊙]	7"	5"	
12	2.20-2.30	712	12½"	12½"	12½"	12½"		7½"	5½"	
13	2.35-2.45	713	13½" [⊙]	13½" [⊙]	13½" [⊙]	13½" [⊙]		8"	6"	
14	2.45-2.55	714	14" [⊙]	14" [⊙]	14" [⊙]	14" [⊙]		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 paid for under the contract unit price for Optional Base. Granular Subbases include Limerock, Cemented Coquina, Shell Rock, Bank Run Shell and Graded Aggregate Base at LBR 100. The base thickness shown is Type B-12.5. All subbase thickness are 4".

⊙ To be used for Widening only, three feet or less.

△ Based on minimum practical thickness.

□ Restricted to non-limited access shoulder base construction.

TABLE 5.6
GENERAL USE OPTIONAL BASE GROUPS AND STRUCTURAL NUMBERS
(STANDARD INDEX 514) (mm)

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	Graded Aggregate Base LBR 100	Type B-12.5	B-12.5 And 100mm Granular, Subbase LBR 100*	RAP Base
			Structural Number (Per mm)							
			(.18)	(.18)	(.18)	(.18)	(.15)	(.30)	(.30&.15)	(NA)
1	16-20	701	100	100	100	100	100	100 [△]		130 [□]
2	20-23	702	120	120	120	120	140	100 [△]		
3	24-27	703	140	140	140	140	160	100 [△]		
4	27-29	704	160	160	160	160	190	100 [△]		
5	31-34	705	180	180	180	180	210	110		
6	34-39	706	200	200	200	200	230	120		
7	39-42	707	220	220	220	220	260	130		
8	42-44	708	240	240	240	240	280	140		
9	44-47	709	260	260	260	260	300	150	100	
10	48-51	710	280	280	280	280	330 [⊖]	160	110	
11	52-55	711	300	300	300	300	350 [⊖]	180	130	
12	55-58	712	320	320	320	320		190	140	
13	59-62	713	340 [⊖]	340 [⊖]	340 [⊖]	340 [⊖]		200	150	
14	62-65	714	360 [⊖]	360 [⊖]	360 [⊖]	360 [⊖]		210	160	
15	66-69	715						220	170	

* For granular subbase, the construction of both the subbase and Type B-12.5 will be paid for under the contract unit price for Optional Base. Granular Subbases include Limerock, Cemented Coquina, Shell Rock, Bank Run Shell and Graded Aggregate Base at LBR 100. The base thickness shown is Type B-12.5. All subbase thickness are 100mm(4").

⊖ To be used for Widening only, one meter or less.

△ Based on minimum practical thickness.

□ Restricted to non-limited access shoulder base construction.

TABLE 5.7
LIMITED USE OPTIONAL BASE GROUPS AND STRUCTURAL NUMBERS
(STANDARD INDEX 514) (inches)

BASE THICKNESS AND OPTION CODES											
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)								
			(.12)	(.12)	(.10)	(.12)	(.15)	(.15)	(.20)		
1	.65 - .75	701	5"	5"	7"	5"	5"	5"	4" [△]		
2	.80 - .90	702	6½"	6½"	8½"	6½"	5½"	5½"	4"		
3	.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 (ESAL) Loads 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 Thickness.

TABLE 5.7

**LIMITED USE OPTIONAL BASE GROUPS AND STRUCTURAL NUMBERS
(STANDARD INDEX 514) (mm)**

BASE THICKNESS AND OPTION CODES										
Base Group	Structural Range	Base Group Pay Item Number	Base Options							Structural Number (Per. mm)
			Limerock Stabilized LBR 70	Shell, LBR 70	Shell Stabilized LBR 70	Sand-Clay LBR 75	Soil Cement (2.0 MPa) (Plant Mixed)	Soil Cement (2.0 MPa) (Road Mixed)	Soil Cement (3.5 MPa) (Plant Mixed)	
			(.12)	(.12)	(.10)	(.12)	(.15)	(.15)	(.20)	
1	15-20	701	130	130	180	130	100	130	100 ^Δ	
2	20-23	702	160	160	210	160	140	140	100	
3	24-27	703	200	200	240	200	160	160	120	
4	27-29	704	220	220	270	220	190	190	140	
5	30-34	705	250	250	300	250	210	210	160	
6	33-39	706	280	280		280	230		180	
7	39-41	707	310	310		310	260		190	
8	42-44	708					280		210	

← Not Recommended For 20 Year Design
Accumulated 18 Kip Equivalent Single Axle
(ESAL) Loads 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.

Δ Based On Minimum Practical Thickness.

TABLE 5.8

NOTES FOR OPTIONAL BASE GROUPS AND STRUCTURAL NUMBERS (STANDARD INDEX 514)

- * For granular subbase, the construction of both the subbase and Type B-12.5 will be paid for under the contract unit price for Optional Base. Granular subbases include Limerock, Cemented Coquina, Shell Rock, Bank Run Shell, and Graded Aggregate Base at LBR 100. The base thickness shown is Type B-12.5. All subbase thickness are 4"(100 mm). The base structural number shown is for the composite base.

‡ To be used for widening only, 3' (one meter) or less.

Δ Base Group 1 based on minimum thickness.

□ Restricted to non-Limited Access shoulder base construction.

General Notes

1. On new construction and complete reconstruction projects where an entirely new base is to be built, the design engineer may specify just the Base Group and any of the unrestricted General Use Optional Bases shown in that base group may be used. 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 will still be bid as Optional Base.

5.4 NEW CONSTRUCTION DESIGN SAMPLE PROBLEM

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.

GIVEN:

New Construction four lane, high volume, part urban, part rural, arterial.

$ESAL_D = 6,635,835$. This value is generally obtained from the District Planning Office. Round up $ESAL_D$ to 7,000,000 Traffic Level C (Section 5.5.4) for use in the design tables in Appendix A.

$M_R = 11,500$ psi (79 MPa). This value is obtained from the State Materials Office. Round up M_R to 80 Mpa for use in the design tables in Appendix A.

FIND:

The pavement thickness from the information provided for a 20 year design with a design speed of 55 mph(90 km/h) for the rural section and with a design speed of 45 mph(70 km/h) for the urban section (curb and gutter).

DATA:

$\%R = 80$ to 90. This value is from Table 5.2 for an Urban Arterial New Construction. $\%R = 75$ to 90 for Rural Arterial New Construction. $\%R = 90$ was chosen by the designer because of the high volume on both sections.

SN_R can be determined from the design tables in Appendix A for the appropriate reliability. From Table A.4A:

$$SN_R = 4.05" \text{ (103 mm)}$$

SOLUTION:

With the SN_R known, the pavement layer thickness can be calculated. Remember that SN_C should be within 0.11"(5 mm) of SN_R .

For the first part of this sample problem using a design speed of 55 mph(90 km/h), we need to use FC-5 according to Table 4.1.

FC-5 has no structural value and is always shown as 80 lb/y²(44 kg/m²). The in-place thickness will average 3/4"(20 mm) with edge rolling down to approximately 1/4"(5 mm). Also assume that a 12"(300 mm) Stabilized Subgrade (LBR-40) is to be used in order to establish a satisfactory working platform. The required base and structural course layer thickness can be determined using the following equation:

$$SN_R = SN_C$$

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

ENGLISH

$$4.05" = (0 \times 0.75") + (a_2 \times D_2) + (a_3 \times D_3) + (0.08 \times 12")$$

$$4.05" = 0 + (a_2 \times D_2) + (a_3 \times D_3) + 0.96"$$

METRIC

$$103 \text{ mm} = (0 \times 40 \text{ mm}) + (a_2 \times D_2) + (a_3 \times D_3) + (0.08 \times 300 \text{ mm})$$

$$103 \text{ mm} = 0 + (a_2 \times D_2) + (a_3 \times D_3) + 24 \text{ mm}$$

The next step is to calculate the value that the base (a₃ x D₃) and structural course (a₂ x D₂) must contribute. To determine this, subtract the stabilized subgrade (a₄ x D₄ = 0.96) from SN_R.

ENGLISH

$$4.05" - 0.96" = (a_2 \times D_2) + (a_3 \times D_3)$$

METRIC

$$103 \text{ mm} - 24 \text{ mm} = (a_2 \times D_2) + (a_3 \times D_3)$$

In this case, the base and structural course must provide the following remaining structural value;

ENGLISH

$$3.09" = (a_2 \times D_2) + (a_3 \times D_3)$$

METRIC

$$79 \text{ mm} = (a_2 \times D_2) + (a_3 \times D_3)$$

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 the optional bases with practical structural course thickness in $\frac{1}{2}$ " (10 mm) 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. From Table 5.9, it can be seen that the following combinations would prove satisfactory:

Base Group 8 with 3.50" (90 mm) of structural course with a SN = 3.16" (82 mm)

Base Group 9 with 3.0" (80 mm) of structural course with a SN = 3.12" (81 mm)

Base Group 10 with 3.0" (80 mm) of structural course with a SN = 3.21" (84 mm)

Because this is a Road with $ESAL_D$ greater than 3 500 000, the minimum thickness must be checked. From Table 5.5, the minimum allowed for this type of road is Optional Base Group 9 with 3" (80 mm) of structural course. One of the combinations selected meets these minimum requirements.

If all the combinations were thinner than the minimum, another combination meeting the minimum requirements would be selected. A theoretical over-design using the minimums is not uncommon when a stabilized subgrade is constructed.

The construction of at least these minimum thickness 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 course would have to provide a structural number of 4.05" (103 mm)

$$SN_R = (a_1 \times D_1) + (a_2 \times D_2) + (a_3 \times D_3)$$

ENGLISH

$$4.05 = (0 \times 0.75") + (a_2 \times D_2) + (a_3 \times D_3)$$

$$4.05 = (a_2 \times D_2) + (a_3 \times D_3)$$

METRIC

$$103 \text{ mm} = (0 \times 20 \text{ mm}) + (a_2 \times D_2) + (a_3 \times D_3)$$

$$103 \text{ mm} = (a_2 \times D_2) + (a_3 \times D_3)$$

From Table 5.9 an Optional Base Group 10 and 5.0" (120 mm) of structural course would give a structural number of 4.09" (102 mm). This would be satisfactory as the base and structural course exceed the required minimums.

For the second part of this sample problem using a design speed of 45 mph (70 km/h), we need to use FC-12.5 or FC-9.5 according to Table 4.1. FC-12.5 or FC-9.5 has the same structural value as Type SP and are considered as structural layers. FC-12.5 is always shown as 160 lb/yd² (88 kg/m²) 1 ½" (40 mm) thick and FC-9.5 is always shown as 110 lb/yd² (66 kg/m²) 1" (30 mm) thick.

For this problem, use Optional Base Group 9 with 1 ½" (40 mm) of Type SP Structural Course and 1 ½" (40 mm) FC-12.5 or

Use Optional Base Group 9 with 2" (50 mm) of Type SP Structural Course and 1" (30 mm) FC-9.5.

CONCLUSION:

The following comparisons are provided:

ENGLISH

For The Design Speed Of 55 mph

<u>Layer/Material</u>	<u>Coefficient</u>		<u>Asphalt Thickness</u>	<u>SN_c</u>
Friction Course, FC-5	0.00	x	3/4"	= 0.00
Structural Course	0.44	x	3.0"	= 1.32
Optional Base Group 9				= 1.80
Type B Stabilization (LBR 40), 12"				= 0.96
			<u>3.75"</u>	<u>4.08</u>

For The Design Speed Of 45 mph

<u>Layer/Material</u>	<u>Coefficient</u>		<u>Asphalt Thickness</u>	<u>SN_c</u>
Friction Course, FC-12.5	0.44	x	1 1/2"	= 0.66
Structural Course	0.44	x	1 1/2"	= 0.66
Optional Base Group 9				= 1.80
Type B Stabilization (LBR 40), 12"				= 0.96
			<u>3.0"</u>	<u>4.08</u>

The pavement description in the plans with a design speed of 55 mph should read:

NEW CONSTRUCTION

OPTIONAL BASE GROUP 9 AND TYPE SP STRUCTURAL COURSE (TRAFFIC C) (300 LBS/SY) AND FRICTION COURSE FC-5 (80 LBS/SY) (RUBBER)

The pavement description in the plans with a design speed of 45 mph should read:

NEW CONSTRUCTION

OPTIONAL BASE GROUP 9 AND TYPE SP STRUCTURAL COURSE (TRAFFIC C) (150 LBS/SY) AND FRICTION COURSE FC-12.5 (160 LBS/SY) (RUBBER)

METRIC

For The Design Speed Of 90 km/h

<u>Layer/Material</u>	<u>Coefficient</u>		<u>Asphalt Thickness</u>	<u>SN_c</u>
Friction Course, FC-5	0.00	x	20 mm =	00
Structural Course	0.44	x	80 mm =	35
Optional Base Group 9			=	47
Type B Stabilization (LBR 40), 300 mm			=	<u>24</u>
			100 mm	106

For The Design Speed Of 80 km/h

<u>Layer/Material</u>	<u>Coefficient</u>		<u>Asphalt Thickness</u>	<u>SN_c</u>
Friction Course, FC-12.5	0.44	x	40 mm =	18
Structural Course			0.44 x	40 mm =
18				
Optional Base Group 9			=	47
Type B Stabilization (LBR 40), 300 mm			=	<u>24</u>
			80 mm	107

The pavement description in the plans with a design speed of 90 km/h should read:

NEW CONSTRUCTION

OPTIONAL BASE GROUP 9 AND TYPE SP STRUCTURAL COURSE (TRAFFIC C) (176 KG/M2) AND FRICTION COURSE FC-5 (44 KG/M2) (RUBBER)

The pavement description in the plans with a design speed of 80 km/h should read:

NEW CONSTRUCTION

OPTIONAL BASE GROUP 9 AND TYPE SP STRUCTURAL COURSE (TRAFFIC C) (88 KG/M2) AND FRICTION COURSE FC-12.5(88 KG/M2) (RUBBER)

Note that the Type B Stabilization is not included in the description. This becomes a part of the plan detail.

Design, Analysis, and Rehabilitation for Windows (DARWin)
Examples.

In addition to using Design Tables, AASHTO DARWin pavement design software can be used for performing pavement design as shown in the examples in pages 5.26.0 to 5.28.0

For F.D.O.T use, the software can be obtained from the Pavement Management Office, by request through the Districts Pavement Design Engineers.

For Consultants, and Local government agencies, the software should be purchased from AASHTO.

1993 AASHTO Pavement Design
DARWin Pavement Design and Analysis System
A Proprietary AASHTOWare
Computer Software Product

Flexible Structural Design Module

Example problem 5.2.1

Flexible Structural Design

18-kip ESALs Over Initial Performance Period	5,000,000
Initial Serviceability	4.2
Terminal Serviceability	2.5
Reliability Level	90%
Overall Standard Deviation	0.45
Roadbed Soil Resilient Modulus	14,000psi
Stage Construction	1
Calculated Design Structural Number	3.57 in

1997 AASHTO Pavement Design
DARWin Pavement Design and Analysis System
A Proprietary AASHTOWare
Computer Software Product

Flexible Structural Design Module

Example problem 5.2.1

Flexible Structural Design

18-kip ESALs Over Initial Performance Period	5 000 000
Initial Serviceability	4.2
Terminal Serviceability	2.5
Reliability Level	90%
Overall Standard Deviation	0.45
Roadbed Soil Resilient Modulus	96 000kPa
Stage Construction	1
Calculated Design Structural Number	91 mm

1993 AASHTO Pavement Design
 DARWin Pavement Design and Analysis System
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 Computer Software Product

Flexible Structural Design Module

Flexible Structural Design

18-kip ESALs Over Initial Performance Period	7,000,000
Initial Serviceability	4.2
Terminal Serviceability	2.5
Reliability Level	90%
Overall Standard Deviation	0.45
Roadbed Soil Resilient Modulus	11,500 psi
Stage Construction	1

Calculated Design Structural Number 4.05 in

Specified Layer Design

<u>Layer</u>	<u>Material</u> <u>Descript.</u>	Struct. Coef. <u>(Ai)</u>	Drain Coef. <u>(Mi)</u>	Thickness <u>(Di)(in)</u>	Width <u>(ft)</u>	Calculated <u>SN(in)</u>
1	FC5	0	1	0.75	12	0.00
2	TYPE SP	0.44	1	3	12	1.32
3	OBG-9	0.18	1	10	12	1.80
4	TYPE B STAB.	0.08	1	12	12	0.96
Total	-	-	-	-	-	<u>4.08</u>

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Flexible Structural Design Module

Flexible Structural Design

18-kip ESALs Over Initial Performance Period	7 000 000
Initial Serviceability	4.2
Terminal Serviceability	2.5
Reliability Level	90%
Overall Standard Deviation	0.45
Roadbed Soil Resilient Modulus	80 000 kPa
Stage Construction	1
 Calculated Design Structural Number	 103 mm

Specified Layer Design

<u>Layer</u>	<u>Material</u> <u>Descript.</u>	Coef. <u>(Ai)</u>	Struct. Drain Coef. <u>(Mi)</u>	Thickness <u>(Di)</u> (mm)	Width <u>(m)</u>	Calculated <u>SN</u> (mm)
1	FC-12.5	0.44	1	38.1	3.6576	17
2	TYPE SP	0.44	1	38.1	3.6576	17
3	OBG-9	0.18	1	254	3.6576	46
4	TYPE B STAB.	0.08	1	304.8	3.6576	24
Total	-	-	-	635	-	<u>104</u>

TABLE 5.9

COMBINED STRUCTURAL NUMBER (INCHES)

Optional Base Group	Structural Course - inches					
	0	1.0	1.5	2.0	2.5	3.0
1		1.16	1.38			
2		1.16	1.38			
3		1.34	1.56	1.78		
4		1.52	1.74	1.96	2.18	
5		1.61	1.83	2.05	2.27	2.49
6		1.79	2.01	2.23	2.45	2.67
7			2.10	2.32	2.54	2.76
8			2.28	2.50	2.72	2.94
9					2.90	3.12
10						3.21
11						3.39
12						
13						
14						
15						

Stabilization And Friction Course Structural Numbers Not Included.

TABLE 5.9 (CONTINUED)

COMBINED STRUCTURAL NUMBER (INCHES)

Optional Base Group	Structural Course - inches					
	3.5	4.0	4.5	5.0	5.5	6.0
1						
2						
3						
4						
5						
6	2.89					
7	2.98					
8	3.16	3.38	3.60			
9	3.34	3.56	3.78			
10	3.43	3.65	3.87	4.09		
11	3.61	3.83	4.05	4.27	4.49	
12	3.79	4.01	4.23	4.45	4.67	4.89
13		4.10	4.32	4.54	4.76	4.98
14		4.28	4.50	4.72	4.94	5.16
15		4.46	4.68	4.90	5.12	5.34

Stabilization And Friction Course Structural Numbers Not Included.

TABLE 5.9

COMBINED STRUCTURAL NUMBER (mm)

Base Group	Structural Course (mm)					
	30	40	50	60	70	80
1	31	36				
2	34	37	43			
3	38	42	46			
4	41	46	50			
5		49	54	58		
6		53	57	61	66	
7		56	61	65	69	74
8				67	73	77
9					76	81
10					80	84

Base Group	Structural Course (mm)						
	90	100	110	120	130	140	150
8	82	86					
9	85	89	94				
10	87	93	97	102			
11	92	97	101	105	109		
12		100	104	109	113	117	
13			108	112	117	121	125
14				116	120	124	129
15					123	128	132

Stabilization And Friction Course Structural Numbers Not Included.

5.5 DESIGN CONSIDERATIONS

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

5.5.1 STABILIZATION

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 Plans Preparation Manual.

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.

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.

The District Construction Engineer should be consulted prior to deciding to eliminate stabilized subgrade in design. The reasons for eliminating stabilized subgrade must be documented in the project file.

In situations where construction time is critical, the following alternates to insitu 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 the Special Provisions covering this concept. The Specifications also provides that when 12"(300 mm) 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"(150 mm) of Granular Subbase meeting the requirements of section 290.

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 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.

5.5.2 BASE

Except as limited by Standard Index 514 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. 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 (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(0.6 m) clearance above ground water to get adequate compaction in the top foot(0.3 m) 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.
- 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 Optional Base Group (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 Optional Base Group 12 for unbound granular base materials, except for trench widening where up to Optional Base Group 14 may be used.

