FLEXIBLE PAVEMENT DESIGN MANUAL
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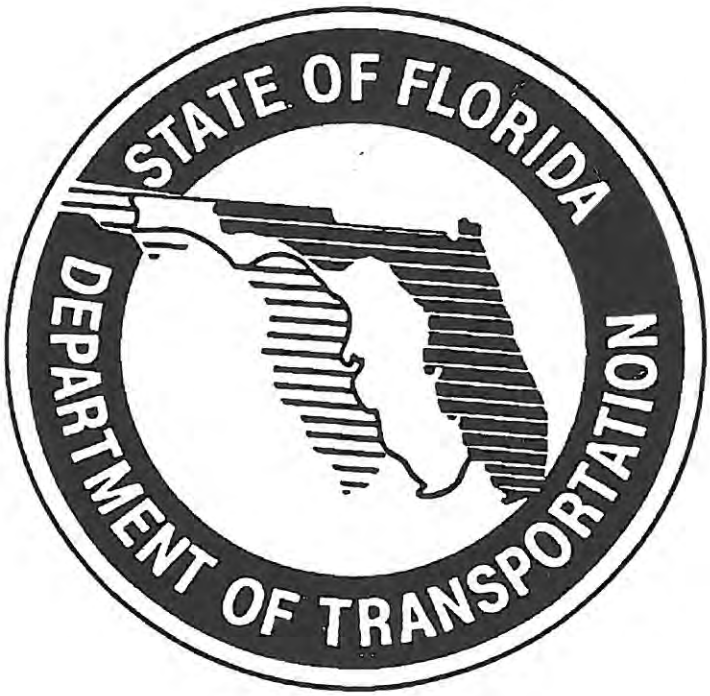

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Failure to fill out the Manual Registration Form will result in the manual holder not receiving the following revisions to this manual.

Revision Date	Comments
03/01/96	Changes to Reliability Levels, FC-2 details in medians, errors, and additional information. Revised pages include this page, Manual Registration Form, v, vii, viii, 1.4.0, 1.5.0, 2.7.0, 3.3.0, 4.3.0, 5.1.0, 5.2.0, 5.6.0, 5.7.0, 5.11.0, 5.13.0 thru 5.16.0, 6.17.0 thru 6.19.0, 6.22.0, A.3.0, A.4.0, A.14.0 thru A.34.0, B.3.0, and B.4.0. Added pages 4.5.0, 4.6.0, A.5.0 thru A.13.0. Deleted pages viii and ix.
12/02/96	Eliminating Friction Course Options, Phasing in FC-5 for FC-2, Phasing in of FC-6 for FC-3, Phasing in of Superpave for Type S, Section 280 ABC Pay Item, New Structural Coefficient for Bank Run Shell, New Equivalency Factors, Increased Allowable Design Periods For Non-Milling Project, errors, and additional information. Revised pages include this page, Manual Registration Form, i thru vii, 1.2.0 thru 1.6.0, 2.1.0 thru 2.8.0, 3.1.0, 3.3.0, 3.7.0, 4.1.0 thru 4.8.0, 5.1.0, 5.2.0, 5.6.0, 5.10.0, 5.12.0 thru 5.21.0, 5.25.0, 5.26.0, 5.28.0 thru 5.32.0, 6.9.0, 6.11.0, 6.16.0 thru 6.26.0, 7.4.0, 8.1.0, 8.2.0, A.3.0, A.4.0, B.3.0 thru B.5.0, B.8.0, D.3.0, D.6.0 thru D.12.0. Added 5.27.0, 7.5.0 thru 7.8.0.

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Approved:

Revised Date: Mar. 1, 1995
Pavement Management Office
Topic Number: 625-010-002-c
Effective: April 1, 1993

Bruce Dietrich, P.E.
State Pavement Design Engineer

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 Statues

1.3 GENERAL

Chapter 334 of the Florida Statues, 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 unless approved variances are obtained in accordance with procedures outlined in the Plans Preparation Manual-Metric, Topic No. 625-000-005.

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 principle 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-c) is published as a complete revision using metric values effective October 1, 1995.

1.5.2 REFERENCES

The design procedures incorporated in this document are based on the 1993 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. Some variables are still under study and revised values will be published from time to time.

1.5.4 APPENDICES

Included with this manual are 4 appendices:

Appendix	Contents
A	Design Tables.
B	Flexible Pavement Design Quality Control Plan.
C	Flexible Pavement Design Analysis Computer Program.
D	Estimating Design 80 kiloNewton Equivalent Single Axle Loads ($ESAL_D$).

1.6 DISTRIBUTION

This document is distributed 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 (904) 488-9220
FAX Number (904) 487-4099

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. 32
Tallahassee, Florida
32399-0450

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

Pavement Design Bulletins for the Flexible Pavement Design Manual are numbered and distributed to all official Manual Holders. Pavement Design Bulletins have a maximum life of 180 (one hundred eighty) days. Within this time period either an official manual revision will be distributed or the Design Bulletin will become void.

Statewide meetings of District Roadway Design Engineers will be held quarterly and a statewide meeting of designers maybe 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, State Materials Office, Federal Highway Administration, industry and other appropriate offices as necessary.

All revisions and updates will be coordinated with the Organization and Procedures Office prior to implementation to ensure conformance with and incorporation into the Departments standard operating system.

The final revisions and addenda will be distributed to registered holders of the manual. In order that revisions are forwarded as necessary, please complete the registration form under the front cover and return the sheet to the address indicated.

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 100 mm 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 3 (or FC-3) is a dense graded mix and is placed approximately 25 mm thick or 55 kg/m^2.
- Friction Course 2 (or FC-2) is an open graded mix and is placed approximately 15 mm thick.

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 S-I (or Type S-I) uses a 12.5 mm top size aggregate.
- Structural Course Type S-II (or Type S-II) uses a 19 mm top size aggregate.
- Structural Course Type S-III (or Type S-III) uses a 9.5 mm top size aggregate.

New Mixes

Several new mixes are being phased into use. Implementation guidelines for these mixes will be refined as experience is gained with the initial projects.

Superpave is a new structural mix that can be used in place of Type S. For designers, it has the same structural coefficient as Type S. However, it should be a more rut resistant mix due to improved mix design specifications that are tailored to the traffic level of the road being designed.

The District Pavement Design Engineer should coordinate closely with the District Materials Engineer on which projects to use Superpave on and to be aware that specification changes may be forthcoming as experience is gained with these mixes. Additional information on Superpave usage is contained in Chapter 5 of this manual.

FC-6 is being developed as a dense graded friction course that uses Superpave specifications and can be used in place of FC-3. It should be used where a Superpave structural course is used and the FC-3 Friction Course criteria applies.

FC-5 is an open graded friction course that is a slightly coarser and thicker (20 mm) mix and can be used in place of FC-2 on high speed multi lane roads. Further guidance on its use will be developed as experience is gained with some initial projects.

Old Mixes

Type I Asphaltic Concrete, Binder, and Sand Bituminous Road Mix (SBRM) may occasionally be encountered on rehabilitation projects but are not currently used by the Department.

Type II and Type III Asphaltic Concrete were also used in the past by the Department. These mixes may still be used as the structural course on low volume rural roads and residential streets.

Leveling and Overbuild Course

The Leveling and Overbuild Courses are nonstructural layers of asphalt concrete. The following Leveling and Overbuild Courses are used by the Department:

- Type S-III.
- Type II and Type III (Primarily for low volume roads).
- Sand Asphalt Hot Mix (SAHM) is used as a leveling course on low volume roads.
- Leveling is placed by a motor grader and is used to provide a level surface prior to placing the structural course.
- Overbuild is placed by a paving machine and is used to provide proper cross-slope and longitudinal profile.

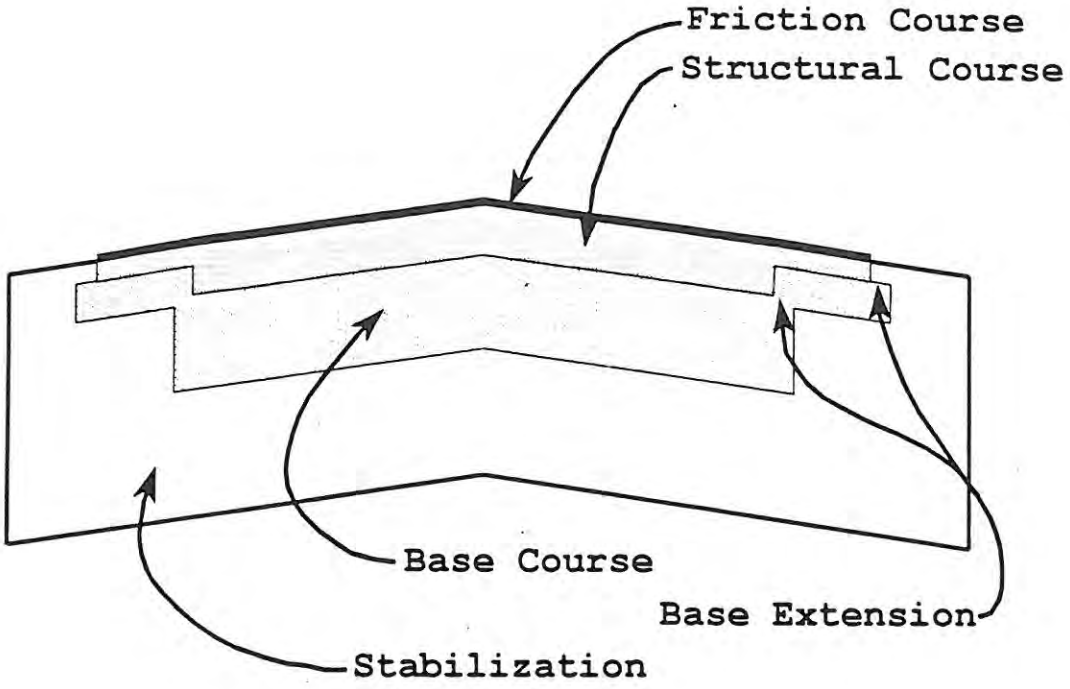
Base Course

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 Base Course (ABC) that together are bid as an Optional Base Material.

Subbase

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

Stabilized Subgrade

The stabilized subgrade is a structural layer that is 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 MODEL

The following definitions relate to the 1993 AASHTO model used for calculating pavement thickness.

2.2.1 VARIABLES

Accumulated 80 kiloNewton Equivalent Single Axle Loads (80 kN ESAL) or $ESAL_D$

The Accumulated 80 kiloNewton Equivalent Single Axle Loads (80 kN ESAL) is the traffic load information used for pavement thickness design. The accumulation of the damage caused by mixed truck traffic during a design period is referred to as the $ESAL_D$.

Resilient Modulus (M_R)

The Resilient Modulus (M_R) is a measurement of the strength 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 an 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 which 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 generally assumed.

Terminal Serviceability (P_T)

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

Change In Serviceability (ΔPSI)

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

2.2.3 UNKNOWNS

Required Structural Number (SN_R)

The Required Structural Number (SN_R) is an index number calculated from traffic load information and roadbed soil strength, 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 deteriorated asphalt pavement by using a rotating shaft (much like a cultivator) with teeth which removes the existing material to the desired depth.

Operational Type Projects

Operational Type Projects are projects that are relatively small such as turn lanes, radius improvements, culvert replacement, etc..

Overlay

Overlay is the placement of additional layers of asphalt 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.

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 1993 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 thicknesses or overlay thickness can be calculated. Figure 3.2 illustrates the processes.

Vehicle loads are expressed in 80 kiloNewton Equivalent Single Axle Loads (80 kN ESAL). This information is normally generated by the District Planning Office and is found in the Design Traffic, Procedure Topic No. 525-030-120-d using the Design Traffic Handbook. A simple procedure for estimating 80 kN ESAL's is given in Appendix D. The summation of the 80 kN ESAL's during the design period is referred to as $ESAL_D$.

FIGURE 3.1

AASHTO DESIGN EQUATION FOR FLEXIBLE PAVEMENT

$$\log_{10}(ESAL_D) =$$

$$Z_R * S_O + 9.36 * \log_{10}(SN_R + 1) - 0.20 +$$

$$\frac{\log_{10}\left(\frac{\Delta PSI}{4.2 - 1.5}\right)}{0.40 + \frac{1094}{(SN_R + 1)^{5.19}}} +$$

$$2.32 * \log_{10}(M_R) - 3.06$$

FIGURE 3.2

AASHTO DESIGN EQUATION INPUT FOR FLEXIBLE PAVEMENT

The unknown to be determined is:

SN_R = Structural Number Required.

The input includes the variables:

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

Z_R = Standard Normal Deviate.

M_R = Resilient Modulus (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:

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.

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 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 that may require the Pavement Design Engineer to specify an Asphalt Base Course. 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), Constructions 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 DOTNET document library.

3.4 QUALITY

The Quality Control of a pavement's design is the Districts 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.

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

FRICTION COURSE POLICY

4.1 FRICTION COURSE OPTIONS

There are two general types of friction courses currently in use by the Department, dense graded and open graded.

Friction Course 3 (or FC-3) is a dense graded mix which is placed 25 mm thick. FC-3 provides a smooth riding surface with adequate friction numbers for skid resistance.

The other friction course Friction Course 2 (or FC-2), consists of an open graded material.

FC-2 is placed approximately 15 mm thick and is controlled by specifications through a minimum spread rate. FC-2 provides a skid resistant surface. The open graded texture provides for the rapid removal of water from between the tire and the pavement to reduce the potential for hydroplanning at higher speeds.

A friction course will be placed on all roads with a design speed of 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 a day or less. On multi lane roadways with a design speed greater than 80 km/h, FC-2 will be used. On all other roadways FC-3 will 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 60 km/h Or Greater.

All Projects

Design Speed	Two Lane	Multi Lane
60 thru 80 km/h	Use FC-3	Use FC-3
Greater than 80 km/h	Use FC-3	FC-2

Low Volume Two Lane Roads

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

Note

FC-5 can be used in placed of FC-2, and, FC-6 can be used in place of FC-3.

4.2 FRICTION COURSE 3 (FC-3)

The following are some of the features of the use of FC-3:

- FC-3 is allowed directly on top of any structural course mix.

- FC-3 is considered part of the structural layer and may be considered as both a structural and friction course.

4.3 FRICTION COURSE 2 (FC-2)

The following are some of the limitations on the use of FC-2:

- FC-2 will not be placed directly on top of Type II or Type III asphalt. Structural Course Type S-I or S-III must be used directly under FC-2.

- FC-2 normally should not be overlaid due to its potential to allow water into the pavement system.

- When a project using FC-2 is not to be open to traffic for a substantial period of time (four months or longer), the friction course (FC-2) should be placed in a separate contract.

- On multi lane non-limited access facilities, FC-2 is not to be placed 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.

  The FC-2 will cover turn lanes and terminate at the edge of the lane or at the edge of the shoulder pavement (if provided).

  The details provided show limits of friction course that minimize hand work but provide for skid resistance in high speed heavily traveled areas for FC-2.

4.4 ADDITIONAL POLICY ITEMS

The following additional policy items will apply:

- Ground tire rubber is to be used in all friction courses for department projects. For all non-department projects on the state highway system (ie. permits, minor intersections by city and county governments, etc.) ground tire rubber in the friction course is also required.

  For projects with less than 350 tons of FC-3, the specifications will allow the contractor to substitute other modifiers for ground tire rubber. The designer should use the ground tire rubber pay item for all FC-3 projects.

- 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 0.3 m beyond the edge of the travel lane, onto the paved shoulder.

FIGURE 4.1

ILLUSTRATION SHOWING LIMITS OF FRICTION COURSE FC-2 AT INTERMEDIATE MEDIAN CROSSOVER

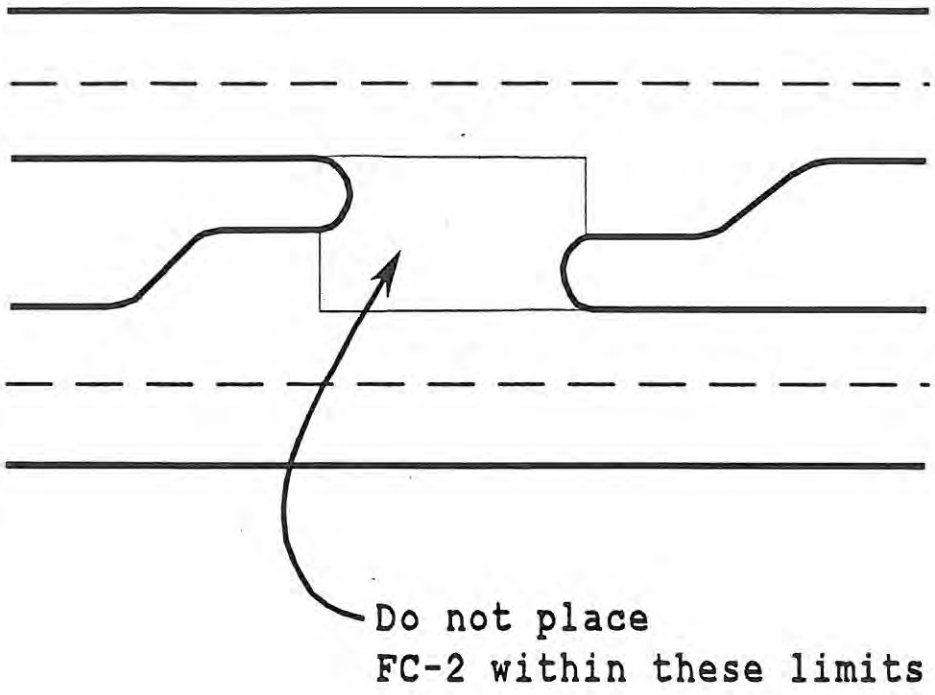


FIGURE 4.2

ILLUSTRATION SHOWING LIMITS OF FRICTION COURSE FC-2 AT INTERMEDIATE MEDIAN CROSSOVER

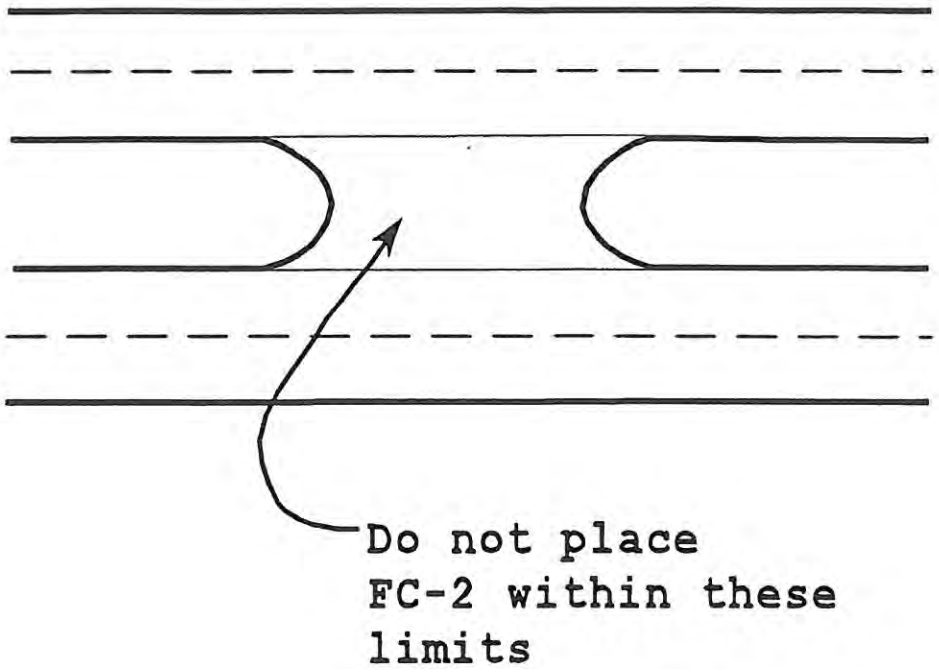
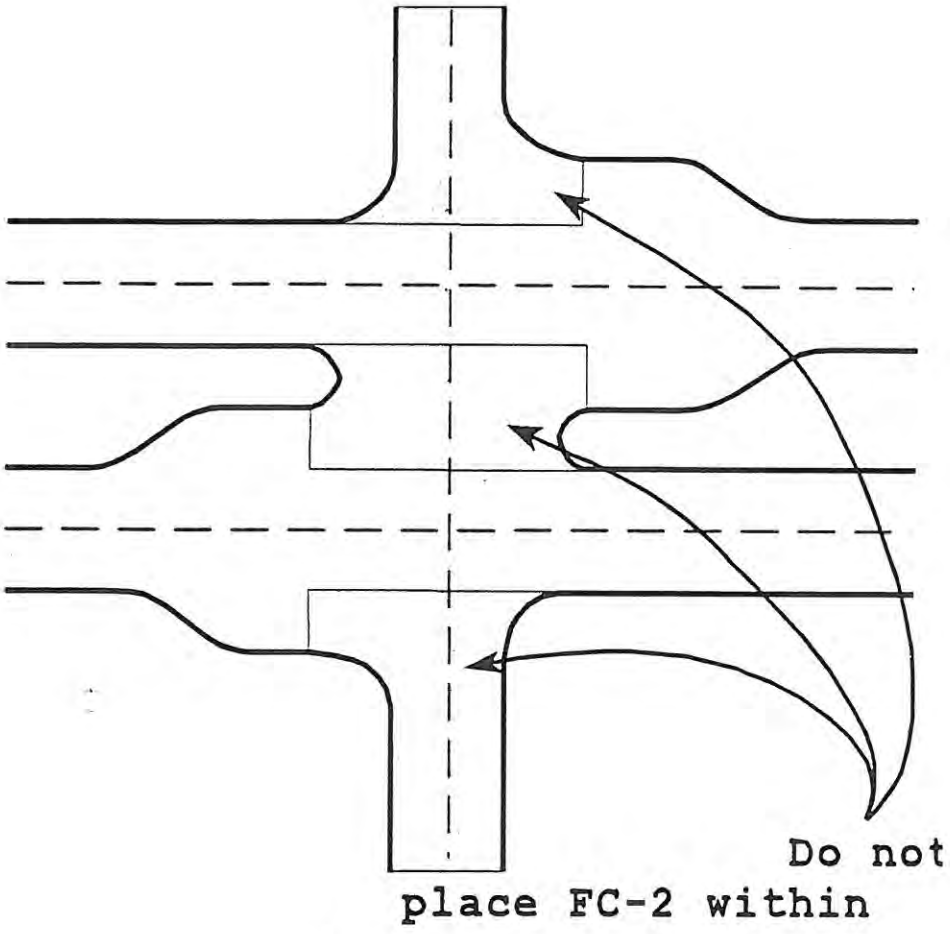


FIGURE 4.3

ILLUSTRATION SHOWING LIMITS OF FRICTION COURSE FC-2 AT MEDIAN AREAS OF LOW VOLUME INTERSECTION



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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 1993 AASHTO Procedure.

For short pavement sections (approximately 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 1993 AASHTO DESIGN GUIDE

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

- The 80 kilonewton Equivalent Single Axle Loads (80 kN ESAL's) are obtained from the District Planning Office. This process can be found in the Design Traffic Forecasting Handbook Procedure Topic No. 525-030-120-d using the Design Traffic Handbook. Appendix D provides a simple procedure for calculating the accumulated 80 kN ESAL's or $ESAL_D$ for the appropriate design period.

- The Resilient Modulus (M_R) used to characterize the strength of the roadbed soil is obtained from the State Materials Office, or from the District Materials Office using 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 a computer program which is available through the State Pavement Management Office.

Each design table uses a different Reliability (%R) and relates Design 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 = 98 MPa (from the State Materials Office)
Use 100 MPa

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

Design 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 10 mm of structural course, which allows a variation of plus or minus 0.08 of the structural number. If desired, an interpolated SN_R value can be used. The solution is:

SN_R = 3.53 (from Table 5.3)

5.2.2 RESILIENT MODULUS (M_R) FROM LBR

If a Design LBR 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 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;

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

SOLUTION:

Sample No. 14 is considered an outlier by inspection and should be eliminated.

This results in 13 good samples.

13 x 90% = 11.7 (Use 12)

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

Use LBR = 22.

CONCLUSION:

90% meet or exceed the Design LBR = 22.

The Pavement Design Engineer can now convert the Design LBR Value to a Resilient Modulus (M_R) using Table 5.1.

Therefore:

M_R = 54 MPa

FIGURE 5.1

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

***** FOR INTERIM USE ONLY *****
***** TO BE REVISED AS MORE INFORMATION *****
***** BECOMES AVAILABLE *****

Converting the Limerock Bearing Ratio (LBR) to Resilient Modulus (M_R) is based on the following equations:

Equation #1 - Limerock Bearing Ratio (LBR) to Soil Support Value (SSV). This equation is based on a recent analysis by the State Materials Office of AASHO Road Test materials test results. It differs from the previously used graphical relationship, both in slope of the line and there is no safety factor imbedded in the equation.

$$SSV = 4.596 * LOG_{10}(LBR) - 0.576$$

Equation #2 - The following equation relates Soil Support Value (SSV) to Resilient Modulus (M_R) in pounds per square inch. This equation is from Appendix FF of the 1993 AASHTO Design Guide.

$$M_R = 10^{\left(\frac{SSV + 18.72}{6.24}\right)}$$

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).

$$M_R(MPa) = \left(6.894 * 10^{-3} \frac{MPa}{psi}\right) * M_R(psi)$$

TABLE 5.1

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

***** FOR INTERIM USE ONLY *****
***** TO BE REVISED AS MORE INFORMATION *****
***** BECOMES AVAILABLE *****

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

Limerock Bearing Ratio (LBR)	Resilient Modulus (M_R) in MPa
10	30
12	35
14	39
16	43
18	47
20	51
22	54
24	58
26	61
28	65
30	68
32	72
34	75
36	78
38	81
40	84

TABLE 5.2

RELIABILITY (%R) FOR DIFFERENT ROADWAY FACILITIES

Facility	New	Rehabilitation
Limited Access	80 - 95	95 - 99
Urban Arterials	80 - 90	90 - 97
Rural Arterials	75 - 90	90 - 95
Collectors	75 - 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, 1993.

For traffic volume ranges, refer to Chapter 2, Roadway Design Criteria, of the Plans Preparation Manual - Metric, Topic No. 625-000-005.

TABLE 5.3

REQUIRED STRUCTURAL NUMBER (SN_R)
90% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 30 MPa TO 100 MPa
(FROM APPENDIX A, TABLE A.4A)

	Resilient Modulus (M_R), MPa														
$ESAL_D$	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100 000	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	1.87	1.83
150 000	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	2.01	1.97
200 000	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	2.11	2.06
250 000	3.41	3.22	3.05	2.92	2.80	2.70	2.61	2.53	2.46	2.40	2.34	2.28	2.23	2.19	2.14
300 000	3.51	3.31	3.15	3.01	2.89	2.79	2.69	2.61	2.54	2.47	2.41	2.35	2.30	2.26	2.21
350 000	3.60	3.40	3.23	3.09	2.96	2.86	2.76	2.68	2.60	2.54	2.47	2.42	2.36	2.31	2.27
400 000	3.68	3.47	3.30	3.16	3.03	2.92	2.83	2.74	2.66	2.59	2.53	2.47	2.42	2.37	2.32
450 000	3.75	3.54	3.37	3.22	3.09	2.98	2.88	2.79	2.71	2.64	2.58	2.52	2.46	2.41	2.37
500 000	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	2.46	2.41
600 000	3.93	3.71	3.53	3.37	3.24	3.12	3.02	2.93	2.85	2.77	2.70	2.64	2.59	2.53	2.48
700 000	4.03	3.80	3.62	3.46	3.32	3.21	3.10	3.01	2.92	2.85	2.78	2.71	2.65	2.60	2.55
800 000	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	2.66	2.60
900 000	4.19	3.96	3.77	3.61	3.47	3.34	3.23	3.13	3.05	2.97	2.89	2.83	2.77	2.71	2.66
1 000 000	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	2.76	2.70
1 500 000	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	2.95	2.89
2 000 000	4.72	4.48	4.27	4.10	3.94	3.80	3.68	3.57	3.48	3.39	3.30	3.23	3.16	3.09	3.03
2 500 000	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	3.21	3.15
3 000 000	5.01	4.76	4.54	4.36	4.20	4.06	3.93	3.82	3.71	3.62	3.53	3.45	3.38	3.31	3.24
3 500 000	5.12	4.86	4.65	4.46	4.30	4.16	4.03	3.91	3.80	3.71	3.62	3.54	3.46	3.39	3.33
4 000 000	5.22	4.96	4.74	4.55	4.39	4.24	4.11	3.99	3.89	3.79	3.70	3.62	3.54	3.47	3.40
4 500 000	5.30	5.04	4.82	4.63	4.47	4.32	4.19	4.07	3.96	3.86	3.77	3.68	3.61	3.53	3.47
5 000 000	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	3.60	3.53
6 000 000	5.52	5.25	5.03	4.83	4.66	4.51	4.38	4.26	4.14	4.04	3.95	3.86	3.78	3.70	3.63
7 000 000	5.64	5.37	5.14	4.94	4.77	4.62	4.48	4.36	4.24	4.14	4.04	3.96	3.87	3.80	3.72
8 000 000	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	3.88	3.80
9 000 000	5.83	5.55	5.32	5.12	4.95	4.79	4.65	4.52	4.41	4.30	4.21	4.11	4.03	3.95	3.88
10 000 000	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	4.02	3.94
15 000 000	6.24	5.95	5.71	5.50	5.32	5.16	5.01	4.88	4.76	4.65	4.54	4.45	4.36	4.28	4.20
20 000 000	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	4.47	4.39
25 000 000	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	4.62	4.54
30 000 000	6.82	6.51	6.26	6.04	5.84	5.67	5.52	5.38	5.25	5.14	5.03	4.93	4.83	4.75	4.66
35 000 000	6.95	6.64	6.38	6.16	5.97	5.79	5.64	5.50	5.37	5.25	5.14	5.04	4.94	4.85	4.77
40 000 000	7.07	6.76	6.49	6.27	6.07	5.90	5.74	5.60	5.47	5.35	5.24	5.13	5.04	4.95	4.87
45 000 000	7.18	6.86	6.59	6.37	6.17	5.99	5.83	5.69	5.56	5.43	5.32	5.22	5.12	5.03	4.95
50 000 000	7.27	6.95	6.68	6.45	6.25	6.07	5.91	5.77	5.64	5.51	5.40	5.30	5.20	5.11	5.02
60 000 000	7.44	7.11	6.84	6.61	6.40	6.22	6.06	5.91	5.78	5.65	5.54	5.43	5.33	5.24	5.16
70 000 000	7.58	7.25	6.98	6.74	6.53	6.35	6.18	6.03	5.90	5.77	5.66	5.55	5.45	5.36	5.27
80 000 000	7.71	7.37	7.09	6.85	6.64	6.46	6.29	6.14	6.00	5.88	5.76	5.65	5.55	5.45	5.37
90 000 000	7.82	7.48	7.20	6.96	6.74	6.56	6.39	6.23	6.10	5.97	5.85	5.74	5.64	5.54	5.45
100 000 000	7.92	7.58	7.29	7.05	6.83	6.64	6.47	6.32	6.18	6.05	5.93	5.82	5.72	5.62	5.53

5.3 LAYER THICKNESS CALCULATIONS FOR NEW CONSTRUCTION

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

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

where:

SN_C = The total calculated strength of the pavement layers.

a_1 = Layer coefficient of the 1st layer.
D_1 = Layer thickness in 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 N^{th} layer.
D_N = Layer thickness in millimeters of the N^{th} 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.

The Calculated Structural Number (SN_C) of the pavement layers should be within 0.08 of the Required Structural Number (SN_R), unless minimum thicknesses from Table 5.5 requires a higher SN_R. Always design to the nearest 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, 200 mm of Limerock (LBR 100) is equivalent to 120 mm of Asphalt Base Course (ABC)-3 in total structural number. Either Optional Base could be constructed to provide a base Structural Number of approximately 1.40.

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

Granular subbases are used only 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

Group	Layer Type	Layer Coef. per mm	Spec. Sect.
Friction Courses	FC-2	0.000	337
	FC-5	0.000	337
	FC-3	0.009	337
	FC-6	0.009	n/a
Structural Courses	Type S (S-I, S-II, S-III)	0.017	331
	Superpave Type SP (SP-9.5, SP-12.5, SP-19.0)	0.017	334
	Type II	0.008	332
	Type III	0.012	333
Base Courses (General use)	Limerock (LBR 100)	0.007	200
	Cemented Coquina (LBR 100)	0.007	250
	Shell Rock (LBR 100)	0.007	250
	Bank Run Shell (LBR 100)	0.007	250
	Graded Aggregate (LBR 100)	0.006	204
	ABC-3 (4500 N Marshall)	0.012	280
Base Courses (Limited use)	Limerock Stab. (LBR 70)	0.005	230
	Shell Stab. (LBR 70)	0.004	260
	Sand Clay (LBR 75)	0.005	240
	ABC-1 (2300 N Marshall)	0.008	280
	ABC-2 (3400 N Marshall)	0.010	280
	SAHM (1500 N Marshall)	0.006	335
	Soil Cement (3.5 MPa)	0.008	270
	Soil Cement (2.0 MPa)	0.006	270
Subbase	Stabilized Subbase	0.004	160-3
	Stabilized Subbase	0.003	180*
Stabilization	Type B Stab. (LBR 40)	0.003	160-2
	Type B Stab. (LBR 30)	0.002	160-2
	Type C Stab.	0.002	160-2
Subgrade	Cement Treated (2.0 MPa)	0.005	170
	Lime Treated	0.003	165

Notes

* Special Provisions

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 300 mm stabilized subgrade is to be constructed.

