# RIGID PAVEMENT DESIGN MANUAL

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FLORIDA DEPARTMENT OF TRANSPORTATION
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UPDATES TO THIS MANUAL WILL BE ANNOUNCED ON PAVEMENT MANAGEMENT WEB SITE.

ADDRESS:http://www.dot.state.fl.us/pavementmanagement

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State Pavement Design Engineer

# RIGID 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 rigid pavement, or develop a properly engineered rehabilitation project.

This design manual addresses methods to properly develop a rehabilitation project 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 SCOPE

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

## 1.4 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 should be met for rigid pavement design for new construction and pavement rehabilitation of FDOT projects.

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.

## 1.5 RIGID PAVEMENT DESIGN MANUAL ORGANIZATION AND REVISIONS

### 1.5.1 BACKGROUND

This manual is published as a revision to add dual units and minor updates to the previous manual dated September 1, 1996.

### 1.5.2 REFERENCES

The design procedures incorporated in this document are based on the 1993 AASHTO Guide for Design of Pavement Structures plus numerous National Cooperative 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 5 appendices:

| Appendix | Contents |
|---|---|
| A | Design Tables. |
| B | Rigid Pavement Design Quality Control Plan. |
| C | Estimating Design 18-kip (80 kilonewton) Equivalent Single Axle Loads ($ESAL_D$). |
| D | Rigid Pavement Design Analysis Computer Program. |
| E | Relationship between Resilient Modulus(Mr) and Limerock Bearing Ratio(LBR). |

## 1.6 DISTRIBUTION

This document is available on line at http://www.dot.state.fl.us/pavementmanagement and also distributed through the Maps and Publications Section. Manuals may be purchased from:

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

Sun Com 994-4050
Telephone (850) 414-4050
FAX Number (850) 414-4915
http://www.dot.state.fl.us/mapsandpublications

Contact the above office for latest price information. Authorized FDOT 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

Comments and suggestions to the Rigid Pavement Design Manual are solicited for changes to the manual by email at http://www.dot.state.fl.us/pavementmanagement or by writing to the address below:

Florida Department Of Transportation
Pavement Management Office
605 Suwannee Street, M.S. 70
Tallahassee, Florida
32399-0450

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

Statewide meetings of District Roadway Design Engineers will be held quarterly and a statewide meeting of designers may be held annually. A major agenda item at these meetings will be the review of design guidance, 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.

## 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. Training on the Departments mainframe computer is available.

## 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 as shown in Figure 2.1 and 2.2. The definitions are presented "top-down" through the pavement structure with the stronger layers on top of the weaker layers. The pavement structure or system as it is sometimes referred to is designed to support traffic loads and distribute them to the roadbed soil or select embankment material.

Concrete Pavement Slab

This is the main structural element in the rigid pavement system. It is normally made up of plain cement concrete pavement. Discussion on the design of this layer depth will be found later on.

Treated Permeable Base

The Treated Permeable Base is a non-structural layer underneath the pavement slab that provides lateral drainage for infiltrated water from pavement joints. Two types of material are available which include Asphalt Treated Permeable Base (ATPB) and Cement Treated Permeable Base (CTPB). This material will be used only in Standard Index 505 Embankment Utilization for the Treated Permeable Base option and will be discussed further in Chapter 4. The standard depth is 4"(100 mm). See figure 2.2.

Special Select Soil and Special Stabilized Subbase

The Special Select Soil is a permeable sandy soil that provides vertical and lateral drainage of infiltrated water through the embankment to the shoulder ditches. The required depth is 60"(1500 mm). This material will be used only in Embankment Utilization for Special Select Soil Option and will be discussed further in Chapter 4. It is normally bid as embankment material. See Figure 2.1.

The Special Stabilized Subbase is a vertically drainable, but stable layer that is 6"(150 mm) thick. This material is used only in Embankment Utilization of special select soil typical section as shown in Standard Index 505 and will be discussed further in Chapter 4.

This layer serves as a working platform for the paving machine to permit the efficient construction of the concrete slab while maintaining sufficient vertical permeability of the special select embankment soil. It is constructed by mixing in 3″(75 mm) of #57 or #89 coarse aggregate into the top 6"(150 mm) of subgrade and compacted. It is bid as Special Stabilized Subbase and Commercial Stabilizing Material (Special). If the special select soils have sufficient stability for construction, these pay items can be deleted. This should only be done with close coordination and agreement of the District Materials Engineer.

Asphalt Structural Course

The asphalt structural course is designed as a separation layer to prevent fines from entering the Asphalt Treated Permeable Base (ATPB) or Cement Treated Permeable Base (CTPB). The structural course used by the Department is Type SP. This material will only be used in Embankment Utilization for treated permeable base option and will be discussed further in Chapter 4. The recommended depth is 1"(30 mm).

Type B Stabilized Subgrade

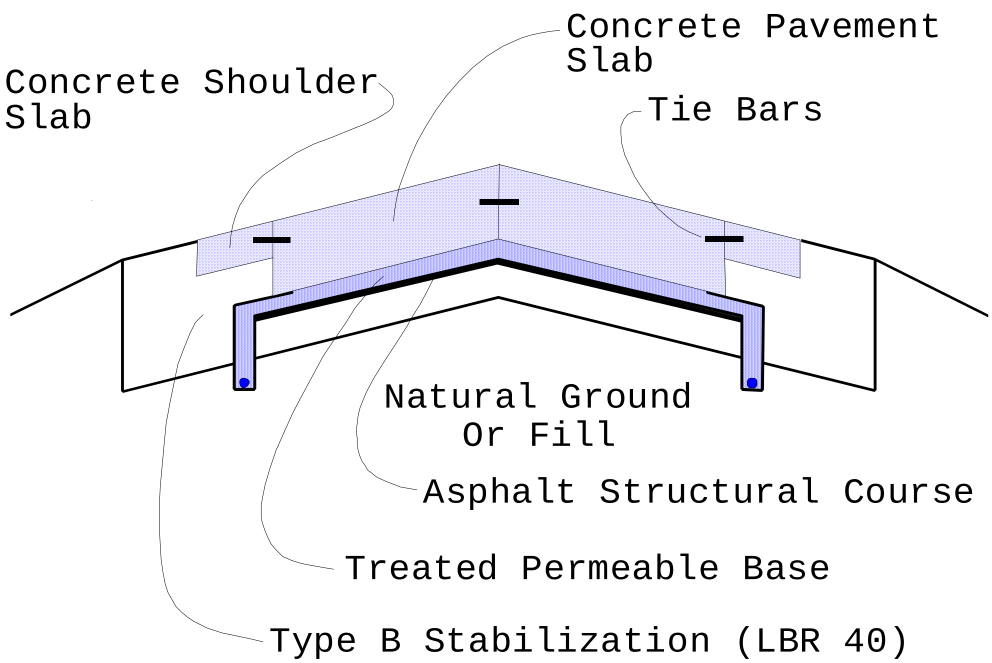
The Type B Stabilized Subgrade is a supporting layer that is 12"(300 mm) thick. This material only is used in Embankment Utilization for treated permeable base option as shown in Standard Index 505 and will be discussed further in Chapter 4. This layer serves as a working platform to permit the efficient construction of the asphalt structural course and treated permeable 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.

Natural Ground Or Fill

The Natural Ground or Fill is the natural material or embankment material upon which the Pavement Structure is constructed.

**FIGURE 2.1**

**ROADWAY TYPICAL SECTION**
**TREATED PERMEABLE BASE**




Not To Scale

## 2.2 AASHTO MODEL

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

### 2.2.1 VARIABLES

<u>Accumulated 18-Kip (80 kilonewton) Equivalent Single Axle Loads 18-Kip (80 kN ESAL) or $ESAL_D$</u>

The Accumulated 18-Kip (80 kilonewton) Equivalent Single Axle Loads 18-Kip (80 kN $ESAL_D$) is the traffic load information used for pavement depth determination. The accumulation of the damage caused by mixed truck traffic during the design period is referred to as the $ESAL_D$.

<u>Modulus Of Subgrade Reaction ($K_G$)</u>

The Modulus Of Subgrade Reaction ($K_G$) represents the hypothetical elastic spring support provided by the subgrade to the slab. The recommended value to use in design for department projects is 200 lbs/inch$^2$/in (pci)(50 KPa/mm) for Special Soil Select material (sand).

<u>Reliability (%R)</u>

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 concrete depth substantially.

The models are based on serviceability and not a specific failure mechanism, such as cracking, pumping, etc.. Recommended values range from 75% to 95% and can be found in Table 3.2. It is important to note that this is not an input value into the AASHTO Design Equation. The use of a converted value known as the Standard Normal Deviate ($Z_R$) is input into the equation.

Standard Normal Deviate ($Z_R$)

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

### 2.2.2 CONSTANTS

Standard Deviation ($S_O$)

A Standard Deviation ($S_O$) of 0.35 is used in the design calculations to represent the variability in construction and loading prediction for rigid pavements.

Modulus Of Elasticity ($E_C$)

The Modulus Of Elasticity ($E_C$) is the Young's modulus or stress to strain ratio or stiffness of the concrete slab. The standard value to use in design for department projects is 4,000,000 psi (27500 MPa).

Concrete Modulus Of Rupture (S'c)

The Concrete Modulus Of Rupture (S'c) is the 28-Day Flexural Strength based on third point loading. This is the extreme fiber stress under the breaking load in a beam-breaking test. The standard value to use in design for department projects is 635 psi(4400 kPa).

Drainage Factor ($C_D$)

The Drainage Factor ($C_D$) is the ability of the pavement surface to drain over a period of time ranging from 1 hour to 72 hours. The standard value to use in design for department projects is 1.0. If standard drainage standards cannot be met, the District Materials Engineer should be consulted for assistance to determine the reduced value.

Joint Transfer Factor (J)

The Joint Transfer Factor (J) is the ability of the concrete joint to transfer the load across the joint. The standard value to use in design for department projects is 3.2.

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 smoothness 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 ($\Delta$PSI)

The Change In Serviceability $\Delta$PSI is the difference between an Initial Serviceability ($P_I$) of 4.2 and a Terminal Serviceability ($P_T$) of 2.5. The Department uses a value of 1.7.

### 2.2.3 UNKNOWNS

Required Depth ($D_R$)

The Required Depth ($D_R$) is the slab depth determined 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 new pavement system on a new alignment.

Reconstruction

Reconstruction is the complete removal of the existing pavement structure along the existing alignment.

Rehabilitation

Rehabilitation is a process to restore the existing pavement to its full serviceability. This could include Concrete Pavement Rehabilitation (CPR) or Crack, Reseat, and Overlay (CRO) of the existing pavement.

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# CHAPTER 3

# PAVEMENT THICKNESS DESIGN PROCESS FOR NEW CONSTRUCTION

## 3.1 DESIGN SOURCE

The American Association of State Highway Officials (AASHO) Road Test at Ottawa, Illinois provided the basis for calculating the required concrete pavement depth. Models were developed that related pavement performance, vehicle loadings, strength of embankment, and the pavement structure.

The purpose of the 1993 AASHTO model in the pavement thickness design process is to calculate the Required Depth ($D_R$) of the concrete pavement. This is the depth of the concrete pavement that must be constructed to carry the mixed vehicle loads to the roadbed soil while providing satisfactory serviceability during the design period.

Figure 3.1 illustrates the 1993 AASHTO Equation used to determine the depth of pavement.

The summation of the vehicle loads over the design period is expressed in the Accumulated 80 kilonewton Equivalent Single Axle Loads ($ESAL_D$). The District Planning Office, Design Traffic Procedure Topic No. 525-030-120, using the Design Traffic Handbook, normally generates this information. A simple procedure for estimating the Accumulated 80 kilonewton Equivalent Single Axle Loads ($ESAL_D$) is given in Appendix C.

## 3.2 DESIGN PERIODS

The design periods that will be used for rigid pavement design vary from 5 to 20 years, depending on the type of construction. The Pavement Design Engineer does have some margin to tailor the pavement design to project constraints or other factors. These Design Periods are summarized in Table 3.1.

FIGURE 3.1

1993 AASHTO DESIGN EQUATION FOR RIGID PAVEMENT

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

$$Z_R * S_O + 7.35 * \log_{10}(D_R+1) - 0.06 \ +$$

$$\frac{\mathrm{Log}_{10}\left(\dfrac{P_I - P_T}{4.5-1.5}\right)}{1 + \dfrac{1.624*10^7}{(D_R+1)^{8.46}}} \ +$$

$$(4.22-0.32*P_T)*$$

$$\log_{10}\left(\frac{S'_C * C_D \ [D_R^{0.75} - 1.132]}{215.63*J\left(D_R^{0.75} - \dfrac{18.42}{(E_C/K_G)^{0.25}}\right)}\right)$$

**FIGURE 3.1**
(Continued)

## 1993 AASHTO DESIGN EQUATION FOR RIGID PAVEMENT

The unknown to be determined is:

$D_R$ = Required Depth Of Concrete Pavement in inches (mm).

The input includes the variables:

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

$Z_R$ = Standard Normal Deviate from normal distribution table for design reliability R.

Note that the Reliability (%R) is not included in this equation. This is replaced by the corresponding Standard Normal Deviate($Z_R$).

$K_G$ = Modulus Of Subgrade Reaction lbs/inch$^2$/in (kPa/mm).

The input includes the constants:

$S_O$ = Standard Deviation.

$P_I$ = Initially Serviceability.

$P_T$ = Terminal Serviceability.

$\Delta$PSI = Change in Serviceability.

$S'_C$ = Concrete Modulus Of Rupture psi (kPa).

$E_C$ = Concrete Modulus Of Elasticity psi (MPa).

$C_D$ = Drainage Coefficient.

J = Joint Transfer Factor.

## 3.3 DESIGN PROCEDURE

In order to design a new rigid pavement, several tasks need to be performed.
The first task is to collect all relevant project data, which would include:

- A history of successful construction and performance with concrete pavements.

- The Treated Permeable Base Option on Index 505 is recommended.

- Traffic loading forecasts ($ESAL_D$).

The next task would be to evaluate concrete material properties, which are generally constant for design purposes and include:

- Concrete Modulus Of Elasticity ($E_c$).

- Concrete Modulus Of Rupture ($S'_c$).

The Pavement Design Engineer also needs to work with the roadway design engineer, District Materials Engineer, and District Drainage Engineer to develop preliminary cut and fill typical sections and evaluate the type of subgrade drainage system to be provided.

If there is not a strong history of successful construction and performance in the area using special select soils under concrete pavements, the Treated Permeable Base option is recommended.

Calculation of the pavement thickness utilizing the design aids provided can be accomplished next.

The Pavement Design Engineer needs to develop pavement details such as:

- Embankment and drainage details.
- Joint details.
- Shoulders details.
- The availability of suitable drainable special select embankment soils

The design of the pavement details is just as important as the design of the pavement depth. Close attention should be paid to their development.

**TABLE 3.1**

**DESIGN PERIODS**

**The following design periods will be used for rigid pavement design:**

| | |
|---|---|
| New Construction or Reconstruction | 20 years |
| Concrete Pavement Rehabilitation (CPR) | 5 to 10 years* |

* CPR design life is not calculated, but should be subjectively estimated based on a projects historical deterioration rate and loadings.

## 3.4 DISTRICT COORDINATION

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

District Design

District Design Engineer’s office should be involved for providing the proposed roadway typical section sheets for such information as, pavement widening, side street work and other related information required for the **Typical Section Package** according to the **Department’s Plans Preparation Manual.**

District Drainage

The District Drainage Office should be involved to determine what special drainage considerations need to be addressed. Several areas, which should be addressed include:

- A high water table that may require the Drainage Engineer to specify the location of outlet pipes.
- Location of edgedrain outlet pipes in an urban area to take advantage of local storm sewers.

When designing the pavement system, the designer needs to refer to the Plans Preparation Manual Section 2.6 Grades, to determine where the bottom of the pavement slab needs to be in relation to the Base Clearance Water Elevation. The bottom of “roadway base”, as referred to in the Plans Preparation Manual, for rigid pavement design purposes, is the bottom of the concrete slab.

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 Maintenance of Traffic (MOT), Constructions Time, Etc.

District Materials

The Treated Permeable Base Option on Index 505 is recommended.

The District Materials Office should be involved to determine the availability and history of successful use of suitable permeable special select soils in the construction area and any other special conditions that may exist.  One example would include an evaluation of existing soils to determine their AASHTO classifications and permeability.

The District Materials Office can also provide recommendations with respect to rehabilitation strategies.  Additional coordination of project field reviews and data collection might be needed.

## 3.5 QUALITY

The Quality Control of a pavement's design is a District responsibility. Upon completion of the design process, an independent design review needs to be performed. A suggested Pavement Design Quality Control Plan is provided in Appendix B.

## 3.6 DESIGN THICKNESS USING THE 1993 AASHTO GUIDE

This process is applicable to all new construction and reconstruction projects in Florida where the Pavement Design Engineer must calculate the concrete pavement depth using the 1993 AASHTO Procedure.

The following is a summary of the steps to be taken to solve for the Required Depth ($D_R$) of the concrete pavement:

- The Accumulated 18-kip (80 kilonewton) Equivalent Single Axle Loads ($ESAL_D$) are obtained from the District Planning Office. The process for this procedure can be found in the Project Traffic Forecasting Procedure Topic No. 525-030-120, using the Design Traffic Handbook. Appendix C provides a simple procedure for calculating the Accumulated 18-kip (80 kilonewton) Equivalent Single Axle Loads ($ESAL_D$) for the appropriate design period.

- The Modulus Of Subgrade Reaction ($K_G$) is obtained from the District Materials Office. The recommended value to use in design for department projects is 200 pci (50 kPa/mm) for Florida select soils. The range in the design tables is provided for non-state system roads where non-select materials may be used.

- Reliability (%R) value is selected from Table 3.2. Recommended values range from 75% to 95% for new or total reconstruction. For asphalt overlays of concrete pavement, see the Flexible Pavement Design Manual for recommended reliability’s and other guidance.

Using these values, the Pavement Design Engineer will calculate the Required Depth ($D_R$) of concrete pavement using the Design Tables in Appendix A, or the Darwin computer program.

Each table uses a different Reliability (%R) value and relates the Accumulated 18-kip (80 kilonewton) Equivalent Single Axle Loads ($ESAL_D$) to the Required Depth ($D_R$) for multiple Modulus Of Subgrade Reaction ($K_G$) values.  An example is in Table 3.3.

**TABLE 3.2**

**RELIABILITY (%R) FOR DIFFERENT ROADWAY FACILITIES**

| **Facility** | **New or Reconstruction** |
|---|---|
| Limited Access | 80 - 95 |
| Urban Arterials | 80 - 90 |
| Rural Arterials | 75 - 90 |
| Collectors | 75 - 85 |

**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).

**TABLE 3.3**
**(FROM TABLE A.7 IN APPENDIX A)**

**REQUIRED DEPTH ($D_R$) IN inch FOR 95% RELIABILITY (%R)**

| ESAL$_D$ | Modulus Of Subgrade Reaction ($K_G$),psi/in 40 | 80 | 110 | 150 | 185 | 200 | 260 | 300 | 330 | 370 |
|---|---|---|---|---|---|---|---|---|---|---|
| **100 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **150 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **200 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **250 000** | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **300 000** | 7 | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **350 000** | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 |
| **400 000** | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 |
| **450 000** | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 |
| **500 000** | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 |
| **600 000** | 7½ | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6½ |
| **700 000** | 8 | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ | 6½ | 6½ |
| **800 000** | 8 | 7½ | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ |
| **900 000** | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 |
| **1 000 000** | 8½ | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7 | 7 | 7 |
| **1 500 000** | 9 | 8½ | 8½ | 8 | 8 | 8 | 8 | 8 | 7½ | 7½ |
| **2 000 000** | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8 | 8 | 8 |
| **2 500 000** | 9½ | 9½ | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ |
| **3 000 000** | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 | 9 | 8½ |
| **3 500 000** | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 |
| **4 000 000** | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9 | 9 |
| **4 500 000** | 10½ | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9½ |
| **5 000 000** | 10½ | 10½ | 10 | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ |
| **6 000 000** | 11 | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 | 10 |
| **7 000 000** | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 |
| **8 000 000** | 11½ | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10½ | 10 |
| **9 000 000** | 11½ | 11 | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10½ |
| **10 000 000** | 11½ | 11½ | 11 | 11 | 11 | 11 | 11 | 11 | 10½ | 10½ |
| **15 000 000** | 12½ | 12 | 12 | 12 | 11½ | 11½ | 11½ | 11½ | 11½ | 11½ |
| **20 000 000** | 13 | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 | 12 | 12 |
| **25 000 000** | 13½ | 13 | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12½ |
| **30 000 000** | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 | 13 | 12½ | 12½ |
| **35 000 000** | 14 | 13½ | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 |
| **40 000 000** | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ | 13½ | 13 |
| **45 000 000** | 14½ | 14 | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ |
| **50 000 000** | 14½ | 14½ | 14½ | 14 | 14 | 14 | 14 | 14 | 13½ | 13½ |
| **60 000 000** | 15 | 15 | 14½ | 14½ | 14½ | 14½ | 14 | 14 | 14 | 14 |
| **70 000 000** | 15½ | 15 | 15 | 15 | 14½ | 14½ | 14½ | 14½ | 14½ | 14½ |
| **80 000 000** | 15½ | 15½ | 15½ | 15 | 15 | 15 | 15 | 15 | 14½ | 14½ |
| **90 000 000** | 16 | 15½ | 15½ | 15½ | 15½ | 15 | 15 | 15 | 15 | 15 |
| **100 000 000** | 16 | 16 | 16 | 15½ | 15½ | 15½ | 15½ | 15½ | 15 | 15 |

## TABLE 3.3
## (FROM TABLE A.7 IN APPENDIX A)

### REQUIRED DEPTH ($D_R$) IN mm FOR 95% RELIABILITY (%R)

| | Modulus Of Subgrade Reaction ($K_G$), kPa/mm | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
| **100 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **150 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **200 000** | 154 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **250 000** | 160 | 153 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **300 000** | 166 | 159 | 154 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **350 000** | 170 | 163 | 158 | 154 | 150 | 150 | 150 | 150 | 150 | 150 |
| **400 000** | 174 | 168 | 163 | 158 | 155 | 151 | 150 | 150 | 150 | 150 |
| **450 000** | 178 | 171 | 166 | 162 | 158 | 156 | 152 | 150 | 150 | 150 |
| **500 000** | 181 | 175 | 170 | 166 | 162 | 159 | 155 | 152 | 150 | 150 |
| **600 000** | 187 | 181 | 176 | 172 | 168 | 165 | 162 | 159 | 156 | 153 |
| **700 000** | 192 | 186 | 181 | 177 | 174 | 170 | 167 | 164 | 162 | 159 |
| **800 000** | 195 | 190 | 185 | 182 | 178 | 175 | 172 | 169 | 167 | 164 |
| **900 000** | 200 | 194 | 189 | 186 | 182 | 179 | 176 | 174 | 171 | 168 |
| **1 000 000** | 203 | 197 | 193 | 189 | 186 | 183 | 180 | 178 | 175 | 173 |
| **1 500 000** | 217 | 211 | 207 | 203 | 200 | 197 | 195 | 192 | 190 | 188 |
| **2 000 000** | 227 | 221 | 217 | 214 | 211 | 208 | 205 | 203 | 201 | 199 |
| **2 500 000** | 235 | 229 | 225 | 222 | 219 | 216 | 214 | 212 | 209 | 207 |
| **3 000 000** | 241 | 236 | 232 | 228 | 226 | 223 | 221 | 218 | 216 | 214 |
| **3 500 000** | 247 | 241 | 237 | 234 | 231 | 229 | 227 | 224 | 222 | 220 |
| **4 000 000** | 252 | 247 | 243 | 239 | 236 | 234 | 232 | 230 | 228 | 226 |
| **4 500 000** | 257 | 251 | 247 | 244 | 241 | 239 | 236 | 234 | 232 | 230 |
| **5 000 000** | 261 | 255 | 251 | 248 | 245 | 243 | 240 | 238 | 236 | 235 |
| **6 000 000** | 268 | 262 | 258 | 255 | 252 | 250 | 248 | 246 | 244 | 242 |
| **7 000 000** | 274 | 269 | 265 | 261 | 259 | 256 | 254 | 252 | 250 | 248 |
| **8 000 000** | 280 | 274 | 270 | 267 | 264 | 262 | 260 | 258 | 256 | 254 |
| **9 000 000** | 284 | 279 | 276 | 272 | 269 | 267 | 265 | 263 | 261 | 259 |
| **10 000 000** | 289 | 283 | 280 | 276 | 274 | 271 | 269 | 267 | 265 | 264 |
| **15 000 000** | 307 | 301 | 297 | 294 | 291 | 289 | 287 | 285 | 283 | 282 |
| **20 000 000** | 320 | 314 | 310 | 307 | 305 | 302 | 300 | 298 | 297 | 295 |
| **25 000 000** | 330 | 325 | 321 | 318 | 315 | 313 | 311 | 309 | 307 | 306 |
| **30 000 000** | 339 | 334 | 330 | 327 | 324 | 322 | 320 | 318 | 316 | 314 |
| **35 000 000** | 347 | 341 | 338 | 334 | 332 | 330 | 327 | 326 | 324 | 322 |
| **40 000 000** | 354 | 348 | 344 | 341 | 339 | 336 | 334 | 332 | 331 | 329 |
| **45 000 000** | 360 | 354 | 350 | 347 | 345 | 342 | 340 | 338 | 337 | 335 |
| **50 000 000** | 365 | 360 | 356 | 353 | 350 | 348 | 346 | 344 | 342 | 341 |
| **60 000 000** | 375 | 370 | 366 | 363 | 360 | 358 | 356 | 354 | 352 | 350 |
| **70 000 000** | 384 | 378 | 374 | 371 | 368 | 366 | 364 | 362 | 360 | 359 |
| **80 000 000** | 391 | 385 | 382 | 378 | 376 | 374 | 372 | 370 | 368 | 366 |
| **90 000 000** | 398 | 392 | 388 | 385 | 383 | 380 | 378 | 376 | 375 | 373 |
| **100 000 000** | 404 | 398 | 394 | 391 | 389 | 386 | 384 | 382 | 381 | 379 |

## 3.7 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, limited access facility, Design Speed is 70 mph (110 km/h).

