PAVEMENT DESIGN MANUAL

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DEPARTMENT OF TRANSPORTATION
HIGHWAYS DIVISION
MATERIALS TESTING AND RESEARCH BRANCH
SOILS ENGINEERING AND PAVEMENT DESIGN SECTION
2530 Likelike Highway
Honolulu, Highway 96819

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CHAPTER 1

DESIGN REQUIREMENTS

1.1 DESIGN VARIABLES

1.1.1 Design Period

This section involves the selection of the design period inputs which determines the structural life of the pavement based on the anticipated traffic loads. This normally determines the thickness of different structural layers used in the pavement design based on the structural properties.

The design period chosen for design of the structural section of a pavement is generally dependent on the classification of the route under consideration. The pavement structural section generally are to be designed to the following:

Highway Conditions	Design Period (years)
High Volume Urban and Tunnels	50
Medium Volume Urban	30
High Volume Rural	30
Medium Volume Rural	20
Low Volume Paved	20

The design period is based on the ADT at the end of the design life.

The material life also affect the life and performance of the pavement and is dependent on the materials used in the pavement design. Material life also involves aging, and wearing effects due to weather conditions, other environmental, other traffic conditions affecting the material performance not directly related to the structural performance. This can include but not limited to asphalt aging, AC raveling, AC rutting, and PCC pavement texture. Material life is considered in the life-cycle cost analysis.

Design period only considers the structural life of the pavement and not the material life.

1.1.2 Traffic

1.1.2.1 General

The design procedures for both highways and low-volume roads are all based on cumulative expected 18-kip equivalent single axle loads (ESAL) during the design life. The procedure for converting mixed traffic into ESALs includes:

a. derivation of load equivalence factors,
b. conversion of mixed traffic to 18-kip equivalent single axle load (ESAL) applications,
c. directional or lane distribution considerations, and
d. determination of the truck traffic volume throughout the design period

1.1.2.2 Load Equivalence Factor

To express varying axle loads in terms of a single design parameter, it is necessary to develop axle load equivalence factors. These factors, when multiplied by the number of axle loads within a given weight category, give the number of 18-kip single axle load applications which will have an equivalent effect on the performance of the pavement structures. The load equivalence factors is base on the following equation:

$$LEF = \left\{\frac{AL}{18{,}000}\right\}^{4.2} \qquad Eq\ 1.1$$

where:

LEF = load equivalancy factor
AL = axle load (lbs)

1.1.2.3 Conversion of Mixed Traffic to ESALs Applications.

The data in the Truck Weight Study, done in cooperation with the FHWA, is used to develop a statistical representation of the magnitude of axle loadings on the 5 axle configurations (2, 3, 4, 5, and 6 or more) which are identified in the Classified Truck Counts. This information is used to develop ESAL constants that represent the estimated total accumulated ESAL per truck for each of the 5 axle configurations, during a 1-year period.

The current one-direction 1-year ESAL Constants (ESALC) using data from 1972, 1973, 1974, and 1975 are as follows:

Vehicle Type	ESALC
2-axle trucks	65
3-axle trucks	525
4-axle trucks	1162
5-axle trucks	1462
6-axle or more	968

1.1.2.4 Directional and Lane Distribution Considerations

If the number of equivalent axle loads represents the total for all lanes and both directions of travel, this number must be distributed by direction. The Directional distribution is usually made by assigning 50 percent of the traffic to each direction, unless special considerations (such as more loaded trucks moving in one direction and more empty trucks in the other) warrant some other distribution.

For multi-lane facilities design lane factors is used to consider the distribution of traffic in several lanes of traffic. For design purposes these factors are as follows:

Number of Lanes in One Direction	Design Lane Factor
1	1.00
2	1.00
3	0.80
4	0.75

1.1.2.5 Determination of Truck Traffic Volume for the Design Life

The various levels of traffic volume is defined as follows:

Traffic Level	Volume
High	>10,000 ADT
Medium	3,000-10,000 ADT
Low	< 3,000 ADT

The above volumes are compared with the design lane traffic. Primary concern is the frequency by the types of trucks in terms of its axle configuration and weight class that the pavement is anticipated to encounter throughout its design period. The annual average daily truck traffic (ADTT) for the various weight class and axle configurations for the design period is developed from classification counts made at various stations throughout the state highway system in the vehicle classification program and from prediction models which are conducted by the Highway Planning Branch.

1.2 MATERIAL PROPERTIES FOR STRUCTURAL DESIGN

1.2.1 Roadbed Soil

1.2.1.1 Flexible Pavement

For flexible pavement the resistance value (R-value) is used for structural design. The R-value is a parameter representing the resistance to deformation of a saturated soil under compression at a given density. The R-value is measured with the Hveem Stabilometer, and is used in the design of flexible and rigid pavements. It is an indication of the ability of the soil to carry the dead load of the structural section and the superimposed traffic live load.

Almost all compacted soils have a tendency to expand when given access to water. As soils expand and take on water, the load supporting ability decreases, as indicated in the laboratory tests by a decreasing R-value. Thus, a prescribed expansion pressure apparatus is used to adjust the basement soil R-value as needed for both flexible and rigid pavements.

The amount of expansion created by increased moisture content and the consequent loss of density is limited by the overlying dead load of the structural section materials placed over the soil. When the loading pressure of the overlying material and the expansive forces within the soil become equal, the expansion is halted and no further loss of R-value occurs. Then the soil is in the most unstable state it will reach with the given dead load pressure of the overlying structural section layers. Under these conditions, the structural section design thickness and strength must not only be sufficient to protect the soil in question from differential deformation or displacement from the traffic live loads, but the thickness or cover must apply adequate dead load pressure to prevent further expansion which would result in decreased stability.

If the soil is identified as potentially expansive, special design and construction considerations should be given. Design alternatives which have been used to compensate for expansive soils are:

a. Replacing the expansive material with a non-expansive material to a depth below which the seasonal moisture content will remain nearly constant, or
b. Providing of an overlaying structural section of sufficient thickness to counteract the expansion pressure by dead-load pressure (surcharging), or
c. Using two-stage construction by placing a thin structural section to permit the underlying material to expand and stabilize before placing leveling and surface courses, or
d. Stabilizing the moisture content by minimizing the access of water through surface and subsurface drainage and the use of a waterproof membrane (i.e., geotextile fabrics or rubberized asphalt membrane), or
e. Relocating the project alignment to a more favorable soil condition.

Treatments (a), (b), and (c) should be used with caution since undesirable soil expansion may occur. Treatment (d) is considered to be the most effective approach if relocation is not feasible.

If the soil is non-expansive, the R-value for design is based on the presumption that the soil will become saturated at some time during its service life. This procedure indicates the lowest strength condition that will most likely occur during this period. The use of positive subgrade and structural section drainage systems will minimize the duration of a saturated lowest-strength condition.

If the basement soil is relatively impermeable, a positive structural section drainage system, as covered under Chapter 2 will serve to minimize water-related structural section damage.

The R-value used in the design are to be from laboratory testing on subgrade soils sampled from the project site. The soil samples for R-value testing are representative of the types of soils found at the project site. The R-value by exudation is determined for an exudation pressure of 300 psi. A map of the locations where the soils were sampled will indicate where soil sampling were done.

1.2.1.2 Rigid Pavement

For rigid pavements, the support that the roadbed soil gives to the concrete pavement is defined in terms of the Westergaard modulus of subgrade reaction (k). It is equal to the load in pounds per square inch on a loaded area (a 30-inch diameter plate) divided by the deflection in inches for the load.

Since the plate-loading test is time consuming and expensive, the k-value is usually estimated by correlation to simpler tests such as the R-value test. The result is valid because exact determination of the k-value is not required. Normal variations from an estimated value will not appreciably affect pavement thickness requirements. A correlation chart is provided in Figure 1-1.

1.2.1.3 Converting CBR Test Results to R-value

This provisions allow for design R-value of non-expansive soils to be obtained using the laboratory California Bearing Ratio tests reults of AASHTO T 193, ASTM D 1883 or MilStd 621A.

Method one uses AASHTO's correlation chart Figure FF.6 of AASHTO Guide for Design of Pavement Structures, Volume 2, dated August 1986. This correlation is applicable with the CBR design curves developed by Kentucky and the R-value design curves used by Washington Department of Highways using an exudation pressure of 300 psi. This correlation chart shall only be used for non-expansive soils and when the CBR laboratory tests is modified as follows:

a. Specimen is to be molded at or near the optimum moisture content as determined by AASHTO T-99,
b. Dynamic compaction is to be used with a hammer weight of 10 lb dropped from a height of 18 in.,
c. Specimen is to be compacted in five equal layers with each layer receiving 10 blows, and
d. Specimen is to be soaked for 4 days.

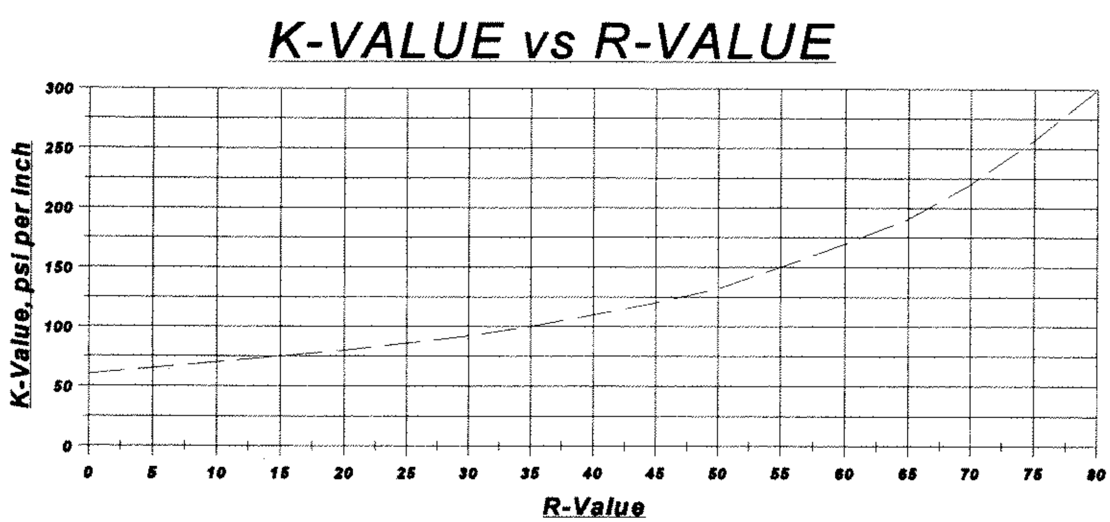
Any soil having an R-value of greater than 55 shall be limited to an R-value of 55.

Method two uses the following correlation equation:

$$R_{value} = \frac{(1500CBR - 1155)}{555} \qquad Eq.\ 1.1a$$

The correlation equation shall only be used for fine-grained non-expansive soils with a soaked CBR of 8 or less. The CBR shall be determined by testing the specimen according to AASHTO T 193 for a range of water content permitted for field compaction test at the specified minimum dry unit weight. The design CBR selected for the correlation shall be the lowest CBR determined according to AASHTO T 193 Paragraph 10.4.

Figure 1-1



1.2.2 Bases and Subbase

1.2.2.1 Introduction

The characteristics of various subbases and bases that may be used in structural sections are discussed in the following sections. Generally, these subbases and bases may be used in various combinations to design the most economical structural section for the specific project.

Because different types of treated and untreated aggregates have different capacities for resisting the forces imposed by traffic, this factor must be considered when determining the thickness of the structural section elements. Treatment of this factor is different for flexible and rigid pavements.

For flexible pavements, this is accomplished with gravel equivalent factors (G_f) which express the relative value of various materials when compared to gravel. It is important to note that the various materials must meet the specified quality requirements, such as grading, to ensure the validity of the assigned gravel factor. Gravel factors for the various types of base materials are provided in Table 1-A.

For rigid pavement, this is accomplished by combining the k-values of the roadbed soil and the subbase or base material. Combined effects of various thicknesses of these materials on the roadbed soil are provided in Figure 1-2. The k-value of the combined treated or untreated base and roadbed soil is limited to the k-value of the base material as determined on Figure 1.1 and Table 1-A.

Since pavement design is a continually evolving field, the following text is not intended to rule out new materials or procedures which may be developed.

When the paragraphs below refers to sections of the Hawaii Standard Specifications for Road and Bridge Constructions it includes the latest revisions made in the Standards Specifications.

1.2.2.2 Aggregate Base (AB)

Aggregate base can be used as a granular layer between the permeable base layer and the basement soil. When used as a granular layer in flexible pavement the R-value shall be the same as the permeable base.

Due to its low permeability aggregate base will not be placed directly below the AC, ACB, or PCC pavement layer or used for any of the layers between the permeable base layer and the surface course layer (PCC or AC).

The material specifications for the aggregate base shall be in accordance with Section 304 of the Hawaii Standard Specifications for Road and Bridge Construction.

1.2.2.3 Asphalt Concrete Base (ACB)

Asphalt concrete base (ACB) is a plant-mixed dense-graded asphalt concrete mix that is similar to that used for the surface course, except that the ACP is placed in a maximum lift thickness of 2¾ to 3 inches, whereas, the ACB is placed in a maximum lift thickness of 6 inches. The mix design and material specifications for the asphalt concrete base shall be in accordance with Sections 301, 302 or 312 of the Hawaii Standard Specifications for Road and Bridge Construction.

1.2.2.4 Permeable Bases (PB)

Untreated permeable base (UPB) consist of high quality coarsely graded crushed aggregate. The UPB provides a highly permeable drainage layer within the structural section. The material specifications for the UPB shall be in accordance with Section 306 of the Hawaii Standard Specifications for Road and Bridge Construction.

Asphalt treated permeable bases (ATPB) are mixtures of high quality coarsely graded crushed aggregate and an asphalt binder material. The mix design and material specifications for the ATPB shall be in accordance with Section 311 of the Hawaii Standard Specifications for Road and Bridge Construction.