Type Of Road	80 kN ESAL's 20 year period	Minimum Structural Course	Minimum Base Group
I	Limited Access	100 mm	9
A	Greater than 3 500 000	80 mm	9
B	300 000 to 3 500 000	50 mm	6
C	Less than 300 000	40 mm	3
D	Residential Streets, Parking Areas, Shoulder Pavement, Bike Paths	30 mm	1

60 mm
40 mm

TABLE 5.6

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

Base Group & Structural Range	Limerock LBR 100 (.007)	Cemented Coquina LBR 100 (.007)	Shell Rock LBR 100 (.007)	Bank Run Shell LBR 100 (.007)	Graded Aggregate Base LBR 100 (.006)	ABC-3 (Min. Marshall Stability 4500 N) (.012)	ABC-3 And 100 mm Granular Base, LBR 100 * (.012) And (.006)	RAP Base (NA)
701 1 (.65-.75)	101 100 .70	201 100 .70	301 100 .70	461 100 .70	501 100 .60	△ 601 100 1.20		□ 691 130
702 2 (.80-.90)	102 120 .84	202 120 .84	302 120 .84	462 120 .84	502 140 .84	△ 602 100 1.20		
703 3 (.95-1.05)	103 140 .98	203 140 .98	303 140 .98	463 140 .98	503 160 .96	△ 603 100 1.20		
704 4 (1.05-1.15)	104 160 1.12	204 160 1.12	304 160 1.12	464 160 1.12	504 190 1.14	604 100 1.20		
705 5 (1.25-1.35)	105 180 1.26	205 180 1.26	305 180 1.26	465 180 1.26	505 210 1.26	605 110 1.32		
706 6 (1.35-1.45)	106 200 1.40	206 200 1.40	306 200 1.40	466 200 1.40	506 230 1.38	606 120 1.44		
707 7 (1.50-1.60)	107 220 1.54	207 220 1.54	307 220 1.54	467 220 1.54	507 260 1.56	607 130 1.56		
708 8 (1.65-1.75)	108 240 1.68	208 240 1.68	308 240 1.68	468 240 1.68	508 280 1.68	608 140 1.68		
709 9 (1.75-1.85)	109 260 1.82	209 260 1.82	309 260 1.82	469 260 1.82	509 300 1.80	609 150 1.80	629 100 1.80	
710 10 (1.90-2.00)	110 280 1.96	210 280 1.96	310 280 1.96	470 280 1.96	⌀ 510 330 1.98	610 160 1.92	630 110 1.92	
711 11 (2.05-2.15)	111 300 2.10	211 300 2.10	311 300 2.10	471 300 2.10	⌀ 511 350 2.10	611 180 2.16	631 130 2.16	
712 12 (2.20-2.30)	112 320 2.24	212 320 2.24	312 320 2.24	472 320 2.24		612 190 2.28	632 140 2.28	
713 13 (2.35-2.45)	⌀ 113 340 2.38	⌀ 213 340 2.38	⌀ 313 340 2.38	⌀ 473 340 2.38		613 200 2.40	633 150 2.40	
714 14 (2.45-2.55)	⌀ 114 360 2.52	⌀ 214 360 2.52	⌀ 314 360 2.52	⌀ 474 360 2.52		614 210 2.52	634 160 2.52	
715 15 (2.60-2.70)						615 220 2.64	635 170 2.64	

TABLE 5.7

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

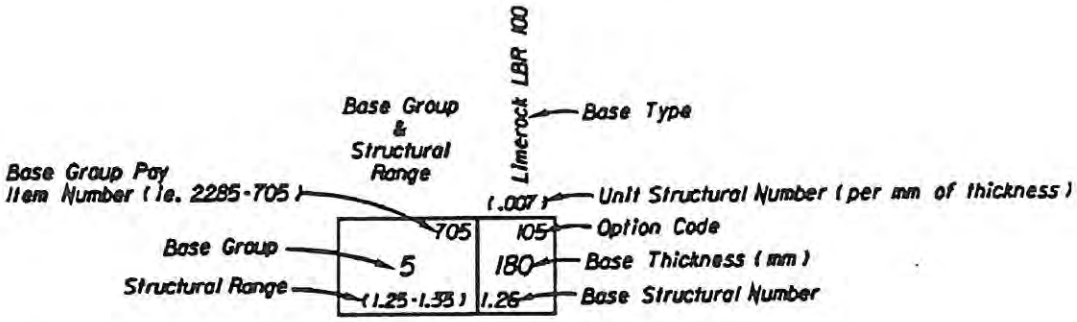
Base Group & Structural Range	Limerock Stabilized LBR 70 (.005)	Shell LBR 70 (.005)	Shell Stabilized LBR 70 (.004)	Sand-Clay LBR 75 (.005)	ABC-11 Min. Marshall Stability 2300 N (.008)	ABC-2 (Min. Marshall Stability 3400 N (.010)	SAHM (Min. Marshall Stability 1500 N (.006)	Soil Cement (2.0 MPa) (Plant Mixed) (.006)	Soil Cement (2.0 MPa) (Road Mixed) (.006)	Soil Cement (3.5 MPa) (Plant Mixed) (.008)
701 1 (.65-.75)	121 130 .65	441 130 .65	451 180 .71	701 130 .65	Δ 631 100 .80	Δ 641 100 1.00	651 100 .60	801 100 .60	821 130 .78	Δ 811 100 .80
702 2 (.80-.90)	122 160 .80	442 160 .80	452 210 .83	702 160 .80	632 100 .80	Δ 642 100 1.00	652 140 .84	802 140 .84	822 140 .84	812 100 .80
703 3 (.95-1.05)	123 200 1.00	443 200 1.00	453 240 .94	703 200 1.00	633 120 .96	643 100 1.00	653 160 .96	803 160 .96	823 160 .96	813 120 .96
703 4 (1.05-1.15)	124 220 1.10	444 220 1.10	454 270 1.06	704 220 1.10	634 140 1.12	644 110 1.10		804 190 1.14	824 190 1.14	814 140 1.12
705 5 (1.25-1.35)	125 250 1.26	445 250 1.26	455 300 1.18	705 250 1.26	635 160 1.28	645 130 1.30		805 210 1.26	825 210 1.26	815 160 1.28
706 6 (1.35-1.45)	126 280 1.40	446 280 1.40		706 280 1.40				806 230 1.38		816 180 1.44
707 7 (1.50-1.60)	127 310 1.55	447 310 1.55		707 310 1.55				807 260 1.56		817 190 1.52
708 8 (1.65-1.75)								808 280 1.68		818 210 1.68
709 9 (1.75-1.85)										
710 10 (1.90-2.00)										
711 11 (2.05-2.15)										
712 12 (2.20-2.30)										
713 13 (2.35-2.45)										
714 14 (2.45-2.55)										
715 15 (2.60-2.70)										

Not Recommended For 20 Year Design Accumulated 80 kN 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.

TABLE 5.8

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



LEGEND

* For granular base, the construction of both the subbase and ABC-3 will be paid for under the contract unit price for Optional Base. Granular bases include Limerock, Cemented Coquina, Shell Rock, Bank Run Shell, and Graded Aggregate Base at LBR 100. The base thickness shown is ABC-3. All subbase thickness are 100 mm. The base structural number shown is for the composite base.

† To be used for widening only, 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. On any type of widening project, the base options to be used must be specified by the designer and shown in the plans.

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

4. The designer may require the use of a single base option, for instance ABC-3 in a high water condition. This will still be bid as Optional Base.

5. The contractor will indicate the basis for his bid by designating the three digit option code on the bid blank.

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 for use in the design tables in Appendix A.

M_R = 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 90 km/h for the rural section and with a design speed of 80 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:

$$SN_R = 4.04$$

SOLUTION:

With the SN_R known, the pavement layer thicknesses can be calculated. Remember that SN_C should be within 0.08 of SN_R.

For the first part of this sample problem using a design speed of 90 km/h, we need to use FC-2 according to Table 4.1.

FC-2 has no structural value and is always shown as 15 mm thick. Also assume that a 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:

$$SN_R = SN_C$$

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

$$4.04 = (0 \times 15 \text{ mm}) + (a_2 \times D_2) + (a_3 \times D_3) + (0.003 \times 300 \text{ mm})$$

$$4.04 = 0 + (a_2 \times D_2) + (a_3 \times D_3) + 0.90$$

The next step is to calculate the value that the base ($a_3 \times D_3$) and structural course ($a_2 \times D_2$) must contribute. To determine this, subtract the stabilized subgrade ($a_4 \times D_4 = 0.90$) from SN_R.

$$4.04 - 0.90 = (a_2 \times D_2) + (a_3 \times D_3)$$

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

$$3.14 = (a_2 \times D_2) + (a_3 \times D_3)$$

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 thicknesses (in 10 mm increments) and provides a band of recommended base and structural course thicknesses. Note that the structural value provided by the stabilization and friction course is not included in the Combined Structural Number shown in the table.

From Table 5.9, it can be seen that the following combinations would prove satisfactory:

Base Group 8 with 90 mm of structural course with a SN = 3.21

Base Group 9 with 80 mm of structural course with a SN = 3.18

Base Group 10 with 70 mm of structural course with a SN = 3.15

Because this is a Type A Road ($ESAL_D$ is greater than 3 500 000), the minimum thicknesses must be checked. From Table 5.5, the minimum allowed for a Type A Road is Optional Base Group 9 with 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 thicknesses is required to provide practical designs that stay within the empirical limits of the AASHO Road Test.

If a stabilized subgrade is not constructed due to unusual conditions, the base and structural course would have to provide a structural number of 4.04.

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

$$4.04 = (0 \times 15 \text{ mm}) + (a_2 \times D_2) + (a_3 \times D_3)$$

$$4.04 = (a_2 \times D_2) + (a_3 \times D_3)$$

From Table 5.9 an Optional Base Group 10 and 120 mm of structural course would give a structural number of 4.00. 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 80 km/h, we need to use FC-3 according to Table 4.1. FC-3 has a structural value of 0.22 and is always shown as 25 mm thick. Also assume that a 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:

$$SN_R = SN_C$$

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

$$4.04 = (0.009 \times 25 \text{ mm}) + (a_2 \times D_2) + (a_3 \times D_3) + (0.003 \times 300 \text{ mm})$$

$$4.04 = 0.22 + (a_2 \times D_2) + (a_3 \times D_3) + 0.90$$

The next step is to calculate the value that the base ($a_3 \times D_3$) and structural course ($a_2 \times D_2$) must contribute. To determine this, subtract the friction course ($a_1 \times D_1 = 0.22$) and the stabilized subgrade ($a_4 \times D_4 = 0.90$) from SN_R.

$$4.04 - 0.90 - 0.22 = (a_2 \times D_2) + (a_3 \times D_3)$$

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

$$2.92 = (a_2 \times D_2) + (a_3 \times D_3)$$

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. From Table 5.9, it can be seen that the following combinations would prove satisfactory:

Base Group 7 with 80 mm of Structural Course with a SN = 2.90

Base Group 9 with 70 mm of Structural Course with a SN = 3.01

Base Group 8 with 80 mm of Structural Course with a SN = 3.04

Because this is a Type A Road ($ESAL_D$ is greater than 3 500 000), the minimum thicknesses must be checked. From Table 5.5, the minimum allowed for a Type A Road is Optional Base Group 9 with 80 mm of Structural Course. One of the combinations selected meets these minimum requirements. Because the FC-3 can be considered a structural layer at 25 mm thick, all of these would be acceptable. For this problem, use Optional Base Group 9 with 70 mm of Structural Course with a SN = 3.01.

If a stabilized subgrade is not constructed due to unusual conditions, the base and structural course would have to provide a structural number of 3.82.

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

$$4.04 = (0.009 \times 25 \text{ mm}) + (a_2 \times D_2) + (a_3 \times D_3)$$

$$4.04 - 0.22 = (a_2 \times D_2) + (a_3 \times D_3)$$

$$3.82 = (a_2 \times D_2) + (a_3 \times D_3)$$

From Table 5.9 an Optional Base Group 10 and 110 mm of structural course would give a structural number of 3.83. This would be satisfactory as the base and structural course exceed the required minimums.

CONCLUSION:

The following comparisons are provided:

For The Design Speed Of 90 km/h

Layer/Material	Coefficient		Asphalt Thickness	SN_c
Friction Course, FC-2	0.000	x	15 mm	= 0.00
Structural Course	0.017	x	80 mm	= 1.36
Optional Base Group 9				= 1.82
Type B Stabilization (LBR 40), 300 mm				= 0.90
			95 mm	4.08

For The Design Speed Of 80 km/h

Layer/Material	Coefficient		Asphalt Thickness	SN_c
Friction Course, FC-3	0.009	x	25 mm	= 0.22
Structural Course	0.017	x	70 mm	= 1.19
Optional Base Group 9				= 1.82
Type B Stabilization (LBR 40), 300 mm				= 0.90
			95 mm	4.13

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

NEW CONSTRUCTION

OPTIONAL BASE GROUP 9 AND 80 mm TYPE S STRUCTURAL COURSE AND 15 mm FRICTION COURSE FC-2 (RUBBER)

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

NEW CONSTRUCTION

OPTIONAL BASE GROUP 9 AND 70 mm TYPE S STRUCTURAL COURSE AND 25 mm FRICTION COURSE FC-3 (RUBBER)

If Superpave Asphaltic Concrete is used for this project, the description would include a traffic level as determined by Table 5.10.

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

NEW CONSTRUCTION

OPTIONAL BASE GROUP 9 AND 80 mm SUPERPAVE STRUCTURAL COURSE (TRAFFIC LEVEL 4) AND 15 mm FRICTION COURSE FC-2 (RUBBER)

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

NEW CONSTRUCTION

OPTIONAL BASE GROUP 9 AND 70 mm SUPERPAVE STRUCTURAL COURSE (TRAFFIC LEVEL 4) AND 25 mm FRICTION COURSE FC-6 (TRAFFIC LEVEL 4)(RUBBER)

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

TABLE 5.9

COMBINED STRUCTURAL NUMBER

Structural Course (mm)

Base Group	30	40	50	60	70	80
1	1.23	1.40				
2	1.35	1.52	1.69			
3	1.49	1.66	1.83			
4	1.63	1.80	1.97			
5		1.94	2.11	2.28		
6		2.08	2.25	2.42	2.59	
7		2.22	2.39	2.56	2.73	2.90
8				2.70	2.87	3.04
9					3.01	3.18
10					3.15	3.32

Structural Course (mm)

Base Group	90	100	110	120	130	140	150
8	3.21	3.38					
9	3.35	3.52	3.69				
10	3.49	3.66	3.83	4.00			
11	3.63	3.80	3.97	4.14	4.31		
12		3.94	4.11	4.28	4.45	4.62	
13			4.25	4.42	4.59	4.76	4.93
14				4.56	4.73	4.90	5.07
15					4.85	5.02	5.19

Stabilization And Friction Course Structural Numbers Not Included.

5.5 DISCUSSION

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 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 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 necessary to support curb and gutter.

The District Construction Engineer should be consulted prior to deciding to eliminate stabilized subgrade. 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 (This concept is under development. Information will be provided in the future).

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 (ABC) 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.
- The bottom of the base is likely to be subjected to exposure to ground water.
- The configuration of base widening and subgrade soil conditions are such that accumulation of rainfall in excavated areas will significantly delay construction.

Construction of unbound granular base course may be required to be done in two layers. Where the plans call for narrow base widening, the construction operation may extend beyond a single day. To avoid the cost of using warning devices during night time, consider that the second course of base material may be temporarily placed in accordance with the detail for Optional Shoulder Treatment as shown in Standard Index 600, General Information For Traffic Control Through Work Zones, Dropoffs In Work Zones.

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.

When Asphalt Base Course only is justified on all or only a portion of a project, it should be bid using Specification Section 280 pay items for ABC-3 only. Use of the tonnage item is encouraged to expedite construction by eliminating the need for coring. Use of the 280 pay item can be phased in to minimize impacts on production.

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. An economic analysis should be made to determine whether a thicker asphalt structural course with the maximum allowed thickness of unbound granular base material will be the least expensive choice. The structural number difference between Optional Base Groups is approximately equal to 10 mm of structural course.

If it is determined during construction that substitution of additional base course for stabilized subgrade is desirable, a new pavement design in accordance with this manual must be performed by a Professional Engineer. The revised pavement design shall be signed and sealed by the Professional Engineer.

5.5.3 STRUCTURAL COURSE

Individual asphalt layers are not shown on the Plans Typical Section, only the overall asphalt thickness as prescribed in the Plans Preparation Manual. Standard Index 513, Layer Thickness for Asphaltic Concrete Structural Courses has been prepared for use by construction personnel and the contractors (see Table 5.11 with notes provided in Table 5.12 and 5.13).

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 as per Standard Index 513 to determine if any problems will be encountered. 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.

Superpave mixes need to be 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 1.5 m or less, where the final layer is paved in one pass with the roadway.

As a practical matter, Superpave mixes for crossroads and other small sections with quantities less than 1000 metric tons can be designed with the same mix (ie. Traffic Level) as the mainline. This should be discussed on a project by project basis with the District Bituminous Engineer.

The following Superpave mixes are substituted by specification for Type S Structural Courses when using Standard Index 513:

Type SP Superpave Mix	Type S Mix
SP-9.5	S-III
SP-12.5	S-I
SP-19.0	S-II

TABLE 5.10

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

DESIGN $ESAL_D$ RANGE			TRAFFIC LEVEL
Less than		300 000	1
300 000	to	1 000 000	2
1 000 000	to	3 000 000	3
3 000 000	to	10 000 000	4
10 000 000	to	30 000 000	5
30 000 000	to	100 000 000	6
Greater than		100 000 000	7

TABLE 5.11

LAYER THICKNESS FOR ASPHALT CONCRETE STRUCTURAL COURSES (STANDARD INDEX 513)

LAYER THICKNESS FOR ASPHALTIC CONCRETE STRUCTURAL COURSES
(Layers Are Listed In Sequence Of Construction)

COURSE THICKNESS (mm)	LAYER THICKNESS (mm)																											
	Type S-II With Type S-I Top Layer				Type S-II With Type S-III Top Layer				Type S-I				Type S-I With Type S-III Top Layer				Type S-III				Type S-II 1st Layer With Type S-I Intermediate And Top Layer				Type S-II 1st Layer With Type S-I Intermediate Layer(s) And Type S-III Top Layer			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
30									30								30											
40									40																			
50													30	20														
60									30	30			30 40	30 20														
70					50	20			40	30			40 50	30 20														
80	50	30			50 60	30 20			40 50	40 30			50	30														
90	50 60	40 30			60 70	30 20			30 50	30 40	30		40 30	30 30	20 30													
100	50 60 70	50 40 30			70	30																			50	30	20	
110	60 70	50 40																			50	30	30		50 50 60	30 40 30	30 20 20	
120	70	50			50	50	20														50 60	40 30	30 30		★	★	★	
130	50	50	30		50 60	50 50	30 20														★	★	★		★	★	★	
140	50 60	50 50	40 30		60 60	50 60	30 20														★	★	★		★	★	★	
150	★	★	★		60 70 70	60 50 60	30 30 20														50 60	40 30	30 30	30 30	★	★	★	★

★ Denotes multiple combinations available. Combination selected must be consistent with the General Notes shown below and the total number of layers shown by ★'s used.

TABLE 5.12

GENERAL NOTES ON LAYER THICKNESS FOR ASPHALT CONCRETE STRUCTURAL COURSES (STANDARD INDEX 513)

1. For combinations not shown in the table, the thickness must be consistent with the following thickness ranges:

Type Mix	Minimum	Maximum
S-I	30 mm	50 mm
S-II	50 mm	70 mm
S-III	20 mm	30 mm

Multiple Layers shall be used when possible. Layer combinations shall be as approved by the Engineer.

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

S-I May not be used in the 1st layer of courses over 90 mm thick nor in the 1st layer of courses over 70 mm thick on limited access facilities.

S-II May not be used in the final (top) structural layer.

S-III Limited to the final (top) structural layer, only layer only.

Above restrictions do not apply to overbuild and leveling.

3. When quantities are bid as tonnage items, equivalent tonnage layer thickness will be constructed (ie: 22 kg = 1 square meter for each 10 mm thickness).

4. The designer should consider stage construction for course thickness greater than 110 mm.

5. When construction includes the paving of adjacent shoulders (≤ 1.5 m wide), the layer thickness for the upper pavement layer and shoulder shall be the same and paved in a single pass. See Design Notes.

6. A minimum of 40 to 50 mm initial lift is required over an Asphalt Rubber Membrane Interlayer (ARMI).

TABLE 5.13

DESIGN NOTES ON LAYER THICKNESS FOR ASPHALT CONCRETE STRUCTURAL COURSES (STANDARD INDEX 513)

It is desirable that the top layer of the roadway overlay and the adjacent shoulder course be constructed in one pass. The following apply when a 1.5 m or less shoulder meeting the minimum standards is to be constructed in conjunction with an overlay of the roadway:

Roadway Course Thickness (mm)	Shoulder Structural Course Thickness(mm)	
30	with any FC	30
40	with any FC	40
50	with FC-2	50*
50	with FC-3	20
60 and up	with FC-2	30
60 and up	with FC-3	20

* The increased thickness is required to insure a 30 mm thickness of structural course on the shoulder under the open graded friction course and to meet the requirements of the Min./Max. criteria of this index.

5.5.4 DESIGN REDUCTION

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 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.

5.5.5 STAGE CONSTRUCTION

Stage construction can be considered at any time. A pavement design that produces a structural course greater than 120 mm should be carefully evaluated because of the thick asphalt layer.

The normal procedure for developing a stage construction project would include calculating a full twenty year pavement design to establish the theoretical base and structural course thickness.

The structural course could be reduced by 30 to 50 mm and the project programmed for the second stage 5 to 7 years after the initial construction and prior to any substantial distress showing. Under these conditions only the FC-2 would need to be milled prior to the second stage provided the initial design assumptions are still valid.

If substantial distress has occurred, a deeper milling depth may be needed, and reduced layer coefficients used.

A stage construction project must be evaluated from both the engineering and economic viewpoint. A problem that may occur on second stage construction may be an unneeded overlay on the paved shoulders. These factors should be considered during the alternatives analysis.

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 1993 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 1993 AASHTO GUIDE

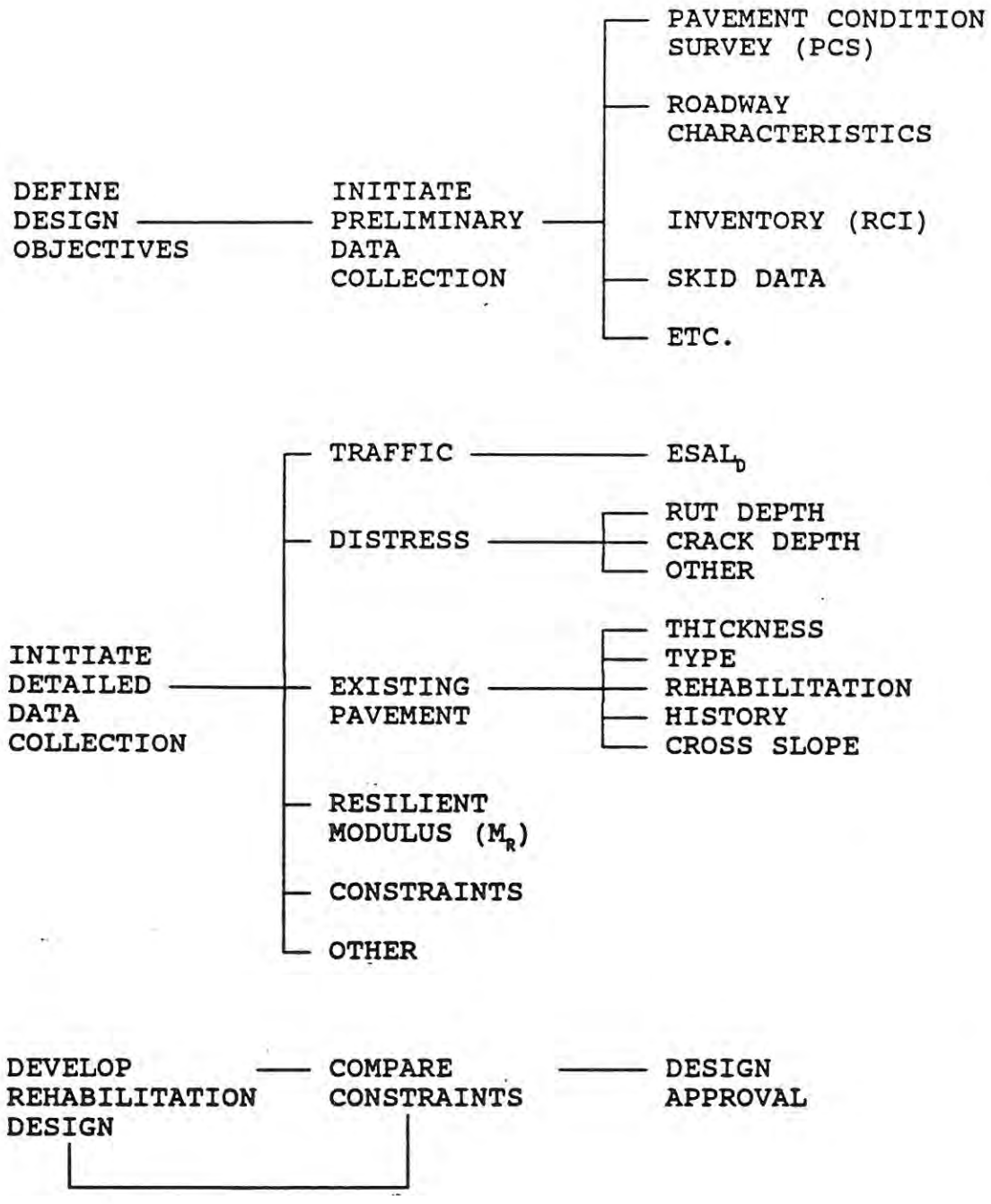
The procedure for calculating the Required Structural Number (SN_R) is the same method detailed under New Construction (Refer to Section 5.2).

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 Dynaflect, and LBR. 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 DYNAFLECT

Nondestructive Dynaflect testing is the preferred method for obtaining the Resilient Modulus(M_R) for a rehabilitation project. The deflection values obtained from the #4 sensor best represents the deflection of the embankment or natural subgrade material. It has several distinct advantages. More test data can be collected and used to statistically calculate the Resilient Modulus(M_R). A plot of the actual Dynaflect 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 Dynaflect 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

EXAMPLE DYNAFLECT DEFLECTION PLOT

State Of Florida
Department Of Transportation
State Materials Office
Dynaflect Deflections - All Sensors

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.

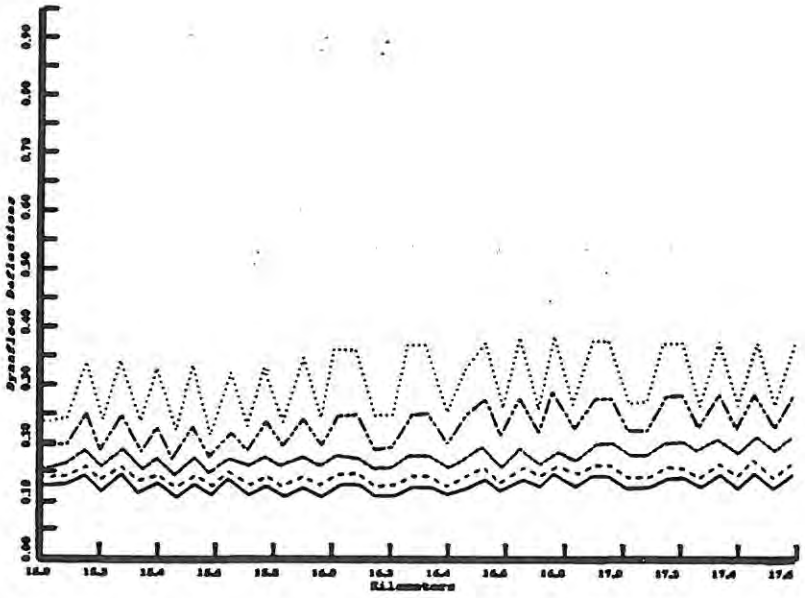


FIGURE 6.3

EXAMPLE DYNAFLECT DEFLECTION PLOT

State Of Florida
Department Of Transportation
State Materials Office
Dynaflect Deflections - All Sensors

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.

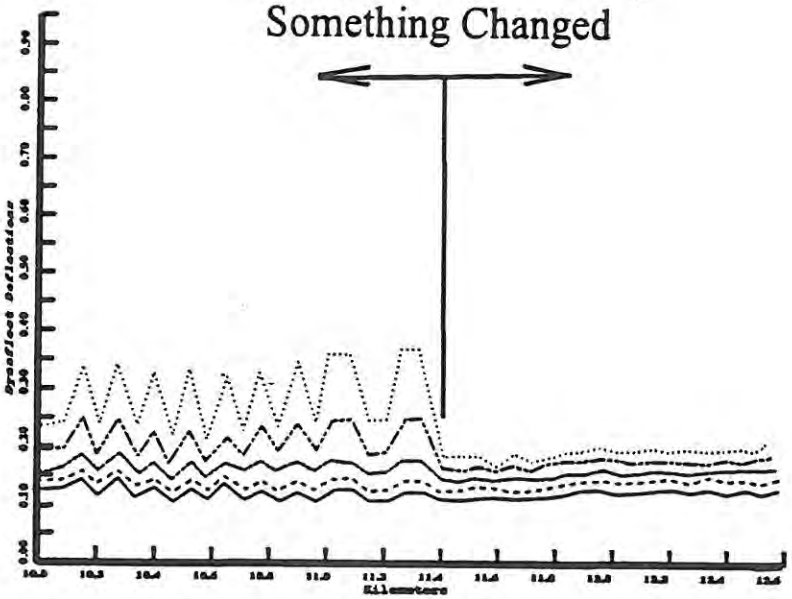


FIGURE 6.4

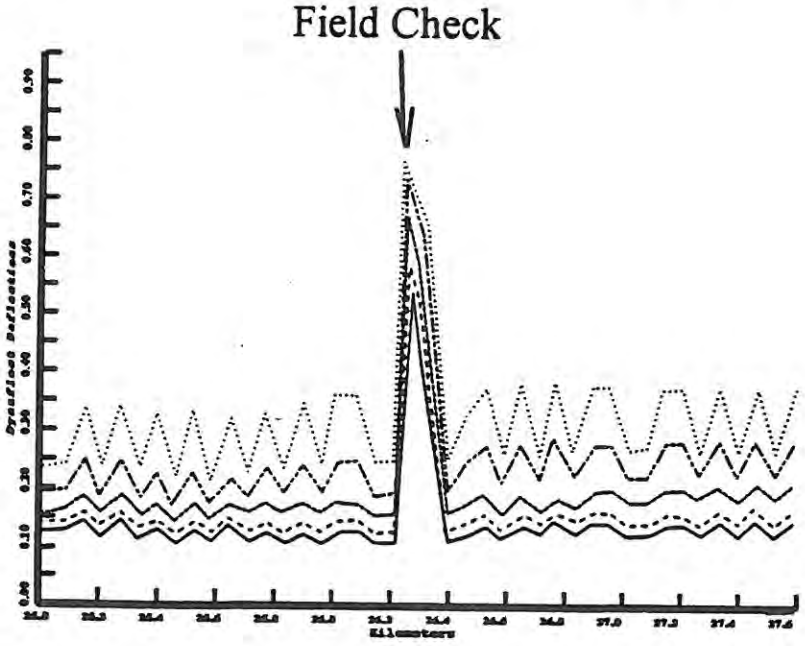
EXAMPLE DYNAFLECT DEFLECTION PLOT

State Of Florida
Department Of Transportation
State Materials Office
Dynaflect Deflections - All Sensors

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 nondestructive testing using the Dynaflect 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.

Dynaflect requests should <u>not</u> be made for:

- Two lane roadway projects less than 1.5 km long.
- Three lane or more roadway projects less than 0.8 km long.

Example projects where Dynaflect should not be required include bridge culvert replacement, intersection improvement, etc. This is a normal policy for the Resilient Modulus (M_R) program and should not be confused with testing that is done for special design purposes, pavement failure investigations or in some extreme cases where Resilient Modulus (M_R) cannot be obtained by other means (LBR, 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. Even though projects may slip, the data will still be valid.

Resilient Modulus (M_R) once obtained, should not change substantially over time. Projects will need to accomplish specific objectives including:

- Repair existing distress (rutting, cracking, etc.).
- Prevent future distress.
- Strengthen the pavement to carry future traffic.

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. 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 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, if available.

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. Pavement Coring and Evaluation Guidelines (Procedure #576-030-005-b) can be obtained from the State Materials Office or through the DOTNET document library. 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, friction course, leveling, overbuild, 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:

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

where:

SN_E = The 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. Layer coefficients for rock base, subbase, and stabilizing are not reduced. Use the values shown in Table 5.4.

TABLE 6.1

REDUCED STRUCTURAL COEFFICIENTS OF ASPHALT MATERIALS PER MILLIMETER

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 (Rutting > 9 mm)

Pavement Condition should be based on the surface appearance of the pavement (cracking, patching, rutting, etc.) and may be supplemented by additional testing.

Layer	Original Design	Pavement Condition		
		Good	Fair	Poor
FC-1 or FC-4	0.008	0.007	0.006	0.005
FC-3	0.009	0.008	0.007	0.006
Type S or SP	0.017	0.013	0.010	0.006
Type I	0.015	0.012	0.009	0.006
Type II	0.008	0.007	0.006	0.005
Type III	0.012	0.010	0.008	0.006
Binder	0.012	0.010	0.008	0.006
ABC-1 (2300 N)	0.008	0.007	0.006	0.004
ABC-2 (3400 N)	0.010	0.008	0.006	0.005
ABC-3 (4500 N)	0.012	0.010	0.008	0.006
SAHM (1500 N)	0.006	0.005	0.004	0.003
SBRM (1500 N)	0.006	0.005	0.004	0.003

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 suspectable 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 overlayed.
- In lieu of leveling.
- For removal of FC-2 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 20 mm of asphalt over the base throughout the project to protect it from traffic and rain.

Consideration should also be given to underlaying 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 Marshal 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 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 1000 metric tons of pavement is milled, a composition of the existing pavement must be included with the Special Provisions.

A Composition Report is not needed when milling FC-2 only. This is primarily due to the thickness of the layer (ie. 15 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.

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.

See exhibit in PPM - for control point setting.

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 120 mm of pavement.

6.5.6 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 depth has 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 in the special provisions for any project with RAP quantities over 1000 metric tons.

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 overlay (mm).

a_S = Layer coefficient of structural course. This value is 0.017.

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 10 mm increment. This process works well when designing an open graded friction course. For a dense graded friction course, use the following:

$$SN_O = SN_R - SN_E - SN_{FC-3}$$

$$a_S \times D_S = SN_R - SN_E - SN_{FC-3}$$

$$D_S = (SN_R - SN_E - SN_{FC-3}) / a_S$$

Where:

SN_{FC-3} = Structural strength of the 25 mm FC-3 Friction Course with a structural coefficient of 0.009.