$ESAL_D$ = 6 775 000. This value is generally obtained from the District Planning Office.

$K_G$ = 200pci (50 kPa/mm). This value is for Special Select Soils.

DATA:

%R = 95%. This value is from Table 3.2 for a limited access facility.

$D_R$ can be obtained from Table A.7 in Appendix A. Round up to the next higher $ESAL_D$ value in the table. For this problem use $ESAL_D$ = 7 000 000.

SOLUTION:

Therefore:

$D_R$ = 10 ½″ (259 mm) for $K_G$ = 200 pci (50 kPa/mm)

Use $D_R$ = 10 ½″ (260 mm) (round to nearest ½″ (10 mm)).

CONCLUSION:

The plans should read:

NEW CONSTRUCTION

10 ½″ (260 mm) PLAIN CEMENT CONCRETE PAVEMENT

Additional details are not included in the plans description but are instead provided as Construction Notes.

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### 3.6.1 DESIGN EXAMPLE

The following is an example illustrating the mechanics of this procedure.

Using the following input:

$ESAL_D$ = 6 000 000 (from the Planning Office)

$K_G$ = 200 pci (50 kPa/mm) (Standard value for Special Select Soil)

R% = 95% (from Table 3.2)

The solution is:

$D_R$ = 9.96" (252 mm) (from Table 3.3)

Rounding off to nearest ½”(10 mm), use $D_R$ = 10”(250 mm).

# CHAPTER 4

## EMBANKMENT AND DRAINAGE DETAILS

### 4.1 GENERAL

The purposes of the embankment and subdrainage system are to support the pavement, provide a construction working platform, and provide subdrainage of infiltrated water with a treated drainage layer.

The subbase and embankment should be designed to prevent pumping. Pumping is the ejection of erodible subbase material due to the presence of free water at the bottom of the slab and the loading of the concrete slabs by heavy trucks. The prevention of pumping is essential to the long-term survivability and good performance of concrete pavement.

All drainage features are designed in the subbase/embankment system.

In the past, the department has used an unbonded rigid subbase such as cement stabilized subbase or econocrete. These designs have caused significant problems due to their rigidity, lack of permeability, and difficulty in achieving non-erodible properties. These are not recommended for use on department projects.

The Treated Permeable Base Option is generally the preferred subdrainage design. It uses standard materials and construction methods and provides rapid lateral drainage.

The Special Select Soil Option should only be used when there is a history in the area of successful construction and performance with concrete pavements, and the special select material, with sufficient permeability, is readily available at a reasonable cost. Although, this typical has been used successfully in the past, construction can be difficult due to the less stable material and problems have been encountered in the field with achieving the proper depth and permeability of the soil.

Before including the Special Select Soil typical section in the bid documents, the District Materials Engineer must have completed an evaluation of the soils in the project area and recommend that materials meeting the requirements are reasonably available.

## 4.2 TREATED PERMEABLE BASE TYPICAL SECTION

The Treated Permeable Base Typical Section utilizes an Asphalt Treated Permeable Base (ATPB) or Cement Treated Permeable Base (CTPB). This highly permeable material provides for the lateral conveyance of the water to drain out of the pavement system. The depth of this layer is 4" (100 mm) deep. This sits on top of a 1" (30 mm) Type SP Structural Course that acts as a separation and waterproofing blanket. This in turn is on top of 12" (300 mm) of Type B Stabilization (LBR 40), which acts as a construction-working platform.

Illustration of this typical section can be seen in Standard Index 505 with more detail provided in Standard Index 287.

When the water reaches the edge of the pavement system, the runoff is routed to the nearest outfall located on the shoulder slope. In an urban area, this may be a storm sewer system.

## 4.3 SPECIAL SELECT SOIL TYPICAL SECTION

The special select soil typical section should only be selected when approved in writing by the District Materials Engineer and shown in the plans.

The special select soil typical section is composed of a deep and moderately permeable special select soil that provides for removal of infiltrated water vertically and laterally through the embankment to the shoulder ditches. This is placed in the top 60" (1500 mm) of embankment. The special select soil must have a minimum average lab permeability of $5 \times 10^{-5}$ $^{cm}/_{sec}$ with no individual test less than $1 \times 10^{-5}$ $^{cm}/_{sec}$. It also must be non-plastic with no more than 12% passing the 75 μm sieve. Due to this moderate permeability requirement, it is necessary to have a minimum of 60"(1500 mm) depth to provide vertical flow conditions and ensure drainability.

This permeability rate and depth of special select material are based on calculations using Figure 45 of Report No. FHWA-TS-80-224 Highway Subdrainage Design Manual, August 1980. An infiltration rate of 0.7 $ft^3$/day/ft(28 cc/hr/cm) of joint is assumed, with an average storm duration of 10 hours and an average interval between storms of 100 hours for drainage of the infiltrated water. If any of these assumptions or design details are changed, a new drainage analysis must be done. A computer program developed by the University of Florida under research project "Evaluation of Joint Infiltration and Drainage of Rigid Pavements" is available to perform analysis for different conditions.

To provide a permeable working platform, 3" (75 mm) of #57 or #89 stone is placed on top of the special select soil and mixed into the top 6" (150 mm). Illustration of this drainage alternate can be seen in Standard Index 505 with more detail for the edgedrain provided in Standard Index 287.

To provide extra insurance that water is quickly removed from the critical lower pavement edge, draincrete edgedrains are provided with outfalls located on the shoulder slope. In an urban area this may be a storm sewer.

Draincrete edgedrains are recommended in areas where flexible pavement shoulders are going to be constructed. This design provides protection to the pipe during and after construction from heavy construction equipment, off-tracking trucks, and other forces. Other edgedrain alternatives may be considered on the recommendation of the District Drainage Engineer, when rigid shoulders are constructed.

The “daylighting of the base”(extending the limits of the special select soil out to the shoulder slope) to provide additional drainage is also recommended.

It is recommended that the Cross Section Sheets show the limits of the concrete slab, the special select soil, and other soils.

The decision to use the Special Select Soil Typical Section is determined on the history of successful use in the area, the availability of sufficient special select soil material, the permeability of the material, and the consistency of the material throughout the length of the project. If the material on the project has to be blended to bring it up to the permeability requirement, an analysis needs to be done to estimate this cost. If this cost substantially exceeds the cost of Treated Permeable Base, or, if adequate special select soil is not available, then Treated Permeable Base should be used.

The district design section is responsible for making a Pavement Type Selection Analysis of all major new alignment or base reconstruction projects. The district design section should refer to the Pavement Type Selection Manual (Document No. 625-010-005) for guidance on this analysis. The District Materials Engineer should work closely with the design section to evaluate the permeability of the existing roadbed soils on the project under consideration, since this can have a major impact on the cost of a rigid pavement system.

Based on the soils classification data from the roadway soils survey and the District Materials Engineers experience, a recommendation should be made to the District Pavement Design Engineer as to whether the soils on the project are likely to provide adequate permeability for a rigid pavement subgrade.

When the preliminary type selection analysis by the design section indicates that a rigid pavement may be selected, the District Materials Office should perform laboratory permeability tests in accordance with FM 1-T 215 of the top 60" (1500 mm) of roadway soils below the proposed roadway grade. This testing is essential to determine if the roadway soils can provide adequate vertical drainage of infiltrated water from the rigid pavement joints.

On a project by project basis, the District Materials Engineer can make a professional recommendation to slightly modify the percent passing the 75 μm gradation for the special select soils definition based on his knowledge of similar good performing rigid pavements with such soils in the area. This recommendation must be concurred with in writing by the District Pavement Design Engineer, District Drainage Engineer, and the State Soils And Materials Engineer. This recommendation will become a part of the Pavement Design Package.

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# CHAPTER 5

# JOINT DETAILS

## 5.1 GENERAL

The purpose of joints is to control cracking caused by shrinkage due to loss of moisture, contraction, and curl due to temperature changes and differentials through the slab.

There are several types of joints. There are transverse joints (sometimes referred to as contraction joints), longitudinal joints, expansion joints and construction joints.

### 5.1.1 JOINT SEALING

All joints are to be sealed to keep incompressibles out of the joint and to minimize the inflow of water, to the extent possible, out of the subgrade. It is not possible to totally seal pavement joints against water infiltration, so it is essential to have a good subdrainage system as described in Chapter 4.
For concrete-to-concrete joints use silicone sealant material. For concrete to asphalt joints use of self-leveling silicone or hot pour sealant material.

Index 305 gives joint dimension details that are in accordance with sealant industry recommendations.

## 5.2 TRANSVERSE (CONTRACTION) JOINTS

Transverse joints are perpendicular to the centerline of the roadway. Their purpose is to prevent uncontrolled cracking.

### 5.2.1 DOWEL BARS

While cutting of the slabs helps control random cracking, it also creates weakened locations on the slabs. This could result in high deflections and stresses at the joints. Dowel bars are used across transverse joints to reduce these stresses and deflections, and provide adequate load transfer. This reduces the potential for pumping of the subbase material.

Dowel bars are placed in concrete parallel to the centerline of the roadway and the surface of the pavement.

**TABLE 5.1**

**LOAD TRANSFER DEVICES**

**English**

| Required Pavement Depth ($D_R$), in | Dowel Bar Diameter, in |
|---|---|
| 6" | 3/4" |
| 7" - 8 ½" | 1" |
| 9" – 10 ½" | 1 ¼" |
| ≥ 11" | 1 ½" |

**Note:** Dowel bar spacing should be 12".
Dowel bar length should be 18".

**Metric**

| Required Pavement Depth ($D_R$), mm | Dowel Bar Diameter, mm |
|---|---|
| 150 - 170 | 20 |
| 180 - 190 | 25 |
| 200 - 270 | 30 |
| ≥ 280 | 40 |

**Note:** Dowel bar spacing should be 300 mm.
Dowel bar length should be 450 mm.

Spacing of the dowel bars should be 12" (300 mm) unless otherwise indicated due to some special reason. The lengths of the dowel bars are 18" (450 mm). The dowel bar diameters are 3/4", 1", 1 ¼", and 1 ½" (20, 25, 30, and 40 mm). Table 5.1 shows the dowel bar diameters for different pavement thickness.

Dowel bars are placed in advance of the concrete pouring operation using a dowel bar basket.

### 5.2.2 TRANSVERSE JOINT SPACING

Transverse joint spacing should not exceed 15'(4.6 m) or twenty-four times the slab thickness, whichever is less. For slab length as a function of the Required Depth ($D_R$), see Table 5.2. The maximum desirable slab length is 15'(4.6 m).

## 5.3 LONGITUDINAL JOINTS

The purpose of longitudinal joints is to prevent uncontrolled cracking of slabs. Longitudinal joints are often tied with rebar to maintain the aggregate interlock between slabs.

### 5.3.1 SUBGRADE DRAG

"Subgrade Drag" is a term for the frictional resistance provided from the subgrade to the slab as the slabs move due to temperature changes.

To avoid a build up of subgrade drag stresses, a maximum distance of 24'(7.2 m) (or two lanes) is allowed between the nearest free edge or an untied joint. This distance also includes tied concrete shoulders.

A "Free Edge" is any edge of pavement that is not tied to another lane or to a concrete shoulder.

**TABLE 5.2**

**RELATIONSHIP BETWEEN REQUIRED DEPTH ($D_R$) AND SLAB LENGTH**

**English**

| Required Depth ($D_R$), in | Slab Length, ft |
|---|---|
| 6 | 12 |
| 6.5 | 13 |
| 7 | 14 |
| 7.5 + | 15 |

**Metric**

| Required Depth ($D_R$), mm | Slab Length, m |
|---|---|
| 150 | 3.6 |
| 160 | 3.8 |
| 170 | 4.1 |
| 180 | 4.3 |
| 190 + | 4.6 |

### 5.3.2 TIE BARS

Deformed reinforcing steel tie bars generally tie longitudinal joints together. The purpose of the tie bar is to tie adjacent lanes and/or shoulders tightly together. Tie bars do not significantly assist in the load transfer directly, but does improve aggregate interlock.

For a No.4 (#13M) Bar (diameter is ½″ (12.7 mm) nominal) the length is 25" (600 mm). For a No.5 (#16M) Bar diameter is 5/8" (15.9 mm)) the length is 30" (850 mm). Formula for Tie Bar Spacing (S) as well as the needed input can be found in Figure 5.1. Maximum spacing of 24″ for #4 bars and 38″ for #5 bars are recommended.

The placement of the bars along a longitudinal joint is a function of the Required Depth ($D_R$) and the Free Edge Distance (B). Tables 5.3 and 5.4 show the Tie Bar Spacing (S) for different Required Depths ($D_R$) and Free Edge Distance (B). When the distance to the closest free edge exceeds 24′, a standard load transfer tied joint with #4 bars at 24″ spacing should be provided. FHWA Report RD-81/122 shows the stress efficiencies provided by tieing longitudinal joints.

### 5.3.3 DESIGN AND CONSTRUCTION CONSIDERATIONS

Tie bars are implanted into the fresh concrete by mechanical means, or, the tie bars are placed in advance of the concrete pouring operation using approved tie bar chairs.

Slab widths are 12' or 14'(3.6 or 4.2 m) unless otherwise indicated in the plans for special reasons. A 14' (4.2 m) wide slab is used for the outside design lane to reduce edge stresses. The travel lane stripe is placed at 2' (0.6 m) from the slab edge.

Avoid putting a longitudinal joint in the middle of a lane, other than ramps.

When designing a joint layout, the joints need to be designed such that the paving machine does not have to be constantly adjusted.

## FIGURE 5.1

## FORMULA FOR TIE BAR SPACING (S)

Using the following formula:

$$S = \frac{F_S * A_S}{B * C_f * W * D_R}$$

Where:

S = Tie bar spacing, ft (m)

$F_s$ = Tie bar allowable working stress, 30,000 psi Grade 40(200 MPa, Grade 300)

$A_s$ = Area of steel, one bar, $in^2$ ($mm^2$)

For No.4 (#13M) tie bar (1/2 (12.7 mm) in diameter),
Use $A_s$ = 0.20 $in^2$ (126 $mm^2$)

For No.5 (#16M) tie bar (5/8 (15.9 mm) in diameter),
Use $A_s$ = 0.31 $in^2$ (198 $mm^2$)

B = Distance to a free edge or untied joint, ft (m)

$C_f$ = Coefficient of friction (1.5 assumed)

W = Unit Weight of concrete 150 $lbf/ft^3$ (24 000 $N/m^3$)

$D_R$ = Required Depth, ft (m)

**TABLE 5.3**

**NO.4 TIE BAR, MAXIMUM SPACING (IN)**

| Slab Thickness $D_R$ (in) | DISTANCE TO FREE EDGE B (FT) 12 | 14 | 24 |
|---|---|---|---|
| 6 | 24 | 24 | 24 |
| 7 | 24 | 24 | 22 |
| 8 | 24 | 24 | 19 |
| 9 | 24 | 24 | 17 |
| 10 | 24 | 24 | 15 |
| 11 | 24 | 24 | 14 |
| 12 | 24 | 22 | 13 |
| 13 | 24 | 21 | 12 |
| 14 | 22 | 19 | 11 |
| 15 | 21 | 18 | 10 |

**Tie Length = 25”**

**TABLE 5.4**

**NO.5 TIE BAR, MAXIMUM SPACING (IN)**

| Slab Thickness $D_R$ (in) | DISTANCE TO FREE EDGE B (FT) 12 | 14 | 24 |
|---|---|---|---|
| 6 | 38 | 38 | 38 |
| 7 | 38 | 38 | 35 |
| 8 | 38 | 38 | 31 |
| 9 | 38 | 38 | 27 |
| 10 | 38 | 38 | 24 |
| 11 | 38 | 38 | 22 |
| 12 | 38 | 35 | 20 |
| 13 | 38 | 32 | 19 |
| 14 | 35 | 30 | 17 |
| 15 | 33 | 28 | 16 |

**Tie Length = 30”**

**TABLE 5.3(METRIC)**

**MAXIMUM #13M TIE BAR SPACING (S)**

For a #10M tie bar with a 600 mm length, read the Free Edge Distance (B), across the row, and the Required Depth ($D_R$), down the column to determine the maximum #13M Tie Bar Spacing (S) of the tie bars.

**Maximum #13M Tie Bar Spacing (S), m**

| **Required Depth** | **Free Edge Distance (B), m** | | |
|---|---|---|---|
| **($D_R$), mm** | **3.6** | **4.2** | **7.2** |
| **150** | 0.6 | 0.6 | 0.6 |
| **160** | 0.6 | 0.6 | 0.6 |
| **170** | 0.6 | 0.6 | 0.6 |
| **180** | 0.6 | 0.6 | 0.6 |
| **190** | 0.6 | 0.6 | 0.6 |
| **200** | 0.6 | 0.6 | 0.5 |
| **210** | 0.6 | 0.6 | 0.5 |
| **220** | 0.6 | 0.6 | 0.5 |
| **230** | 0.6 | 0.6 | 0.4 |
| **240** | 0.6 | 0.6 | 0.4 |
| **250** | 0.6 | 0.6 | 0.4 |
| **260** | 0.6 | 0.6 | 0.4 |
| **270** | 0.6 | 0.6 | 0.4 |
| **280** | 0.6 | 0.6 | 0.4 |
| **290** | 0.6 | 0.6 | 0.4 |
| **300** | 0.6 | 0.6 | 0.3 |
| **310** | 0.6 | 0.6 | 0.3 |
| **320** | 0.6 | 0.6 | 0.3 |
| **330** | 0.6 | 0.5 | 0.3 |
| **340** | 0.6 | 0.5 | 0.3 |
| **350** | 0.6 | 0.5 | 0.3 |
| **360** | 0.6 | 0.5 | 0.3 |
| **370** | 0.5 | 0.5 | 0.3 |
| **380** | 0.5 | 0.5 | 0.3 |
| **390** | 0.5 | 0.5 | 0.3 |
| **400** | 0.5 | 0.5 | 0.3 |

**TABLE 5.4 (METRIC)**

**MAXIMUM #16M TIE BAR SPACING (S)**

For a #16M tie bar with a 850 mm length, read the Free Edge Distance (B), across the row, and the Required Depth ($D_R$), down the column to determine the maximum #16M Tie Bar Spacing (S) of the tie bars.

**Maximum #16M Tie Bar Spacing (S), m**

| Required Depth ($D_R$), mm | Free Edge Distance (B), m 3.6 | 4.2 | 7.2 |
|---|---|---|---|
| **150** | 1.0 | 1.0 | 1.0 |
| **160** | 1.0 | 1.0 | 1.0 |
| **170** | 1.0 | 1.0 | 1.0 |
| **180** | 1.0 | 1.0 | 0.9 |
| **190** | 1.0 | 1.0 | 0.9 |
| **200** | 1.0 | 1.0 | 0.8 |
| **210** | 1.0 | 1.0 | 0.8 |
| **220** | 1.0 | 1.0 | 0.8 |
| **230** | 1.0 | 1.0 | 0.7 |
| **240** | 1.0 | 1.0 | 0.7 |
| **250** | 1.0 | 1.0 | 0.7 |
| **260** | 1.0 | 1.0 | 0.6 |
| **270** | 1.0 | 1.0 | 0.6 |
| **280** | 1.0 | 1.0 | 0.6 |
| **290** | 1.0 | 1.0 | 0.6 |
| **300** | 1.0 | 0.9 | 0.5 |
| **310** | 1.0 | 0.9 | 0.5 |
| **320** | 1.0 | 0.9 | 0.5 |
| **330** | 1.0 | 0.8 | 0.5 |
| **340** | 1.0 | 0.8 | 0.5 |
| **350** | 0.9 | 0.8 | 0.4 |
| **360** | 0.9 | 0.8 | 0.4 |
| **370** | 0.9 | 0.8 | 0.4 |
| **380** | 0.8 | 0.7 | 0.4 |
| **390** | 0.8 | 0.7 | 0.4 |
| **400** | 0.8 | 0.7 | 0.4 |

## 5.4 EXPANSION JOINTS

The purpose of an expansion joint is to provide for the expansion of concrete due to infiltration of incompressible material into the joints and during periods of extreme temperature change.

Expansion joints are also provided in areas where there is an abrupt change in geometry ("T" intersections, bridges, ramps and terminals) or an immovable structure (i.e. parking areas, toll plazas, buildings, bridge approach slabs, etc.). Refer to Standard Index 305.

Expansion joints are also included in areas where there are concrete curbs, traffic separators, manholes, and drainage structures (i.e. grates, inlets, etc.). The cost of expansion joints is included in the cost of the concrete pavement.

For expansion joints at a bridge approach, refer to Standard Index 306. These joints are paid for at the contract unit price for Bridge Approach Expansion Joint.

## 5.5 CONSTRUCTION JOINTS

The purpose of a construction joint is to provide a clean transition from one concrete pouring operation to the next. An example would be fresh concrete against old concrete from one day to the next. These could be both longitudinal and transverse joints.

The transverse construction joint is doweled and is formed using a header.

Longitudinal construction joints are often tied using rebar.

## 5.6 VENDOR COMBINATION EXPANSION AND CONTRACTION ASSEMBLIES

Vendor combination expansion and contraction assemblies are used for their ease of assembly and construction. Manufacturers of vendor combinations expansion and contraction assemblies can be found in the department's Qualified Products List.

## 5.7 JOINT LAYOUT

The purpose of providing a joint layout is to show non-standard joint geometries to avoid discontinuities that can lead to random cracking.

Types of joint layouts that provide guidance can be found in the Standard Index 305 and include Thru Intersections, 'T' Intersection, and ramps. Other irregular areas should have joint layouts carefully detailed in the plans.

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# CHAPTER 6

# SHOULDER DESIGN

## 6.1 GENERAL

The purpose of shoulders is to provide edge support of the mainline pavement, assist off-tracking vehicles, increase safety, provide additional pavement widths for lane shifts during rehabilitation, provide refuge for disabled vehicles, and prevent erosion from pavement runoff.