5.5.3 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 PPM exhibit TYP-6A for example). The thickness of the asphalt pad should be determined by constructibility 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, a standard plan note should be added, stating that the cost of curb pad is to be included in the cost of curb and gutter. The Base Group may need to be increased to provide for a minimum of 1 ½" (40 mm) of asphalt curb pad.

5.5.4 STRUCTURAL COURSE

Individual asphalt layers are not shown on the Plans Typical Section, only the overall asphalt spread rate as prescribed in the Plans Preparation Manual.

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

The Pavement Design Engineer shall sketch out the construction sequence of the Typical Section to ensure constructibility. 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 Table 5.10. The same Traffic Level as the roadway should be used for shoulders 5'(1.5 m) or less, where the final layer is paved in one pass with the roadway. For shoulders wider than 5'(1.5m) refer to chapter 8 of this manual.

As a practical matter, Superpave mixes for crossroads and other small sections with quantities less than 1000 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 Bituminous Engineer.

The following Traffic Level C Superpave mixes can be substituted by specification for Type S Structural Courses

Traffic Level C	
Type SP	Type S
<u>Superpave Mix</u>	<u>Mix</u>
SP-9.5	S-III
SP-12.5	S-I
SP-19	S-II

5.5.5

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

<u>AASHTO REVISED DESIGN ESAL_D RANGE (MILLION)</u>	<u>TRAFFIC LEVEL</u>	<u>PREVIOUS TRAFFIC LEVELS</u>
< 0.3	A	1
0.3 to < 3	B	2,3
3 to < 10	C	4
10 to < 30	D	5
>= 30	E	6,7

Traffic Levels D and E by specification require the Type SP mix to be coarse graded. This will affect layer thickness as shown in section 5.5.5 and needs to be considered in developing constructability sketches particularly for narrow shoulders. Tables 5.10 - 5.14 are available to evaluate constructable options for the contractor.

5.5.6

LAYER THICKNESS

SPECIFICATION REQUIREMENTS ON LAYER THICKNESS FOR TYPE SP STRUCTURAL COURSES

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

FINE MIXES

<u>Type Mix</u>	<u>Minimum</u>	<u>Maximum</u>
SP-9.5	3/4" (20 mm)	1 1/4" (30 mm)
SP-12.5	1 1/4" (30 mm)	2 1/2" (60 mm)
SP-19.0	2" (50 mm)	2 3/4" (70 mm)

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-12.5 May not be used in the 1st layer of courses over 3 1/2" (90 mm) thick nor in the 1st layer of courses over 2 3/4" (70 mm) thick on limited access facilities.

SP-19.0 May not be used in the final (top) structural layer.

SP-9.5 Limited to the final (top) structural layer, one layer only below the Friction Course.

COARSE MIXES

<u>Type Mix</u>	<u>Minimum</u>	<u>Maximum</u>
SP- 9.5	1 1/2" (40 mm)	2" (50 mm)
SP-12.5	2" (50 mm)	3" (80 mm)
SP-19.0	3" (80 mm)	3 1/2" (90 mm)

In addition to the minimum and maximum thickness requirements,

SP-19.0 May not be used in the final (top) structural layer.

Above restrictions do not apply to overbuild and leveling.

On variable thickness overbuild layers, the minimum allowable thickness may be reduced by 1/2" (10 mm), and the maximum allowable thickness may be increased 1/2" (10 mm). Leveling and overbuild is further discussed in section 6-8.2.

Structural and Friction Courses are bid as tonnage items, equivalent tonnage layer thickness will be constructed i.e: 100# = one square yard inch (22 kg = 1 square meter for each 10 mm thickness).

When construction includes the paving of adjacent shoulders $\leq 5'$ (≤ 1.5 m wide), the layer thickness for the upper Structural pavement layer and shoulder should be the same and paved in a single pass unless otherwise specified in plans.

A minimum of 1/2" (40 mm) initial lift is required over an Asphalt Rubber Membrane Interlayer (ARMI).

TABLE 5.10

**DESIGN NOTES ON LAYER THICKNESS FOR ASPHALT CONCRETE
STRUCTURAL COURSES**

For projects requiring FC-5, it is desirable that the top structural layer of the roadway overlay and a narrow adjacent shoulder course be constructed in one pass. The following apply when a 5'(1.5 m) or less shoulder is to be constructed in conjunction with an overlay of the road.

<u>Roadway Course Thickness inch(mm)</u>	<u>Shoulder Structural Course Thickness inch(mm)</u>	
	<u>A to C (FINE)</u>	<u>D and E(COARSE)</u>
1.0" (30 mm)	1" (30 mm)	N/A
1.5" (40 mm)	1.5" (40 mm)	1.5" (40 mm)
2.0" (50 mm)	2.0" (50 mm)	2.0" (50 mm)*
2.5" (60 mm)	1" (30 mm)	2.5" (60 mm)
3.0" (80 mm)	1" (30 mm)	1.5" (40 mm)
3.5" (90 mm)	1" (30 mm)	1.5" (40 mm)

* The increased thickness is required to insure a 1.0"(30 mm) thickness of structural course on the shoulder under the open graded friction course. For projects, requiring FC-12.5 and FC-9.5, a single lift may be sufficient Structural thickness for the shoulder pavement.

TABLE 5.11 COARSE MIXES

LAYER THICKNESS FOR ASPHALTIC CONCRETE STRUCTURAL COURSES (Layers are Listed in Sequence Of Construction)																			
COURSE THICKNESS (inches)	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-9.5 2nd Layer and Top Layer			SP-12.5 1st Layer with SP-9.5 2nd Layer and Top Layer		
	1	2	1	2	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1																			
1 1/2											1 1/2								
2					2						2								
2 1/2					2 1/2														
3					3						1 1/2	1 1/2							
3 1/2											2	1 1/2							
4					2	2		2	2		2	2							
					2 1/2	1 1/2		2 1/2	1 1/2										
4 1/2			3	1 1/2	2 1/2	2		3	1 1/2										
					2	2 1/2					1 1/2	1 1/2	1 1/2						
5	3	2	3	2	3	2		3	2		2	1 1/2	1 1/2				2	1 1/2	1 1/2
			3 1/2	1 1/2	2	3					1 1/2	1 1/2	2						
5 1/2	3 1/2	2	3 1/2	2	3	2 1/2		2	2	1 1/2	2	2	1 1/2				2	2	1 1/2
					2 1/2	3					2	1 1/2	2				2	1 1/2	2
6	3 1/2	2 1/2			3	3		2	2	2	2	2	2	3	1 1/2	1 1/2	2	2	2
	3	3			2	2	2	2 1/2	2	1 1/2							3	1 1/2	1 1/2

Minimum And Maximum Layer Thickness For Coarse Mixes

Type Mix	Min.	Max.
SP-9.5	1 1/2" (40 mm)	2" (50 mm)
SP-12.5	2" (50 mm)	3" (80 mm)
SP-19.0	3" (80 mm)	3 1/2" (90 mm)

TABLE 5.12 FINE MIXES

LAYER THICKNESS FOR ASPHALTIC CONCRETE STRUCTURAL COURSES
(Layers are Listed in Sequence Of Construction)

COURSE THICKNESS (Inches)	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	1	2	3	1	2	1	2	3	1	2	3
1												1							
1 1/2							1 1/2												
2							2		1 1/4	3/4									
2 1/2							2 1/2												
							1 1/4	1 1/4	1 1/2	1									
3				2	1		1 1/2	1 1/2	2	1									
3 1/2	2	1 1/2		2 1/2	1		2	1 1/2	1 1/4	1 1/4	1								
4	2 1/2	1 1/2		3	1														
	2	2																	
4 1/2	2 1/2	2																	
	2	2 1/2																	
5	2	1 1/2	1 1/2	2	2	1								2	1 1/2	1 1/2			
	2 1/2	2 1/2																	
5 1/2	2	2	1 1/2	2 1/2	2	1								2 1/2	1 1/2	1 1/2			
														2	2				
6	2 1/2	2	1 1/2	2 1/2	2 1/2	1								2 1/2	2	1 1/2			
	2	2	2											2	2	2			

Minimum And Maximum Layer Thickness For Fine Mixes

Type Mix	Min.	Max.
SP-9.5	3/4" (20 mm)	1 1/4" (30 mm)
SP-12.5	1 1/4" (30 mm)	2 1/2" (60 mm)
SP-19.0	2" (50 mm)	2 3/4" (70 mm)

TABLE 5.13 COARSE MIXES (METRIC)

LAYER THICKNESS FOR ASPHALTIC CONCRETE STRUCTURAL COURSES (Layers are Listed in Sequence Of Construction)																				
COURSE THICKNESS (mm)	LAYER THICKNESS (mm)																			
	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-9.5 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	3	1	2	1	2	3
30																				
40														40						
50							50							50						
60							60													
70							70													
80							80							40	40					
90														50	40					
100							50	50		50	50		50	50						
										60	40									
110							60	50		70	40									
							50	60		60	50									
120				80	40		60	60		80	40		40	40	40					
130	80	50		80	50		80	50		80	50		50	40	40			50	40	40
				90	40		50	80												
140	90	50		90	50		80	60		50	50	40	50	50	40			50	50	40
							60	80					50	40	50			50	40	50
150	90	60					80	70		60	50	40	50	50	50			50	50	50
	80	70					50	50	50	50	50	50						70	40	40

Minimum And Maximum Layer Thickness For Coarse Mixes

<u>Type Mix</u>	<u>Min.</u>	<u>Max.</u>
SP- 9.5	1 1/2" (40 mm)	2" (50 mm)
SP-12.5	2" (50 mm)	3" (80 mm)
SP-19.0	3" (80 mm)	3 1/2" (90 mm)

TABLE 5.14 FINE MIXES (METRIC)

LAYER THICKNESS FOR ASPHALTIC CONCRETE STRUCTURAL COURSES (Layers are Listed in Sequence Of Construction)																		
COURSE THICKNESS (mm)	LAYER THICKNESS (mm)																	
	SP-19 with SP-12.5 Top Layer			SP-19 with SP-9.5 Top Layer			SP-12.5			SP-12.5 with SP-9.5 Top Layer			SP-9.5			SP-19 1st Layer with SP-12.5 2nd Layer and Top Layer		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
30							30						30					
40							40											
50							50			30	20							
60							30	30		30	30							
							60			40	20							
70				50	20		40	30		40	30							
										50	20							
80	50	30		50	30		40	40		50	30							
				60	20		50	30										
90	50	40		60	30		30	30	30	40	30	20						
	60	30		70	20		50	40		30	30	30						
100	50	50		70	30													
	60	40																
	70	30																
110	60	50														50	30	30
	70	40																
120	70	50		50	50	20										50	40	30
																60	30	30
130	50	50	30	50	50	30												
				60	50	20												
140	50	50	40	60	50	30												
	60	50	30	60	60	20												

LAYER THICKNESS FOR ASPHALTIC CONCRETE STRUCTURAL COURSES
(Layers are Listed in Sequence Of Construction)

150				60	60	30										50	40	30	30
				70	50	30										60	30	30	30
				70	60	20													

Minimum And Maximum Layer Thickness For Fine Mixes

<u>Type Mix</u>	<u>Min.</u>	<u>Max.</u>
SP-9.5	3/4" (20 mm)	1 1/4" (30 mm)
SP-12.5	1 1/4"(30 mm)	2 1/2" (60 mm)
SP-19.0	2" (50 mm)	2 3/4" (70 mm)

5.5.7 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 course. A minimum Base Group 9 and 2" (50 mm) structural course should be provided. The transition from mainline thickness to ramp thickness will occur just beyond the gore. (See Standard Index 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 larger than the reduced thickness.

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CHAPTER 6

PAVEMENT THICKNESS DESIGN PROCESS FOR REHABILITATION PROJECTS

6.1 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 6.1.

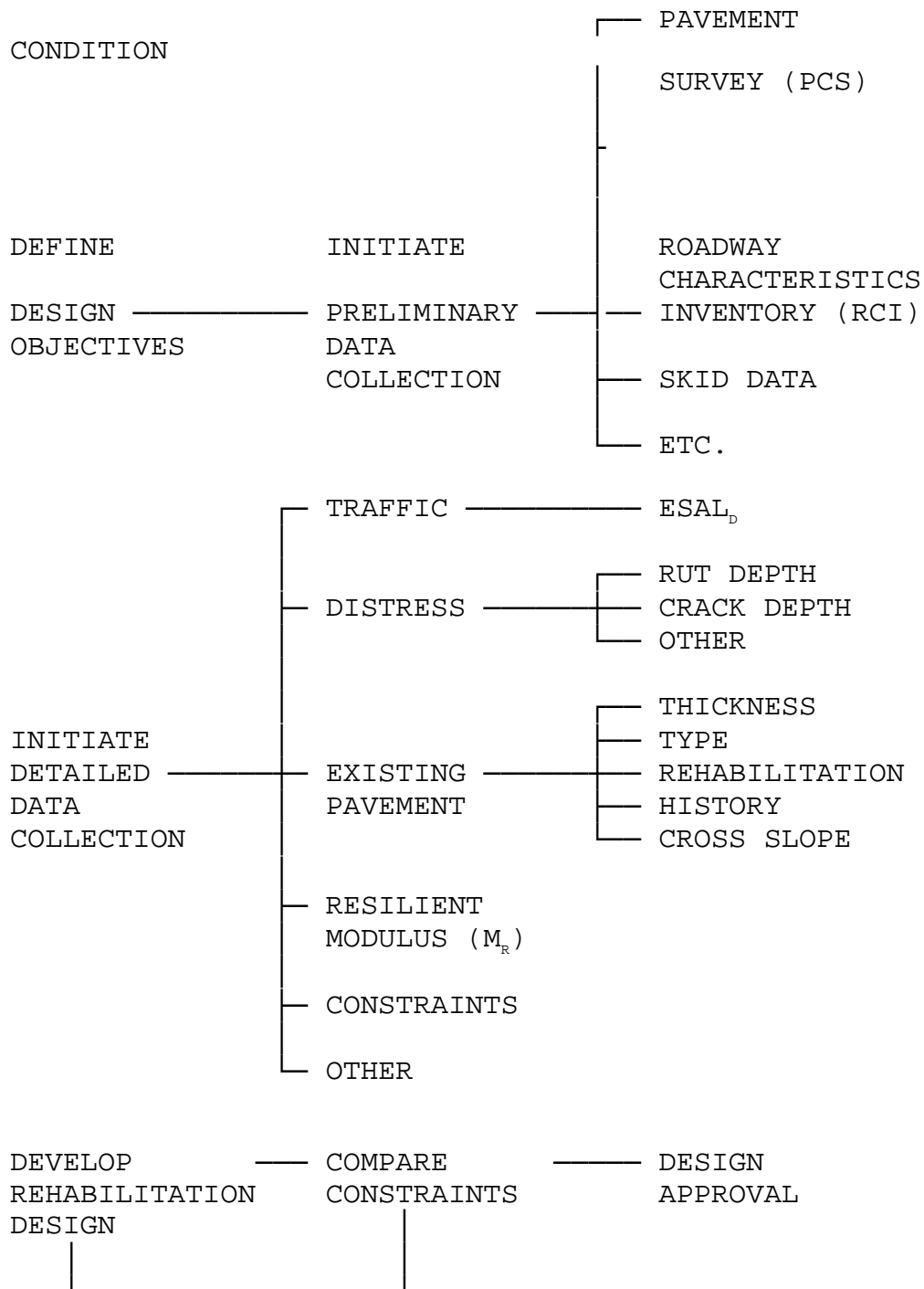
6.2 REQUIRED STRUCTURAL NUMBER (SN_R) CALCULATIONS USING THE AASHTO GUIDE

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

6.3 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. Two 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, and Soil Test Data. This information needs to be obtained as early as possible in the design process.

**FIGURE 6.1
FLEXIBLE PAVEMENT REHABILITATION PROCESS**



6.3.1 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 Figure 6.2, Figure 6.3, and Figure 6.4. Note that in Figure 6.2 the plot is constant compared to Figure 6.3 and Figure 6.4. In Figure 6.3, a significant change takes place in the Pavement Structure. In Figure 6.4, a "Blip" occurs in the plot warranting a field check.

6.3.2 RESILIENT MODULUS (M_R) FROM LBR

If it is not practical to obtain Deflection testing and a Design LBR Value is available, the Pavement Design Engineer can convert the Design LBR Value to a Resilient Modulus (M_R) using Table 5.1.

FIGURE 6.2

DEFLECTION PLOT EXAMPLE

State Of Florida
Department Of Transportation
State Materials Office
Pavement Deflections

Project # 25060-1415 WPI# 9111994
State Road 16, Eastbound Traffic Lane
Testing Date 01/20/94

Not to proper production scale.
Illustration of concept only.

Example of normal pavement deflections.

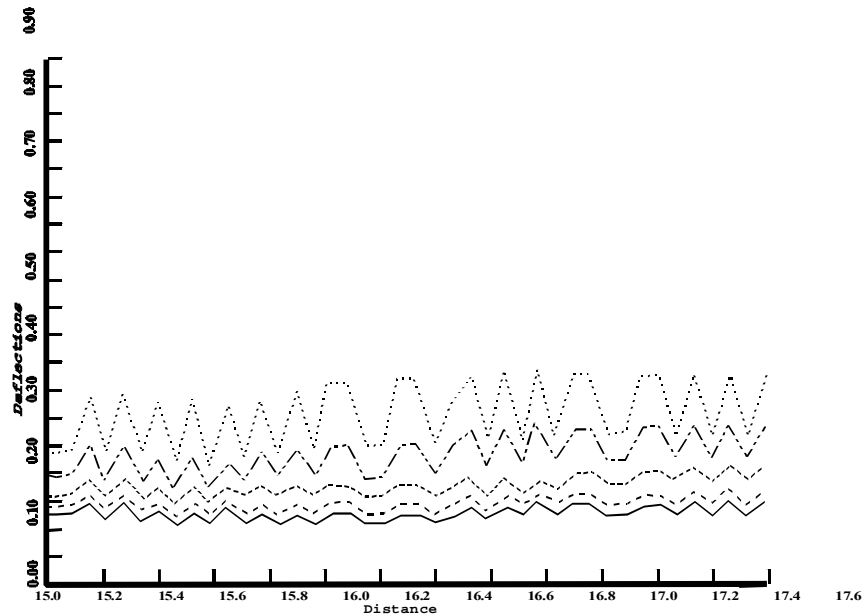


FIGURE 6.3

DEFLECTION PLOT EXAMPLE

State Of Florida
Department Of Transportation
State Materials Office
Pavement Deflections

Project # 25070-1415 WPI# 9111995
State Road 17, Westbound Traffic Lane
Testing Date 01/21/94

Not to proper production scale.
Illustration of concept only.

Example of a pavement change.