PB provides a highly permeable drainage layer within the structural section. The permeable bases extends laterally from one foot outside the edge of pavement on the high side to the outside edge of the collector trench on the low side of the structural section. The PB layer is an integral part of the structural strength. The ATPB is used with the flexible pavements and UPB may be used with the flexible or rigid pavements.

1.2.2.5 Aggregate Subbase (AS)

Aggregate subbase (AS) is normally specified as the lowest element of any structural section because it generally results in the most economical design. It consist of one 6" layer placed on the basement soil. The material specifications for the aggregate subbase shall be in accordance with Section 305 of the Hawaii Standard Specifications for Road and Bridge Construction.

When designing with permeable bases aggregate subbase will be used as a granular layer between the permeable base and the basement soil. This is done with a geotextile permeable separator placed between the aggregate subbase and the permeable base. The combined granular layer and permeable separator act as a protective system to prevent intrusion of fine material from the surrounding soil into the permeable base.

When aggregate base is used as a granular layer placed below the permeable base the R-value of the aggregate base will be the same as the permeable base.

1.2.2.6 Working Table (WT)

Working tables (WT) are normally recommended when the roadbed soil is soft or too wet to support construction equipment. The working table can be a layer of granular material or coarse aggregate. The working table will not be considered in the structural design of the pavement structure. At times it may be advisable to place a geotextile permeable separator below the working table to prevent mixing of the material with the roadbed soil during its placement.

TABLE 1-A

STRUCTURAL PROPERTIES
of
SUBBASES AND BASES
for
FLEXIBLE PAVEMENTS

Title	Symbol	Gravel Factor	R-Value
Asphalt Concrete Base	ACB	$0.95G_{f\ of\ ACP}$	90
Asphalt Treated Permeable Base	ATPB	1.4	60
Untreated Permeable Base	UPB	1.1	55
Aggregate Subbase	ASB	1.0	60

EFFECT OF VARIOUS THICKNESSES
OF
AGGREGATE SUBBASE AND UNTREATED PERMEABLE BASE ON k VALUE

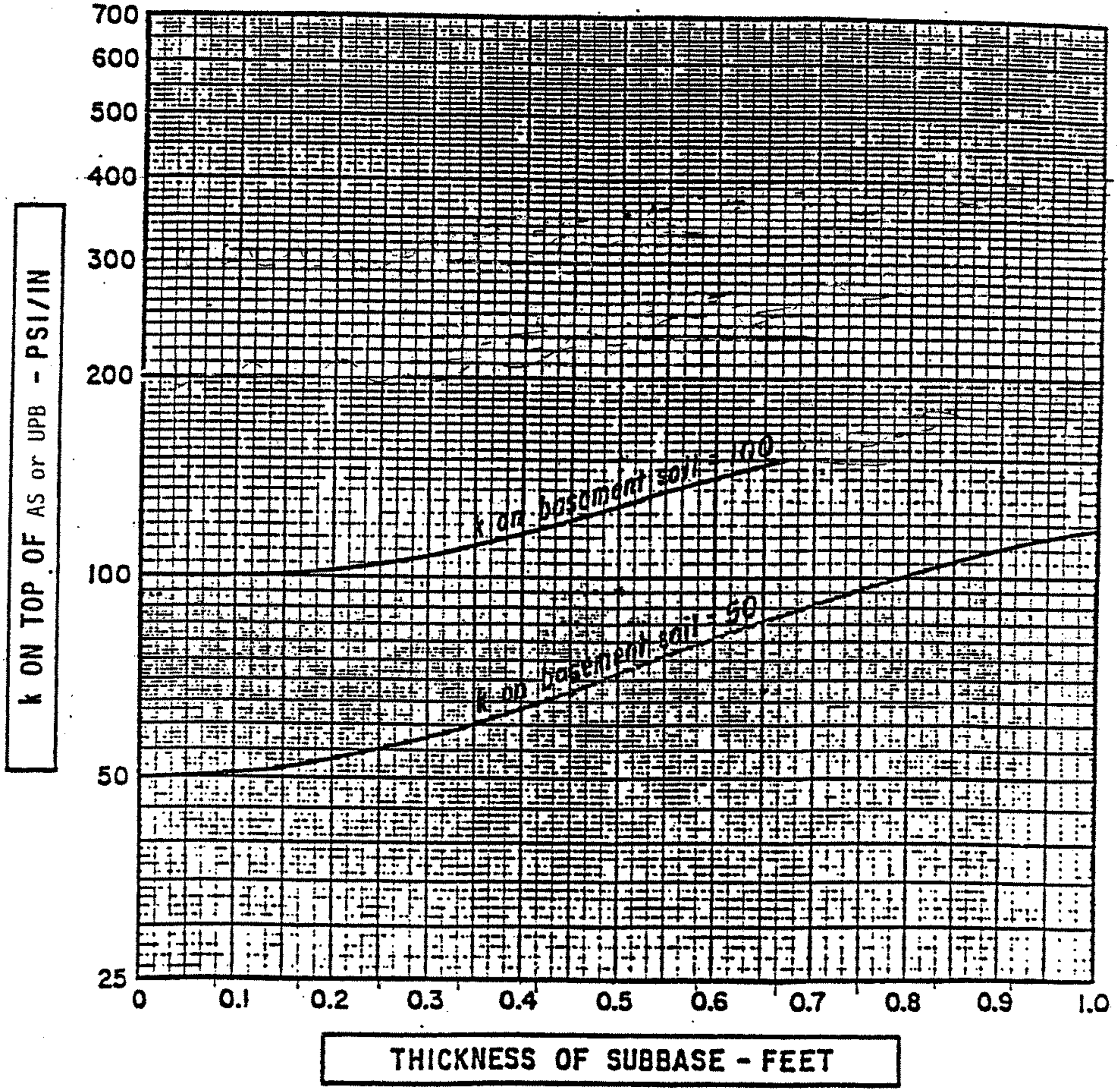


FIGURE 1-2

1.2.3 Concrete Pavements

1.2.3.1 Asphalt Concrete (ACP)

Asphalt Concrete consists of a mixture of bituminous material (paving asphalt) and a close graded aggregate ranging from coarse to very fine particles. Special attention is given to mix design and compaction in the construction phase to minimize voids and to assure stability, durability, and maximum service life. The mix design and material specifications for the asphalt concrete shall be in accordance with Section 401 of the Hawaii Standard Specifications for Road and Bridge Construction.

The gravel equivalent of asphalt concrete are as follows:

Condition	Gravel Factor	
$t_{ACP} \leq 0.5'$	$G_f = \dfrac{5.67}{(TI)^{1/2}}$	*Eq* 1.4
$t_{ACP} > 0.5'$	$G_f = 7\dfrac{t_{ACP}^{1/3}}{(TI)^{1/2}}$	*Eq* 1.5

where:

t_{ACP} = thickness of the asphalt concrete (ft)
t_{ACP} = $t_{ACP} + t_{ACB}$ if asphalt concrete base (ACB) used
G_f = gravel factor
TI = traffic index as defined in equation 3.2

When asphalt concrete base is used, the combined thickness of the AC and ACB can be used for equation 1.4 and 1.5 provided the gravel factor for the asphalt concrete base (ACB) as determined in Table 1-A is met.

1.2.3.2 Portland Cement Concrete (PCCP)

Consideration of the flexural strength of the concrete is applicable in the design procedure of the fatigue criterion, which controls cracking of the pavement under repetitive loadings.

Bending of a concrete pavement under axle loads produces both compressive and flexural stresses. However, the ratios of compressive stresses to compressive strength are too small to influence slab thickness design. Ratios of flexural stress to flexural strength are much higher, often exceeding values of 0.5. As a result, flexural stresses and flexural strength of the concrete are used in thickness design. Flexural strength of the concrete is used in thickness design. Flexural strength is determined by modulus of rupture tests, usually made on 6x6x30-in. beams.

For specific projects, the concrete mix should be designed to give both adequate durability and flexural strength at the lowest possible cost.

The mix design and material specifications for the concrete shall be in accordance with Section 411 of the Hawaii Standard Specifications for Road and Bridge Construction. The modulus of rupture (flexural strength) of Portland cement concrete for design purposes shall be the minimum 28-day flexural strength of 650 psi based on AASHTO T97 as specified in Section 411.

1.2.4 Surface Treatments

1.2.4.1 Introduction

There are a number of asphalt surface treatments that maybe be considered in the design of the structural section. They generally do not contribute to the strength of the structural section but fulfill other purposes as will be discussed.

1.2.4.2 Penetration Treatment

Penetration treatment consist of an application of liquid asphalt to an underlying compacted roadbed material. It is used principally as a surface stabilizing agent on light traffic detours, medians, and parking areas, and as a dust palliative.

1.2.4.3 Prime Coat

A prime coat is an application of liquid asphalt used to prepare an untreated base for and AC surface course. The prime coat penetrates the compacted base to the extent that it fills surface voids, hardens the top, and helps bind it to the AC surface course. A contract item for sand cover should be provided where any traffic will have to use the primed area prior to paving.

The prime coat is generally used to:

a. Minimizing the likelihood of raveling or displacement of the underlying material when traffic must be routed through the work on the aggregate base
b. Protecting the aggregate base or aggregate subbase surface by preventing erosion of fines at the interfaces
c. Protecting the base if extended inclement weather and/or extended delays in placing the surfacing are anticipated, or
d. Protecting thin asphalt concrete layers of 4" or less from the loss of adherence to the aggregate base due to the traffic load-induced horizontal shearing forces at the asphalt concrete and aggregate base interface.

A prime coat may be warranted, depending on other factors unique to a given project, even though the condition described in "a." above do not exist and the AC thickness is greater than 4" and less than 6". No prime coat should be applied when the AC thickness is 6" or greater unless the conditions described in "a." and "b." above exist. The material specifications for the prime coat shall be in accordance with Section 408 of the Hawaii Standard Specifications for Road and Bridge Construction.

Since there may be environmental concerns with the use of prime coat, it should only be considered when necessary and appropriate measures are taken. The preferred method is to provide for an ACP thickness that will eliminate the use of prime coat.

1.2.4.4 Tack Coat

A tack coat consists of an asphaltic emulsion which is applied to all vertical surfaces of pavement, curbs, gutters, and construction joints against which asphaltic surfacing is to be placed. It generally is also applied to existing asphalt surfaces before placing a layer of AC.

1.2.4.5 Prime Coat for Untreated Permeable Bases

This consist of an asphaltic emulsion applied on the top of the permeable base after the filler material is placed. The primary purpose is to provide some stability during the placement of the pavement layer.

CHAPTER 2

HIGHWAY PAVEMENT STRUCTURAL SECTION DRAINAGE DESIGN for NEW PAVEMENT CONSTRUCTION

2.1 INTRODUCTION

Premature distress occur in both flexible and rigid pavements when free water gains access to the structural section and roadbed soil, altering the mechanical properties of these materials by increasing the moisture content and allowing excess pore pressures to develop under impact from traffic. Free water reduces the frictional strength of the structural section and foundation materials by creating buoyancy within these materials. Potential problems associated with this condition include pumping action, differential expansion(swelling) of the roadbed soils, erosion and piping of fine materials creating subgrade support voids, stripping of asphalt concrete aggregates, and accelerated oxidation of asphalt binder. Rapid removal of water from the structural section is essential and is generally dependent on the inclusion of a positive drainage system.

CALTRANS requires a drainage layer for all the pavements. Exceptions, such as for areas where the mean annual rainfall is very low (less then 5 inches) or where the basement soil is free draining (a permeability greater than or equal to 100 ft per day) must be justified in the structural section submittal. CALTRANS second exception would apply only if the pavement layer is placed directly on the basement soil.

Lava bedrock depend on fractures within the rock formation to drain water through the material. Fine material can fill the cracks to prevent water from penetrating freely through the rock formation. This has been observed in actual construction activities. Permeable bases should be used to properly drain pavement structures in these formations.

Rapid drainage of a pavement structural section is essential to minimize the length of time the structural section is saturated. This can best be achieved by placing a highly permeable drainage layer system under the full width of the pavement surface during initial construction. The basic components of a flexible and rigid pavement structural section drainage system are:

a. a highly permeable drainage layer
b. a collector system
c. outlets, vents, and cleanouts

2.2 DRAINAGE DESIGN FOR FLEXIBLE PAVEMENTS

2.2.1 Background

Water can enter into flexible pavement as surface water through cracks, joints, asphalt concrete infiltration, and as groundwater from intercepted aquifers, such as a high water table or a localized spring. The saturation of, or the presence of, water in the pavement structural section decreases the supporting strength, or load-carrying capacity, of succeeding untreated layers underlying the asphalt concrete. This results in increased deflection under traffic loads, thereby leading to structural cracking and a pumping action which accelerates the fatigue failure of asphalt concrete.

Both sources of water must be considered and provisions must be made to handle both. The structural section drainage system, which is designed to handle surface water inflow, is generally separate from the subsurface drainage system that is designed to accommodate encroaching groundwater.

The provisions herein is intended to handle only surface water inflow and not encroaching groundwater. The estimated groundwater inflow should be determined separately by a combination of field investigations, analytical techniques and graphical methods.

2.2.2 Drainage Components and Related Design Considerations for Flexible Pavements.

2.2.2.1 Drainage Layer

A drainage layer consisting of either asphalt treated permeable base, or untreated permeable base is to be placed immediately below the asphalt concrete pavement or asphalt concrete base for interception of surface water that enters the structural section. The drainage layer is extended laterally from one foot outside the edge of traveled way on the high side to the outside edge of the collector trench on the low side. Unbound materials shall not be placed above the permeable base. This includes the shoulders and the one foot extension outside the travelway. A typical asphalt concrete section with a treated or untreated permeable base is shown in Figures 2-1 and 2-2.

The estimated quantity of surface water that will penetrate the asphalt concrete pavement (Q in cubic feet per day per lineal foot of roadway) may be determined by the equation:

$$Q = 2WI \qquad \text{Eq. 2.1}$$

where:

W = width, in feet of the drainage layer measured normal to the center line

I = infiltration rate, in inches per hour.