Several types of shoulders are available for concrete pavement. They are concrete, asphalt, and grass. Table 6.1 provides guidance on the use of these different type of materials and typical sections for different types of shoulders.

Details for the design of the shoulders are dependent on the type of materials used in the embankment. Embankment alternates include Treated Permeable Base (Cement or Asphalt) or Special Select Soil and Special Stabilized Subbase.

On outside shoulders, 2'(0.6 m) of the marked shoulder is cast with the outside truck lane slab. The rest of the shoulder when concrete may be cast integrally with the mainline and saw cut, or cast later on. The pavement will be striped for a 12' (3.6 m) lane with a saw cut or construction joint offset by 2' (0.6 m). The slab width is 14' (4.2 m) but the pavement marking is at 12' (3.6 m).

The offset of the joint has strong advantages of greatly reducing loading stresses at the critical low outside truck lane edge.

**TABLE 6.1**

**SHOULDER TYPE SELECTION**

Limited Access (Urban)

Tapered Depth Concrete

Full Depth (Tied) Concrete*

Asphalt

Limited Access (Rural), Non-Limited Access, Arterials And Collectors

Partial Depth (Tied) Concrete

Asphalt

**Notes**

* For future Maintenance Of Traffic or Widening.

## 6.2 CONCRETE

The following are some of the different types of concrete shoulders that are available:

Tapered Depth

Tapered depth shoulder is recommended for use on Limited Access facilities (See Figure 6.2).

Tapered depth shoulder is a shoulder in which the depth of the shoulder tapers out depending on the width and slope of the shoulder. The minimum depth should not be less than 6" (150 mm).

Full Depth (Tied)

Full depth (tied) concrete shoulders may be used on Limited Access (Urban) facilities where use for future Maintenance Of Traffic or Widening is likely (See Figure 6.3).

Partial Depth (Tied)

Partial depth (tied) concrete shoulders may be used on Limited Access (Rural) facilities, Non-Limited Access, Arterials, and Collectors (See Figure 6.4). The design thickness can be based on 3% of a mainline 20 year calculated 18-kip (80 kN) ESAL for truck off tracking on the shoulder.

If the shoulders are likely to be used to carry a substantial amount of traffic as a part of a Maintenance Of Traffic (MOT) scheme, the Pavement Design Engineer may design the shoulder in the same manner as a roadway, based on an ESAL estimate of shoulder traffic during Maintenance Of Traffic periods.

The minimum thickness is 6" (150 mm).

### 6.2.1 DESIGN AND CONSTRUCTION CONSIDERATIONS

Some design and construction considerations include the following when using concrete shoulders.

- Transverse joints should match the mainline joints.
- Transverse joints should be doweled if likely to be used for maintenance of traffic in the future.

## 6.3 ASPHALT

Asphalt shoulders can be used for Limited Access facilities, Non-Limited Access Arterials and Collectors when adjacent to 14’(4.2 m) slab. (See Figure 6.1).

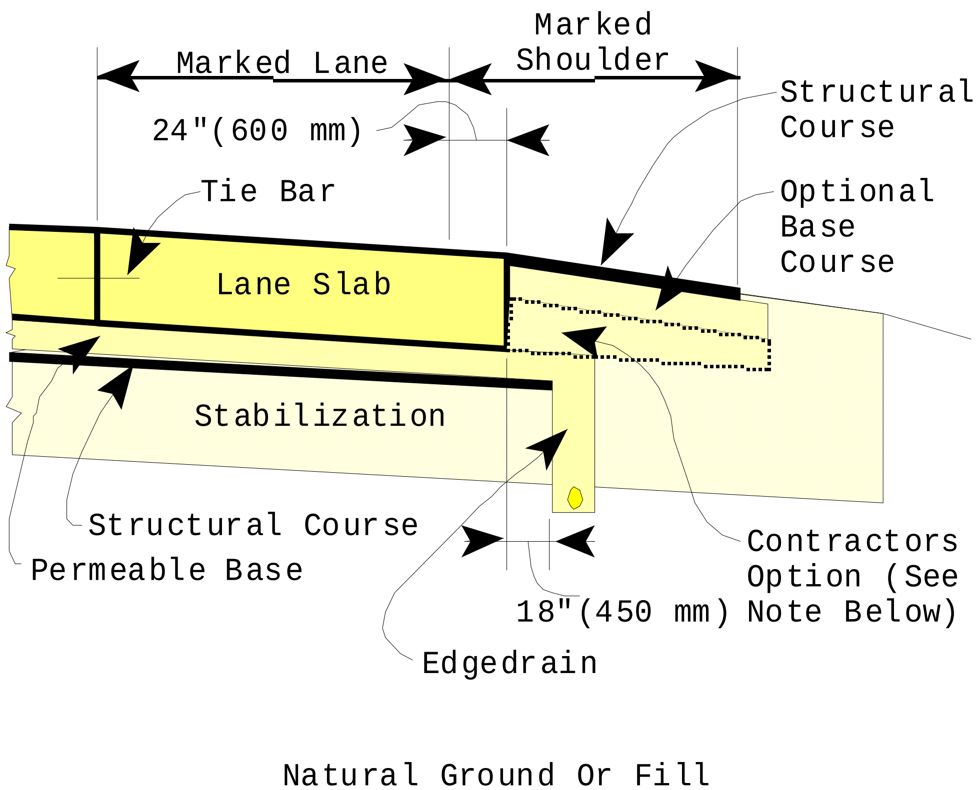
For additional information on the design of asphalt shoulders please refer to the Flexible Pavement Design Manual, Document # 625-010-002.

## 6.4 GRASS

Grass shoulders can be used for non-state low volume roads.

**FIGURE 6.1**

**ASPHALT SHOULDER WITH PERMEABLE BASE**



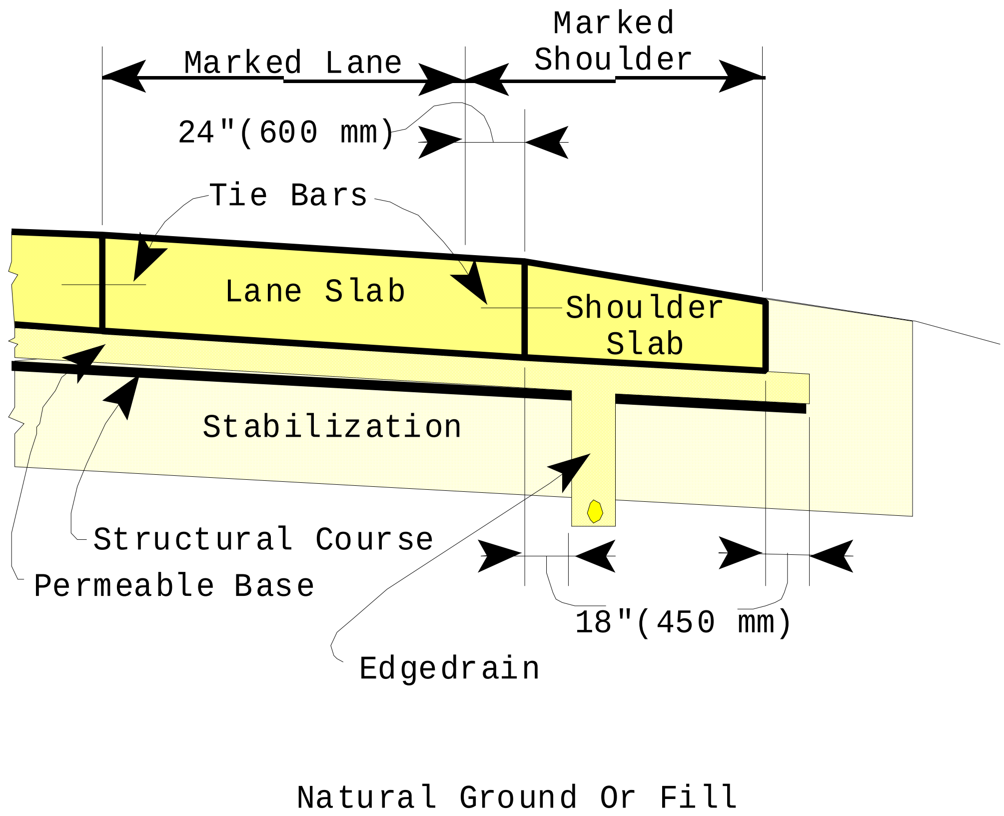

Notes:
The above illustrations not to scale.

Thickness for the Permeable Base is 4" (100 mm), Structural Course is 1" (30 mm), and Stabilization is 12" (300 mm).

For additional information and details, see Standard Index 287, Concrete Pavement Subdrainage and Standard Index 505, Embankment Utilization.

**FIGURE 6.2**

**TAPERED DEPTH CONCRETE SHOULDER WITH PERMEABLE BASE**




Notes:

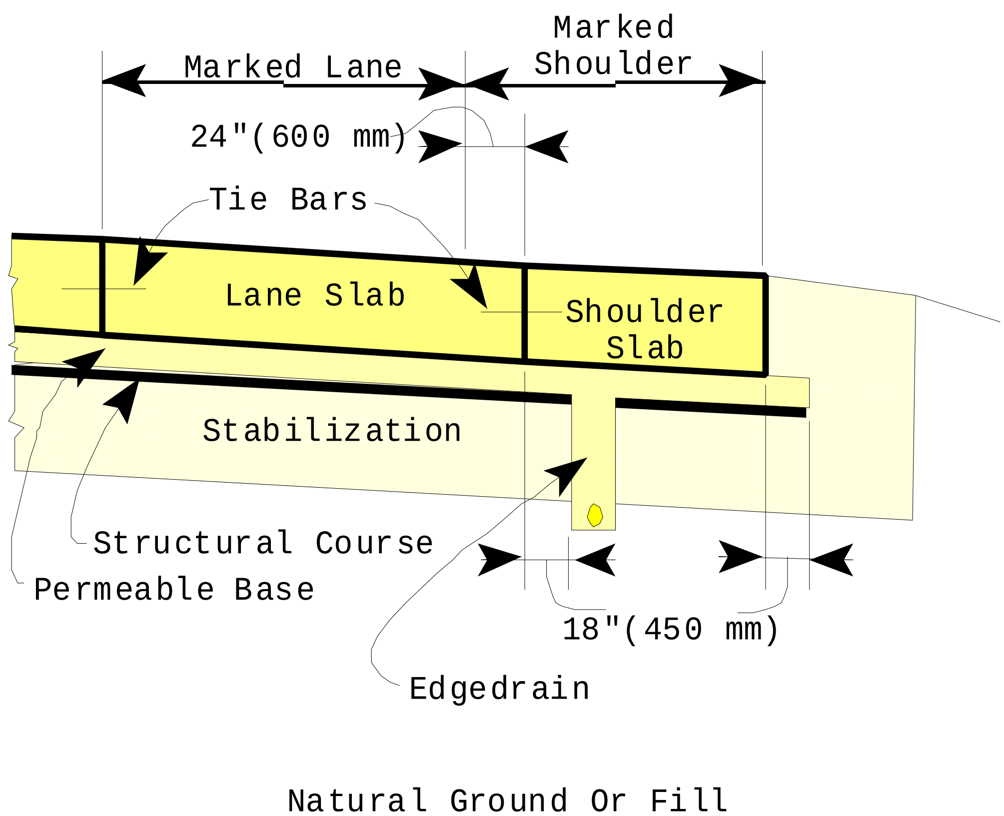
The above illustrations not to scale.

Thickness for the Lane Slab and Shoulder Slab varies. Thickness for the Permeable Base is 4" (100 mm), Structural Course is 1”(30 mm), and Stabilization is 12" (300 mm).

For additional information and details, see Standard Index 287, Concrete Pavement Subdrainage and Standard Index 505, Embankment Utilization.

**FIGURE 6.3**

**FULL DEPTH (TIED) CONCRETE SHOULDER WITH PERMEABLE BASE**




Notes:

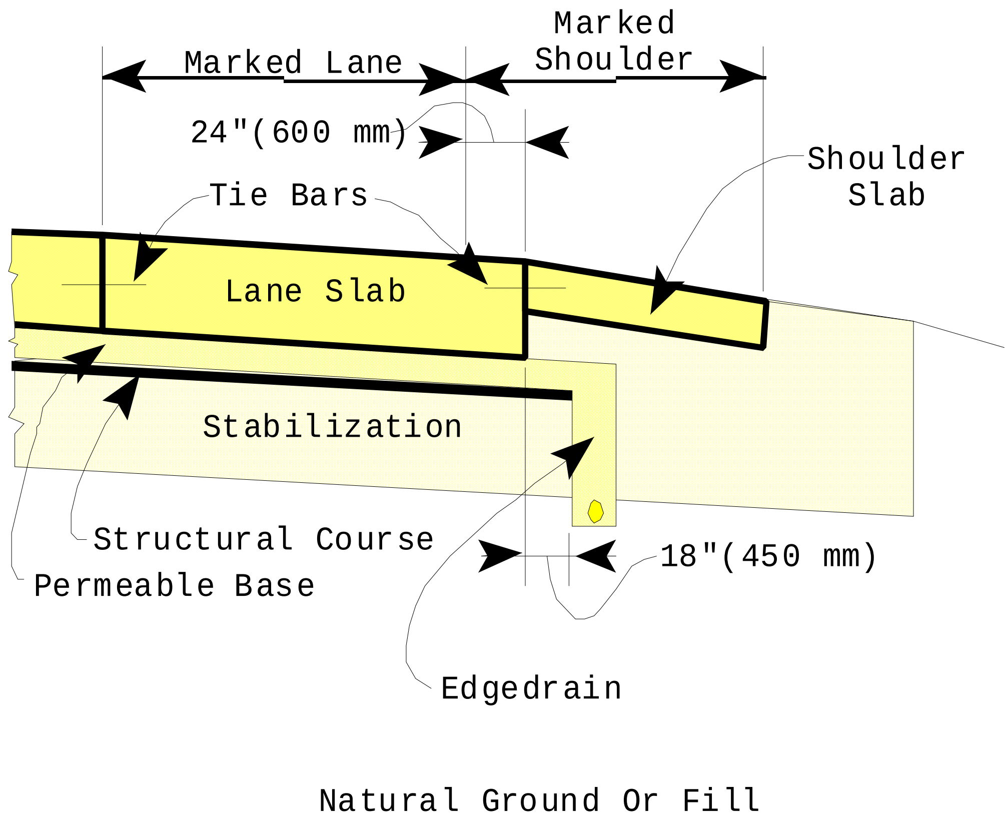
The above illustrations not to scale.

Thickness for the Lane Slab and Shoulder Slab varies. Thickness for the Permeable Base is 4" (100 mm), Structural Course is 1" (30 mm), and Stabilization is 12"(300 mm).

For additional information and details, see Standard Index 287, Concrete Pavement Subdrainage and Standard Index 505, Embankment Utilization.

FIGURE 6.4

**PARTIAL DEPTH (TIED) CONCRETE SHOULDER WITH PERMEABLE BASE**




Notes:

The above illustrations not to scale.

Thickness for the Lane Slab and Shoulder Slab varies. Thickness for the Permeable Base is 4" (100 mm), Structural Course is 1" (30 mm), and Stabilization is 12" (300 mm).

For additional information and details, see Standard Index 287, Concrete Pavement Subdrainage and Standard Index 505, Embankment Utilization.

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# CHAPTER 7

# PAVEMENT WIDENING

## 7.1 GENERAL

Pavement widening falls into two different areas, strip widening and lane addition.

Strip widening is where additional width is added to the existing pavement width because the existing width is less than the departments required design lane width criteria. Many times this is generally done for safety considerations. An example would be widening from a 10' (3 m) lane to a 12' (3.6 m) lane. This is a common need for roads constructed early in the departments' history. The minimum practical width of widening should be 3'(0.9 m).

Lane addition is where lanes greater than or equal to 12' (3.6 meters) are added. This is a common need when a facility is expanded for capacity considerations.

Intersection improvements is a hybrid of the two where the roadway may be widened on both sides less than 7' (2.1 m) to accommodate a middle turn lane on a four lane undivided section. Other improvements could be made which would include the addition of complete turn lanes, which could occur where we have adequate median space.

Very little strip widening has been done on concrete pavement. A limited amount of lane additions have also been performed. This may be due to cost, Right-Of-Way restrictions, age of existing pavement, vertical and horizontal controls, and/or other complications.

## 7.2 EVALUATION

Several questions need to be asked when evaluating the proposal to widen an existing pavement. These questions are:

> Is the existing pavement condition adequate to provide extended life without extensive rehabilitation?
> Is the existing programmed in the future for widening, reconstruction, realignment, etc.?

## 7.3 REQUIRED DESIGN INFORMATION

For widening, the existing roadway pavement typical section needs to be researched. This could include such information as slab thickness, slab dimensions, embankment soils, and drainage. On older pavements the thickness needs to be checked in the center of the road and at the roads edge. Some older pavements in service today were built with a thickened edge.

The 18-kip (80 kilonewton) Equivalent Single Axle Loads ($ESAL_D$) should be requested for lane addition projects to assist in evaluation of the remaining life of the existing pavement and the thickness desirable for the design lane. For strip widening, the 18-kip (80 kilonewton) Equivalent Single Axle Load ($ESAL_D$) calculations are not necessary.

## 7.4 PAVEMENT THICKNESS DETERMINATION

Before any thickness determination can be done on the proposed concrete pavement for strip widening or lane addition, an analysis on the remaining life of the existing pavement needs to be performed. This analysis should closely examine any deterioration of the existing pavement.

For a strip-widening project, a formal analysis does not need to be done for the pavement thickness. The best solution is to match the existing pavement. Some benefits in matching the existing pavement thickness include:

- Any flow of water between the existing slab and the subgrade will not be disrupted, pooled, or dammed.

- Trenching adjacent to the existing slab below the slab bottom that may cause a weakening of subgrade support along the pavement edge may be avoided.

- Preservation of any existing edgedrains systems may be possible.

For a lane addition project, a formal analysis needs to be done in order to determine the proposed thickness. If the calculated thickness is less than the existing, the thickness of the new lane should match the existing thickness.

If the calculated thickness for a lane addition project is greater than the existing thickness, then the calculated thickness may be used if adequate drainage can be assured. Actual pavement performance may be different than that predicted by the AASHTO Equation. Engineering judgment should be used to evaluate the remaining life and thickness required.

## 7.5 EMBANKMENT AND DRAINAGE DETAILS

Embankment and drainage details are very critical to the performance of the pavement system.

### 7.5.1 EMBANKMENT CONSIDERATIONS

Several embankment considerations need to be addressed when doing any type of widening. These considerations include:

- Existing utility clearance relative to the depth of excavation could be a concern especially in older urban areas.
- The loss of subgrade support along the pavement edge and settlement of adjacent pavement and structures due to excavation.
- Traffic Control Plans (TCP) in cases where the width of the existing pavement is less than 12' (3.6 m). This will affect the selection of barricades.

**7.5.2 DRAINAGE**

The recommended type of edgedrain system for widening is the Draincrete edgedrain system as shown in Standard Index 287. This design is used because the strength of the draincrete material provides lateral support of the existing pavement base and supports heavy loads on the pavement surface over the pipe during and after construction from heavy construction equipment, off-tracking trucks, and other forces. Other edgedrain alternatives may be considered on the recommendation of the District Drainage Engineer, when rigid shoulders are constructed.

Project information needs to be obtained on the existing drainage. This is important in the location of edgedrain outfalls. If the outfall is tied into the existing storm water drainage system in an urban area, any normal flows will need to be below the outlet end of the pipe. If no drainage system is available, the outfall end of the pipe will need to be located where it will not cause problems to pedestrians, traffic, and/or maintenance.

## 7.6 JOINT DETAILS

Joint details are very important to the performance of the concrete pavement.  Failure to follow these guidelines can result in slab cracking.

### 7.6.1 TRANSVERSE JOINT SPACING

Transverse joints should normally match the existing pavement if spacing is 15' (4.6 m) or less.  This includes contraction and expansion joints.  Closer joint spacing should be provided when the length of the existing slab is greater than 15' (4.6 m) or there is a significant number of existing mid slab transverse cracks.

### 7.6.2 LONGITUDINAL JOINTS

It is preferable not to tie a new concrete widening section greater than 6’ to the existing pavement.  This is due to the potential for stress build-ups due to differential shrinkage of the new concrete adjacent to the existing. If tieing to the existing is desired, then existing transverse joints must be matched and tie bars offset from the transverse joints by 3' (0.9 m). An additional dowelled transverse joint should be added at the middle of the widened slabs when less than or equal to 6’(1.8 m) wide and greater than 10’(3 m) in length. For additional guidance on tie bar spacing, refer to Tables 5.3 and 5.4.

Joint details should be provided for areas composed of mixed geometry.  Examples of this include ramps, intersections, etc.. An exception would be widening where the same details for each slab may be repetitive such as lane additions.

## 7.7 SHOULDER DETAILS

When adding a lane, the shoulders should be appropriate for the facility.  If concrete is used, it may be best not to tie the lane and the shoulder to the existing pavement in order to avoid any unnecessary stress build up.

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# CHAPTER 8

# DISTRESS

## 8.1 GENERAL

Factors that can lead to concrete pavement deterioration includes:

- Heavy loads imposed by trucks.
- Stresses induced by temperature changes.
- Free water retained in the pavement structure.
- Loss of subgrade support due to pumping.
- Inadequate maintenance.

## 8.2 IDENTIFICATION AND CAUSES OF DISTRESS

The tool that the Department uses to maintain system information on distressed pavements is a data base called the "Pavement Condition Survey". The State Materials Office in Gainesville maintains this.

The Pavement Condition Survey includes information on the following signs of distress:

- Pumping.
- Faulting.
- Cracking, which includes transverse cracking, longitudinal cracking, corner cracking, and shattered slabs.
- Joint distress, which includes poor joint condition, and spalling.
- Surface defects, which includes surface deterioration, and patching.

- Shoulder deterioration (not included in the pavement condition survey).

- Ride quality.

## 8.3 PUMPING

The "pumping" of concrete is a process where the action of a heavy wheel load across a transverse joint will cause the expulsion of water and fine base material in suspension underneath the pavement slabs to escape through the pavement joints at the edge of pavement.

Three conditions that must exist for pumping to occur include:

- Presence of free water.

- Erodible base material.

- Heavy wheel loads.

The mechanism of pumping is as follows:

1 Water enters into the base from joints and cracks in the pavement (See Figure 8.1A).

2 As a wheel load approaches a pavement joint (on the approach slab) the water underneath the pavement moves slowly to the next slab. Some fine base material also moves in this direction (See Figure 8.1B).

3 When the wheel load crosses the joint to the other side (on the leave slab), the water underneath the pavement moves rapidly backs to the adjacent slab. This high speed water causes more erosion of the pavement base. Some water is ejected up through the joint with some of the base material (See Figure 8.1C). Evidence of base material can be seen as stains on the shoulder.

4 The final result is a void under the leave slab and a possible buildup of material under the approach slab. The void creates a cantilevered effect on the concrete pavement. This results in cracking and faulting of the slab (See Figure 8.1D).

The severity of pumping is measured in terms of:

- Light - Visible deposits of material, light stains, shoulder settlement at the transverse joint, or, may include one or all of these.

- Moderate - Visible deposits of material, moderate stains, shoulder settlement at the transverse joint, moderate faulting at the shoulders, or may include one or all of these.

- Severe - Visible deposits of material, heavy stains, shoulder settlement at the transverse joint, or moderate faulting at the shoulders, or may include one or all of these.

Items that also contribute to pumping are poor load transfer, and/or low stiffness subbase.

## 8.4 FAULTING

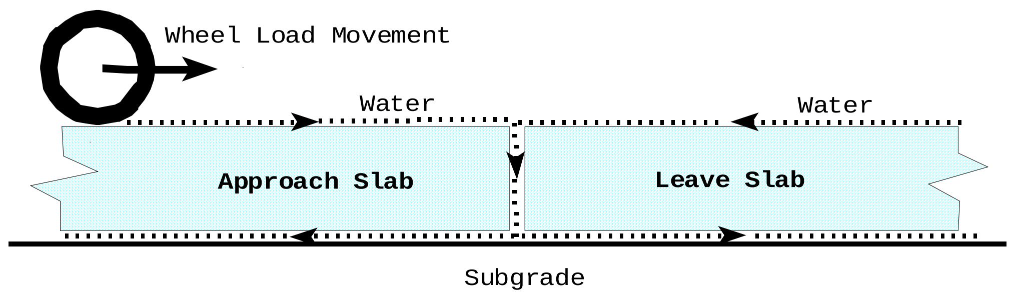
In new pavement, the elevations of each slab at the transverse joint are the same. In faulted pavement, a difference in the elevation between the slabs at the transverse joint exists.