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 for use in the design tables in Appendix A.

M_R = 73 MPa. This value is obtained from the State Materials Office. Round up M_R to 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 90 km/h and with a design speed of 80 km/h.

DATA:

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

Material[1]	Thickness[1]	Coefficient	SN_E
FC-2	15 mm	0.000	0.00
Type S	40 mm	0.006 (2)	0.24
Type I	25 mm	0.006 (2)	0.15
Binder	50 mm	0.006 (2)	0.30
Limerock (LBR 100)	200 mm	0.007 (3)	1.40
Stab (LBR 40)	300 mm	0.003 (3)	0.90
			2.99

(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:

$$SN_R = 3.96$$

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-2):

$$SN_O = SN_R - SN_E$$

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

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

Using:

$$SN_E = 2.99 - 0.24 \text{ (milled Type S)} = 2.75$$

So:

$$D_S = (3.96 - 2.75) / 0.017$$

$$D_S = 71.2 \text{ mm}$$

Knowing that the asphalt layer thickness is normally calculated to the nearest 10 mm, use D_S = 70 mm.

The thickness of an overlay can be calculated using the following equation for a dense graded friction course (FC-3):

$$SN_O = SN_R - SN_E - SN_{FC-3}$$

$$a_S \times D_S = SN_R - SN_E - SN_{FC-3}$$

$$D_S = (SN_R - SN_E - SN_{FC-3}) / a_S$$

$$D_S = (3.96 - 2.75 - 0.22) / 0.017$$

$$D_S = 58.2$$

Knowing that the asphalt layer thickness is normally calculated to the nearest 10 mm, use D_S = 60 mm.

CONCLUSION:

The following comparisons are provided.

Resurfacing Design For The Design Speed Of 90 km/h

For the first part of this sample problem using a design speed of 90 km/h, we need to use FC-2 according to Table 4.1. FC-2 has no structural value and is always shown as 15 mm thick.

Layer/Material	Coefficient	Asphalt Thickness	SN_O
Friction Course, FC-2	0.000	x 15 mm =	0.00
Structural Course, Type S	0.017	x 70 mm =	1.19
		85 mm	1.19

Resurfacing Design For The Design Speed Of 80 km/h

For the second part of this sample problem using a design speed of 80 km/h, we need to use FC-3 according to Table 4.1. FC-3 has a structural value of 0.22 and is always shown as 25 mm thick.

Layer/Material	Coefficient	Asphalt Thickness	SN_O
Friction Course, FC-3	0.009	x 25 mm =	0.22
Structural Course, Type S	0.017	x 60 mm =	1.02
		85 mm	1.24

To check:

$$SN_R = SN_O + SN_E$$

$3.96 \cong 1.19 + 2.75 = 3.94$ (first part, FC-2)

$3.96 \cong 1.24 + 2.75 = 3.99$ (second part, FC-3)

So:

This is within 0.08 or the nearest 10 mm of structural course.

For new construction payment is in square meters, but for overlays, payment is in metric tons. This is explained further in the next section.

For the roadway plans, the thickness has been converted from thickness in millimeters to 22 kg/m^2 for each 10 mm thickness, so:

70 mm structural course / 10 mm x 22 kg/m^2
= 154 kg/m^2

60 mm structural course / 10 mm x 22 kg/m^2
= 132 kg/m^2

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

RESURFACING

RESURFACE 154 kg/m^2 TYPE S STRUCTURAL COURSE AND 15 mm FRICTION COURSE FC-2 (RUBBER).

The pavement description in the plans with a design speed of 60 km/h should read:

RESURFACING

RESURFACE WITH 132 kg/m^2 TYPE S STRUCTURAL COURSE AND 25 mm FRICTION COURSE FC-3 (RUBBER).

If Superpave Asphaltic Concrete is used for this project, the description would include a traffic level as determined by Table 5.13.

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

RESURFACING

RESURFACE 154 kg/m^2 SUPERPAVE STRUCTURAL COURSE (TRAFFIC LEVEL 4) AND 15 mm FRICTION COURSE FC-2 (RUBBER).

The pavement description in the plans with a design speed of 60 km/h should read:

RESURFACING

RESURFACE WITH 132 kg/m^2 SUPERPAVE STRUCTURAL COURSE (TRAFFIC LEVEL 4) AND 25 mm FRICTION COURSE FC-6 (TRAFFIC LEVEL 4)(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 asphalt items on resurfacing projects, or widening and resurfacing projects, by the metric ton (t). The main reason 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.

On reconstruction projects where additional lanes are being constructed in addition to overlays of existing pavement, it will be the District's responsibility to determine if structural course at these locations should be paid for by the square meter (m^2) or by the metric ton (t). When the asphalt construction is controlled by a known profile grade on the underlying layers, then a square meter (m^2) item can be used.

Structural course shall be paid for by the square meter on new construction projects. Friction Course shall be paid for by the square meter on all projects.

Overlay projects normally assume a weight of 22 kg/m^2 per 10 mm thickness. The Pavement Design Engineer should verify this assumption with the District Materials Office. There is no reason to refine this number unless the Pavement Design Engineer knows that the weight of the aggregate will change the design by at least 10 mm for pavement or overlay of 60 mm thickness or greater, or 5 mm if thinner. If the design calls for 40 mm of structural course, 88 kg/m^2 of structural course is what should be constructed. If this misses the theoretical design thickness by a small percentage, it is still well within the tolerances set for construction. See Standard Specification 330-14.

6.8.2 LEVELING AND OVERBUILD

The District Materials Office will provide recommendations with respect to leveling and overbuild. The following minimum values recommended by the State Materials Office are;

- S-III Overbuild, minimum spread rate without a structural course is 40 kg/m^2,
- S-III Overbuild, minimum spread rate with a structural course is 33 kg/m^2, and,
- S-III Leveling, minimum spread rate is 27 kg/m^2.

For roads with a high volume of heavy trucks, thick layers of Overbuild or Leveling (especially Type II or Type III) should not be specified.

6.8.3 OPERATIONAL PROJECTS

On resurfacing projects such as skid hazard, intersection improvements, etc., where only a minimum amount of overbuild and an open graded friction course (FC-2) are required, and no structural course is provided, the plans should specify:

"TYPE S OVERBUILD (___ kg/m^2) (TYPE S-III ONLY)"

with the appropriate friction course. Overbuild should be specified rather than leveling because overbuild is placed with mechanical spreading and screeding equipment, whereas leveling is placed using motor graders. Overbuild will normally provide a smoother, more uniformly textured surface than leveling. This can be particularly critical to the placement and long-term performance of the FC-2.

Projects using FC-2 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. Use of Type S-III Overbuild with dense-graded Friction Course (FC-3) is not required.

When FC-3 is used as an alternate to FC-2 and no structural course is provided, Type S-III Overbuild should be used with the FC-2. It may also be used with FC-3 depending on the pavement condition.

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, at least two lifts of structural asphalt will probably be required to restore a smooth ride. An S-III overbuild or an FC-3 layer can serve as one of these lifts. The District Bituminous Engineer should be consulted for a recommendation in these cases.

Use 3 FC6 ONLY WFT?

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

6.8.5 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 judgement 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 open to traffic or other action 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 40 to 50 mm initial structural asphalt lift is recommended over the ARMI to provide this heat, with a 50 mm lift preferred. This will require that the initial lift thickness be specified on the plans since it may not be consistent with Standard Index 513. Special consideration should be given to construction sequencing if paved shoulders are being added.

For low volume roads (less than 3 500 000 $ESAL_D$), a minimum of 40 mm of structural course with 25 mm of Friction Course FC-3 should be provided over an ARMI. If paved shoulders are being added, the FC-3 can serve as the shoulder structural course. For moderate volume (greater than 3 500 000 $ESAL_D$) Non-Interstate roadways, a minimum of 50 mm of structural course is required over the ARMI. For high volume roads such as Interstates and Expressways, 90 mm of structural course should be provided over the ARMI.

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.

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 must be specified by the Pavement Design Engineer and shown in the plans to ensure layer coefficients equal or greater than the existing base.

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.

7.7 WIDENING DESIGN SAMPLE PROBLEM

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

GIVEN:

The existing two lane rural roadway is to be milled 70 mm and resurfaced with 60 mm Type S and 25 mm FC-3. The existing lanes are 3.3 m wide. The road needs to be brought up to current standards by widening the lane to 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 in accordance with Standard Index 513.

DATA:

Field data from the existing pavement as evaluated by the District Bituminous Engineer includes the following information.

Material	Thickness	Condition
FC-4	25 mm	poor
Type S	45 mm	poor
Type I	25 mm	fair
Binder	50 mm	fair
Limerock	280 mm	good
Stabilization	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:

25 mm FC-3

140 mm Structural Course

= + 60 mm Structural Course (New) +
25 mm Type I (Existing) +
50 mm Binder (Existing)

= 135 mm, use 140 mm Structural Course to match the existing asphalt thickness after milling

Optional Base Group 10

= SN_E (Limerock)

= (0.007 x 280 mm)

= 1.96 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 140 mm TYPE S STRUCTURAL COURSE AND 25 mm FRICTION COURSE FC-3 (RUBBER)

OPTIONAL BASES ALLOWED	OPTION NUMBER
280 mm LIMEROCK (LBR 100)	110
280 mm CEMENTED COQUINA (LBR 100)	210
280 mm SHELL ROCK (LBR 100)	310
280 mm BANK RUN SHELL (LBR 100)	410
160 mm ABC-3 (MIN MARSHALL STABILITY 4500 N)	610

Graded Aggregate Base was not selected because its structural coefficient (0.006) is less than the existing limerock structural coefficient (0.007).

This selection will 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 for a Type D road. Table 5.5 lists the following:

30 mm Structural Course

Optional Base Group 1

The resurfacing and widening design includes 60 mm of structural course on the resurfacing and 140 mm structural course on the widening with 25 mm of FC-3 Friction Course on top of both.

Looking at Standard Index 513 for a thickness of 60 mm of structural course on the mainline, the shoulder design should be design as follows:

25 mm Friction Course FC-3

20 mm Structural Course

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:

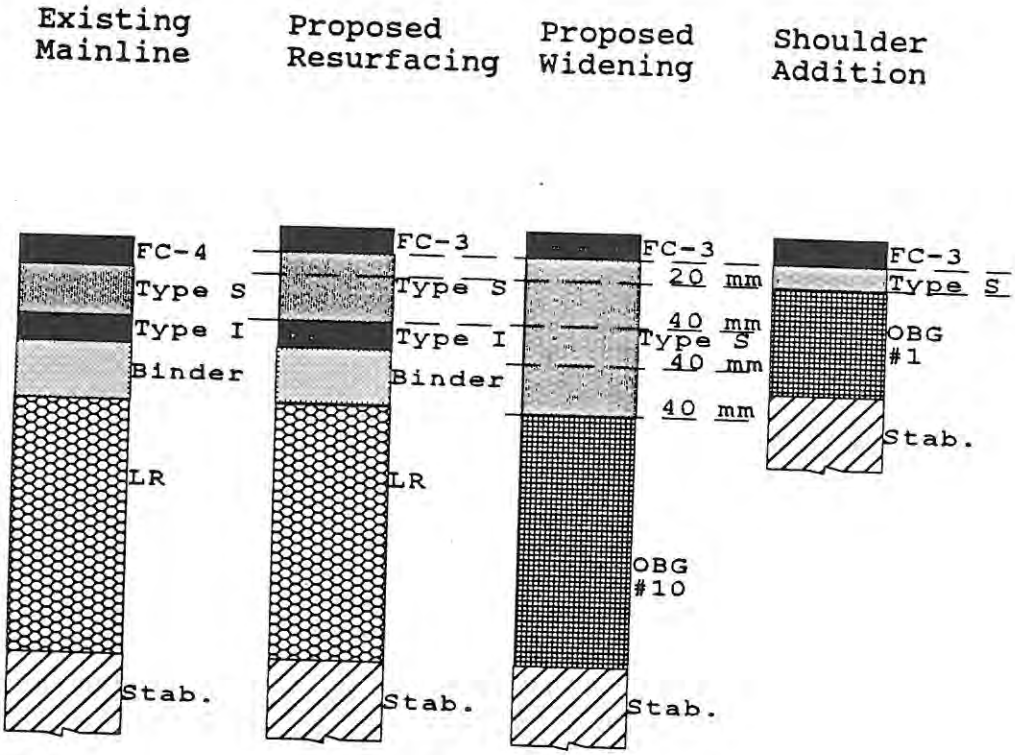
SHOULDER

OPTIONAL BASE GROUP 1 AND 20 mm TYPE S STRUCTURAL COURSE AND 25 mm FRICTION COURSE FC-3 (RUBBER)

Note that the 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 30 mm of Structural Course and Optional Base Group 1.

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

If 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 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.

8.2 SINGLE FRICTION COURSE USE

The following shoulder structural course should be used if the mainline roadway has the following structural course thickness:

Roadway Structural Course	Shoulder Structural Course
30 mm with any FC	30 mm
40 mm with any FC	40 mm
50 mm with FC-2	50 mm*
50 mm with FC-3	20 mm
60 mm and up with FC-2	30 mm
60 mm and up with FC-3	20 mm

* The increased thickness is required to insure a 30 mm minimum thickness of Structural Course on the shoulder under the open graded friction course and to meet the requirements of Standard Index 513 with regard to the minimum and maximum Layer Thickness Criteria.

More detailed information can be found in Table 5.12 and 5.13.

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 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_o) is the same for all the design tables.

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

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

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

- Determine the appropriate Reliability (%R).
- Using the known Resilient Modulus (M_R) value, select the table with the proper range. Ranges provided include the Resilient Modulus (M_R) between 30 to 100 MPa, 100 to 300 MPa, and 300 to 650 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 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 80 kN Equivalent Single Axle Loads ($ESAL_D$) value.

- The value intersected is the Structural Number Required(SN_R) of the pavement system.

If the Resilient Modulus (M_R) value and/or the 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. This should not be necessary except in rare cases.

TABLE A.1A

REQUIRED STRUCTURAL NUMBER (SN_R)
75% 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	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	1.68	1.64
150 000	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	1.80	1.76
200 000	2.96	2.79	2.65	2.53	2.43	2.34	2.27	2.20	2.13	2.08	2.03	1.98	1.93	1.89	1.85
250 000	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	1.97	1.93
300 000	3.17	2.99	2.84	2.71	2.60	2.51	2.43	2.35	2.29	2.22	2.17	2.12	2.07	2.03	1.99
350 000	3.25	3.06	2.91	2.78	2.67	2.57	2.49	2.41	2.34	2.28	2.23	2.17	2.13	2.08	2.04
400 000	3.32	3.13	2.97	2.84	2.73	2.63	2.54	2.47	2.40	2.33	2.28	2.22	2.17	2.13	2.09
450 000	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	2.17	2.13
500 000	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	2.21	2.17
600 000	3.55	3.35	3.18	3.04	2.92	2.81	2.72	2.64	2.57	2.50	2.44	2.38	2.33	2.28	2.23
700 000	3.64	3.43	3.26	3.12	3.00	2.89	2.79	2.71	2.63	2.56	2.50	2.44	2.39	2.34	2.29
800 000	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	2.39	2.34
900 000	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	2.44	2.39
1 000 000	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	2.48	2.43
1 500 000	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	2.66	2.60
2 000 000	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	2.78	2.73
2 500 000	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	2.89	2.83
3 000 000	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	2.98	2.92
3 500 000	4.67	4.43	4.23	4.05	3.90	3.76	3.64	3.53	3.44	3.35	3.26	3.19	3.12	3.06	3.00
4 000 000	4.77	4.52	4.31	4.14	3.98	3.84	3.72	3.61	3.51	3.42	3.34	3.26	3.19	3.12	3.06
4 500 000	4.85	4.60	4.39	4.21	4.06	3.92	3.79	3.68	3.58	3.49	3.40	3.32	3.25	3.19	3.12
5 000 000	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	3.24	3.18
6 000 000	5.05	4.80	4.59	4.40	4.24	4.10	3.97	3.85	3.75	3.65	3.57	3.49	3.41	3.34	3.28
7 000 000	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	3.43	3.36
8 000 000	5.26	5.00	4.79	4.60	4.43	4.28	4.15	4.03	3.93	3.83	3.74	3.65	3.58	3.50	3.43
9 000 000	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	3.57	3.50
10 000 000	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	3.63	3.56
15 000 000	5.74	5.46	5.24	5.04	4.86	4.71	4.57	4.44	4.33	4.23	4.13	4.04	3.95	3.88	3.80
20 000 000	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	4.06	3.98
25 000 000	6.14	5.86	5.62	5.41	5.23	5.07	4.93	4.79	4.68	4.57	4.46	4.37	4.28	4.20	4.12
30 000 000	6.29	6.00	5.76	5.55	5.36	5.20	5.06	4.92	4.80	4.69	4.59	4.49	4.40	4.32	4.24
35 000 000	6.41	6.12	5.88	5.66	5.48	5.31	5.17	5.03	4.91	4.80	4.69	4.60	4.51	4.42	4.34
40 000 000	6.53	6.23	5.98	5.77	5.58	5.41	5.26	5.13	5.01	4.89	4.79	4.69	4.60	4.51	4.43
45 000 000	6.63	6.33	6.08	5.86	5.67	5.50	5.35	5.21	5.09	4.98	4.87	4.77	4.68	4.59	4.51
50 000 000	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	4.66	4.58
60 000 000	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	4.79	4.71
70 000 000	7.01	6.70	6.44	6.21	6.02	5.84	5.68	5.54	5.41	5.30	5.19	5.08	4.99	4.90	4.82
80 000 000	7.13	6.81	6.55	6.32	6.12	5.95	5.79	5.64	5.51	5.39	5.28	5.18	5.08	4.99	4.91
90 000 000	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	5.08	4.99
100 000 000	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	5.15	5.07

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	1.64	1.58	1.52	1.47	1.43	1.38	1.35	1.31	1.28	1.25	1.22	1.15	1.10	1.05	1.00
150 000	1.76	1.70	1.64	1.58	1.54	1.49	1.45	1.41	1.38	1.35	1.32	1.25	1.19	1.14	1.09
200 000	1.85	1.78	1.72	1.67	1.62	1.57	1.53	1.49	1.46	1.42	1.39	1.32	1.26	1.21	1.16
250 000	1.93	1.85	1.79	1.73	1.68	1.64	1.59	1.55	1.52	1.48	1.45	1.38	1.32	1.26	1.21
300 000	1.99	1.91	1.85	1.79	1.74	1.69	1.65	1.60	1.57	1.53	1.50	1.43	1.36	1.31	1.26
350 000	2.04	1.97	1.90	1.84	1.78	1.74	1.69	1.65	1.61	1.58	1.54	1.47	1.40	1.34	1.29
400 000	2.09	2.01	1.94	1.88	1.83	1.78	1.73	1.69	1.65	1.61	1.58	1.50	1.44	1.38	1.33
450 000	2.13	2.05	1.98	1.92	1.86	1.81	1.77	1.72	1.68	1.65	1.61	1.54	1.47	1.41	1.36
500 000	2.17	2.09	2.02	1.95	1.90	1.85	1.80	1.76	1.72	1.68	1.64	1.56	1.50	1.44	1.38
600 000	2.23	2.15	2.08	2.02	1.96	1.91	1.86	1.81	1.77	1.73	1.70	1.62	1.55	1.49	1.43
700 000	2.29	2.21	2.14	2.07	2.01	1.96	1.91	1.86	1.82	1.78	1.74	1.66	1.59	1.53	1.47
800 000	2.34	2.26	2.18	2.12	2.06	2.00	1.95	1.90	1.86	1.82	1.78	1.70	1.63	1.57	1.51
900 000	2.39	2.30	2.23	2.16	2.10	2.04	1.99	1.94	1.90	1.86	1.82	1.74	1.66	1.60	1.54
1 000 000	2.43	2.35	2.27	2.20	2.14	2.08	2.03	1.98	1.93	1.89	1.85	1.77	1.70	1.63	1.57
1 500 000	2.60	2.51	2.43	2.35	2.29	2.23	2.17	2.12	2.07	2.03	1.99	1.90	1.82	1.75	1.69
2 000 000	2.73	2.63	2.55	2.47	2.40	2.34	2.28	2.22	2.18	2.13	2.09	1.99	1.91	1.84	1.78
2 500 000	2.83	2.73	2.64	2.56	2.49	2.42	2.36	2.31	2.26	2.21	2.17	2.07	1.99	1.91	1.85
3 000 000	2.92	2.82	2.72	2.64	2.57	2.50	2.44	2.38	2.33	2.28	2.23	2.13	2.05	1.97	1.91
3 500 000	3.00	2.89	2.79	2.71	2.63	2.56	2.50	2.44	2.39	2.34	2.29	2.19	2.10	2.03	1.96
4 000 000	3.06	2.95	2.86	2.77	2.69	2.62	2.56	2.50	2.44	2.39	2.35	2.24	2.15	2.07	2.00
4 500 000	3.12	3.01	2.91	2.82	2.74	2.67	2.61	2.55	2.49	2.44	2.39	2.28	2.19	2.11	2.04
5 000 000	3.18	3.06	2.96	2.87	2.79	2.72	2.65	2.59	2.54	2.48	2.43	2.33	2.23	2.15	2.08
6 000 000	3.28	3.16	3.05	2.96	2.88	2.80	2.73	2.67	2.61	2.56	2.51	2.40	2.30	2.22	2.14
7 000 000	3.36	3.24	3.13	3.04	2.95	2.88	2.81	2.74	2.68	2.63	2.57	2.46	2.36	2.28	2.20
8 000 000	3.43	3.31	3.20	3.11	3.02	2.94	2.87	2.80	2.74	2.68	2.63	2.52	2.41	2.33	2.25
9 000 000	3.50	3.38	3.27	3.17	3.08	3.00	2.92	2.86	2.79	2.74	2.68	2.56	2.46	2.37	2.29
10 000 000	3.56	3.44	3.32	3.22	3.13	3.05	2.98	2.91	2.84	2.79	2.73	2.61	2.51	2.42	2.34
15 000 000	3.80	3.67	3.55	3.45	3.35	3.26	3.18	3.11	3.04	2.98	2.92	2.79	2.68	2.58	2.50
20 000 000	3.98	3.84	3.72	3.61	3.51	3.42	3.34	3.26	3.19	3.13	3.06	2.93	2.81	2.71	2.62
25 000 000	4.12	3.98	3.86	3.74	3.64	3.55	3.46	3.38	3.31	3.24	3.18	3.04	2.92	2.81	2.72
30 000 000	4.24	4.10	3.97	3.86	3.75	3.65	3.57	3.49	3.41	3.34	3.28	3.13	3.01	2.90	2.80
35 000 000	4.34	4.20	4.07	3.95	3.84	3.75	3.66	3.58	3.50	3.43	3.36	3.21	3.09	2.97	2.88
40 000 000	4.43	4.29	4.15	4.04	3.93	3.83	3.74	3.65	3.58	3.50	3.44	3.28	3.15	3.04	2.94
45 000 000	4.51	4.36	4.23	4.11	4.00	3.90	3.81	3.72	3.64	3.57	3.50	3.35	3.22	3.10	3.00
50 000 000	4.58	4.43	4.30	4.18	4.07	3.97	3.87	3.79	3.71	3.63	3.56	3.41	3.27	3.16	3.05
60 000 000	4.71	4.56	4.42	4.30	4.19	4.08	3.99	3.90	3.82	3.74	3.67	3.51	3.37	3.25	3.15
70 000 000	4.82	4.66	4.52	4.40	4.29	4.18	4.08	4.00	3.91	3.84	3.76	3.60	3.46	3.34	3.23
80 000 000	4.91	4.75	4.62	4.49	4.37	4.27	4.17	4.08	4.00	3.92	3.84	3.68	3.54	3.41	3.30
90 000 000	4.99	4.84	4.70	4.57	4.45	4.35	4.25	4.16	4.07	3.99	3.92	3.75	3.60	3.48	3.36
100 000 000	5.07	4.91	4.77	4.64	4.52	4.42	4.32	4.22	4.14	4.06	3.98	3.81	3.67	3.54	3.42

TABLE A.1C

REQUIRED STRUCTURAL NUMBER (SN_R)
75% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 300 MPa TO 650 MPa

	Resilient Modulus (M_R), MPa														
$ESAL_D$	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
100 000	1.00	0.96	0.93	0.89	0.86	0.84	0.81	0.79	0.76	0.74	0.72	0.70	0.68	0.67	0.65
150 000	1.09	1.05	1.01	0.98	0.95	0.92	0.89	0.87	0.84	0.82	0.80	0.78	0.76	0.74	0.73
200 000	1.16	1.12	1.08	1.04	1.01	0.98	0.95	0.92	0.90	0.88	0.85	0.83	0.82	0.80	0.78
250 000	1.21	1.17	1.13	1.09	1.06	1.03	1.00	0.97	0.95	0.92	0.90	0.88	0.86	0.84	0.82
300 000	1.26	1.21	1.17	1.13	1.10	1.07	1.04	1.01	0.98	0.96	0.94	0.92	0.90	0.88	0.86
350 000	1.29	1.25	1.21	1.17	1.13	1.10	1.07	1.04	1.02	0.99	0.97	0.95	0.93	0.91	0.89
400 000	1.33	1.28	1.24	1.20	1.16	1.13	1.10	1.07	1.05	1.02	1.00	0.98	0.96	0.94	0.92
450 000	1.36	1.31	1.27	1.23	1.19	1.16	1.13	1.10	1.07	1.05	1.02	1.00	0.98	0.96	0.94
500 000	1.38	1.34	1.29	1.25	1.22	1.18	1.15	1.12	1.10	1.07	1.05	1.02	1.00	0.98	0.96
600 000	1.43	1.38	1.34	1.30	1.26	1.23	1.20	1.17	1.14	1.11	1.09	1.06	1.04	1.02	1.00
700 000	1.47	1.42	1.38	1.34	1.30	1.26	1.23	1.20	1.17	1.15	1.12	1.10	1.08	1.06	1.04
800 000	1.51	1.46	1.41	1.37	1.33	1.30	1.27	1.23	1.21	1.18	1.15	1.13	1.11	1.09	1.07
900 000	1.54	1.49	1.44	1.40	1.36	1.33	1.29	1.26	1.23	1.21	1.18	1.16	1.13	1.11	1.09
1 000 000	1.57	1.52	1.47	1.43	1.39	1.35	1.32	1.29	1.26	1.23	1.21	1.18	1.16	1.14	1.12
1 500 000	1.69	1.64	1.59	1.54	1.50	1.46	1.43	1.39	1.36	1.33	1.31	1.28	1.26	1.23	1.21
2 000 000	1.78	1.72	1.67	1.62	1.58	1.54	1.50	1.47	1.44	1.41	1.38	1.35	1.33	1.30	1.28
2 500 000	1.85	1.79	1.74	1.69	1.64	1.60	1.57	1.53	1.50	1.47	1.44	1.41	1.38	1.36	1.34
3 000 000	1.91	1.85	1.79	1.74	1.70	1.66	1.62	1.58	1.55	1.52	1.49	1.46	1.43	1.41	1.38
3 500 000	1.96	1.90	1.84	1.79	1.74	1.70	1.66	1.63	1.59	1.56	1.53	1.50	1.47	1.45	1.42
4 000 000	2.00	1.94	1.88	1.83	1.78	1.74	1.70	1.66	1.63	1.60	1.57	1.54	1.51	1.48	1.46
4 500 000	2.04	1.98	1.92	1.87	1.82	1.78	.174	1.70	1.66	1.63	1.60	1.57	1.54	1.52	1.49
5 000 000	2.08	2.01	1.96	1.90	1.86	1.81	1.77	1.73	1.70	1.66	1.63	1.60	1.57	1.55	1.52
6 000 000	2.14	2.08	2.02	1.96	1.91	1.87	1.83	1.79	1.75	1.72	1.68	1.65	1.62	1.60	1.57
7 000 000	2.20	2.13	2.07	2.02	1.97	1.92	1.88	1.84	1.80	1.76	1.73	1.70	1.67	1.64	1.62
8 000 000	2.25	2.18	2.12	2.06	2.01	1.96	1.92	1.88	1.84	1.80	1.77	1.74	1.71	1.68	1.65
9 000 000	2.29	2.22	2.16	2.10	2.05	2.00	1.96	1.92	1.88	1.84	1.81	1.78	1.75	1.72	1.69
10 000 000	2.34	2.26	2.20	2.14	2.09	2.04	1.99	1.95	1.91	1.88	1.84	1.81	1.78	1.75	1.72
15 000 000	2.50	2.42	2.35	2.29	2.24	2.18	2.14	2.09	2.05	2.01	1.97	1.94	1.91	1.88	1.85
20 000 000	2.62	2.54	2.47	2.40	2.35	2.29	2.24	2.19	2.15	2.11	2.07	2.04	2.00	1.97	1.94
25 000 000	2.72	2.64	2.56	2.50	2.43	2.38	2.33	2.28	2.23	2.19	2.15	2.11	2.08	2.05	2.02
30 000 000	2.80	2.72	2.65	2.57	2.51	2.45	2.40	2.35	2.30	2.26	2.22	2.18	2.14	2.11	2.08
35 000 000	2.88	2.79	2.71	2.64	2.57	2.52	2.46	2.41	2.36	2.32	2.28	2.24	2.20	2.17	2.13
40 000 000	2.94	2.85	2.77	2.70	2.63	2.57	2.52	2.46	2.42	2.37	2.33	2.29	2.25	2.22	2.18
45 000 000	3.00	2.91	2.83	2.75	2.68	2.62	2.57	2.51	2.46	2.42	2.37	2.33	2.30	2.26	2.23
50 000 000	3.05	2.96	2.88	2.80	2.73	2.67	2.61	2.56	2.51	2.46	2.42	2.37	2.34	2.30	2.26
60 000 000	3.15	3.05	2.96	2.89	2.82	2.75	2.69	2.64	2.58	2.54	2.49	2.45	2.41	2.37	2.33
70 000 000	3.23	3.13	3.04	2.96	2.89	2.82	2.76	2.70	2.65	2.60	2.56	2.51	2.47	2.43	2.40
80 000 000	3.30	3.20	3.11	3.03	2.95	2.89	2.82	2.76	2.71	2.66	2.61	2.57	2.53	2.49	2.45
90 000 000	3.36	3.26	3.17	3.09	3.01	2.94	2.88	2.82	2.76	2.71	2.66	2.62	2.58	2.54	2.50
100 000 000	3.42	3.32	3.23	3.14	3.06	2.99	2.93	2.87	2.81	2.76	2.71	2.67	2.62	2.58	2.54

TABLE A.2A

REQUIRED STRUCTURAL NUMBER (SN_R)
80% 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	2.72	2.56	2.43	2.32	2.23	2.15	2.08	2.01	1.95	1.90	1.85	1.81	1.77	1.73	1.69
150 000	2.91	2.74	2.60	2.49	2.39	2.30	2.22	2.16	2.09	2.04	1.99	1.94	1.90	1.86	1.82
200 000	3.05	2.87	2.73	2.61	2.50	2.41	2.33	2.26	2.20	2.14	2.09	2.04	1.99	1.95	1.91
250 000	3.16	2.98	2.83	2.71	2.60	2.50	2.42	2.35	2.28	2.22	2.17	2.12	2.07	2.03	1.98
300 000	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	2.09	2.05
350 000	3.34	3.15	2.99	2.86	2.75	2.65	2.56	2.48	2.41	2.35	2.29	2.24	2.19	2.14	2.10
400 000	3.42	3.22	3.06	2.93	2.81	2.71	2.62	2.54	2.47	2.40	2.34	2.29	2.24	2.19	2.15
450 000	3.49	3.29	3.12	2.98	2.86	2.76	2.67	2.59	2.52	2.45	2.89	2.33	2.28	2.24	2.19
500 000	3.55	3.34	3.18	3.04	2.92	2.81	2.72	2.64	2.56	2.49	2.43	2.38	2.32	2.28	2.23
600 000	3.65	3.45	3.27	3.13	3.01	2.90	2.80	2.72	2.64	2.57	2.51	2.45	2.40	2.35	2.30
700 000	3.74	3.53	3.36	3.21	3.08	2.97	2.87	2.79	2.71	2.64	2.57	2.51	2.46	2.41	2.36
800 000	3.83	3.61	3.43	3.28	3.15	3.04	2.94	2.85	2.77	2.70	2.63	2.57	2.51	2.46	2.41
900 000	3.90	3.68	3.50	3.35	3.21	3.10	3.00	2.91	2.82	2.75	2.68	2.62	2.56	2.51	2.46
1 000 000	3.96	3.74	3.56	3.40	3.27	3.15	3.05	2.96	2.87	2.80	2.73	2.67	2.61	2.55	2.50
1 500 000	4.22	3.99	3.80	3.64	3.50	3.37	3.26	3.16	3.07	2.99	2.92	2.85	2.79	2.73	2.68
2 000 000	4.41	4.18	3.98	3.81	3.66	3.53	3.42	3.32	3.22	3.14	3.06	2.99	2.93	2.87	2.81
2 500 000	4.56	4.32	4.12	3.95	3.80	3.66	3.55	3.44	3.34	3.26	3.18	3.10	3.04	2.97	2.92
3 000 000	4.69	4.44	4.24	4.06	3.91	3.77	3.65	3.54	3.45	3.36	3.27	3.20	3.13	3.07	3.01
3 500 000	4.79	4.55	4.34	4.16	4.01	3.87	3.74	3.63	3.53	3.44	3.36	3.28	3.21	3.14	3.08
4 000 000	4.89	4.65	4.43	4.25	4.09	3.95	3.83	3.71	3.61	3.52	3.43	3.36	3.28	3.22	3.15
4 500 000	4.97	4.72	4.51	4.33	4.17	4.03	3.90	3.78	3.68	3.59	3.50	3.42	3.35	3.28	3.21
5 000 000	5.05	4.79	4.58	4.40	4.24	4.09	3.96	3.85	3.74	3.65	3.56	3.48	3.41	3.34	3.27
6 000 000	5.18	4.92	4.71	4.52	4.36	4.21	4.08	3.96	3.86	3.76	3.67	3.59	3.51	3.44	3.37
7 000 000	5.29	5.03	4.81	4.62	4.46	4.31	4.18	4.06	3.95	3.85	3.76	3.68	3.60	3.53	3.46
8 000 000	5.39	5.13	4.91	4.72	4.55	4.40	4.27	4.15	4.04	3.93	3.84	3.76	3.68	3.60	3.53
9 000 000	5.48	5.21	4.99	4.80	4.63	4.48	4.34	4.22	4.11	4.01	3.91	3.83	3.75	3.67	3.60
10 000 000	5.56	5.29	5.07	4.87	4.70	4.55	4.41	4.29	4.18	4.08	3.98	3.89	3.81	3.73	3.66
15 000 000	5.87	5.60	5.36	5.16	4.99	4.83	4.69	4.56	4.45	4.34	4.24	4.15	4.06	3.98	3.91
20 000 000	6.10	5.82	5.58	5.37	5.19	5.03	4.89	4.76	4.64	4.53	4.43	4.34	4.25	4.17	4.09
25 000 000	6.28	5.99	5.75	5.54	5.36	5.19	5.05	4.92	4.80	4.68	4.58	4.49	4.40	4.31	4.24
30 000 000	6.43	6.14	5.89	5.68	5.49	5.33	5.18	5.05	4.92	4.81	4.71	4.61	4.52	4.44	4.36
35 000 000	6.56	6.26	6.01	5.80	5.61	5.44	4.29	5.16	5.03	4.92	4.81	4.72	4.62	4.54	4.46
40 000 000	6.67	6.37	6.12	5.90	5.71	5.54	5.39	5.26	5.13	5.01	4.91	4.81	4.72	4.63	4.55
45 000 000	6.77	6.47	6.22	6.00	5.80	5.63	5.48	5.34	5.22	5.10	4.99	4.89	4.80	4.71	4.63
50 000 000	6.87	6.56	6.30	6.08	5.89	5.71	5.56	5.42	5.29	5.18	5.07	4.97	4.87	4.78	4.70
60 000 000	7.03	6.71	6.45	6.23	6.03	5.86	5.70	5.56	5.43	5.31	5.20	5.10	5.00	4.91	4.83
70 000 000	7.16	6.85	6.58	6.35	6.15	5.98	5.82	5.67	5.54	5.42	5.31	5.21	5.11	5.02	4.94
80 000 000	7.28	6.96	6.69	6.46	6.26	6.08	5.92	5.78	5.65	5.52	5.41	5.31	5.21	5.12	5.03
90 000 000	7.39	7.07	6.80	6.56	6.36	6.18	6.02	5.87	5.74	5.61	5.50	5.39	5.30	5.20	5.12
100 000 000	7.49	7.16	6.89	6.65	6.45	6.26	6.10	5.95	5.82	5.69	5.58	5.47	5.37	5.28	5.19