If local rainfall data is available for the project site the following equation may be used to determine the Infiltration Rate, "I":

$$I = 0.33 I_{DHR} \qquad \text{Eq 2.2}$$

where:

I_{DHR} = Design hourly rainfall intensity as shown in Appendix B

The required thickness, t_d(in feet), of the drainage layer may be calculated using the equation:

$$t_d = \frac{Q}{ks} \qquad \text{Eq 2.3}$$

where:

k = the permeability of the material used in the drainage layer, in feet per day

s = the pavement cross slope, in feet per foot

The permeability of the various drainage layers should consider the long term effects to which the material will undergo. It is conceivable that in the permeable base fine material will cake around the aggregate which will eventually reduce the permeability. Also, degradation of the layer as it undergoes repeated traffic loading is also possible. These and other long term effects should be considered in determining the design permeability. Base on these considerations the design permeability of the various permeable bases shall be as follows:

Type	Permeability (k)
ATPB	8,000 ft per day
UPB	10,000 ft per day

Final thickness for the permeable base layer is determined by adding one (1) inch to the calculated permeable layer thickness, to allow for construction tolerances, then rounding up to the next higher full inch.

Drainage layers should not be placed directly on the roadway bed. A separator consisting of a geotextile permeable separator on a 6" layer granular material should be used to protect the permeable layer from infiltration of fines from the subgrade.

2.2.2.2 Collector System

A 6-inch diameter perforated plastic pipe is to be installed in a longitudinal collector trench as shown in Figures 2-1 and 2-2. In areas where grades are equal to or greater than 4%, intermediate cross-drain interceptors, as shown in Figure 2-3 should be provided at an approximate spacing of 500 feet. This will limit the longitudinal seepage distance in the drainage layer, thereby minimizing the drainage time and preventing the buildup of a hydrostatic head under the asphalt concrete surface layer. Longitudinal collector trenches and cross drain interceptor trenches must be sloped to drain.

In addition, a cross drain similar to that shown in Figure 2-3 must be provided at the low-end terminal of the permeable base and at low points along the road way profile. Care must be taken to coordinate the cross drains with the longitudinal structural section drainage system. Drainage layers in roadway intersections and interchanges may require additional collectors trenches, pipes, and outlets to assure rapid drainage of the structural section.

A standard longitudinal collector trench width of 18 inches has been adopted for new construction to accommodate compaction and consolidation of the permeable trench material along side and above the 6-inch perforated plastic pipe. The permeable trench material specified for use in the collector trenches should be untreated permeable base material.

Geotextile permeable separator is to be place as shown in Figures 2-1, 2-2 and 2-3 to provide protection against clogging of the permeable base by intrusion of fines. When the roadbed soil has significant amounts of fines which are smaller than the AOS of the permeable separator, 6 to 12 inches of a well graded granular material shall be placed between the roadbed soil and the permeable base to prevent the clogging of the permeable base by the migration of fines through the permeable separator. Most of the native soils have fines that are smaller than the AOS of the permeable separator that are considered effective for filtration. Therefore, at least 6 inches of well graded granular material are required.

On curvilinear alignments, super-elevation of the roadway may create depressions at the low side of pavement where the collected water can not be drained away. An adjustment of the profile grade may be necessary to eliminate these depressions.

When a super-elevation cross slope begins to drain the water through the permeable base to the low side of pavement, the edge drain at the high side of superelevation is no longer required for pavement structure drainage but may be needed for subsurface drainage such as subsurface water infiltrating from cut slopes. Conversely, as the superelevation transition returns to the normal roadway cross slope, the standard edge drain should begin to collect water flowing back to the original side.

Whenever possible, collector pipes should be connected to culverts or drainage structures.

2.2.2.3 Outlet, Vents and Cleanouts

Plastic pipe (unperforated) outlets should be provided when collector pipes cannot be connected to culverts or drainage structures. Outlet pipes should be provided at proper intervals for the pavement structural section drainage system to be free-draining. The spacing of outlets (including vents and cleanouts) should be limited to approximately 200 feet.

The trench for the outlet pipe must be backfilled with material of low permeability, or provided with a cut-off wall or diaphragm, to prevent piping.

The outlets must be connected to culverts or drainage structures, or discharged into gutters or drainage ditches. Ready access to outlets, and the provision of intervening cleanouts when outlet spacing exceeds a maximum distance of 250 feet, should be provided to facilitate cleaning of the structural section drainage system. Connect the outlet pipes to the underdrain pipe at a 45 degree angle to allow for easy access of a water hose to flush out the underdrain pipe.

2.2.3 Structural Considerations for Drainage Layers

The normal flexible pavement design procedure, as covered under Section 3.2, is followed to develop asphalt concrete pavement structural sections which incorporate a drainage layer to accommodate surface infiltration. The drainage layer shall consist of untreated permeable base or asphalt treated permeable base placed directly below the asphalt concrete or asphalt concrete plus the asphalt concrete base. The gravel factor (G_f) for permeable bases can be found in Table 1-A.

2.3 DRAINAGE DESIGN FOR RIGID PAVEMENTS

2.3.1 Background

The primary cause of deterioration of rigid pavement is the trapping and retention of surface water inflow, in a "choker" type section, coupled with exposure to heavy truck traffic. Those combination creates the potential for severe pavement damage, especially in heavily traveled truck lanes. Heavy trucks depress the edges of curled slabs at the transverse joints. When the structural section is saturated, the resultant pumping action results in the erosion of the cement treated base or aggregate subbase, which were specified for the construction of concrete pavements. In addition, the pumping action along the outer edge of the pavement has resulted in the erosion and movement of fine materials from the existing aggregate base under the adjoining shoulders. The fine materials from both sources are transported by pumping action and deposited under the trailing edge of the pavement slabs, resulting in step faulting, uneven slab support, and slab rocking and cracking.

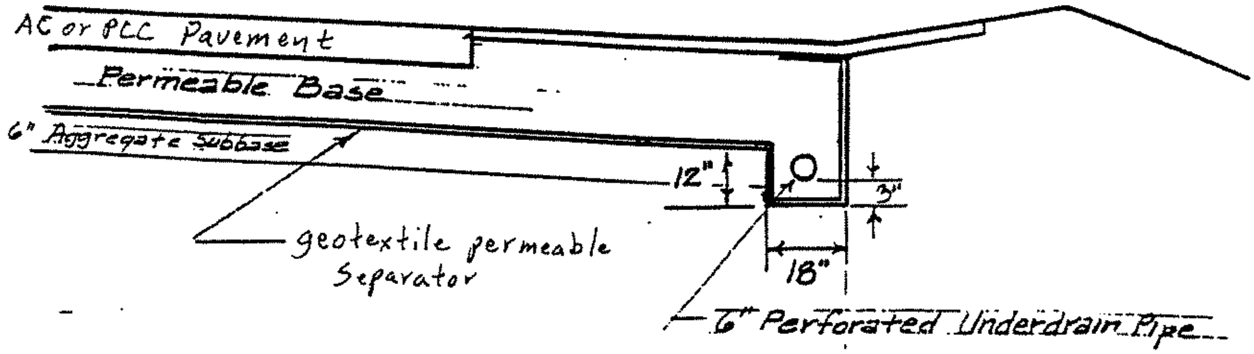
Failure of the inner edge of the shoulder also results from loss of aggregate base support.

2.3.2 Drainage Components and Other Design Considerations for Rigid Pavements

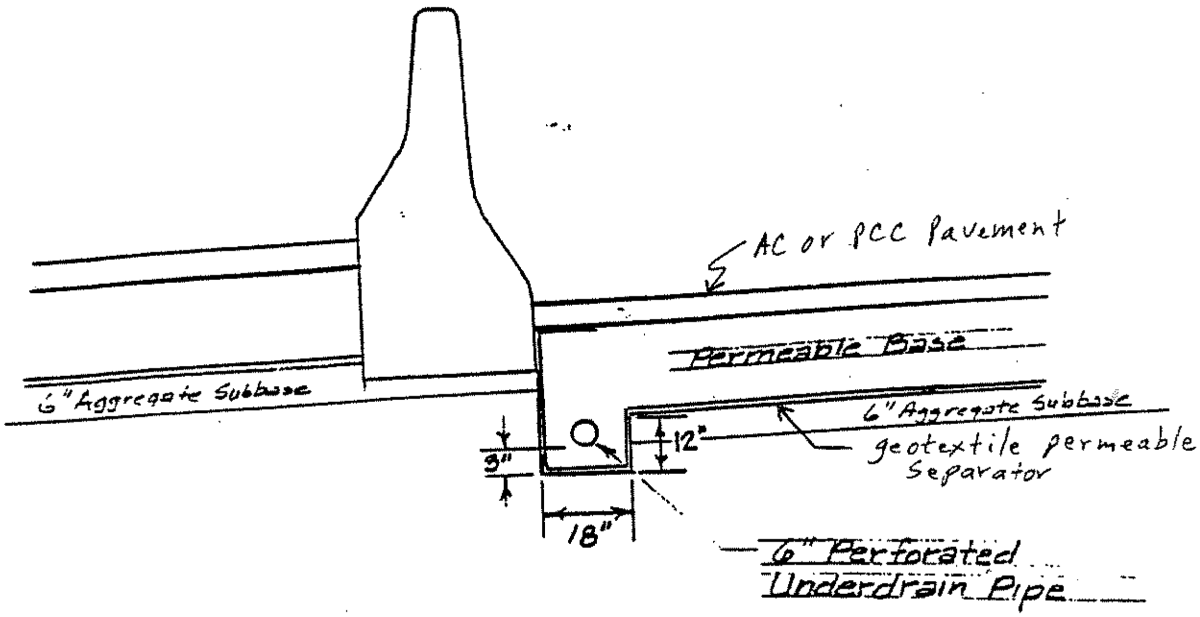
Accept as noted below the drainage design and their components in rigid pavements shall be similar to that of flexible pavements except that the drainage layer will consist of untreated permeable base placed directly below the PCC pavement.

Due to the severity of the pumping action causes to the bases of rigid pavements, use of permeable bases to effectively remove the water is important in preserving pavement life. Permeable bases should always be placed directly under the PCC pavements.

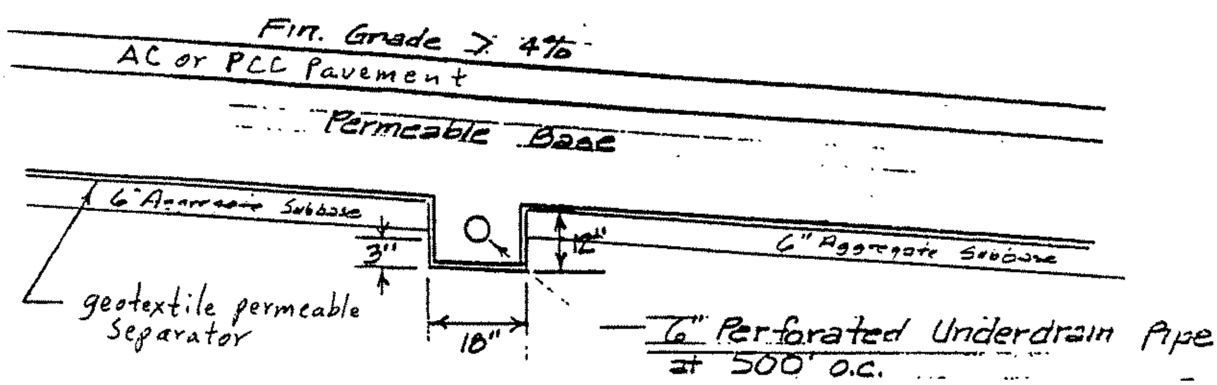
The normal rigid pavement design procedure, as covered under Section 3.3, is followed to develop portland cement concrete pavement structural sections which incorporate a drainage layer to accommodate surface infiltration. The Westergaard modulus of subgrade reaction (k) for permeable bases can be found in Figure 1-2.



TYPICAL SECTION - LONGITUDINAL UNDERDRAIN
Figure 2-1



TYPICAL SECTION — LONGITUDINAL UNDERDRAIN AT DIVIDED MEDIAN
Figure 2-2



TYPICAL SECTION - TRANSVERSE UNDERDRAIN
Figure 2-3

CHAPTER 3

HIGHWAY PAVEMENT STRUCTURAL DESIGN for NEW PAVEMENT CONSTRUCTION

3.1 INTRODUCTION

This chapter describes the application of design procedures for both flexible and rigid highway pavements. Flexible pavement design includes asphalt concrete (AC) surfaces of AC Mix IV or Superpave Mix. Rigid pavement design includes plain jointed Portland cement concrete pavements (PCCP).

The design procedures for flexible pavements are based on the Hveem Stabilometer method developed and used by the California Department of Transportation. The design procedures for rigid pavement are based on the design procedures of the Portland Cement Association "Thickness Design for Concrete Highway and Street Pavements". Modifications are made to the above procedures to address local requirements and preferences.

Generally, the pavement section shall be designed for the lowest R-value found among the types of soils found in the project area. In cases where the project is several miles or more in length, the R-value may not vary significantly for long stretches of the roadway. For these conditions, it may be economically advantageous to design a pavement section for each of the stretches of the roadway where the differences in the R-values are significant instead of using one pavement section, designed for the lowest R-value, for the entire length of the project.

3.2 FLEXIBLE PAVEMENT STRUCTURAL SECTION DESIGN

3.2.1 Introduction

The flexible pavement structural section usually are constructed of an asphalt cement bound layer or layers placed on an asphalt treated or an untreated permeable base layer and 6" of an untreated aggregate subbase layer separated by a permeable separator. The asphalt cement bound layer shall consist of AC surface course with or without a binder layer or AC surface course and an asphalt concrete base. AC Mix V is not generally used because most of our roadways have traffic loads not normally suited for the Mix V.

Asphalt concrete pavement when compared to rigid pavement, has the advantage of being able to adjust more readily to differential settlement that is likely to occur where the roadway is constructed on relatively flexible or variable quality basement soil. In addition, it can be more readily repaired or recycled. Also, reconstruction of flexible pavements can be performed in a day without leaving open excavation.

The primary disadvantages of asphalt concrete pavements are that it generally requires a higher level of maintenance then rigid pavements and require significant rehabilitation measures like overlay or surface treatment due to age hardening about 10 years after initial construction.