Faulting can be caused by the erosion (on the leave slab) and build up (on the approach slab) of base fines by the action of pumping. A lack of load transfer also contributes to faulting.

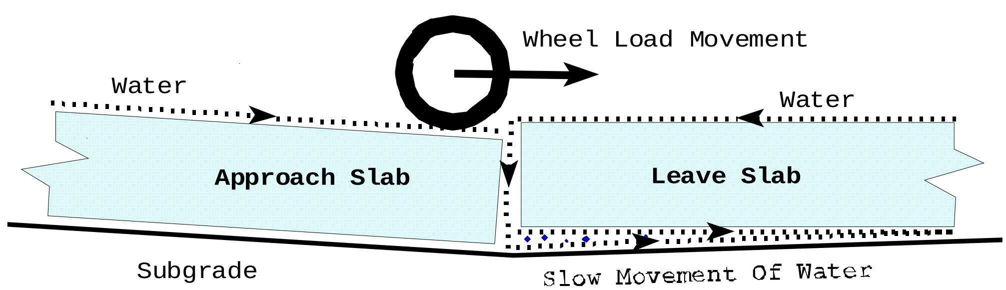
The severity of faulting is measured in increments of thirty-seconds of an inch (0.8 mm). The larger the fault measurement, the more severe.

**FIGURE 8.1**

**MECHANISM OF PUMPING**



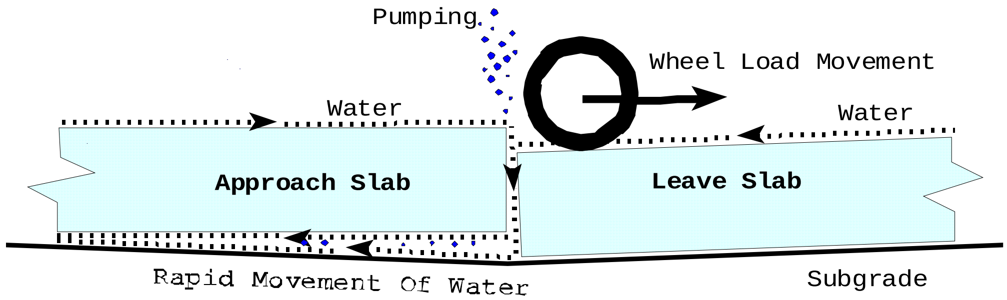

**A. Water enters base from joints and cracks.**



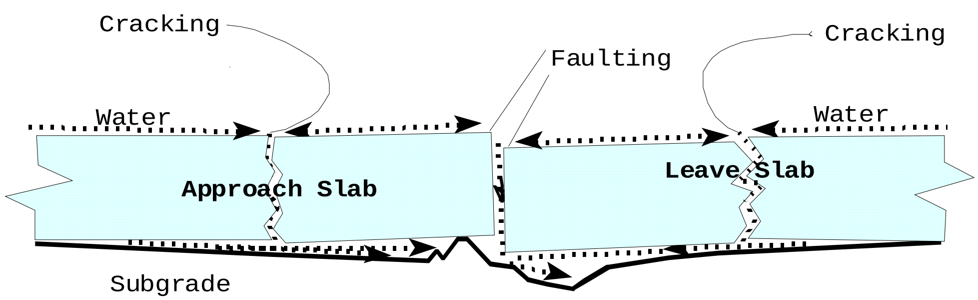

**B. Water moves slowly to the leave slab. Some eroded fine material also moves.**

**FIGURE 8.1**
**(Continued)**

**MECHANISM OF PUMPING**




**C. Water moves rapidly to the Approach Slab with some eroded fine material. Some of this material is ejected out.**




**D. Void under Leave Slab. Erodable material under Approach Slab. Slab faulting and cracking.**

## 8.5 CRACKING

Cracking occurs when a concrete slab breaks into two or more pieces.

The types of cracking are:

- Transverse Cracking - Occurs at right angles to the centerline.
- Longitudinal Cracking - Generally runs parallel to the centerline.
- Corner Cracking - Intersects both longitudinal and transverse joint.
- Intersecting Cracks (Sometimes referred to as a shattered slab) - Occurs when one or more of the different types of cracks connect or cross within a slab.

### 8.5.1 GENERAL CAUSE

Cracking is generally contributed to by:

- Shrinkage
- Loss of slab support due to voids.
- Settlement of the embankment.
- Misaligned dowels.

### 8.5.2 TRANSVERSE CRACKING

Transverse cracking is contributed to by:

- Improper joint spacing, installation, depth or dimensions.
- Improper alignment of load transfers assemblies.
- Thermal gradient warping and movement stresses.
- Stiff, unbonded subbase.
- Shrinkage due to rapid moisture loss during construction.
- Heavy trucks loading.
- A combination of any of these.

### 8.5.3 LONGITUDINAL CRACKING

Longitudinal cracking is contributed to by:

- Sawing joints too late.
- Insufficient cut depth.
- Loss of subgrade support.
- Thermal gradient warping and movement stresses.
- Heavy trucks loadings.
- One or all of the above.

### 8.5.4 CORNER CRACKING

Corner cracking is caused by:

- The loss of subgrade support due to pumping.
- Stiff unbonded subbase.
- Warping.
- Tie bars placed too close to a transverse joint.
- Heavy truck loadings.
- Combinations of the above.

### 8.5.5 INTERSECTING CRACKS

Intersecting Cracks (Sometimes referred to as a shattered slab) is caused by the continuing deterioration of one or more or a combination of transverse, longitudinal, and corner cracks.

### 8.5.6 CRACK SEVERITY

The severity of transverse, longitudinal, and corner cracking is measured in terms of:

- Light - Visible cracks less than 1/8" (3 mm) wide.
- Moderate - Cracks 1/8" to 1/2" (3 to 10 mm) wide, and/or little faulting, and/or intrusion of debris.
- Severe - Cracks greater than 1/2" (10 mm) wide, and/or loss of aggregate interlock, intrusion of water and debris, faulting, and/or spalling.

For intersecting cracks:

- Moderate - Slab is broken into several pieces with some interlock remaining. Replacement is necessary.

- Severe - Slab is broken into pieces that are acting independently. Replacement is necessary.

The severity of cracking is of great concern because it is a measure of the degree of distress and it assists in directing the rehabilitation strategy (i.e. slab replacement verses clean and reseal random cracks).

## 8.6 JOINT DISTRESS

Joint distress is when Poor Joint Condition and/or Spalling occur.

### 8.6.1 POOR JOINT CONDITION

Poor Joint Condition is the loss or deterioration of joint seals.

This condition is due to:

- Cracking which are the most common, splitting, and erosion of the sealant.

- Hardening of the sealant due to age and oxidation.

- Loss of face bond of the sealant material to the reservoir.

- Improper cleaning of the reservoir prior to insulation.

- Moisture condition prior to installation.

- Joint dimensions of reservoir and sealant.

The severity of Poor Joint Condition is measured in terms of:

- Partially Sealed - Joint seal has deteriorated to the extent that adhesion or cohesion has failed and water is infiltrating into the joint.

- Not Sealed - Joint seal is either non-existent or has deteriorated to the extent that both water and incompressible materials are infiltrating the joint.

### 8.6.2 SPALLING

Spalling is the cracking and disintegration at the slab edges. Spalling may be caused by the intrusion of incompressible material, which restricts slab expansion and contraction. Incompressible materials are usually rocks and sand. Spalling also occurs at cracks due to irregular shape of the cracks and poor load transfer.

The severity of spalling is measured in terms of:

- Light - Spalled areas are less than 1.5" (40 mm) wide.

- Moderate - Spalled areas are 1.5" to 3" (40 to 75 mm) wide.

- Severe - Spalled areas are greater than 3" (75 mm) wide.

## 8.7 SURFACE DEFECTS

Surface defects are when Surface Deterioration and/or Patching occur.

### 8.7.1 SURFACE DETERIORATION

Surface Deterioration is the disintegration and loss of the concrete wearing surface. Surface deterioration is due to:

- Poor construction materials such as poor aggregate, cement, additives, mixing operations, etc.

- Poor construction methods such as poor placement, curing, finishing, cutting, etc.

- Traffic such as (tire rims, chains, and metal).

- Chemical reactants.

The severity of Surface Deterioration is measured in terms of:

- Moderate - Some coarse aggregate has been exposed and the wearing surface has disintegrated up to a depth of a 1/2" (10 mm).

- Severe - Most coarse aggregate has been exposed and some has been removed. The wearing surface has disintegrated to a depth of 1/2" (10 mm) or greater.

### 8.7.2 PATCHING

Patches are the corrections made to pavement defects.

Patching is due to:

- Maintenance forces correct or improve a section of pavement that has deteriorated and may provide a solution that can perform as well as the existing material.

- The performance of the patching material depends on the correct application and materials (concrete, asphalt, and other), workmanship (preparation, finishing, and curing), traffic conditions, etc.

The severity of Patching is measured in terms of:

- Fair - The patch is providing marginal performance and is expected to serve its function for a few years.

- Poor - The patch has deteriorated to the extent that it no longer serves its function and should be replaced as soon as possible.

## 8.8 SHOULDER DISTRESS

Each type of shoulder has its own distress mechanism.

### 8.8.1 FORMS OF SHOULDER DISTRESS

Shoulder distress is when one or all of the following occur:

For Concrete shoulders:

- Pumping.
- Faulting.
- Cracking.
- Joint Distress.
- Surface Defects.

For Asphalt shoulders:

- Deterioration of asphalt adjacent to the transverse joint. This results in the development of depressions that are sometimes referred to as "Birdbaths" or shoulder drop-offs.
- Irregular movement of shoulder material.
- Drop off in the elevation between the roadway and the shoulder.

For Grass Shoulders:

- Erosion of the shoulder material.

### 8.8.2 CAUSE OF SHOULDER DISTRESS

Shoulder Distress is caused by:

For Concrete shoulders:

- Pumping of water under the shoulder.
- Faulting due to loss of slab support.
- Off-tracking of heavy trucks.
- May include one or all of these.

For Asphalt shoulders:

- Pumping of water under the shoulder.
- Off-tracking of heavy trucks.
- Time (environmental deterioration).
- May include one or all of these.

For Grass shoulders:

- Erosion due to pumping and runoff, and/or,
- Off-tracking of heavy trucks.

The severity of Shoulder Distress is not measured in the field, but noted in the survey.

## 8.9 POOR RIDE QUALITY

Poor ride quality is caused by changes in the longitudinal profile of the road

- Poor ride quality is due to;
- Faulting.
- Cracking.
- Surface defects.
- Repair work such as patching, slab replacement, and spall repair.
- Lack of control on the original construction.
- May include one or all of these.

The severity of Poor Ride Quality is measure on a scale of 0 to 10 with 10 being the best. Ride profilers are used by the State Materials Office to measure ride quality. The International Roughness Index values from profiler data are converted to a scale of 0 to 10 with 10 being an excellent ride.

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# CHAPTER 9

# PAVEMENT REHABILITATION

## 9.1 GENERAL

Several items need to be researched before any type of rehabilitation activity is considered. One such issue would include looking at future programming. Would this pavement in the next couple of years undergo any type of widening, reconstruction, etc. Such research could save needed funds or avoid compromising the design.

Another item for consideration would be to look at the rate of deterioration and what are the mechanisms causing the distress. Each rehabilitation alternative considered must address the cause of the distress such as drainage, and not simply fix the resulting cracking or other visible distress.

Before detailed design activities take place, the designer needs to do a life cycle cost analysis to weigh the long term possibilities. The Value Engineering Section has a Manual on Life Cycle Cost Analysis For Transportation Projects (July 1990) that can be a helpful tool to assist in the analysis.

## 9.2 DEPARTMENT RECOMMENDED OPTIONS

Several options are available to the designer as rehabilitation options. One option is Concrete Pavement Rehabilitation (CPR). This alternative can include slab replacement, patching, diamond grinding, installation of edgedrains, cleaning and resealing joints, and routing and sealing random cracks.

This option is used when the life cycle cost of Concrete Pavement Rehabilitation is less than the cost of the other alternatives.

Another alternative involves Crack, Reseat and Overlay (CRO) Existing Concrete Pavement. This alternative involves cracking and reseating the existing concrete pavement and overlaying it with an Asphalt Rubber Membrane Interlayer (ARMI), Structural Asphalt, and Asphalt Friction Course.

Rubblization and Overlay is another alternative using specialized equipment which reduces the nominal size of PCC pieces to about 6”(150 mm) and essentially reduces the slab to a high-strength granular base course and overlaying it with Structural Asphalt, and Asphalt Friction Course.

Other alternatives not discussed in detail here include replacing the existing pavement or reconstruction. These alternatives involve removing or recycling all of the existing pavement and replacing it with a new pavement. This could be concrete or asphalt as determined by the pavement type selection process.

Careful analysis of life cycle costs of these alternatives will determine which is the most cost effective.

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# CHAPTER 10

# CONCRETE PAVEMENT REHABILITATION (CPR)

## 10.1 GENERAL

Concrete Pavement Rehabilitation (CPR) involves several operations, which must be done, in sequence in order to avoid compromising other operations. An example of sequencing would include performing slab replacement before grinding. Doing this out of order would compromise the ride of the pavement.

Figure 10.1 is provided to aid the designer in specifying the sequencing of construction operations.

## 10.2 SLAB REPLACEMENT

Slab replacement includes partial slab, full slab, and multiple slab replacement. The purpose of slab replacement is to replace shattered and/or severely broken slabs.

Table 10.1 is provided to assist the designer in estimating quantities when evaluating the needed rehabilitation.

Types of slab replacement include:

- Full slab replacement, which includes the slab from joint to joint.

- Multiple slab replacement, which includes several connecting, slabs. These are sometimes found in areas over pipes and large embankment such as overpasses.

- Partial slab replacement, which includes slabs where a part of the slab has disintegrated, and/or the corners have cracked.

# TABLE 10.1

## SLAB REPAIR AND REPLACEMENT CRITERIA

| Distress Pattern | Severity / Description | Repair Method | Reference Figure |
|---|---|---|---|
| Cracking | | | |
| Longitudinal | **Light** / < 1/8 in., no faulting, spalling < ½ in. wide<br>**Moderate** / 1/8 in. < width < ½ in, spalling < 3 in wide<br>**Severe** / width > ½ in, spalling > 3 in, faulting > ½ in. | **Light** / none<br>**Mod.**/ clean & seal<br>**Severe**/ replace | 10.2, 10.3 |
| Transverse | **Light** / < 1/8 in., no faulting, spalling < ½ in. wide<br>**Moderate** / 1/8 in. < width < ½ in, spalling < 3 in wide<br>**Severe** / width > ½ in, spalling > 3 in, faulting > ½ in. | **Light** / none<br>**Mod.**/ clean & seal<br>**Severe** / replace | 10.2, 10.3, 10.4, 10.5 |
| Corner Breaks | A corner of the slab is separated by a crack that intersects the adjacent longitudinal and transverse joint, describing an approximate 45 ° angle with the direction of traffic. | Full depth replacement, partial slab | 10.4, 10.5 |
| Intersecting random cracks<br><br>(Shattered Slab) | Cracking patterns that divide the slab into three or more segments | Full depth replacement, partial slab allowed only if at least one half of slab in traffic direction is undamaged. | 10.3, 10.4 |
| Joint Deficiencies | | | |
| Spall<br><br>Non-Wheel-path | **Light** / spall width < 1.5 in., less than 1/3 slab depth, < 12 in. in length<br>**Moderate** / 1.5 in < spall width < 3 in., < 1/3 slab depth, < 12 in. in length<br>**Severe** / spall width > 3 in. or length > 12 in. | **Light /** none<br>**Mod.** / none<br>**Severe** / full depth replacement, partial slab | 10.5, 10.6 |
| Spall<br><br>Wheel-path | **Light** / spall width < 1.5 in., less than 1/3 slab depth, < 12 in. in length<br>**Moderate** / 1.5 in < spall width < 3 in., < 1/3 slab depth, < 12 in. in length<br>**Severe** / spall width > 3 in. or length > 12 in. | **Light /** none<br>**Mod.** / full depth<br>**Severe** / full depth | 10.5, 10.6 |

| | | | |
|---|---|---|---|
| Surface Deterioration | | | |
| Map Cracking | A series of interconnected random cracks extending only into the upper slab surface<br>Low / surface is intact with no scaling<br>Moderate / scaling and loss of surface material | Low / do nothing<br>Mod/ diamond grind | 10.7 |
| Scaling | Deterioration of the upper concrete surface, usually less than 0.5 inches in depth. | Remove affected area by grinding | 10.7 |
| Pop outs<br><br>Non-Wheel-path | Small pieces of surface pavement broken loose, normally ranging from 1 to 4 in. diameter and ½ to 2 inches in depth<br>**Light** / not deemed to be a traffic hazard<br>**Severe** / flying debris deemed a traffic hazard | **Light** / keep under observation<br>**Severe** / full depth replacement | 10.4 |
| Pop outs<br><br>Wheel-path | Small pieces of surface pavement broken loose, normally > 3" diameter and 2" inches in depth<br>**Light** / deemed to be a traffic hazard<br>**Severe** / flying debris deemed a traffic hazard | **Light** / **Severe** / full depth replacement | 10.4 |
| Miscellaneous Distress | | | |
| Faulting | Elevation differences across joints or cracks<br>**Light** / Fault Index < 4<br>**Moderate** / 4 < Fault Index < 16<br>**Severe** / Fault index > 16 | **Light** / none<br>**Mod.** / grind<br>**Severe** / grind | |
| Lane to shoulder drop off | **Light** / 0 < drop off < 1 in.<br>**Moderate** / 1 in. < drop off < 3 in.<br>**Severe** / drop off > 3 in. | **Light** / none<br>**Mod.** / Build up<br>**Severe** / Build up | N/A |
| Water Bleeding or pumping | Seeping or ejection of water through joints or cracks | Install appropriate drainage, edge drain, permeable sub base, reseal joints, etc. | N/A |
| Blow ups | Upward movement at transverse joints or cracks often accompanied by shattering of the concrete. | Full depth repair | 10.3, 10.4 |

# TABLE 10.1

## SLAB REPAIR AND REPLACEMENT CRITERIA (METRIC)

| Distress Pattern | Severity / Description | Repair Method | Reference Figure |
|---|---|---|---|
| Cracking | | | |
| Longitudinal | **Light** / < 3 mm., no faulting, spalling < 10 mm. wide<br>**Moderate** / 3 mm. < width < 10 mm, spalling < 80 mm wide<br>**Severe** / width > 10 mm, spalling > 80 mm, faulting > 10 mm. | **Light** / none<br>**Mod.**/ clean & seal<br>**Severe**/ replace | 10.2, 10.3 |
| Transverse | **Light** / < 3 mm., no faulting, spalling < 10 mm. wide<br>**Moderate** / 3 mm. < width < 10 mm, spalling < 80 mm wide<br>**Severe** / width > 10 mm, spalling > 80 mm, faulting > 10 mm. | **Light** / none<br>**Mod.**/ clean & seal<br>**Severe** / replace | 10.2, 10.3, 10.4, 10.5 |
| Corner Breaks | A corner of the slab is separated by a crack that intersects the adjacent longitudinal and transverse joint, describing an approximate 45 ° angle with the direction of traffic. | Full depth replacement, partial slab | 10.4, 10.5 |
| Intersecting random cracks<br><br>(Shattered Slab) | Cracking patterns that divide the slab into three or more segments | Full depth replacement, partial slab allowed only if at least one half of slab in traffic direction is undamaged. | 10.3, 10.4 |
| Joint Deficiencies | | | |
| Spall<br><br>Non- Wheel-path | **Light** / spall width < 40 mm, less than 1/3 slab depth, < 300 mm in length<br>**Moderate** / 40 mm < spall width < 80 mm., < 1/3 slab depth, < 300 mm in length<br>**Severe** / spall width > 80 mm or length > 300 mm | **Light /** none<br>**Mod.** / none<br>**Severe** / full depth replacement, partial slab | 10.5, 10.6 |
| Spall<br><br>Wheel- path | **Light** / spall width < 40 mm, less than 1/3 slab depth, < 300 mm in length<br>**Moderate** / 40 mm < spall width < 80 mm., < 1/3 slab depth, < 300 mm in length<br>**Severe** / spall width > 80 mm or length > 300 mm | **Light /** none<br>**Mod.** / full depth<br>**Severe** / full depth | 10.5, 10.6 |

| | | | |
|---|---|---|---|
| Surface Deterioration | | | |
| Map Cracking | A series of interconnected random cracks extending only into the upper slab surface<br>Low / surface is intact with no scaling<br>Moderate / scaling and loss of surface material | Low / do nothing<br>Mod/ diamond grind | 10.7 |
| Scaling | Deterioration of the upper concrete surface, usually less than 10 mm depth. | Remove affected area by grinding | 10.7 |
| Pop outs<br><br>Non-Wheel-path | Small pieces of surface pavement broken loose, normally ranging from 30 to 100 mm. diameter and 10 to 50 mm in depth<br>**Light** / Not deemed to be a traffic hazard<br>**Severe** / flying debris deemed a traffic hazard | **Light** / keep under observation<br>**Severe** / full depth replacement | 10.4 |
| Pop outs<br><br>Wheel-path | Small pieces of surface pavement broken loose, normally > 80 mm diameter and 50 mm in depth<br>**Light** / Not deemed to be a traffic hazard<br>**Severe** / flying debris deemed a traffic hazard | **Light** / **Severe** / full depth replacement | 10.4 |
| Miscellaneous Distress | | | |
| Faulting | Elevation differences across joints or cracks<br>**Light** / Fault Index < 4<br>**Moderate** / 4 < Fault Index < 16<br>**Severe** / Fault index > 16 | **Light** / none<br>**Mod.** / grinding<br>**Severe** / grind | |
| Lane to shoulder drop off | **Light** / 0 < drop off < 30 mm<br>**Moderate** / 30 mm. < drop off < 80 mm.<br>**Severe** / drop off > 80 mm. | **Light** / none<br>**Mod.** / Build up<br>**Severe** / Build up | N/A |
| Water Bleeding or pumping | Seeping or ejection of water through joints or cracks | Install appropriate drainage, edge drain, permeable sub base, reseal joints, etc. | N/A |
| Blow ups | Upward movement at transverse joints or cracks often accompanied by shattering of the concrete. | Full depth repair | 10.3, 10.4 |

Minimum recommended Full Depth Repair dimensions are 12’(3.6 m) wide (or full lane width) by 6’(1.8 m) long. If less than a full slab is replaced, the remaining slab that is not replaced should also have these minimum dimensions.

One construction concern to be addressed in the Traffic Control Plans is if the removed slabs have to remain open overnight. Normally, it is desirable to replace the slabs as soon as possible. The designers should coordinate with the construction and materials offices and indicate in the plans and specifications the use of High Early Strength Concrete when required. A minimum compressive strength of 2200 psi(15 MPa) is needed prior to opening to traffic. The State Materials Office can be consulted on the use of these materials.

Full slab replacements should be full lane width and a minimum of 6’(1.8 m) in length. Dowel bars should be retrofitted into each end of the repair. If repairs extend beyond 15’(4.6 m), an intermediate, doweled transverse joint is to be provided. The longitudinal joints for slab replacements should not be tied.

Slab replacement and other quantity estimates are to be made in the field in cooperation with construction personnel and carefully documented on a slab by slab basis. If necessary, lanes should be closed and cores taken of representative cracks to determine the depth of cracking and spalling.

Historical rates of deterioration are to be reviewed and plan quantities increased to account for deterioration expected to occur between the field survey and actual construction. A final check of quantities is to be made just prior to finalizing the plans for letting.