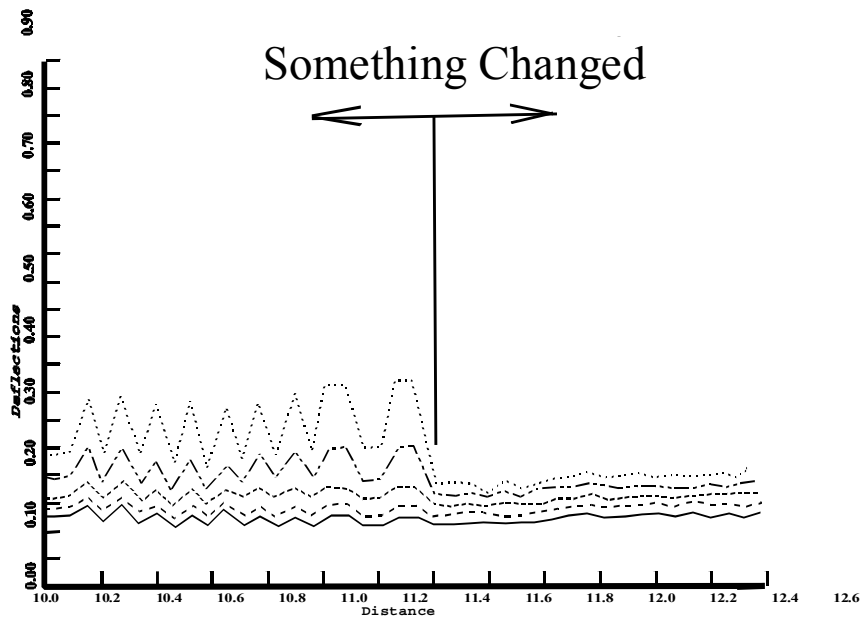


FIGURE 6.4

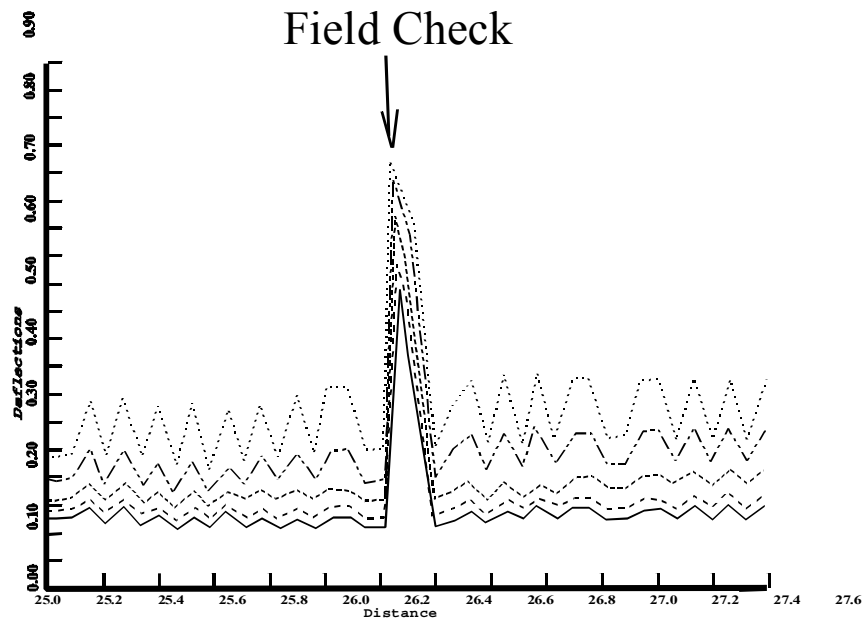
DEFLECTION PLOT EXAMPLE

State Of Florida
Department Of Transportation
State Materials Office
Pavement Deflections

Project # 25080-1415 WPI# 9111996
State Road 18, Northbound Traffic Lane
Testing Date 01/22/94

Not to proper production scale.
Illustration of concept only.

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



6.4 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.

6.4.1 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 and testing confidence limits.

Deflection testing requests should not be made for:

- Two lane roadway projects less than 1 mile (1.5 km) long.
- Three lanes or more roadway projects less than 0.5 miles (0.8 km) long.

Example projects where Deflection testing should not be required include bridge or culvert replacement, intersection improvement, etc.

Scheduling the Maintenance Of Traffic (MOT) 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.

6.4.2 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.

6.4.3 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.

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 No. 675-030-005 can be obtained from the State Materials Office or through the department's INTERNET and INTRANET 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, leveling, overbuild, use of automatic screed control, and an Asphalt Rubber Membrane Interlayer (ARMI) when required.

6.4.4 REDUCED LAYER COEFFICIENTS

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 6.1.

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:

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

where:

SN_E = Total strength of the existing pavement layers.

a_1 = Reduced layer coefficient of the 1st layer.

D_1 = Layer thickness of the 1st layer.

a_2 = etc.

D_2 = etc.

a_N = Layer coefficient of the Nth layer.

D_N = Layer thickness in millimeters 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 6.1, 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 6.1

**REDUCED STRUCTURAL COEFFICIENTS OF ASPHALT MATERIALS
PER UNIT THICKNESS
Recommended Criteria**

- Good** - No Cracking, minor rutting/distortion
Fair - Crack Rated 8 or higher, minor rutting and / or distortion
Poor - Cracking or Rutting rated 7 or less

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

<u>Layer</u>	<u>Original Design</u>	<u>Pavement Condition</u>		
		<u>Good</u>	<u>Fair</u>	<u>Poor</u>
FC-2 or FC-5	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-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
SAHM	0.15	0.13	0.11	0.08
SBRM	0.15	0.13	0.11	0.08

AASHTO SUGGESTED LAYER COEFFICIENT

FOR FRACTURED SLAB PAVEMENT

<u>MATERIAL</u>	<u>SLAB CONDITION</u>	<u>COEFFICIENT</u>
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.

6.5 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.

6.5.1 CANDIDATE PROJECTS

Milling may be appropriate for the following reasons:

- Remove badly cracked asphalt.
- To correct cross-slope.
- Avoid raising the grade excessively (ie. 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.
- In lieu of leveling.
- For removal of FC-2 or FC-5 when overlaying.
- If the overall project cost would be less with milling than without.

Cracked pavement should be milled out where possible to avoid reflective cracking in the overlay. It is usually desirable to leave at least 3/4" (20 mm) 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 the same day of the milling operation, or the use of prime coat. 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 Bituminous 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, an Asphalt Rubber Membrane Interlayer (ARMI) and/or additional overlay thickness should be considered. Generally it is not practical to mill to a depth greater than 5" (120 mm). Use of Asphalt Rubber Membrane Interlayer (ARMI) is discussed further in section 6.8.5.

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

6.5.2 COMPOSITION REPORTS

If greater than 5000 tons of the same pavement structure is milled, a composition of the existing pavement should be prepared and placed on the Internet by the State Materials Office. The composition report is now available on the Internet at:

<http://www11.myflorida.com/statematerialsoffice/Bituminous/CentralBitLab/AsphaltCompositions/Compositions.htm>

A Composition Report is not needed when milling FC-2 or FC-5 only. This is primarily due to the thickness of the layer ie. 1/2" or 3/4" (15 or 20 mm) and the small amount of material to do an analysis on. Coring for structural information is still recommended, even if a composition report is not required.

If the milling depth varies from point to point (ie. lane to lane, site to site), the composition reports must reflect this change.

6.5.3 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 construction.

This must be reflected in the composition reports. The milling depth should be uniform within a lane except when the milling slope has been set to correct a cross slope problem.

6.5.4 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 Bituminous Engineer to ensure cross-slope is addressed in design.

Existing cross-slope should be checked from the Design Survey and from the cross-slope measurements shown on the Pavement Evaluation and Coring Report. If a Design Survey has not been made and cross-slope problems are suspected, then a survey should be requested according to Survey Guidelines for RRR Projects (section 25.3.4 of the Plans Preparation Manual(PPM)Vol.1)

If the existing cross-slope is not adequate, sufficient overbuild material must be provided by the Roadway Designer in the quantity estimate to correct the deficiency. The District Bituminous Engineer will provide recommendations with regard to specifying the use of transverse screed control for the paver. 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 Bituminous 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.

The milling depth should be uniform within a lane except when the milling slope has been set to correct a cross slope problem.

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

If rutting has been a problem in an area, careful

consideration should be given to the feasibility of increasing the cross-slope to 3% on highways with high truck volumes. This will extend the pavement life considerably if rutting is the principal cause of distress.

6.5.5 RUTTED PAVEMENT

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

If rutting was caused by age and consolidation, it may be more economical to level and overlay.

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. Special tests on various layers and cross sectional coring or trenching may be warranted to identify problem layers in the top 5" (120 mm) of pavement.

6.5.6 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 (153°F) and crack resistant down to temperatures of -22°C (-8°F). The resilient Modulus 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.

In high traffic levels and slow moving or standing truck traffic and particularly those sections with a history of rutting, asphalt concrete mixes containing modified binder PG 76-22 with more stiffness at higher temperatures will provide more rut resistance than asphalt mixes with a standard asphalt binder.

Examples

For toll booths, intersections with slow truck traffic, pavement sections with history of rutting and weigh stations with standing traffic, use a PG 76-22 asphalt binder. A minimum of 1000 tons of modified structural mix is generally recommended per project or group of projects to make the most efficient use of the material.

For high traffic levels D and E, PG 76-22 is recommended for the top structural layer, if budget is available.

The PG 76-22 layer spread rate should be shown separately on the typical section and a separate pay item used.

The PG 76-22 modification is not necessary on the top layer of inside lanes that are expected to have less than 20% of the design ESAL's

If an FC-9.5 or FC-12.5 is needed on a traffic level D or E project, a plan note should be added to designate the traffic level for the friction course. This is necessary since the structural friction courses are level C by specification, unless shown otherwise in the plans. This should be done with careful consideration in urban areas, since higher compaction levels will be required. An alternative may be to stay with a level C design and add PG 76-22 for extra rut resistance.

The District Bituminous Engineer should be consulted for use of this modified binder.

6.5.7 MILLING DEPTH

The District Bituminous 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.

It should be noted that laboratory testing of the project field cores can not be completed until the milling depths have been set. The cores are then cut and tested to provide a composition report for the Recycled Asphalt Pavement (RAP). This must be taken into consideration with the timing of these various operations. A composition report 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.

6.6 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(mm).

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, this thickness needs to be rounded to the nearest 1/2"(10 mm) increment. This process works well when designing an open graded friction course. For a dense graded friction course, use the following:

$$SN_o = SN_R - SN_E - SN_{FC-12.5}$$

$$a_s \times D_s = SN_R - SN_E - SN_{FC-12.5}$$

$$D_s = (SN_R - SN_E - SN_{FC-12.5}) / a_s$$

Where: SN_o = Structural strength of the 1 1/2"(40 mm) FC-12.5 or 1 "(30 mm) FC-9.5 thick with structural coefficient of 0.44.

6.7 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:

Pavement Overlay, four lane, high volume, rural, arterial.

$ESAL_D = 3,997,200$. This value is generally obtained from the District Planning Office. Round up $ESAL_D$ to 4,000,000 Traffic Level C for use in the design tables in Appendix A.

$M_R = 10,600$ psi (73 MPa.) This value is obtained from the State Materials Office. Round up M_R to 11,000 psi (75 MPa) for use in the design tables in Appendix A.

FIND:

The pavement thickness for a resurfacing and a milling project from the information provided for a 14 year design with a design speed of 55 mph (90 km/h) on part of the project and with a design speed of 45 mph (70 km/h) on the remaining project.

DATA(ENGLISH)

The following field data is from an old pavement. The layers are rated in poor condition. Determine the SN_E .

<u>Material</u> ⁽¹⁾	<u>Thickness</u> ⁽¹⁾	<u>Coefficient</u>	<u>SN_E</u>
FC-2	0.5	0.00	0.00
Type S	1.5	0.15 (2)	0.23
Type I	1.0	0.15 (2)	0.15
Binder	2.0	0.15 (2)	0.30
Limerock (LBR 100)	8.0	0.18 (3)	1.44
Type B Stab. (LBR 40)	12.0	0.08 (3)	<u>0.96</u>
			3.08

(1) From Field coring report

(2) From Table 6.1

(3) From Table 5.4

If the final design indicates that 2" (50 mm) of asphalt is to be milled, assume that all of the Type S Structural Course is removed.

DATA(METRIC):

The following field data is from an old pavement. The layers are rated in poor condition. Determine the SN_E .

<u>Material</u> ⁽¹⁾	<u>Thickness</u> ⁽¹⁾	<u>Coefficient</u>	<u>SN_E</u>
FC-2	15 mm	0.00	0.00
Type S	40 mm	0.15 (2)	6.00
Type I	25 mm	0.15 (2)	3.75
Binder	50 mm	0.15 (2)	7.50
Limerock (LBR 100)	200 mm	0.18 (3)	36.00
Type B Stab. (LBR 40)	300 mm	0.08 (3)	<u>24.00</u>
			77.25

- (1) From Field coring report
- (2) From Table 6.1
- (3) From Table 5.4

If the final design indicates that 50 mm of asphalt is to be milled, assume that all of the Type S Structural Course is removed.

%R = 90 to 95. This value is from Table 5.2 for Rural Arterial Rehabilitation. %R = 94 was chosen by the designer because of the high volume.

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

From Table A.6A:

$$SN_R = 3.94" (101 \text{ mm})$$

SOLUTION:

Once the SN_R and the SN_E (after milling) are determined, the thickness of an overlay can be calculated using the following equation for an open graded friction course (FC-5):

$$SN_O = SN_R - SN_E$$

$$a_s \times D_s = SN_R - SN_E$$

$$D_s = (SN_R - SN_E) / a_s$$

Using ENGLISH

$$SN_E = 3.08'' - 0.23'' \text{ (milled Type S)} = 2.85 \text{ in}$$

So:

$$D_s = (3.94 - 2.85) / 0.44$$

$$D_s = 2.48 \text{ in}$$

Using in (METRIC)

$$SN_E = 77 \text{ mm} - 6 \text{ mm (milled Type S)} = 71 \text{ mm}$$

So:

$$D_s = (101 - 71) / 0.44$$

$$D_s = 68 \text{ mm}$$

Knowing that the asphalt layer thickness is normally calculated to the nearest $\frac{1}{2}$ " (10 mm), use $D_s = 2 \frac{1}{2}$ " or (70 mm).

The thickness of an overlay can be calculated using the following equation for a dense graded friction course FC-12.5:

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

$$a_s \times D_s = SN_R - SN_E - SN_{FC-12.5}$$

$$D_s = (SN_R - SN_E - SN_{FC-12.5}) / a_s$$

ENGLISH

$$D_s = (3.94 - 2.85 - 0.66) / 0.44$$

$$D_s = 0.98 \text{ in}$$

(METRIC)

$$D_s = (101 - 71 - 18) / 0.44$$

$$D_s = 28 \text{ mm}$$

Knowing that the asphalt layer thickness is normally calculated to the nearest 1/2" (10 mm), use $D_s = 1"$ (30 mm).

CONCLUSION:

The following comparisons are provided.

Resurfacing Design For The Design Speed Of 55 mph (90 km/h)

For the first part of this sample problem using a design speed of 55 mph (90 km/h), we need to use FC-5 according to Table 4.1. FC-5 has no structural value and is always shown as 80 lb/yd², 3/4" (44 kg/m², 20 mm) thick.

ENGLISH

<u>Layer/Material</u>	<u>Coefficient</u>	<u>Asphalt Thickness</u>	<u>SN₀</u>
Friction Course, FC-5	.00	x 3/4" =	0.0
Structural Course, Type SP	.44	x <u>2 1/2"</u> =	<u>1.1</u>
		3 1/4" =	1.1

METRIC

<u>Layer/Material</u>	<u>Coefficient</u>	<u>Asphalt Thickness</u>	<u>SN₀</u>
Friction Course, FC-5	.00	x 20 mm =	0.0
Structural Course, Type SP	.44	x <u>70 mm</u> =	<u>31.0</u>
		90 mm =	31.0

Resurfacing Design For The Design Speed Of 45 mph (70 km/h)

For the second part of this sample problem using a design speed of 45 mph (70 km/h), we need to use FC-12.5 according to Table 4.1. FC-12.5 has a structural coefficient of 0.44 and is always shown as 160 lb/yd², (88 kg/m², 40 mm) thick.

ENGLISH

<u>Layer/Material</u>	<u>Coefficient</u>	<u>Asphalt Thickness</u>	<u>SN₀</u>
Friction Course, FC-12.5	0.44	x 1 1/2" =	0.66
Structural Course, Type SP	0.44	x <u>1.0"</u> =	<u>0.44</u>
		2 1/2" =	1.10

(METRIC)

<u>Layer/Material</u>	<u>Coefficient</u>	<u>Asphalt Thickness</u>	<u>SN_o</u>
Friction Course, FC-12.5	0.44	x 40 mm	= 18.0
Structural Course, Type SP	0.44	x $\frac{30 \text{ mm}}{70 \text{ mm}}$	= <u>13.0</u> 31.0

To check:

ENGLISH

$$SN_R = SN_o + SN_E$$

$$3.94 = 1.10 + 2.85 = 3.95 \text{ in (first part, FC-5)}$$

$$3.94 = 1.10 + 2.85 = 3.95 \text{ in (second part, FC-12.5)}$$

(METRIC)

$$101 \approx 31 + 71 = 102 \text{ mm (first part, FC-5)}$$

$$101 \approx 31 + 71 = 102 \text{ mm (second part, FC-12.5)}$$

So:

This is within the nearest 1/2" (10 mm) of structural course.

For the roadway plans, the thickness has been converted from thickness in inches to 100 lb = one square yard inch (22 kg/m² for each 10 mm) thickness, so:

ENGLISH

$$2.5" \text{ structural course/ } 1" \times 100 \text{ lb/sy} \\ = 250 \text{ lb/sy}$$

$$1.0" \text{ structural course/ } 1" \times 100 \text{ lb/sy} \\ = 100 \text{ lb/sy}$$

(METRIC)

70 mm structural course / 10 mm x 22 kg/m²
= 154 kg/m²

30 mm structural course / 10 mm x 22 kg/m²
= 66 kg/m²

The pavement description in the plans with a design speed of 55 mph(90 km/h) should read:

RESURFACING

ENGLISH

TYPE SP STRUCTURAL COURSE (TRAFFIC C) (250 LBS/SY)
AND FRICTION COURSE FC-5 (80 LBS/SY)(RUBBER).

(METRIC)

RESURFACING

TYPE SP STRUCTURAL COURSE (TRAFFIC C) (154 KG/M²)
AND FRICTION COURSE FC-5 (44 KG/M²)(RUBBER).

The pavement description in the plans with a design speed of 45 mph(70 km/h) should read:

RESURFACING

ENGLISH

TYPE SP STRUCTURAL COURSE (TRAFFIC C) (100 LB/SY)
AND FRICTION COURSE FC-12.5(160 LBS/SY)(RUBBER).

(METRIC)

RESURFACING

TYPE SP STRUCTURAL COURSE (TRAFFIC C) (66 KG/M²)
AND FRICTION COURSE FC-12.5(88 KG/M²)(RUBBER).

6.8 SPECIAL CONSIDERATIONS FOR REHABILITATION PROJECTS

It is essential that the Pavement Design Engineer coordinate 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 Management Office is available to assist on complex projects where statewide experience may be of value.

6.8.1 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 (ie. transitions, driveways, intersections, etc.) in which the quantities are hard to determine.

Overlay projects normally assume a weight of 100 lb is one square yard inch (22 kg/m^2 per 10 mm) thickness. The Pavement Design Engineer should verify this assumption with the District Materials Office. In some areas of the state, where contractors predominately use granite, up to a maximum of 105 lb/sy (23 kg/m^2 per 10 mm) can be used in design. This should only be done on written recommendation of the District Materials Engineer.

6.8.2 LEVELING AND OVERBUILD

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

- Leveling by specification is placed by a motor grader and is used to provide a level surface prior to placing the structural course.
- Overbuild by specification is placed by a paving machine and is used to provide proper cross-slope and longitudinal profile.
- SP-9.5 Overbuild, minimum spread rate with or without a structural course is 75 lb/sy(44 kg/m²).
- SP-9.5 Leveling, minimum spread rate is 50 lb/sy (27 kg/m²) and not more than 75 lb/sy(44 kg/m²) per layer.
- . For Overbuild greater than 1 1/4"(30 mm), Type SP-12.5 may be used.
- . Use the minimum and maximum layer thickness as noted in section 5.5.6 for uniform thickness overbuild layers.
- . All overbuild layers shall be Type SP Asphalt Concrete. On variable thickness overbuild layers, the minimum allowable thickness may be reduced by 1/2"(10 mm) and the maximum allowable thickness may be increased 1/2"(10 mm).

6.8.3 OPERATIONAL PROJECTS

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

"TYPE SP 9.5 (TRAFFIC C) OVERBUILD 75 LBS/SY(44 _____ KG/M²)"

Overbuild should be specified rather than leveling because overbuild is placed with a paver, whereas leveling is placed using motor graders.

FC-5 can be placed directly on the milled surface provided the underlying layers are in good structural shape.

Projects using FC-5 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.
- A need for motor grader applied leveling does not exist.

Friction course selection should continue to be in accordance with current Friction Course Policy.

6.8.4 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 Bituminous Engineer should be consulted for a recommendation in these cases.

Document the basis for the overlay thickness and don't worry about exceeding the theoretical structural number requirements.

6.8.5 AESTHETIC TREATMENTS

ARCHITECTURAL PAVERS

Since they are inherently rougher and more costly than conventional pavement, the use of architectural pavers is not recommended on the state highway system.