TABLE A.2B

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

$ESAL_D$	Resilient Modulus (M_R), MPa														
	100	110	120	130	140	150	160	170	180	190	200	225	250	275	300
100 000	1.69	1.63	1.57	1.52	1.47	1.43	1.39	1.35	1.32	1.29	1.26	1.19	1.14	1.09	1.04
150 000	1.82	1.75	1.69	1.63	1.58	1.54	1.50	1.46	1.42	1.39	1.36	1.29	1.23	1.18	1.13
200 000	1.91	1.84	1.78	1.72	1.67	1.62	1.58	1.54	1.50	1.47	1.44	1.36	1.30	1.25	1.20
250 000	1.98	1.91	1.85	1.79	1.73	1.69	1.64	1.60	1.56	1.53	1.50	1.42	1.36	1.30	1.25
300 000	2.05	1.97	1.90	1.84	1.79	1.74	1.70	1.65	1.62	1.58	1.55	1.47	1.41	1.35	1.30
350 000	2.10	2.02	1.96	1.89	1.84	1.79	1.74	1.70	1.66	1.62	1.59	1.51	1.45	1.39	1.34
400 000	2.15	2.07	2.00	1.94	1.88	1.83	1.78	1.74	1.70	1.66	1.63	1.55	1.48	1.42	1.37
450 000	2.19	2.11	2.04	1.98	1.92	1.87	1.82	1.78	1.74	1.70	1.66	1.58	1.52	1.46	1.40
500 000	2.23	2.15	2.08	2.01	1.96	1.90	1.85	1.81	1.77	1.73	1.69	1.61	1.54	1.48	1.43
600 000	2.30	2.22	2.14	2.08	2.02	1.96	1.91	1.87	1.83	1.79	1.75	1.67	1.60	1.53	1.48
700 000	2.36	2.27	2.20	2.13	2.07	2.01	1.96	1.92	1.87	1.83	1.80	1.71	1.64	1.58	1.52
800 000	2.41	2.33	2.25	2.18	2.12	2.06	2.01	1.96	1.92	1.88	1.84	1.75	1.68	1.62	1.56
900 000	2.46	2.37	2.29	2.22	2.16	2.10	2.05	2.00	1.96	1.92	1.88	1.79	1.72	1.56	1.59
1 000 000	2.50	2.41	2.33	2.26	2.20	2.14	2.09	2.04	1.99	1.95	1.91	1.82	1.75	1.68	1.62
1 500 000	2.68	2.58	2.50	2.42	2.35	2.29	2.23	2.18	2.13	2.09	2.05	1.95	1.87	1.80	1.74
2 000 000	2.81	2.71	2.62	2.54	2.47	2.40	2.34	2.29	2.24	2.19	2.15	2.05	1.97	1.90	1.83
2 500 000	2.92	2.81	2.72	2.64	2.56	2.49	2.43	2.38	2.32	2.28	2.23	2.13	2.05	1.97	1.90
3 000 000	3.01	2.90	2.80	2.72	2.64	2.57	2.51	2.45	2.40	2.35	2.30	2.20	2.11	2.03	1.96
3 500 000	3.08	2.97	2.87	2.79	2.71	2.64	2.57	2.51	2.46	2.41	2.36	2.26	2.16	2.09	2.02
4 000 000	3.15	3.04	2.94	2.85	2.77	2.70	2.63	2.57	2.51	2.46	2.41	2.31	2.21	2.13	2.06
4 500 000	3.21	3.10	3.00	2.91	2.82	2.75	2.68	2.62	2.56	2.51	2.46	2.35	2.26	2.18	2.10
5 000 000	3.27	3.15	3.05	2.96	2.87	2.80	2.73	2.67	2.61	2.56	2.51	2.39	2.30	2.21	2.14
6 000 000	3.37	3.25	3.14	3.05	2.96	2.88	2.81	2.75	2.69	2.63	2.58	2.47	2.37	2.28	2.21
7 000 000	3.46	3.33	3.22	3.13	3.04	2.96	2.89	2.82	2.76	2.70	2.65	2.53	2.43	2.34	2.26
8 000 000	3.53	3.41	3.30	3.20	3.11	3.03	2.95	2.88	2.82	2.76	2.71	2.59	2.49	2.40	2.32
9 000 000	3.60	3.47	3.36	3.26	3.17	3.09	3.01	2.94	2.88	2.82	2.76	2.64	2.53	2.44	2.36
10 000 000	3.66	3.53	3.42	3.32	3.22	3.14	3.06	2.99	2.93	2.87	2.81	2.69	2.58	2.49	2.40
15 000 000	3.91	3.77	3.65	3.55	3.45	3.36	3.28	3.20	3.13	3.07	3.01	2.87	2.76	2.66	2.57
20 000 000	4.09	3.95	3.83	3.71	3.61	3.52	3.43	3.36	3.28	3.22	3.15	3.01	2.89	2.79	2.70
25 000 000	4.24	4.09	3.97	3.85	3.74	3.65	3.56	3.48	3.51	3.34	3.27	3.13	3.00	2.89	2.80
30 000 000	4.36	4.21	4.08	3.96	3.86	3.76	3.67	3.59	3.51	3.44	3.37	3.22	3.10	2.98	2.89
35 000 000	4.46	4.31	4.18	4.06	3.95	3.85	3.76	3.68	3.60	3.53	3.46	3.31	3.18	3.06	2.96
40 000 000	4.55	4.40	4.27	4.15	4.04	3.94	3.84	3.76	3.68	3.60	3.53	3.38	3.25	3.13	3.03
45 000 000	4.63	4.48	4.34	4.22	4.11	4.01	3.92	3.83	3.75	3.67	3.60	3.45	3.31	3.19	3.09
50 000 000	4.70	4.55	4.41	4.29	4.18	4.08	3.98	3.89	3.81	3.74	3.66	3.51	3.37	3.25	3.14
60 000 000	4.83	4.68	4.54	4.41	4.30	4.19	4.10	4.01	3.92	3.85	3.77	3.61	3.47	3.35	3.24
70 000 000	4.94	4.78	4.65	4.52	4.40	4.29	4.20	4.11	4.02	3.94	3.87	3.70	3.56	3.43	3.32
80 000 000	5.03	4.88	4.73	4.61	4.49	4.38	4.28	4.19	4.11	4.03	3.95	3.78	3.64	3.51	3.39
90 000 000	5.12	4.96	4.82	4.69	4.57	4.46	4.36	4.27	4.18	4.10	4.03	3.85	3.71	3.58	3.46
100 000 000	5.19	5.03	4.89	4.76	4.64	4.53	4.43	4.34	4.25	4.17	4.09	3.92	3.77	3.64	3.52

TABLE A.2C

REQUIRED STRUCTURAL NUMBER (SN_R)
80% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 300 MPa TO 650 MPa

	Resilient Modulus (M_R), MPa														
$ESAL_D$	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
100 000	1.04	1.00	0.96	0.93	0.90	0.87	0.84	0.82	0.80	0.77	0.75	0.73	0.72	0.70	0.68
150 000	1.13	1.09	1.05	1.02	0.98	0.95	0.93	0.90	0.88	0.85	0.83	0.81	0.79	0.77	0.76
200 000	1.20	1.16	1.12	1.08	1.05	1.02	0.99	0.96	0.94	0.91	0.89	0.87	0.85	0.83	0.81
250 000	1.25	1.21	1.17	1.13	1.10	1.06	1.04	1.01	0.98	0.96	0.94	0.91	0.89	0.87	0.86
300 000	1.30	1.25	1.21	1.17	1.14	1.11	1.08	1.05	1.02	1.00	0.97	0.95	0.93	0.91	0.89
350 000	1.34	1.29	1.25	1.21	1.17	1.14	1.11	1.08	1.06	1.03	1.01	0.98	0.96	0.94	0.92
400 000	1.37	1.32	1.28	1.24	1.21	1.17	1.14	1.11	1.09	1.06	1.04	1.01	0.99	0.97	0.95
450 000	1.40	1.35	1.31	1.27	1.23	1.20	1.17	1.14	1.11	1.09	1.06	1.04	1.02	1.00	0.98
500 000	1.43	1.38	1.34	1.30	1.26	1.23	1.19	1.16	1.14	1.11	1.09	1.06	1.04	1.02	1.00
600 000	1.48	1.43	1.38	1.34	1.30	1.27	1.24	1.21	1.18	1.15	1.13	1.10	1.08	1.06	1.04
700 000	1.52	1.47	1.42	1.38	1.34	1.31	1.27	1.24	1.22	1.19	1.16	1.14	1.12	1.09	1.07
800 000	1.56	1.51	1.46	1.42	1.38	1.34	1.31	1.28	1.25	1.22	1.19	1.17	1.15	1.13	1.10
900 000	1.59	1.54	1.49	1.45	1.41	1.37	1.34	1.31	1.28	1.25	1.22	1.20	1.17	1.15	1.13
1 000 000	1.62	1.57	1.52	1.48	1.44	1.40	1.36	1.33	1.30	1.27	1.25	1.22	1.20	1.18	1.16
1 500 000	1.74	1.69	1.64	1.59	1.55	1.51	1.47	1.44	1.41	1.38	1.35	1.32	1.30	1.27	1.25
2 000 000	1.83	1.77	1.72	1.67	1.63	1.59	1.55	1.52	1.48	1.45	1.42	1.40	1.37	1.35	1.32
2 500 000	1.90	1.84	1.79	1.74	1.69	1.65	1.61	1.58	1.55	1.51	1.48	1.46	1.43	1.41	1.38
3 000 000	1.96	1.90	1.85	1.80	1.75	1.71	1.67	1.63	1.60	1.56	1.53	1.51	1.48	1.45	1.43
3 500 000	2.02	1.95	1.90	1.84	1.80	1.75	1.71	1.68	1.64	1.61	1.58	1.55	1.52	1.50	1.47
4 000 000	2.06	2.00	1.94	1.89	1.84	1.79	1.75	1.72	1.68	1.65	1.62	1.59	1.56	1.53	1.51
4 500 000	2.10	2.04	1.98	1.93	1.88	1.83	1.79	1.75	1.72	1.68	1.65	1.62	1.59	1.57	1.54
5 000 000	2.14	2.07	2.01	1.96	1.91	1.87	1.82	1.78	1.75	1.71	1.68	1.65	1.62	1.59	1.57
6 000 000	2.21	2.14	2.08	2.02	1.97	1.92	1.88	1.84	1.80	1.77	1.74	1.70	1.68	1.65	1.62
7 000 000	2.26	2.20	2.13	2.08	2.02	1.98	1.93	1.89	1.85	1.82	1.78	1.75	1.72	1.69	1.67
8 000 000	2.32	2.25	2.18	2.12	2.07	2.02	1.98	1.93	1.90	1.86	1.82	1.79	1.76	1.73	1.71
9 000 000	2.36	2.29	2.22	2.17	2.11	2.06	2.02	1.97	1.93	1.90	1.86	1.83	1.80	1.77	1.74
10 000 000	2.40	2.33	2.26	2.20	2.15	2.10	2.05	2.01	1.97	1.93	1.90	1.86	1.83	1.80	1.77
15 000 000	2.57	2.49	2.42	2.36	2.30	2.25	2.20	2.15	2.11	2.07	2.03	2.00	1.96	1.93	1.90
20 000 000	2.70	2.62	2.54	2.48	2.41	2.36	2.31	2.26	2.21	2.17	2.13	2.10	2.06	2.03	2.00
25 000 000	2.80	2.71	2.64	2.57	2.51	2.45	2.39	2.34	2.30	2.26	2.21	2.18	2.14	2.11	2.07
30 000 000	2.89	2.80	2.72	2.65	2.58	2.52	2.47	2.42	2.37	2.33	2.28	2.24	2.21	2.17	2.14
35 000 000	2.96	2.87	2.79	2.72	2.65	2.59	2.53	2.48	2.43	2.39	2.34	2.30	2.27	2.23	2.20
40 000 000	3.03	2.93	2.85	2.78	2.71	2.65	2.59	2.54	2.49	2.44	2.40	2.36	2.32	2.28	2.25
45 000 000	3.09	2.99	2.91	2.83	2.76	2.70	2.64	2.59	2.54	2.49	2.44	2.40	2.36	2.33	2.29
50 000 000	3.14	3.05	2.96	2.88	2.81	2.75	2.69	2.63	2.58	2.53	2.49	2.44	2.40	2.37	2.33
60 000 000	3.24	3.14	3.05	2.97	2.90	2.83	2.77	2.71	2.66	2.61	2.56	2.52	2.48	2.44	2.40
70 000 000	3.32	3.22	3.13	3.05	2.97	2.90	2.84	2.78	2.73	2.68	2.63	2.59	2.54	2.50	2.47
80 000 000	3.39	3.29	3.20	3.12	3.04	2.97	2.90	2.84	2.79	2.74	2.69	2.64	2.60	2.56	2.52
90 000 000	3.46	3.36	3.26	3.18	3.10	3.03	2.96	2.90	2.84	2.79	2.74	2.69	2.65	2.61	2.57
100 000 000	3.52	3.41	3.32	3.23	3.15	3.08	3.01	2.95	2.89	2.84	2.79	2.74	2.70	2.66	2.62

TABLE A.3A

REQUIRED STRUCTURAL NUMBER (SN_R)
85% 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	2.81	2.65	2.52	2.40	2.31	2.22	2.15	2.08	2.02	1.97	1.92	1.87	1.83	1.79	1.76
150 000	3.01	2.83	2.69	2.57	2.47	2.38	2.30	2.23	2.17	2.11	2.06	2.01	1.96	1.92	1.88
200 000	3.15	2.97	2.82	2.70	2.59	2.50	2.41	2.34	2.27	2.21	2.16	2.11	2.06	2.02	1.98
250 000	3.27	3.08	2.93	2.80	2.69	2.59	2.51	2.43	2.36	2.30	2.24	2.19	2.14	2.10	2.05
300 000	3.37	3.18	3.02	2.88	2.77	2.67	2.58	2.50	2.43	2.37	2.31	2.26	2.21	2.16	2.12
350 000	3.46	3.26	3.10	2.96	2.84	2.74	2.65	2.57	2.50	2.43	2.37	2.32	2.27	2.22	2.17
400 000	3.53	3.33	3.17	3.03	2.91	2.80	2.71	2.63	2.55	2.49	2.42	2.37	2.32	2.27	2.22
450 000	3.60	3.40	3.23	3.09	2.96	2.86	2.76	2.68	2.60	2.53	2.47	2.42	2.36	2.31	2.27
500 000	3.66	3.46	3.29	3.14	3.02	2.91	2.81	2.73	2.65	2.58	2.52	2.46	2.40	2.35	2.31
600 000	3.77	3.56	3.39	3.24	3.11	3.00	2.90	2.81	2.73	2.66	2.59	2.53	2.48	2.43	2.38
700 000	3.87	3.65	3.47	3.32	3.19	3.07	2.97	2.88	2.80	2.73	2.66	2.60	2.54	2.49	2.44
800 000	3.95	3.73	3.55	3.39	3.26	3.14	3.04	2.95	2.86	2.79	2.72	2.66	2.60	2.55	2.50
900 000	4.03	3.80	3.62	3.46	3.32	3.20	3.10	3.00	2.92	2.84	2.77	2.71	2.65	2.60	2.55
1 000 000	4.09	3.87	3.68	3.52	3.38	3.26	3.15	3.06	2.97	2.89	2.82	2.76	2.70	2.64	2.59
1 500 000	4.36	4.12	3.93	3.76	3.61	3.49	3.37	3.27	3.18	3.10	3.02	2.95	2.89	2.83	2.77
2 000 000	4.55	4.31	4.11	3.94	3.78	3.65	3.53	3.43	3.33	3.25	3.17	3.09	3.03	2.96	2.91
2 500 000	4.70	4.46	4.25	4.08	3.92	3.79	3.66	3.56	3.46	3.37	3.29	3.21	3.14	3.08	3.02
3 000 000	4.83	4.58	4.37	4.19	4.04	3.90	3.77	3.66	3.56	3.47	3.39	3.31	3.24	3.17	3.11
3 500 000	4.94	4.69	4.48	4.29	4.14	3.99	3.87	3.76	3.65	3.56	3.47	3.39	3.32	3.25	3.19
4 000 000	5.03	4.78	4.57	4.38	4.22	4.08	3.95	3.84	3.73	3.64	3.55	3.47	3.39	3.32	3.26
4 500 000	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	3.39	3.32
5 000 000	5.19	4.94	4.72	4.53	4.37	4.22	4.09	3.98	3.87	3.77	3.68	3.60	3.52	3.45	3.38
6 000 000	5.33	5.07	4.85	4.66	4.49	4.34	4.21	4.09	3.98	3.88	3.79	3.71	3.63	3.55	3.49
7 000 000	5.44	5.18	4.96	4.76	4.60	4.45	4.31	4.19	4.08	3.98	3.88	3.80	3.72	3.64	3.57
8 000 000	5.54	5.28	5.05	4.86	4.69	4.54	4.40	4.28	4.17	4.06	3.97	3.88	3.80	3.72	3.65
9 000 000	5.63	5.36	5.14	4.94	4.77	4.62	4.48	4.36	4.24	4.14	4.04	3.95	3.87	3.79	3.72
10 000 000	5.71	5.44	5.21	5.02	4.84	4.69	4.55	4.43	4.31	4.21	4.11	4.02	3.94	3.86	3.79
15 000 000	6.03	5.75	5.51	5.31	5.13	4.97	4.83	4.70	4.58	4.47	4.37	4.28	4.19	4.11	4.04
20 000 000	6.26	5.98	5.73	5.53	5.34	5.18	5.03	4.90	4.78	4.67	4.57	4.47	4.38	4.30	4.22
25 000 000	6.45	6.15	5.91	5.70	5.51	5.34	5.20	5.06	4.94	4.83	4.72	4.62	4.53	4.45	4.37
30 000 000	6.60	6.30	6.05	5.84	5.65	5.48	5.33	5.19	5.07	4.95	4.85	4.75	4.66	4.57	4.49
35 000 000	6.73	6.43	6.18	5.96	5.77	5.60	5.44	5.31	5.18	5.06	4.96	4.86	4.76	4.68	4.60
40 000 000	6.85	6.54	6.29	6.06	5.87	5.70	5.54	5.41	5.28	5.16	5.05	4.95	4.86	4.77	4.69
45 000 000	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	4.85	4.77
50 000 000	7.04	6.73	6.47	6.24	6.05	5.87	5.72	5.57	5.44	5.32	5.21	5.11	5.02	4.93	4.84
60 000 000	7.21	6.89	6.62	6.39	6.19	6.02	5.86	5.71	5.58	5.46	5.35	5.25	5.15	5.06	4.97
70 000 000	7.35	7.03	6.75	6.52	6.32	6.14	5.98	5.83	5.70	5.58	5.46	5.36	5.26	5.17	5.08
80 000 000	7.47	7.14	6.87	6.63	6.43	6.25	6.08	5.94	5.80	5.68	5.56	5.46	5.36	5.27	5.18
90 000 000	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	5.35	5.27
100 000 000	7.68	7.35	7.07	6.83	6.62	6.43	6.27	6.11	5.98	5.85	5.73	5.63	5.53	5.43	5.34

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	1.76	1.69	1.63	1.58	1.53	1.48	1.44	1.41	1.37	1.34	1.31	1.24	1.18	1.13	1.09
150 000	1.88	1.81	1.75	1.69	1.64	1.60	1.55	1.52	1.48	1.45	1.41	1.34	1.28	1.23	1.18
200 000	1.98	1.90	1.84	1.78	1.73	1.68	1.64	1.60	1.56	1.52	1.49	1.42	1.35	1.30	1.25
250 000	2.05	1.98	1.91	1.85	1.80	1.75	1.70	1.66	1.62	1.59	1.55	1.48	1.41	1.35	1.30
300 000	2.12	2.04	1.97	1.91	1.85	1.80	1.76	1.72	1.68	1.64	1.60	1.53	1.46	1.40	1.35
350 000	2.17	2.09	2.02	1.96	1.90	1.85	1.81	1.76	1.72	1.68	1.65	1.57	1.50	1.44	1.39
400 000	2.22	2.14	2.07	2.01	1.95	1.90	1.85	1.80	1.76	1.72	1.69	1.61	1.54	1.48	1.42
450 000	2.27	2.19	2.11	2.05	1.99	1.93	1.89	1.84	1.80	1.76	1.72	1.64	1.57	1.51	1.46
500 000	2.31	2.22	2.15	2.08	2.02	1.97	1.92	1.87	1.83	1.79	1.76	1.67	1.60	1.54	1.48
600 000	2.38	2.29	2.22	2.15	2.09	2.03	1.98	1.93	1.89	1.85	1.81	1.73	1.66	1.59	1.53
700 000	2.44	2.35	2.27	2.21	2.14	2.09	2.03	1.99	1.94	1.90	1.86	1.78	1.70	1.64	1.58
800 000	2.50	2.41	2.33	2.26	2.19	2.13	2.08	2.03	1.99	1.94	1.90	1.82	1.74	1.67	1.62
900 000	2.55	2.45	2.37	2.30	2.23	2.18	2.12	2.07	2.03	1.98	1.94	1.85	1.78	1.71	1.65
1 000 000	2.59	2.50	2.41	2.34	2.27	2.21	2.16	2.11	2.06	2.02	1.98	1.89	1.81	1.74	1.68
1 500 000	2.77	2.67	2.58	2.50	2.43	2.37	2.31	2.26	2.21	2.16	2.12	2.02	1.94	1.87	1.80
2 000 000	2.91	2.80	2.71	2.63	2.55	2.49	2.42	2.37	2.32	2.27	2.22	2.12	2.04	1.96	1.90
2 500 000	3.02	2.91	2.81	2.73	2.65	2.58	2.52	2.46	2.40	2.35	2.31	2.21	2.12	2.04	1.97
3 000 000	3.11	3.00	2.90	2.81	2.73	2.66	2.59	2.53	2.48	2.43	2.38	2.27	2.18	2.10	2.03
3 500 000	3.19	3.07	2.97	2.88	2.80	2.73	2.66	2.60	2.54	2.49	2.44	2.33	2.24	2.16	2.09
4 000 000	3.26	3.14	3.04	2.95	2.86	2.79	2.72	2.66	2.60	2.55	2.50	2.39	2.29	2.21	2.13
4 500 000	3.32	3.21	3.10	3.01	2.92	2.84	2.77	2.71	2.65	2.60	2.55	2.43	2.34	2.25	2.18
5 000 000	3.38	3.26	3.15	3.06	2.97	2.89	2.82	2.76	2.70	2.64	2.59	2.48	2.38	2.29	2.21
6 000 000	3.49	3.36	3.25	3.15	3.06	2.98	2.91	2.84	2.78	2.72	2.67	2.55	2.45	2.36	2.28
7 000 000	3.57	3.45	3.33	3.23	3.14	3.06	2.99	2.92	2.85	2.79	2.74	2.62	2.51	2.42	2.34
8 000 000	3.65	3.52	3.41	3.31	3.21	3.13	3.05	2.98	2.92	2.86	2.80	2.68	2.57	2.48	2.40
9 000 000	3.72	3.59	3.48	3.37	3.28	3.19	3.11	3.04	2.97	2.91	2.86	2.73	2.62	2.53	2.44
10 000 000	3.79	3.65	3.54	3.43	3.33	3.25	3.17	3.09	3.03	2.97	2.91	2.78	2.67	2.57	2.49
15 000 000	4.04	3.90	3.78	3.66	3.56	3.47	3.39	3.31	3.24	3.17	3.11	2.97	2.85	2.75	2.66
20 000 000	4.22	4.08	3.95	3.84	3.73	3.64	3.55	3.47	3.40	3.33	3.26	3.12	2.99	2.89	2.79
25 000 000	4.37	4.22	4.09	3.98	3.87	3.77	3.68	3.60	3.52	3.45	3.38	3.23	3.11	2.99	2.90
30 000 000	4.49	4.34	4.21	4.09	3.98	3.88	3.79	3.71	3.63	3.55	3.49	3.33	3.20	3.09	2.98
35 000 000	4.60	4.45	4.31	4.19	4.08	3.98	3.89	3.80	3.72	3.64	3.57	3.42	3.28	3.17	3.06
40 000 000	4.69	4.54	4.40	4.28	4.17	4.06	3.97	3.88	3.80	3.72	3.65	3.49	3.36	3.24	3.13
45 000 000	4.77	4.62	4.48	4.36	4.24	4.14	4.04	3.95	3.87	3.79	3.72	3.56	3.42	3.30	3.19
50 000 000	4.84	4.69	4.55	4.43	4.31	4.21	4.11	4.02	3.94	3.86	3.79	3.62	3.48	3.36	3.25
60 000 000	4.97	4.82	4.68	4.55	4.43	4.33	4.23	4.14	4.05	3.97	3.90	3.73	3.59	3.46	3.35
70 000 000	5.08	4.92	4.78	4.65	4.54	4.43	4.33	4.24	4.15	4.07	4.00	3.83	3.68	3.55	3.43
80 000 000	5.18	5.02	4.88	4.75	4.63	4.52	4.42	4.32	4.24	4.16	4.08	3.91	3.76	3.63	3.51
90 000 000	5.27	5.10	4.96	4.83	4.71	4.60	4.50	4.40	4.32	4.23	4.16	3.98	3.83	3.70	3.58
100 000 000	5.34	5.18	5.04	4.90	4.78	4.67	4.57	4.47	4.38	4.30	4.22	4.05	3.89	3.76	3.64

TABLE A.3C

REQUIRED STRUCTURAL NUMBER (SN_R)
85% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 300 MPa TO 650 MPa

	Resilient Modulus (M_R), MPa														
$ESAL_D$	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
100 000	1.09	1.04	1.01	0.97	0.94	0.91	0.88	0.86	0.84	0.81	0.79	0.77	0.75	0.74	0.72
150 000	1.18	1.14	1.10	1.06	1.03	1.00	0.97	0.94	0.92	0.89	0.87	0.85	0.83	0.81	0.80
200 000	1.25	1.20	1.16	1.13	1.09	1.06	1.03	1.00	0.98	0.95	0.93	0.91	0.89	0.87	0.85
250 000	1.30	1.26	1.22	1.18	1.14	1.11	1.08	1.05	1.03	1.00	0.98	0.96	0.94	0.92	0.90
300 000	1.35	1.30	1.26	1.22	1.19	1.15	1.12	1.09	1.07	1.04	1.02	1.00	0.97	0.95	0.94
350 000	1.39	1.34	1.30	1.26	1.22	1.19	1.16	1.13	1.10	1.08	1.05	1.03	1.01	0.99	0.97
400 000	1.42	1.38	1.33	1.29	1.25	1.22	1.19	1.16	1.13	1.11	1.08	1.06	1.04	1.02	1.00
450 000	1.46	1.41	1.36	1.32	1.28	1.25	1.22	1.19	1.16	1.13	1.11	1.08	1.06	1.04	1.02
500 000	1.48	1.43	1.39	1.35	1.31	1.27	1.24	1.21	1.18	1.16	1.13	1.11	1.09	1.06	1.04
600 000	1.53	1.48	1.44	1.39	1.36	1.32	1.29	1.26	1.23	1.20	1.17	1.15	1.13	1.11	1.09
700 000	1.58	1.53	1.48	1.44	1.40	1.36	1.33	1.29	1.26	1.24	1.21	1.19	1.16	1.14	1.12
800 000	1.62	1.56	1.52	1.47	1.43	1.39	1.36	1.33	1.30	1.27	1.24	1.22	1.19	1.17	1.15
900 000	1.65	1.60	1.55	1.50	1.46	1.43	1.39	1.36	1.33	1.30	1.27	1.25	1.22	1.20	1.18
1 000 000	1.68	1.63	1.58	1.53	1.49	1.45	1.42	1.39	1.35	1.33	1.30	1.27	1.25	1.23	1.20
1 500 000	1.80	1.75	1.70	1.65	1.60	1.56	1.53	1.49	1.46	1.43	1.40	1.38	1.35	1.33	1.30
2 000 000	1.90	1.84	1.78	1.73	1.69	1.65	1.61	1.57	1.54	1.51	1.48	1.45	1.42	1.40	1.38
2 500 000	1.97	1.91	1.85	1.80	1.76	1.71	1.67	1.64	1.60	1.57	1.54	1.51	1.48	1.46	1.43
3 000 000	2.03	1.97	1.91	1.86	1.81	1.77	1.73	1.69	1.66	1.62	1.59	1.56	1.53	1.51	1.48
3 500 000	2.09	2.02	1.96	1.91	1.86	1.82	1.78	1.74	1.70	1.67	1.64	1.61	1.58	1.55	1.53
4 000 000	2.13	2.07	2.01	1.95	1.90	1.86	1.82	1.78	1.74	1.71	1.68	1.65	1.62	1.59	1.56
4 500 000	2.18	2.11	2.05	1.99	1.94	1.90	1.85	1.81	1.78	1.74	1.71	1.68	1.65	1.62	1.60
5 000 000	2.21	2.15	2.09	2.03	1.98	1.93	1.89	1.85	1.81	1.78	1.74	1.71	1.68	1.65	1.63
6 000 000	2.28	2.21	2.15	2.09	2.04	1.99	1.95	1.91	1.87	1.83	1.80	1.77	1.74	1.71	1.68
7 000 000	2.34	2.27	2.21	2.15	2.09	2.05	2.00	1.96	1.92	1.88	1.85	1.81	1.78	1.75	1.73
8 000 000	2.40	2.32	2.26	2.20	2.14	2.09	2.05	2.00	1.96	1.93	1.89	1.86	1.83	1.80	1.77
9 000 000	2.44	2.37	2.30	2.24	2.19	2.13	2.09	2.04	2.00	1.96	1.93	1.89	1.86	1.83	1.80
10 000 000	2.49	2.41	2.34	2.28	2.22	2.17	2.12	2.08	2.04	2.00	1.96	1.93	1.90	1.87	1.84
15 000 000	2.66	2.58	2.51	2.44	2.38	2.33	2.27	2.23	2.18	2.14	2.10	2.07	2.03	2.00	1.97
20 000 000	2.79	2.71	2.63	2.56	2.50	2.44	2.39	2.34	2.29	2.25	2.21	2.17	2.13	2.10	2.07
25 000 000	2.90	2.81	2.73	2.66	2.59	2.53	2.48	2.43	2.38	2.33	2.29	2.25	2.22	2.18	2.15
30 000 000	2.98	2.89	2.81	2.74	2.67	2.61	2.55	2.50	2.45	2.41	2.36	2.32	2.28	2.25	2.21
35 000 000	3.06	2.97	2.89	2.81	2.74	2.68	2.62	2.57	2.51	2.47	2.42	2.38	2.34	2.31	2.27
40 000 000	3.13	3.04	2.95	2.87	2.80	2.74	2.68	2.62	2.57	2.52	2.48	2.44	2.40	2.36	2.32
45 000 000	3.19	3.10	3.01	2.93	2.86	2.79	2.73	2.67	2.62	2.57	2.53	2.48	2.44	2.41	2.37
50 000 000	3.25	3.15	3.06	2.98	2.91	2.84	2.78	2.72	2.67	2.62	2.57	2.53	2.49	2.45	2.41
60 000 000	3.35	3.25	3.16	3.07	3.00	2.93	2.86	2.81	2.75	2.70	2.65	2.61	2.56	2.52	2.49
70 000 000	3.43	3.33	3.24	3.15	3.07	3.00	2.94	2.88	2.82	2.77	2.72	2.67	2.63	2.59	2.55
80 000 000	3.51	3.40	3.31	3.22	3.14	3.07	3.00	2.94	2.88	2.83	2.78	2.73	2.69	2.65	2.61
90 000 000	3.58	3.47	3.37	3.29	3.21	3.13	3.06	3.00	2.94	2.89	2.84	2.79	2.74	2.70	2.66
100 000 000	3.64	3.53	3.43	3.34	3.26	3.19	3.12	3.05	2.99	2.94	2.89	2.84	2.79	2.75	2.71