## 10.3 PARTIAL DEPTH SPALL REPAIR

The purpose of partial depth spall repair is to patch areas that are spalled, but shallow (less than half the slab depth) enough not to require full depth portions of the slab to be replaced.

If the repair is along a joint or crack, it is extremely important that a preformed joint insert is carefully placed along the joint (or crack) to allow for slab expansion and to keep patch material from entering the joint. Compression failures are one of the most common problems with partial depth patches.

Due to the poor performance of these repairs, they are generally not recommended.

The Value Added Portland Cement Concrete Pavement Specification may not be applied to this type repairs.

## 10.4 INSTALLATION OF EDGEDRAINS

Draincrete edgedrains are used in projects where edgedrains are non-functioning or nonexistent. This provides excellent structural support for heavy vehicles that may off track from the pavement edge as well as good lateral soil support.

Geocomposites are not recommended in Concrete Pavement Rehabilitation Projects because of the potential for settlement of the backfill under load, and clogging of the filter fabric.
See Standard Index 287 for edgedrain details for rehabilitation projects.

## 10.5 DIAMOND GRINDING

The purpose of diamond grinding is to restore faulted pavement and to improve ride. Grinding is recommended for any concrete restoration project unless there are special reasons not to.

One factor that affects the cost of grinding significantly is the type of aggregate used in the concrete slab. Aggregate that is hard (has a higher hardness number) such as river gravel could cost more to grind compared to a softer material such as limerock. The designer needs to consult with the District Materials Engineer about the type of aggregate used in the existing pavement in making the cost estimate.

## 10.6 CLEAN AND RESEAL JOINTS

All joints should be cleaned and resealed on any rehabilitation project. The purpose of cleaning and resealing joints is to reduce the intrusion of water into the base and keep incompressible out of the joints. The Pavement Design Engineer should be familiar with Standard Index 305.

## 10.7 ROUT AND SEAL RANDOM CRACKS

The purpose of routing and sealing random cracks is to reduce the intrusion of water into the base and keep incompressible out of the joints. Using special saws or routers due to the random nature of crack propagation does this.

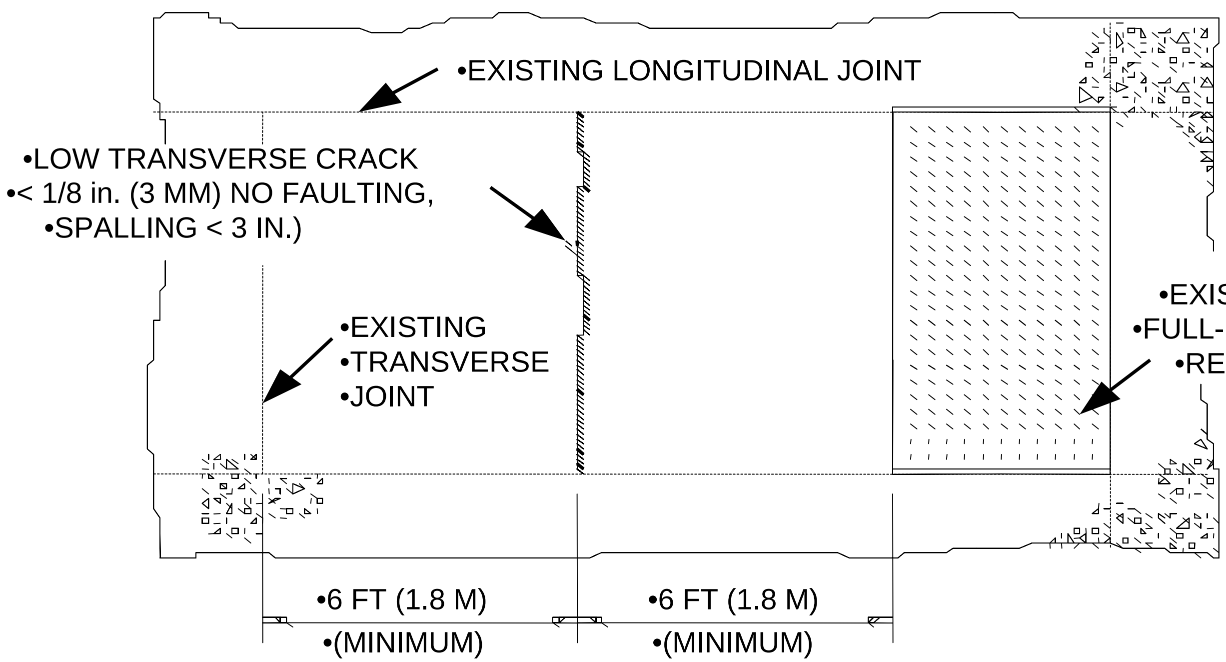
## 10.8 OTHER

Restoration of load transfer has been tried in undoweled pavements in Florida, but was not successful. Until further research and demonstrated success is performed in Florida, the general use of load transfer restoration is not recommended.

# FIGURE 10.1

# REPAIR METHOD REFERENCE FIGURES

•REPAIR METHOD:  NONE




•FIGURE 10.2

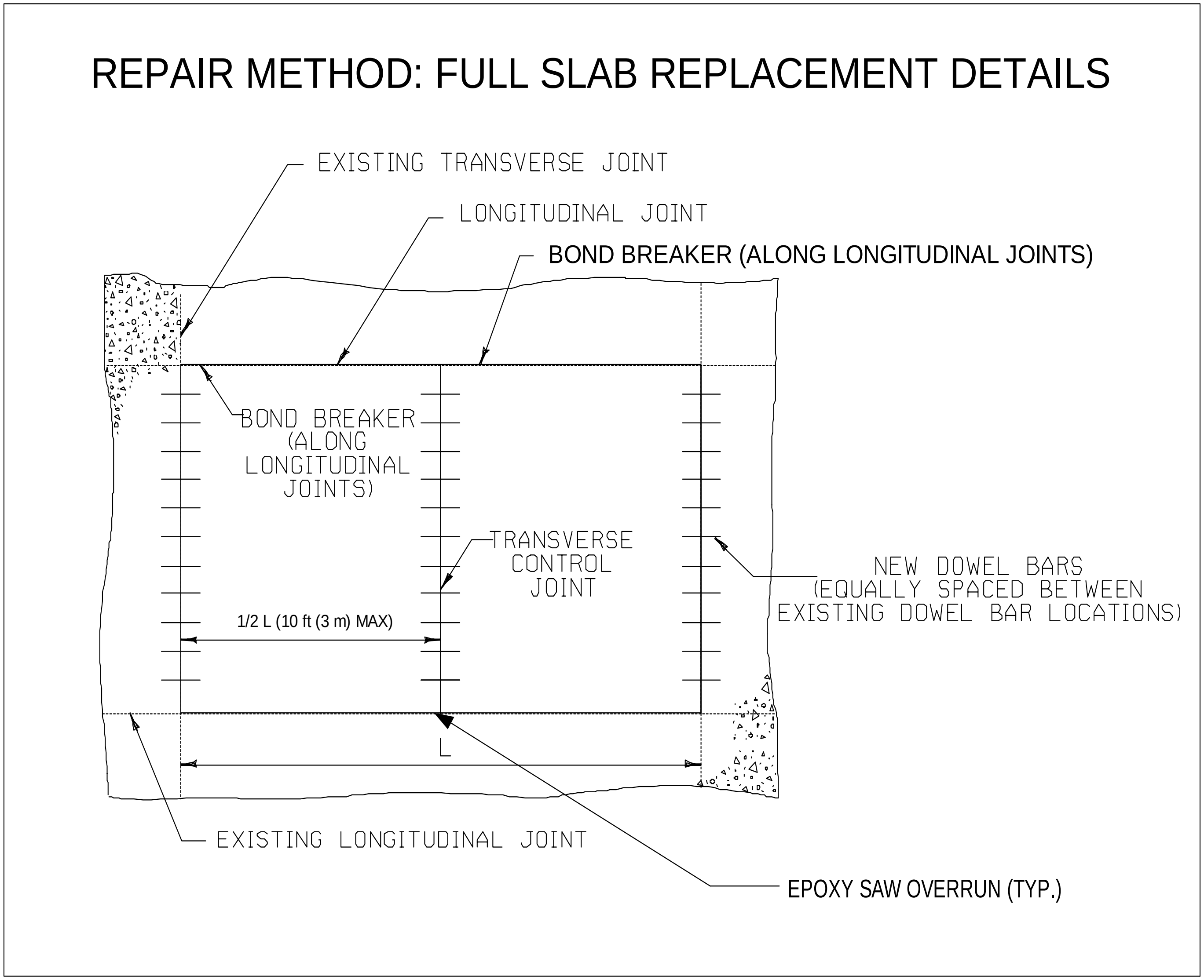

REPAIR METHOD: FULL SLAB REPLACEMENT DETAILS
EXISTING TRANSVERSE JOINT
LONGITUDINAL JOINT
BOND BREAKER (ALONG LONGITUDINAL JOINTS)
BOND BREAKER (ALONG LONGITUDINAL JOINTS)
TRANSVERSE CONTROL JOINT
NEW DOWEL BARS (EQUALLY SPACED BETWEEN EXISTING DOWEL BAR LOCATIONS)
1/2 L (10 ft (3 m) MAX)
L
EXISTING LONGITUDINAL JOINT
EPOXY SAW OVERRUN (TYP.)

FIGURE 10.3

# REPAIR METHOD: PARTIAL SLAB REPLACEMENT DETAILS

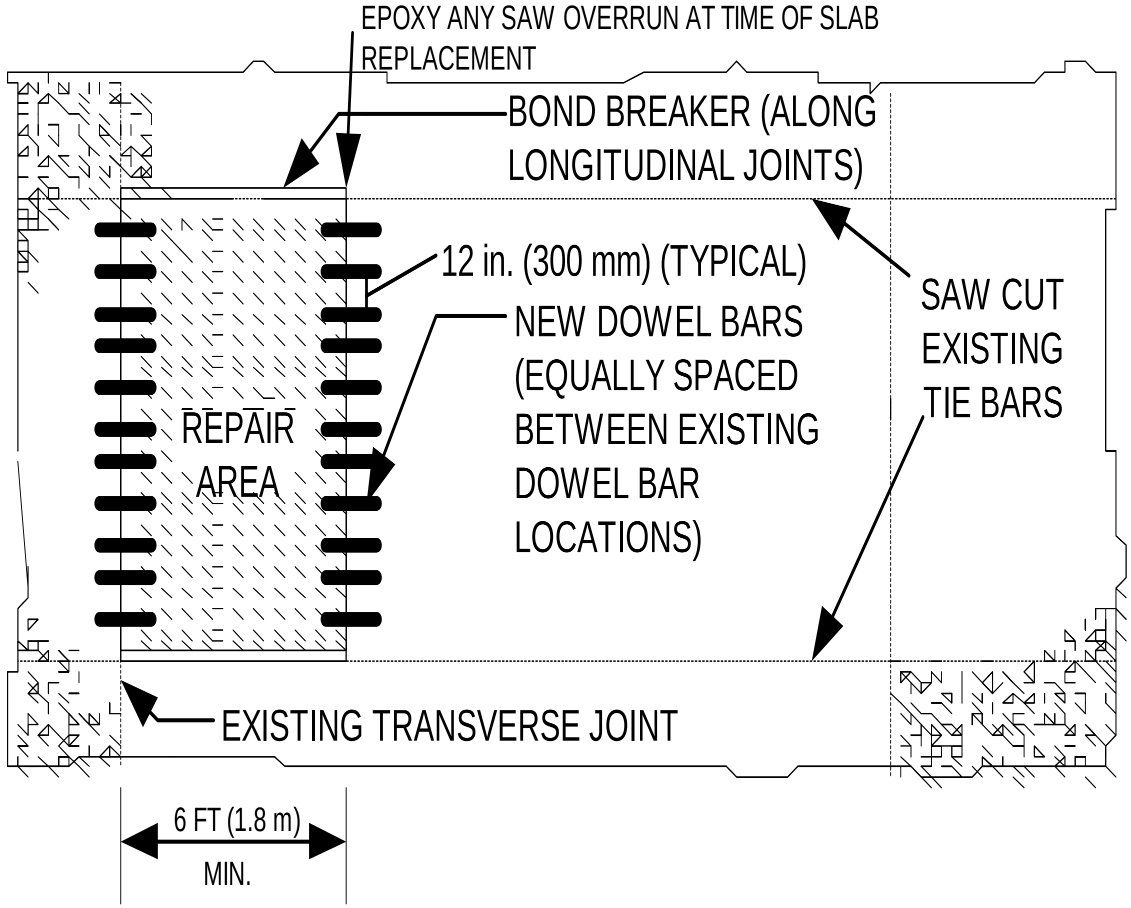
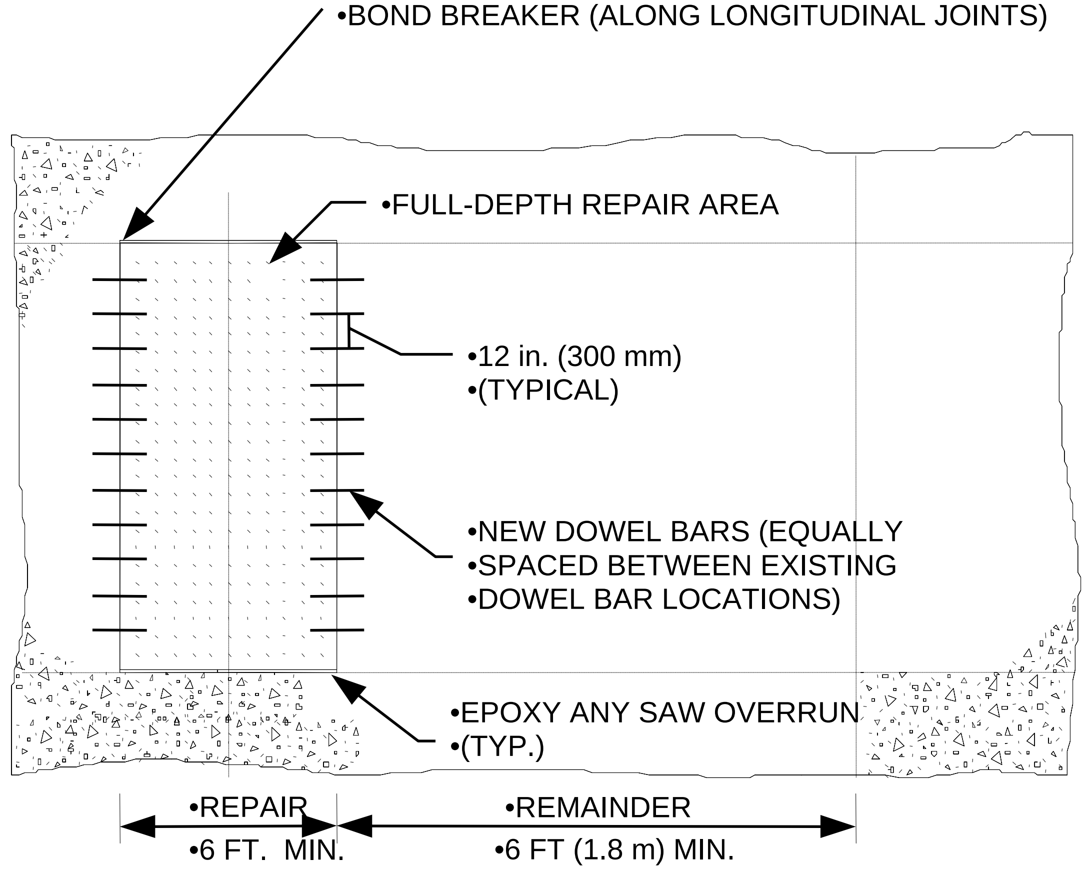



FIGURE 10.4

## •REPAIR METHOD: Full-Depth Repair on Both Sides of the Joint




•FIGURE 10.5

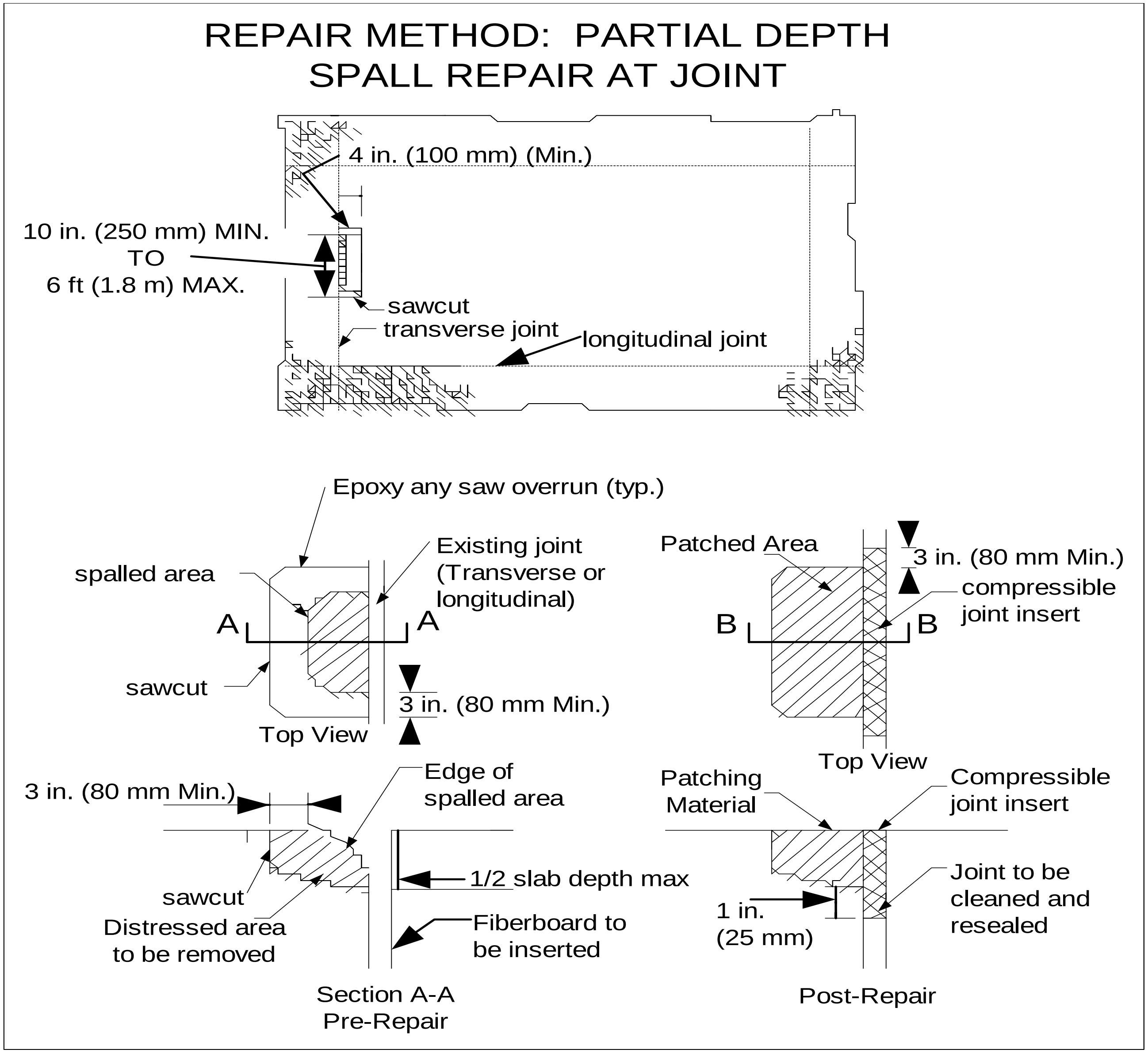
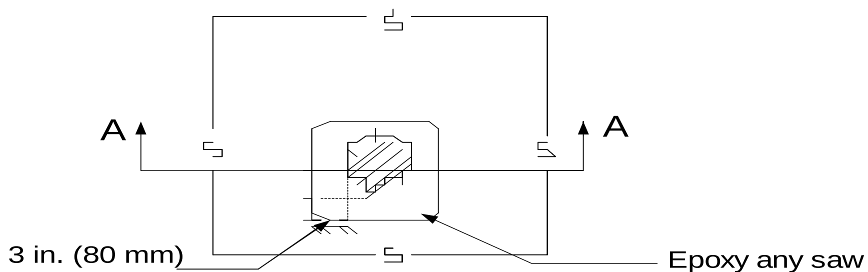
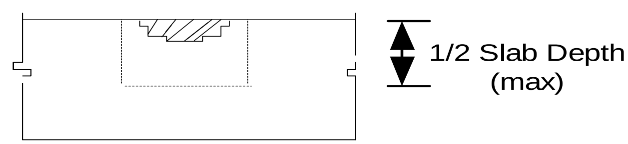

REPAIR METHOD: PARTIAL DEPTH
SPALL REPAIR AT JOINT
4 in. (100 mm) (Min.)
10 in. (250 mm) MIN.
TO
6 ft (1.8 m) MAX.
sawcut
transverse joint
longitudinal joint
Epoxy any saw overrun (typ.)
spalled area
Existing joint
(Transverse or
longitudinal)
A
A
sawcut
3 in. (80 mm Min.)
Top View
Patched Area
3 in. (80 mm Min.)
compressible
joint insert
B
B
Top View
3 in. (80 mm Min.)
Edge of
spalled area
1/2 slab depth max
sawcut
Distressed area
to be removed
Fiberboard to
be inserted
Section A-A
Pre-Repair
Patching
Material
Compressible
joint insert
Joint to be
cleaned and
resealed
1 in.
(25 mm)
Post-Repair

FIGURE 10.6

# REPAIR METHOD: PARTIAL DEPTH SPALL REPAIR AT CENTER OF SLAB




Top View




Repair Detail

FIGURE 10.7

# CHAPTER 11

# OTHER RECOMMENDED REHABILITATION ALTERNATIVES

## 11.1 GENERAL

Several other rehabilitation alternatives are available to the designer. Some of these have been tried several times with good results. These alternatives are usually cost effective only if the existing concrete pavement is significantly deteriorated. If the Pavement Design Engineer decides to use one of these alternatives, information is available that will guide the Pavement Design Engineer during the design process.

## 11.2 CRACK, RESEAT, AND OVERLAY (CRO) EXISTING PAVEMENT

This alternative involves cracking the existing concrete pavement up, reseating the existing pavement, and overlaying the existing pavement with an Asphalt Rubber Membrane Interlayer (ARMI), Asphalt Structural Course, and Friction Course.

### 11.2.1 BREAKING THE EXISTING PAVEMENT

The existing pavement should be broken according to specifications into properly sized pieces to reduce thermal expansion and contraction of the concrete, thereby retarding any reflective cracking.

### 11.2.2 RESEATING THE CRACKED PAVEMENT

The cracked pavement should be reseated firmly into place using rubber wheeled rollers. The purpose of reseating the existing pavement is to provide the following benefits:

- Eliminate any slab pieces that may rock, slide, or push.
- Remove any jagged edges.

### 11.2.3 ASPHALT RUBBER MEMBRANE INTERLAYER (ARMI)

The purpose of the Asphalt Rubber Membrane Interlayer (ARMI) is to retard any reflective cracking that may occur, and provide a waterproofing layer to keep any water remaining under the slabs from pumping into the asphalt layers.

More information about this material as well as information on the design of additional asphalt layers can be found in the Flexible Pavement Design Manual (Document No. 625-010-002).

### 11.2.4 ASPHALT OVERLAY

The purpose of the asphalt overlay is to provide additional structural strength to the pavement system and to provide a new riding surface on top of the prepared surface. This should include an Asphalt Structural Course and a Friction Course. Information on the design of these layers can be found in the Flexible Pavement Design Manual.

### 11.2.5 DESIGN AND CONSTRUCTION CONSIDERATIONS

In designing the project, the cracked and reseated concrete pavement can be treated as a base. Using the Flexible Pavement Design Manual, the cracked and reseated pavement layer coefficients that can be used include the following:

| | Structural Coefficients | | |
|---|---|---|---|
| Material | Good | Fair | Poor |
| Reseated Concrete | 0.23 | 0.20 | 0.18 |

Design details need to be developed for the pavement where there is a transition into a bridge approach slab. It is usually advisable to remove some of the slabs so that thin asphalt feathering is not required, due to its potential to oxidize and delaminate with time. An appropriate thickness transition length should be provided for high-speed facilities.