When the use of pavers is desirable for aesthetic purposes, they should be limited to areas with design speeds of 35 mph (60 km/h) or less. They should be designed in accordance with technical guidelines published by the National Concrete Masonry Association (NCMA) in Herndon, Va. These guidelines can be ordered by calling the NCMA at 703-435-4900.

IMPRINTED ASPHALT

As a smoother and less costly alternative to pavers, consideration should also be given to using imprinted asphalt pavement to achieve the desired aesthetic treatment.

6.8.6 CRACK RELIEF LAYERS

The use of an Asphalt Rubber Membrane Interlayer (ARMI) as 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. An ARMI should normally be used over cracked and reseated concrete pavement.

An ARMI 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 Bituminous Engineer should be consulted for a recommendation on when an ARMI layer is needed.

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 an ARMI layer with at least a minimum structural overlay thickness based on the type of vehicle loadings. The ARMI layer helps to reduce the stress concentrations while the structural thickness will reduce deflections and help insulate the cracked pavement to reduce temperature movements.

Research is underway to develop computer models to better estimate the additional design life that an ARMI will provide for a specific pavement. Until this research is complete, the Pavement Design Engineer will have to use engineering judgment to estimate the additional life extension anticipated and then evaluate the cost effectiveness of the ARMI layer.

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.

The ARMI must be covered prior to being opened to traffic or other action should be taken to prevent windshield breakage from loose cover material. The State Materials Office recommends that an ARMI 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 ARMI with the overlay.

A 1 1/2" (40 mm) minimum initial structural asphalt lift is required over the ARMI to provide this heat, with a 2" (50 mm) 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.

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.

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CHAPTER 7

PAVEMENT WIDENING

7.1 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 following guidelines will assist in providing a well engineered design.

7.2 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" to 5" thickness of structural asphalt is a reasonable limit depending on truck volumes, for inside traffic lanes which have less truck use.

On selected projects, it may be necessary to justify and use an Asphalt Base(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. 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 Index 600.

DAY TWO

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

Standard Index 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 his 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.

7.3 BASE AND SUBGRADE

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

The Pavement Design Engineer must visualize what is left when future milling occurs to insure 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.

7.4 STABILIZATION

Stabilization should be considered when adding lanes or shoulders and on some operational type projects. The use of stabilizing in trench widening strips is generally not recommended. When stabilization is eliminated, the reasons should be documented in the project file. When stabilization is not provided, single course base layers should not be used.

7.6 LEVELING

The use of a leveling course should be evaluated with construction personnel. In some cases all leveling will be placed prior to the base widening being constructed. In other cases, it may be desirable to place the leveling over both the main roadway and the widening area to remove construction variances.

7.7 WIDENING DESIGN SAMPLE PROBLEM

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

GIVEN:

The existing two lane rural roadway Traffic Level C is to be milled 3" (70 mm) and resurfaced with 2.5" (60 mm) Type SP and 1.5" (40 mm) FC-12.5. The existing lanes are 11' (3.3 m) wide. The road needs to be brought up to current standards by widening the lane to 12' (3.6 m).

FIND:

The pavement design for widening 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 Bituminous Engineer includes the following information.

<u>Material</u>	<u>Thickness</u>	<u>Condition</u>
FC-4	1" (25 mm)	poor
Type S	2" (45 mm)	poor
Type I	1" (25 mm)	fair
Binder	2" (50 mm)	fair
Limerock	10.5" (280 mm)	good
Stabilization	12" (300 mm)	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:

- = 1.5" (40 mm) Friction course.
5.5" (140 mm) Structural course
- = + 2.5" (60 mm) Structural Course (New) +
1" (25 mm) Type I (Remaining)+
2" (50 mm) Binder (Remaining)
- = use 5.5" (140 mm) Structural Course and
1.5" (40 mm) Friction Course to match the
existing asphalt thickness after milling
- Optional Base Group 10
- = SN_E (Limerock)
- = (0.18 x 10.5" (280 mm))
- = 1.89" or Optional Base Group 10

Existing stabilization is assumed.

A construction sketch of the design is provided (See Figure 7.1) showing the widening structural layers.

The pavement description in the plans should read:

WIDENING

OPTIONAL BASE GROUP 10, AND TYPE SP STRUCTURAL
COURSE (TRAFFIC C) 550 LBS/SY (308 KG/M²) AND
FRICTION COURSE FC-12.5 160 LBS/SY (88
KG/M²) (RUBBER)

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

The pavement design for the shoulder includes:

Existing shoulder stabilization is adequate and traffic loadings are moderate. This results in using the minimums for design found in Table 5.5. Table 5.5 lists the following:

1"(30 mm) Structural Course

Optional Base Group 1

FC-12.5 is sufficient for the structural course.

The resurfacing and widening design includes 200 lb/sy (110 kg/m²) structural course on the widening, 250 lb/sy(132 kg/m²) of structural course on the resurfacing and widening with 160 lb/yd²(88 kg/m²) of FC-12.5 Friction Course on top of existing, widening and shoulder.

The shoulder design should be design as follows:

Friction Course FC-12.5 160 lb/yd²(88 kg/m²)

Optional Base Group 1

A construction sketch of the design is provided (See Figure 7.1) showing the shoulder structural layers.

The pavement description in the plans should read:

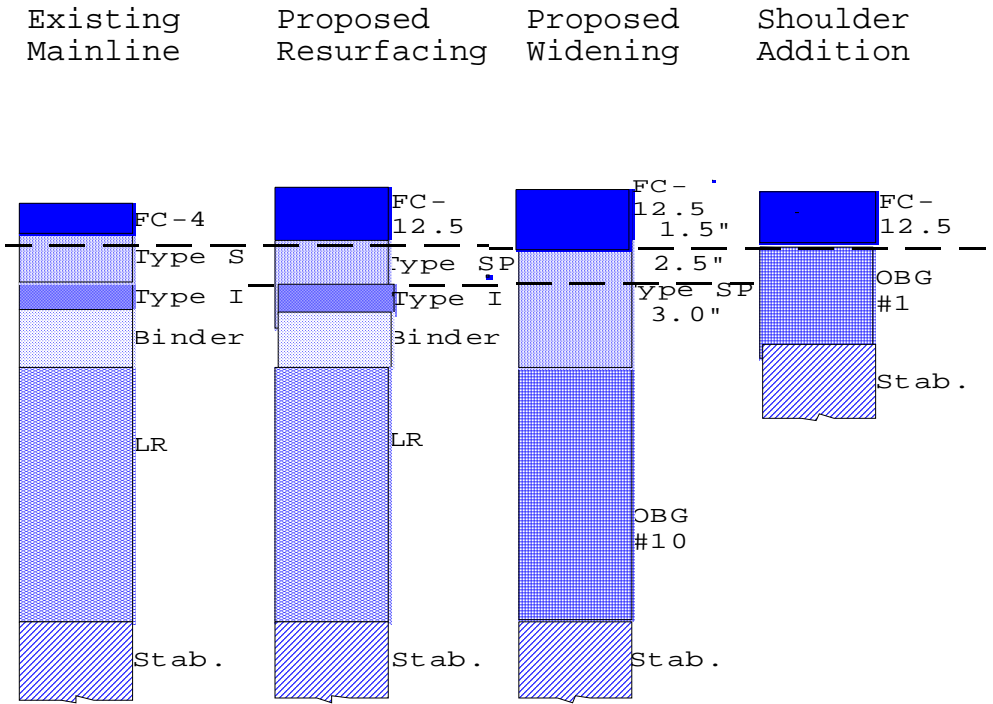
SHOULDER

OPTIONAL BASE GROUP 1 AND FRICTION COURSE FC-12.5
160 LBS/SY (88 KG/M2)(RUBBER)

Note that the 12"(300 mm) Type B Stabilization is not included in the description since the existing stabilization is adequate.

**FIGURE 7.1
WIDENING DETAIL FOR SAMPLE PROBLEM**

The following is an example of what is needed to be done when designing a widening project.



Not To Scale

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CHAPTER 8

SHOULDER DESIGN

8.1 DESIGN GUIDANCE

On low volume roadways, shoulders can be designed using the minimum values shown in Table 5.5. A typical minimum design would be 160 lb/yd² (88 kg/m²) of FC-12.5 or 110 lb/yd² (66 kg/m²) of FC-9.5 and Optional Base Group 1. For very low volume two lane roads (see table 4.1) a friction course may not be required.

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 stabilizing 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 type roadways (ESAL_D = 10 million or more), a shoulder thickness design may use 3% of the ESAL_D for the structural number calculated. 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 may be warranted.

When paved 5' (1.5 m) or less shoulders are to be constructed in conjunction with an overlay of the roadway, it is desirable that the top layer of the roadway overlay and the adjacent shoulder structural course be constructed in one pass.

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APPENDIX A

DESIGN TABLES

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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(80-kN) Equivalent Single Axle Loads ($ESAL_D$) and the Resilient Modulus (M_R) are provided.

The Change In Serviceability (Δ PSI) and the Standard Deviation (S_0) is the same for all the design tables.

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

<u>Reliability (%R)</u>	<u>Standard Normal Deviation (Z_R)</u>
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(30 to 100 Mpa and 100 to 300 MPa.) 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(80-kN) 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-kip(80-kN) Equivalent Single Axle Loads ($ESAL_D$) value.
- The value intersected is the Structural Number Required(SN_R) in(mm) of the pavement system.

If the Resilient Modulus (M_R) value and/or the 18-kip(80-kN) 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 4000 PSI TO 18000 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 18000 PSI TO 32000 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 4000 PSI TO 18000 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 18000 PSI TO 32000 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 4000 PSI TO 18000 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 18000 PSI TO 32000 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 4000 PSI TO 18000 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 18000 PSI TO 32000 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 4000 PSI TO 18000 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 18000 PSI TO 32000 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
50 000 000	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
60 000 000	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
70 000 000	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
80 000 000	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
90 000 000	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
100 000 000	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
110 000 000	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 4000 PSI TO 18000 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 18000 PSI TO 32000 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 4000 PSI TO 18000 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 18000 PSI TO 32000 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 4000 PSI TO 18000 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 18000 PSI TO 32000 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 4000 PSI TO 18000 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 18000 PSI TO 32000 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 4000 PSI TO 18000 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 18000 PSI TO 32000 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

METRIC TABLES

TABLE A.1A

REQUIRED STRUCTURAL NUMBER (SN_R)
 75% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

ESAL _D	Resilient Modulus (M_R), MPa														
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100 000	67	63	60	57	55	53	51	50	48	47	46	45	43	43	42
150 000	72	67	64	61	59	57	55	53	52	50	49	48	47	46	45
200 000	75	71	67	64	62	59	57	56	54	53	51	50	49	48	47
250 000	78	73	70	67	64	62	60	58	56	55	53	52	51	50	49
300 000	80	76	72	69	66	64	62	60	58	56	55	54	53	51	50
350 000	82	78	74	71	68	65	63	61	59	58	56	55	54	53	52
400 000	84	79	75	72	69	67	65	63	61	59	58	56	55	54	53
450 000	86	81	77	74	71	68	66	64	62	60	59	58	56	55	54
500 000	87	82	78	75	72	69	67	65	63	61	60	59	57	56	55
600 000	90	85	81	77	74	71	69	67	65	63	62	60	59	58	57
700 000	92	87	83	79	76	73	71	69	67	65	63	62	61	59	58
800 000	94	89	85	81	78	75	72	70	68	66	65	63	62	61	59
900 000	96	91	86	82	79	76	74	72	70	68	66	65	63	62	61
1 000 000	98	92	88	84	81	78	75	73	71	69	67	66	64	63	62
1 500 000	104	99	94	90	86	83	80	78	76	74	72	70	69	67	66
2 000 000	109	103	98	94	90	87	84	82	79	77	75	74	72	71	69
2 500 000	113	107	102	97	94	90	87	85	82	80	78	76	75	73	72
3 000 000	116	110	105	100	96	93	90	87	85	83	81	79	77	76	74
3 500 000	119	112	107	103	99	95	92	90	87	85	83	81	79	77	76
4 000 000	121	115	109	105	101	97	94	92	89	87	85	83	81	79	78
4 500 000	123	117	111	107	103	99	96	93	91	88	86	84	82	81	79
5 000 000	125	119	113	109	105	101	98	95	92	90	88	86	84	82	81
6 000 000	128	122	116	112	108	104	101	98	95	93	90	88	86	85	83
7 000 000	131	125	119	114	110	106	103	100	97	95	93	91	89	87	85
8 000 000	134	127	121	117	112	109	105	102	100	97	95	93	91	89	87
9 000 000	136	129	123	119	114	111	107	104	101	99	97	94	92	91	89
10 000 000	138	131	125	120	116	112	109	106	103	101	98	96	94	92	90
15 000 000	146	139	133	128	123	119	116	113	110	107	105	102	100	98	96
20 000 000	151	144	138	133	129	125	121	118	115	112	109	107	105	103	101
25 000 000	156	149	142	137	133	129	125	122	119	116	113	111	109	107	105
30 000 000	160	152	146	141	136	132	128	125	122	119	116	114	112	110	108
35 000 000	163	155	149	144	139	135	131	128	125	122	119	117	114	112	110
40 000 000	166	158	152	146	142	137	134	130	127	124	121	119	117	114	112
45 000 000	168	161	154	149	144	140	136	132	129	126	123	121	119	116	114
50 000 000	170	163	156	151	146	142	138	134	131	128	125	123	121	118	116
60 000 000	174	167	160	154	149	145	141	138	134	131	129	126	124	122	119
70 000 000	178	170	163	158	153	148	144	141	137	134	132	129	127	124	122
80 000 000	181	173	166	160	155	151	147	143	140	137	134	131	129	127	125
90 000 000	184	175	169	163	158	153	149	145	142	139	136	134	131	129	127
100 000 000	186	178	171	165	160	155	151	148	144	141	138	136	133	131	129

TABLE A.1B

REQUIRED STRUCTURAL NUMBER (SN_R)
 75% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 100 MPa TO 300 MPa

Resilient Modulus (M_R), MPa

ESAL _D	100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100 000	42	40	39	37	36	35	34	33	32	32	31	29	28	27	25
150 000	45	43	42	40	39	38	37	36	35	34	33	32	30	29	28
200 000	47	45	44	42	41	40	39	38	37	36	35	33	32	31	29
250 000	49	47	45	44	43	41	40	39	38	38	37	35	33	32	31
300 000	50	49	47	45	44	43	42	41	40	39	38	36	35	33	32
350 000	52	50	48	47	45	44	43	42	41	40	39	37	36	34	33
400 000	53	51	49	48	46	45	44	43	42	41	40	38	36	35	34
450 000	54	52	50	49	47	46	45	44	43	42	41	39	37	36	34
500 000	55	53	51	50	48	47	46	45	44	43	42	40	38	36	35
600 000	57	55	53	51	50	48	47	46	45	44	43	41	39	38	36
700 000	58	56	54	52	51	50	48	47	46	45	44	42	40	39	37
800 000	59	57	55	54	52	51	49	48	47	46	45	43	41	40	38
900 000	61	58	56	55	53	52	50	49	48	47	46	44	42	41	39
1 000 000	62	59	57	56	54	53	51	50	49	48	47	45	43	41	40
1 500 000	66	64	62	60	58	56	55	54	53	51	50	48	46	44	43
2 000 000	69	67	65	63	61	59	58	56	55	54	53	51	48	47	45
2 500 000	72	69	67	65	63	61	60	59	57	56	55	52	50	48	47
3 000 000	74	71	69	67	65	63	62	60	59	58	57	54	52	50	48
3 500 000	76	73	71	69	67	65	63	62	61	59	58	56	53	51	50
4 000 000	78	75	72	70	68	66	65	63	62	61	59	57	55	53	51
4 500 000	79	76	74	72	70	68	66	65	63	62	61	58	56	54	52
5 000 000	81	78	75	73	71	69	67	66	64	63	62	59	57	55	53
6 000 000	83	80	77	75	73	71	69	68	66	65	64	61	58	56	54
7 000 000	85	82	79	77	75	73	71	69	68	67	65	62	60	58	56
8 000 000	87	84	81	79	77	75	73	71	70	68	67	64	61	59	57
9 000 000	89	86	83	80	78	76	74	72	71	69	68	65	62	60	58
10 000 000	90	87	84	82	79	77	75	74	72	71	69	66	64	61	59
15 000 000	96	93	90	87	85	83	81	79	77	76	74	71	68	66	63
20 000 000	101	97	94	92	89	87	85	83	81	79	78	74	71	69	66
25 000 000	105	101	98	95	92	90	88	86	84	82	81	77	74	71	69
30 000 000	108	104	101	98	95	93	90	88	87	85	83	79	76	74	71
35 000 000	110	106	103	100	97	95	93	91	89	87	85	81	78	75	73
40 000 000	112	109	105	102	100	97	95	93	91	89	87	83	80	77	75
45 000 000	114	111	107	104	101	99	97	94	92	91	89	85	82	79	76
50 000 000	116	112	109	106	103	101	98	96	94	92	90	86	83	80	77
60 000 000	119	116	112	109	106	104	101	99	97	95	93	89	86	82	80
70 000 000	122	118	115	112	109	106	104	101	99	97	95	91	88	85	82
80 000 000	125	121	117	114	111	108	106	103	101	99	97	93	90	86	84
90 000 000	127	123	119	116	113	110	108	105	103	101	99	95	91	88	85
100 000 000	129	125	121	118	115	112	109	107	105	103	101	97	93	90	87

TABLE A.2A

REQUIRED STRUCTURAL NUMBER (SN_R)
 80% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

ESAL _D	Resilient Modulus (M_R), MPa														
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100 000	69	65	62	59	57	54	53	51	50	48	47	46	45	44	43
150 000	74	69	66	63	61	58	56	55	53	52	50	49	48	47	46
200 000	77	73	69	66	63	61	59	57	56	54	53	52	51	49	48
250 000	80	76	72	69	66	64	61	60	58	56	55	54	52	51	50
300 000	83	78	74	71	68	65	63	61	60	58	57	55	54	53	52
350 000	85	80	76	73	70	67	65	63	61	60	58	57	56	54	53
400 000	87	82	78	74	71	69	66	64	63	61	59	58	57	56	54
450 000	88	83	79	76	73	70	68	66	64	62	61	59	58	57	56
500 000	90	85	81	77	74	71	69	67	65	63	62	60	59	58	57
600 000	93	87	83	79	76	73	71	69	67	65	64	62	61	59	58
700 000	95	90	85	81	78	75	73	71	69	67	65	64	62	61	60
800 000	97	92	87	83	80	77	75	72	70	68	67	65	64	62	61
900 000	99	93	89	85	82	79	76	74	72	70	68	66	65	64	62
1 000 000	101	95	90	86	83	80	77	75	73	71	69	68	66	65	64
1 500 000	107	101	96	92	89	85	83	80	78	76	74	72	71	69	68
2 000 000	112	106	101	97	93	90	87	84	82	80	78	76	74	73	71
2 500 000	116	110	105	100	96	93	90	87	85	83	81	79	77	75	74
3 000 000	119	113	108	103	99	96	93	90	87	85	83	81	79	78	76
3 500 000	122	115	110	106	102	98	95	92	90	87	85	83	81	80	78
4 000 000	124	118	112	108	104	100	97	94	92	89	87	85	83	82	80
4 500 000	126	120	114	110	106	102	99	96	93	91	89	87	85	83	82
5 000 000	128	122	116	111	107	104	101	98	95	93	90	88	86	85	83
6 000 000	131	125	119	115	110	107	103	100	98	95	93	91	89	87	85
7 000 000	134	128	122	117	113	109	106	103	100	98	95	93	91	89	88
8 000 000	137	130	124	120	115	112	108	105	102	100	97	95	93	91	90
9 000 000	139	132	127	122	117	114	110	107	104	102	99	97	95	93	91
10 000 000	141	134	129	124	119	115	112	109	106	103	101	99	97	95	93
15 000 000	149	142	136	131	126	122	119	116	113	110	108	105	103	101	99
20 000 000	155	148	142	136	132	128	124	121	118	115	112	110	108	106	104
25 000 000	159	152	146	141	136	132	128	125	122	119	116	114	112	109	107
30 000 000	163	156	149	144	139	135	131	128	125	122	119	117	115	112	110
35 000 000	166	159	153	147	142	138	134	131	128	125	122	120	117	115	113
40 000 000	169	162	155	150	145	141	137	133	130	127	124	122	120	117	115
45 000 000	172	164	158	152	147	143	139	135	132	129	127	124	122	119	117
50 000 000	174	166	160	154	149	145	141	137	134	131	129	126	124	121	119
60 000 000	178	170	164	158	153	149	145	141	138	135	132	129	127	125	122
70 000 000	182	174	167	161	156	152	148	144	141	138	135	132	130	127	125
80 000 000	185	177	170	164	159	154	150	147	143	140	137	135	132	130	128
90 000 000	188	179	172	166	161	157	153	149	146	142	140	137	134	132	130
100 000 000	190	182	175	169	164	159	155	151	148	144	142	139	136	134	132