3.2.2 Design Factors for Flexible Pavement

3.2.2.1 Basis of the Design

Design of the flexible pavement structural section is based on a relationship between the "gravel equivalent" (GE) of the structural section materials, the Traffic Index (TI), and the R-value (R) of the underlying material. This relationship was developed by California Department of Transportation through research and field experimentation and is represented by the equation:

$$GE = 0.0032\,(TI)(100 - R) \qquad Eq\ 3.1$$

where:

GE	=	gravel equivalent in feet
TI	=	traffic index
R	=	R-value of the material to be covered

Gravel Equivalent (GE). The gravel equivalent (GE) requirement for the structural section can be provided by a wide variety of pavement, base, and subbase materials in various combinations of layer thickness that are designed primarily to spread and transmit the live load to the underlying roadbed. Base and subbase types are listed in Table 1-A and discussed in Section 1.2.2.

Traffic Index (TI). The Traffic Index (TI) is a measure of the number of ESALs expected in the design lane over the design life period. The TI does not vary directly with the ESALs but rather according to the following exponential formula:

$$TI = 9\left(\frac{ESAL}{1{,}000{,}000}\right)^{0.119} \qquad Eq\ 3.2$$

where:

TI	=	Traffic Index
ESAL	=	Equivalent 18-kip Single Axle Loads

The ESALs for each axle configuration are determined by the following equation:

$$ESAL = ADTT(EALC)(L_D) \qquad Eq.\ 3.$$

where:

L_d	=	Design Period in years
EALC	=	ESAL constants (see para. 1.1.2.3)
ADTT	=	Average Daily Truck Traffic corresponding to the ESALC used

The total ESAL that the pavement will encounter during its design life is the sum of the ESAL for each axle configuration.

R-value. Generally the pavement section are designed for the lowest R-value found among the types of soils found in the project area. In cases where the project is several miles or more in length, the R-value may not vary significantly for long stretches of the roadway. For these conditions, it may be economically advantageous to design a pavement section for each of the stretches of the roadway where the differences in the R-values are significant instead of using one pavement section, designed for the lowest R-value, for the entire length of the project.

3.2.2.2 Basic Design Data

The basic design data required for flexible pavement design includes:

a. Site plans of the project and typical sections of the pavement structure. Site plans are needed to determine the requirements of a soil investigation and testing program. The typical sections are needed to determine the number of lanes of the new roadway.

b. Average daily truck traffic. (ADTT) for the design life. This information is developed and transformed into the traffic index (TI), as described above, for use in the structural section design. In lieu of the ADTT, the average daily traffic (ADT) and the percent trucks (T_{24}) may be provided.

c. Truck traffic distribution for the design period. This information is used with the ADTT and the 1-year ESAL constants (ESALC) to determine the ESAL and TI.

d. R-values of the basement soils. When the basement soil is expansive the R-value for the soil is the "expansion pressure R-value", which will result in a thick subbase but not affect the other layers.

3.2.2.3 Structural Section Safety Factors

Construction tolerances allowed by the contract specifications could result in a structural section that is slightly deficient in thickness. To compensate for this possibility, a safety factor is applied by increasing the design thickness of the pavement. It is not considered necessary to apply a safety factor to the overall structural section but rather to one of the relatively thin elements where the tolerable variation in thickness might result in a significant reduction in structural strength and load carrying capacity of the structural section. Thus, a compensating safety factor, in terms of gravel equivalent (GE) is added to the asphalt pavement layer GE and subtracted from the subbase layer GE. When there is no subbase, the safety factor will be subtracted from the base layer unless the layer is of minimum thickness.

TABLE 3-A

GRAVEL EQUIVALENT SAFETY FACTORS

Base Type	GE Increase(ft)	Add to
ACB, and TPB	0.24	ACP
UPB	0.20	ACP
Ful Depth AC	0.10	ACP

The safety factor varies with the base material selected and its assign gravel factor (G_f). Safety factors to be applied in terms of GE are shown in TABLE 3-A for both drained and undrained structural sections.

3.2.3 Design Procedure for Flexible Pavement

3.2.3.1 Normal Design Method

The following are some basic rules in going through the design of flexible pavement:

a. The TI is determined to the nearest 0.5.
b. Design thickness of each layer rounded up as follows:

Layer	Round Up	Minimum
AC pavement	0.5"	2.5"
ACB	0.5"	4.0"
Aggregate Base	1.0"	6.0"
Permeable Base	1.0"	6.0"
Subbase	1.0"	6.0"

c. The required GE for each successive layer of the structural section is determined by equation 3.1 starting with the ACP and proceeding downward.
d. Safety factors are applied by increasing the GE of the AC by the amount indicated in TABLE 3-A. An equal GE is subtracted from the subbase layer (base layer when there is no subbase). When full depth AC is used, there

may not be an underlying layer from which to subtract the safety factor GE. In these cases, a full depth AC section will slightly exceed the required cover.

e. ACB material shall have a minimum thickness of 4 inches. When the calculated thickness of base material is less than the desired 4 inches minimum thickness, either increase the thickness to the minimum without changing the thickness or the overlying layers or eliminate the layer and increase the thickness of the AC layer to compensate for the reduction in GE.

f. Permeable bases shall have a minimum thickness of 6 inches. When the calculated thickness of the permeable base is less than the desired 6 inches minimum thickness, the thickness shall be increased to the minimum thickness without changing the thickness of the overlying layers.

g. When aggregate subbase or aggregate base is used as a granular layer separating the permeable base from the basement soil the R-value of the aggregate subbase base or aggregate base shall be the same as the permeable base.

h. When the computed thickness of granular layer is greater than 6 inches, the difference between the computed thickness and 6 inches shall be added to the permeable base. The granular layer shall than remain at 6 inches.

i. When the basement soil has an R-value of 45 or more resulting in a computed thickness of granular layer subbase is less than 6 inches, considerations may be given to eliminating the granular layer and replacing it with permeable base provided the drainage considerations in Chapter 2 are met and the drainage layer is protected from any intrusion of fine material to clog the drainage layer. If aggregate base is used the GE of the aggregate base will be the same as the permeable base.

j. The thickness of each material layer is calculated by dividing the GE by the appropriate G_f. Note that the G_f of AC is not a constant value. As the TI increases, the G_f decreases. Also, the G_f of the AC gradually increases for any given TI as the total thickness of AC increases above 6 inches. Since the G_f factor of the ACB is a function of the AC the G_f factor varies similarly.

k. The design procedure provides the minimum allowable thickness of AC for the project conditions. This thickness may be increased when appropriate to minimize construction costs, reduce construction time, match layer placement with existing adjacent lanes, reduce the number of layers, etc., provided the minimum GE and construction requirements are satisfied.

l. Construction convenience and/or materials availability may at times make it advantageous to the contractor to replace the aggregate subbase layer with additional base. Except in cases where the required thickness of aggregate subbase is less than the minimum of 6 inches, this substitution should not be done as a design option.

3.2.3.2 Adjustments to the Design Thickness.

The design thickness determined by the procedures described above are not intended to prohibit other combinations and thickness of material. Adjustments to the thickness of the various layers, other than permeable bases, may be made to accommodate construction restrictions or practices, provided the minimum GE requirements, including safety factors, of the basement soil and each layer in the structural section are satisfied.

3.2.3.3 Full-Depth Asphalt Concrete Structural Section Design.

In some instances, it may be desirable to reduce the total thickness of the structural section by placing AC directly on the subgrade soil. This can be done using the standard design procedures to calculate the total required GE, including the safety factor of 0.10, to determine the actual thickness of AC required. In cases where a working table is required, the GE of the working table is not subtracted from the required total GE, of AC required. Drainage layers may be placed below or at an appropriate level within the full depth AC. The drainage layer should be placed at a location where it will be protected from infiltration of fine material that will reduce its permeability.

3.2.4 Structural Design of Shoulder Sections

The structural section design of shoulders shall be the same structural section as the adjacent design travelway lane when designed according to paragraph 3.2

3.2.5 Structural Design of Ramp Sections

The structural section design of ramps including the shoulders shall be the same as the structural section as the design lane of adjacent roadway that feeds into the ramp when designed according to paragraph 3.2

PCCP should be used for exit ramp termini where there is a high potential for exposure to heavy truck.

3.3 RIGID PAVEMENT STRUCTURAL SECTION DESIGN

3.3.1 Introduction

Rigid pavement structural sections are usually constructed of a layer of Portland cement concrete that is placed over an untreated permeable base layer and 6 inches of untreated subbase layer separated by a permeable separator.

When compared to flexible pavements, rigid pavement has the advantage of requiring less maintenance during its design life.

The design procedures presented in this manual is adopted from the Portland Cement Association design manual "Thickness Design for Concrete Highway and Street Pavements"(1984). The design procedures given in this manual apply to plain concrete pavements. The procedures are based on the knowledge of pavement theory, performance, and research experience from the following sources:

a. Theoretical studies of pavement slab behavior by Westergaard. {Pickett and Ray, and recently developed finite-element computer analyses.
b. Model and full-scale tests such as Arlington Tests and several research projects conducted by PCA and other agencies on subbases, joints and concrete shoulders.
c. Experimental pavements subjected to controlled traffic, such as the Bates Test Road, the Pittsburgh Test Highway, the Maryland Road Test, the AASHTO Road Test, and studies of inservice highway pavements made by various departments of transportation.

All PCC slab thickness is determined for the design condition of no doweled transverse joints.

3.3.2 Design Factors for Rigid Pavement

The design procedures given in this guide apply to plain concrete pavement without dowels with an untreated permeable base and 6 inches of an untreated subbase layer separated by a permeable separator.

Thickness design requires the following design inputs:

a. Design period
b. Flexural strength of the concrete, modulus off rupture, MR
c. Strength of the roadbed and permeable base and subbase combination (k)
d. The weights, frequencies, and types of truck axle loads that the pavement will carry
d. Load safety factor of 1.3
e. Concrete shoulders

Design period. The determination of the design period of the roadway is generally dependent on the classification of the route under consideration. Refer to paragraph 1.1.1.

Flexural strength of concrete. The flexural strength of concrete (modulus of rupture, MR) for design purposes shall be 650 psi. For additional information refer to paragraph 1.2.3.2 Portland Cement Concrete.

Strength of the supporting materials. The strengths of the roadbed is based on the Westergaard modulus of subgrade reaction (k) as discussed in paragraph 1.2.1.2. Combined effects of various thicknesses of subbase and base materials on the roadbed soil are provided in Figures 1-2 as discussed in paragraph 1.2.2.1.

Traffic effects. The effect of traffic is dependent on the weights, frequencies, and type of truck axle loads that the pavement will carry. These variables are included in Figure 3-1. The chart gives various ranges of loading condition for two category of trucks in determining the average daily truck traffic (ADTT). The load factor constants were developed using data from 1972, 1973, 1974, and 1975 truck weight study.

Shoulders. When shoulders are considered in the design, the shoulders shall have the same pavement section as the design pavement lane, be at least 3 feet wide, and is tied to the pavement travel lane on both sides of the pavement. Type 2AG, 2AGM and 2DG concrete curb-and-gutters can may be considered in the design if these curb-and-gutters are monolithically poured, of equal or greater thickness as the design pavement lane, tied to the design pavement lane and the lower structural layers are the same as the design pavement lane.

Other factors. Reinforcement may be needed to control cracks due to irregular slab size and intrusion of utilities into the slab itself. This, however, should not reduce the slab thickness.

3.3.3 Design Procedure for Rigid Pavement

3.3.3.1 General

The methods in this chapter are used when detail axle-load-distribution data have been determined or estimated as described in Chapter 1.

Figure 3-2 is a worksheet showing the format for completing design problems. The computer program "PCAPAV version 2.10" available from the Portland Cement Association may also be used. Both the worksheet and PCAPAV requires as input data following design factors as discussed in Section 3.3.2.

a. K- value of the subgrade and the permeable base subbase combination as recommended in the second paragraph in section 1.2.2. See "R-value(R)" under section "3.2.2.1 Basis of the Design" for requirements for determination of R-value.
b. Concrete flexural strength (MR) of 650 psi at 28 days
c. Load safety factor of 1.3
d. "No" for Doweled joints
e. Concrete shoulder: select "yes" when concrete shoulders are considered in the design or k"no" when concrete shoulders are not considered in the design
f. design period
g. axle-load distribution
h. expected number of axle-load repetitions during the design period determined from figure 3.1

Both a fatigue analysis (to control cracking) and an erosion analysis (to control foundation and shoulder erosion, pumping, and faulting) are shown on the design worksheet.

The fatigue analysis will usually control the design of light-traffic pavements (residential streets and secondary roads).

The erosion analysis will usually control the design of medium and heavy traffic pavements.

For pavements carrying a normal mix of axle weights, single-axle loads are usually more severe in the fatigue analysis, and tandem-axle loads are more severe in the erosion analysis.

Add reinforcement to control cracking due to irregular shapes of slabs and obstructions within the slab itself. This, however, will not reduce the slab thickness.

The calculation of the pavement thickness requires the expect repetitions of axle loads the pavement is to experience during its design life. In Figure 3.2, columns 1, 2, and 3 need to be completed before beginning fatigue or erosion analysis.

a. Fill in Column 1 "Axle load" with the larger of the values in each of the load ranges found on Figure 3-1. (example: for 20-22, use 22)
b. Fill in Column 2 with the result of the values in Column in 1 multiplied by the "Load safety factor, LSF".
c. Fill in Column 3, "Expected repetitions", with the results of multipling the values from the "Total Repetitions" column on Figure 3-1 by the design period.

3.3.3.2 Fatigue Analysis

Results of fatigue analysis, and thus the charts and figures used, are for undoweled joints.

For pavements without concrete shoulders: use Table 3A and Figure 3-3.