Another area where design details need to be provided would be in the area of a bridge underpass. Reduction in clearance below standards at an underpass due to the extra asphalt must be avoided. Vertical clearance information can be found in Chapter 2, Design Geometrics and Criteria, of the Plans Preparation Manual - Procedure No. 625-000-007.

The solution may be to remove the concrete pavement in advance of the underpass and provide additional base material before placement of the Asphalt Structural Course and Friction Course.

If the pavement system still has a large amount of water in the pavement system, using edgedrains may provide an outlet for the water before the cracking and reseating operation is performed.

## 11.3 RECYCLING

Another alternative that the department has utilized is the complete recycling of the existing concrete pavement as an aggregate source for a new pavement. This option is desirable when cost effective and where problems with the subbase have been encountered and must be addressed.

This has been tried in some areas of the state successfully where the cost of removing the pavement, crushing the slabs, and sorting out the material, has provided life cycle cost savings.

## 11.4 RUBBLIZATION

The existing pavement slab is fractured into aggregate -sized particles, which destroys the slab action. Rubblization is usually appropriate when deterioration of the existing pavement renders normal crack/seat or break/seat methods ineffective.

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# CHAPTER 12

# NEW TECHNOLOGIES

## 12.1 GENERAL

New technology is important to the designer because the Department benefits by the reduction in life cycle costs, the introduction of new materials, and/or improved methods of construction.

## 12.2 NEW CONSTRUCTION AND REHABILITATION

Construction projects that are experimental in nature but will provide the department with valuable design and performance information.

Experimental projects should be carefully coordinated with the State Materials Office Pavement Evaluation Section to set up control and experimental limits so that detailed performance and evaluations can be made over time.

## 12.3 NEW PRODUCTS

New products are tested to determine their effectiveness under Florida conditions.

Examples may include materials such as concrete additives, polymers for spall repair, etc.. This includes any single component that will improve the performance of the concrete.

Other examples may include components such as edgedrains, joint seals, etc.. This includes items which would replace several materials in a system such as concrete material additives, curing compounds, joint seals, polymers for spall repair, etc.

**APPENDIX A**

**DESIGN TABLES**

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## A.1 INSTRUCTIONS

The following are Required Depth ($D_R$) Design Tables for 75%, 80%, 85%, 90%, 92%, 94% and 95% Reliability (%R).

Selected values of the 18-kip (80 KN) Equivalent Single Axle Loads ($ESAL_D$) and the Modulus Of Subgrade Reaction ($K_G$) are provided.

The Standard Deviation ($S_O$), Initial Serviceability ($P_I$), Terminal Serviceability ($P_T$), change in Serviceability ($\Delta PSI$), Concrete Modulus Of Rupture ($S'_C$), Concrete Modulus Of Elasticity ($E_C$), Drainage Coefficient ($C_D$), and the Load Transfer Factor (J) is the same for all 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 |

To find the Required Depth ($D_R$) of the concrete pavement, use the following method:

- Determine the appropriate Reliability (%R).
- Select the design Modulus Of Subgrade Reaction ($K_G$) value at the top of the table.

- Select the design Accumulated 18-kip (80 KN) Equivalent Single Axle Loads ($ESAL_D$) value at the left of the table.

- Read down the column of the selected Modulus Of Subgrade Reaction ($K_G$) value and read across the row of the selected Accumulated 18-kip (80 KN) Equivalent Single Axle Loads ($ESAL_D$) value.

- The value intersected is the Required Depth ($D_R$) of the concrete pavement.

If the Modulus Of Subgrade Reaction ($K_G$) value and/or the 18-kip (80 KN) Equivalent Single Axle Loads ($ESAL_D$) value is not listed in the design tables provided, the Required Depth ($D_R$) of the concrete pavement can be interpolated. This should not be necessary except in rare cases.

**TABLE A.1**

**REQUIRED DEPTH ($D_R$) IN inch FOR 75% RELIABILITY (%R)**

| | Modulus Of Subgrade Reaction ($K_G$),psi/in | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **40** | **80** | **110** | **150** | **185** | **200** | **260** | **300** | **330** | **370** |
| **100 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **150 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **200 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **250 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **300 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **350 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **400 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **450 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **500 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **600 000** | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **700 000** | 7 | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **800 000** | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 |
| **900 000** | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 |
| **1 000 000** | 7½ | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 |
| **1 500 000** | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ | 6½ | 6½ |
| **2 000 000** | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 |
| **2 500 000** | 8½ | 8 | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7½ | 7 |
| **3 000 000** | 8½ | 8½ | 8½ | 8 | 8 | 8 | 8 | 7½ | 7½ | 7½ |
| **3 500 000** | 9 | 8½ | 8½ | 8½ | 8 | 8 | 8 | 8 | 8 | 7½ |
| **4 000 000** | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8 | 8 | 8 | 8 |
| **4 500 000** | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8½ | 8 | 8 |
| **5 000 000** | 9½ | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8½ | 8½ |
| **6 000 000** | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ |
| **7 000 000** | 10 | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 | 9 |
| **8 000 000** | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 |
| **9 000 000** | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9 | 9 |
| **10 000 000** | 10½ | 10 | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ |
| **15 000 000** | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 |
| **20 000 000** | 11½ | 11½ | 11 | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ |
| **25 000 000** | 12 | 11½ | 11½ | 11½ | 11 | 11 | 11 | 11 | 11 | 11 |
| **30 000 000** | 12 | 12 | 12 | 11½ | 11½ | 11½ | 11½ | 11½ | 11 | 11 |
| **35 000 000** | 12½ | 12 | 12 | 12 | 12 | 11½ | 11½ | 11½ | 11½ | 11½ |
| **40 000 000** | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 | 12 | 12 | 11½ |
| **45 000 000** | 13 | 12½ | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 | 12 |
| **50 000 000** | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12 | 12 | 12 |
| **60 000 000** | 13½ | 13 | 13 | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ |
| **70 000 000** | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| **80 000 000** | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 |
| **90 000 000** | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ | 13½ | 13½ |
| **100 000 000** | 14½ | 14 | 14 | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ |

**TABLE A.2**

**REQUIRED DEPTH ($D_R$) IN inch FOR 80% RELIABILITY (%R)**

| | Modulus Of Subgrade Reaction ($K_G$),psi/in | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **40** | **80** | **110** | **150** | **185** | **200** | **260** | **300** | **330** | **370** |
| **100 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **150 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **200 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **250 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **300 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **350 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **400 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **450 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **500 000** | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **600 000** | 7 | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **700 000** | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 |
| **800 000** | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 |
| **900 000** | 7½ | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6 | 6 | 6 |
| **1 000 000** | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6 | 6 |
| **1 500 000** | 8 | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 | 7 | 6½ |
| **2 000 000** | 8½ | 8 | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7 | 7 |
| **2 500 000** | 8½ | 8½ | 8 | 8 | 8 | 8 | 7½ | 7½ | 7½ | 7½ |
| **3 000 000** | 9 | 8½ | 8½ | 8½ | 8 | 8 | 8 | 8 | 8 | 7½ |
| **3 500 000** | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8 | 8 | 8 | 8 |
| **4 000 000** | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8½ | 8 | 8 |
| **4 500 000** | 9½ | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8½ |
| **5 000 000** | 9½ | 9½ | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ |
| **6 000 000** | 10 | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 | 9 |
| **7 000 000** | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 |
| **8 000 000** | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9½ | 9 |
| **9 000 000** | 10½ | 10 | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ |
| **10 000 000** | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 | 9½ | 9½ | 9½ |
| **15 000 000** | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10½ | 10½ | 10 |
| **20 000 000** | 11½ | 11½ | 11½ | 11 | 11 | 11 | 11 | 11 | 11 | 10½ |
| **25 000 000** | 12 | 12 | 11½ | 11½ | 11½ | 11½ | 11½ | 11 | 11 | 11 |
| **30 000 000** | 12½ | 12 | 12 | 12 | 12 | 11½ | 11½ | 11½ | 11½ | 11½ |
| **35 000 000** | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 | 12 | 12 | 11½ |
| **40 000 000** | 13 | 12½ | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 | 12 |
| **45 000 000** | 13 | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12 | 12 |
| **50 000 000** | 13½ | 13 | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12½ |
| **60 000 000** | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 | 13 | 12½ |
| **70 000 000** | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 |
| **80 000 000** | 14½ | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ | 13½ |
| **90 000 000** | 14½ | 14½ | 14 | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ |
| **100 000 000** | 14½ | 14½ | 14½ | 14 | 14 | 14 | 14 | 14 | 14 | 13½ |

**TABLE A.3**

**REQUIRED DEPTH ($D_R$) IN inch FOR 85% RELIABILITY (%R)**

| $ESAL_D$ | Modulus Of Subgrade Reaction ($K_G$),psi/in 40 | 80 | 110 | 150 | 185 | 200 | 260 | 300 | 330 | 370 |
|---|---|---|---|---|---|---|---|---|---|---|
| **100 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **150 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **200 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **250 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **300 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **350 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **400 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **450 000** | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **500 000** | 7 | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **600 000** | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 |
| **700 000** | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 |
| **800 000** | 7½ | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6 | 6 | 6 |
| **900 000** | 7½ | 7 | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6 |
| **1 000 000** | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ |
| **1 500 000** | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 |
| **2 000 000** | 8½ | 8½ | 8 | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7½ |
| **2 500 000** | 9 | 8½ | 8½ | 8½ | 8 | 8 | 8 | 8 | 8 | 7½ |
| **3 000 000** | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8 | 8 | 8 | 8 |
| **3 500 000** | 9½ | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8½ | 8½ | 8 |
| **4 000 000** | 9½ | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8½ |
| **4 500 000** | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ |
| **5 000 000** | 10 | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 | 8½ |
| **6 000 000** | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 |
| **7 000 000** | 10½ | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9 |
| **8 000 000** | 10½ | 10½ | 10 | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ |
| **9 000 000** | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 | 9½ | 9½ |
| **10 000 000** | 11 | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 | 10 |
| **15 000 000** | 11½ | 11½ | 11 | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ |
| **20 000 000** | 12 | 11½ | 11½ | 11½ | 11½ | 11½ | 11 | 11 | 11 | 11 |
| **25 000 000** | 12½ | 12 | 12 | 12 | 12 | 11½ | 11½ | 11½ | 11½ | 11½ |
| **30 000 000** | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 | 12 | 12 | 11½ |
| **35 000 000** | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 |
| **40 000 000** | 13 | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12½ | 12 |
| **45 000 000** | 13½ | 13 | 13 | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12 |
| **50 000 000** | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 | 12½ | 12½ |
| **60 000 000** | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 |
| **70 000 000** | 14½ | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ | 13½ |
| **80 000 000** | 14½ | 14½ | 14 | 14 | 14 | 14 | 14 | 13½ | 13½ | 13½ |
| **90 000 000** | 15 | 14½ | 14½ | 14½ | 14 | 14 | 14 | 14 | 14 | 14 |
| **100 000 000** | 15 | 15 | 14½ | 14½ | 14½ | 14½ | 14½ | 14 | 14 | 14 |

## TABLE A.4

### REQUIRED DEPTH ($D_R$) IN inch FOR 90% RELIABILITY (%R)

| | Modulus Of Subgrade Reaction ($K_G$),psi/in | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **40** | **80** | **110** | **150** | **185** | **200** | **260** | **300** | **330** | **370** |
| **100 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **150 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **200 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **250 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **300 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **350 000** | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **400 000** | 7 | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **450 000** | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 |
| **500 000** | 7 | 7 | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **600 000** | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 |
| **700 000** | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6 | 6 |
| **800 000** | 7½ | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6½ |
| **900 000** | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ | 6½ | 6½ |
| **1 000 000** | 8 | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ | 6½ |
| **1 500 000** | 8½ | 8 | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7½ | 7 |
| **2 000 000** | 9 | 8½ | 8½ | 8 | 8 | 8 | 8 | 8 | 7½ | 7½ |
| **2 500 000** | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8 | 8 | 8 | 7½ |
| **3 000 000** | 9½ | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8½ | 8 |
| **3 500 000** | 9½ | 9½ | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ |
| **4 000 000** | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 | 9 | 8½ |
| **4 500 000** | 10 | 9½ | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 |
| **5 000 000** | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9 | 9 | 9 |
| **6 000 000** | 10½ | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9½ |
| **7 000 000** | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 | 9½ | 9½ | 9½ |
| **8 000 000** | 11 | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 | 10 |
| **9 000 000** | 11 | 10½ | 10½ | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 |
| **10 000 000** | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10½ | 10 | 10 |
| **15 000 000** | 12 | 11½ | 11½ | 11½ | 11 | 11 | 11 | 11 | 11 | 11 |
| **20 000 000** | 12½ | 12 | 12 | 12 | 11½ | 11½ | 11½ | 11½ | 11½ | 11½ |
| **25 000 000** | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 | 12 | 12 | 11½ |
| **30 000 000** | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12 | 12 | 12 |
| **35 000 000** | 13½ | 13 | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12½ |
| **40 000 000** | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 | 12½ | 12½ | 12½ |
| **45 000 000** | 14 | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 | 13 |
| **50 000 000** | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ | 13 | 13 | 13 |
| **60 000 000** | 14½ | 14 | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ |
| **70 000 000** | 14½ | 14½ | 14½ | 14 | 14 | 14 | 14 | 14 | 14 | 13½ |
| **80 000 000** | 15 | 15 | 14½ | 14½ | 14½ | 14½ | 14 | 14 | 14 | 14 |
| **90 000 000** | 15½ | 15 | 15 | 15 | 14½ | 14½ | 14½ | 14½ | 14½ | 14½ |
| **100 000 000** | 152 | 15½ | 15 | 15 | 15 | 15 | 14½ | 14½ | 14½ | 14½ |

**TABLE A.5**

**REQUIRED DEPTH ($D_R$) IN inch FOR 92% RELIABILITY (%R)**

| | Modulus Of Subgrade Reaction ($K_G$),psi/in | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **40** | **80** | **110** | **150** | **185** | **200** | **260** | **300** | **330** | **370** |
| **100 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **150 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **200 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **250 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **300 000** | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **350 000** | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **400 000** | 7 | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **450 000** | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 |
| **500 000** | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 |
| **600 000** | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 |
| **700 000** | 7½ | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6 |
| **800 000** | 7½ | 7½ | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ |
| **900 000** | 8 | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ | 6½ |
| **1 000 000** | 8 | 8 | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ |
| **1 500 000** | 8½ | 8½ | 8 | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7½ |
| **2 000 000** | 9 | 8½ | 8½ | 8½ | 8½ | 8 | 8 | 8 | 8 | 8 |
| **2 500 000** | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8½ | 8 | 8 |
| **3 000 000** | 9½ | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8½ |
| **3 500 000** | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 | 8½ | 8½ |
| **4 000 000** | 10 | 9½ | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 |
| **4 500 000** | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 |
| **5 000 000** | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9½ | 9 |
| **6 000 000** | 10½ | 10½ | 10 | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ |
| **7 000 000** | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 | 10 | 9½ |
| **8 000 000** | 11 | 10½ | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 |
| **9 000 000** | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10½ | 10 | 10 |
| **10 000 000** | 11½ | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10½ | 10½ |
| **15 000 000** | 12 | 12 | 11½ | 11½ | 11½ | 11½ | 11 | 11 | 11 | 11 |
| **20 000 000** | 12½ | 12½ | 12 | 12 | 12 | 12 | 11½ | 11½ | 11½ | 11½ |
| **25 000 000** | 13 | 12½ | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 | 12 |
| **30 000 000** | 13 | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12½ | 12½ |
| **35 000 000** | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 | 12½ | 12½ | 12½ |
| **40 000 000** | 14 | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 | 13 |
| **45 000 000** | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ | 13 | 13 | 13 |
| **50 000 000** | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ | 13½ | 13½ |
| **60 000 000** | 14½ | 14½ | 14 | 14 | 14 | 14 | 14 | 14 | 13½ | 13½ |
| **70 000 000** | 15 | 14½ | 14½ | 14½ | 14½ | 14 | 14 | 14 | 14 | 14 |
| **80 000 000** | 15 | 15 | 15 | 14½ | 14½ | 14½ | 14½ | 14½ | 14½ | 14 |
| **90 000 000** | 15½ | 15 | 15 | 15 | 15 | 15 | 14½ | 14½ | 14½ | 14½ |
| **100 000 000** | 15½ | 15½ | 15½ | 15 | 15 | 15 | 15 | 15 | 15 | 14½ |

**TABLE A.6**

**REQUIRED DEPTH ($D_R$) IN inch FOR 94% RELIABILITY (%R)**

| ESAL$_D$ | Modulus Of Subgrade Reaction ($K_G$),psi/in 40 | 80 | 110 | 150 | 185 | 200 | 260 | 300 | 330 | 370 |
|---|---|---|---|---|---|---|---|---|---|---|
| **100 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **150 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **200 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **250 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **300 000** | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **350 000** | 7 | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **400 000** | 7 | 7 | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 |
| **450 000** | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 |
| **500 000** | 7½ | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6 | 6 | 6 |
| **600 000** | 7½ | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6 |
| **700 000** | 7½ | 7½ | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ |
| **800 000** | 8 | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ | 6½ |
| **900 000** | 8 | 8 | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 | 7 |
| **1 000 000** | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 |
| **1 500 000** | 8½ | 8½ | 8½ | 8 | 8 | 8 | 8 | 7½ | 7½ | 7½ |
| **2 000 000** | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8 | 8 | 8 | 8 |
| **2 500 000** | 9½ | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8½ |
| **3 000 000** | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ |
| **3 500 000** | 10 | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 | 9 |
| **4 000 000** | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9 | 9 | 9 |
| **4 500 000** | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9½ | 9 |
| **5 000 000** | 10½ | 10 | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ |
| **6 000 000** | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 | 9½ | 9½ |
| **7 000 000** | 11 | 10½ | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 |
| **8 000 000** | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10½ | 10 | 10 |
| **9 000 000** | 11½ | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10½ | 10½ |
| **10 000 000** | 11½ | 11½ | 11 | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ |
| **15 000 000** | 12 | 12 | 12 | 11½ | 11½ | 11½ | 11½ | 11½ | 11½ | 11 |
| **20 000 000** | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 | 12 | 12 | 11½ |
| **25 000 000** | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12½ | 12 | 12 |
| **30 000 000** | 13½ | 13 | 13 | 13 | 13 | 13 | 12½ | 12½ | 12½ | 12½ |
| **35 000 000** | 14 | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 | 13 |
| **40 000 000** | 14 | 13½ | 13½ | 13½ | 13½ | 13½ | 13½ | 13 | 13 | 13 |
| **45 000 000** | 14½ | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ | 13½ |
| **50 000 000** | 14½ | 14½ | 14 | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ |
| **60 000 000** | 15 | 14½ | 14½ | 14½ | 14½ | 14 | 14 | 14 | 14 | 14 |
| **70 000 000** | 15 | 15 | 15 | 14½ | 14½ | 14½ | 14½ | 14½ | 14½ | 14 |
| **80 000 000** | 15½ | 15½ | 15 | 15 | 15 | 15 | 14½ | 14½ | 14½ | 14½ |
| **90 000 000** | 15½ | 15½ | 15½ | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| **100 000 000** | 16 | 16 | 15½ | 15½ | 15½ | 15½ | 15 | 15 | 15 | 15 |

**TABLE A.7**

**REQUIRED DEPTH ($D_R$) IN inch FOR 95% RELIABILITY (%R)**

| | Modulus Of Subgrade Reaction ($K_G$),psi/in | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **40** | **80** | **110** | **150** | **185** | **200** | **260** | **300** | **330** | **370** |
| **100 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **150 000** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **200 000** | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **250 000** | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **300 000** | 7 | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **350 000** | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 | 6 |
| **400 000** | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 | 6 |
| **450 000** | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 | 6 |
| **500 000** | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6 | 6 | 6 |
| **600 000** | 7½ | 7½ | 7 | 7 | 7 | 6½ | 6½ | 6½ | 6½ | 6½ |
| **700 000** | 8 | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ | 6½ | 6½ |
| **800 000** | 8 | 7½ | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 | 6½ |
| **900 000** | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7 | 7 | 7 | 7 |
| **1 000 000** | 8½ | 8 | 8 | 7½ | 7½ | 7½ | 7½ | 7 | 7 | 7 |
| **1 500 000** | 9 | 8½ | 8½ | 8 | 8 | 8 | 8 | 8 | 7½ | 7½ |
| **2 000 000** | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ | 8 | 8 | 8 |
| **2 500 000** | 9½ | 9½ | 9 | 9 | 9 | 9 | 8½ | 8½ | 8½ | 8½ |
| **3 000 000** | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 | 9 | 9 | 8½ |
| **3 500 000** | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9 | 9 | 9 | 9 |
| **4 000 000** | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9 | 9 |
| **4 500 000** | 10½ | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ | 9½ | 9½ |
| **5 000 000** | 10½ | 10½ | 10 | 10 | 10 | 10 | 9½ | 9½ | 9½ | 9½ |
| **6 000 000** | 11 | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 | 10 | 10 |
| **7 000 000** | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10 | 10 | 10 | 10 |
| **8 000 000** | 11½ | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10½ | 10 |
| **9 000 000** | 11½ | 11 | 11 | 11 | 11 | 10½ | 10½ | 10½ | 10½ | 10½ |
| **10 000 000** | 11½ | 11½ | 11 | 11 | 11 | 11 | 11 | 11 | 10½ | 10½ |
| **15 000 000** | 12½ | 12 | 12 | 12 | 11½ | 11½ | 11½ | 11½ | 11½ | 11½ |
| **20 000 000** | 13 | 12½ | 12½ | 12½ | 12 | 12 | 12 | 12 | 12 | 12 |
| **25 000 000** | 13½ | 13 | 13 | 13 | 12½ | 12½ | 12½ | 12½ | 12½ | 12½ |
| **30 000 000** | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 | 13 | 12½ | 12½ |
| **35 000 000** | 14 | 13½ | 13½ | 13½ | 13½ | 13 | 13 | 13 | 13 | 13 |
| **40 000 000** | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ | 13½ | 13 |
| **45 000 000** | 14½ | 14 | 14 | 14 | 14 | 13½ | 13½ | 13½ | 13½ | 13½ |
| **50 000 000** | 14½ | 14½ | 14½ | 14 | 14 | 14 | 14 | 14 | 13½ | 13½ |
| **60 000 000** | 15 | 15 | 14½ | 14½ | 14½ | 14½ | 14 | 14 | 14 | 14 |
| **70 000 000** | 15½ | 15 | 15 | 15 | 14½ | 14½ | 14½ | 14½ | 14½ | 14½ |
| **80 000 000** | 15½ | 15½ | 15½ | 15 | 15 | 15 | 15 | 15 | 14½ | 14½ |
| **90 000 000** | 16 | 15½ | 15½ | 15½ | 15½ | 15 | 15 | 15 | 15 | 15 |
| **100 000 000** | 16 | 16 | 16 | 15½ | 15½ | 15½ | 15½ | 15½ | 15 | 15 |