TABLE A.4A

REQUIRED STRUCTURAL NUMBER (SN_R)
90% 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	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	1.87	1.83
150 000	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	2.01	1.97
200 000	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	2.11	2.06
250 000	3.41	3.22	3.05	2.92	2.80	2.70	2.61	2.53	2.46	2.40	2.34	2.28	2.23	2.19	2.14
300 000	3.51	3.31	3.15	3.01	2.89	2.79	2.69	2.61	2.54	2.47	2.41	2.35	2.30	2.26	2.21
350 000	3.60	3.40	3.23	3.09	2.96	2.86	2.76	2.68	2.60	2.54	2.47	2.42	2.36	2.31	2.27
400 000	3.68	3.47	3.30	3.16	3.03	2.92	2.83	2.74	2.66	2.59	2.53	2.47	2.42	2.37	2.32
450 000	3.75	3.54	3.37	3.22	3.09	2.98	2.88	2.79	2.71	2.64	2.58	2.52	2.46	2.41	2.37
500 000	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	2.46	2.41
600 000	3.93	3.71	3.53	3.37	3.24	3.12	3.02	2.93	2.85	2.77	2.70	2.64	2.59	2.53	2.48
700 000	4.03	3.80	3.62	3.46	3.32	3.21	3.10	3.01	2.92	2.85	2.78	2.71	2.65	2.60	2.55
800 000	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	2.66	2.60
900 000	4.19	3.96	3.77	3.61	3.47	3.34	3.23	3.13	3.05	2.97	2.89	2.83	2.77	2.71	2.66
1 000 000	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	2.76	2.70
1 500 000	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	2.95	2.89
2 000 000	4.72	4.48	4.27	4.10	3.94	3.80	3.68	3.57	3.48	3.39	3.30	3.23	3.16	3.09	3.03
2 500 000	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	3.21	3.15
3 000 000	5.01	4.76	4.54	4.36	4.20	4.06	3.93	3.82	3.71	3.62	3.53	3.45	3.38	3.31	3.24
3 500 000	5.12	4.86	4.65	4.46	4.30	4.16	4.03	3.91	3.80	3.71	3.62	3.54	3.46	3.39	3.33
4 000 000	5.22	4.96	4.74	4.55	4.39	4.24	4.11	3.99	3.89	3.79	3.70	3.62	3.54	3.47	3.40
4 500 000	5.30	5.04	4.82	4.63	4.47	4.32	4.19	4.07	3.96	3.86	3.77	3.68	3.61	3.53	3.47
5 000 000	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	3.60	3.53
6 000 000	5.52	5.25	5.03	4.83	4.66	4.51	4.38	4.26	4.14	4.04	3.95	3.86	3.78	3.70	3.63
7 000 000	5.64	5.37	5.14	4.94	4.77	4.62	4.48	4.36	4.24	4.14	4.04	3.96	3.87	3.80	3.72
8 000 000	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	3.88	3.80
9 000 000	5.83	5.55	5.32	5.12	4.95	4.79	4.65	4.52	4.41	4.30	4.21	4.11	4.03	3.95	3.88
10 000 000	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	4.02	3.94
15 000 000	6.24	5.95	5.71	5.50	5.32	5.16	5.01	4.88	4.76	4.65	4.54	4.45	4.36	4.28	4.20
20 000 000	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	4.47	4.39
25 000 000	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	4.62	4.54
30 000 000	6.82	6.51	6.26	6.04	5.84	5.67	5.52	5.38	5.25	5.14	5.03	4.93	4.83	4.75	4.66
35 000 000	6.95	6.64	6.38	6.16	5.97	5.79	5.64	5.50	5.37	5.25	5.14	5.04	4.94	4.85	4.77
40 000 000	7.07	6.76	6.49	6.27	6.07	5.90	5.74	5.60	5.47	5.35	5.24	5.13	5.04	4.95	4.87
45 000 000	7.18	6.86	6.59	6.37	6.17	5.99	5.83	5.69	5.56	5.43	5.32	5.22	5.12	5.03	4.95
50 000 000	7.27	6.95	6.68	6.45	6.25	6.07	5.91	5.77	5.64	5.51	5.40	5.30	5.20	5.11	5.02
60 000 000	7.44	7.11	6.84	6.61	6.40	6.22	6.06	5.91	5.78	5.65	5.54	5.43	5.33	5.24	5.16
70 000 000	7.58	7.25	6.98	6.74	6.53	6.35	6.18	6.03	5.90	5.77	5.66	5.55	5.45	5.36	5.27
80 000 000	7.71	7.37	7.09	6.85	6.64	6.46	6.29	6.14	6.00	5.88	5.76	5.65	5.55	5.45	5.37
90 000 000	7.82	7.48	7.20	6.96	6.74	6.56	6.39	6.23	6.10	5.97	5.85	5.74	5.64	5.54	5.45
100 000 000	7.92	7.58	7.29	7.05	6.83	6.64	6.47	6.32	6.18	6.05	5.93	5.82	5.72	5.62	5.53

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	1.83	1.77	1.70	1.65	1.60	1.55	1.51	1.47	1.44	1.41	1.37	1.30	1.24	1.19	1.14
150 000	1.97	1.89	1.83	1.77	1.72	1.67	1.63	1.59	1.55	1.51	1.48	1.41	1.35	1.29	1.24
200 000	2.06	1.99	1.92	1.86	1.81	1.76	1.71	1.67	1.63	1.60	1.56	1.49	1.42	1.36	1.31
250 000	2.14	2.07	2.00	1.93	1.88	1.83	1.78	1.74	1.70	1.66	1.63	1.55	1.48	1.42	1.37
300 000	2.21	2.13	2.06	1.99	1.94	1.88	1.84	1.79	1.75	1.71	1.68	1.60	1.53	1.47	1.42
350 000	2.27	2.19	2.11	2.05	1.99	1.94	1.89	1.84	1.80	1.76	1.72	1.64	1.57	1.51	1.46
400 000	2.32	2.24	2.16	2.09	2.03	1.98	1.93	1.88	1.84	1.80	1.77	1.68	1.61	1.55	1.49
450 000	2.37	2.28	2.20	2.14	2.08	2.02	1.97	1.92	1.88	1.84	1.80	1.72	1.65	1.58	1.53
500 000	2.41	2.32	2.24	2.17	2.11	2.06	2.00	1.96	1.91	1.87	1.83	1.75	1.68	1.61	1.55
600 000	2.48	2.39	2.31	2.24	2.18	2.12	2.07	2.02	1.97	1.93	1.89	1.81	1.73	1.66	1.61
700 000	2.55	2.45	2.37	2.30	2.24	2.18	2.12	2.07	2.03	1.98	1.94	1.85	1.78	1.71	1.65
800 000	2.60	2.51	2.43	2.35	2.29	2.23	2.17	2.12	2.07	2.03	1.99	1.90	1.82	1.75	1.69
900 000	2.66	2.56	2.48	2.40	2.33	2.27	2.21	2.16	2.11	2.07	2.03	1.94	1.86	1.79	1.73
1 000 000	2.70	2.60	2.52	2.44	2.37	2.31	2.25	2.20	2.15	2.11	2.07	1.97	1.89	1.82	1.76
1 500 000	2.89	2.79	2.69	2.61	2.54	2.47	2.41	2.36	2.30	2.26	2.21	2.11	2.03	1.95	1.89
2 000 000	3.03	2.92	2.83	2.74	2.66	2.59	2.53	2.47	2.42	2.37	2.32	2.22	2.13	2.05	1.98
2 500 000	3.15	3.03	2.93	2.84	2.76	2.69	2.63	2.56	2.51	2.46	2.41	2.30	2.21	2.13	2.06
3 000 000	3.24	3.13	3.02	2.93	2.85	2.77	2.71	2.64	2.59	2.53	2.48	2.37	2.28	2.19	2.12
3 500 000	3.33	3.21	3.10	3.01	2.92	2.85	2.78	2.71	2.65	2.60	2.55	2.43	2.34	2.25	2.18
4 000 000	3.40	3.28	3.17	3.07	2.99	2.91	2.84	2.77	2.71	2.66	2.60	2.49	2.39	2.30	2.23
4 500 000	3.47	3.34	3.23	3.13	3.05	2.97	2.89	2.83	2.77	2.71	2.66	2.54	2.44	2.35	2.27
5 000 000	3.53	3.40	3.29	3.19	3.10	3.02	2.95	2.88	2.81	2.76	2.70	2.58	2.43	2.39	2.31
6 000 000	3.63	3.50	3.39	3.29	3.20	3.11	3.04	2.97	2.90	2.84	2.79	2.66	2.56	2.46	2.38
7 000 000	3.72	3.59	3.48	3.37	3.28	3.19	3.11	3.04	2.98	2.91	2.86	2.73	2.62	2.53	2.27
8 000 000	3.80	3.67	3.55	3.45	3.35	3.26	3.18	3.11	3.04	2.98	2.92	2.79	2.68	2.58	2.50
9 000 000	3.88	3.74	3.62	3.51	3.42	3.33	3.25	3.17	3.10	3.04	2.98	2.85	2.73	2.64	2.55
10 000 000	3.94	3.81	3.68	3.58	3.48	3.39	3.30	3.23	3.16	3.09	3.03	2.90	2.78	2.68	2.59
15 000 000	4.20	4.06	3.93	3.82	3.71	3.62	3.53	3.45	3.38	3.31	3.24	3.10	2.98	2.87	2.77
20 000 000	4.39	4.24	4.11	4.00	3.89	3.79	3.70	3.62	3.54	3.47	3.40	3.25	3.12	3.01	2.91
25 000 000	4.54	4.39	4.26	4.14	4.03	3.93	3.83	3.75	3.67	3.60	3.53	3.37	3.24	3.12	3.02
30 000 000	4.66	4.51	4.38	4.26	4.14	4.04	3.95	3.86	3.78	3.70	3.63	3.47	3.34	3.22	3.11
35 000 000	4.77	4.62	4.48	4.36	4.24	4.14	4.04	3.96	3.87	3.80	3.72	3.56	3.42	3.30	3.19
40 000 000	4.87	4.71	4.57	4.45	4.33	4.23	4.13	4.04	3.96	3.88	3.81	3.64	3.50	3.37	3.26
45 000 000	4.95	4.79	4.65	4.53	4.41	4.30	4.21	4.12	4.03	3.95	3.88	3.71	3.57	3.44	3.33
50 000 000	5.02	4.87	4.73	4.60	4.48	4.37	4.28	4.18	4.10	4.02	3.94	3.77	3.63	3.50	3.39
60 000 000	5.16	5.00	4.85	4.72	4.60	4.50	4.40	4.30	4.22	4.13	4.06	3.89	3.74	3.61	3.49
70 000 000	5.27	5.11	4.96	4.83	4.71	4.60	4.50	4.40	4.32	4.23	4.16	3.98	3.83	3.70	3.58
80 000 000	5.37	5.20	5.06	4.92	4.80	4.69	4.59	4.49	4.41	4.32	4.24	4.07	3.91	3.78	3.66
90 000 000	5.45	5.29	5.14	5.01	4.89	4.77	4.67	4.57	4.48	4.40	4.32	4.14	3.99	3.85	3.73
100 000 000	5.53	5.37	5.22	5.08	4.96	4.85	4.74	4.65	4.56	4.47	4.39	4.21	4.05	3.91	3.79

TABLE A.4C

REQUIRED STRUCTURAL NUMBER (SN_R)
90% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 300 MPa TO 650 MPa

	Resilient Modulus (M_R), MPa														
$ESAL_D$	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
100 000	1.14	1.10	1.06	1.03	0.99	0.96	0.94	0.91	0.89	0.86	0.84	0.82	0.80	0.78	0.77
150 000	1.24	1.20	1.15	1.12	1.08	1.05	1.02	1.00	0.97	0.95	0.92	0.90	0.88	0.86	0.85
200 000	1.31	1.26	1.22	1.18	1.15	1.12	1.09	1.06	1.03	1.01	0.98	0.96	0.94	0.92	0.90
250 000	1.37	1.32	1.28	1.24	1.20	1.17	1.14	1.11	1.08	1.06	1.03	1.01	0.99	0.97	0.95
300 000	1.42	1.37	1.32	1.28	1.25	1.21	1.18	1.15	1.12	1.10	1.07	1.05	1.03	1.01	0.99
350 000	1.46	1.41	1.36	1.32	1.28	1.25	1.22	1.19	1.16	1.13	1.11	1.09	1.06	1.04	1.02
400 000	1.49	1.44	1.40	1.36	1.32	1.28	1.25	1.22	1.19	1.16	1.14	1.12	1.09	1.07	1.05
450 000	1.53	1.47	1.43	1.39	1.35	1.31	1.28	1.25	1.22	1.19	1.17	1.14	1.12	1.10	1.08
500 000	1.55	1.50	1.46	1.41	1.37	1.34	1.30	1.27	1.24	1.22	1.19	1.17	1.14	1.12	1.10
600 000	1.61	1.55	1.51	1.46	1.42	1.39	1.35	1.32	1.29	1.26	1.24	1.21	1.19	1.16	1.14
700 000	1.65	1.60	1.55	1.50	1.46	1.43	1.39	1.36	1.33	1.30	1.27	1.25	1.22	1.20	1.18
800 000	1.69	1.64	1.59	1.54	1.50	1.46	1.43	1.39	1.36	1.33	1.31	1.28	1.26	1.23	1.21
900 000	1.73	1.67	1.62	1.57	1.53	1.49	1.46	1.42	1.39	1.36	1.34	1.31	1.29	1.26	1.24
1 000 000	1.76	1.70	1.65	1.60	1.56	1.52	1.49	1.45	1.42	1.39	1.36	1.34	1.31	1.29	1.27
1 500 000	1.89	1.83	1.77	1.72	1.68	1.64	1.60	1.56	1.53	1.50	1.47	1.44	1.42	1.39	1.37
2 000 000	1.98	1.92	1.86	1.81	1.77	1.72	1.68	1.65	1.61	1.58	1.55	1.52	1.49	1.47	1.44
2 500 000	2.06	1.99	1.94	1.88	1.84	1.79	1.75	1.71	1.68	1.64	1.61	1.58	1.55	1.53	1.50
3 000 000	2.12	2.06	2.00	1.94	1.89	1.85	1.81	1.77	1.73	1.70	1.67	1.64	1.61	1.58	1.55
3 500 000	2.18	2.11	2.05	1.99	1.94	1.90	1.86	1.82	1.78	1.74	1.71	1.68	1.65	1.62	1.60
4 000 000	2.23	2.16	2.10	2.04	1.99	1.94	1.90	1.86	1.82	1.78	1.75	1.72	1.69	1.66	1.64
4 500 000	2.27	2.20	2.14	2.08	2.03	1.98	1.94	1.90	1.86	1.82	1.79	1.76	1.73	1.70	1.67
5 000 000	2.31	2.24	2.18	2.12	2.07	2.02	1.97	1.93	1.89	1.85	1.82	1.79	1.76	1.73	1.70
6 000 000	2.38	2.31	2.24	2.18	2.13	2.08	2.03	1.99	1.95	1.91	1.88	1.85	1.81	1.78	1.76
7 000 000	2.44	2.37	2.30	2.24	2.19	2.14	2.09	2.04	2.00	1.97	1.93	1.90	1.86	1.83	1.80
8 000 000	2.50	2.42	2.35	2.29	2.24	2.18	2.14	2.09	2.05	2.01	1.97	1.94	1.91	1.88	1.85
9 000 000	2.55	2.47	2.40	2.34	2.28	2.23	2.18	2.13	2.09	2.05	2.01	1.98	1.95	1.91	1.88
10 000 000	2.59	2.52	2.44	2.38	2.32	2.27	2.22	2.17	2.13	2.09	2.05	2.01	1.98	1.95	1.92
15 000 000	2.77	2.69	2.61	2.55	2.48	2.43	2.37	2.32	2.28	2.24	2.19	2.16	2.12	2.09	2.06
20 000 000	2.91	2.82	2.74	2.67	2.61	2.54	2.49	2.44	2.39	2.35	2.30	2.26	2.23	2.19	2.16
25 000 000	3.02	2.93	2.85	2.77	2.70	2.64	2.58	2.53	2.48	2.43	2.39	2.35	2.31	2.28	2.24
30 000 000	3.11	3.02	2.93	2.86	2.79	2.72	2.66	2.61	2.56	2.51	2.46	2.42	2.38	2.35	2.31
35 000 000	3.19	3.10	3.01	2.93	2.86	2.79	2.73	2.68	2.62	2.57	2.53	2.49	2.45	2.41	2.37
40 000 000	3.26	3.17	3.08	3.00	2.92	2.86	2.79	2.74	2.68	2.63	2.59	2.54	2.50	2.46	2.42
45 000 000	3.33	3.23	3.14	3.06	2.98	2.91	2.85	2.79	2.73	2.68	2.64	2.59	2.55	2.51	2.47
50 000 000	3.39	3.28	3.19	3.11	3.03	2.96	2.90	2.84	2.78	2.73	2.68	2.64	2.59	2.55	2.52
60 000 000	3.49	3.38	3.29	3.20	3.13	3.05	2.99	2.93	2.87	2.82	2.77	2.72	2.67	2.63	2.59
70 000 000	3.58	3.47	3.37	3.29	3.21	3.13	3.06	3.00	2.94	2.89	2.84	2.79	2.74	2.70	2.66
80 000 000	3.66	3.55	3.45	3.36	3.28	3.20	3.13	3.07	3.01	2.95	2.90	2.85	2.80	2.76	2.72
90 000 000	3.73	3.62	3.52	3.43	3.34	3.27	3.20	3.13	3.07	3.01	2.96	2.91	2.86	2.82	2.77
100 000 000	3.79	3.68	3.58	3.49	3.40	3.32	3.25	3.18	3.12	3.06	3.01	2.96	2.91	2.87	2.82

TABLE A.5A

REQUIRED STRUCTURAL NUMBER (SN_R)
92% 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	2.99	2.82	2.68	2.56	2.46	2.37	2.29	2.22	2.16	2.10	2.05	2.00	1.96	1.91	1.87
150 000	3.20	3.02	2.87	2.74	2.63	2.54	2.45	2.38	2.31	2.25	2.19	2.14	2.09	2.05	2.01
200 000	3.36	3.17	3.01	2.87	2.76	2.66	2.57	2.49	2.42	2.36	2.30	2.25	2.20	2.15	2.11
250 000	3.48	3.28	3.12	2.98	2.86	2.76	2.67	2.59	2.52	2.45	2.39	2.33	2.28	2.23	2.19
300 000	3.59	3.38	3.22	3.07	2.95	2.84	2.75	2.67	2.59	2.52	2.46	2.41	2.35	2.30	2.26
350 000	3.68	3.47	3.30	3.15	3.03	2.92	2.82	2.74	2.66	2.59	2.53	2.47	2.41	2.36	2.32
400 000	3.76	3.55	3.37	3.22	3.10	2.98	2.89	2.80	2.72	2.65	2.58	2.52	2.47	2.42	2.37
450 000	3.83	3.62	3.44	3.29	3.16	3.04	2.94	2.85	2.77	2.70	2.63	2.57	2.52	2.47	2.42
500 000	3.90	3.68	3.50	3.34	3.21	3.10	2.99	2.90	2.82	2.75	2.68	2.62	2.56	2.51	2.46
600 000	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	2.59	2.54
700 000	4.11	3.88	3.69	3.53	3.40	3.27	3.17	3.07	2.98	2.91	2.83	2.77	2.71	2.65	2.60
800 000	4.19	3.97	3.77	3.61	3.47	3.35	3.24	3.14	3.05	2.97	2.90	2.83	2.77	2.71	2.66
900 000	4.27	4.04	3.85	3.68	3.54	3.41	3.30	3.20	3.11	3.03	2.96	2.89	2.82	2.77	2.71
1 000 000	4.34	4.11	3.91	3.74	3.60	3.47	3.36	3.26	3.17	3.08	3.01	2.94	2.87	2.81	2.76
1 500 000	4.61	4.37	4.17	3.99	3.84	3.71	3.59	3.48	3.39	3.30	3.22	3.14	3.07	3.01	2.95
2 000 000	4.81	4.57	4.36	4.18	4.02	3.88	3.76	3.65	3.55	3.46	3.37	3.30	3.22	3.16	3.10
2 500 000	4.97	4.72	4.51	4.32	4.16	4.02	3.90	3.78	3.68	3.59	3.50	3.42	3.35	3.28	3.21
3 000 000	5.10	4.85	4.63	4.45	4.28	4.14	4.01	3.89	3.79	3.69	3.60	3.52	3.45	3.38	3.31
3 500 000	5.21	4.95	4.74	4.55	4.39	4.24	4.11	3.99	3.88	3.79	3.69	3.61	3.53	3.46	3.40
4 000 000	5.31	5.05	4.83	4.64	4.47	4.33	4.19	4.08	3.97	3.87	3.78	3.69	3.61	3.54	3.47
4 500 000	5.40	5.14	4.91	4.72	4.55	4.41	4.27	4.15	4.04	3.94	3.85	3.76	3.68	3.61	3.54
5 000 000	5.48	5.21	4.99	4.80	4.63	4.48	4.34	4.22	4.11	4.01	3.91	3.83	3.74	3.67	3.60
6 000 000	5.61	5.35	5.12	4.92	4.75	4.60	4.46	4.34	4.23	4.12	4.03	3.94	3.86	3.78	3.71
7 000 000	5.73	5.46	5.23	5.03	4.86	4.71	4.57	4.44	4.33	4.22	4.13	4.04	3.95	3.87	3.80
8 000 000	5.84	5.56	5.33	5.13	4.95	4.80	4.66	4.53	4.42	4.31	4.21	4.12	4.04	3.96	3.88
9 000 000	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	4.03	3.96
10 000 000	6.01	5.73	5.50	5.29	5.11	4.96	4.81	4.68	4.57	4.46	4.36	4.27	4.18	4.10	4.02
15 000 000	6.34	6.05	5.81	5.60	5.41	5.25	5.10	4.97	4.85	4.73	4.63	4.54	4.45	4.36	4.28
20 000 000	6.58	6.28	6.03	5.82	5.63	5.46	5.31	5.18	5.05	4.94	4.83	4.73	4.64	4.56	4.48
25 000 000	6.77	6.47	6.21	5.99	5.80	5.63	5.48	5.34	5.21	5.10	4.99	4.89	4.80	4.71	4.63
30 000 000	6.93	6.62	6.36	6.14	5.94	5.77	5.62	5.48	5.35	5.23	5.12	5.02	4.92	4.84	4.75
35 000 000	7.07	6.75	6.49	6.26	6.07	5.89	5.73	5.59	5.46	5.34	5.23	5.13	5.03	4.94	4.86
40 000 000	7.19	6.87	6.60	6.37	6.17	6.00	5.84	5.69	5.56	5.44	5.33	5.23	5.13	5.04	4.96
45 000 000	7.29	6.97	6.70	6.47	6.27	6.09	5.93	5.78	5.65	5.53	5.42	5.31	5.22	5.13	5.04
50 000 000	7.39	7.06	6.79	6.56	6.36	6.18	6.01	5.87	5.73	5.61	5.50	5.39	5.29	5.20	5.12
60 000 000	7.56	7.23	6.95	6.71	6.51	6.32	6.16	6.01	5.88	5.75	5.64	5.53	5.43	5.34	5.25
70 000 000	7.70	7.37	7.09	6.85	6.64	6.45	6.29	6.13	6.00	5.87	5.75	5.65	5.54	5.45	5.36
80 000 000	7.83	7.49	7.21	6.96	6.75	6.56	6.39	6.24	6.10	5.98	5.86	5.75	5.65	5.55	5.46
90 000 000	7.94	7.60	7.32	7.07	6.85	6.66	6.49	6.34	6.20	6.07	5.95	5.84	5.74	5.64	5.55
100 000 000	8.05	7.70	7.41	7.16	6.95	6.75	6.58	6.43	6.28	6.15	6.03	5.92	5.82	5.72	5.63

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	1.87	1.80	1.74	1.69	1.64	1.59	1.55	1.51	1.47	1.44	1.41	1.34	1.28	1.22	1.17
150 000	2.01	1.94	1.87	1.81	1.76	1.71	1.66	1.62	1.59	1.55	1.52	1.44	1.38	1.32	1.27
200 000	2.11	2.03	1.96	1.90	1.85	1.80	1.75	1.71	1.67	1.63	1.60	1.52	1.45	1.40	1.34
250 000	2.19	2.11	2.04	1.98	1.92	1.87	1.82	1.78	1.74	1.70	1.66	1.58	1.51	1.45	1.40
300 000	2.26	2.18	2.10	2.04	1.98	1.93	1.88	1.83	1.79	1.75	1.72	1.64	1.57	1.50	1.45
350 000	2.32	2.23	2.16	2.09	2.03	1.98	1.93	1.88	1.84	1.80	1.76	1.68	1.61	1.55	1.49
400 000	2.37	2.28	2.21	2.14	2.08	2.02	1.97	1.93	1.88	1.84	1.80	1.72	1.65	1.58	1.53
450 000	2.42	2.33	2.25	2.18	2.12	2.06	2.01	1.96	1.92	1.88	1.84	1.76	1.68	1.62	1.56
500 000	2.46	2.37	2.29	2.22	2.16	2.10	2.05	2.00	1.96	1.91	1.88	1.79	1.71	1.65	1.59
600 000	2.54	2.44	2.36	2.29	2.23	2.17	2.11	2.06	2.02	1.97	1.94	1.85	1.77	1.70	1.64
700 000	2.60	2.51	2.42	2.35	2.28	2.22	2.17	2.12	2.07	2.03	1.99	1.90	1.82	1.75	1.69
800 000	2.66	2.56	2.48	2.40	2.34	2.27	2.22	2.17	2.12	2.07	2.03	1.94	1.86	1.79	1.73
900 000	2.71	2.61	2.53	2.45	2.38	2.32	2.26	2.21	2.16	2.12	2.07	1.98	1.90	1.83	1.76
1 000 000	2.76	2.66	2.57	2.49	2.42	2.36	2.30	2.25	2.20	2.15	2.11	2.01	1.93	1.86	1.80
1 500 000	2.95	2.85	2.75	2.67	2.59	2.53	2.46	2.41	2.35	2.30	2.26	2.16	2.07	1.99	1.93
2 000 000	3.10	2.98	2.89	2.80	2.72	2.65	2.58	2.52	2.47	2.42	2.37	2.26	2.17	2.09	2.02
2 500 000	3.21	3.10	3.00	2.90	2.82	2.75	2.68	2.62	2.56	2.51	2.46	2.35	2.26	2.17	2.10
3 000 000	3.31	3.19	3.09	2.99	2.91	2.83	2.76	2.70	2.64	2.59	2.54	2.42	2.33	2.24	2.17
3 500 000	3.40	3.27	3.17	3.07	2.98	2.91	2.84	2.77	2.71	2.65	2.60	2.49	2.39	2.30	2.22
4 000 000	3.47	3.35	3.24	3.14	3.05	2.97	2.90	2.83	2.77	2.71	2.66	2.54	2.44	2.35	2.27
4 500 000	3.54	3.41	3.30	3.20	3.11	3.03	2.96	2.89	2.82	2.77	2.71	2.59	2.49	2.40	2.32
5 000 000	3.60	3.47	3.36	3.26	3.17	3.08	3.01	2.94	2.87	2.82	2.76	2.64	2.53	2.44	2.36
6 000 000	3.71	3.58	3.46	3.36	3.26	3.18	3.10	3.03	2.96	2.90	2.85	2.72	2.61	2.52	2.43
7 000 000	3.80	3.67	3.55	3.44	3.35	3.26	3.18	3.11	3.04	2.98	2.92	2.79	2.68	2.58	2.50
8 000 000	3.88	3.75	3.63	3.52	3.42	3.33	3.25	3.18	3.11	3.04	2.98	2.85	2.74	2.64	2.55
9 000 000	3.96	3.82	3.70	3.59	3.49	3.40	3.32	3.24	3.17	3.10	3.04	2.91	2.79	2.69	2.60
10 000 000	4.02	3.88	3.76	3.65	3.55	3.46	3.37	3.30	3.22	3.16	3.10	2.96	2.84	2.74	2.65
15 000 000	4.28	4.14	4.01	3.90	3.79	3.69	3.60	3.52	3.45	3.38	3.31	3.17	3.04	2.93	2.83
20 000 000	4.48	4.33	4.20	4.08	3.97	3.87	3.78	3.69	3.61	3.54	3.47	3.32	3.19	3.07	2.97
25 000 000	4.63	4.48	4.34	4.22	4.11	4.01	3.91	3.83	3.75	3.67	3.60	3.44	3.31	3.19	3.08
30 000 000	4.75	4.60	4.46	4.34	4.23	4.12	4.03	3.94	3.86	3.78	3.71	3.55	3.41	3.29	3.18
35 000 000	4.86	4.71	4.57	4.44	4.33	4.22	4.13	4.04	3.95	3.87	3.80	3.64	3.50	3.37	3.26
40 000 000	4.96	4.80	4.66	4.53	4.42	4.31	4.21	4.12	4.04	3.96	3.88	3.72	3.57	3.45	3.33
45 000 000	5.04	4.88	4.74	4.61	4.50	4.39	4.29	4.20	4.11	4.02	3.96	3.79	3.64	3.51	3.40
50 000 000	5.12	4.96	4.81	4.69	4.57	4.46	4.36	4.27	4.18	4.10	4.02	3.85	3.70	3.57	3.46
60 000 000	5.25	5.09	4.94	4.81	4.69	4.58	4.48	4.39	4.30	4.22	4.14	3.97	3.81	3.78	3.56
70 000 000	5.36	5.20	5.05	4.92	4.80	4.69	4.59	4.49	4.40	4.32	4.24	4.06	3.91	3.77	3.65
80 000 000	5.46	5.30	5.15	5.02	4.89	4.78	4.68	4.58	4.49	4.41	4.43	4.15	3.99	3.86	3.73
90 000 000	5.55	5.38	5.24	5.10	4.98	4.86	4.76	4.66	4.57	4.49	4.41	3.23	4.07	3.93	3.80
100 000 000	5.63	5.46	5.31	5.18	5.05	4.94	4.83	4.73	4.64	4.56	4.48	4.29	4.14	3.99	3.87

TABLE A.5C

REQUIRED STRUCTURAL NUMBER (SN_R)
92% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 300 MPa TO 650 MPa

	Resilient Modulus (M_R), MPa														
$ESAL_D$	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
100 000	1.17	1.13	1.09	1.06	1.02	0.99	0.96	0.94	0.91	0.89	0.87	0.85	0.83	0.81	0.79
150 000	1.27	1.23	1.18	1.15	1.11	1.08	1.05	1.02	1.00	0.97	0.95	0.93	0.91	0.89	0.87
200 000	1.34	1.30	1.25	1.22	1.18	1.15	1.12	1.09	1.06	1.04	1.01	0.99	0.97	0.95	0.93
250 000	1.40	1.35	1.31	1.27	1.23	1.20	1.17	1.14	1.11	1.09	1.06	1.04	1.02	1.00	0.98
300 000	1.45	1.40	1.36	1.31	1.28	1.24	1.21	1.18	1.15	1.13	1.10	1.08	1.06	1.04	1.02
350 000	1.49	1.44	1.40	1.35	1.32	1.28	1.25	1.22	1.19	1.16	1.14	1.11	1.09	1.07	1.05
400 000	1.53	1.48	1.43	1.39	1.35	1.31	1.28	1.25	1.22	1.19	1.17	1.14	1.12	1.10	1.08
450 000	1.56	1.51	1.46	1.42	1.38	1.34	1.31	1.28	1.25	1.22	1.20	1.17	1.15	1.13	1.11
500 000	1.59	1.54	1.49	1.45	1.41	1.37	1.34	1.31	1.28	1.25	1.22	1.20	1.17	1.15	1.13
600 000	1.64	1.59	1.54	1.50	1.46	1.42	1.38	1.35	1.32	1.29	1.27	1.24	1.22	1.19	1.17
700 000	1.69	1.63	1.58	1.54	1.50	1.46	1.42	1.39	1.36	1.33	1.30	1.28	1.25	1.23	1.21
800 000	1.73	1.67	1.62	1.58	1.53	1.50	1.46	1.43	1.40	1.37	1.34	1.31	1.29	1.26	1.24
100 000	1.76	1.71	1.66	1.61	1.57	1.53	1.49	1.46	1.43	1.40	1.37	1.34	1.32	1.29	1.27
1 000 000	1.80	1.74	1.69	1.64	1.60	1.56	1.52	1.49	1.45	1.42	1.40	1.37	1.34	1.32	1.30
1 500 000	1.93	1.87	1.81	1.76	1.72	1.67	1.64	1.60	1.57	1.53	1.50	1.48	1.45	1.42	1.40
2 000 000	2.02	1.96	1.90	1.85	1.80	1.76	1.72	1.68	1.65	1.62	1.58	1.56	1.53	1.50	1.48
2 500 000	2.10	2.04	1.98	1.92	1.88	1.83	1.79	1.75	1.71	1.68	1.65	1.62	1.59	1.56	1.54
3 000 000	2.17	2.10	2.04	1.99	1.94	1.89	1.85	1.81	1.77	1.74	1.70	1.67	1.64	1.62	1.59
3 500 000	2.22	2.16	2.09	2.04	1.99	1.94	1.90	1.86	1.82	1.78	1.75	1.72	1.69	1.66	1.63
4 000 000	2.27	2.20	2.14	2.08	2.03	1.98	1.94	1.90	1.86	1.82	1.79	1.76	1.73	1.70	1.67
4 500 000	2.32	2.25	2.18	2.13	2.07	2.02	1.98	1.94	1.90	1.86	1.83	1.80	1.77	1.74	1.71
5 000 000	2.36	2.29	2.22	2.16	2.11	2.06	2.02	1.97	1.93	1.90	1.86	1.83	1.80	1.77	1.74
6 000 000	2.43	2.36	2.29	2.23	2.18	2.13	2.08	2.03	1.99	1.96	1.92	1.89	1.85	1.82	1.80
7 000 000	2.50	2.42	2.35	2.29	2.23	2.18	2.13	2.09	2.05	2.01	1.97	1.94	1.90	1.87	1.84
8 000 000	2.55	2.48	2.41	2.34	2.28	2.23	2.18	2.14	2.09	2.05	2.02	1.98	1.95	1.92	1.89
9 000 000	2.60	2.52	2.45	2.39	2.33	2.28	2.23	2.18	2.14	2.10	2.06	2.02	1.99	1.96	1.93
10 000 000	2.65	2.57	2.50	2.43	2.37	2.32	2.27	2.22	2.17	2.13	2.09	2.06	2.02	1.99	1.96
15 000 000	2.83	2.75	2.67	2.60	2.54	2.48	2.42	2.37	2.33	2.28	2.24	2.20	2.17	2.13	2.10
20 000 000	2.97	2.88	2.80	2.73	2.66	2.60	2.54	2.49	2.44	2.40	2.35	2.31	2.27	2.24	2.21
25 000 000	3.08	2.99	2.91	2.83	2.76	2.70	2.64	2.58	2.53	2.49	2.44	2.40	2.36	2.32	2.29
30 000 000	3.18	3.08	3.00	2.92	2.85	2.78	2.72	2.66	2.61	2.56	2.52	2.47	2.43	2.40	2.36
35 000 000	3.26	3.16	3.07	2.99	2.92	2.85	2.79	2.73	2.68	2.63	2.58	2.54	2.50	2.46	2.42
40 000 000	3.33	3.23	3.14	3.06	2.99	2.92	2.85	2.79	2.74	2.69	2.64	2.60	2.55	2.51	2.48
45 000 000	3.40	3.30	3.20	3.12	3.04	2.97	2.91	2.85	2.79	2.74	2.69	2.65	2.60	2.56	2.52
50 000 000	3.46	3.35	3.26	3.18	3.10	3.03	2.96	2.90	2.84	2.79	2.74	2.69	2.65	2.61	2.57
60 000 000	3.56	3.46	3.36	3.27	3.19	3.12	3.05	2.99	2.93	2.88	2.82	2.78	2.73	2.69	2.65
70 000 000	3.65	3.54	3.45	3.36	3.27	3.20	3.13	3.07	3.01	2.95	2.90	2.85	2.80	2.76	2.72
80 000 000	3.73	3.62	3.52	3.43	3.35	3.27	3.20	3.13	3.07	3.02	2.96	2.91	2.86	2.82	2.78
90 000 000	3.80	3.69	3.59	3.50	3.41	3.34	3.26	3.20	3.13	3.08	3.02	2.97	2.92	2.88	2.83
100 000 000	3.87	3.76	3.65	3.56	3.47	3.39	3.32	3.25	3.19	3.13	3.07	3.02	2.97	2.93	2.88