For pavements with concrete shoulders: use Table 3B and Figure 3-3.
The procedure for fatigue analysis is as follows:

a. Select a trial thickness
b. Enter as items 8 and 11 on the worksheet from the appropriate table the equivalent stress factors depending on trial thickness and k value.
c. Divide these by the concrete modulus of rupture and enter as items 9 and 12.
d. Fill column , "Allowable repetitions", with the values determined from Figure 3.3 for the values in Column 2.
e. Compute Column 5 by dividing Column 3 by Column 4, multiplying by 100.

f. Determine the total of all values inColumn 5 and enter this value in Column 5 in the "Total" row at the bottom of the "Tandem Axles" table on Figure 3-2.

3.3.3.3 Erosion Analysis

The procedure for erosion analysis is as follows:

For pavement without concrete shoulders: use Table 3-D and Figure 3-4.

For pavement with concrete shoulders: use Table 3-F and Figure 3-5.

The procedure for erosion analysis is as follows:

a. Enter the erosion factors from the appropriate table as items 10 single axle and 13 fir tandem axle in the worksheet.
b. Fill in Column 6, "Allowable Repetitions", from Fig 3-4 or Fig 3-5.
c. Compute column 7 by dividing column 3 by column 6, multiplying by 100.
d. Determine the total of all values in Column 7 and enter this value in Column 7 in the "Total" row at the bottom of the "Tandem Axles" table on Figure 3-2.

3.3.4 Determination of Final Pavement Structure

In the use of the charts, precise interpolation of allowable repetitions is not required. If the intersection line runs off the chart, the allowable load repetitions are considered to be unlimited.

The trial thickness is not an adequate design if either of the totals of fatigue or erosion damage are greater than 100%. A greater trial thickness should be selected for another run. A less trial thickness is selected if the totals are much lower than 100%.

The Portland Cement Concrete pavement layer is not to be less than 6 inches in thickness.

3.3.5 Design for Early Strength Concrete

When project considerations require paving lanes be open to traffic earlier than designed for a fatigue and erosion analysis can be made by determining the damage caused by the traffic for the time period between opening day and 28th-day based on the opening-day concrete strength when concrete was last placed. No increase should be made beyond the design 28-day flexural strength of 650 psi. This result should then be added to the results of the original analysis. The cumulated results should be less then 100% for it to be adequate.

3.3.6 Pavement Joints

Plain portland cement concrete pavement require transverse and longitudinal joints to prevent unsightly cracking. The slab formed by the transverse and longitudinal joints shall meet the following size requirements:

1. Maximum length in feet, the smaller of:
   a. the slab thickness in inches multiplied by 2, this value taken as feet without any inches to foot conversion, or
   b. 15 feet
2. Length to width ratio 1.25 maximum

Transverse joints shall be skewed with a 2 feet offset in the direction of travel for every 12 feet along a line perpendicular to the longitudinal joints or the edge or the pavement whichever is most parallel to the anticipated movement of the slabs in the longitudinal direction.

Transverse joints shall be spaced at successive intervals of 12', 15', 13', and 14' in the direction of travel.

Install isolation joints at structures and at intersections with other rigid pavements. Do not install isolation joints for transverse or longitudinal joints.

See Section 411 of the Standard Specifications for joint construction specifications.

See Appendix C for typical details.

3.4 STRUCTURAL DESIGN OF SHOULDER AND RAMP SECTIONS

3.4.1 Structural Design of Shoulders

The structural section design of shoulders shall be the same as the structural section of the design lane of the adjacent travelway when designed according to paragraphs 3.2 and 3.3.

3.4.2 Structural Design of Ramp Sections

The structural section design of ramps including the shoulders shall be the same as the structural section of the design lane of the adjacent roadway that feeds into the ramp when designed according to paragraphs 3.2 and 3.3.

PCCP should be used for exit ramp termini where there is a high potential for exposure to heavy traffic. This is necessary because heavy trucks create severe damage to the asphalt concrete pavement near the termini of the heavy traffic exit ramps, generally caused by the dissolving action of oil drippings combined with the braking of trucks.

CALCULATIONS OF 1 -YEAR AXLE LOAD REPETITIONS (ONE -WAY TRAFFIC)

Single Axle	2-AXLES ADTT=		3-AXLES ADTT=		4-AXLES ADTT=		5-AXLES ADTT=		6-AXLES ADTT=		TOTAL ADTT=
LOADS (kips)	FACTORS	REPETITION	FACTORS	REPETITION	FACTORS	REPETITION	FACTORS	REPETITION	FACTORS	REPETITION	REPETITIONS
20-22	3.5		6.1		35.5		75.8		64.4		
22-24	2.4		0.9		44.7		21.5		115.5		
24-26	1.7		0.4		30.3		1.7		21.7		
26-28	0.3		0.3		11.5		0.3				
28-30	0.3		0.3		11.5		0.3				
30-32			0.2		2.1						
32-34			0.2		2.1						
34-36			0.2		2.1						
TANDEM AXLE LOADS (kips)											
30-32			25.4		20.3		9.1		21.7		
32-34			18.5		14.7		10.4				
34-36			5.2		18.7		6.7				
36-38			5.2		6.3		9.3				
38-40			3.3		4.2		3.8				
40-42			1.5		2.8		2.0				
42-44					2.8		1.3				
44-46					1.4		1.7				
46-48			0.2				1.3				
48-50			0.2				1.3				

Figure 3-1

Calculation of Pavement Thickness

Project ______________________________

Trial thickness ____________ in.

Subbase-subgrade *k* ____________ pci

Modulus of rupture, MR ____________ psi

Load safety factor, LSF ____________

Doweled joints: yes ____ no ____

Concrete shoulder: yes ____ no ____

Design period ______ years

Axle load, kips	Multiplied by LSF	Expected repetitions	Fatigue analysis		Erosion analysis	
			Allowable repetitions	Fatigue, percent	Allowable repetitions	Damage, percent
1	2	3	4	5	6	7

8. Equivalent stress ________

9. Stress ratio factor ________

10. Erosion factor ________

Single Axles

11. Equivalent stress ________

12. Stress ratio factor ________

13. Erosion factor ________

Tandem Axles

			Total		Total	

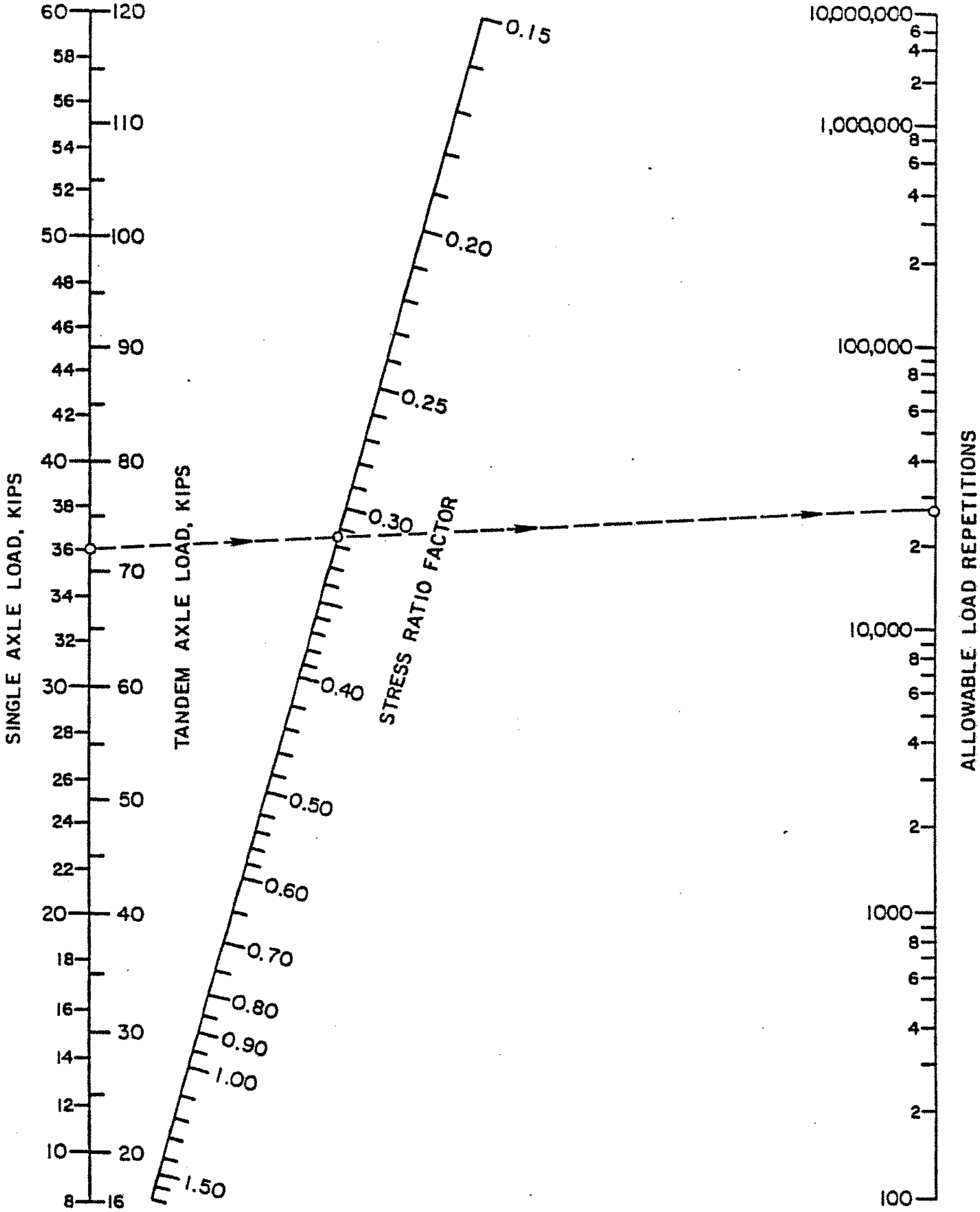
Figure 3-2

Table 3A Equivalent Stress — No Concrete Shoulder (Single Axle/Tandem Axle)

Slab thickness, in.	k of subgrade-subbase, pci						
	50	100	150	200	300	500	700
4	825/679	726/585	671/542	634/516	584/486	523/457	484/443
4.5	699/586	616/500	571/460	540/435	498/406	448/378	417/363
5	602/516	531/436	493/399	467/376	432/349	390/321	363/307
5.5	526/461	464/387	431/353	409/331	379/305	343/278	320/264
6	465/416	411/348	382/316	362/296	336/271	304/246	285/232
6.5	417/380	367/317	341/286	324/267	300/244	273/220	256/207
7	375/349	331/290	307/262	292/244	271/222	246/199	231/188
7.5	340/323	300/268	279/241	265/224	246/203	224/181	210/169
8	311/300	274/249	255/223	242/208	225/188	205/167	192/155
8.5	285/281	252/232	234/208	222/193	206/174	188/154	177/143
9	264/264	232/218	216/195	205/181	190/163	174/144	163/133
9.5	245/248	215/205	200/183	190/170	176/153	161/134	151/124
10	228/235	200/193	186/173	177/160	164/144	150/126	141/117
10.5	213/222	187/183	174/164	165/151	153/136	140/119	132/110
11	200/211	175/174	163/155	154/143	144/129	131/113	123/104
11.5	188/201	165/165	153/148	145/136	135/122	123/107	116/98
12	177/192	155/158	144/141	137/130	127/116	116/102	109/93
12.5	168/183	147/151	136/135	129/124	120/111	109/97	103/89
13	159/176	139/144	129/129	122/119	113/106	103/93	97/85
13.5	152/168	132/138	122/123	116/114	107/102	98/89	92/81
14	144/162	125/133	116/118	110/109	102/98	93/85	88/78

Table 3B Equivalent Stress — Concrete Shoulder (Single Axle/Tandem Axle)

Slab thickness, in.	k of subgrade-subbase, pci						
	50	100	150	200	300	500	700
4	640/534	559/468	517/439	489/422	452/403	409/388	383/384
4.5	547/461	479/400	444/372	421/356	390/338	355/322	333/316
5	475/404	417/349	387/323	367/308	341/290	311/274	294/267
5.5	418/360	368/309	342/285	324/271	302/254	276/238	261/231
6	372/325	327/277	304/255	289/241	270/225	247/210	234/203
6.5	334/295	294/251	274/230	260/218	243/203	223/188	212/180
7	302/270	266/230	248/210	236/198	220/184	203/170	192/162
7.5	275/250	243/211	226/193	215/182	201/168	185/155	176/148
8	252/232	222/196	207/179	197/168	185/155	170/142	162/135
8.5	232/216	205/182	191/166	182/156	170/144	157/131	150/125
9	215/202	190/171	177/155	169/146	158/134	146/122	139/116
9.5	200/190	176/160	164/146	157/137	147/126	136/114	129/108
10	186/179	164/151	153/137	146/129	137/118	127/107	121/101
10.5	174/170	154/143	144/130	137/121	128/111	119/101	113/95
11	164/161	144/135	135/123	129/115	120/105	112/95	106/90
11.5	154/153	136/128	127/117	121/109	113/100	105/90	100/85
12	145/146	128/122	120/111	114/104	107/95	99/86	95/81
12.5	137/139	121/117	113/106	108/99	101/91	94/82	90/77
13	130/133	115/112	107/101	102/95	96/86	89/78	85/73
13.5	124/127	109/107	102/97	97/91	91/83	85/74	81/70
14	118/122	104/103	97/93	93/87	87/79	81/71	77/67