TABLE A.2B

REQUIRED STRUCTURAL NUMBER (SN_R)
 80% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 100 MPa TO 300 MPa

Resilient Modulus (M_R), MPa

ESAL _D	100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100 000	43	41	40	39	37	36	35	34	33	33	32	30	29	28	26
150 000	46	44	43	41	40	39	38	37	36	35	34	33	31	30	29
200 000	48	47	45	44	42	41	40	39	38	37	36	35	33	32	30
250 000	50	48	47	45	44	43	42	41	40	39	38	36	34	33	32
300 000	52	50	48	47	45	44	43	42	41	40	39	37	36	34	33
350 000	53	51	50	48	47	45	44	43	42	41	40	38	37	35	34
400 000	54	52	51	49	48	46	45	44	43	42	41	39	38	36	35
450 000	56	54	52	50	49	47	46	45	44	43	42	40	38	37	36
500 000	57	55	53	51	50	48	47	46	45	44	43	41	39	38	36
600 000	58	56	54	53	51	50	49	47	46	45	44	42	40	39	37
700 000	60	58	56	54	52	51	50	49	48	47	46	43	42	40	39
800 000	61	59	57	55	54	52	51	50	49	48	47	44	43	41	39
900 000	62	60	58	56	55	53	52	51	50	49	48	45	43	42	40
1 000 000	64	61	59	57	56	54	53	52	51	49	48	46	44	43	41
1 500 000	68	65	63	61	60	58	57	55	54	53	52	50	48	46	44
2 000 000	71	69	66	64	63	61	59	58	57	56	55	52	50	48	46
2 500 000	74	71	69	67	65	63	62	60	59	58	57	54	52	50	48
3 000 000	76	73	71	69	67	65	64	62	61	60	58	56	53	52	50
3 500 000	78	75	73	71	69	67	65	64	62	61	60	57	55	53	51
4 000 000	80	77	75	72	70	68	67	65	64	62	61	58	56	54	52
4 500 000	82	79	76	74	72	70	68	66	65	64	62	60	57	55	53
5 000 000	83	80	77	75	73	71	69	68	66	65	64	61	58	56	54
6 000 000	85	82	80	77	75	73	71	70	68	67	65	63	60	58	56
7 000 000	88	85	82	79	77	75	73	72	70	69	67	64	62	59	57
8 000 000	90	86	84	81	79	77	75	73	72	70	69	66	63	61	59
9 000 000	91	88	85	83	80	78	76	75	73	71	70	67	64	62	60
10 000 000	93	90	87	84	82	80	78	76	74	73	71	68	65	63	61
15 000 000	99	96	93	90	87	85	83	81	79	78	76	73	70	67	65
20 000 000	104	100	97	94	92	89	87	85	83	82	80	76	73	71	68
25 000 000	107	104	101	98	95	93	90	88	86	85	83	79	76	73	71
30 000 000	110	107	103	101	98	95	93	91	89	87	85	82	78	76	73
35 000 000	113	109	106	103	100	98	95	93	91	89	88	84	81	78	75
40 000 000	115	112	108	105	102	100	97	95	93	91	90	86	82	79	77
45 000 000	117	114	110	107	104	102	99	97	95	93	91	87	84	81	78
50 000 000	119	115	112	109	106	103	101	99	97	95	93	89	85	82	80
60 000 000	122	119	115	112	109	106	104	102	100	98	96	92	88	85	82
70 000 000	125	121	118	115	112	109	106	104	102	100	98	94	90	87	84
80 000 000	128	124	120	117	114	111	109	106	104	102	100	96	92	89	86
90 000 000	130	126	122	119	116	113	111	108	106	104	102	98	94	91	88
100 000 000	132	128	124	121	118	115	112	110	108	106	104	99	96	92	89

TABLE A.3A

REQUIRED STRUCTURAL NUMBER (SN_R)
 85% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

ESAL _D	Resilient Modulus (M_R), MPa														
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100 000	71	67	64	61	59	56	54	53	51	50	49	48	46	45	44
150 000	76	72	68	65	63	60	58	57	55	53	52	51	50	49	48
200 000	80	75	72	68	66	63	61	59	58	56	55	53	52	51	50
250 000	83	78	74	71	68	66	64	62	60	58	57	55	54	53	52
300 000	85	81	77	73	70	68	65	63	62	60	59	57	56	55	54
350 000	88	83	79	75	72	69	67	65	63	62	60	59	57	56	55
400 000	90	84	80	77	74	71	69	67	65	63	61	60	59	58	56
450 000	91	86	82	78	75	72	70	68	66	64	63	61	60	59	57
500 000	93	88	83	80	76	74	71	69	67	65	64	62	61	60	59
600 000	96	90	86	82	79	76	73	71	69	67	66	64	63	62	60
700 000	98	93	88	84	81	78	75	73	71	69	67	66	64	63	62
800 000	100	95	90	86	83	80	77	75	73	71	69	67	66	65	63
900 000	102	96	92	88	84	81	79	76	74	72	70	69	67	66	65
1 000 000	104	98	93	89	86	83	80	78	75	73	72	70	68	67	66
1 500 000	110	105	100	95	92	88	85	83	81	78	77	75	73	72	70
2 000 000	115	109	104	100	96	93	90	87	85	82	80	78	77	75	74
2 500 000	119	113	108	103	99	96	93	90	88	85	83	81	80	78	76
3 000 000	122	116	111	106	102	99	96	93	90	88	86	84	82	80	79
3 500 000	125	119	114	109	105	101	98	95	93	90	88	86	84	82	81
4 000 000	128	121	116	111	107	103	100	97	95	92	90	88	86	84	83
4 500 000	130	123	118	113	109	105	102	99	96	94	92	90	88	86	84
5 000 000	132	125	120	115	111	107	104	101	98	96	93	91	89	87	86
6 000 000	135	129	123	118	114	110	107	104	101	98	96	94	92	90	88
7 000 000	138	131	126	121	117	113	109	106	103	101	98	96	94	92	91
8 000 000	141	134	128	123	119	115	112	108	106	103	101	98	96	94	93
9 000 000	143	136	130	125	121	117	114	110	108	105	102	100	98	96	94
10 000 000	145	138	132	127	123	119	115	112	109	107	104	102	100	98	96
15 000 000	153	146	140	135	130	126	122	119	116	113	111	109	106	104	102
20 000 000	159	152	145	140	135	131	128	124	121	118	116	113	111	109	107
25 000 000	164	156	150	144	140	136	132	128	125	122	120	117	115	113	111
30 000 000	167	160	154	148	143	139	135	132	129	126	123	120	118	116	114
35 000 000	171	163	157	151	146	142	138	135	131	128	126	123	121	119	117
40 000 000	174	166	159	154	149	145	141	137	134	131	128	126	123	121	119
45 000 000	176	168	162	156	151	147	143	139	136	133	130	128	125	123	121
50 000 000	179	171	164	158	153	149	145	141	138	135	132	130	127	125	123
60 000 000	183	175	168	162	157	153	149	145	142	138	136	133	131	128	126
70 000 000	186	178	171	165	160	156	152	148	145	141	139	136	133	131	129
80 000 000	189	181	174	168	163	158	154	151	147	144	141	138	136	134	131
90 000 000	192	184	177	171	166	161	157	153	149	146	143	141	138	136	134
100 000 000	195	186	179	173	168	163	159	155	152	148	145	143	140	138	136

TABLE A.3B

REQUIRED STRUCTURAL NUMBER (SN_R)
 85% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 100 MPa TO 300 MPa

		Resilient Modulus (M_R), MPa														
ESAL _D		100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100 000		44	43	41	40	39	38	37	36	35	34	33	31	30	29	28
150 000		48	46	44	43	42	40	39	38	37	37	36	34	32	31	30
200 000		50	48	47	45	44	43	41	40	40	39	38	36	34	33	32
250 000		52	50	48	47	46	44	43	42	41	40	39	37	36	34	33
300 000		54	52	50	48	47	46	45	43	42	42	41	39	37	36	34
350 000		55	53	51	50	48	47	46	45	44	43	42	40	38	37	35
400 000		56	54	52	51	49	48	47	46	45	44	43	41	39	37	36
450 000		57	55	54	52	50	49	48	47	46	45	44	42	40	38	37
500 000		59	56	55	53	51	50	49	48	46	45	45	42	41	39	38
600 000		60	58	56	54	53	52	50	49	48	47	46	44	42	40	39
700 000		62	60	58	56	54	53	52	50	49	48	47	45	43	41	40
800 000		63	61	59	57	56	54	53	51	50	49	48	46	44	42	41
900 000		65	62	60	58	57	55	54	53	51	50	49	47	45	43	42
1 000 000		66	63	61	59	58	56	55	53	52	51	50	48	46	44	43
1 500 000		70	68	65	63	62	60	59	57	56	55	54	51	49	47	46
2 000 000		74	71	69	67	65	63	61	60	59	58	56	54	52	50	48
2 500 000		76	74	71	69	67	65	64	62	61	60	59	56	54	52	50
3 000 000		79	76	73	71	69	67	66	64	63	62	60	58	55	53	52
3 500 000		81	78	75	73	71	69	67	66	64	63	62	59	57	55	53
4 000 000		83	80	77	75	73	71	69	67	66	65	63	60	58	56	54
4 500 000		84	81	79	76	74	72	70	69	67	66	65	62	59	57	55
5 000 000		86	83	80	78	75	73	72	70	68	67	66	63	60	58	56
6 000 000		88	85	82	80	78	76	74	72	71	69	68	65	62	60	58
7 000 000		91	87	85	82	80	78	76	74	72	71	69	66	64	61	59
8 000 000		93	89	86	84	81	79	77	76	74	72	71	68	65	63	61
9 000 000		94	91	88	85	83	81	79	77	75	74	72	69	66	64	62
10 000 000		96	93	90	87	85	82	80	78	77	75	74	70	68	65	63
15 000 000		102	99	96	93	90	88	86	84	82	80	79	75	72	70	67
20 000 000		107	103	100	97	95	92	90	88	86	84	83	79	76	73	71
25 000 000		111	107	104	101	98	96	93	91	89	87	86	82	79	76	73
30 000 000		114	110	107	104	101	98	96	94	92	90	88	84	81	78	76
35 000 000		117	113	109	106	103	101	99	96	94	92	91	87	83	80	78
40 000 000		119	115	112	108	106	103	101	98	96	94	93	89	85	82	79
45 000 000		121	117	114	110	108	105	103	100	98	96	94	90	87	84	81
50 000 000		123	119	115	112	109	107	104	102	100	98	96	92	88	85	82
60 000 000		126	122	119	115	112	110	107	105	103	101	99	95	91	88	85
70 000 000		129	125	121	118	115	112	110	107	105	103	101	97	93	90	87
80 000 000		131	127	124	120	117	115	112	110	107	105	103	99	95	92	89
90 000 000		134	129	126	122	119	117	114	112	109	107	105	101	97	94	91
100 000 000		136	131	128	124	121	118	116	113	111	109	107	103	99	95	92

TABLE A.4A

REQUIRED STRUCTURAL NUMBER (SN_R)
 90% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

ESAL _D	Resilient Modulus (M_R), MPa														
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100 000	74	70	67	64	61	59	57	55	54	52	51	50	49	47	47
150 000	79	75	71	68	65	63	61	59	57	56	54	53	52	51	50
200 000	83	79	75	71	68	66	64	62	60	59	57	56	55	53	52
250 000	86	82	77	74	71	69	66	64	62	61	59	58	57	55	54
300 000	89	84	80	76	73	71	68	66	64	63	61	60	58	57	56
350 000	91	86	82	78	75	72	70	68	66	64	63	61	60	59	58
400 000	93	88	84	80	77	74	72	69	68	66	64	63	61	60	59
450 000	95	90	85	82	78	76	73	71	69	67	65	64	62	61	60
500 000	97	91	87	83	80	77	74	72	70	68	67	65	64	62	61
600 000	100	94	89	86	82	79	77	74	72	70	69	67	66	64	63
700 000	102	96	92	88	84	81	79	76	74	72	70	69	67	66	65
800 000	104	99	94	90	86	83	80	78	76	74	72	70	69	67	66
900 000	106	100	96	91	88	85	82	79	77	75	73	72	70	69	67
1 000 000	108	102	97	93	89	86	83	81	79	77	75	73	71	70	69
1 500 000	115	109	104	99	95	92	89	86	84	82	80	78	76	75	73
2 000 000	120	114	108	104	100	96	93	91	88	86	84	82	80	78	77
2 500 000	124	117	112	108	104	100	97	94	91	89	87	85	83	81	80
3 000 000	127	121	115	111	106	103	100	97	94	92	89	87	86	84	82
3 500 000	130	123	118	113	109	105	102	99	96	94	92	90	88	86	84
4 000 000	132	126	120	115	111	108	104	101	99	96	94	92	90	88	86
4 500 000	135	128	122	118	113	110	106	103	100	98	96	93	91	90	88
5 000 000	136	130	124	119	115	111	108	105	102	100	97	95	93	91	89
6 000 000	140	133	127	123	118	114	111	108	105	102	100	98	96	94	92
7 000 000	143	136	130	125	121	117	114	110	108	105	103	100	98	96	94
8 000 000	146	139	133	128	123	119	116	113	110	107	105	102	100	98	96
9 000 000	148	141	135	130	125	122	118	115	112	109	107	104	102	100	98
10 000 000	150	143	137	132	127	123	120	117	114	111	108	106	104	102	100
15 000 000	158	151	145	139	135	131	127	124	121	118	115	113	111	108	107
20 000 000	164	157	150	145	140	136	132	129	126	123	120	118	115	113	111
25 000 000	169	161	155	149	145	140	137	133	130	127	124	122	119	117	115
30 000 000	173	165	159	153	148	144	140	136	133	130	128	125	123	120	118
35 000 000	176	169	162	156	151	147	143	139	136	133	130	128	125	123	121
40 000 000	179	171	165	159	154	150	146	142	139	136	133	130	128	126	123
45 000 000	182	174	167	161	156	152	148	144	141	138	135	132	130	128	125
50 000 000	184	176	170	164	159	154	150	146	143	140	137	134	132	130	127
60 000 000	189	180	174	168	162	158	154	150	146	143	140	138	135	133	131
70 000 000	192	184	177	171	166	161	157	153	150	146	143	141	138	136	134
80 000 000	196	187	180	174	168	164	160	156	152	149	146	143	141	138	136
90 000 000	198	190	183	176	171	166	162	158	155	151	148	146	143	141	138
100 000 000	201	192	185	179	173	169	164	160	157	153	150	148	145	143	140

TABLE A.4B

REQUIRED STRUCTURAL NUMBER (SN_R)
 90% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 100 MPa TO 300 MPa

		Resilient Modulus (M_R), MPa														
ESAL _D		100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100 000		47	45	43	42	41	39	38	37	36	36	35	33	32	30	29
150 000		50	48	46	45	44	42	41	40	39	38	38	36	34	33	31
200 000		52	50	49	47	46	45	43	42	41	40	40	38	36	35	33
250 000		54	52	51	49	48	46	45	44	43	42	41	39	38	36	35
300 000		56	54	52	51	49	48	47	45	44	43	43	41	39	37	36
350 000		58	55	54	52	50	49	48	47	46	45	44	42	40	38	37
400 000		59	57	55	53	52	50	49	48	47	46	45	43	41	39	38
450 000		60	58	56	54	53	51	50	49	48	47	46	44	42	40	39
500 000		61	59	57	55	54	52	51	50	49	47	47	44	42	41	39
600 000		63	61	59	57	55	54	52	51	50	49	48	46	44	42	41
700 000		65	62	60	58	57	55	54	53	51	50	49	47	45	43	42
800 000		66	64	62	60	58	56	55	54	53	51	50	48	46	44	43
900 000		67	65	63	61	59	58	56	55	54	52	51	49	47	45	44
1 000 000		69	66	64	62	60	59	57	56	55	53	52	50	48	46	45
1 500 000		73	71	68	66	64	63	61	60	58	57	56	54	51	49	48
2 000 000		77	74	72	69	68	66	64	63	61	60	59	56	54	52	50
2 500 000		80	77	74	72	70	68	67	65	64	62	61	58	56	54	52
3 000 000		82	79	77	74	72	70	69	67	66	64	63	60	58	56	54
3 500 000		84	81	79	76	74	72	70	69	67	66	65	62	59	57	55
4 000 000		86	83	80	78	76	74	72	70	69	67	66	63	61	58	56
4 500 000		88	85	82	79	77	75	73	72	70	69	67	64	62	60	58
5 000 000		89	86	83	81	79	77	75	73	71	70	69	65	63	61	59
6 000 000		92	89	86	83	81	79	77	75	74	72	71	67	65	62	60
7 000 000		94	91	88	85	83	81	79	77	75	74	72	69	66	64	62
8 000 000		96	93	90	87	85	83	81	79	77	76	74	71	68	66	63
9 000 000		98	95	92	89	87	84	82	80	79	77	76	72	69	67	65
10 000 000		100	97	93	91	88	86	84	82	80	78	77	73	71	68	66
15 000 000		107	103	100	97	94	92	90	87	86	84	82	79	75	73	70
20 000 000		111	108	104	101	99	96	94	92	90	88	86	82	79	76	74
25 000 000		115	111	108	105	102	100	97	95	93	91	89	86	82	79	77
30 000 000		118	114	111	108	105	102	100	98	96	94	92	88	85	82	79
35 000 000		121	117	114	110	108	105	103	100	98	96	94	90	87	84	81
40 000 000		123	119	116	113	110	107	105	102	100	98	96	92	89	86	83
45 000 000		125	122	118	115	112	109	107	104	102	100	98	94	90	87	84
50 000 000		127	123	120	117	114	111	108	106	104	102	100	96	92	89	86
60 000 000		131	127	123	120	117	114	111	109	107	105	103	99	95	91	88
70 000 000		134	130	126	123	119	117	114	112	109	107	105	101	97	94	91
80 000 000		136	132	128	125	122	119	116	114	112	110	108	103	99	96	93
90 000 000		138	134	130	127	124	121	118	116	114	112	110	105	101	98	95
100 000 000		140	136	132	129	126	123	120	118	116	113	111	107	103	99	96

TABLE A.5A

REQUIRED STRUCTURAL NUMBER (SN_R)
 92% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