TABLE A.6A

REQUIRED STRUCTURAL NUMBER (SN_R)
94% 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	3.07	2.90	2.75	2.63	2.52	2.43	2.35	2.28	2.22	2.16	2.10	2.05	2.01	1.97	1.93
150 000	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	2.11	2.06
200 000	3.44	3.25	3.09	2.95	2.83	2.73	2.64	2.56	2.49	2.42	2.36	2.31	2.26	2.21	2.17
250 000	3.57	3.37	3.20	3.06	2.94	2.83	2.74	2.66	2.58	2.51	2.45	2.39	2.34	2.29	2.25
300 000	3.68	3.47	3.30	3.15	3.03	2.92	2.82	2.74	2.66	2.59	2.53	2.47	2.41	2.36	2.32
350 000	3.77	3.56	3.38	3.24	3.11	2.99	2.90	2.81	2.73	2.66	2.59	2.53	2.48	2.43	2.38
400 000	3.85	3.64	3.46	3.31	3.18	3.06	2.96	2.87	2.79	2.72	2.65	2.59	2.53	2.48	2.43
450 000	3.93	3.71	3.53	3.37	3.24	3.12	3.02	2.93	2.85	2.77	2.70	2.64	2.58	2.53	2.48
500 000	3.99	3.77	3.59	3.43	3.30	3.18	3.07	2.98	2.90	2.82	2.75	2.69	2.63	2.57	2.52
600 000	4.11	3.88	3.69	3.53	3.40	3.27	3.17	3.07	2.98	2.91	2.84	2.77	2.71	2.65	2.60
700 000	4.21	3.98	3.79	3.62	3.48	3.36	3.25	3.15	3.06	2.98	2.91	2.84	2.78	2.72	2.67
800 000	4.30	4.06	3.87	3.70	3.56	3.43	3.32	3.22	3.13	3.05	2.97	2.91	2.84	2.78	2.73
900 000	4.37	4.14	3.94	3.77	3.63	3.50	3.39	3.28	3.19	3.11	3.03	2.96	2.90	2.84	2.78
1 000 000	4.44	4.21	4.01	3.84	3.69	3.56	3.45	3.34	3.25	3.16	3.09	3.01	2.95	2.89	2.83
1 500 000	4.72	4.48	4.27	4.09	3.94	3.80	3.68	3.57	3.47	3.38	3.30	3.22	3.15	3.09	3.03
2 000 000	4.92	4.67	4.46	4.28	4.12	3.98	3.85	3.74	3.64	3.55	3.46	3.38	3.31	3.24	3.18
2 500 000	5.08	4.83	4.61	4.43	4.27	4.12	3.99	3.88	3.77	3.68	3.59	3.51	3.43	3.36	3.30
3 000 000	5.21	4.96	4.74	4.55	4.39	4.24	4.11	3.99	3.88	3.79	3.70	3.61	3.54	3.46	3.40
3 500 000	5.33	5.07	4.85	4.66	4.49	4.34	4.21	4.09	3.98	3.88	3.79	3.70	3.63	3.55	3.48
4 000 000	5.43	5.16	4.94	4.75	4.58	4.43	4.30	4.18	4.06	3.96	3.87	3.78	3.70	3.63	3.56
4 500 000	5.51	5.25	5.02	4.83	4.66	4.51	4.37	4.25	4.14	4.04	3.94	3.86	3.78	3.70	3.63
5 000 000	5.59	5.33	5.10	4.90	4.73	4.58	4.44	4.32	4.21	4.11	4.01	3.92	3.84	3.76	3.69
6 000 000	5.73	5.46	5.23	5.03	4.86	4.71	4.57	4.44	4.33	4.22	4.13	4.04	3.95	3.87	3.80
7 000 000	5.85	5.58	5.35	5.15	4.97	4.81	4.67	4.55	4.43	4.32	4.23	4.13	4.05	3.97	3.90
8 000 000	5.96	5.68	5.45	5.24	5.07	4.91	4.77	4.64	4.52	4.41	4.31	4.22	4.14	4.06	3.98
9 000 000	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	4.13	4.05
10 000 000	6.14	5.85	5.61	5.41	5.23	5.07	4.92	4.79	4.67	4.56	4.46	4.37	4.28	4.20	4.12
15 000 000	6.47	6.18	5.93	5.72	5.53	5.36	5.21	5.08	4.96	4.84	4.74	4.64	4.55	4.47	4.39
20 000 000	6.71	6.41	6.16	5.94	5.75	5.58	5.43	5.29	5.16	5.05	4.94	4.84	4.75	4.66	4.58
25 000 000	6.91	6.60	6.34	6.12	5.92	5.75	5.60	5.45	5.33	5.21	5.10	5.00	4.91	4.82	4.73
30 000 000	7.07	6.75	6.49	6.27	6.07	5.89	5.74	5.59	5.46	5.34	5.23	5.13	5.04	4.95	4.86
35 000 000	7.21	6.89	6.62	6.39	6.19	6.01	5.85	5.71	5.58	5.46	5.35	5.24	5.15	5.06	4.97
40 000 000	7.33	7.00	6.73	6.50	6.30	6.12	5.96	5.81	5.68	5.56	5.45	5.34	5.24	5.15	5.07
45 000 000	7.43	7.11	6.84	6.60	6.40	6.22	6.05	5.91	5.77	5.65	5.53	5.43	5.33	5.24	5.15
50 000 000	7.53	7.20	6.93	6.69	6.49	6.30	6.14	5.99	5.85	5.73	5.61	5.51	5.41	5.32	5.23
60 000 000	7.70	7.37	7.09	6.85	6.64	6.45	6.29	6.14	6.00	5.87	5.75	5.65	5.55	5.45	5.36
70 000 000	7.85	7.51	7.23	6.98	6.77	6.58	6.41	6.26	6.12	5.99	5.88	5.77	5.66	5.57	5.48
80 000 000	7.98	7.64	7.35	7.10	6.89	6.70	6.52	6.37	6.23	6.10	5.98	5.87	5.77	5.67	5.58
90 000 000	8.10	7.75	7.46	7.21	6.99	6.80	6.62	6.47	6.33	6.19	6.07	5.96	5.86	5.76	5.67
100 000 000	8.20	7.85	7.56	7.30	7.08	6.89	6.71	6.56	6.41	6.28	6.16	6.05	5.94	5.84	5.75

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	1.93	1.85	1.79	1.73	1.68	1.63	1.59	1.55	1.52	1.48	1.45	1.38	1.31	1.26	1.21
150 000	2.06	1.99	1.92	1.86	1.81	1.76	1.71	1.67	1.63	1.59	1.56	1.48	1.42	1.36	1.31
200 000	2.17	2.09	2.02	1.95	1.90	1.85	1.80	1.76	1.71	1.68	1.64	1.56	1.50	1.44	1.38
250 000	2.25	2.17	2.09	2.03	1.97	1.92	1.87	1.82	1.78	1.74	1.71	1.63	1.56	1.50	1.44
300 000	2.32	2.23	2.16	2.09	2.03	1.98	1.93	1.88	1.84	1.80	1.76	1.68	1.61	1.55	1.49
350 000	2.38	2.29	2.22	2.15	2.09	2.03	1.98	1.93	1.89	1.85	1.81	1.73	1.65	1.59	1.53
400 000	2.43	2.34	2.27	2.20	2.13	2.08	2.03	1.98	1.93	1.89	1.85	1.77	1.69	1.63	1.57
450 000	2.48	2.39	2.31	2.24	2.18	2.12	2.07	2.02	1.97	1.93	1.89	1.80	1.73	1.66	1.60
500 000	2.52	2.43	2.35	2.28	2.22	2.16	2.10	2.05	2.01	1.97	1.93	1.84	1.76	1.69	1.64
600 000	2.60	2.51	2.42	2.35	2.28	2.22	2.17	2.12	2.07	2.03	1.99	1.90	1.82	1.75	1.69
700 000	2.67	2.57	2.49	2.41	2.34	2.28	2.23	2.17	2.13	2.08	2.04	1.95	1.87	1.80	1.74
800 000	2.73	2.63	2.54	2.47	2.40	2.33	2.28	2.22	2.17	2.13	2.09	1.99	1.91	1.84	1.78
900 000	2.78	2.68	2.59	2.52	2.44	2.38	2.32	2.27	2.22	2.17	2.13	2.03	1.95	1.88	1.81
1 000 000	2.83	2.73	2.64	2.56	2.49	2.42	2.36	2.31	2.26	2.21	2.17	2.07	1.98	1.91	1.85
1 500 000	3.03	2.92	2.82	2.74	2.66	2.59	2.53	2.47	2.42	2.37	2.32	2.21	2.13	2.05	1.98
2 000 000	3.18	3.06	2.96	2.87	2.79	2.72	2.65	2.59	2.53	2.48	2.43	2.32	2.23	2.15	2.08
2 500 000	3.30	3.18	3.07	2.98	2.90	2.82	2.75	2.69	2.63	2.58	2.52	2.41	2.32	2.23	2.16
3 000 000	3.40	3.28	3.17	3.07	2.99	2.91	2.84	2.77	2.71	2.65	2.60	2.49	2.39	2.30	2.22
3 500 000	3.48	3.36	3.25	3.15	3.06	2.98	2.91	2.84	2.78	2.72	2.67	2.55	2.45	2.36	2.28
4 000 000	3.56	3.43	3.32	3.22	3.13	3.05	2.97	2.91	2.84	2.78	2.73	2.61	2.50	2.41	2.33
4 500 000	3.63	3.50	3.39	3.29	3.19	3.11	3.03	2.96	2.90	2.84	2.78	2.66	2.55	2.46	2.38
5 000 000	3.69	3.56	3.45	3.34	3.25	3.16	3.09	3.02	2.95	2.89	2.83	2.71	2.60	2.51	2.42
6 000 000	3.80	3.67	3.55	3.44	3.35	3.26	3.18	3.11	3.04	2.98	2.92	2.79	2.68	2.58	2.50
7 000 000	3.90	3.76	3.64	3.53	3.43	3.35	3.26	3.19	3.12	3.06	3.00	2.86	2.75	2.65	2.56
8 000 000	3.98	3.84	3.72	3.61	3.51	3.42	3.34	3.26	3.19	3.12	3.06	2.93	2.81	2.71	2.62
9 000 000	4.05	3.92	3.79	3.68	3.58	3.49	3.40	3.32	3.25	3.18	3.12	2.98	2.87	2.76	2.67
10 000 000	4.12	3.98	3.86	3.74	3.64	3.55	3.46	3.38	3.31	3.24	3.18	3.04	2.92	2.81	2.72
15 000 000	4.39	4.24	4.11	3.99	3.88	3.79	3.70	3.61	3.54	3.46	3.40	3.25	3.12	3.01	2.91
20 000 000	4.58	4.43	4.30	4.18	4.07	3.96	3.87	3.79	3.71	3.63	3.56	3.41	3.27	3.15	3.05
25 000 000	4.73	4.58	4.45	4.32	4.21	4.11	4.01	3.92	3.84	3.76	3.69	3.53	3.39	3.27	3.16
30 000 000	4.86	4.71	4.57	4.44	4.33	4.22	4.13	4.04	3.95	3.88	3.80	3.64	3.50	3.37	3.26
35 000 000	4.97	4.81	4.67	4.55	4.43	4.33	4.23	4.14	4.05	3.97	3.90	3.73	3.59	3.46	3.35
40 000 000	5.07	4.91	4.77	4.64	4.52	4.41	4.31	4.22	4.14	4.06	3.98	3.81	3.66	3.54	3.42
45 000 000	5.15	4.99	4.85	4.72	4.60	4.49	4.39	4.30	4.21	4.13	4.06	3.88	3.83	3.60	3.49
50 000 000	5.23	5.07	4.92	4.79	4.67	4.56	4.46	4.37	4.28	4.20	4.12	3.95	3.80	3.67	3.55
60 000 000	5.36	5.20	5.05	4.92	4.80	4.69	4.59	4.49	4.40	4.32	4.24	4.06	3.91	3.77	3.65
70 000 000	5.48	5.31	5.17	5.03	4.91	4.80	4.69	4.60	4.51	4.42	4.34	4.16	4.01	3.87	3.75
80 000 000	5.58	5.41	5.26	5.13	5.00	4.89	4.78	4.69	4.60	4.51	4.43	4.25	4.09	3.95	3.83
90 000 000	5.67	5.50	5.35	5.21	5.09	4.97	4.87	4.77	4.68	4.59	4.51	4.33	4.17	4.03	3.90
100 000 000	5.75	5.58	5.43	5.29	5.16	5.05	4.94	4.84	4.75	4.66	4.58	4.40	4.24	4.09	3.97

TABLE A.6C

REQUIRED STRUCTURAL NUMBER (SN_R)
94% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 300 MPa TO 650 MPa

	Resilient Modulus (M_R), MPa														
$ESAL_D$	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
100 000	1.21	1.17	1.13	1.09	1.06	1.03	1.00	0.97	0.94	0.92	0.90	0.88	0.86	0.84	0.82
150 000	1.31	1.26	1.22	1.18	1.15	1.12	1.09	1.06	1.03	1.01	0.98	0.96	0.94	0.92	0.90
200 000	1.38	1.34	1.29	1.25	1.22	1.18	1.15	1.12	1.10	1.07	1.05	1.02	1.00	0.98	0.96
250 000	1.44	1.39	1.35	1.31	1.27	1.24	1.20	1.17	1.15	1.12	1.10	1.07	1.05	1.03	1.01
300 000	1.49	1.44	1.40	1.35	1.32	1.28	1.25	1.22	1.19	1.16	1.14	1.11	1.09	1.07	1.05
350 000	1.53	1.48	1.44	1.39	1.36	1.32	1.29	1.26	1.23	1.20	1.17	1.15	1.13	1.11	1.08
400 000	1.57	1.52	1.47	1.43	1.39	1.35	1.32	1.29	1.26	1.23	1.21	1.18	1.16	1.14	1.12
450 000	1.60	1.55	1.50	1.46	1.42	1.38	1.35	1.32	1.29	1.26	1.23	1.21	1.19	1.16	1.14
500 000	1.64	1.58	1.53	1.49	1.45	1.41	1.38	1.34	1.31	1.29	1.26	1.23	1.21	1.19	1.17
600 000	1.69	1.63	1.58	1.54	1.50	1.46	1.42	1.39	1.36	1.33	1.30	1.28	1.25	1.23	1.21
700 000	1.74	1.68	1.63	1.58	1.54	1.50	1.47	1.43	1.40	1.37	1.34	1.32	1.29	1.27	1.25
800 000	1.78	1.72	1.67	1.62	1.58	1.54	1.50	1.47	1.44	1.41	1.38	1.35	1.33	1.30	1.28
900 000	1.81	1.76	1.70	1.66	1.61	1.57	1.53	1.50	1.47	1.44	1.41	1.38	1.36	1.33	1.31
1 000 000	1.85	1.79	1.74	1.69	1.64	1.60	1.56	1.53	1.50	1.47	1.44	1.41	1.38	1.36	1.34
1 500 000	1.98	1.92	1.86	1.81	1.76	1.72	1.68	1.64	1.61	1.58	1.55	1.52	1.49	1.47	1.44
2 000 000	2.08	2.01	1.96	1.90	1.85	1.81	1.77	1.73	1.69	1.66	1.63	1.60	1.57	1.55	1.52
2 500 000	2.16	2.09	2.03	1.98	1.93	1.88	1.84	1.80	1.76	1.73	1.70	1.66	1.64	1.61	1.58
3 000 000	2.22	2.16	2.09	2.04	1.99	1.94	1.90	1.86	1.82	1.78	1.75	1.72	1.69	1.66	1.63
3 500 000	2.28	2.21	2.15	2.09	2.04	1.99	1.95	1.91	1.87	1.83	1.80	1.77	1.74	1.71	1.68
4 000 000	2.33	2.26	2.20	2.14	2.09	2.04	1.99	1.95	1.91	1.87	1.84	1.81	1.78	1.75	1.72
4 500 000	2.38	2.31	2.24	2.18	2.13	2.08	2.03	1.99	1.95	1.91	1.88	1.84	1.81	1.78	1.76
5 000 000	2.42	2.35	2.28	2.22	2.17	2.12	2.07	2.03	1.99	1.95	1.91	1.88	1.85	1.82	1.79
6 000 000	2.50	2.42	2.35	2.29	2.23	2.18	2.13	2.09	2.05	2.01	1.97	1.94	1.91	1.87	1.85
7 000 000	2.56	2.48	2.41	2.35	2.29	2.24	2.19	2.14	2.10	2.06	2.02	1.99	1.96	1.92	1.89
8 000 000	2.62	2.54	2.47	2.40	2.34	2.29	2.24	2.19	2.15	2.11	2.07	2.03	2.00	1.97	1.94
9 000 000	2.67	2.59	2.52	2.45	2.39	2.34	2.28	2.24	2.19	2.15	2.11	2.08	2.04	2.01	1.98
10 000 000	2.72	2.64	2.56	2.49	2.43	2.38	2.32	2.28	2.23	2.19	2.15	2.11	2.08	2.05	2.01
15 000 000	2.91	2.82	2.74	2.67	2.60	2.54	2.49	2.44	2.39	2.34	2.30	2.26	2.23	2.19	2.16
20 000 000	3.05	2.96	2.87	2.80	2.73	2.67	2.61	2.56	2.51	2.46	2.41	2.37	2.33	2.30	2.26
25 000 000	3.16	3.07	2.98	2.90	2.83	2.77	2.71	2.65	2.60	2.55	2.51	2.46	2.42	2.39	2.35
30 000 000	3.26	3.16	3.07	2.99	2.92	2.85	2.79	2.73	2.68	2.63	2.58	2.54	2.50	2.46	2.42
35 000 000	3.35	3.24	3.15	3.07	3.00	2.93	2.86	2.80	2.75	2.70	2.65	2.61	2.56	2.52	2.48
40 000 000	3.42	3.32	3.22	3.14	3.06	2.99	2.93	2.87	2.81	2.76	2.71	2.66	2.62	2.58	2.54
45 000 000	3.49	3.38	3.29	3.20	3.12	3.05	2.99	2.92	2.87	2.81	2.76	2.72	2.67	2.63	2.59
50 000 000	3.55	3.44	3.35	3.26	3.18	3.11	3.04	2.98	2.92	2.86	2.81	2.76	2.72	2.68	2.64
60 000 000	3.65	3.55	3.45	3.36	3.28	3.20	3.13	3.07	3.01	2.95	2.90	2.85	2.80	2.76	2.72
70 000 000	3.75	3.63	3.54	3.44	3.36	3.28	3.21	3.15	3.08	3.03	2.97	2.92	2.88	2.83	2.79
80 000 000	3.83	3.71	3.61	3.52	3.43	3.36	3.28	3.22	3.15	3.09	3.04	2.99	2.94	2.89	2.85
90 000 000	3.90	3.79	3.68	3.59	3.50	3.42	3.35	3.28	3.22	3.16	3.10	3.05	3.00	2.95	2.91
100 000 000	3.97	3.85	3.75	3.65	3.56	3.48	3.41	3.34	3.27	3.21	3.15	3.10	3.05	3.00	2.96

TABLE A.7A

REQUIRED STRUCTURAL NUMBER (SN_R)
95% 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	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	2.00	1.96
150 000	3.34	3.14	2.99	2.85	2.74	2.64	2.56	2.48	2.41	2.34	2.29	2.23	2.18	2.14	2.10
200 000	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	2.24	2.20
250 000	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	2.33	2.28
300 000	3.74	3.53	3.35	3.20	3.08	2.96	2.87	2.78	2.70	2.63	2.57	2.51	2.45	2.40	2.35
350 000	3.83	3.61	3.44	3.29	3.16	3.04	2.94	2.85	2.77	2.70	2.63	2.57	2.52	2.46	2.42
400 000	3.91	3.69	3.51	3.36	3.23	3.11	3.01	2.92	2.83	2.76	2.69	2.63	2.57	2.52	2.47
450 000	3.99	3.76	3.58	3.42	3.29	3.17	3.07	2.97	2.89	2.81	2.74	2.68	2.62	2.57	2.52
500 000	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	2.61	2.56
600 000	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	2.69	2.64
700 000	4.27	4.04	3.84	3.68	3.54	3.41	3.30	3.20	3.11	3.03	2.95	2.89	2.82	2.76	2.71
800 000	4.36	4.12	3.93	3.76	3.61	3.49	3.37	3.27	3.18	3.10	3.02	2.95	2.89	2.83	2.77
900 000	4.44	4.20	4.00	3.83	3.68	3.55	3.44	3.34	3.24	3.16	3.08	3.01	2.94	2.88	2.83
1 000 000	4.51	4.27	4.07	3.90	3.75	3.62	3.50	3.39	3.30	3.21	3.13	3.06	3.00	2.93	2.88
1 500 000	4.79	4.54	4.33	4.15	4.00	3.86	3.74	3.63	3.53	3.43	3.35	3.27	3.20	3.14	3.08
2 000 000	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	3.29	3.23
2 500 000	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	3.41	3.35
3 000 000	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	3.52	3.45
3 500 000	5.40	5.13	4.91	4.72	4.55	4.40	4.27	4.15	4.04	3.94	3.85	3.76	3.68	3.61	3.54
4 000 000	5.50	5.23	5.01	4.81	4.64	4.49	4.36	4.24	4.12	4.02	3.93	3.84	3.76	3.69	3.61
4 500 000	5.59	5.32	5.09	4.90	4.72	4.57	4.44	4.31	4.20	4.10	4.00	3.91	3.83	3.76	3.68
5 000 000	5.67	5.40	5.17	4.97	4.80	4.64	4.51	4.38	4.27	4.17	4.07	3.98	3.90	3.82	3.75
6 000 000	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	3.93	3.86
7 000 000	5.93	5.65	5.42	5.21	5.04	4.88	4.74	4.61	4.49	4.39	4.29	4.20	4.11	4.03	3.95
8 000 000	6.03	5.75	5.52	5.31	5.13	4.97	4.83	4.70	4.58	4.48	4.38	4.28	4.20	4.11	4.04
9 000 000	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	4.19	4.11
10 000 000	6.21	5.93	5.69	5.48	5.30	5.13	4.99	4.86	4.74	4.63	4.52	4.43	4.34	4.26	4.18
15 000 000	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	4.53	4.45
20 000 000	6.79	6.49	6.23	6.01	5.82	5.65	5.50	5.36	5.23	5.12	5.01	4.91	4.81	4.73	4.64
25 000 000	6.99	6.68	6.42	6.19	6.00	5.82	5.67	5.53	5.40	5.28	5.17	5.07	4.97	4.88	4.80
30 000 000	7.15	6.83	6.57	6.34	6.14	5.97	5.81	5.66	5.53	5.41	5.30	5.20	5.10	5.01	4.93
35 000 000	7.29	6.97	6.70	6.47	6.27	6.09	5.93	5.78	5.65	5.53	5.42	5.31	5.21	5.12	5.04
40 000 000	7.41	7.09	6.82	6.58	6.38	6.20	6.03	5.89	5.75	5.63	5.52	5.41	5.31	5.22	5.13
45 000 000	7.52	7.19	6.92	6.68	6.47	6.29	6.13	5.98	5.84	5.72	5.61	5.50	5.40	5.31	5.22
50 000 000	7.62	7.29	7.01	6.77	6.56	6.38	6.21	6.06	5.93	5.80	5.69	5.58	5.48	5.39	5.30
60 000 000	7.79	7.46	7.17	6.93	6.72	6.53	6.36	6.21	6.07	5.94	5.83	5.72	5.62	5.52	5.43
70 000 000	7.94	7.60	7.31	7.07	6.85	6.66	6.49	6.34	6.20	6.07	5.95	5.84	5.73	5.64	5.55
80 000 000	8.07	7.73	7.44	7.19	6.97	6.78	6.60	6.45	6.31	6.18	6.05	5.94	5.84	5.74	5.65
90 000 000	8.19	7.84	7.54	7.29	7.07	6.88	6.70	6.55	6.40	6.27	6.15	6.04	5.93	5.83	5.74
100 000 000	8.30	7.94	7.64	7.39	7.17	6.97	6.79	6.63	6.49	6.36	6.23	6.12	6.01	5.92	5.82

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	1.96	1.88	1.82	1.76	1.71	1.66	1.62	1.58	1.54	1.51	1.47	1.40	1.34	1.28	1.23
150 000	2.10	2.02	1.95	1.89	1.83	1.78	1.74	1.70	1.66	1.62	1.59	1.51	1.44	1.89	1.33
200 000	2.20	2.12	2.05	1.99	1.93	1.88	1.83	1.78	1.74	1.71	1.67	1.59	1.52	1.47	1.41
250 000	2.28	2.20	2.13	2.06	2.00	1.95	1.90	1.85	1.81	1.77	1.74	1.66	1.58	1.52	1.47
300 000	2.35	2.27	2.19	2.13	2.07	2.01	1.96	1.91	1.87	1.83	1.79	1.71	1.64	1.57	1.52
350 000	2.42	2.33	2.25	2.18	2.12	2.06	2.01	1.96	1.92	1.88	1.84	1.76	1.68	1.62	1.56
400 000	2.47	2.38	2.30	2.23	2.17	2.11	2.06	2.01	1.96	1.92	1.88	1.80	1.72	1.66	1.60
450 000	2.52	2.43	2.35	2.28	2.21	2.15	2.10	2.05	2.00	1.96	1.92	1.83	1.76	1.69	1.63
500 000	2.56	2.47	2.39	2.32	2.25	2.19	2.14	2.09	2.04	2.00	1.96	1.87	1.79	1.72	1.66
600 000	2.64	2.55	2.46	2.39	2.32	2.26	2.20	2.15	2.10	2.0	2.02	1.93	1.85	1.78	1.72
700 000	2.71	2.61	2.53	2.45	2.38	2.32	2.26	2.21	2.16	2.12	2.12	2.02	1.94	1.87	1.80
800 000	2.77	2.67	2.58	2.51	2.43	2.37	2.31	2.26	2.21	2.16	2.16	2.06	1.98	1.91	1.84
900 000	2.83	2.72	2.63	2.55	2.48	2.42	2.36	2.30	2.25	2.21	2.20	2.10	2.02	1.94	1.88
1 000 000	2.88	2.77	2.68	2.60	2.53	2.46	2.40	2.34	2.29	2.24	2.35	2.25	2.16	2.08	2.01
1 500 000	3.08	2.97	2.87	2.78	2.70	2.63	2.57	2.51	2.45	2.40	2.47	2.36	2.27	2.18	2.11
2 000 000	3.23	3.11	3.01	2.92	2.83	2.76	2.69	2.63	2.57	2.52	2.56	2.45	2.35	2.27	2.19
2 500 000	3.35	3.23	3.12	3.03	2.94	2.86	2.79	2.73	2.67	2.62	2.64	2.53	2.42	2.34	2.26
3 000 000	3.45	3.33	3.22	3.12	3.03	2.95	2.88	2.81	2.75	2.70	2.71	2.59	2.49	2.40	2.32
3 500 000	3.54	3.41	3.30	3.20	3.11	3.03	2.95	2.89	2.82	2.77	2.77	2.65	2.54	2.45	2.37
4 000 000	3.61	3.49	3.37	3.27	3.18	3.10	3.02	2.95	2.89	2.83	2.83	2.70	2.59	2.40	2.42
4 500 000	3.68	3.55	3.44	3.34	3.24	3.16	3.08	3.01	2.94	2.88	2.88	2.75	2.65	2.54	2.46
5 000 000	3.75	3.62	3.50	3.39	3.30	3.21	3.13	3.06	3.00	2.93	2.97	2.83	2.72	2.62	2.54
6 000 000	3.86	3.72	3.60	3.50	3.40	3.31	3.23	3.16	3.09	3.02	3.04	2.91	2.79	2.69	2.60
7 000 000	3.95	3.82	3.70	3.59	3.49	3.40	3.31	3.24	3.17	3.10	3.11	2.97	2.85	2.75	2.66
8 000 000	4.04	3.90	3.78	3.66	3.56	3.47	3.39	3.31	3.24	3.17	3.17	3.03	2.91	2.81	2.71
9 000 000	4.11	3.97	3.85	3.73	3.63	3.54	3.45	3.38	3.30	3.23	3.23	3.08	2.96	2.85	2.76
10 000 000	4.18	4.04	3.91	3.80	3.70	3.60	3.51	3.43	3.36	3.29	3.45	3.30	3.17	3.05	2.95
15 000 000	4.45	4.30	4.17	4.05	3.94	3.84	3.75	3.67	3.59	3.52	3.62	3.46	3.32	3.20	3.10
20 000 000	4.64	4.49	4.36	4.24	4.13	4.02	3.93	3.84	3.76	3.69	3.75	3.59	3.45	3.32	3.21
25 000 000	4.80	4.65	4.51	4.38	4.27	4.17	4.07	3.98	3.90	3.82	3.86	3.69	3.55	3.42	3.31
30 000 000	4.93	4.77	4.63	4.51	4.39	4.28	4.19	4.10	4.01	3.93	3.96	3.79	3.64	3.51	3.40
35 000 000	5.04	4.88	4.74	4.61	4.49	4.39	4.29	4.20	4.11	4.03	4.04	3.87	3.72	3.59	3.47
40 000 000	5.13	4.97	4.83	4.70	4.58	4.48	4.38	4.28	4.20	4.12	4.11	3.94	3.79	3.66	3.54
45 000 000	5.22	5.06	4.92	4.78	4.67	4.56	4.45	4.36	4.27	4.19	4.18	4.01	3.86	3.72	3.60
50 000 000	5.30	5.14	4.99	4.86	4.74	4.63	4.53	4.43	4.34	4.26	4.30	4.12	3.97	3.83	3.71
60 000 000	5.43	5.27	5.12	4.99	4.87	4.75	4.65	4.55	4.46	4.38	4.40	4.22	4.07	3.93	3.80
70 000 000	5.55	5.38	5.23	5.10	4.97	4.86	4.76	4.66	4.57	4.48	4.49	4.31	4.15	4.01	3.88
80 000 000	5.65	5.48	5.33	5.20	5.07	4.96	4.85	4.75	4.66	4.57	4.57	4.39	4.23	4.09	3.96
90 000 000	5.74	5.57	5.42	5.28	5.16	5.04	4.93	4.83	4.74	4.65	4.57	4.89	4.23	4.09	3.96
100 000 000	5.82	5.65	5.50	5.36	5.23	5.12	5.01	4.91	4.81	4.73	4.65	4.46	4.30	4.15	4.02

TABLE A.7C

REQUIRED STRUCTURAL NUMBER (SN_R)
95% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 300 MPa TO 650 MPa