# METRIC TABLES

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**TABLE A.1**

**REQUIRED DEPTH ($D_R$) IN mm FOR 75% RELIABILITY (%R)**

| | Modulus Of Subgrade Reaction ($K_G$), MPa/m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
| **100 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **150 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **200 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **250 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **300 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **350 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **400 000** | 151 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **450 000** | 154 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **500 000** | 157 | 151 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **600 000** | 163 | 156 | 151 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **700 000** | 167 | 161 | 156 | 151 | 150 | 150 | 150 | 150 | 150 | 150 |
| **800 000** | 172 | 165 | 160 | 156 | 152 | 150 | 150 | 150 | 150 | 150 |
| **900 000** | 175 | 168 | 163 | 159 | 155 | 152 | 150 | 150 | 150 | 150 |
| **1 000 000** | 178 | 172 | 167 | 163 | 159 | 156 | 152 | 150 | 150 | 150 |
| **1 500 000** | 191 | 185 | 180 | 176 | 173 | 170 | 167 | 164 | 161 | 158 |
| **2 000 000** | 200 | 194 | 190 | 186 | 183 | 180 | 177 | 174 | 172 | 169 |
| **2 500 000** | 208 | 202 | 197 | 194 | 191 | 188 | 185 | 182 | 180 | 178 |
| **3 000 000** | 214 | 208 | 204 | 200 | 197 | 194 | 192 | 189 | 187 | 185 |
| **3 500 000** | 219 | 213 | 209 | 206 | 203 | 200 | 197 | 195 | 193 | 190 |
| **4 000 000** | 224 | 218 | 214 | 210 | 207 | 205 | 202 | 200 | 198 | 196 |
| **4 500 000** | 228 | 222 | 218 | 215 | 212 | 209 | 207 | 204 | 202 | 200 |
| **5 000 000** | 232 | 226 | 222 | 218 | 215 | 213 | 210 | 208 | 206 | 204 |
| **6 000 000** | 238 | 232 | 228 | 225 | 222 | 220 | 217 | 215 | 213 | 211 |
| **7 000 000** | 244 | 238 | 234 | 231 | 228 | 226 | 223 | 221 | 219 | 217 |
| **8 000 000** | 249 | 243 | 239 | 236 | 233 | 231 | 228 | 226 | 224 | 222 |
| **9 000 000** | 253 | 248 | 244 | 240 | 238 | 235 | 233 | 231 | 229 | 227 |
| **10 000 000** | 257 | 252 | 248 | 244 | 242 | 239 | 237 | 235 | 233 | 231 |
| **15 000 000** | 273 | 268 | 264 | 261 | 258 | 255 | 253 | 251 | 249 | 248 |
| **20 000 000** | 285 | 280 | 276 | 273 | 270 | 267 | 265 | 263 | 261 | 260 |
| **25 000 000** | 295 | 289 | 285 | 282 | 279 | 277 | 275 | 273 | 271 | 269 |
| **30 000 000** | 303 | 297 | 293 | 290 | 287 | 285 | 283 | 281 | 279 | 278 |
| **35 000 000** | 310 | 304 | 300 | 297 | 294 | 292 | 290 | 288 | 286 | 285 |
| **40 000 000** | 316 | 310 | 306 | 303 | 301 | 298 | 296 | 294 | 292 | 291 |
| **45 000 000** | 321 | 316 | 312 | 309 | 306 | 304 | 302 | 300 | 298 | 296 |
| **50 000 000** | 325 | 321 | 317 | 314 | 311 | 309 | 307 | 305 | 303 | 301 |
| **60 000 000** | 335 | 329 | 325 | 322 | 320 | 317 | 315 | 313 | 312 | 310 |
| **70 000 000** | 343 | 337 | 333 | 330 | 327 | 325 | 323 | 321 | 319 | 318 |
| **80 000 000** | 349 | 344 | 340 | 337 | 334 | 332 | 330 | 328 | 326 | 324 |
| **90 000 000** | 355 | 350 | 346 | 343 | 340 | 338 | 336 | 334 | 332 | 330 |
| **100 000 000** | 351 | 355 | 351 | 348 | 346 | 343 | 341 | 339 | 338 | 336 |

## TABLE A.2

## REQUIRED DEPTH ($D_R$) IN mm FOR 80% RELIABILITY (%R)

| | Modulus Of Subgrade Reaction ($K_G$), MPa/m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
| **100 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **150 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **200 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **250 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **300 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **350 000** | 151 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **400 000** | 155 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **450 000** | 158 | 151 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **500 000** | 161 | 155 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **600 000** | 167 | 160 | 155 | 151 | 150 | 150 | 150 | 150 | 150 | 150 |
| **700 000** | 172 | 165 | 160 | 155 | 152 | 150 | 150 | 150 | 150 | 150 |
| **800 000** | 176 | 169 | 164 | 160 | 156 | 153 | 150 | 150 | 150 | 150 |
| **900 000** | 179 | 173 | 168 | 164 | 160 | 157 | 153 | 150 | 150 | 150 |
| **1 000 000** | 183 | 176 | 171 | 167 | 164 | 160 | 157 | 154 | 151 | 150 |
| **1 500 000** | 196 | 189 | 185 | 181 | 177 | 174 | 171 | 169 | 166 | 163 |
| **2 000 000** | 205 | 199 | 194 | 191 | 188 | 185 | 182 | 179 | 177 | 174 |
| **2 500 000** | 212 | 206 | 202 | 199 | 195 | 193 | 190 | 187 | 185 | 183 |
| **3 000 000** | 219 | 213 | 208 | 205 | 202 | 199 | 197 | 194 | 192 | 190 |
| **3 500 000** | 224 | 218 | 214 | 210 | 207 | 205 | 202 | 200 | 198 | 196 |
| **4 000 000** | 229 | 223 | 219 | 215 | 212 | 210 | 207 | 205 | 203 | 201 |
| **4 500 000** | 233 | 227 | 223 | 219 | 217 | 214 | 212 | 209 | 207 | 205 |
| **5 000 000** | 235 | 231 | 227 | 223 | 220 | 218 | 215 | 213 | 211 | 209 |
| **6 000 000** | 243 | 237 | 233 | 230 | 227 | 225 | 222 | 220 | 218 | 216 |
| **7 000 000** | 249 | 243 | 239 | 236 | 233 | 231 | 228 | 226 | 224 | 222 |
| **8 000 000** | 254 | 248 | 244 | 241 | 238 | 236 | 233 | 231 | 229 | 228 |
| **9 000 000** | 258 | 253 | 249 | 246 | 243 | 240 | 238 | 236 | 234 | 232 |
| **10 000 000** | 262 | 257 | 253 | 250 | 247 | 245 | 242 | 240 | 238 | 236 |
| **15 000 000** | 279 | 273 | 269 | 266 | 263 | 261 | 259 | 257 | 255 | 253 |
| **20 000 000** | 291 | 285 | 281 | 278 | 276 | 273 | 271 | 269 | 267 | 266 |
| **25 000 000** | 301 | 295 | 291 | 288 | 285 | 283 | 281 | 279 | 277 | 275 |
| **30 000 000** | 309 | 303 | 299 | 296 | 294 | 291 | 289 | 287 | 285 | 284 |
| **35 000 000** | 316 | 310 | 306 | 303 | 301 | 298 | 296 | 294 | 292 | 291 |
| **40 000 000** | 322 | 316 | 313 | 309 | 307 | 304 | 302 | 300 | 299 | 297 |
| **45 000 000** | 328 | 322 | 318 | 315 | 312 | 310 | 308 | 306 | 304 | 303 |
| **50 000 000** | 333 | 327 | 323 | 320 | 317 | 315 | 313 | 311 | 309 | 308 |
| **60 000 000** | 342 | 336 | 332 | 329 | 326 | 324 | 322 | 320 | 318 | 317 |
| **70 000 000** | 349 | 344 | 340 | 337 | 334 | 332 | 330 | 328 | 326 | 324 |
| **80 000 000** | 356 | 351 | 347 | 344 | 341 | 339 | 337 | 335 | 333 | 331 |
| **90 000 000** | 362 | 357 | 353 | 350 | 347 | 345 | 343 | 341 | 339 | 337 |
| **100 000 000** | 368 | 362 | 358 | 355 | 353 | 350 | 348 | 346 | 345 | 343 |

## TABLE A.3

## REQUIRED DEPTH ($D_R$) IN mm FOR 85% RELIABILITY (%R)

| | Modulus Of Subgrade Reaction ($K_G$), MPa/m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
| **100 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **150 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **200 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **250 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **300 000** | 151 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **350 000** | 156 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **400 000** | 160 | 153 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **450 000** | 163 | 156 | 151 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **500 000** | 166 | 159 | 154 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **600 000** | 172 | 165 | 160 | 156 | 152 | 150 | 150 | 150 | 150 | 150 |
| **700 000** | 176 | 170 | 165 | 161 | 157 | 153 | 150 | 150 | 150 | 150 |
| **800 000** | 181 | 174 | 169 | 165 | 161 | 158 | 155 | 152 | 150 | 150 |
| **900 000** | 184 | 178 | 173 | 169 | 165 | 162 | 159 | 156 | 153 | 150 |
| **1 000 000** | 188 | 181 | 176 | 172 | 169 | 166 | 163 | 160 | 157 | 154 |
| **1 500 000** | 201 | 195 | 190 | 186 | 183 | 180 | 177 | 174 | 172 | 169 |
| **2 000 000** | 210 | 204 | 200 | 196 | 193 | 190 | 188 | 185 | 183 | 180 |
| **2 500 000** | 218 | 212 | 208 | 204 | 201 | 198 | 196 | 193 | 191 | 189 |
| **3 000 000** | 224 | 218 | 214 | 211 | 208 | 205 | 202 | 200 | 198 | 196 |
| **3 500 000** | 229 | 224 | 219 | 216 | 213 | 210 | 208 | 206 | 204 | 202 |
| **4 000 000** | 234 | 228 | 224 | 221 | 218 | 215 | 213 | 211 | 209 | 207 |
| **4 500 000** | 238 | 233 | 229 | 225 | 222 | 220 | 217 | 215 | 213 | 211 |
| **5 000 000** | 242 | 237 | 232 | 229 | 226 | 224 | 221 | 219 | 217 | 215 |
| **6 000 000** | 249 | 243 | 239 | 236 | 233 | 231 | 228 | 226 | 224 | 222 |
| **7 000 000** | 255 | 249 | 245 | 242 | 239 | 237 | 234 | 232 | 230 | 229 |
| **8 000 000** | 260 | 254 | 250 | 247 | 244 | 242 | 240 | 238 | 236 | 234 |
| **9 000 000** | 265 | 259 | 255 | 252 | 249 | 247 | 244 | 242 | 240 | 239 |
| **10 000 000** | 269 | 263 | 259 | 256 | 253 | 251 | 249 | 247 | 245 | 243 |
| **15 000 000** | 285 | 280 | 276 | 273 | 270 | 268 | 266 | 264 | 262 | 260 |
| **20 000 000** | 298 | 292 | 288 | 285 | 283 | 280 | 278 | 276 | 274 | 272 |
| **25 000 000** | 308 | 302 | 298 | 295 | 292 | 290 | 288 | 286 | 284 | 283 |
| **30 000 000** | 316 | 310 | 307 | 303 | 301 | 298 | 296 | 294 | 293 | 291 |
| **35 000 000** | 323 | 318 | 314 | 311 | 308 | 306 | 304 | 302 | 300 | 298 |
| **40 000 000** | 329 | 324 | 320 | 317 | 314 | 312 | 310 | 308 | 306 | 305 |
| **45 000 000** | 335 | 330 | 326 | 323 | 320 | 318 | 316 | 314 | 312 | 310 |
| **50 000 000** | 340 | 335 | 331 | 328 | 325 | 323 | 321 | 319 | 317 | 316 |
| **60 000 000** | 349 | 344 | 340 | 337 | 334 | 332 | 330 | 328 | 326 | 325 |
| **70 000 000** | 357 | 352 | 348 | 345 | 342 | 340 | 338 | 336 | 334 | 333 |
| **80 000 000** | 364 | 359 | 355 | 352 | 349 | 347 | 345 | 343 | 341 | 340 |
| **90 000 000** | 371 | 365 | 361 | 358 | 355 | 353 | 351 | 349 | 347 | 346 |
| **100 000 000** | 376 | 371 | 367 | 364 | 361 | 359 | 357 | 355 | 353 | 352 |

## TABLE A.4

## REQUIRED DEPTH ($D_R$) IN mm FOR 90% RELIABILITY (%R)

| | Modulus Of Subgrade Reaction ($K_G$), MPa/m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
| **100 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **150 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **200 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **250 000** | 152 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **300 000** | 157 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **350 000** | 161 | 154 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **400 000** | 165 | 159 | 153 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **450 000** | 169 | 162 | 157 | 153 | 150 | 150 | 150 | 150 | 150 | 150 |
| **500 000** | 172 | 165 | 160 | 156 | 152 | 150 | 150 | 150 | 150 | 150 |
| **600 000** | 178 | 171 | 166 | 162 | 158 | 155 | 152 | 150 | 150 | 150 |
| **700 000** | 183 | 176 | 171 | 167 | 163 | 160 | 157 | 154 | 151 | 150 |
| **800 000** | 187 | 180 | 176 | 172 | 168 | 165 | 162 | 159 | 156 | 153 |
| **900 000** | 191 | 184 | 180 | 176 | 172 | 169 | 166 | 163 | 160 | 157 |
| **1 000 000** | 194 | 188 | 183 | 179 | 176 | 173 | 170 | 167 | 164 | 161 |
| **1 500 000** | 207 | 201 | 197 | 193 | 190 | 187 | 184 | 182 | 179 | 177 |
| **2 000 000** | 217 | 211 | 207 | 203 | 200 | 197 | 195 | 192 | 190 | 188 |
| **2 500 000** | 224 | 219 | 215 | 211 | 208 | 206 | 203 | 201 | 198 | 196 |
| **3 000 000** | 231 | 225 | 221 | 218 | 215 | 212 | 210 | 207 | 205 | 203 |
| **3 500 000** | 236 | 231 | 227 | 223 | 220 | 218 | 215 | 213 | 211 | 209 |
| **4 000 000** | 241 | 236 | 232 | 228 | 225 | 223 | 220 | 218 | 216 | 214 |
| **4 500 000** | 246 | 240 | 236 | 233 | 230 | 227 | 225 | 223 | 221 | 219 |
| **5 000 000** | 250 | 244 | 240 | 237 | 234 | 231 | 229 | 227 | 225 | 223 |
| **6 000 000** | 256 | 251 | 247 | 244 | 241 | 238 | 236 | 234 | 232 | 230 |
| **7 000 000** | 262 | 257 | 253 | 250 | 247 | 244 | 242 | 240 | 238 | 236 |
| **8 000 000** | 268 | 262 | 258 | 255 | 252 | 250 | 248 | 246 | 244 | 242 |
| **9 000 000** | 272 | 267 | 263 | 260 | 257 | 255 | 252 | 250 | 249 | 247 |
| **10 000 000** | 277 | 271 | 267 | 264 | 261 | 259 | 257 | 255 | 253 | 251 |
| **15 000 000** | 294 | 288 | 284 | 281 | 279 | 276 | 274 | 272 | 270 | 269 |
| **20 000 000** | 306 | 301 | 297 | 294 | 291 | 289 | 287 | 285 | 283 | 281 |
| **25 000 000** | 317 | 311 | 307 | 304 | 301 | 299 | 297 | 295 | 293 | 292 |
| **30 000 000** | 325 | 320 | 316 | 313 | 310 | 308 | 306 | 304 | 302 | 300 |
| **35 000 000** | 333 | 327 | 323 | 320 | 317 | 315 | 313 | 311 | 309 | 308 |
| **40 000 000** | 339 | 334 | 330 | 327 | 324 | 322 | 320 | 318 | 316 | 314 |
| **45 000 000** | 345 | 339 | 335 | 332 | 330 | 327 | 325 | 323 | 322 | 320 |
| **50 000 000** | 350 | 345 | 341 | 338 | 335 | 333 | 331 | 329 | 327 | 325 |
| **60 000 000** | 360 | 354 | 350 | 347 | 344 | 342 | 340 | 338 | 336 | 335 |
| **70 000 000** | 368 | 362 | 358 | 355 | 353 | 350 | 348 | 346 | 345 | 343 |
| **80 000 000** | 375 | 369 | 365 | 362 | 360 | 357 | 355 | 354 | 352 | 350 |
| **90 000 000** | 381 | 376 | 372 | 369 | 366 | 364 | 362 | 360 | 358 | 357 |
| **100 000 000** | 387 | 382 | 378 | 375 | 372 | 370 | 368 | 366 | 364 | 362 |

# TABLE A.5

## REQUIRED DEPTH ($D_R$) IN mm FOR 92% RELIABILITY (%R)

| | Modulus Of Subgrade Reaction ($K_G$), MPa/m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
| **100 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **150 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **200 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **250 000** | 155 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **300 000** | 160 | 153 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **350 000** | 164 | 157 | 152 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **400 000** | 168 | 162 | 156 | 152 | 150 | 150 | 150 | 150 | 150 | 150 |
| **450 000** | 172 | 165 | 160 | 156 | 152 | 150 | 150 | 153 | 150 | 150 |
| **500 000** | 175 | 169 | 164 | 159 | 156 | 152 | 150 | 150 | 150 | 150 |
| **600 000** | 181 | 174 | 169 | 165 | 162 | 158 | 155 | 152 | 150 | 150 |
| **700 000** | 186 | 179 | 175 | 170 | 167 | 164 | 160 | 157 | 154 | 152 |
| **800 000** | 190 | 184 | 179 | 175 | 171 | 168 | 165 | 162 | 159 | 157 |
| **900 000** | 194 | 187 | 183 | 179 | 176 | 172 | 169 | 167 | 164 | 161 |
| **1 000 000** | 197 | 191 | 186 | 183 | 179 | 176 | 173 | 170 | 168 | 165 |
| **1 500 000** | 210 | 204 | 200 | 197 | 193 | 191 | 188 | 185 | 183 | 181 |
| **2 000 000** | 220 | 214 | 210 | 207 | 204 | 201 | 198 | 196 | 194 | 192 |
| **2 500 000** | 228 | 222 | 218 | 215 | 212 | 209 | 207 | 204 | 202 | 200 |
| **3 000 000** | 234 | 229 | 225 | 221 | 218 | 216 | 213 | 211 | 209 | 207 |
| **3 500 000** | 240 | 234 | 230 | 227 | 224 | 222 | 219 | 217 | 215 | 213 |
| **4 000 000** | 245 | 239 | 235 | 232 | 229 | 227 | 224 | 222 | 220 | 218 |
| **4 500 000** | 249 | 244 | 240 | 236 | 234 | 231 | 229 | 227 | 225 | 223 |
| **5 000 000** | 253 | 248 | 244 | 240 | 238 | 235 | 233 | 231 | 229 | 227 |
| **6 000 000** | 260 | 255 | 251 | 248 | 245 | 242 | 240 | 238 | 236 | 234 |
| **7 000 000** | 266 | 261 | 257 | 254 | 251 | 248 | 246 | 244 | 242 | 240 |
| **8 000 000** | 272 | 266 | 262 | 259 | 256 | 254 | 252 | 250 | 248 | 246 |
| **9 000 000** | 276 | 271 | 267 | 264 | 261 | 259 | 257 | 255 | 253 | 251 |
| **10 000 000** | 281 | 275 | 271 | 268 | 265 | 263 | 261 | 259 | 257 | 255 |
| **15 000 000** | 298 | 293 | 289 | 286 | 283 | 281 | 278 | 276 | 275 | 273 |
| **20 000 000** | 311 | 305 | 302 | 298 | 296 | 293 | 291 | 289 | 288 | 286 |
| **25 000 000** | 321 | 316 | 312 | 309 | 306 | 304 | 302 | 300 | 298 | 296 |
| **30 000 000** | 330 | 324 | 320 | 317 | 315 | 312 | 310 | 308 | 307 | 305 |
| **35 000 000** | 337 | 332 | 328 | 325 | 322 | 320 | 318 | 316 | 314 | 313 |
| **40 000 000** | 344 | 338 | 335 | 331 | 329 | 327 | 324 | 323 | 321 | 319 |
| **45 000 000** | 350 | 344 | 340 | 337 | 335 | 332 | 330 | 329 | 327 | 325 |
| **50 000 000** | 355 | 350 | 346 | 343 | 340 | 338 | 336 | 334 | 332 | 331 |
| **60 000 000** | 365 | 359 | 355 | 352 | 350 | 347 | 345 | 343 | 342 | 340 |
| **70 000 000** | 373 | 367 | 364 | 360 | 358 | 356 | 354 | 352 | 350 | 348 |
| **80 000 000** | 380 | 375 | 371 | 368 | 365 | 363 | 361 | 359 | 357 | 356 |
| **90 000 000** | 387 | 381 | 377 | 374 | 372 | 369 | 367 | 365 | 364 | 362 |
| **100 000 000** | 393 | 387 | 383 | 380 | 378 | 375 | 373 | 371 | 370 | 368 |

# TABLE A.6

## REQUIRED DEPTH ($D_R$) IN mm FOR 94% RELIABILITY (%R)

| | Modulus Of Subgrade Reaction ($K_G$), MPa/m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
| **100 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **150 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **200 000** | 154 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **250 000** | 160 | 153 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **300 000** | 166 | 159 | 154 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **350 000** | 170 | 163 | 158 | 154 | 150 | 150 | 150 | 150 | 150 | 150 |
| **400 000** | 174 | 168 | 163 | 158 | 155 | 151 | 150 | 150 | 150 | 150 |
| **450 000** | 178 | 171 | 166 | 162 | 159 | 155 | 152 | 150 | 150 | 150 |
| **500 000** | 181 | 175 | 170 | 166 | 162 | 159 | 155 | 152 | 150 | 150 |
| **600 000** | 187 | 181 | 176 | 172 | 168 | 165 | 162 | 159 | 155 | 153 |
| **700 000** | 192 | 186 | 181 | 177 | 174 | 170 | 167 | 164 | 162 | 159 |
| **800 000** | 196 | 190 | 185 | 182 | 178 | 175 | 172 | 169 | 167 | 164 |
| **900 000** | 200 | 194 | 189 | 186 | 182 | 179 | 175 | 174 | 171 | 169 |
| **1 000 000** | 203 | 197 | 193 | 189 | 186 | 183 | 180 | 178 | 175 | 173 |
| **1 500 000** | 217 | 211 | 207 | 203 | 200 | 198 | 195 | 193 | 190 | 188 |
| **2 000 000** | 227 | 221 | 217 | 214 | 211 | 208 | 206 | 203 | 201 | 199 |
| **2 500 000** | 235 | 229 | 225 | 222 | 219 | 216 | 214 | 212 | 210 | 208 |
| **3 000 000** | 241 | 236 | 232 | 228 | 226 | 223 | 221 | 219 | 216 | 215 |
| **3 500 000** | 247 | 242 | 238 | 234 | 231 | 229 | 227 | 224 | 222 | 221 |
| **4 000 000** | 252 | 247 | 243 | 239 | 237 | 234 | 232 | 230 | 228 | 226 |
| **4 500 000** | 257 | 251 | 247 | 244 | 241 | 239 | 236 | 234 | 232 | 230 |
| **5 000 000** | 261 | 255 | 251 | 248 | 245 | 243 | 241 | 238 | 237 | 235 |
| **6 000 000** | 268 | 262 | 258 | 255 | 253 | 250 | 248 | 246 | 244 | 242 |
| **7 000 000** | 274 | 269 | 265 | 261 | 259 | 256 | 254 | 252 | 250 | 249 |
| **8 000 000** | 280 | 274 | 270 | 267 | 264 | 262 | 260 | 258 | 256 | 254 |
| **9 000 000** | 285 | 279 | 275 | 272 | 269 | 267 | 265 | 263 | 261 | 259 |
| **10 000 000** | 289 | 283 | 280 | 276 | 274 | 271 | 269 | 267 | 265 | 264 |
| **15 000 000** | 307 | 301 | 297 | 294 | 292 | 289 | 387 | 285 | 283 | 282 |
| **20 000 000** | 320 | 314 | 310 | 307 | 305 | 302 | 300 | 298 | 297 | 295 |
| **25 000 000** | 330 | 325 | 321 | 318 | 315 | 313 | 311 | 309 | 307 | 306 |
| **30 000 000** | 339 | 334 | 330 | 327 | 324 | 322 | 320 | 318 | 316 | 315 |
| **35 000 000** | 347 | 341 | 338 | 334 | 332 | 330 | 328 | 325 | 324 | 322 |
| **40 000 000** | 354 | 348 | 344 | 341 | 339 | 336 | 334 | 332 | 331 | 329 |
| **45 000 000** | 360 | 354 | 350 | 347 | 345 | 342 | 340 | 339 | 337 | 335 |
| **50 000 000** | 365 | 360 | 356 | 353 | 350 | 348 | 346 | 344 | 342 | 341 |
| **60 000 000** | 375 | 370 | 366 | 363 | 360 | 358 | 356 | 354 | 352 | 350 |
| **70 000 000** | 384 | 378 | 374 | 371 | 368 | 366 | 364 | 362 | 361 | 359 |
| **80 000 000** | 391 | 385 | 382 | 378 | 376 | 374 | 372 | 370 | 368 | 366 |
| **90 000 000** | 398 | 392 | 388 | 385 | 383 | 380 | 378 | 376 | 375 | 373 |
| **100 000 000** | 404 | 398 | 394 | 391 | 389 | 386 | 384 | 382 | 381 | 379 |