ESAL _D	Resilient Modulus (M_R), MPa														
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100 000	76	72	68	65	62	60	58	56	55	53	52	51	50	49	48
150 000	81	77	73	69	67	64	62	60	59	57	56	54	53	52	51
200 000	85	80	76	73	70	67	65	63	61	60	58	57	56	55	53
250 000	88	83	79	76	73	70	68	66	64	62	61	59	58	57	56
300 000	91	86	82	78	75	72	70	68	66	64	62	61	60	58	57
350 000	93	88	84	80	77	74	72	69	67	66	64	63	61	60	59
400 000	95	90	86	82	78	76	73	71	69	67	65	64	63	61	60
450 000	97	92	87	83	80	77	75	72	70	68	67	65	64	63	61
500 000	99	93	89	85	81	79	76	74	72	70	68	66	65	64	62
600 000	102	96	91	87	84	81	78	76	74	72	70	68	67	66	64
700 000	104	98	94	90	86	83	80	78	76	74	72	70	69	67	66
800 000	106	101	96	92	88	85	82	80	77	75	73	72	70	69	67
900 000	108	102	98	93	90	87	84	81	79	77	75	73	72	70	69
1 000 000	110	104	99	95	91	88	85	83	80	78	76	75	73	71	70
1 500 000	117	111	106	101	97	94	91	88	86	84	82	80	78	76	75
2 000 000	122	116	110	106	102	98	95	93	90	88	86	84	82	80	79
2 500 000	126	120	114	110	106	102	99	96	93	91	89	87	85	83	81
3 000 000	129	123	117	113	109	105	102	99	96	94	91	89	87	86	84
3 500 000	132	126	120	115	111	108	104	101	98	96	94	92	90	88	86
4 000 000	135	128	123	118	113	110	106	103	101	98	96	94	92	90	88
4 500 000	137	130	125	120	115	112	108	105	102	100	98	95	93	91	90
5 000 000	139	132	127	122	117	114	110	107	104	102	99	97	95	93	91
6 000 000	142	136	130	125	121	117	113	110	107	105	102	100	98	96	94
7 000 000	145	139	133	128	123	119	116	113	110	107	105	102	100	98	96
8 000 000	148	141	135	130	126	122	118	115	112	109	107	104	102	100	98
9 000 000	150	143	137	132	128	124	120	117	114	111	109	106	104	102	100
10 000 000	153	145	139	134	130	126	122	119	116	113	111	108	106	104	102
15 000 000	161	153	147	142	137	133	129	126	123	120	117	115	113	111	109
20 000 000	167	159	153	148	143	139	135	131	128	125	123	120	118	116	113
25 000 000	172	164	158	152	147	143	139	135	132	129	127	124	122	119	117
30 000 000	176	168	161	156	151	146	142	139	136	133	130	127	125	123	121
35 000 000	179	171	165	159	154	149	145	142	139	136	133	130	128	125	123
40 000 000	182	174	167	162	157	152	148	144	141	138	135	133	130	128	126
45 000 000	185	177	170	164	159	154	150	147	143	140	137	135	132	130	128
50 000 000	187	179	172	166	161	157	153	149	145	142	139	137	134	132	130
60 000 000	192	183	176	170	165	160	156	152	149	146	143	140	138	135	133
70 000 000	195	187	180	174	168	164	159	156	152	149	146	143	141	138	136
80 000 000	199	190	183	177	171	166	162	158	155	152	149	146	143	141	139
90 000 000	202	193	186	179	174	169	165	161	157	154	151	148	146	143	141
100 000 000	204	195	188	182	176	171	167	163	159	156	153	150	148	145	143

TABLE A.5B

REQUIRED STRUCTURAL NUMBER (SN_R)
 92% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 100 MPa TO 300 MPa

Resilient Modulus (M_R), MPa

ESAL _D	100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100 000	48	46	44	43	41	40	39	38	37	36	36	34	32	31	30
150 000	51	49	47	46	45	43	42	41	40	39	38	37	35	33	32
200 000	53	52	50	48	47	46	44	43	42	41	40	39	37	35	34
250 000	56	54	52	50	49	47	46	45	44	43	42	40	38	37	36
300 000	57	55	53	52	50	49	48	46	45	44	44	41	40	38	37
350 000	59	57	55	53	52	50	49	48	47	46	45	43	41	39	38
400 000	60	58	56	54	53	51	50	49	48	47	46	44	42	40	39
450 000	61	59	57	55	54	52	51	50	49	48	47	45	43	41	40
500 000	62	60	58	56	55	53	52	51	50	49	48	45	43	42	40
600 000	64	62	60	58	56	55	54	52	51	50	49	47	45	43	42
700 000	66	64	61	60	58	56	55	54	53	51	50	48	46	44	43
800 000	67	65	63	61	59	58	56	55	54	53	52	49	47	45	44
900 000	69	66	64	62	60	59	57	56	55	54	53	50	48	46	45
1 000 000	70	67	65	63	61	60	58	57	56	55	54	51	49	47	46
1 500 000	75	72	70	68	66	64	62	61	60	58	57	55	53	51	49
2 000 000	79	76	73	71	69	67	66	64	63	61	60	57	55	53	51
2 500 000	81	79	76	74	72	70	68	66	65	64	62	60	57	55	53
3 000 000	84	81	78	76	74	72	70	68	67	66	64	61	59	57	55
3 500 000	86	83	80	78	76	74	72	70	69	67	66	63	61	58	56
4 000 000	88	85	82	80	77	75	74	72	70	69	67	64	62	60	58
4 500 000	90	87	84	81	79	77	75	73	72	70	69	66	63	61	59
5 000 000	91	88	85	83	80	78	76	75	73	71	70	67	64	62	60
6 000 000	94	91	88	85	83	81	79	77	75	74	72	69	66	64	62
7 000 000	96	93	90	87	85	83	81	79	77	75	74	71	68	65	63
8 000 000	98	95	92	89	87	85	82	81	79	77	76	72	69	67	65
9 000 000	100	97	94	91	88	86	84	82	80	79	77	74	71	68	66
10 000 000	102	98	95	93	90	88	86	84	82	80	79	75	72	69	67
15 000 000	109	105	102	99	96	94	91	89	87	86	84	80	77	74	72
20 000 000	113	110	106	103	101	98	96	94	92	90	88	84	81	78	75
25 000 000	117	114	110	107	104	102	99	97	95	93	91	87	84	81	78
30 000 000	121	117	113	110	107	105	102	100	98	96	94	90	86	83	81
35 000 000	123	119	116	113	110	107	105	102	100	98	96	92	89	85	83
40 000 000	126	122	118	115	112	109	107	105	102	100	98	94	91	87	85
45 000 000	128	124	120	117	114	111	109	106	104	102	100	96	92	89	86
50 000 000	130	126	122	119	116	113	111	108	106	104	102	98	94	91	88
60 000 000	133	129	125	122	119	116	114	111	109	107	105	101	97	93	90
70 000 000	136	132	128	125	122	119	116	114	112	109	108	103	99	96	93
80 000 000	139	134	131	127	124	121	119	116	114	112	110	105	101	98	95
90 000 000	141	137	133	129	126	123	121	118	116	114	112	107	103	100	96
100 000 000	143	139	135	131	128	125	123	120	118	116	114	109	105	101	98

TABLE A.6A

REQUIRED STRUCTURAL NUMBER (SN_R)
 94% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

ESAL _D	Resilient Modulus (M_R), MPa														
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100 000	78	73	70	67	64	62	60	58	56	55	53	52	51	50	49
150 000	83	79	75	71	68	66	64	62	60	59	57	56	55	53	52
200 000	87	82	78	75	72	69	67	65	63	61	60	58	57	56	55
250 000	91	85	81	78	74	72	69	67	65	64	62	61	59	58	57
300 000	93	88	84	80	77	74	72	69	67	66	64	63	61	60	59
350 000	96	90	86	82	79	76	73	71	69	67	66	64	63	62	60
400 000	98	92	88	84	81	78	75	73	71	69	67	66	64	63	62
450 000	100	94	89	85	82	79	77	74	72	70	69	67	65	64	63
500 000	101	96	91	87	84	81	78	76	73	71	70	68	67	65	64
600 000	104	98	94	90	86	83	80	78	76	74	72	70	69	67	66
700 000	107	101	96	92	88	85	82	80	78	76	74	72	70	69	68
800 000	109	103	98	94	90	87	84	82	79	77	75	74	72	71	69
900 000	111	105	100	96	92	89	86	83	81	79	77	75	73	72	71
1 000 000	113	107	102	97	94	90	87	85	82	80	78	76	75	73	72
1 500 000	120	114	108	104	100	96	93	91	88	86	84	82	80	78	77
2 000 000	125	118	113	109	104	101	98	95	92	90	88	86	84	82	81
2 500 000	129	122	117	112	108	105	101	98	96	93	91	89	87	85	84
3 000 000	132	126	120	115	111	108	104	101	98	96	94	92	90	88	86
3 500 000	135	128	123	118	114	110	107	104	101	98	96	94	92	90	88
4 000 000	138	131	125	120	116	112	109	106	103	101	98	96	94	92	90
4 500 000	140	133	127	123	118	114	111	108	105	102	100	98	96	94	92
5 000 000	142	135	129	124	120	116	113	110	107	104	102	99	97	95	94
6 000 000	145	139	133	128	123	119	116	113	110	107	105	102	100	98	96
7 000 000	148	141	136	131	126	122	119	115	112	110	107	105	103	101	99
8 000 000	151	144	138	133	128	124	121	118	115	112	109	107	105	103	101
9 000 000	154	146	140	135	131	127	123	120	117	114	111	109	107	105	103
10 000 000	156	148	142	137	133	129	125	122	119	116	113	111	109	106	105
15 000 000	164	157	150	145	140	136	132	129	126	123	120	118	115	113	111
20 000 000	170	163	156	151	146	142	138	134	131	128	125	123	120	118	116
25 000 000	175	167	161	155	150	146	142	138	135	132	129	127	124	122	120
30 000 000	179	171	165	159	154	149	145	142	139	136	133	130	128	125	123
35 000 000	183	175	168	162	157	153	149	145	142	138	136	133	131	128	126
40 000 000	186	178	171	165	160	155	151	147	144	141	138	135	133	131	128
45 000 000	189	180	173	167	162	158	154	150	146	143	140	138	135	133	131
50 000 000	191	183	176	170	164	160	156	152	148	145	142	140	137	135	133
60 000 000	195	187	180	174	168	164	159	156	152	149	146	143	141	138	136
70 000 000	199	191	183	177	172	167	163	159	155	152	149	146	144	141	139
80 000 000	202	194	186	180	175	170	165	162	158	155	152	149	146	144	141
90 000 000	205	197	189	183	177	172	168	164	160	157	154	151	149	146	144
100 000 000	208	199	192	185	180	175	170	166	163	159	156	153	151	148	146

TABLE A.6B

REQUIRED STRUCTURAL NUMBER (SN_R)
 94% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 100 MPa TO 300 MPa

		Resilient Modulus (M_R), MPa														
ESAL _D		100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100 000		49	47	45	44	43	41	40	39	38	38	37	35	33	32	31
150 000		52	50	49	47	46	45	43	42	41	40	40	38	36	34	33
200 000		55	53	51	50	48	47	46	44	43	43	42	40	38	36	35
250 000		57	55	53	51	50	49	47	46	45	44	43	41	39	38	37
300 000		59	57	55	53	52	50	49	48	47	46	45	43	41	39	38
350 000		60	58	56	54	53	51	50	49	48	47	46	44	42	40	39
400 000		62	59	57	56	54	53	51	50	49	48	47	45	43	41	40
450 000		63	61	59	57	55	54	52	51	50	49	48	46	44	42	41
500 000		64	62	60	58	56	55	53	52	51	50	49	47	45	43	41
600 000		66	64	61	60	58	56	55	54	53	51	50	48	46	44	43
700 000		68	65	63	61	59	58	56	55	54	53	52	49	47	46	44
800 000		69	67	64	63	61	59	58	56	55	54	53	51	48	47	45
900 000		71	68	66	64	62	60	59	57	56	55	54	52	49	48	46
1 000 000		72	69	67	65	63	61	60	59	57	56	55	52	50	48	47
1 500 000		77	74	72	69	67	66	64	63	61	60	59	56	54	52	50
2 000 000		81	78	75	73	71	69	67	66	64	63	62	59	57	55	53
2 500 000		84	81	78	76	73	72	70	68	67	65	64	61	59	57	55
3 000 000		86	83	80	78	76	74	72	70	69	67	66	63	61	58	56
3 500 000		88	85	82	80	78	76	74	72	70	69	68	65	62	60	58
4 000 000		90	87	84	82	79	77	75	74	72	71	69	66	64	61	59
4 500 000		92	89	86	83	81	79	77	75	73	72	71	67	65	62	60
5 000 000		94	90	87	85	82	80	78	76	75	73	72	69	66	64	61
6 000 000		96	93	90	87	85	83	81	79	77	76	74	71	68	65	63
7 000 000		99	95	92	90	87	85	83	81	79	77	76	73	70	67	65
8 000 000		101	97	94	92	89	87	85	83	81	79	78	74	71	69	66
9 000 000		103	99	96	93	91	88	86	84	82	81	79	76	73	70	68
10 000 000		105	101	98	95	92	90	88	86	84	82	81	77	74	71	69
15 000 000		111	108	104	101	99	96	94	92	90	88	86	82	79	76	74
20 000 000		116	112	109	106	103	101	98	96	94	92	90	86	83	80	77
25 000 000		120	116	113	110	107	104	102	99	97	95	94	90	86	83	80
30 000 000		123	119	116	113	110	107	105	102	100	98	96	92	89	86	83
35 000 000		126	122	119	115	112	110	107	105	103	101	99	95	91	88	85
40 000 000		128	124	121	118	115	112	109	107	105	103	101	97	93	90	87
45 000 000		131	127	123	120	117	114	111	109	107	105	103	98	95	91	88
50 000 000		133	129	125	122	119	116	113	111	109	106	105	100	96	93	90
60 000 000		136	132	128	125	122	119	116	114	112	110	108	103	99	96	93
70 000 000		139	135	131	128	124	122	119	117	114	112	110	106	102	98	95
80 000 000		141	137	133	130	127	124	121	119	117	114	112	108	104	100	97
90 000 000		144	140	136	132	129	126	123	121	119	116	114	110	106	102	99
100 000 000		146	142	138	134	131	128	125	123	120	118	116	112	107	104	101

TABLE A.7A

REQUIRED STRUCTURAL NUMBER (SN_R)
 95% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

		Resilient Modulus (M_R), MPa														
ESAL _D		30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100	000	79	75	71	68	65	63	61	59	57	56	54	53	52	51	50
150	000	85	80	76	72	70	67	65	63	61	59	58	57	55	54	53
200	000	89	84	79	76	73	70	68	66	64	62	61	59	58	57	56
250	000	92	87	82	79	76	73	71	68	66	65	63	62	60	59	58
300	000	95	89	85	81	78	75	73	70	69	67	65	64	62	61	60
350	000	97	92	87	83	80	77	75	72	70	68	67	65	64	62	61
400	000	99	94	89	85	82	79	76	74	72	70	68	67	65	64	63
450	000	101	95	91	87	83	80	78	75	73	71	70	68	67	65	64
500	000	103	97	92	88	85	82	79	77	75	73	71	69	68	66	65
600	000	106	100	95	91	87	84	82	79	77	75	73	71	70	68	67
700	000	108	102	97	93	90	86	84	81	79	77	75	73	72	70	69
800	000	110	105	100	95	92	88	86	83	81	79	77	75	73	72	70
900	000	112	106	101	97	93	90	87	85	82	80	78	76	75	73	72
1 000	000	114	108	103	99	95	92	89	86	84	81	79	78	76	74	73
1 500	000	121	115	110	105	101	98	95	92	89	87	85	83	81	80	78
2 000	000	127	120	115	110	106	102	99	96	94	91	89	87	85	83	82
2 500	000	131	124	119	114	110	106	103	100	97	95	92	90	88	87	85
3 000	000	134	127	122	117	113	109	106	103	100	97	95	93	91	89	87
3 500	000	137	130	125	120	115	112	108	105	102	100	98	95	93	91	90
4 000	000	139	133	127	122	118	114	111	107	105	102	100	97	95	93	92
4 500	000	142	135	129	124	120	116	113	109	107	104	101	99	97	95	93
5 000	000	144	137	131	126	122	118	114	111	108	106	103	101	99	97	95
6 000	000	147	140	134	129	125	121	117	114	111	109	106	104	102	100	98
7 000	000	150	143	137	132	128	124	120	117	114	111	109	106	104	102	100
8 000	000	153	146	140	135	130	126	123	119	116	113	111	109	106	104	102
9 000	000	155	148	142	137	132	128	125	121	118	116	113	111	108	106	104
10 000	000	158	150	144	139	134	130	127	123	120	117	115	112	110	108	106
15 000	000	166	159	152	147	142	138	134	131	127	125	122	119	117	115	113
20 000	000	172	165	158	153	148	143	139	136	133	130	127	124	122	120	118
25 000	000	177	169	163	157	152	148	144	140	137	134	131	128	126	124	122
30 000	000	181	173	167	161	156	151	147	144	140	137	134	132	129	127	125
35 000	000	185	177	170	164	159	154	150	147	143	140	137	135	132	130	128
40 000	000	188	180	173	167	162	157	153	149	146	143	140	137	135	132	130
45 000	000	191	182	175	169	164	160	155	152	148	145	142	139	137	135	132
50 000	000	193	185	178	172	166	162	158	154	150	147	144	142	139	137	134
60 000	000	198	189	182	176	170	166	161	158	154	151	148	145	142	140	138
70 000	000	201	193	186	179	174	169	165	161	157	154	151	148	145	143	141
80 000	000	205	196	189	182	177	172	167	164	160	157	154	151	148	146	143
90 000	000	208	199	191	185	179	174	170	166	162	159	156	153	150	148	146
100 000	000	210	201	194	187	182	177	172	168	165	161	158	155	153	150	148

TABLE A.7B

REQUIRED STRUCTURAL NUMBER (SN_R)
 95% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 100 MPa TO 300 MPa

		Resilient Modulus (M_R), MPa														
ESAL _D		100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100 000		50	48	46	45	43	42	41	40	39	38	37	36	34	33	31
150 000		53	51	49	48	47	45	44	43	42	41	40	38	37	35	34
200 000		56	54	52	50	49	48	46	45	44	43	42	40	39	37	36
250 000		58	56	54	52	51	49	48	47	46	45	44	42	40	39	37
300 000		60	58	56	54	52	51	50	48	47	46	45	43	41	40	38
350 000		61	59	57	55	54	52	51	50	49	48	47	45	43	41	40
400 000		63	60	58	57	55	54	52	51	50	49	48	46	44	42	41
450 000		64	62	60	58	56	55	53	52	51	50	49	46	45	43	41
500 000		65	63	61	59	57	56	54	53	52	51	50	47	45	44	42
600 000		67	65	62	61	59	57	56	55	53	52	51	49	47	45	44
700 000		69	66	64	62	60	59	57	56	55	54	53	50	48	46	45
800 000		70	68	66	64	62	60	59	57	56	55	54	51	49	47	46
900 000		72	69	67	65	63	61	60	58	57	56	55	52	50	48	47
1 000 000		73	70	68	66	64	62	61	59	58	57	56	53	51	49	48
1 500 000		78	75	73	71	69	67	65	64	62	61	60	57	55	53	51
2 000 000		82	79	76	74	72	70	68	67	65	64	63	60	57	55	54
2 500 000		85	82	79	77	75	73	71	69	68	66	65	62	60	57	56
3 000 000		87	84	82	79	77	75	73	71	70	68	67	64	61	59	57
3 500 000		90	86	84	81	79	77	75	73	72	70	69	66	63	61	59
4 000 000		92	88	86	83	81	79	77	75	73	72	70	67	64	62	60
4 500 000		93	90	87	85	82	80	78	76	75	73	72	68	66	63	61
5 000 000		95	92	89	86	84	81	79	78	76	74	73	70	67	65	62
6 000 000		98	94	91	89	86	84	82	80	78	77	75	72	69	67	64
7 000 000		100	97	94	91	88	86	84	82	80	79	77	74	71	68	66
8 000 000		102	99	96	93	90	88	86	84	82	80	79	75	72	70	67
9 000 000		104	101	98	95	92	90	88	86	84	82	80	77	74	71	69
10 000 000		106	102	99	96	94	91	89	87	85	83	82	78	75	72	70
15 000 000		113	109	106	103	100	97	95	93	91	89	87	84	80	77	75
20 000 000		118	114	111	107	105	102	100	97	95	93	92	88	84	81	79
25 000 000		122	118	114	111	108	106	103	101	99	97	95	91	87	84	81
30 000 000		125	121	117	114	111	109	106	104	102	100	98	94	90	87	84
35 000 000		128	124	120	117	114	111	109	106	104	102	100	96	92	89	86
40 000 000		130	126	123	119	116	114	111	109	106	104	102	98	94	91	88
45 000 000		132	128	125	121	118	116	113	111	108	106	104	100	96	93	90
50 000 000		134	130	127	123	120	117	115	112	110	108	106	102	98	94	91
60 000 000		138	134	130	126	123	121	118	115	113	111	109	105	101	97	94
70 000 000		141	137	133	129	126	123	121	118	116	114	112	107	103	100	96
80 000 000		143	139	135	132	129	126	123	121	118	116	114	109	105	102	98
90 000 000		146	141	137	134	131	128	125	123	120	118	116	111	107	104	100
100 000 000		148	143	139	136	133	130	127	124	122	120	118	113	109	105	102