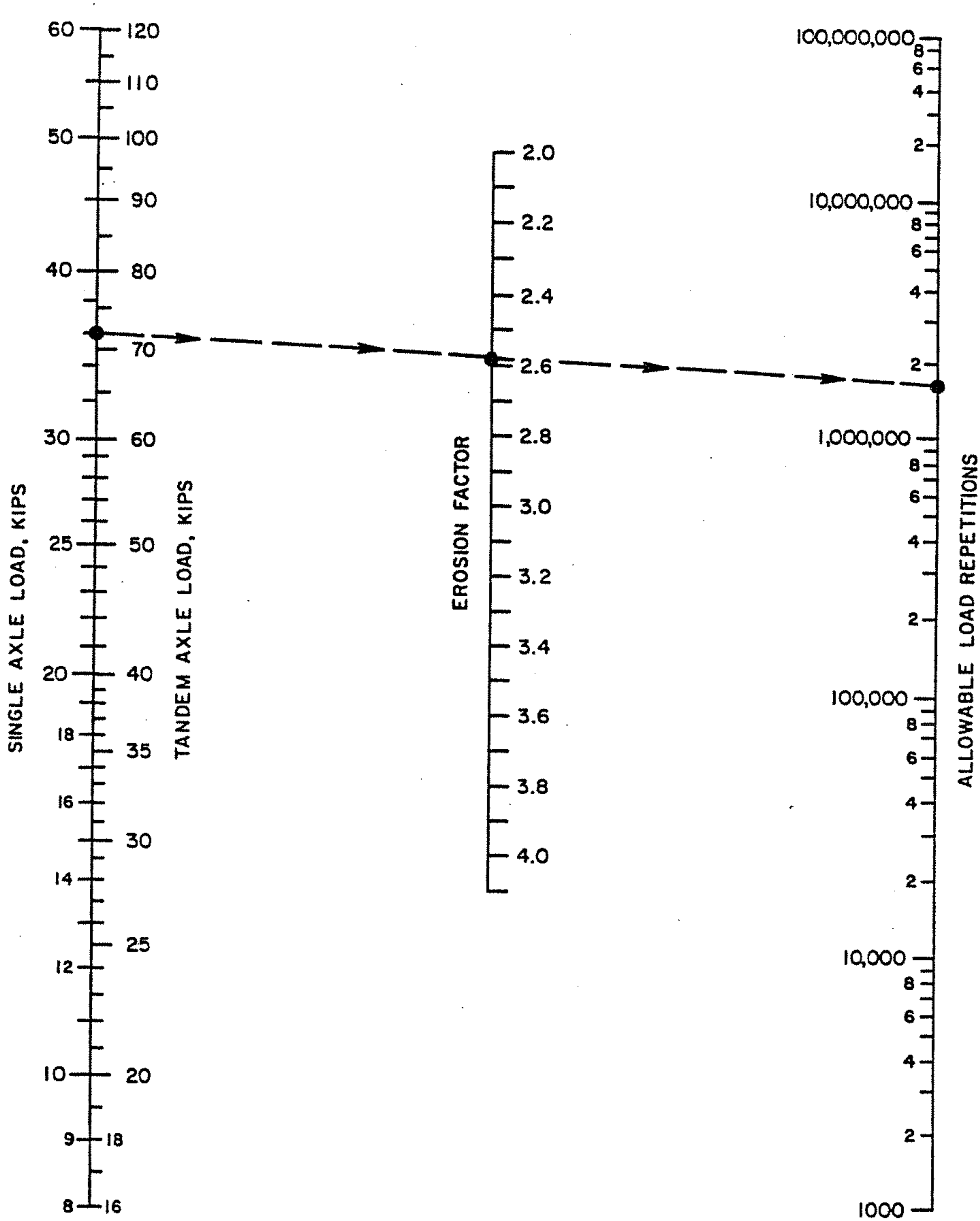


.. Fatigue analysis—allowable load repetitions based on stress ratio factor (with and without concrete shoulder).

Figure 3-3

Table 3D Erosion Factors — Aggregate-Interlock Joints, No Concrete Shoulder (Single Axle/Tandem Axle)

Slab thickness, in.	*k* of subgrade-subbase, pci					
	50	100	200	300	500	700
4	3.94/4.03	3.91/3.95	3.88/3.89	3.86/3.86	3.82/3.83	3.77/3.80
4.5	3.79/3.91	3.76/3.82	3.73/3.75	3.71/3.72	3.68/3.68	3.64/3.65
5	3.66/3.81	3.63/3.72	3.60/3.64	3.58/3.60	3.55/3.55	3.52/3.52
5.5	3.54/3.72	3.51/3.62	3.48/3.53	3.46/3.49	3.43/3.44	3.41/3.40
6	3.44/3.64	3.40/3.53	3.37/3.44	3.35/3.40	3.32/3.34	3.30/3.30
6.5	3.34/3.56	3.30/3.46	3.26/3.36	3.25/3.31	3.22/3.25	3.20/3.21
7	3.26/3.49	3.21/3.39	3.17/3.29	3.15/3.24	3.13/3.17	3.11/3.13
7.5	3.18/3.43	3.13/3.32	3.09/3.22	3.07/3.17	3.04/3.10	3.02/3.06
8	3.11/3.37	3.05/3.26	3.01/3.16	2.99/3.10	2.96/3.03	2.94/2.99
8.5	3.04/3.32	2.98/3.21	2.93/3.10	2.91/3.04	2.88/2.97	2.87/2.93
9	2.98/3.27	2.91/3.16	2.86/3.05	2.84/2.99	2.81/2.92	2.79/2.87
9.5	2.92/3.22	2.85/3.11	2.80/3.00	2.77/2.94	2.75/2.86	2.73/2.81
10	2.86/3.18	2.79/3.06	2.74/2.95	2.71/2.89	2.68/2.81	2.66/2.76
10.5	2.81/3.14	2.74/3.02	2.68/2.91	2.65/2.84	2.62/2.76	2.60/2.72
11	2.77/3.10	2.69/2.98	2.63/2.86	2.60/2.80	2.57/2.72	2.54/2.67
11.5	2.72/3.06	2.64/2.94	2.58/2.82	2.55/2.76	2.51/2.68	2.49/2.63
12	2.68/3.03	2.60/2.90	2.53/2.78	2.50/2.72	2.46/2.64	2.44/2.59
12.5	2.64/2.99	2.55/2.87	2.48/2.75	2.45/2.68	2.41/2.60	2.39/2.55
13	2.60/2.96	2.51/2.83	2.44/2.71	2.40/2.65	2.36/2.56	2.34/2.51
13.5	2.56/2.93	2.47/2.80	2.40/2.68	2.36/2.61	2.32/2.53	2.30/2.48
14	2.53/2.90	2.44/2.77	2.36/2.65	2.32/2.58	2.28/2.50	2.25/2.44



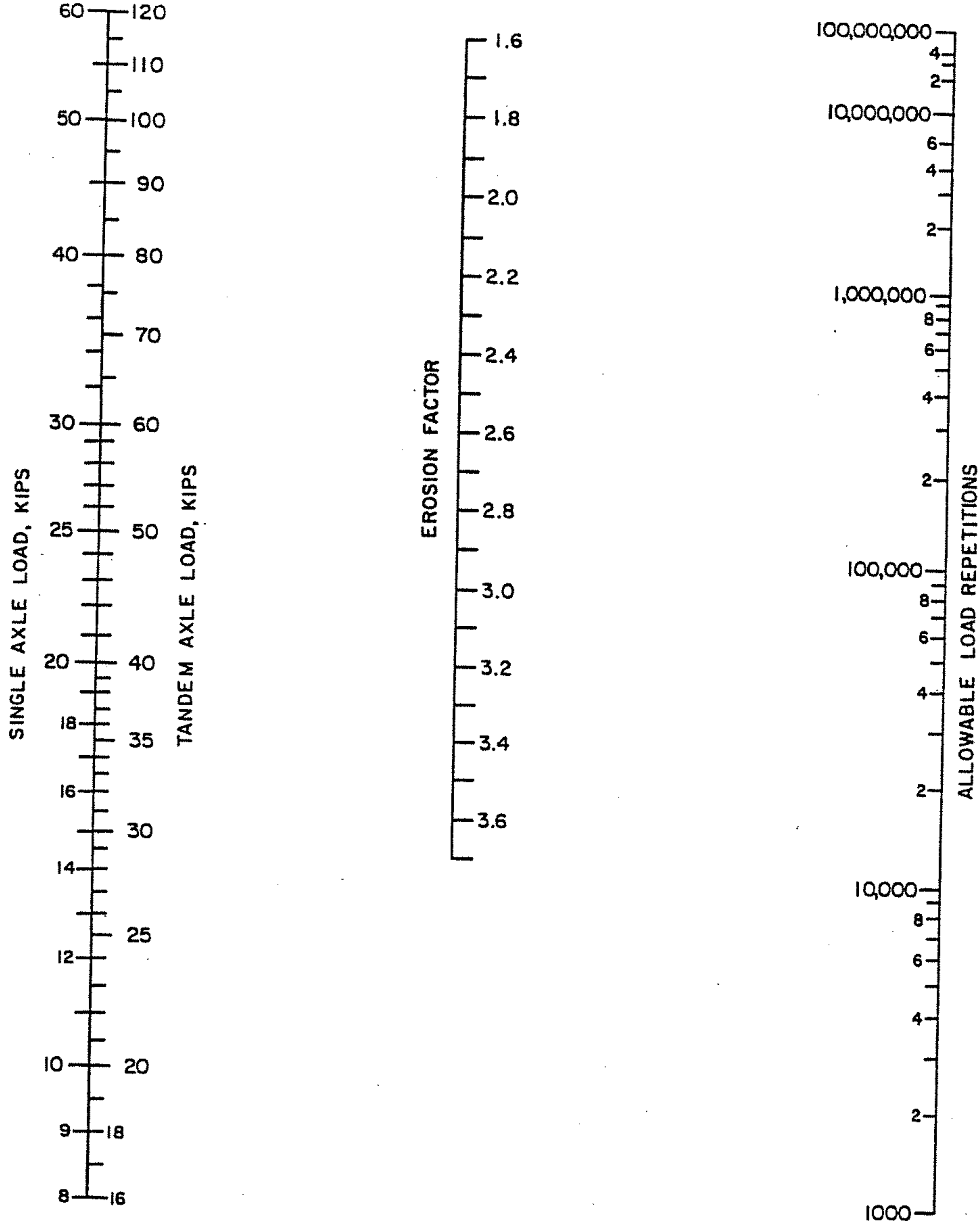
Erosion analysis—allowable load repetitions based on erosion factor (without concrete shoulder).

Figure 3-4

Table 3E - Deleted

Table 3F Erosion Factors — Aggregate-Interlock Joints, Concrete Shoulder (Single Axle/Tandem Axle)

Slab thickness, in.	k of subgrade-subbase, pci					
	50	100	200	300	500	700
4	3.46/3.49	3.42/3.39	3.38/3.32	3.36/3.29	3.32/3.26	3.28/3.24
4.5	3.32/3.39	3.28/3.28	3.24/3.19	3.22/3.16	3.19/3.12	3.15/3.09
5	3.20/3.30	3.16/3.18	3.12/3.09	3.10/3.05	3.07/3.00	3.04/2.97
5.5	3.10/3.22	3.05/3.10	3.01/3.00	2.99/2.95	2.96/2.90	2.93/2.86
6	3.00/3.15	2.95/3.02	2.90/2.92	2.88/2.87	2.86/2.81	2.83/2.77
6.5	2.91/3.08	2.86/2.96	2.81/2.85	2.79/2.79	2.76/2.73	2.74/2.68
7	2.83/3.02	2.77/2.90	2.73/2.78	2.70/2.72	2.68/2.66	2.65/2.61
7.5	2.76/2.97	2.70/2.84	2.65/2.72	2.62/2.66	2.60/2.59	2.57/2.54
8	2.69/2.92	2.63/2.79	2.57/2.67	2.55/2.61	2.52/2.53	2.50/2.48
8.5	2.63/2.88	2.56/2.74	2.51/2.62	2.48/2.55	2.45/2.48	2.43/2.43
9	2.57/2.83	2.50/2.70	2.44/2.57	2.42/2.51	2.39/2.43	2.36/2.38
9.5	2.51/2.79	2.44/2.65	2.38/2.53	2.36/2.46	2.33/2.38	2.30/2.33
10	2.46/2.75	2.39/2.61	2.33/2.49	2.30/2.42	2.27/2.34	2.24/2.28
10.5	2.41/2.72	2.33/2.58	2.27/2.45	2.24/2.38	2.21/2.30	2.19/2.24
11	2.36/2.68	2.28/2.54	2.22/2.41	2.19/2.34	2.16/2.26	2.14/2.20
11.5	2.32/2.65	2.24/2.51	2.17/2.38	2.14/2.31	2.11/2.22	2.09/2.16
12	2.28/2.62	2.19/2.48	2.13/2.34	2.10/2.27	2.06/2.19	2.04/2.13
12.5	2.24/2.59	2.15/2.45	2.09/2.31	2.05/2.24	2.02/2.15	1.99/2.10
13	2.20/2.56	2.11/2.42	2.04/2.28	2.01/2.21	1.98/2.12	1.95/2.06
13.5	2.16/2.53	2.08/2.39	2.00/2.25	1.97/2.18	1.93/2.09	1.91/2.03
14	2.13/2.51	2.04/2.36	1.97/2.23	1.93/2.15	1.89/2.06	1.87/2.00



Erosion analysis—allowable load repetitions based on erosion factor (with concrete shoulder).

Figure 3-5

CHAPTER 4

PAVEMENT REHABILITATION PROCEDURES

4.1 Introduction

Procedures for rehabilitating the pavement either structurally or functionally (non-structural) are described in this chapter. Pavement rehabilitation is used to restore the functional quality that has been loss to the deteriorative effects of the traffic loads and exposure to the environment.

4.1.1 Structural Failure

Traffic loading causes progressive weakening of the strength of the pavement section. For asphalt concrete (AC) pavements, alligator cracking, rutting, and depressions in the wheel paths are indications of weakening of the pavement section. Alligator cracking is the result of flexure in the asphalt layer either through fatigue or bending which exceeds the tensile strength of the AC layer. Rutting and depressions indicate bearing failure of the materials in the pavement section or of the subgrade. Rutting and depressions due to instability of the asphalt concrete mixture in the surface course is not considered structural failure of the pavement section. For Portland cement concrete (PCC) pavement, faulting and slabs consisting of several pieces defined by cracks and the joints of the slab indicate structural failure. Faulting is caused by the loss of load transfer across joints and cracks, cracks are caused by fatigue, and contributing to both conditions is the loss of support under the slab through erosion of the material directly under the slab.