$ESAL_D$	Resilient Modulus (M_R), MPa														
	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
100 000	1.23	1.19	1.15	1.11	1.08	1.05	1.02	0.99	0.96	0.94	0.92	0.90	0.88	0.86	0.84
150 000	1.33	1.29	1.24	1.21	1.17	1.14	1.11	1.08	1.05	1.03	1.00	0.98	0.96	0.94	0.92
200 000	1.41	1.36	1.32	1.28	1.24	1.21	1.17	1.14	1.12	1.09	1.07	1.04	1.02	1.00	0.98
250 000	1.47	1.42	1.37	1.33	1.29	1.26	1.23	1.20	1.17	1.14	1.12	1.09	1.07	1.05	1.03
300 000	1.52	1.47	1.42	1.38	1.34	1.30	1.27	1.24	1.21	1.19	1.16	1.14	1.11	1.09	1.07
350 000	1.56	1.51	1.46	1.42	1.38	1.34	1.31	1.28	1.25	1.22	1.20	1.17	1.15	1.13	1.11
400 000	1.60	1.55	1.50	1.45	1.41	1.38	1.34	1.31	1.28	1.25	1.23	1.20	1.18	1.16	1.14
450 000	1.63	1.58	1.53	1.49	1.45	1.41	1.37	1.34	1.31	1.28	1.26	1.23	1.21	1.19	1.16
500 000	1.66	1.61	1.56	1.52	1.47	1.44	1.40	1.37	1.34	1.31	1.28	1.26	1.23	1.21	1.19
600 000	1.72	1.66	1.61	1.57	1.52	1.49	1.45	1.42	1.39	1.36	1.33	1.30	1.28	1.25	1.23
700 000	1.76	1.71	1.66	1.61	1.57	1.53	1.49	1.46	1.43	1.40	1.37	1.34	1.32	1.29	1.27
800 000	1.80	1.75	1.70	1.65	1.61	1.57	1.53	1.49	1.46	1.43	1.40	1.38	1.35	1.33	1.30
900 000	1.84	1.78	1.73	1.68	1.64	1.60	1.56	1.53	1.49	1.46	1.43	1.41	1.38	1.36	1.33
1 000 000	1.88	1.82	1.76	1.71	1.67	1.63	1.59	1.56	1.52	1.49	1.46	1.43	1.41	1.38	1.36
1 500 000	2.01	1.95	1.89	1.84	1.79	1.75	1.71	1.67	1.64	1.60	1.57	1.54	1.52	1.49	1.47
2 000 000	2.11	2.05	1.99	1.93	1.88	1.84	1.80	1.76	1.72	1.69	1.66	1.63	1.60	1.57	1.55
2 500 000	2.19	2.12	2.06	2.01	1.96	1.91	1.87	1.83	1.79	1.76	1.72	1.69	1.66	1.64	1.61
3 000 000	2.26	2.19	2.13	2.07	2.02	1.97	1.93	1.89	1.85	1.81	1.78	1.75	1.72	1.69	1.66
3 500 000	2.32	2.25	2.18	2.13	2.07	2.02	1.98	1.94	1.90	1.86	1.83	1.79	1.76	1.74	1.71
4 000 000	2.37	2.30	2.23	2.17	2.12	2.07	2.02	1.98	1.94	1.90	1.87	1.84	1.81	1.78	1.75
4 500 000	2.42	2.34	2.28	2.22	2.16	2.11	2.06	2.02	1.98	1.94	1.91	1.87	1.84	1.81	1.78
5 000 000	2.46	2.39	2.32	2.26	2.20	2.15	2.10	2.06	2.02	1.98	1.94	1.91	1.88	1.85	1.82
6 000 000	2.54	2.46	2.39	2.33	2.27	2.22	2.17	2.12	2.08	2.04	2.00	1.97	1.94	1.90	1.88
7 000 000	2.60	2.52	2.45	2.39	2.33	2.27	2.22	2.18	2.13	2.09	2.06	2.02	1.99	1.96	1.93
8 000 000	2.66	2.58	2.51	2.44	2.38	2.33	2.27	2.23	2.18	2.14	2.10	2.07	2.03	2.00	1.97
9 000 000	2.71	2.63	2.56	2.49	2.43	2.37	2.32	2.27	2.23	2.19	2.15	2.11	2.07	2.04	2.01
10 000 000	2.76	2.68	2.60	2.53	2.47	2.41	2.36	2.31	2.27	2.22	2.18	2.15	2.11	2.08	2.05
15 000 000	2.95	2.86	2.78	2.71	2.64	2.58	2.53	2.47	2.43	2.38	2.34	2.30	2.26	2.22	2.19
20 000 000	3.10	3.00	2.92	2.84	2.77	2.71	2.65	2.60	2.54	2.50	2.45	2.41	2.37	2.33	2.30
25 000 000	3.21	3.12	3.03	2.95	2.88	2.81	2.75	2.69	2.64	2.59	2.55	2.50	2.46	2.42	2.39
30 000 000	3.31	3.21	3.12	3.04	2.97	2.90	2.83	2.78	2.72	2.67	2.62	2.58	2.54	2.50	2.46
35 000 000	3.40	3.30	3.20	3.12	3.04	2.97	2.91	2.85	2.79	2.74	2.69	2.65	2.60	2.56	2.52
40 000 000	3.47	3.37	3.27	3.19	3.11	3.04	2.97	2.91	2.85	2.80	2.75	2.70	2.66	2.62	2.58
45 000 000	3.54	3.43	3.34	3.25	3.17	3.10	3.03	2.97	2.91	2.86	2.81	2.76	2.71	2.67	2.63
50 000 000	3.60	3.49	3.40	3.31	3.23	3.15	3.09	3.02	2.96	2.91	2.86	2.81	2.76	2.72	2.68
60 000 000	3.71	3.60	3.50	3.41	3.33	3.25	3.18	3.11	3.05	3.00	2.94	2.89	2.85	2.80	2.76
70 000 000	3.80	3.69	3.59	3.50	3.41	3.33	3.26	3.19	3.13	3.07	3.02	2.97	2.92	2.87	2.83
80 000 000	3.88	3.77	3.67	3.57	3.49	3.41	3.33	3.27	3.20	3.14	3.09	3.03	2.99	2.94	2.89
90 000 000	3.96	3.84	3.74	3.64	3.56	3.47	3.40	3.33	3.27	3.20	3.15	3.09	3.04	3.00	2.95
100 000 000	4.02	3.91	3.80	3.71	3.62	3.53	3.46	3.39	3.32	3.26	3.20	3.15	3.10	3.05	3.00

TABLE A.8A

REQUIRED STRUCTURAL NUMBER (SN_R)
96% 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	3.18	2.99	2.84	2.72	2.61	2.52	2.43	2.36	2.29	2.23	2.18	2.12	2.08	2.03	1.99
150 000	3.40	3.20	3.04	2.91	2.79	2.69	2.60	2.52	2.45	2.39	2.33	2.27	2.22	2.18	2.14
200 000	3.56	3.36	3.19	3.05	2.93	2.82	2.73	2.65	2.57	2.50	2.44	2.39	2.33	2.29	2.24
250 000	3.69	3.48	3.31	3.16	3.04	2.93	2.83	2.75	2.67	2.60	2.54	2.48	2.42	2.37	2.33
300 000	3.80	3.59	3.41	3.26	3.13	3.02	2.92	2.83	2.75	2.68	2.61	2.55	2.50	2.45	2.40
350 000	3.90	3.68	3.50	3.35	3.21	3.10	3.00	2.90	2.82	2.75	2.68	2.62	2.56	2.51	2.46
400 000	3.98	3.76	3.58	3.42	3.28	3.17	3.06	2.97	2.89	2.81	2.74	2.68	2.62	2.57	2.52
450 000	4.05	3.83	3.64	3.49	3.35	3.23	3.12	3.03	2.94	2.87	2.80	2.73	2.67	2.62	2.57
500 000	4.12	3.90	3.71	3.55	3.41	3.29	3.18	3.08	3.00	2.92	2.84	2.78	2.72	2.66	2.61
600 000	4.24	4.01	3.82	3.65	3.51	3.39	3.28	3.18	3.09	3.01	2.93	2.86	2.80	2.74	2.69
700 000	4.34	4.11	3.91	3.75	3.60	3.47	3.36	3.26	3.17	3.08	3.01	2.94	2.87	2.82	2.76
800 000	4.43	4.19	4.00	3.83	3.68	3.55	3.43	3.33	3.24	3.15	3.08	3.00	2.94	2.88	2.82
900 000	4.51	4.27	4.07	3.90	3.75	3.62	3.50	3.40	3.30	3.22	3.14	3.06	3.00	2.94	2.88
1 000 000	4.58	4.34	4.14	3.96	3.81	3.68	3.56	3.46	3.36	3.27	3.19	3.12	3.05	2.99	2.93
1 500 000	4.86	4.61	4.40	4.22	4.07	3.93	3.80	3.69	3.59	3.50	3.41	3.33	3.26	3.20	3.13
2 000 000	5.07	4.81	4.60	4.41	4.25	4.11	3.98	3.87	3.76	3.66	3.58	3.50	3.42	3.35	3.29
2 500 000	5.23	4.97	4.75	4.56	4.40	4.25	4.12	4.00	3.90	3.80	3.71	3.62	3.55	3.48	3.41
3 000 000	5.36	5.10	4.88	4.69	4.52	4.37	4.24	4.12	4.01	3.91	3.82	3.73	3.65	3.58	3.51
3 500 000	5.48	5.21	4.99	4.80	4.63	4.48	4.34	4.22	4.11	4.01	3.91	3.83	3.75	3.67	3.60
4 000 000	5.58	5.31	5.09	4.89	4.72	4.57	4.43	4.31	4.20	4.09	4.00	3.91	3.83	3.75	3.68
4 500 000	5.67	5.40	5.17	4.97	4.80	4.65	4.51	4.39	4.27	4.17	4.07	3.98	3.90	3.82	3.75
5 000 000	5.75	5.48	5.25	5.05	4.88	4.72	4.58	4.46	4.34	4.24	4.14	4.05	3.97	3.89	3.81
6 000 000	5.89	5.62	5.38	5.18	5.00	4.85	4.71	4.58	4.46	4.36	4.26	4.17	4.08	4.00	3.93
7 000 000	6.01	5.73	5.50	5.29	5.12	4.96	4.81	4.69	4.57	4.46	4.36	4.27	4.18	4.10	4.02
8 000 000	6.12	5.84	5.60	5.39	5.21	5.05	4.91	4.78	4.66	4.55	4.45	4.35	4.27	4.19	4.11
9 000 000	6.22	5.93	5.69	5.48	5.30	5.14	4.99	4.86	4.74	4.63	4.53	4.43	4.35	4.26	4.18
10 000 000	6.30	6.01	5.77	5.56	5.38	5.21	5.07	4.94	4.81	4.70	4.60	4.50	4.42	4.33	4.25
15 000 000	6.64	6.34	6.09	5.87	5.68	5.52	5.36	5.23	5.10	4.99	4.88	4.78	4.69	4.60	4.52
20 000 000	6.89	6.58	6.32	6.10	5.91	5.73	5.58	5.44	5.31	5.19	5.09	4.99	4.89	4.80	4.72
25 000 000	7.09	6.77	6.51	6.28	6.08	5.91	5.75	5.61	5.48	5.36	5.25	5.15	5.05	4.96	4.88
30 000 000	7.25	6.93	6.66	6.43	6.23	6.05	5.89	5.75	5.62	5.50	5.38	5.28	5.18	5.09	5.01
35 000 000	7.39	7.07	6.79	6.56	6.36	6.18	6.02	5.87	5.73	5.61	5.50	5.39	5.30	5.20	5.12
40 000 000	7.51	7.19	6.91	6.67	6.47	6.29	6.12	5.97	5.84	5.71	5.60	5.49	5.39	5.30	5.21
45 000 000	7.62	7.29	7.01	6.78	6.57	6.38	6.22	6.07	5.93	5.81	5.69	5.58	5.48	5.39	5.30
50 000 000	7.72	7.39	7.11	6.87	6.66	6.47	6.30	6.15	6.01	5.89	5.77	5.66	5.56	5.47	5.38
60 000 000	7.90	7.56	7.27	7.03	6.81	6.62	6.45	6.30	6.16	6.03	5.91	5.80	5.70	5.60	5.51
70 000 000	8.05	7.70	7.41	7.17	6.95	6.76	6.58	6.43	6.29	6.16	6.04	5.92	5.82	5.72	5.63
80 000 000	8.18	7.83	7.54	7.29	7.07	6.87	6.70	6.54	6.40	6.26	6.14	6.03	5.92	5.83	5.73
90 000 000	8.30	7.95	7.65	7.39	7.17	6.97	6.80	6.64	6.49	6.36	6.24	6.12	6.02	5.92	5.83
100 000 000	8.41	8.05	7.75	7.49	7.27	7.07	6.89	6.73	6.58	6.45	6.32	6.21	6.10	6.00	5.91

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	1.99	1.92	1.85	1.80	1.74	1.69	1.65	1.61	1.57	1.54	1.50	1.43	1.37	1.31	1.26
150 000	2.14	2.06	1.99	1.93	1.87	1.82	1.77	1.73	1.69	1.65	1.62	1.54	1.47	1.41	1.36
200 000	2.24	2.16	2.09	2.02	1.96	1.91	1.86	1.82	1.78	1.74	1.70	1.62	1.55	1.49	1.44
250 000	2.33	2.24	2.17	2.10	2.04	1.99	1.94	1.89	1.85	1.81	1.77	1.69	1.62	1.55	1.50
300 000	2.40	2.31	2.23	2.17	2.10	2.05	2.00	1.95	1.91	1.86	1.83	1.74	1.67	1.60	1.55
350 000	2.46	2.37	2.29	2.22	2.16	2.10	2.05	2.00	1.96	1.91	1.88	1.79	1.72	1.65	1.59
400 000	2.52	2.42	2.34	2.27	2.21	2.15	2.10	2.05	2.00	1.96	1.92	1.83	1.76	1.69	1.63
450 000	2.57	2.47	2.39	2.32	2.25	2.19	2.14	2.09	2.04	2.00	1.96	1.87	1.79	1.72	1.66
500 000	2.61	2.52	2.43	2.36	2.29	2.23	2.18	2.13	2.08	2.03	1.99	1.90	1.82	1.76	1.70
600 000	2.69	2.59	2.51	2.43	2.36	2.30	2.24	2.19	2.14	2.10	2.06	1.96	1.88	1.81	1.75
700 000	2.76	2.66	2.57	2.50	2.42	2.36	2.30	2.25	2.20	2.15	2.11	2.02	1.93	1.86	1.80
800 000	2.82	2.72	2.63	2.55	2.48	2.41	2.35	2.30	2.25	2.20	2.16	2.06	1.98	1.90	1.84
900 000	2.88	2.77	2.68	2.60	2.53	2.46	2.40	2.35	2.29	2.25	2.20	2.10	2.02	1.94	1.88
1 000 000	2.93	2.82	2.73	2.65	2.57	2.51	2.44	2.39	2.33	2.29	2.24	2.14	2.05	1.98	1.91
1 500 000	3.13	3.02	2.92	2.83	2.75	2.68	2.61	2.55	2.50	2.45	2.40	2.29	2.20	2.12	2.05
2 000 000	3.29	3.17	3.06	2.97	2.89	2.81	2.74	2.68	2.62	2.57	2.52	2.40	2.31	2.22	2.15
2 500 000	3.41	3.29	3.18	3.08	3.00	2.92	2.85	2.78	2.72	2.66	2.61	2.50	2.40	2.31	2.23
3 000 000	3.51	3.39	3.28	3.18	3.09	3.01	2.93	2.87	2.80	2.75	2.69	2.57	2.47	2.38	2.30
3 500 000	3.60	3.47	3.36	3.26	3.17	3.08	3.01	2.94	2.88	2.82	2.76	2.64	2.53	2.44	2.36
4 000 000	3.68	3.55	3.43	3.33	3.24	3.15	3.08	3.01	2.94	2.88	2.82	2.70	2.59	2.50	2.41
4 500 000	3.75	3.62	3.50	3.40	3.30	3.22	3.14	3.06	3.00	2.94	2.88	2.75	2.64	2.55	2.46
5 000 000	3.81	3.68	3.56	3.46	3.36	3.27	3.19	3.12	3.05	2.99	2.93	2.80	2.69	2.59	2.51
6 000 000	3.93	3.79	3.67	3.56	3.46	3.37	3.29	3.21	3.14	3.08	3.02	2.89	2.77	2.67	2.58
7 000 000	4.02	3.89	3.76	3.65	3.55	3.46	3.37	3.30	3.23	3.16	3.10	2.96	2.84	2.74	2.65
8 000 000	4.11	3.97	3.84	3.73	3.63	3.53	3.45	3.37	3.30	3.23	3.17	3.03	2.91	2.80	2.71
9 000 000	4.18	4.04	3.92	3.80	3.70	3.60	3.52	3.44	3.36	3.29	3.23	3.09	2.96	2.86	2.76
10 000 000	4.25	4.11	3.98	3.87	3.76	3.67	3.58	3.50	3.42	3.35	3.29	3.14	3.02	2.91	2.81
15 000 000	4.52	4.38	4.24	4.12	4.01	3.91	3.82	3.73	3.65	3.58	3.51	3.36	3.23	3.11	3.01
20 000 000	4.72	4.57	4.43	4.31	4.20	4.09	4.00	3.91	3.83	3.75	3.68	3.52	3.38	3.26	3.15
25 000 000	4.88	4.72	4.58	4.46	4.34	4.24	4.14	4.05	3.97	3.89	3.82	3.65	3.51	3.38	3.27
30 000 000	5.01	4.85	4.71	4.58	4.46	4.36	4.26	4.17	4.08	4.00	3.93	3.76	3.61	3.49	3.37
35 000 000	5.12	4.96	4.82	4.69	4.57	4.46	4.36	4.27	4.18	4.10	4.02	3.85	3.71	3.58	3.46
40 000 000	5.21	5.05	4.91	4.78	4.66	4.55	4.45	4.36	4.27	4.19	4.11	3.94	3.79	3.65	3.54
45 000 000	5.30	5.14	4.99	4.86	4.74	4.63	4.53	4.43	4.35	4.26	4.19	4.01	3.86	3.72	3.60
50 000 000	5.38	5.22	5.07	4.94	4.81	4.70	4.60	4.51	4.42	4.33	4.25	4.08	3.92	3.79	3.67
60 000 000	5.51	5.35	5.20	5.07	4.94	4.83	4.73	4.63	4.54	4.45	4.37	4.19	4.04	3.90	3.78
70 000 000	5.63	5.46	5.31	5.18	5.05	4.94	4.83	4.74	4.64	4.56	4.48	4.30	4.14	4.00	3.87
80 000 000	5.73	5.56	5.41	5.28	5.15	5.03	4.93	4.83	4.74	4.65	4.57	4.38	4.22	4.08	3.95
90 000 000	5.83	5.65	5.50	5.36	5.24	5.12	5.01	4.91	4.82	4.73	4.65	4.46	4.30	4.16	4.03
100 000 000	5.91	5.74	5.58	5.44	5.31	5.20	5.09	4.99	4.89	4.80	4.72	4.53	4.37	4.22	4.09

TABLE A.8C

REQUIRED STRUCTURAL NUMBER (SN_R)
96% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 300 MPa TO 650 MPa

	Resilient Modulus (M_R), MPa														
$ESAL_D$	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
100 000	1.26	1.21	1.17	1.14	1.10	1.07	1.04	1.01	0.99	0.96	0.94	0.92	0.90	0.88	0.86
150 000	1.36	1.31	1.27	1.23	1.20	1.16	1.13	1.10	1.08	1.05	1.03	1.01	0.98	0.96	0.94
200 000	1.44	1.39	1.34	1.30	1.27	1.23	1.20	1.17	1.14	1.12	1.09	1.07	1.05	1.03	1.01
250 000	1.50	1.45	1.40	1.36	1.32	1.29	1.25	1.22	1.19	1.17	1.14	1.12	1.10	1.08	1.05
300 000	1.55	1.50	1.45	1.41	1.37	1.33	1.30	1.27	1.24	1.21	1.19	1.16	1.14	1.12	1.10
350 000	1.59	1.54	1.49	1.45	1.41	1.37	1.34	1.31	1.28	1.25	1.22	1.20	1.17	1.15	1.13
400 000	1.63	1.58	1.53	1.48	1.44	1.41	1.37	1.34	1.31	1.28	1.25	1.23	1.21	1.18	1.16
450 000	1.66	1.61	1.56	1.52	1.48	1.44	1.40	1.37	1.34	1.31	1.28	1.26	1.23	1.21	1.19
500 000	1.70	1.64	1.59	1.55	1.50	1.47	1.43	1.40	1.37	1.34	1.31	1.28	1.26	1.24	1.21
600 000	1.75	1.69	1.64	1.60	1.55	1.52	1.48	1.45	1.41	1.38	1.36	1.33	1.31	1.28	1.26
700 000	1.80	1.74	1.69	1.64	1.60	1.56	1.52	1.49	1.45	1.42	1.40	1.37	1.34	1.32	1.30
800 000	1.84	1.78	1.73	1.68	1.64	1.60	1.56	1.52	1.49	1.46	1.43	1.40	1.38	1.35	1.33
900 000	1.88	1.82	1.76	1.72	1.67	1.63	1.59	1.56	1.52	1.49	1.46	1.44	1.41	1.38	1.36
1 000 000	1.91	1.85	1.80	1.75	1.70	1.66	1.62	1.59	1.55	1.52	1.49	1.46	1.44	1.41	1.39
1 500 000	2.05	1.98	1.93	1.88	1.83	1.78	1.74	1.70	1.67	1.64	1.61	1.58	1.55	1.52	1.50
2 000 000	2.15	2.08	2.02	1.97	1.92	1.87	1.83	1.79	1.76	1.72	1.69	1.66	1.63	1.60	1.58
2 500 000	2.23	2.16	2.10	2.05	1.99	1.95	1.90	1.86	1.83	1.79	1.76	1.73	1.70	1.67	1.64
3 000 000	2.30	2.23	2.17	2.11	2.06	2.01	1.96	1.92	1.88	1.85	1.81	1.78	1.75	1.72	1.69
3 500 000	2.36	2.29	2.22	2.17	2.11	2.06	2.02	1.97	1.93	1.90	1.86	1.83	1.80	1.77	1.74
4 000 000	2.41	2.34	2.27	2.21	2.16	2.11	2.06	2.02	1.98	1.94	1.90	1.87	1.84	1.81	1.78
4 500 000	2.46	2.39	2.32	2.26	2.20	2.15	2.10	2.06	2.02	1.98	1.94	1.91	1.88	1.85	1.82
5 000 000	2.51	2.43	2.36	2.30	2.24	2.19	2.14	2.10	2.05	2.02	1.98	1.94	1.91	1.88	1.85
6 000 000	2.58	2.50	2.43	2.37	2.31	2.26	2.21	2.16	2.12	2.08	2.04	2.01	1.97	1.94	1.91
7 000 000	2.65	2.57	2.50	2.43	2.37	2.32	2.27	2.22	2.17	2.13	2.10	2.06	2.02	1.99	1.96
8 000 000	2.71	2.63	2.55	2.49	2.43	2.37	2.32	2.27	2.22	2.18	2.14	2.11	2.07	2.04	2.01
9 000 000	2.76	2.68	2.60	2.54	2.47	2.42	2.36	2.31	2.27	2.23	2.19	2.15	2.11	2.08	2.05
10 000 000	2.81	2.73	2.65	2.58	2.52	2.46	2.40	2.36	2.31	2.27	2.22	2.19	2.15	2.12	2.08
15 000 000	3.01	2.92	2.83	2.76	2.69	2.63	2.57	2.52	2.47	2.42	2.38	2.34	2.30	2.27	2.23
20 000 000	3.15	3.06	2.97	2.89	2.82	2.76	2.70	2.64	2.59	2.54	2.50	2.46	2.42	2.38	2.34
25 000 000	3.27	3.17	3.08	3.00	2.93	2.86	2.80	2.74	2.69	2.64	2.59	2.55	2.51	2.47	2.43
30 000 000	3.37	3.27	3.18	3.10	3.02	2.95	2.89	2.83	2.77	2.72	2.67	2.63	2.58	2.54	2.51
35 000 000	3.46	3.36	3.26	3.18	3.10	3.03	2.96	2.90	2.84	2.79	2.74	2.69	2.65	2.61	2.57
40 000 000	3.54	3.43	3.33	3.25	3.17	3.09	3.03	2.97	2.91	2.85	2.80	2.75	2.71	2.67	2.63
45 000 000	3.60	3.50	3.40	3.31	3.23	3.16	3.09	3.02	2.96	2.91	2.86	2.81	2.76	2.72	2.68
50 000 000	3.67	3.56	3.46	3.37	3.29	3.21	3.14	3.08	3.02	2.96	2.91	2.86	2.81	2.77	2.73
60 000 000	3.78	3.66	3.56	3.47	3.39	3.31	3.24	3.17	3.11	3.05	3.00	2.95	2.90	2.85	2.81
70 000 000	3.87	3.76	3.65	3.56	3.47	3.39	3.32	3.25	3.19	3.13	3.08	3.02	2.97	2.93	2.88
80 000 000	3.95	3.84	3.73	3.64	3.55	3.47	3.40	3.33	3.26	3.20	3.14	3.09	3.04	2.99	2.95
90 000 000	4.03	3.91	3.80	3.71	3.62	3.54	3.46	3.39	3.33	3.26	3.21	3.15	3.10	3.05	3.01
100 000 000	4.09	3.98	3.87	3.77	3.68	3.60	3.52	3.45	3.38	3.32	3.26	3.21	3.16	3.11	3.06

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	3.25	3.06	2.91	2.78	2.67	2.57	2.49	2.41	2.34	2.28	2.23	2.17	2.13	2.08	2.04
150 000	3.47	3.27	3.11	2.97	2.85	2.75	2.66	2.58	2.51	2.44	2.38	2.33	2.28	2.23	2.18
200 000	3.64	3.43	3.26	3.12	2.99	2.89	2.79	2.71	2.63	2.56	2.50	2.44	2.39	2.34	2.29
250 000	3.77	3.56	3.38	3.24	3.11	3.00	2.90	2.81	2.73	2.66	2.59	2.53	2.48	2.43	2.38
300 000	3.88	3.67	3.49	3.33	3.20	3.09	2.99	2.90	2.81	2.74	2.67	2.61	2.55	2.50	2.45
350 000	3.98	3.76	3.58	3.42	3.29	3.17	3.06	2.97	2.89	2.81	2.74	2.68	2.62	2.57	2.52
400 000	4.07	3.84	3.65	3.50	3.36	3.24	3.13	3.04	2.95	2.87	2.80	2.74	2.68	2.62	2.57
450 000	4.14	3.91	3.72	3.56	3.42	3.30	3.19	3.10	3.01	2.93	2.86	2.79	2.73	2.68	2.62
500 000	4.21	3.98	3.79	3.63	3.48	3.36	3.25	3.15	3.06	2.98	2.91	2.84	2.78	2.72	2.67
600 000	4.33	4.10	3.90	3.73	3.59	3.46	3.35	3.25	3.16	3.07	3.00	2.93	2.87	2.81	2.75
700 000	4.43	4.20	4.00	3.83	3.68	3.55	3.43	3.33	3.24	3.15	3.08	3.01	2.94	2.88	2.82
800 000	4.52	4.28	4.08	3.91	3.76	3.63	3.51	3.41	3.31	3.22	3.15	3.07	3.01	2.94	2.89
900 000	4.60	4.36	4.16	3.98	3.83	3.70	3.58	3.47	3.38	3.29	3.21	3.13	3.07	3.00	2.94
1 000 000	4.67	4.43	4.23	4.05	3.90	3.76	3.64	3.53	3.43	3.35	3.26	3.19	3.12	3.05	3.00
1 500 000	4.96	4.71	4.50	4.31	4.15	4.01	3.89	3.77	3.67	3.57	3.49	3.41	3.34	3.27	3.20
2 000 000	5.16	4.91	4.69	4.50	4.34	4.20	4.07	3.95	3.84	3.74	3.66	3.57	3.50	3.43	3.36
2 500 000	5.33	5.07	4.85	4.66	4.49	4.34	4.21	4.09	3.98	3.88	3.79	3.70	3.63	3.55	3.48
3 000 000	5.46	5.20	4.98	4.78	4.61	4.46	4.33	4.21	4.10	4.00	3.90	3.81	3.73	3.66	3.59
3 500 000	5.58	5.31	5.09	4.89	4.72	4.57	4.43	4.31	4.20	4.09	4.00	3.91	3.83	3.75	3.68
4 000 000	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	3.83	3.76
4 500 000	5.77	5.50	5.27	5.07	4.90	4.74	4.60	4.48	4.36	4.26	4.16	4.07	3.98	3.91	3.83
5 000 000	5.85	5.58	5.35	5.15	4.97	4.81	4.67	4.55	4.43	4.33	4.23	4.14	4.05	3.97	3.90
6 000 000	6.00	5.72	5.48	5.28	5.10	4.94	4.80	4.67	4.55	4.45	4.35	4.25	4.17	4.09	4.01
7 000 000	6.12	5.84	5.60	5.39	5.21	5.05	4.91	4.78	4.66	4.55	4.45	4.36	4.27	4.19	4.11
8 000 000	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	4.27	4.20
9 000 000	6.33	6.04	5.79	5.58	5.40	5.24	5.09	4.96	4.83	4.72	4.62	4.52	4.43	4.35	4.27
10 000 000	6.41	6.12	5.88	5.66	5.48	5.31	5.17	5.03	4.91	4.80	4.69	4.60	4.51	4.42	4.34
15 000 000	6.76	6.45	6.20	5.98	5.79	5.62	5.46	5.33	5.20	5.08	4.98	4.88	4.78	4.70	4.61
20 000 000	7.01	6.70	6.43	6.21	6.01	5.84	5.68	5.54	5.41	5.29	5.18	5.08	4.99	4.90	4.81
25 000 000	7.21	6.89	6.62	6.39	6.19	6.02	5.86	5.71	5.58	5.46	5.35	5.24	5.15	5.06	4.97
30 000 000	7.37	7.05	6.78	6.55	6.34	6.16	6.00	5.85	5.72	5.60	5.48	5.38	5.28	5.19	5.10
35 000 000	7.51	7.19	6.91	6.68	6.47	6.29	6.12	5.97	5.84	5.72	5.60	5.49	5.40	5.30	5.21
40 000 000	7.64	7.31	7.03	6.79	6.58	6.40	6.23	6.08	5.94	5.82	5.70	5.60	5.49	5.40	5.31
45 000 000	7.75	7.42	7.13	6.89	6.68	6.49	6.33	6.18	6.04	5.91	5.79	5.69	5.58	5.49	5.40
50 000 000	7.85	7.51	7.23	6.99	6.77	6.58	6.41	6.26	6.12	5.99	5.88	5.77	5.66	5.57	5.48
60 000 000	8.03	7.69	7.40	7.15	6.93	6.74	6.57	6.41	6.27	6.14	6.02	5.91	5.81	5.71	5.62
70 000 000	8.18	7.83	7.54	7.29	7.07	6.87	6.70	6.54	6.40	6.27	6.14	6.03	5.93	5.83	5.74
80 000 000	8.32	7.96	7.66	7.41	7.19	6.99	6.81	6.65	6.51	6.37	6.25	6.14	6.03	5.93	5.84
90 000 000	8.44	8.08	7.78	7.52	7.29	7.09	6.92	6.75	6.61	6.47	6.35	6.23	6.13	6.03	5.93
100 000 000	8.55	8.18	7.88	7.62	7.39	7.19	7.01	6.85	6.70	6.56	6.44	6.32	6.21	6.11	6.01

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	2.04	1.96	1.90	1.84	1.78	1.74	1.69	1.65	1.61	1.57	1.54	1.47	1.40	1.34	1.29
150 000	2.18	2.10	2.03	1.97	1.91	1.86	1.81	1.77	1.73	1.69	1.66	1.58	1.51	1.45	1.40
200 000	2.29	2.21	2.13	2.07	2.01	1.96	1.91	1.86	1.82	1.78	1.74	1.66	1.59	1.53	1.47
250 000	2.38	2.29	2.22	2.15	2.09	2.03	1.98	1.93	1.89	1.85	1.81	1.73	1.66	1.59	1.53
300 000	2.45	2.36	2.29	2.22	2.15	2.09	2.04	1.99	1.95	1.91	1.87	1.78	1.71	1.64	1.59
350 000	2.52	2.43	2.34	2.27	2.21	2.15	2.10	2.05	2.00	1.96	1.92	1.83	1.76	1.69	1.63
400 000	2.57	2.48	2.40	2.32	2.26	2.20	2.14	2.09	2.05	2.00	1.96	1.87	1.80	1.73	1.67
450 000	2.62	2.53	2.45	2.37	2.30	2.24	2.19	2.14	2.09	2.04	2.00	1.91	1.83	1.77	1.70
500 000	2.67	2.57	2.49	2.41	2.34	2.28	2.23	2.17	2.13	2.08	2.04	1.95	1.87	1.80	1.74
600 000	2.75	2.65	2.57	2.49	2.42	2.35	2.30	2.24	2.19	2.15	2.10	2.01	1.93	1.86	1.79
700 000	2.82	2.72	2.63	2.55	2.48	2.41	2.36	2.30	2.25	2.20	2.16	2.06	1.98	1.90	1.84
800 000	2.89	2.78	2.69	2.61	2.54	2.47	2.41	2.35	2.30	2.25	2.21	2.11	2.02	1.95	1.88
900 000	2.94	2.84	2.74	2.66	2.59	2.52	2.46	2.40	2.35	2.30	2.25	2.15	2.06	1.99	1.92
1 000 000	3.00	2.89	2.79	2.71	2.63	2.56	2.50	2.44	2.39	2.34	2.29	2.19	2.10	2.02	1.96
1 500 000	3.20	3.09	2.99	2.90	2.81	2.74	2.67	2.61	2.55	2.50	2.45	2.34	2.25	2.17	2.10
2 000 000	3.36	3.24	3.13	3.04	2.95	2.87	2.80	2.74	2.68	2.62	2.57	2.46	2.36	2.28	2.20
2 500 000	3.48	3.36	3.25	3.15	3.06	2.98	2.91	2.84	2.78	2.72	2.67	2.55	2.45	2.36	2.28
3 000 000	3.59	3.46	3.35	3.25	3.16	3.07	3.00	2.93	2.87	2.81	2.75	2.63	2.53	2.43	2.35
3 500 000	3.68	3.55	3.44	3.33	3.24	3.15	3.08	3.01	2.94	2.88	2.82	2.70	2.59	2.50	2.42
4 000 000	3.76	3.63	3.51	3.41	3.31	3.22	3.15	3.07	3.01	2.94	2.89	2.76	2.65	2.55	2.47
4 500 000	3.83	3.70	3.58	3.47	3.38	3.29	3.21	3.13	3.07	3.00	2.94	2.81	2.70	2.60	2.52
5 000 000	3.90	3.76	3.64	3.53	3.43	3.35	3.26	3.19	3.12	3.06	3.00	2.86	2.75	2.65	2.56
6 000 000	4.01	3.87	3.75	3.64	3.54	3.45	3.36	3.29	3.22	3.15	3.09	2.95	2.83	2.73	2.64
7 000 000	4.11	3.97	3.84	3.73	3.63	3.54	3.45	3.37	3.30	3.23	3.17	3.03	2.91	2.80	2.71
8 000 000	4.20	4.05	3.93	3.81	3.71	3.61	3.53	3.45	3.37	3.30	3.24	3.10	2.97	2.87	2.77
5 000 000	4.27	4.13	4.00	3.88	3.78	3.68	3.59	3.51	3.44	3.37	3.30	3.16	3.03	2.92	2.83
10 000 000	4.34	4.20	4.07	3.95	3.84	3.75	3.66	3.57	3.50	3.43	3.36	3.21	3.08	2.97	2.88
15 000 000	4.61	4.47	4.33	4.21	4.10	4.00	3.90	3.82	3.74	3.66	3.59	3.43	3.30	3.18	3.08
20 000 000	4.81	4.66	4.52	4.40	4.28	4.18	4.08	3.99	3.91	3.83	3.76	3.60	3.46	3.33	3.23
25 000 000	4.97	4.82	4.68	4.55	4.43	4.33	4.23	4.14	4.05	3.97	3.90	3.73	3.59	3.46	3.35
30 000 000	5.10	4.94	4.80	4.67	4.56	4.45	4.35	4.25	4.17	4.09	4.01	3.84	3.69	3.56	3.45
35 000 000	5.21	5.05	4.91	4.78	4.66	4.55	4.45	4.36	4.27	4.19	4.11	3.94	3.79	3.65	3.54
40 000 000	5.31	5.15	5.01	4.87	4.75	4.64	4.54	4.45	4.36	4.27	4.20	4.02	3.87	3.73	3.61
45 000 000	5.40	5.24	5.09	4.96	4.84	4.72	4.62	4.52	4.44	4.35	4.27	4.10	3.94	3.81	3.68
50 000 000	5.48	5.31	5.17	5.03	4.91	4.80	4.69	4.60	4.51	4.42	4.34	4.16	4.01	3.87	3.75
60 000 000	5.62	5.45	5.30	5.16	5.04	4.93	4.82	4.72	4.63	4.54	4.46	4.28	4.12	3.98	3.86
70 000 000	5.74	5.57	5.41	5.28	5.15	5.04	4.93	4.83	4.74	4.65	4.57	4.39	4.22	4.08	3.95
80 000 000	5.84	5.67	5.51	5.38	5.25	5.13	5.02	4.92	4.83	4.74	4.66	4.47	4.31	4.17	4.04
90 000 000	5.93	5.76	5.60	5.46	5.34	5.22	5.11	5.01	4.91	4.82	4.74	4.55	4.39	4.24	4.11
100 000 000	6.01	5.84	5.68	5.54	5.41	5.29	5.19	5.08	4.99	4.90	4.82	4.63	4.46	4.31	4.18