TABLE A.8A

REQUIRED STRUCTURAL NUMBER (SN_R)
 96% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

ESAL _D	Resilient Modulus (M_R), MPa														
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100 000	81	76	72	69	66	64	62	60	58	57	55	54	53	52	51
150 000	86	81	77	74	71	68	66	64	62	61	59	58	56	55	54
200 000	90	85	81	77	74	72	69	67	65	64	62	61	59	58	57
250 000	94	88	84	80	77	74	72	70	68	66	64	63	61	60	59
300 000	96	91	86	83	79	77	74	72	70	68	66	65	63	62	61
350 000	99	93	89	85	81	79	76	74	72	70	68	66	65	64	62
400 000	101	95	91	87	83	80	78	75	73	71	70	68	66	65	64
450 000	103	97	92	88	85	82	79	77	75	73	71	69	68	66	65
500 000	105	99	94	90	86	83	81	78	76	74	72	70	69	68	66
600 000	108	102	97	93	89	86	83	81	78	76	74	73	71	70	68
700 000	110	104	99	95	91	88	85	83	80	78	76	75	73	71	70
800 000	112	106	101	97	93	90	87	84	82	80	78	76	75	73	72
900 000	114	108	103	99	95	92	89	86	84	82	80	78	76	74	73
1 000 000	116	110	105	101	97	93	90	88	85	83	81	79	77	76	74
1 500 000	123	117	112	107	103	100	96	94	91	89	87	85	83	81	79
2 000 000	129	122	117	112	108	104	101	98	95	93	91	89	87	85	83
2 500 000	133	126	121	116	112	108	105	102	99	96	94	92	90	88	86
3 000 000	136	129	124	119	115	111	108	104	102	99	97	95	93	91	89
3 500 000	139	132	127	122	117	114	110	107	104	102	99	97	95	93	91
4 000 000	142	135	129	124	120	116	112	109	106	104	101	99	97	95	93
4 500 000	144	137	131	126	122	118	114	111	108	106	103	101	99	97	95
5 000 000	146	139	133	128	124	120	116	113	110	107	105	103	101	99	97
6 000 000	149	142	137	131	127	123	119	116	113	110	108	106	103	101	100
7 000 000	153	145	139	134	130	126	122	119	116	113	111	108	106	104	102
8 000 000	155	148	142	137	132	128	124	121	118	115	113	110	108	106	104
9 000 000	158	150	144	139	134	130	127	123	120	117	115	112	110	108	106
10 000 000	160	153	146	141	136	132	129	125	122	119	117	114	112	110	108
15 000 000	168	161	154	149	144	140	136	133	129	126	124	121	119	117	115
20 000 000	175	167	160	155	150	145	142	138	135	132	129	126	124	122	120
25 000 000	180	172	165	159	154	150	146	142	139	136	133	131	128	126	124
30 000 000	184	176	169	163	158	154	149	146	142	139	137	134	131	129	127
35 000 000	187	179	172	166	161	157	153	149	145	142	139	137	134	132	130
40 000 000	191	182	175	169	164	159	155	152	148	145	142	139	137	134	132
45 000 000	193	185	178	172	167	162	158	154	150	147	144	142	139	137	134
50 000 000	196	187	180	174	169	164	160	156	153	149	146	144	141	139	136
60 000 000	200	192	184	178	173	168	164	160	156	153	150	147	145	142	140
70 000 000	204	195	188	182	176	171	167	163	159	156	153	150	148	145	143
80 000 000	208	199	191	185	179	174	170	166	162	159	156	153	150	148	145
90 000 000	211	202	194	188	182	177	172	168	165	161	158	155	153	150	148
100 000 000	213	204	197	190	184	179	175	171	167	164	160	157	155	152	150

TABLE A.8B

REQUIRED STRUCTURAL NUMBER (SN_R)
 96% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 100 MPa TO 300 MPa

		Resilient Modulus (M_R), MPa														
ESAL _D		100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100	000	51	49	47	46	44	43	42	41	40	39	38	36	35	33	32
150	000	54	52	50	49	47	46	45	44	43	42	41	39	37	36	35
200	000	57	55	53	51	50	48	47	46	45	44	43	41	39	38	36
250	000	59	57	55	53	52	50	49	48	47	46	45	43	41	39	38
300	000	61	59	57	55	53	52	51	49	48	47	46	44	42	41	39
350	000	62	60	58	56	55	53	52	51	50	49	48	45	43	42	40
400	000	64	61	59	58	56	55	53	52	51	50	49	46	45	43	41
450	000	65	63	61	59	57	56	54	53	52	51	50	47	45	44	42
500	000	66	64	62	60	58	57	55	54	53	52	51	48	46	45	43
600	000	68	66	64	62	60	58	57	56	54	53	52	50	48	46	44
700	000	70	67	65	63	61	60	58	57	56	55	54	51	49	47	46
800	000	72	69	67	65	63	61	60	58	57	56	55	52	50	48	47
900	000	73	70	68	66	64	62	61	59	58	57	56	53	51	49	48
1 000	000	74	72	69	67	65	64	62	61	59	58	57	54	52	50	48
1 500	000	79	77	74	72	70	68	66	65	63	62	61	58	56	54	52
2 000	000	83	80	78	75	73	71	70	68	66	65	64	61	59	56	55
2 500	000	86	83	81	78	76	74	72	70	69	68	66	63	61	59	57
3 000	000	89	86	83	81	78	76	74	73	71	70	68	65	63	60	58
3 500	000	91	88	85	83	80	78	76	75	73	71	70	67	64	62	60
4 000	000	93	90	87	84	82	80	78	76	75	73	72	68	66	63	61
4 500	000	95	92	89	86	84	82	80	78	76	74	73	70	67	65	62
5 000	000	97	93	90	88	85	83	81	79	77	76	74	71	68	66	64
6 000	000	100	96	93	90	88	85	83	81	80	78	77	73	70	68	65
7 000	000	102	99	95	93	90	88	86	84	82	80	79	75	72	69	67
8 000	000	104	101	97	95	92	90	87	85	84	82	80	77	74	71	69
9 000	000	106	103	99	96	94	91	89	87	85	84	82	78	75	72	70
10 000	000	108	104	101	98	95	93	91	89	87	85	83	80	76	74	71
15 000	000	115	111	108	105	102	99	97	95	93	91	89	85	82	79	76
20 000	000	120	116	112	109	106	104	101	99	97	95	93	89	86	83	80
25 000	000	124	120	116	113	110	107	105	103	101	99	97	93	89	86	83
30 000	000	127	123	119	116	113	110	108	106	104	101	100	95	92	88	86
35 000	000	130	126	122	119	116	113	111	108	106	104	102	98	94	91	88
40 000	000	132	128	125	121	118	115	113	110	108	106	104	100	96	93	90
45 000	000	134	130	127	123	120	117	115	112	110	108	106	102	98	94	91
50 000	000	136	132	129	125	122	119	117	114	112	110	108	103	99	96	93
60 000	000	140	136	132	128	125	123	120	117	115	113	111	106	102	99	96
70 000	000	143	139	135	131	128	125	123	120	118	116	114	109	105	101	98
80 000	000	145	141	137	134	131	128	125	122	120	118	116	111	107	103	100
90 000	000	148	143	140	136	133	130	127	125	122	120	118	113	109	105	102
100 000	000	150	145	142	138	135	132	129	126	124	122	120	115	111	107	104

TABLE A.9A

REQUIRED STRUCTURAL NUMBER (SN_R)
 97% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

		Resilient Modulus (M_R), MPa														
ESAL _D		30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100	000	82	78	74	70	68	65	63	61	59	58	56	55	54	53	52
150	000	88	83	79	75	72	70	67	65	64	62	60	59	58	56	55
200	000	92	87	83	79	76	73	71	69	67	65	63	62	61	59	58
250	000	96	90	86	82	79	76	73	71	69	67	66	64	63	62	60
300	000	99	93	88	85	81	78	76	73	71	69	68	66	65	63	62
350	000	101	95	91	87	83	80	78	75	73	71	70	68	66	65	64
400	000	103	97	93	89	85	82	79	77	75	73	71	69	68	67	65
450	000	105	99	94	90	87	84	81	79	76	74	72	71	69	68	67
500	000	107	101	96	92	88	85	82	80	78	76	74	72	70	69	68
600	000	110	104	99	95	91	88	85	82	80	78	76	74	73	71	70
700	000	112	106	101	97	93	90	87	84	82	80	78	76	75	73	72
800	000	115	109	104	99	95	92	89	86	84	82	80	78	76	75	73
900	000	117	111	105	101	97	94	91	88	86	83	81	79	78	76	75
1 000	000	119	112	107	103	99	95	92	90	87	85	83	81	79	77	76
1 500	000	126	119	114	109	105	102	99	96	93	91	88	86	85	83	81
2 000	000	131	124	119	114	110	106	103	100	97	95	93	91	89	87	85
2 500	000	135	129	123	118	114	110	107	104	101	98	96	94	92	90	88
3 000	000	139	132	126	121	117	113	110	107	104	101	99	97	95	93	91
3 500	000	142	135	129	124	120	116	112	109	106	104	101	99	97	95	93
4 000	000	144	137	131	126	122	118	115	112	109	106	104	101	99	97	95
4 500	000	146	139	134	129	124	120	117	114	111	108	105	103	101	99	97
5 000	000	149	142	136	131	126	122	119	115	112	110	107	105	103	101	99
6 000	000	152	145	139	134	129	125	122	118	115	113	110	108	106	104	102
7 000	000	155	148	142	137	132	128	125	121	118	115	113	110	108	106	104
8 000	000	158	151	145	139	135	131	127	124	121	118	115	113	110	108	106
9 000	000	160	153	147	142	137	133	129	126	123	120	117	115	112	110	108
10 000	000	163	155	149	144	139	135	131	128	124	122	119	117	114	112	110
15 000	000	171	164	157	152	147	142	139	135	132	129	126	124	121	119	117
20 000	000	178	170	163	158	153	148	144	141	137	134	131	129	126	124	122
25 000	000	183	175	168	162	157	153	149	145	142	138	136	133	131	128	126
30 000	000	187	179	172	166	161	156	152	148	145	142	139	136	134	132	129
35 000	000	191	182	175	169	164	159	155	152	148	145	142	139	137	134	132
40 000	000	194	185	178	172	167	162	158	154	151	148	145	142	139	137	135
45 000	000	197	188	181	175	169	165	160	157	153	150	147	144	142	139	137
50 000	000	199	191	183	177	172	167	163	159	155	152	149	146	144	141	139
60 000	000	204	195	188	181	176	171	167	163	159	156	153	150	147	145	142
70 000	000	208	199	191	185	179	174	170	166	162	159	156	153	150	148	145
80 000	000	211	202	194	188	182	177	173	169	165	162	159	156	153	150	148
90 000	000	214	205	197	191	185	180	175	171	168	164	161	158	155	153	150
100 000	000	217	208	200	193	187	182	178	174	170	166	163	160	158	155	153

TABLE A.9B

REQUIRED STRUCTURAL NUMBER (SN_R)
 97% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 100 MPa TO 300 MPa

Resilient Modulus (M_R), MPa

ESAL _D	100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100 000	52	50	48	47	45	44	43	42	41	40	39	37	36	34	33
150 000	55	53	52	50	49	47	46	45	44	43	42	40	38	37	35
200 000	58	56	54	52	51	50	48	47	46	45	44	42	40	39	37
250 000	60	58	56	54	53	52	50	49	48	47	46	44	42	40	39
300 000	62	60	58	56	55	53	52	51	49	48	47	45	43	42	40
350 000	64	61	59	58	56	55	53	52	51	50	49	46	45	43	41
400 000	65	63	61	59	57	56	54	53	52	51	50	48	46	44	42
450 000	67	64	62	60	58	57	55	54	53	52	51	48	46	45	43
500 000	68	65	63	61	59	58	56	55	54	53	52	49	47	46	44
600 000	70	67	65	63	61	60	58	57	56	54	53	51	49	47	45
700 000	72	69	67	65	63	61	60	58	57	56	55	52	50	48	47
800 000	73	71	68	66	64	63	61	60	58	57	56	53	51	49	48
900 000	75	72	70	67	66	64	62	61	59	58	57	55	52	50	49
1 000 000	76	73	71	69	67	65	63	62	61	59	58	56	53	51	50
1 500 000	81	78	76	73	71	69	68	66	65	63	62	59	57	55	53
2 000 000	85	82	79	77	75	73	71	69	68	67	65	62	60	58	56
2 500 000	88	85	82	80	78	76	74	72	71	69	68	65	62	60	58
3 000 000	91	88	85	82	80	78	76	74	73	71	70	67	64	62	60
3 500 000	93	90	87	84	82	80	78	76	75	73	72	68	66	63	61
4 000 000	95	92	89	86	84	82	80	78	76	75	73	70	67	65	63
4 500 000	97	94	91	88	86	83	81	79	78	76	75	71	68	66	64
5 000 000	99	95	92	90	87	85	83	81	79	77	76	73	70	67	65
6 000 000	102	98	95	92	90	87	85	83	82	80	78	75	72	69	67
7 000 000	104	101	97	95	92	90	87	85	84	82	80	77	74	71	69
8 000 000	106	103	100	97	94	92	89	87	85	84	82	78	75	73	70
9 000 000	108	105	101	98	96	93	91	89	87	85	84	80	77	74	72
10 000 000	110	106	103	100	97	95	93	91	89	87	85	81	78	75	73
15 000 000	117	113	110	107	104	101	99	97	95	93	91	87	84	81	78
20 000 000	122	118	115	112	109	106	104	101	99	97	95	91	88	85	82
25 000 000	126	122	119	115	112	110	107	105	103	101	99	95	91	88	85
30 000 000	129	125	122	119	116	113	110	108	106	104	102	97	94	90	87
35 000 000	132	128	125	121	118	115	113	110	108	106	104	100	96	93	90
40 000 000	135	131	127	124	121	118	115	113	110	108	106	102	98	95	92
45 000 000	137	133	129	126	123	120	117	115	112	110	108	104	100	96	93
50 000 000	139	135	131	128	125	122	119	117	114	112	110	106	102	98	95
60 000 000	142	138	134	131	128	125	122	120	117	115	113	109	105	101	98
70 000 000	145	141	137	134	131	128	125	122	120	118	116	111	107	103	100
80 000 000	148	144	140	136	133	130	127	125	122	120	118	113	109	106	102
90 000 000	150	146	142	139	135	132	130	127	125	122	120	115	111	108	104
100 000 000	153	148	144	141	137	134	131	129	126	124	122	117	113	109	106

TABLE A.10A

REQUIRED STRUCTURAL NUMBER (SN_R)
 99% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa

		Resilient Modulus (M_R), MPa														
ESAL _D		30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100	000	89	84	80	76	73	70	68	66	64	62	61	60	58	57	56
150	000	95	90	85	81	78	75	73	71	69	67	65	64	62	61	60
200	000	99	94	89	85	82	79	76	74	72	70	68	67	65	64	63
250	000	103	97	93	89	85	82	79	77	75	73	71	69	68	66	65
300	000	106	100	95	91	88	84	82	79	77	75	73	71	70	68	67
350	000	108	103	98	93	90	87	84	81	79	77	75	73	72	70	69
400	000	111	105	100	96	92	89	86	83	81	79	77	75	73	72	70
450	000	113	107	102	97	94	90	87	85	82	80	78	76	75	73	72
500	000	115	108	103	99	95	92	89	86	84	82	80	78	76	75	73
600	000	118	112	106	102	98	95	92	89	86	84	82	80	78	77	75
700	000	120	114	109	104	100	97	94	91	89	86	84	82	80	79	77
800	000	123	116	111	107	103	99	96	93	91	88	86	84	82	81	79
900	000	125	118	113	109	105	101	98	95	92	90	88	86	84	82	81
1 000	000	127	120	115	110	106	103	99	97	94	91	89	87	85	84	82
1 500	000	134	128	122	117	113	109	106	103	100	98	95	93	91	89	88
2 000	000	140	133	127	122	118	114	111	108	105	102	100	98	96	94	92
2 500	000	144	137	131	126	122	118	115	111	108	106	103	101	99	97	95
3 000	000	148	141	135	130	125	121	118	114	112	109	106	104	102	100	98
3 500	000	151	144	138	132	128	124	120	117	114	111	109	107	104	102	100
4 000	000	153	146	140	135	130	126	123	119	116	114	111	109	107	105	103
4 500	000	156	148	142	137	133	129	125	122	119	116	113	111	109	106	105
5 000	000	158	151	144	139	135	130	127	123	120	118	115	113	110	108	106
6 000	000	162	154	148	143	138	134	130	127	124	121	118	116	113	111	109
7 000	000	165	157	151	146	141	137	133	130	126	124	121	118	116	114	112
8 000	000	168	160	154	148	144	139	135	132	129	126	123	121	118	116	114
9 000	000	170	163	156	151	146	142	138	134	131	128	125	123	120	118	116
10 000	000	173	165	158	153	148	144	140	136	133	130	127	125	122	120	118
15 000	000	182	174	167	161	156	152	148	144	141	138	135	132	130	127	125
20 000	000	188	180	173	167	162	157	153	150	146	143	140	137	135	133	130
25 000	000	194	185	178	172	167	162	158	154	151	147	144	142	139	137	135
30 000	000	198	189	182	176	171	166	162	158	154	151	148	145	143	140	138
35 000	000	202	193	186	180	174	169	165	161	157	154	151	148	146	143	141
40 000	000	205	196	189	183	177	172	168	164	160	157	154	151	148	146	144
45 000	000	208	199	192	185	180	175	170	166	163	159	156	153	151	148	146
50 000	000	211	202	194	188	182	177	173	169	165	162	158	156	153	150	148
60 000	000	215	206	199	192	186	181	177	173	169	165	162	159	157	154	152
70 000	000	220	210	202	196	190	185	180	176	172	169	165	162	160	157	155
80 000	000	223	214	206	199	193	188	183	179	175	172	168	165	163	160	157
90 000	000	226	217	209	202	196	191	186	182	178	174	171	168	165	162	160
100 000	000	229	220	211	205	198	193	188	184	180	177	173	170	167	165	162

TABLE A.10B

REQUIRED STRUCTURAL NUMBER (SN_R)
 99% RELIABILITY (%R)
 RESILIENT MODULUS (M_R) RANGE 100 MPa TO 300 MPa

		Resilient Modulus (M_R), MPa														
ESAL _D		100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100	000	56	54	52	50	49	48	46	45	44	43	42	40	39	37	36
150	000	60	58	56	54	52	51	50	49	48	46	46	43	42	40	39
200	000	63	60	58	57	55	54	52	51	50	49	48	46	44	42	41
250	000	65	63	61	59	57	56	54	53	52	51	50	47	45	44	42
300	000	67	65	63	61	59	57	56	55	53	52	51	49	47	45	44
350	000	69	66	64	62	60	59	57	56	55	54	53	50	48	46	45
400	000	70	68	66	64	62	60	59	57	56	55	54	51	49	47	46
450	000	72	69	67	65	63	61	60	59	57	56	55	52	50	48	47
500	000	73	70	68	66	64	63	61	60	58	57	56	53	51	49	48
600	000	75	73	70	68	66	64	63	61	60	59	58	55	53	51	49
700	000	77	74	72	70	68	66	64	63	62	60	59	57	54	52	50
800	000	79	76	74	71	69	68	66	64	63	62	60	58	55	53	52
900	000	81	78	75	73	71	69	67	66	64	63	62	59	57	55	53
1	000 000	82	79	76	74	72	70	68	67	65	64	63	60	58	55	54
1	500 000	88	85	82	79	77	75	73	71	70	68	67	64	62	59	57
2	000 000	92	89	86	83	81	79	77	75	73	72	70	67	65	62	60
2	500 000	95	92	89	86	84	82	80	78	76	75	73	70	67	65	63
3	000 000	98	95	92	89	86	84	82	80	78	77	75	72	69	67	64
3	500 000	100	97	94	91	89	86	84	82	80	79	77	74	71	68	66
4	000 000	103	99	96	93	91	88	86	84	82	81	79	76	73	70	68
4	500 000	105	101	98	95	92	90	88	86	84	82	81	77	74	71	69
5	000 000	106	103	99	97	94	91	89	87	85	84	82	78	75	73	70
6	000 000	109	106	102	99	97	94	92	90	88	86	85	81	78	75	72
7	000 000	112	108	105	102	99	97	94	92	90	88	87	83	80	77	74
8	000 000	114	110	107	104	101	99	96	94	92	90	89	85	81	78	76
9	000 000	116	112	109	106	103	101	98	96	94	92	90	86	83	80	77
10	000 000	118	114	111	108	105	102	100	98	96	94	92	88	84	81	79
15	000 000	125	121	118	114	112	109	106	104	102	100	98	94	90	87	84
20	000 000	130	126	123	119	116	114	111	109	107	105	103	98	95	91	88
25	000 000	135	130	127	123	120	118	115	113	110	108	106	102	98	95	92
30	000 000	138	134	130	127	124	121	118	116	113	111	109	105	101	97	94
35	000 000	141	137	133	130	126	124	121	118	116	114	112	107	103	100	97
40	000 000	144	139	135	132	129	126	123	121	118	116	114	110	105	102	99
45	000 000	146	142	138	134	131	128	125	123	120	118	116	112	107	104	101
50	000 000	148	144	140	136	133	130	127	125	122	120	118	113	109	106	102
60	000 000	152	147	143	140	136	133	131	128	126	123	121	116	112	109	105
70	000 000	155	150	146	143	139	136	133	131	128	126	124	119	115	111	108
80	000 000	157	153	149	145	142	139	136	133	131	129	126	121	117	113	110
90	000 000	160	155	151	148	144	141	138	136	133	131	129	124	119	115	112
100	000 000	162	157	153	150	146	143	140	138	135	133	130	125	121	117	114

APPENDIX B

FLEXIBLE PAVEMENT DESIGN QUALITY CONTROL PLAN

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B.1 QUALITY CONTROL PLAN

All flexible pavement designs will be reviewed independently 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)

Consists of all planned and systematic actions necessary to provide adequate confidence that a design, structure, system, or component will perform satisfactorily and conform with project requirements.