4.1.2 Non-Structural Failure

Loss of functional quality from distresses other than traffic loading is considered non-structural failure. For asphalt concrete (AC) pavements, block cracking, transverse cracking, longitudinal cracking, raveling, and rutting and depressions due to instability of the AC mixture are distresses for which the primary cause is not structural failure of the pavement section. For Portland cement concrete (PCC) pavements spalling, scaling, popouts, map cracking, and failure of joint sealant are non-structural failures. Other conditions that affect both AC and PCC pavements are items such as utility trenches and settlement of embankments.

4.2 Scope

These procedures apply to both asphalt concrete (AC) and Portland cement concrete (PCC) pavements for existing roadways that are to remains in service. These procedures do not apply to the design of pavement sections for the widening of existing roadways. Evaluation of the condition of the existing pavement including the need to drain the pavement section is required.

4.3 Rehabilitation Procedures for Asphalt Concrete (AC) Pavements

4.3.1 Non-Structural Rehabilitation

Structural rehabilitation of the entire roadway within the project limits is not required and a rehabilitation strategy that satisfies the functional requirements of the roadway pavement can be applied for the following conditions:

- The areas requiring repair because of structural distress amounts to less than 15% of the total pavement area proposed for rehabilitation,
- Only none structural distresses are found,

Repair of the structurally distressed areas is required, (localized or spot repair). Design the pavement section for the localized or spot repair in accordance with the structural design procedures of the State of Hawaii, DOT, Highways Division, using a design life of ten years.

4.3.2 Structural Rehabilitation

Structural rehabilitation is required for the following conditions:

- The areas requiring repair because of structural distress amounts to 15% or greater of the total pavement area proposed for rehabilitation.
- The proposed pavement grade is to be lower than the existing pavement grade.

The entire roadway area (the travel way lanes and shoulders), within the project limits is to be rehabilitated with a pavement section designed in accordance with the structural design procedures of the State of Hawaii, DOT, Highways Division and as modified herein.

Structural distresses may be determined by observation of alligator cracking, and depressions and rutting that are caused by the failure of the pavement structure from traffic loads. Depressions and rutting caused by the instability of the AC mix and raveling are not structural defects.

4.4 Rehabilitation Procedures for Portland Cement Concrete (PCC) Pavements

No rehabilitation procedures available for PCC pavements at this time (9/10/01).

4.5 Pavement Section Drainage

The Federal Aid Policy Guide dated April 8, 1999 recognizes the need for draining of the pavement section under NS 23 CFR 626, Non-Regulatory Supplement, (1) General Pavement Design Considerations, b. Pavement Design Factors, (2) Foundation , paragraphs (c) and (d).

Excerpts from the paragraphs:

> "(c) Drainage is an important factor in pavement design, and should be considered "on all projects. However, inadequate subsurface drainage continues to be a significant cause of pavement distress, particularly in Portland cement concrete pavements. During ....."

> "(d) The developments in permeable base technology and longitudinal edgedrains make positive pavement drainage possible and affordable. Accordingly, pavement design procedures need to consider the effects of moisture on the performance of the pavement. Where the drainage analysis or past performance indicates the potential for reduced service life due to saturated structural layers or pumping, the design needs to include positive measures to minimize that potential. NHI ....."

For both structural and functional rehabilitation provide measures to minimize the potential of increased maintenance and reduced service life in the rehabilitated pavement section due to moisture in the pavement section.

4.5.1 Drainage Evaluation for Functional Rehabilitation

As a minimum, provide positive measures to minimize the effects of moisture damage in the pavement if any one or more of the following conditions are found in the roadway:

- moisture or pumping is observed on the roadway or in the pavement structure,
- distresses (such as popouts, delamination of the AC layers, potholes, and patching), observed on the pavement section where moisture may be the probable cause of the distresses,
- historical information that may indicate potential for increase in pavement maintenance requirements due to distresses caused by moisture in the pavement.

When the effect of moisture has been determined to affect the performance of the pavement, remedial measures will need to be taken as deemed appropriate by the design engineer except geocomposite drains will not be used.

4.5.2 Drainage Analysis for Structural Rehabilitation

Design for pavement section drainage is to be based on the analysis of the infiltration of water into the pavement due to rainfall and the ability of the pavement materials to drain 50% of the drainable water in 24 hours.

4.5.3 Underdrain

When subdrainage systems are needed, underdrain system using flexible or rigid plastic perforated pipe and aggregates with high permeability wrapped in filter fabric should be used. Geocomposite edge drains are not acceptable. When pipes are used in areas where traffic is to be supported, effects of the traffic loads on the pipe needs to be considered.

CHAPTER 5

ECONOMIC EVALUATION OF ALTERNATIVE PAVEMENT TYPES

5.1 Introduction

The two types of pavement generally considered for new pavement construction are rigid (PCCP) and flexible pavements (ACP). Since factors that influence cost differs significantly from project to project, each must be studied individually. Therefore the design engineer must consider these factors based on his best judgement when determining which type to specify.

Whatever the factors are that control the selection of the pavement type, they should be documented in the Pavement Type Justification report.

A detailed economic comparison of pavement type is required except for the following conditions:

a. Where a short section of an existing pavement will be widened or resurfaced with a similar material
b. Where unavoidable future flooding or a high water table dictates the use of Portland cement concrete pavement
c. Where it is economically unreasonable to locate and construct the highway so that unequal settlement or expansion will be eliminated, thus dictating the use of asphalt concrete pavement.
d. Where short freeway to freeway connections are being made between pavements of the same type.

Pavements with untreated bases experienced higher maintenance cost because it require significant digout repairs of the existing pavements in addition to the maintenance overlays during its design life due to water collecting in the pavement layer causing fatigue cracking and potholes.

5.2 Pavement Type Determination

The choice of pavement type should consider the following factors, which are listed and discussed in Appendix B of the AASHTO Guide for Design of Pavement Structures. The primary factors listed are:

a. Traffic
b. Soils characteristics
c. Weather

d. Construction considerations
e. Recycling
f. Cost comparison

Other factors to consider are the following

a. Performance of similar pavements in the project area
b. Adjacent existing pavements
c. Conservation of material and energy
e. Availability of local materials or contractor capabilities
f. Traffic, worker, and public safety
g. Incorporation of new or experimental features
h. Stimulation of competition
i. Municipal preference, participation local government preference and recognition of local industry

Another consideration that may have a possible effect on the final decision is the presence of grade controls, such as median barrier, drainage facilities, lateral and head clearances, and structures which may limit the structural section design or rehabilitation strategies. The pavement type selection should consider how these appurtenant features affect the mainline pavement.

The design or rehabilitation strategy should also minimize the exposure and maximize the safety of the construction or maintenance forces and their equipment. After considering the various governing factor and other specific items involved with the project under study, alternative structural sections should be developed for analysis. Once the alternative structural sections are chosen, an economic analysis should be done. This analysis is basically to consider the most economical structural section elements among the various alternatives. If a detailed analysis is not required, per Section 5.1, a less comprehensive analysis must still be done.

If a detailed economic analysis is required, it should follow the procedure in Section 5.3. It is important to note that economics alone does not always dictate the final choice for structural sections or their alternative elements. After analyzing all of the information available, the structural section or rehabilitation strategy is recommended in the pavement type justification report. Include the information and rationale used to select the recommended pavement section in the pavement justification report.

5.3 Economic Analysis

General Economic Comparison. Life-cycle economic comparisons must be made between the properly designed structural sections that would be approved for construction if selected. The structural section chosen in the economic comparison must be included in the final plans unless a revision is subsequently approved. In this event a short memorandum is prepared referring to the original documentation, stating the details of the change, the reasons for the change, and the revised total life-cycle cost when required.

The economic comparison of structural sections should be based on total expected life-cycle costs. The following general guidelines should be used:

a. The structural sections to be compared should be shown by sketches so that quantities can be computed and checked.
b. An economic life-cycle period of that equal to design life listed in Section 1.1.1 but not less than 30 years should be used for each project. The economic analysis will be based on the assumption that the pavement structural section will be maintained to carry the projected traffic for at least the economic life-cycle period.
c. A discount rate of 0% is to be used to convert costs to present worth.
d. Total life-cycle costs are generally computed for the entire pavement structural section, including shoulders, for a length of one mile in one direction of travel on divided highways and both directions in undivided highways.

The total expected life-cycle cost analysis for a PCCP and ACP structural section should include the following items as appropriate:

a Initial costs
b. Maintenance costs
c. Rehabilitation costs
d. Salvage Value

Initial Cost. Computing the initial cost of construction involves the calculation of material quantities to be provided in each pavement structure and multiplying by their unit prices. Material quantities are generally direct functions of their thickness in the pavement structure. They are also functions of thickness of other layers and the width of pavement and shoulders.

The cost of in-place material in a pavement structure is not directly proportional to the volume required. Unit material price is dependent on material quantity to be provided, construction procedure employed, length of project, etc. Therefore, care should be taken to estimate quantities and true expected costs carefully.

Initial costs should include the surface material, base, subbase and excavation of the roadway and shoulders. It should also include the structural section drainage system and permeable separator. For PCCP, it should include tie bars when PCC shoulders are used.

Maintenance Costs. The estimation of all cost which are essential to maintaining pavement investment at a desirable specified level of service, or at a specified rate of deteriorating service, is essential to a proper economic analysis. The level of maintenance, i.e., the type and extent of maintenance operations, determines the rate of loss of riding quality or serviceability index.

There are various maintenance operations which are carried out for a highway. Maintenance of pavement, shoulders, drainage, erosion, vegetation, and structures are some of the major categories. For pavement economic analysis only those categories of maintenance which directly affect the performance of a pavement should be considered.

For AC pavements this normally includes maintenance of pavement surface, for both roadway and shoulders due to aging of the asphalt. The rationale is that the pavement structurally adequate for the traffic loads during its design life.

Maintenance costs for ACP include maintenance overlays, patching, and filling potholes.

A maintenance overlay of 1.5" - 2.5" at 10 years interval is used when the pavement is designed with an asphalt treated base on treated or untreated permeable base. Cold planing is to be considered when grades must be maintained.

Maintenance costs for PCCP include retexturing at 30 years.

Rehabilitation Costs. Rehabilitation cost includes future overlays and upgrading made necessary when the riding quality of a pavement decreases to a certain minimum level of acceptability. Work undertaken to extend the service life of an existing facility. This includes placement of additional surfacing material and/or other work necessary to return an existing roadway, including shoulders, to a condition of structural or functional adequacy. This could include partial removal and replacement of the pavement structure.

Pavement rehabilitation projects can substantially increase the service life of a significant length of roadway. Rehabilitation work may include:

1. Resurfacing to provide improved structural capacity or serviceability;
2. Replacing or restoring malfunctioning joint for PCCP;
3. Grinding or grooving of PCCP to restore smoothness or skid resistance, providing adequate structural thickness remains;

4. Removing and replacing deteriorated material;
5. Reworking or strengthening of base or subbase;
6. Recycling of existing materials; and
7. Adding underdrains.

Since rehabilitation may include several of the work listed above, rehabilitation is an expensive alternative to designing for a longer pavement life initially.

Rehabilitation strategies is very expensive especially when user delay cost is considered.

The approach used in this manual is to design for a structurally longer pavement life initially, and do maintenance strategies to maintain the roadway. In addition, because rehabilitation strategies necessitate construction activities be done under traffic condition, reducing the lane closure to a minimum is the best alternative for both the driving motorist and construction workers. As a result, with the design life equaling the economic analysis period, one need not consider rehabilitation strategies and cost.

However, if rehabilitation strategies are considered a 50 yrs analysis period should be considered. Strategies and procedures for rehabilitation of the various types of pavements are currently under development.

Work Zone User Delay Cost. Any time construction activities occur under traffic, it will affect the motorist in time and money. FHWA-SA-98-079 provides guidelines in establishing and determining user delay cost.

Salvage Value. Salvage value can be significant because it can involve the value of reusable materials at the end of the design period. Salvage value of a material depends on several factors, such as volume and position of the material, contamination, age or durability, anticipated used at the end of the design period, etc. For the purpose of the economic analysis the salvage value shall be zero at the end of the design life.

Life-cycle Cost Analysis. The computation of the life-cycle cost is to be based on the present worth cost method. The present worth cost for the pavement type can be stated as the following:

$$PWC = IC + (RC + SC + DC)PW$$
$$+ (MC)(PF2) - (SV)(PW$$

where:

PWC	=	Present worth cost
IC	=	Initial cost
RC	=	Rehabilitation cost
EC	=	Engineering cost
SC	=	Supplemental work cost
DC	=	Work zone user delay cost
PWF	=	Present worth factors
MC	=	Maintenance cost
SV	=	Salvage value

An economic life-cycle cost comparison format for a period equaling the design life but not less than 30 years is used for the analysis.

It is recognized that flexible (asphalt concrete) pavements generally requires some significant maintenance or rehabilitation during the design life, whereas rigid (portland cement concrete) pavements will require minimal work until after the design period has transpired.

Appendix A

PAVEMENT STRUCTURAL SECTION

TERMINOLOGIES

APPENDIX A
PAVEMENT STRUCTURAL SECTION TERMINOLOGIES

Alligator Cracking. Interconnected or interlaced load associated (fatigue) cracks in asphalt concrete pavement forming a series of small polygons that resemble the typical patter of an alligator's skin.

Analysis Period. The period of time for which the economic analysis is to be made; ordinarily will include at least one rehabilitation activity. This is also referred to as "economic life-cycle period".

Asphalt Treated Permeable Base (ATPB). A highly permeable open-graded mixture of crushed coarse aggregate and asphalt binder place as the base layer to assure adequate drainage of the structural section, as well as structural support.

Base. A layer of selected, processed, and/or treated aggregate material of planned thickness and quality placed immediately below the pavement and above the subbase or basement soil to support the pavement.

Base Course. See Base.

Basement Material. The material in excavation or embankments underlying the lowest layer of subbase, base, pavement surface or other specified layer which is to be placed.

Block Cracking. Interconnected cracks on flexible pavement, that are not load associated, which form a series of large polygons usually with sharp corners or angles.

Blow-up. Localized upward buckling or a shattering of a rigid pavement slab at or near a transverse joint or crack.