TABLE A.9C

REQUIRED STRUCTURAL NUMBER (SN_R)
97% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 300 MPa TO 650 MPa

	Resilient Modulus (M_R), MPa														
$ESAL_D$	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
100 000	1.29	1.25	1.21	1.17	1.13	1.10	1.07	1.04	1.02	0.99	0.97	0.95	0.93	0.91	0.89
150 000	1.40	1.35	1.30	1.27	1.23	1.19	1.16	1.13	1.11	1.08	1.06	1.03	1.01	0.99	0.97
200 000	1.47	1.42	1.38	1.34	1.30	1.26	1.23	1.20	1.17	1.15	1.12	1.10	1.08	1.06	1.04
250 000	1.53	1.48	1.44	1.39	1.36	1.32	1.29	1.26	1.23	1.20	1.17	1.15	1.13	1.11	1.09
300 000	1.59	1.53	1.49	1.44	1.40	1.37	1.33	1.30	1.27	1.24	1.22	1.19	1.17	1.15	1.13
350 000	1.63	1.58	1.53	1.48	1.44	1.41	1.37	1.34	1.31	1.28	1.25	1.23	1.21	1.18	1.16
400 000	1.67	1.61	1.57	1.52	1.48	1.44	1.41	1.37	1.34	1.31	1.29	1.26	1.24	1.22	1.19
450 000	1.70	1.65	1.60	1.55	1.51	1.47	1.44	1.40	1.37	1.34	1.32	1.29	1.27	1.24	1.22
500 000	1.74	1.68	1.63	1.58	1.54	1.50	1.47	1.43	1.40	1.37	1.34	1.32	1.29	1.27	1.25
600 000	1.79	1.73	1.68	1.64	1.59	1.55	1.52	1.48	1.45	1.42	1.39	1.36	1.34	1.32	1.29
700 000	1.84	1.78	1.73	1.68	1.64	1.60	1.56	1.52	1.49	1.46	1.43	1.40	1.38	1.35	1.33
800 000	1.88	1.82	1.77	1.72	1.68	1.64	1.60	1.56	1.53	1.50	1.47	1.44	1.41	1.39	1.37
900 000	1.92	1.86	1.81	1.76	1.71	1.67	1.63	1.59	1.56	1.53	1.50	1.47	1.44	1.42	1.40
1 000 000	1.96	1.89	1.84	1.79	1.74	1.70	1.66	1.63	1.59	1.56	1.53	1.50	1.47	1.45	1.42
1 500 000	2.10	2.03	1.97	1.92	1.87	1.83	1.78	1.75	1.71	1.68	1.64	1.61	1.59	1.56	1.53
2 000 000	2.20	2.13	2.07	2.02	1.96	1.92	1.87	1.83	1.80	1.76	1.73	1.70	1.67	1.64	1.62
2 500 000	2.28	2.21	2.15	2.09	2.04	1.99	1.95	1.91	1.87	1.83	1.80	1.77	1.74	1.71	1.68
3 000 000	2.35	2.28	2.22	2.16	2.10	2.06	2.01	1.97	1.93	1.89	1.86	1.82	1.79	1.76	1.74
3 500 000	2.42	2.34	2.28	2.21	2.16	2.11	2.06	2.02	1.98	1.94	1.91	1.87	1.84	1.81	1.78
4 000 000	2.47	2.39	2.33	2.27	2.21	2.16	2.11	2.07	2.02	1.99	1.95	1.92	1.88	1.85	1.82
4 500 000	2.52	2.44	2.37	2.31	2.25	2.20	2.15	2.11	2.07	2.03	1.99	1.95	1.92	1.89	1.86
5 000 000	2.56	2.48	2.41	2.35	2.29	2.24	2.19	2.14	2.10	2.06	2.02	1.99	1.96	1.93	1.90
6 000 000	2.64	2.56	2.49	2.42	2.36	2.31	2.26	2.21	2.17	2.13	2.09	2.05	2.02	1.99	1.96
7 000 000	2.71	2.63	2.55	2.49	2.43	2.37	2.32	2.27	2.22	2.18	2.14	2.11	2.07	2.04	2.01
8 000 000	2.77	2.69	2.61	2.54	2.48	2.42	2.37	2.32	2.27	2.23	2.19	2.15	2.12	2.09	2.05
9 000 000	2.83	2.74	2.66	2.59	2.53	2.47	2.42	2.37	2.32	2.28	2.24	2.20	2.16	2.13	2.09
10 000 000	2.88	2.79	2.71	2.64	2.57	2.51	2.46	2.41	2.36	2.32	2.28	2.24	2.20	2.17	2.13
15 000 000	3.08	2.98	2.90	2.82	2.75	2.69	2.63	2.58	2.53	2.48	2.43	2.39	2.35	2.32	2.28
20 000 000	3.23	3.13	3.04	2.96	2.89	2.82	2.76	2.70	2.65	2.60	2.55	2.51	2.47	2.43	2.39
25 000 000	3.35	3.25	3.15	3.07	3.00	2.93	2.86	2.80	2.75	2.70	2.65	2.61	2.56	2.52	2.49
30 000 000	3.45	3.34	3.25	3.17	3.09	3.02	2.95	2.89	2.83	2.78	2.73	2.69	2.64	2.60	2.56
35 000 000	3.54	3.43	3.33	3.25	3.17	3.10	3.03	2.97	2.91	2.85	2.80	2.76	2.71	2.67	2.63
40 000 000	3.61	3.51	3.41	3.32	3.24	3.16	3.10	3.03	2.97	2.92	2.87	2.82	2.77	2.73	2.69
45 000 000	3.68	3.57	3.48	3.39	3.30	3.23	3.16	3.09	3.03	2.98	2.92	2.87	2.83	2.78	2.74
50 000 000	3.75	3.64	3.54	3.44	3.36	3.28	3.21	3.15	3.09	3.03	2.97	2.92	2.88	2.83	2.79
60 000 000	3.86	3.74	3.64	3.55	3.46	3.38	3.31	3.24	3.18	3.12	3.07	3.01	2.96	2.92	2.87
70 000 000	3.95	3.84	3.73	3.64	3.55	3.47	3.40	3.33	3.26	3.20	3.14	3.09	3.04	2.99	2.95
80 000 000	4.04	3.92	3.81	3.72	3.63	3.55	3.47	3.40	3.33	3.27	3.21	3.16	3.11	3.06	3.01
90 000 000	4.11	3.99	3.89	3.79	3.70	3.62	3.54	3.47	3.40	3.34	3.28	3.22	3.17	3.12	3.07
100 000 000	4.18	4.06	3.95	3.85	3.76	3.68	3.60	3.53	3.46	3.40	3.34	3.28	3.23	3.18	3.13

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	3.51	3.31	3.14	3.00	2.88	2.78	2.69	2.61	2.53	2.47	2.40	2.35	2.30	2.25	2.21
150 000	3.74	3.53	3.36	3.21	3.08	2.97	2.87	2.79	2.71	2.64	2.57	2.51	2.46	2.41	2.36
200 000	3.92	3.70	3.52	3.37	3.23	3.12	3.01	2.92	2.84	2.77	2.70	2.64	2.58	2.53	2.48
250 000	4.06	3.84	3.65	3.49	3.35	3.23	3.13	3.03	2.95	2.87	2.80	2.74	2.68	2.62	2.57
300 000	4.18	3.95	3.76	3.60	3.46	3.33	3.22	3.13	3.04	2.96	2.89	2.82	2.76	2.70	2.65
350 000	4.28	4.05	3.85	3.69	3.54	3.42	3.31	3.21	3.12	3.04	2.96	2.89	2.83	2.77	2.72
400 000	4.37	4.13	3.94	3.77	3.62	3.49	3.38	3.28	3.19	3.10	3.03	2.96	2.89	2.83	2.78
450 000	4.44	4.21	4.01	3.84	3.69	3.56	3.45	3.34	3.25	3.16	3.09	3.02	2.95	2.89	2.83
500 000	4.52	4.28	4.08	3.90	3.75	3.62	3.51	3.40	3.31	3.22	3.14	3.07	3.00	2.94	2.88
600 000	4.64	4.40	4.19	4.02	3.87	3.73	3.61	3.50	3.41	3.32	3.24	3.16	3.09	3.03	2.97
700 000	4.75	4.50	4.30	4.12	3.96	3.83	3.70	3.59	3.49	3.40	3.32	3.24	3.17	3.11	3.05
800 000	4.84	4.59	4.38	4.20	4.05	3.91	3.78	3.67	3.57	3.48	3.39	3.32	3.25	3.18	3.12
900 000	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	3.24	3.18
1 000 000	5.00	4.75	4.53	4.35	4.19	4.05	3.92	3.81	3.70	3.61	3.52	3.44	3.37	3.30	3.23
1 500 000	5.29	5.03	4.81	4.62	4.46	4.31	4.18	4.06	3.95	3.85	3.76	3.68	3.60	3.52	3.46
2 000 000	5.51	5.24	5.02	4.82	4.65	4.50	4.37	4.24	4.13	4.03	3.94	3.85	3.77	3.69	3.62
2 500 000	5.68	5.41	5.18	4.98	4.81	4.65	4.52	4.39	4.28	4.17	4.08	3.99	3.91	3.83	3.76
3 000 000	5.82	5.54	5.31	5.11	4.94	4.78	4.64	4.51	4.40	4.29	4.20	4.10	4.02	3.94	3.87
3 500 000	5.94	5.66	5.43	5.22	5.05	4.89	4.75	4.62	4.50	4.40	4.30	4.20	4.12	4.04	3.96
4 000 000	6.04	5.76	5.53	5.32	5.14	4.98	4.84	4.71	4.59	4.48	4.38	4.29	4.20	4.12	4.05
4 500 000	6.14	5.85	5.61	5.41	5.23	5.07	4.92	4.79	4.67	4.56	4.46	4.37	4.28	4.20	4.12
5 000 000	6.22	5.94	5.70	5.49	5.31	5.14	5.00	4.87	4.75	4.64	4.53	4.44	4.35	4.27	4.19
6 000 000	6.37	6.08	5.84	5.63	5.44	5.28	5.13	5.00	4.87	4.76	4.66	4.56	4.47	4.39	4.31
7 000 000	6.50	6.21	5.96	5.74	5.56	5.39	5.24	5.11	4.98	4.87	4.77	4.67	4.58	4.49	4.41
8 000 000	6.61	6.32	6.06	5.85	5.66	5.49	5.34	5.20	5.08	4.96	4.86	4.76	4.67	4.58	4.50
9 000 000	6.71	6.41	6.16	5.94	5.75	5.58	5.43	5.29	5.16	5.05	4.94	4.84	4.75	4.66	4.58
10 000 000	6.80	6.50	6.24	6.02	5.83	5.66	5.51	5.37	5.24	5.12	5.02	4.92	4.82	4.74	4.65
15 000 000	7.16	6.85	6.58	6.35	6.15	5.98	5.82	5.67	5.54	5.42	5.31	5.21	5.11	5.02	4.94
20 000 000	7.42	7.10	6.83	6.59	6.39	6.21	6.04	5.90	5.76	5.64	5.53	5.42	5.32	5.23	5.14
25 000 000	7.63	7.30	7.02	6.78	6.57	6.39	6.22	6.07	5.94	5.81	5.70	5.59	5.49	5.40	5.31
30 000 000	7.81	7.47	7.19	6.94	6.73	6.54	6.37	6.22	6.08	5.96	5.84	5.73	5.63	5.53	5.44
35 000 000	7.96	7.61	7.32	7.08	6.86	6.67	6.50	6.35	6.21	6.08	5.96	5.85	5.75	5.65	5.56
40 000 000	8.09	7.74	7.45	7.20	6.98	6.79	6.61	6.46	6.32	6.19	6.07	5.95	5.85	5.75	5.66
45 000 000	8.20	7.85	7.56	7.30	7.08	6.89	6.72	6.56	6.41	6.28	6.16	6.05	5.94	5.84	5.75
50 000 000	8.31	7.95	7.66	7.40	7.18	6.98	6.81	6.65	6.50	6.37	6.25	6.13	6.03	5.93	5.83
60 000 000	8.50	8.13	7.83	7.57	7.34	7.14	6.97	6.80	6.66	6.52	6.40	6.28	6.17	6.07	5.98
70 000 000	8.66	8.29	7.98	7.72	7.49	7.28	7.10	6.94	6.79	6.65	6.52	6.41	6.30	6.20	6.10
80 000 000	8.80	8.42	8.11	7.84	7.61	7.41	7.22	7.06	6.90	6.76	6.64	6.52	6.41	6.30	6.21
90 000 000	8.92	8.54	8.23	7.96	7.72	7.51	7.33	7.16	7.01	6.87	6.74	6.62	6.51	6.40	6.30
100 000 000	9.03	8.65	8.34	8.06	7.82	7.61	7.43	7.26	7.10	6.96	6.83	6.71	6.59	6.49	6.39

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	2.21	2.12	2.05	1.99	1.93	1.88	1.83	1.79	1.75	1.71	1.67	1.59	1.53	1.47	1.41
150 000	2.36	2.27	2.20	2.13	2.07	2.01	1.96	1.92	1.87	1.83	1.80	1.71	1.64	1.58	1.52
200 000	2.48	2.39	2.31	2.24	2.17	2.12	2.06	2.01	1.97	1.93	1.89	1.80	1.73	1.66	1.60
250 000	2.57	2.48	2.39	2.32	2.26	2.20	2.14	2.09	2.04	2.00	1.96	1.87	1.79	1.73	1.67
300 000	2.65	2.55	2.47	2.39	2.33	2.26	2.21	2.16	2.11	2.06	2.02	1.93	1.85	1.78	1.72
350 000	2.72	2.62	2.53	2.46	2.39	2.32	2.27	2.21	2.16	2.12	2.08	1.98	1.90	1.83	1.77
400 000	2.78	2.68	2.59	2.51	2.44	2.38	2.32	2.26	2.21	2.17	2.12	2.03	1.95	1.87	1.81
450 000	2.83	2.73	2.64	2.56	2.49	2.42	2.36	2.31	2.26	2.21	2.17	2.07	1.99	1.91	1.85
500 000	2.88	2.78	2.69	2.61	2.53	2.47	2.40	2.35	2.30	2.25	2.21	2.11	2.02	1.95	1.88
600 000	2.97	2.86	2.77	2.69	2.61	2.54	2.48	2.42	2.37	2.32	2.27	2.17	2.08	2.01	1.94
700 000	3.05	2.94	2.84	2.76	2.68	2.61	2.54	2.48	2.43	2.38	2.33	2.23	2.14	2.06	1.99
800 000	3.12	3.00	2.91	2.82	2.74	2.67	2.60	2.54	2.49	2.43	2.39	2.28	2.19	2.11	2.04
900 000	3.18	3.06	2.96	2.87	2.79	2.72	2.65	2.59	2.53	2.48	2.43	2.32	2.23	2.15	2.08
1 000 000	3.23	3.12	3.01	2.92	2.84	2.77	2.70	2.64	2.58	2.53	2.48	2.37	2.27	2.19	2.12
1 500 000	3.46	3.33	3.22	3.13	3.04	2.96	2.89	2.82	2.76	2.70	2.65	2.53	2.43	2.34	2.26
2 000 000	3.62	3.49	3.38	3.28	3.19	3.10	3.03	2.96	2.89	2.83	2.78	2.66	2.55	2.46	2.38
2 500 000	3.76	3.62	3.51	3.40	3.31	3.22	3.14	3.07	3.00	2.94	2.88	2.76	2.65	2.55	2.47
3 000 000	3.87	3.73	3.61	3.51	3.41	3.32	3.24	3.16	3.09	3.03	2.97	2.84	2.73	2.63	2.54
3 500 000	3.96	3.83	3.70	3.59	3.49	3.40	3.32	3.25	3.17	3.11	3.05	2.91	2.80	2.70	2.61
4 000 000	4.05	3.91	3.78	3.67	3.57	3.48	3.40	3.32	3.25	3.18	3.12	2.98	2.86	2.76	2.67
4 500 000	4.12	3.98	3.86	3.74	3.64	3.55	3.46	3.38	3.31	3.24	3.18	3.04	2.92	2.81	2.72
5 000 000	4.19	4.05	3.92	3.81	3.70	3.61	3.52	3.44	3.37	3.30	3.23	3.09	2.97	2.86	2.77
6 000 000	4.31	4.17	4.04	3.92	3.81	3.72	3.63	3.55	3.47	3.40	3.33	3.19	3.06	2.95	2.85
7 000 000	4.41	4.27	4.13	4.02	3.91	3.81	3.72	3.64	3.56	3.49	3.42	3.27	3.14	3.03	2.93
8 000 000	4.50	4.35	4.22	4.10	3.99	3.89	3.80	3.71	3.64	3.56	3.49	3.34	3.21	3.09	2.99
9 000 000	4.58	4.43	4.30	4.18	4.07	3.97	3.87	3.79	3.71	3.63	3.56	3.41	3.27	3.15	3.05
10 000 000	4.65	4.50	4.37	4.25	4.13	4.03	3.94	3.85	3.77	3.69	3.62	3.47	3.33	3.21	3.10
15 000 000	4.94	4.78	4.64	4.52	4.40	4.29	4.20	4.11	4.02	3.94	3.87	3.70	3.56	3.43	3.32
20 000 000	5.14	4.98	4.84	4.71	4.59	4.49	4.39	4.29	4.21	4.12	4.05	3.88	3.73	3.60	3.48
25 000 000	5.31	5.15	5.00	4.87	4.75	4.64	4.53	4.44	4.35	4.27	4.19	4.02	3.86	3.73	3.61
30 000 000	5.44	5.28	5.13	5.00	4.88	4.76	4.66	4.56	4.47	4.39	4.31	4.13	3.98	3.84	3.72
35 000 000	5.56	5.39	5.24	5.11	4.98	4.87	4.77	4.67	4.58	4.49	4.41	4.23	4.07	3.94	3.81
40 000 000	5.66	5.49	5.34	5.21	5.08	4.97	4.86	4.76	4.67	4.58	4.50	4.32	4.16	4.02	3.89
45 000 000	5.75	5.58	5.43	5.29	5.17	5.05	4.94	4.84	4.75	4.66	4.58	4.40	4.24	4.09	3.97
50 000 000	5.83	5.66	5.51	5.37	5.24	5.13	5.02	4.92	4.82	4.74	4.65	4.47	4.31	4.16	4.03
60 000 000	5.98	5.80	5.65	5.51	5.38	5.26	5.15	5.05	4.95	4.86	4.78	4.59	4.43	4.28	4.15
70 000 000	6.10	5.92	5.77	5.62	5.49	5.37	5.26	5.16	5.06	4.97	4.89	4.70	4.53	4.38	4.25
80 000 000	6.21	6.03	5.87	5.72	5.59	5.47	5.36	5.26	5.16	5.07	4.98	4.79	4.62	4.47	4.34
90 000 000	6.30	6.12	5.96	5.82	5.68	5.56	5.45	5.34	5.25	5.15	5.07	4.87	4.70	4.55	4.42
100 000 000	6.39	6.21	6.05	5.90	5.76	5.64	5.53	5.42	5.32	5.23	5.14	4.95	4.78	4.62	4.49

TABLE A.10C

REQUIRED STRUCTURAL NUMBER (SN_R)
99% RELIABILITY (%R)
RESILIENT MODULUS (M_R) RANGE 300 MPa TO 650 MPa

	Resilient Modulus (M_R), MPa														
$ESAL_D$	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
100 000	1.41	1.36	1.32	1.28	1.24	1.21	1.18	1.15	1.12	1.09	1.07	1.05	1.03	1.00	0.99
150 000	1.52	1.47	1.42	1.38	1.34	1.31	1.27	1.24	1.22	1.19	1.16	1.14	1.12	1.09	1.07
200 000	1.60	1.55	1.50	1.46	1.42	1.38	1.35	1.32	1.29	1.26	1.23	1.21	1.18	1.16	1.14
250 000	1.67	1.61	1.56	1.52	1.48	1.44	1.40	1.37	1.34	1.31	1.29	1.26	1.24	1.21	1.19
300 000	1.72	1.67	1.62	1.57	1.53	1.49	1.45	1.42	1.39	1.36	1.33	1.31	1.28	1.26	1.24
350 000	1.77	1.71	1.66	1.61	1.57	1.53	1.50	1.46	1.43	1.40	1.37	1.34	1.32	1.30	1.27
400 000	1.81	1.75	1.70	1.65	1.61	1.57	1.53	1.50	1.46	1.43	1.41	1.38	1.35	1.33	1.31
450 000	1.85	1.79	1.74	1.69	1.64	1.60	1.56	1.53	1.50	1.47	1.44	1.41	1.38	1.36	1.34
500 000	1.88	1.82	1.77	1.72	1.67	1.63	1.59	1.56	1.53	1.49	1.47	1.44	1.41	1.39	1.36
600 000	1.94	1.88	1.82	1.77	1.73	1.69	1.65	1.61	1.58	1.55	1.52	1.49	1.46	1.43	1.41
700 000	1.99	1.93	1.87	1.82	1.78	1.73	1.69	1.66	1.62	1.59	1.56	1.53	1.50	1.48	1.45
800 000	2.04	1.97	1.92	1.86	1.82	1.77	1.73	1.70	1.66	1.63	1.60	1.57	1.54	1.51	1.49
900 000	2.08	2.01	1.96	1.90	1.85	1.81	1.77	1.73	1.70	1.66	1.63	1.60	1.57	1.55	1.52
1 000 000	2.12	2.05	1.99	1.94	1.89	1.84	1.80	1.76	1.73	1.69	1.66	1.63	1.60	1.58	1.55
1 500 000	2.26	2.20	2.13	2.08	2.02	1.98	1.93	1.89	1.85	1.82	1.78	1.75	1.72	1.69	1.67
2 000 000	2.38	2.30	2.24	2.18	2.12	2.07	2.03	1.99	1.95	1.91	1.87	1.84	1.81	1.78	1.75
2 500 000	2.47	2.39	2.32	2.26	2.21	2.15	2.11	2.06	2.02	1.98	1.95	1.91	1.88	1.85	1.82
3 000 000	2.54	2.46	2.40	2.33	2.27	2.22	2.17	2.13	2.08	2.05	2.01	1.97	1.94	1.91	1.88
3 500 000	2.61	2.53	2.46	2.39	2.33	2.28	2.23	2.18	2.14	2.10	2.06	2.03	1.99	1.96	1.93
4 000 000	2.67	2.59	2.51	2.45	2.39	2.33	2.28	2.23	2.19	2.15	2.11	2.07	2.04	2.01	1.97
4 500 000	2.72	2.64	2.56	2.50	2.43	2.38	2.33	2.28	2.23	2.19	2.15	2.11	2.08	2.05	2.01
5 000 000	2.77	2.68	2.61	2.54	2.48	2.42	2.37	2.32	2.27	2.23	2.19	2.15	2.12	2.08	2.05
6 000 000	2.85	2.77	2.69	2.62	2.55	2.49	2.44	2.39	2.34	2.30	2.26	2.22	2.18	2.15	2.11
7 000 000	2.93	2.84	2.76	2.69	2.62	2.56	2.50	2.45	2.40	2.36	2.32	2.28	2.24	2.20	2.17
8 000 000	2.99	2.90	2.82	2.75	2.68	2.62	2.56	2.51	2.46	2.41	2.37	2.33	2.29	2.25	2.22
9 000 000	3.05	2.96	2.87	2.80	2.73	2.67	2.61	2.56	2.51	2.46	2.42	2.37	2.34	2.30	2.26
10 000 000	3.10	3.01	2.93	2.85	2.78	2.71	2.66	2.60	2.55	2.50	2.46	2.42	2.38	2.34	2.30
15 000 000	3.32	3.22	3.13	3.05	2.97	2.90	2.84	2.78	2.73	2.68	2.63	2.58	2.54	2.50	2.47
20 000 000	3.48	3.38	3.28	3.20	3.12	3.05	2.98	2.92	2.86	2.81	2.76	2.71	2.67	2.63	2.59
25 000 000	3.61	3.50	3.40	3.32	3.24	3.16	3.09	3.03	2.97	2.91	2.86	2.81	2.77	2.72	2.68
30 000 000	3.72	3.61	3.51	3.42	3.33	3.26	3.19	3.12	3.06	3.00	2.95	2.90	2.85	2.81	2.77
35 000 000	3.81	3.70	3.60	3.50	3.42	3.34	3.27	3.20	3.14	3.08	3.03	2.98	2.93	2.88	2.84
40 000 000	3.89	3.78	3.68	3.58	3.50	3.42	3.34	3.27	3.21	3.15	3.09	3.04	2.99	2.95	2.90
45 000 000	3.97	3.85	3.75	3.65	3.56	3.48	3.41	3.34	3.27	3.21	3.16	3.10	3.05	3.00	2.96
50 000 000	4.03	3.92	3.81	3.71	3.62	3.54	3.47	3.40	3.33	3.27	3.21	3.16	3.11	3.06	3.01
60 000 000	4.15	4.03	3.92	3.82	3.73	3.65	3.57	3.50	3.43	3.37	3.31	3.25	3.20	3.15	3.10
70 000 000	4.25	4.13	4.02	3.92	3.83	3.74	3.66	3.59	3.52	3.45	3.39	3.34	3.28	3.23	3.18
80 000 000	4.34	4.22	4.10	4.00	3.91	3.82	3.74	3.67	3.60	3.53	3.47	3.41	3.36	3.30	3.25
90 000 000	4.42	4.29	4.18	4.08	3.98	3.89	3.81	3.74	3.67	3.60	3.54	3.48	3.42	3.37	3.32
100 000 000	4.49	4.36	4.25	4.14	4.05	3.96	3.88	3.80	3.73	3.66	3.60	3.54	3.48	3.43	3.38

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-c). 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 material properties used in the 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, thicknesses, 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 (Dynaflect) from the State Materials Office.
  - A composition report must be requested based on the milling recommendations for all projects involving milling greater than 1000 metric tons.

- The $ESAL_D$ calculations, signed and certified. This may be either a copy of the report prepared by the Planning Office or calculations using the design computer program. The basis for the input data used for these calculations must be stated.

- Design calculations (including pavement layer thicknesses).

- 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 in accordance with Standard Index 513.

- A drawing of the final pavement design typical section or an adequate narrative description.

B.4.2 DISTRIBUTION

In addition to retaining the original documentation in the District Project Design File, one copy of the approved pavement design with supporting documentation will be transmitted to the State Pavement Design Engineer or entered into the DOTNET pavement design program (preferred method, see Appendix C). This transmittal will normally occur between Phase I and Phase II Plans Submittal. The very latest should be at Phase III Plans Submittal.

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 not covered by Certification Acceptance, 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, DESAL, 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 judgement 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. _____
WPI No. _____ County _____

Flexible Pavement Design Review	Satisfactory Yes/No
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.	____
Milling Depth and Purpose.	____
Overlay Structural Number (SN_O) Calculations . . .	____
Leveling/Overbuild Recommendation.	____
Composition Report	____

Projects That Do Not Require Design Calculations

Existing Pavement Evaluation . . . . . ____

Asphalt Thickness. . . . . ____

Base Type and Thickness. . . . . ____

Future Milling Considerations. . . . . ____

Structural Evaluation. . . . . ____

Plans Review

Plans Conform to Pavement Design . . . . . ____

Design Details Adequately Covered. . . . . ____

Standard Indexes Properly Referenced . . . . . ____

Project is Constructable with Current Technology . ____

Comments

_____

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QA by _____ Date _____

FLORIDA DEPARTMENT OF TRANSPORTATION
FLEXIBLE PAVEMENT DESIGN SUMMARY SHEET

Prepared by _____ Date Prep. _____
WPI # _____ 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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C.1 PROGRAM OVERVIEW

The Flexible Pavement Design and Analysis Program is a window driven system of SAS Version 6 computer programs. This program is designed to be used as a tool in the development of the Department's pavement designs.

By entering the Work Program Item Number (WPI) for a state project, the system will initially retrieve the State and Federal Aid Project Numbers and project description information from the Work Program Administration (WPA) database. The Pavement Design Engineer can then enter additional design information through full-screen edit windows which will then let the programs generate trial pavement designs.

These trial pavement designs can then be modified as needed and saved in a permanent database for later retrieval and/or modification. Pavement Design Summary Sheets can be generated and routed to remote printers or to a data set.

C.2 ACCESS TO THE PROGRAM

Access to the Flexible Pavement Design And Analysis Program is through TSO on the FDOT DOTNET Statewide Computer Network. Contact your District Computer Engineer or the FDOT Infocenter at (904) 488-8008 for information on accessing TSO through DOTNET. The program can be processed by anyone with access to TSO. However, to save any pavement designs, security access through RACF must be requested through the District Pavement Design Engineer to the State Pavement Management Office.

After accessing TSO, a Master Application Menu will be displayed. Entering 5;f;2 on the Option Line and pressing ENTER will take you directly (after a few seconds) to the Pavement Design and Analysis Main Menu. You can also step through the menus by entering 5 "Use Engineering Programs and Services", then F "Roadway Design" from the Engmenu System Main Option Menu, and then 2 "Pavement Design and Analysis" from the ENGMENU System Roadway Design Options Menu.

Another access method is to terminate ISPF from the Master Application Menu and enter PDMENU from the TSO READY prompt, which will also take you directly to the Pavement Design and Analysis Program Main Menu.

C.3 USER'S GUIDE

A User's Guide that provides some additional information regarding the various program windows is available through CICS in DOTNET under the document name PDMENU GUIDE. It can be retrieved using Officevision Option 6 "Stored Documents".

APPENDIX D

ESTIMATING DESIGN 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 Ottowa, 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 80 000 Newtons (80 kN Equivalent Single Axle Load or $ESAL_D$) was accepted as the base for these calculations. Table D.1 illustrates the relationship of axle weight to damage.

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

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

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

TABLE D.1

RELATIONSHIP OF AXLE WEIGHT TO DAMAGE

	Total Axle Load in kN	Equivalent Damage in ESAL's
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:

$$ESAL_D = \sum_{y=1}^{y=x} (AADT \times T_{24} \times D_F \times L_F \times E_{80} \times 365)$$

where:

$ESAL_D$ = Number of accumulated 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_{80} = Equivalency factor which is the damage caused by one average heavy truck measured in 80 kilonewtons Equivalent Single Axle Loads. These factors will be periodically updated based on Weigh-In-Motion (WIM) data. E_{80} values can be determined from Table D.3.

TABLE D.2

LANE FACTORS (L_F) FOR DIFFERENT TYPES OF FACILITIES

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

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

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

where:

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

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

Ln = Natural Logarithm.

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

TABLE D.3

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

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

D.3 SAMPLE PROBLEMS

Several sample problems have been provided that 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_{80} = 0.89 (from Table D.3)

L_F = Determined using the equation from Table D.2

FIND:

The $ESAL_D$ for a 20 year design period beginning in 2005.

SOLUTION:

Using the following equations:

For the year 2005 to 2013.

$$ESAL_D = \sum_{y=2005}^{y=2013} (AADT \times T_{24} \times D_F \times L_F \times E_{80} \times 365)$$

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

For the year 2014 to 2025.

$$ESAL_D = \sum_{y=2014}^{y=2025} (AADT \times T_{24} \times D_F \times L_F \times E_{80} \times 365)$$

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

Calculating:

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

* Values are rounded for simplicity.

CONCLUSION:

Note that the 20 year 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.

T_{24} = 10%
1990 Estimated AADT = 17 000
2006 Estimated AADT = 25 000

DATA:

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

D_F = 0.50 (for two way traffic)
E_{80} = 0.96 (from Table D.3)

L_F = Determined using the equation from Table D.2

FIND:

The $ESAL_D$ for a 14 year design period beginning in 1990.

SOLUTION:

Using the following equation:

For the year 1990 to 2003.

$$ESAL_D = \sum_{y=1990}^{y=2003} (AADT \times T_{24} \times D_F \times L_F \times E_{80} \times 365)$$

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

Calculating:

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

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

4 329 400 - 244 300 = 4 085 100 ESALs

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