Quality assurance involves establishing project related policies, procedures, standards, training, guidelines, and systems necessary to produce quality.

Quality Control (QC)

This 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 (Document 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 as 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.
- Leveling and/or overbuild recommendations.
- A copy of the signed and sealed Nondestructive Testing Report from the State Materials Office.
- A composition report must be requested based on the milling recommendations for all projects involving milling greater than 5000 tons.

- Existing cross-slope from design survey and method of correction if required
 - The ESAL_p 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 insure 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 (concurrent with the transmittal to the State Pavement Design Engineer).

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 Pavement Design Department is friction course selection. It is highly recommended that the Pavement Design Engineer become thoroughly familiar with the Departments 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 insure 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 qualified Professional 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 maintained by State Project Number order 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 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 shipping plans to Tallahassee. 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.

**FLEXIBLE PAVEMENT DESIGN
QUALITY CONTROL CHECKLIST**

State Proj. No. _____ Federal Aid No. _____
FP ID No. _____ County _____

Satisfactory
Yes/No/NA

Flexible Pavement Design Review

- Pavement Design Summary Sheet. _____
- Project Location and Description _____
- Traffic Data and ESAL_D Calculations _____
- Resilient Modulus (M_R) _____
- 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 _____

Rehabilitation

- Field Evaluation of Project. _____
- Pavement Coring and Evaluation _____
- Distress Evaluation. _____
- Existing Cross-Slope and Correction method _____
- Milling Depth and Purpose. _____
- Overlay Structural Number (SN_0) Calculations . . . _____
- Leveling/Overbuild Recommendation. _____
- Composition 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. _____
Standard Indexes Properly Referenced _____
Project is Constructable 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	Concurrence By	Concurrence By
Res. Engineer	Dist. Des. Engineer	FHWA (If Needed)
Date _____	Date _____	Date _____

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APPENDIX C

FLEXIBLE PAVEMENT DESIGN ANALYSIS COMPUTER PROGRAM

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AASHTOWARE DARWin (Design, Analysis and Rehabilitation for Windows) is a computerized release of the pavement design models presented in the AASHTO Guide for the Design of pavement structures.

APPENDIX D

ESTIMATING DESIGN 18-KIP(80-KILONEWTON)
EQUIVALENT SINGLE AXLE LOADS (ESAL_D)

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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 tire, single axle, carrying 18,000lb 18-kip(80 000 Newtons, 80-kN) Equivalent Single Axle Load or ESAL_p) 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_p 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

	<u>Total Axle Load</u> <u>in KIP(kN)</u>	<u>Equivalent Damage</u> <u>in ESAL's</u>
Single Axle	62	0.40
	80	1.00
	98	2.17
Tandem Axle	133	0.70
	151	1.11
	169	1.69
	196	2.99

D.2 BASIC EQUATION

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

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

where:

$ESAL_D$ = Number of accumulated 18-kip(80-kilonewton) 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(80-kilonewtons) Equivalent Single Axle Loads. These factors will be periodically updated based on Weigh-In-Motion (WIM) data. $E_{18}(E_{80})$ values can be determined from Table D.3.

TABLE D.2

LANE FACTORS (L_F) FOR DIFFERENT TYPES OF FACILITIES

Number of Lanes 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:

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

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} (E_{80}) FOR DIFFERENT TYPES OF FACILITIES

	<u>Flexible Pavement</u>	<u>Rigid Pavement</u>
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 illustrate this process.

D.3.1 SAMPLE PROBLEM #1

The District Planning Engineer has provided the following information about a high volume, urban, arterial, four lane divided two way project 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 other facilities within the urban area become available in the year 2013 thus causing the traffic assignment (AADT) to drop and T_{24} to change.

$T_{24} = 12\%$
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.

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

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

For the years 2014 to 2025.

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

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

Calculating:

<u>Year</u>	<u>AADT</u>	<u>L_F</u>	<u>Annual ESAL*</u>	<u>Accumulated ESAL</u>
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 lane divided two way project 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.

$$\begin{aligned}T_{24} &= 10\% \\1990 \text{ Estimated AADT} &= 17,000 \\2006 \text{ Estimated AADT} &= 25,000\end{aligned}$$

DATA:

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

$$\begin{aligned}D_F &= 0.50 \text{ (for two way traffic)} \\E_{80} &= 0.96 \text{ (from Table D.3)}\end{aligned}$$

$$L_F = \text{Determined using the equation from Table D.2}$$

FIND:

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

SOLUTION:

Using the following equation:

For the years 1990 to 2003.

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

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

Calculating:

<u>Year</u>	<u>AADT</u>	<u>L_F</u>	<u>Annual ESAL*</u>	<u>Accumulated ESAL</u>
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	0.82	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 ESAL₀ = 4,000,000).

If the project was delayed one year, the new ESAL₀ would be:

$$4,329,400 - 244,300 = 4,085,100 \text{ ESALs}$$

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 (ie. resurfacing verses milling and resurfacing). This gives the designer flexibility in design and programming of this project.

APPENDIX E

**RELATIONSHIP BETWEEN RESILIENT MODULUS(M_r) AND
LIMEROCK BEARING RATIO(LBR)**

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(904) 372-5304

State Materials Office
Post Office Box 1029
Gainesville, Florida 32602

M E M O R A N D U M

DATE: February 2, 1993
TO: Mr. W. N. Lofroos, State Pavement Design Engineer
FROM: Robert Ho, *[Signature]* Soils Materials Engineer
COPIES TO: L. L. Smith
SUBJECT: Office of Inspector General Audit -
September 21, 1992

With reference to your memorandum dated November 16, 1992 requesting assistance to respond to the above audit concerning the soils area, I have spent some time researching our old files in this Office. As a result, I have compiled the following for your consideration and discussion.

1) Relationship between SSV & LBR

After considerable research into some over 30-year files, laboratory tests performed by FDOT (State Road Department) in the late fifties on embankment soil (silty clay), sand gravel subbase and limestone base material from the AASHO Road Test were located. These tests include:

a) Embankment Soil (silty clay)

Gradation (80% minus 200 material)
LL = 31% PI = 16% classified as A-6

b) Sand Gravel Subbase

Gradation (8.3% minus 200 material)
Non-plastic T-99 density 128 pcf @ 6.8%
Florida Bearing Value = 98 psi

c) Crushed Limestone Base

Gradation (9% minus 200 material)
Non-plastic
CBR = 170 T-180 density = 144.6 pcf @ 6.1%

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 FROM: Robert Ho
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From AASHO Road Test report No. 2 on Materials and Construction (dated July 1961), field CBR on embankment soil yielded an average value of about 3. From another AASHO Road Test Report entitled Cooperative Materials Testing Program by Shook & Fang (1961), the average of five state laboratory results gave a CBR value of about 6. Averaging the field and laboratory average values results in a CBR value of 4.5 or a LBR value of 6 (rounded up). Therefore the coordinates of one point on the SSV vs log(LBR) relationship are SSV = 3 and LBR = 6 for the embankment soil.

In the same Report No. 2 above, the average CBR of the crushed stone base was quoted as 108 (LBR = 135) with ranges between 52 and 160 (LBR 65 - 200). The lone CBR test by FDOT at the time yielded a value of 170 (LBR = 212). These two averaged to be 173. Because of the paucity of data and to be on the conservative side, it is assumed that a LBR of 200 is equivalent to a SSV of 10.

With the above two points, the SSV vs log (LBR) relationship was computed to be

$$SSV = 4.596 \log (LBR) - 0.576 \dots\dots(1)$$

2) Comparison with Other SSV vs/log(LBR) Relationships

Several relationships had been proposed over the years by various investigators. Mr. Gartner Jr. in the early sixties assumed the following:

<u>SSV</u>	<u>LBR</u>
3	7
10	100

This yields equation

$$SSV = 6.061 \log(LBR) - 2.121 \dots\dots\dots(2)$$

Zimpfer in 1973 recommended the following relationship based on information supplied by all five District Materials Engineers.

<u>SSV</u>	<u>LBR</u>
4	5
10	200

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FROM: Robert Ho
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This yields equation

$$SSV = 3.748 \log(LBR) + 1.377 \dots \dots \dots (3)$$

Based on statistical correlations of performance measurements on several satellite projects in Florida, Lytton and Michalak (1978) recommended the following equation for embankment soils

$$SSV = 5 \log(LBR) \dots \dots \dots (4)$$

The present FDOT Flexible Pavement design manual has the following relationship

$$SSV = 3.325 \log(LBR) + 0.672 \dots \dots \dots (5)$$

The five equations are plotted on figure 1 for comparison. Equation (5) gives the upper bound while equation (4) gives the lower bound for LBR values less than 10. For a SSV of 10, equation (5) yields a LBR value of 640 which is excessive and not supported by any test data. The remaining four equations yield LBR values of 100 or 200 for SSV of 10. CBR tests on crushed stone base from the AASHO Road Test resulted in an average LBR value of 173 when converted from CBR values. This makes SSV in equations (2) and (4) unconservative for the same LBR value. Of the remaining two equations (1) and (3), the two points at SSV = 3 or 10 for equation (1) were based on CBR tests on AASHO Road Test soil materials. The point at SSV = 3 for equation (3) was not correlated to CBR tests. Based on this discussion, equation (1) is recommended as the SSV vs log(LBR) relationship for use in flexible pavement design in Florida.

3). Soil Strength Test Frequency

The planning and selection of the number of field and laboratory tests depend on the variability of the subsoil strata along a project. A minimum number of three LBR tests per soil classification to a maximum number of ten for larger projects is recommended for the determination of design LBR of the subgrade soil. This maximum number of LBR tests is required to predict the mean LBR to within $\pm 2\%$ at a confidence level of 95%. Yoder and

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FROM: Robert Ho
February 2, 1993
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Witczak (1975) recommended that the 90th percentile value of the test results would give the optimum design. This means that 90% of the test results will be equal to or greater than the design LBR value which is then used to obtain SSV from SSV vs log(LBR) relationship.

4) LBR Test Method

The development of the LBR test method in Florida was clearly documented in a 1960 Florida State Road Department Research Report No. 22. The LBR test is basically a CBR test with the following modifications to suit Florida conditions.

- a) Samples are compacted to AASHTO T-180 density in 6-inch molds.
- b) Samples are soaked two days instead of four.
- c) Standard limerock value is taken as 800 psi instead of 1000 psi for the CBR test at 0.1 inch penetration of the piston.

FDOT's experience with the LBR test in the last 30 years has established it as a pavement design method comparable to the CBR test used by other states.

5) Modulus of Subgrade reaction, k

The modulus of subgrade reaction k, is generally determined in the field by 30-inch diameter plate load test. The ratio of the pressure on the plate, p to its deflection, y is assumed to be constant and is calculated for a pressure of 10 psi:

$$k = p/y$$

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FROM: Robert Ho
February 2, 1993
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It is very impracticable and time consuming to conduct 30-inch plate load test. For this reason, it is rarely performed for design of highway pavements. The modulus is not very sensitive in the analysis for rigid highway pavements. A k value of 200 pci for Florida sand subgrade is a reasonable design value. The Corps of Engineers gives typical values according to soil types. (Table 7.4, Yoder & Witczak). Note that for A-3 sands (SP), the table shows k value ranging from 200 to 300 pci. The k values for embankment soil from the AASHO Road test (from 30-inch plate) ranged from 100 pci in the Spring to 240 pci in the Summer.

I trust this is the information you require. Please call me if would like to discuss any of these items.

RH:jg

Attachments

12/92
HO

FIG 1

SSV VS LBR

46 5490

MINUTES
X 70 DIVISIONS
CYCLES

LBR

(5) DESIGN MANUAL

(1) HOZ

(3) ZIMMER

(2) GARTNER

(4) LYTTON

SSV

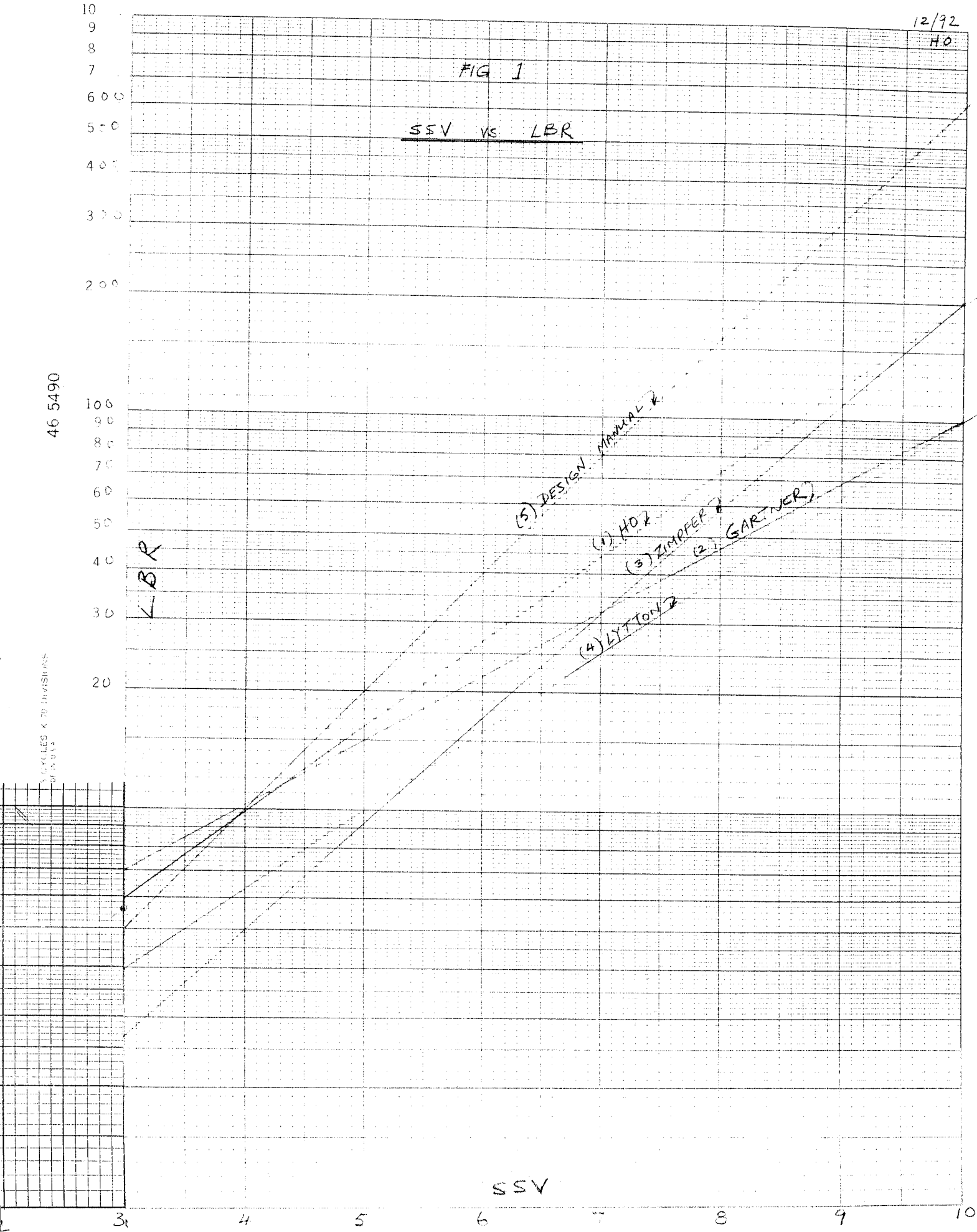


TABLE 7.4. Characteristics Pertinent to Road and Runway Foundation^a

Major Divisions (1)	Letter (2)	Name (4)	Value as Foundation When Not Subject to Frost Action (5)	Value as Base Directly under Wearing Surface (6)	Potential Frost Action (7)	Compressibility and Expansion (8)	Drainage Characteristics (9)	Compaction Equipment (10)	Unit Dry Weight (pcf) (11)	Field CBR (12)	Subgrade Modulus <i>k</i> (pci) (13)
Coarse-grained soils	GW	Gravel or sandy gravel, well graded	Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	125-140	60-80	300 or more
	GP	Gravel or sandy gravel, poorly graded	Good to excellent	Poor to fair	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	120-130	35-60	300 or more
	GU	Gravel or sandy gravel, uniformly graded	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	115-125	25-50	300 or more
	GM	Silty gravel or silty sandy gravel	Good to excellent	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	130-145	40-80	300 or more
	GC	Clayey gravel or clayey sandy gravel	Good	Poor	Slight to medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40	200-300
	SW	Sand or gravelly sand, well graded	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	110-130	20-40	200-300
	SP	Sand or gravelly sand, poorly graded	Fair to good	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	105-120	15-25	200-300
	SU	Sand or gravelly sand, uniformly graded	Fair to good	Not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	100-115	10-20	200-300
	SM	Silty sand or silty gravelly sand	Good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	120-135	20-40	200-300
	SC	Clayey sand or clayey gravelly sand	Fair to good	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	105-130	10-20	200-300
Fine-grained soils	ML	Silts, sandy silts, gravelly silts, or diatomaceous soils	Fair to poor	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	100-125	5-15	100-200
	CL	Lean clays, sandy clays, or gravelly clays	Fair to poor	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired equipment, sheepsfoot roller	100-125	5-15	100-200
	OL	Organic silts or lean organic clays	Poor	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired equipment, sheepsfoot roller	90-105	4-8	100-200
	MH	Micaceous clays or diatomaceous soils	Poor	Not suitable	Medium to very high	High	Fair to poor	Rubber-tired equipment, sheepsfoot roller	80-100	4-8	100-200
	CH	Fat clays	Poor to very poor	Not suitable	Medium	High	Practically impervious	Rubber-tired equipment, sheepsfoot roller	90-110	3-5	50-100
	OH	Fat organic clays	Poor to very poor	Not suitable	Medium	High	Practically impervious	Rubber-tired equipment, sheepsfoot roller	80-105	3-5	50-100
Peat and other fibrous organic soils	Pt	Peat, humus, and other	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical			

^a From Corps of Engineers.