# TABLE A.7

## REQUIRED DEPTH ($D_R$) IN mm FOR 95% RELIABILITY (%R)

| | Modulus Of Subgrade Reaction ($K_G$), MPa/m | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$ESAL_D$** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
| **100 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **150 000** | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **200 000** | 154 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **250 000** | 160 | 153 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **300 000** | 166 | 159 | 154 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| **350 000** | 170 | 163 | 158 | 154 | 150 | 150 | 150 | 150 | 150 | 150 |
| **400 000** | 174 | 168 | 163 | 158 | 155 | 151 | 150 | 150 | 150 | 150 |
| **450 000** | 178 | 171 | 166 | 162 | 158 | 156 | 152 | 150 | 150 | 150 |
| **500 000** | 181 | 175 | 170 | 166 | 162 | 159 | 155 | 152 | 150 | 150 |
| **600 000** | 187 | 181 | 176 | 172 | 168 | 165 | 162 | 159 | 156 | 153 |
| **700 000** | 192 | 186 | 181 | 177 | 174 | 170 | 167 | 164 | 162 | 159 |
| **800 000** | 195 | 190 | 185 | 182 | 178 | 175 | 172 | 169 | 167 | 164 |
| **900 000** | 200 | 194 | 189 | 186 | 182 | 179 | 176 | 174 | 171 | 168 |
| **1 000 000** | 203 | 197 | 193 | 189 | 186 | 183 | 180 | 178 | 175 | 173 |
| **1 500 000** | 217 | 211 | 207 | 203 | 200 | 197 | 195 | 192 | 190 | 188 |
| **2 000 000** | 227 | 221 | 217 | 214 | 211 | 208 | 205 | 203 | 201 | 199 |
| **2 500 000** | 235 | 229 | 225 | 222 | 219 | 216 | 214 | 212 | 209 | 207 |
| **3 000 000** | 241 | 236 | 232 | 228 | 226 | 223 | 221 | 218 | 216 | 214 |
| **3 500 000** | 247 | 241 | 237 | 234 | 231 | 229 | 227 | 224 | 222 | 220 |
| **4 000 000** | 252 | 247 | 243 | 239 | 236 | 234 | 232 | 230 | 228 | 226 |
| **4 500 000** | 257 | 251 | 247 | 244 | 241 | 239 | 236 | 234 | 232 | 230 |
| **5 000 000** | 261 | 255 | 251 | 248 | 245 | 243 | 240 | 238 | 236 | 235 |
| **6 000 000** | 268 | 262 | 258 | 255 | 252 | 250 | 248 | 246 | 244 | 242 |
| **7 000 000** | 274 | 269 | 265 | 261 | 259 | 256 | 254 | 252 | 250 | 248 |
| **8 000 000** | 280 | 274 | 270 | 267 | 264 | 262 | 260 | 258 | 256 | 254 |
| **9 000 000** | 284 | 279 | 276 | 272 | 269 | 267 | 265 | 263 | 261 | 259 |
| **10 000 000** | 289 | 283 | 280 | 276 | 274 | 271 | 269 | 267 | 265 | 264 |
| **15 000 000** | 307 | 301 | 297 | 294 | 291 | 289 | 287 | 285 | 283 | 282 |
| **20 000 000** | 320 | 314 | 310 | 307 | 305 | 302 | 300 | 298 | 297 | 295 |
| **25 000 000** | 330 | 325 | 321 | 318 | 315 | 313 | 311 | 309 | 307 | 306 |
| **30 000 000** | 339 | 334 | 330 | 327 | 324 | 322 | 320 | 318 | 316 | 314 |
| **35 000 000** | 347 | 341 | 338 | 334 | 332 | 330 | 327 | 326 | 324 | 322 |
| **40 000 000** | 354 | 348 | 344 | 341 | 339 | 336 | 334 | 332 | 331 | 329 |
| **45 000 000** | 360 | 354 | 350 | 347 | 345 | 342 | 340 | 338 | 337 | 335 |
| **50 000 000** | 365 | 360 | 356 | 353 | 350 | 348 | 346 | 344 | 342 | 341 |
| **60 000 000** | 375 | 370 | 366 | 363 | 360 | 358 | 356 | 354 | 352 | 350 |
| **70 000 000** | 384 | 378 | 374 | 371 | 368 | 366 | 364 | 362 | 360 | 359 |
| **80 000 000** | 391 | 385 | 382 | 378 | 376 | 374 | 372 | 370 | 368 | 366 |
| **90 000 000** | 398 | 392 | 388 | 385 | 383 | 380 | 378 | 376 | 375 | 373 |
| **100 000 000** | 404 | 398 | 394 | 391 | 389 | 386 | 384 | 382 | 381 | 379 |

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# APPENDIX B

# RIGID PAVEMENT DESIGN QUALITY CONTROL PLAN

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## B.1 QUALITY CONTROL PLAN

All rigid 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 to 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 RIGID PAVEMENT DESIGNS

Pavement designs will be developed in accordance with the Rigid Pavement Design Manual (Document No. 625-010-006). 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 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

  - Modulus Of Subgrade Reaction ($K_G$).
  - Material properties used if different than those in the design manual.

  Concrete Pavement Rehabilitation (CPR) And Lane Widening

  - Existing pavement layer information (layer types, thickness, and condition).
  - A copy of the Pavement Coring and Evaluation Report.
  - Drainage recommendations.

- The $ESAL_D$ calculations are normally signed and certified by the Planning Office. The basis for the input data used for these calculations must be stated.

- Required Depth ($D_R$) calculations.

- Documentation addressing any special features such as cross slope, coordination with adjacent projects, stage construction, drainage considerations, etc.

- Sketch of a possible construction sequence, including any widening and shoulders, to insure constructability in accordance with the standards.

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

- Joint Design Details showing Plan View in areas where geometric changes occur (i.e. intersections, ramps, etc.)

### B.4.2 DISTRIBUTION

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

For Federal Aid Projects not exempt from FHWA oversight, 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 intersection improvement, short roadway connectors on bridge replacement projects, and roadway widening projects, the Modulus Of Subgrade Reaction ($K_G$), 18-kip (80-kN) Equivalent Single Axle Loads ($ESAL_D$), and computation of Required Depth ($D_R$) 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

Every attempt should be made to follow written procedures. Situations will occur where following the pavement design procedure will result in a Required Depth ($D_R$) that cannot be met. This could occur when a design is required in a widening area.

The Pavement Design Engineer will have to exercise engineering judgment on what should be done in these cases. When this occurs, the Pavement Design Engineer is advised to document the project, make special note of the problem, and provide additional explanation as to how the recommended design was developed.

Consultation with other engineers (Construction, Drainage, Materials, etc.) is highly recommended and should be noted in the design file.

## B.5 DISTRICT QUALITY CONTROL

The quality control process will include three activities:

- The checking and review of pavement designs for compliance with policies, procedures, standards, guidelines and good engineering practice.

- The checking and review of plans to insure that the approved pavement designs are correctly incorporated.

- Documentation of the Quality Control Process. An independent qualified Professional Engineer will carry out the Quality Control Process. 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 Financial Item 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.

**RIGID PAVEMENT DESIGN**
**QUALITY CONTROL CHECKLIST**

FP ID No. ____________________ County ___________________

Satisfactory
Rigid Pavement Design Review Yes/No

Rigid Pavement Design Summary Sheet . . . . . . . . . ____

Project Location and Description. . . . . . . . . . . ____

Traffic Data and $ESAL_D$ Calculations . . . . . . . . . ____

Modulus Of Subgrade Reaction ($K_G$) . . . . . . . . . . ____

Required Depth ($D_R$) Calculations . . . . . . . . . . ____

Drainage 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 . . . . . . . . . . . . . . . . . ____

Projects That Do Not Require Design Calculations

Existing Pavement Evaluation. . . . . . . . . . . . . ____

Structural Evaluation . . . . . . . . . . . . . . . . ____

Plans Review

Plans Conform to Pavement Design (Dimensions, etc.)_____

Design Details Adequately Covered . . . . . . . . . ._____

Standard Indexes Properly Referenced . . . . . . . ._____

Constructable with the Current Technology . . . . ._____

Comments

QA by ____________________ Date ____________________

**FLORIDA DEPARTMENT OF TRANSPORTATION**
**RIGID PAVEMENT DESIGN SUMMARY SHEET**

| | |
|---|---|
| Prepared by ________________ | Date Prep.______________ |
| FP ID # ______________________ | US # ______ SR #______ |
| From ______________ | To ___________________ |
| County _____________________ | Begin MP ______________ |
| Project Length _____________ | End MP _______________ |
| Type Of Work _______________ | %R ____________________ |
| Opening Year _______________ | $K_G$ ____________________ |
| Design Year ________________ | Design Speed __________ |
| $ESAL_D$ _____________________ | Design Seq. # ________ |
| $D_R$ __________________________ | Proj. Name ___________ |

Existing Pavement

Proposed Design

| | | |
|---|---|---|
| Approved By | Concurrence By | Concurrence By |
| Responsible Eng. | Dist. Des. Eng. | FHWA-If Needed |
| Date ____________ | Date ____________ | Date _________ |

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# APPENDIX C

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

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## C.1 BACKGROUND

One of the products of the AASHO (American Association Of State Highway Officials) Road Test conducted near Ottawa, Illinois from 1958 to 1960 was a method for relating the relative damage caused by different axle loadings. This evolved into a procedure that permitted the calculation of the accumulated damage caused by mixed vehicle loadings over a pavement design period. The four tire, single axle, carrying 18 000 lbs (18-kip)(80 000 Newton (80 kN)) Equivalent Single Axle Load or $ESAL_D$ was accepted as the base for these calculations. Table C.1 illustrates the relationship of axle weight to damage.

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

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

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

**TABLE C.1**

**RELATIONSHIP OF AXLE WEIGHT TO DAMAGE**
**(D=12", $P_t$=2.5)**

| | Total Axle Load in kip (kN) | Equivalent Damage in ESAL's |
|---|---|---|
| Single Axle | 14(62) | 0.34 |
| | 18(**80)** | **1.00** |
| | 22(98) | 2.41 |
| Tandem Axle | 30(133) | 1.14 |
| | 34(151) | 1.97 |
| | 38(169) | 3.18 |
| | 44(196) | 6.01 |

## C.2 BASIC EQUATION

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

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

where:

$ESAL_D$ = Number of accumulated 18-kip(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, the entire variable 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 C.2.

$E_{18}$ = Equivalency factor which is the damage caused by one average heavy truck measured in 18-kip(80-kilonewtons) Equivalent Single Axle Loads.  These factors will be periodically updated based on Weigh-In-Motion (WIM) data. $E_{18}$ values can be determined from Table C.3 or the latest Planning guidance.

**TABLE C.2**

**LANE FACTORS ($L_F$) FOR DIFFERENT TYPES OF FACILITIES**

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

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

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

where:

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

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

Ln = Natural Logarithm.

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

**TABLE C.3**

**EQUIVALENCY FACTORS $E_{18}(E_{80})$ 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 |

## C.3 SAMPLE PROBLEMS

Several sample problems have been provided that illustrate this process.

### C.3.1 SAMPLE PROBLEM #1

The District Planning Engineer has provided the following information about a high volume, urban, arterial, four lanes divided two way project that will open in the year 2005. The Pavement Type Selection Process indicates that the best alternative is rigid 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 = 12 000
2025 Estimated AADT = 34 000

DATA:

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

$D_F$ = 0.50 (for two way traffic)
$E_{18}$ = 1.22 (from Table C.3)

$L_F$ = 0.85 for AADT = 12 000 (from Table C.2)
$L_F$ = 0.82 for AADT = 16 000 (from Table C.2)
$L_F$ = 0.81 for AADT = 20 000 (from Table C.2)
$L_F$ = 0.77 for AADT = 30 000 (from Table C.2)
$L_F$ = 0.75 for AADT = 40 000 (from Table C.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.

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

$$ESAL_D = \sum_{y=2005}^{y=2013} (AADT \times 0.12 \times 0.50 \times L_F \times 1.22 \times 365)$$

For the year 2014 to 2025.

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

$$ESAL_D = \sum_{y=2014}^{y=2025} (AADT \times 0.08 \times 0.50 \times L_F \times 1.22 \times 365)$$

Calculating:

| Year | AADT | $L_F$ | Annual ESAL* | Accumulated ESAL |
|---|---|---|---|---|
| 2005 | 12 000 | 0.85 | 272 524 | 272 524 |
| 2006 | 12 500 | 0.84 | 280 539 | 553 063 |
| 2007 | 13 000 | 0.84 | 291 761 | 884 824 |
| 2008 | 13 500 | 0.84 | 302 982 | 1 147 806 |
| 2009 | 14 000 | 0.83 | 310 463 | 1 458 269 |
| 2010 | 14 500 | 0.83 | 321 551 | 1 779 820 |
| 2011 | 15 000 | 0.83 | 332 639 | 2 112 459 |
| 2012 | 15 500 | 0.82 | 339 586 | 2 452 045 |
| 2013 | 16 000 | 0.82 | 350 540 | 2 802 585 |
| 2014 | 12 000 | 0.85 | 181 682 | 2 984 267 |
| 2015 | 14 000 | 0.84 | 209 469 | 3 193 736 |
| 2016 | 16 000 | 0.82 | 233 693 | 3 427 429 |
| 2017 | 18 000 | 0.81 | 259 699 | 3 687 128 |
| 2018 | 20 000 | 0.81 | 288 554 | 3 975 682 |
| 2019 | 22 000 | 0.80 | 313 491 | 4 289 173 |

| | | | | |
|---|---|---|---|---|
| 2020 | 24 000 | 0.79 | 337 716 | 4 626 889 |
| 2021 | 26 000 | 0.78 | 361 227 | 4 988 116 |
| 2022 | 28 000 | 0.78 | 389 014 | 5 377 130 |
| 2023 | 30 000 | 0.77 | 411 457 | 5 788 587 |
| 2024 | 32 000 | 0.77 | 438 888 | 6 227 475 |
| 2025 | 34 000 | 0.76 | 460 262 | 6 687 737 |

* Values are rounded for simplicity.

CONCLUSION:

Note that the 20 year accumulated value ($ESAL_D$) is 6, 227,475 ESALs or 7,000,000 ESALs.

## C.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 rigid pavement.

GIVEN:

The following input is provided.

$T_{24}$ = 10%
1990 Estimated AADT = 8 000
2010 Estimated AADT = 18 000

DATA:

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

$D_F$ = 0.50 (for two way traffic)
$E_{18}$ = 1.35 (from Table C.3)

$L_F$ = 0.88 for AADT = 8 000 (from Table C.2)
$L_F$ = 0.85 for AADT = 12 000 (from Table C.2)
$L_F$ = 0.82 for AADT = 16 000 (from Table C.2)
$L_F$ = 0.81 for AADT = 20 000 (from Table C.2)

FIND:

The $ESAL_D$ for a 20 year design period beginning in 1990.

SOLUTION:

Using the following equation:

For the year 1990 to 2010.

$$ESAL_D = \sum_{y=1990}^{y=2010} (AADT \times T_{24} \times D_F \times L_F \times E_{18} \times 365)$$

$$ESAL_D = \sum_{y=1990}^{y=2010} (AADT \times 0.10 \times 0.50 \times L_F \times 1.35 \times 365)$$

Calculating:

| Year | AADT | $L_F$ | Annual ESAL* | Accumulated ESAL |
|---|---|---|---|---|
| 1990 | 8 000 | 0.88 | 173 448 | 173 448 |
| 1991 | 8 500 | 0.87 | 182 194 | 355 642 |
| 1992 | 9 000 | 0.87 | 192 912 | 548 554 |
| 1993 | 9 500 | 0.86 | 201 288 | 749 842 |
| 1994 | 10 000 | 0.86 | 211 883 | 961 725 |
| 1995 | 10 500 | 0.86 | 222 477 | 1 184 202 |
| 1996 | 11 000 | 0.85 | 230 361 | 1 414 563 |
| 1997 | 11 500 | 0.85 | 240 832 | 1 655 395 |
| 1998 | 12 000 | 0.85 | 251 303 | 1 906 698 |
| 1999 | 12 500 | 0.84 | 258 694 | 2 165 392 |
| 2000 | 13 000 | 0.84 | 269 042 | 2 434 434 |
| 2001 | 13 500 | 0.84 | 279 389 | 2 713 823 |
| 2002 | 14 000 | 0.83 | 286 288 | 3 000 111 |
| 2003 | 14 500 | 0.83 | 296 512 | 3 296 623 |
| 2004 | 15 000 | 0.83 | 306 737 | 3 603 360 |
| 2005 | 15 500 | 0.82 | 313 143 | 3 916 503 |
| 2006 | 16 000 | 0.82 | 323 244 | 4 239 747 |
| 2007 | 16 500 | 0.82 | 333 345 | 4 573 092 |
| 2008 | 17 000 | 0.82 | 343 447 | 4 916 539 |
| 2009 | 17 500 | 0.81 | 349 237 | 5 265 776 |
| 2010 | 18 000 | 0.81 | 359 215 | 5 624 991 |

* Values are rounded for simplicity.

CONCLUSION:

Note that the 20 year (2009) accumulated value is 5,265,776 ESALs (rounding $ESAL_D$ = 6,000,000).

If the project design period delayed one year and the design period reduced to 19 years, the new $ESAL_D$ would be:

5,624,991 - 173,448 = 5,451,543 ESALs
(Rounding $ESAL_D$ = 6,000,000).

# APPENDIX D

## RIGID PAVEMENT DESIGN ANALYSIS COMPUTER PROGRAM

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

# APPENDIX E

## RELATIONSHIP BETWEEN RESILIENT MODULUS(Mr) AND LIMEROCK BEARING RATIO(LBR)

5-19-93
wlp

**FLORIDA** **DEPARTMENT OF TRANSPORTATIO**

LAWTON CHILES
GOVERNOR

BEN G. WATTS
SECRETARY

State Materials Office
Post Office Box 1029
Gainesville, Florida 32602

(904) 372-5304

**M E M O R A N D U M**

DATE: February 2, 1993

TO: Mr. W. N. Lofroos, State Pavement Design Engineer

FROM: Robert Ho, Soils Materials Engineer

COPIES TO: L. L. Smith

SUBJECT: Office of Inspector General Audit - September 21, 1992

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

1) Relationship between SSV & LBR

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

a) Embankment Soil (silty clay)

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

b) Sand Gravel Subbase

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

c) Crushed Limestone Base

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

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

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

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

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

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

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

| SSV | LBR |
|---|---|
| 3 | 7 |
| 10 | 100 |

This yields equation

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

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

| SSV | LBR |
|---|---|
| 4 | 5 |
| 10 | 200 |

This yields equation

SSV = 3.748 log(LBR) + 1.377.........(3)

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

SSV = 5 log(LBR)...............(4)

The present FDOT Flexible Pavement design manual has the following relationship

SSV = 3.325 log(LBR) + 0.672 .........(5)

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

3) Soil Strength Test Frequency

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

Witczak (1975) recommended that the 90th percentile value of the test results would give the optimum design. This means that 90% of the test results will be equal to or greater than the design LBR value which is then used to obtain SSV from SSV vs log(LBR) relationship. P. 33

4) LBR Test Method

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

a) Samples are compacted to AASHTO T-180 density in 6-inch molds.

b) Samples are soaked two days instead of four.

c) Standard limerock value is taken as 800 psi instead of 1000 psi for the CBR test at 0.1 inch penetration of the piston.

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

5) Modulus of Subgrade reaction, k

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

$$k = p/y$$

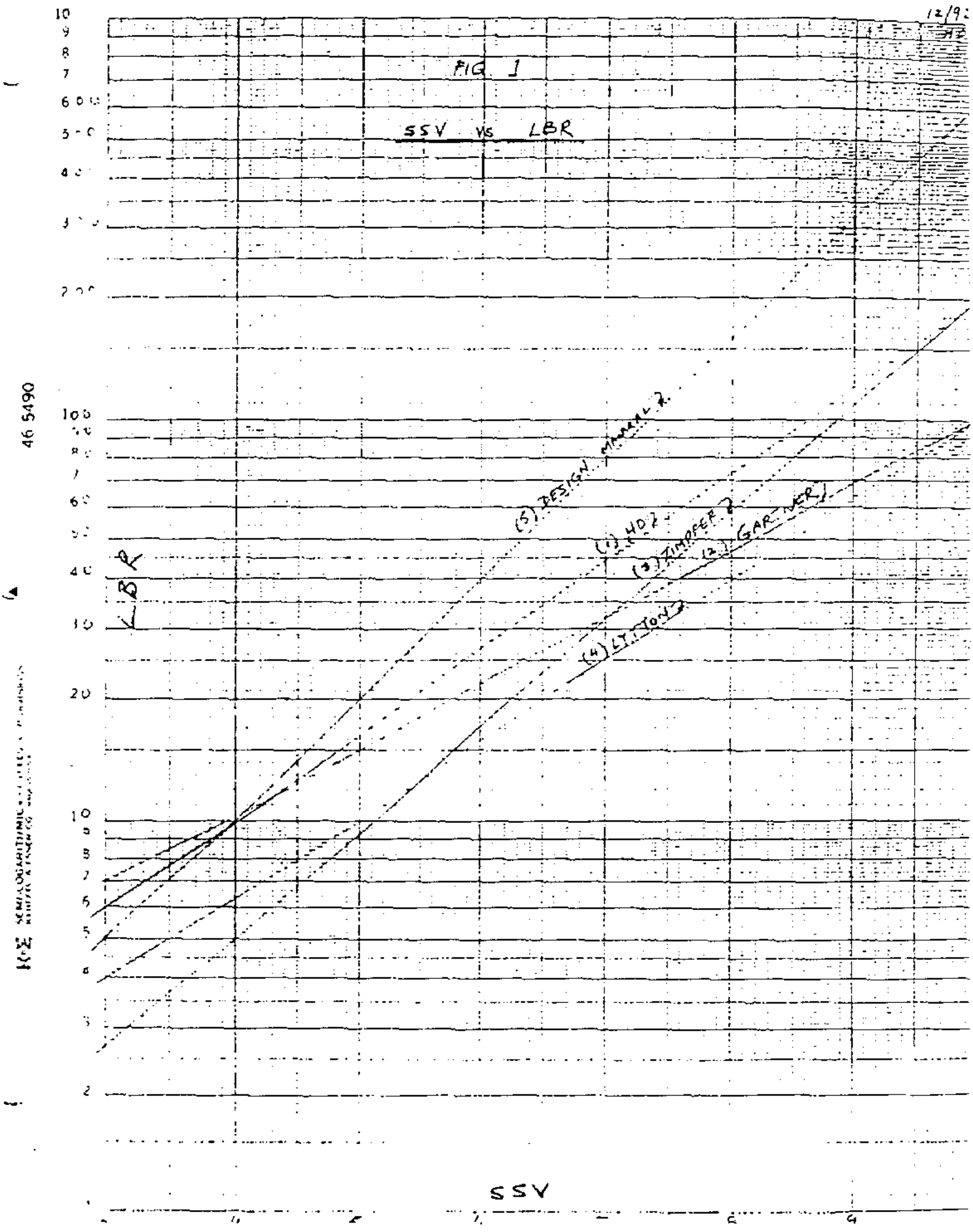
TO: W. N. Lofroos
FROM: Robert Ho
February 2, 1993
Page 5

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

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

RH:jg

Attachments



12/93
FIG 1
SSV vs LBR
(5) DESIGN MANUAL?
(1) HDZ?
(3) ZIMPFER?
(2) GARNER
(4) LITTON?
LBR
SSV
46 5490
K&E SEMI-LOGARITHMIC

TABLE 7.4. Characteristics Pertinent to Road and Runway Foundation*

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

A-3