Borrow. Natural soil obtained from sources outside the roadway prism to make up a deficiency in excavation quantities.

Cement Treated Permeable Base (CTPB). A highly permeable open-graded mixture
of coarse aggregate, portland cement, and water placed as the base layer to provide adequate drainage of the structural section, as well as structural support.

Chip Seal. A high viscosity asphaltic emulsion surface coat which incorporates rolled in rock screenings (chips) over an asphalt concrete pavement, as preventive maintenance, to extend the service life.

Cold Recycling. The rehabilitation of asphalt concrete pavement without the application of heat by milling and mixing with new binder and/or rejuvenating agents in place.

Composite Pavement. A pavement structure or structural section composed of an asphalt concrete wearing surface and Portland cement concrete slab: an asphalt concrete overlay on a PCC slab is also referred to as a composite pavement.

Construction Joint. A joint made necessary by a prolonged interruption in the placing of concrete.

Contraction Joint. See Weaken Plane Joint.

Deformed Bar. A reinforcing bar for rigid slabs conforming to "Requirements of Deformations" in AASHTO Designations M31, M42, or M53.

Dense Graded Asphalt Concrete (DGAC). A uniformly graded asphalt concrete mixture (aggregate and paving asphalt) containing a small percentage of voids, used primarily as a surface layer to provide the structural strength needed to distribute loads to underlying layers of the structural section.

Design Period. The period of time that an initially constructed or rehabilitated pavement structure is designed to perform before reaching its terminal serviceability or a condition that requires major rehabilitation or reconstruction; this is also referred to as the performance period.

Dowel. A load transfer device in a rigid slab usually consisting of a plain round steel bar.

Drainage Coefficients. AASHTO Design Guide factors used to modify layer coefficients in flexible pavement or stresses in rigid pavements as a function of how well the pavement structure can handle the adverse effect of water infiltration.

Drip Track Ravel. Progressive disintegration of the surface between wheel paths on asphalt concrete pavement, caused by oil and fuel dripping from vehicles. This is most prevalent adjacent to intersections where vehicles slow or stop.

Edge Drain System. A drainage system, consisting of a slotted plastic collector pipe encapsulated in treated permeable material and a filter fabric barrier, with unslotted plastic pipe vents, outlets, and cleanouts, designed to drain the structural section of both rigid and flexible pavements.

Embankment. A prism of earth that is constructed from excavated or borrowed soil and/or rock, extending from original ground to the grading plane, and designed to provide a stable support for the structural roadbed section.

Equivalent Single Axle Loads (ESALs). Summation of equivalent 18,000-pound single axle loads used to convert mixed traffic to design traffic for the design period.

Expansion Joint. A joint located to provide for expansion of a rigid slab, without damage to itself, adjacent slabs or structures.

Faulting ("Step-off"). Differential vertical displacement, primarily at transverse joints of abutting rigid slabs which creates a "step off" in the pavement surface profile.

Flexible Pavement. A traffic load carrying system that is made up of one or more layers that are designed to transmit and distribute that loading to the underlying roadbed material. The highest quality layer is the surface course, (generally asphalt concrete) which is usually underlaid by a lesser quality base, and in turn a subbase. It is called flexible because it can tolerate deflection bending under heavy loads. A pavement structure which maintains intimate contact with and distributes loads to the subgrade and depends on aggregate interlock, particle friction, and cohesion for stability.

Fog Seal. A combination of mixing-type asphaltic emulsion and water which is applied to the surface of asphalt concrete pavement to seal the surface, primarily used for pavement maintenance.

Grading Plane. The surface of the basement material upon which the lowest layer of subbase, base pavement, surfacing, or other specified layer, is placed.

Hot Recycling. The use of reclaimed asphalt concrete pavement which is combined with virgin aggregates, asphalt and sometimes rejuvenating agents at a central hot-mix plant and place in the structural section in lieu of all new materials.

Joint Seals. Pourable, or extrudable, or premolded materials that are placed primarily in transverse and longitudinal joints in or along the edge of concrete pavement to deter the entry of water and incompressible materials.

Layer Coefficient. An AASHTO Design Guide term denoting the empirical relationship between structural number (SN) and layer thickness which expresses the relative ability of a material to function as a structural component of the pavement.

Lean Concrete Base. Mixture of aggregate, Portland cement, water, and optional admixtures, primarily used as a base for Portland cement concrete pavement.

Leveling Course. The layer, generally of asphalt concrete or other treated or processed material, that is placed over the rough or undulating surface of an existing surface to improve the surface profile or ride quality before placement of subsequent layers.

Load Transfer Device. A mechanical means designed to carry loads across a joint in a rigid slab.

Longitudinal Joint. A joint normally placed between traffic lanes in rigid pavement to control longitudinal cracking and the joint between the traveled ways and the shoulder.

Maintenance. The preservation of the entire roadway, including surface, shoulders, roadsides, structures, and such traffic control devices as are necessary for its safe and efficient utilization.

Modulus of Subgrade Reaction (k). Westergaard's modulus of subgrade reaction for use, under AASHTO Design Guide methods, in rigid pavement design (the load in pounds per square inch on a loaded area of the roadbed soil or subbase divided by the deflection in inches of the roadbed soil or subbase, psi/in.).

Open Graded Asphalt Concrete (OGAC). An open-graded mixture of aggregate and a relatively high asphalt content which provides good skid resistance and a high permeability OGAC is design to accommodate rapid surface drainage and prevent potential hydroplaning while at the same time providing an effective seal of underlying asphalt concrete pavement.

Overlay. A layer, usually asphalt concrete, placed on existing asphalt or Portland cement concrete pavement to restore ride quality, to increase structural strength (load carrying capacity), and to extend the service life.

Panel Length. The distance between adjacent transverse joints in a traffic lane.

Pavement. The surface layer of the structural section that carries traffic. Except for special or experimental surface layers, the pavement is either Portland cement concrete or asphalt concrete.

Pavement Management System (PMS). A management system to assess the condition of pavement, and to prioritize and program the rehabilitation of pavement consistent with available funding.

Pavement Performance. The trend of serviceability with load applications.

Pavement Rehabilitation. Work undertaken to extend the service life of an existing facility. This includes placement of additional surfacing and/or other work necessary to return an existing roadway, including shoulders, to a condition of structural or functional adequacy, for a minimum period. This might include the partial or complete removal and replacement of the structural section.

Pavement Reinforcing Fabric. Engineering grade synthetic fabric that is placed as an interlayer in asphalt concrete overlays primarily to minimize surface water infiltration and retard reflection cracking through the overlay, from cracks or joints in the existing pavement.

Pavement Structure. See Structural Section

Pavement Surfacing. See Surface Course

Performance Period. See Design Period.

Prepared Roadbed. In-place soils compacted or stabilized according to provisions of applicable specifications.

Present Serviceability Index (PSI). Term from the AASHTO Design Guide, which is a number derived by formula for estimating the serviceability rating from measurements of certain physical features of the pavement.

Prime Coat. The application of a low viscosity liquid bituminous material to an absorbent surface (preparatory to placing subsequent structural section layers or fabric) for the purpose of hardening or toughening the surface and promoting adhesion between it and the superimposed constructed layer or interlayer.

Pumping. The ejection of foundation material, either wet or dry, through joints or cracks, or along edges of rigid slabs resulting from vertical movements of the slab under traffic. This phenomena is especially pronounced with saturated structural sections.

Raveling. Progressive disintegration of the surface downward on asphalt concrete pavement by the dislodgement of aggregate particles and binder. Stripping usually precedes raveling.

Reinforcement. Steel embedded in a rigid slab to resist tensile stresses and detrimental opening of cracks.

Resilient Modulus. A measure of the modulus of elasticity of roadbed soil or other pavement material.

Resurfacing. A supplement surface layer or replacement layer placed on an existing pavement to restore its riding qualities or to increase its structural (load carrying) strength.

Rigid Pavement. A pavement structure primarily portland cement concrete pavement which distributes the superimposed axle loads over a relatively wide area of underlying structural section layers and soil because of its rigidity and high modulus of elasticity.

Roadbed. The graded portion of a highway between top and side slopes, prepared as a foundation for the pavement structure and shoulder. Where the medians are so wide as to include areas of undisturbed land, a divided highway is considered as including 2 separate roadbeds.

Roadbed Material. The material below the subgrade in cuts and embankments and in embankment foundations, extending to such depth as affects the support of the pavement structure.

Rubberized Asphalt. A mixture of paving asphalt combined with specified percentage of granulated reclaimed rubber for use as the binder in asphalt concrete and in stress absorbing membrane interlayers within or under asphalt concrete layers. Primary applications where benefits appear to be significant are for providing more resilience and more durable wearing surface for overlays. Rubberized asphalt joint sealant is used to keep incompressible materials out of joints in concrete pavement and retard surface water infiltration in concrete pavement.

Rutting. Longitudinal depressions that develop in the wheel paths of flexible pavement under traffic. This permanent and sometimes progressive deformation is most often caused by unstable asphalt concrete pavement or inadequate strength of the underlying foundation.

R-value. Resistance value of treated or untreated soil or aggregate as determined by the stabilometer test (California Test 301). This is a measure of the supporting strength of the basement soil and subsequent layers used in the design of structural sections.

Seal Coat. A bituminous coating, with or without aggregate, applied to the surface of a pavement for the purpose of waterproofing, preserving, or rejuvenating a cracked or raveling bituminous surface, or to provide increased skid resistance or resistance to abrasion by traffic.

Selected Material. A suitable native material obtained from a specified source such as a particular roadway cut or borrow area, or a suitable material having specified characteristics to be used for a specific purpose.

Serviceability. The ability at time of observation of a pavement to serve traffic (cars and trucks) which use the facility.

Settlement. Localized vertical displacement of pavement due to slippage or consolidation of the underlying foundation, often resulting in pavement cracking, poor ride quality and deterioration.

Shoulder Backing. A material that is placed adjacent to the outside edge of the shoulder surfacing to protect the edge from spalling, and to provide edge support.

Single Axle Load. The total load transmitted by all wheels whose centers may be included between two parallel transverse vertical planes 40 inches apart, extending across the full width of the vehicle.

Slab Cracking. Rigid pavement cracks generally resulting from a combination of heavy wheel loading. pumping action, and the resultant loss of uniform base support.

Slurry Seal. A mixture of mixing-type asphaltic emulsion, fine mineral aggregate and water proportioned, mixed and spread primarily on asphalt concrete pavement for maintenance purposes.

Spalling. Cracking, breaking, or chipping a rigid pavement along joints, edges, or cracks in which small portions of the slab are dislodged. Spalling is caused primarily by incompressible material confined in the opening or non-uniform slab support in conjunction with vertical movement does to wheel load impact.

Stress Absorbing Membrane Interlayer(SAMI). An interlayer placed within or at the bottom of an asphalt concrete overlay or layer to retard reflective cracking. It does not add to the structural strength of the pavement. Examples of SAMIs include: an interlayer of rubberized asphalt fabric, or oven graded asphalt concert. It is given and equivalency of 0.10-foot AC in AC overlay designed to prevent reflection cracking.

Stripping. The loss of adhesive bond, most often caused by the presence of water, between asphalt concrete an aggregate in asphalt concrete, which may result in raveling, loss of stability and load carrying capacity of the asphalt concrete mixture.

Structural Number(SN). An index number from the AASHTO Design Guide, which is derived from an analysis of traffic, roadbed soil conditions, and environment which may be converted to thickness of flexible pavement layers through the use of suitable layer coefficients related to the type of material being used in each layer of the pavement structure.

Structural Section. The planned traffic support layers of specified materials, normally consisting of subbase, base, and pavement placed over the basement soil. The structural section is also commonly called pavement structural section.

Structural Section Drainage System. A drainage system consisting of a permeable base layer and a collector system which include a perforated plastic pile encapsulated in a permeable material and a permeable separator barrier with unperforated plastic pipe as vents, outlets and cleanouts to rapidly drain the structural section of both asphalt and Portland cement concrete pavements. Also, called underdrains.

Subbase. A layer of aggregate of designed thickness and specified quality placed on the basement soils as the foundation for a base material.

Subgrade. The top surface of a roadbed upon which the pavement structure and shoulders are constructed.

Surface Attrition ("Abrasion"). Abnormal surface abrasion wear of pavement, resulting from either a poor quality surface or exposure to abnormal abrasive action or both.

Surface Course. One or more layers of a pavement structure designed to accommodate the traffic load, the top layer of which resists skidding, traffic abrasion, and the disintegrating effects of climate. The top layer of AC pavement is sometimes called the "wearing course".

Surface Polish. The loss of the original pavement surface texture due to traffic.

Surface Recycling. In place heating of the surface of asphalt concrete pavement followed by scarification, remixing, and compaction, generally to a depth of about 3/4 inch. This is considered to be a maintenance procedure.

Tack Coat (Paint Binder). The application of bituminous material to an existing surface to provide bond between the superimposed construction and the existing surface.

Tandem Axle Load. The total load transmitted to the road by two consecutive axles whose center may be included between parallel vertical planes spaced more than 40 inches and not more than 96 inches apart, extending across the full width of the vehicle.

Thin Bonded Concrete Overlays (BCO). An overlay, of existing concrete pavement which is designed to improve ride and structural condition. Generally BCOs are about 3 inches thick, consisting of conventional low slump Portland cement concrete or concrete containing polymers, or latex, or magnesium phosphate, or other additives designed to accommodate placement, improve bonding, and improve durability. Bonding is accomplished by epoxy or other types of adhesives.

Tie Bars. Devices, usually deformed reinforcing bars placed at intervals, to hold slabs on adjoining lanes and exterior lane-to-shoulder joints together and to prevent differential vertical movement of rigid pavement slabs.

Traffic Equivalence Factor (e). An AASHTO term denoting a numerical factor that expresses the relationship of a given axle load to another axle load in terms of their effect on the serviceability of a pavement structure. In the AASHTO Guide all axle loads are equated in terms of the equivalent number of repetions of an 18-kip single axle.

Transverse Cracking. Cracks in asphalt concrete pavement approximately at right angles to the center line, most often created by thermal forces exceeding the tensile strength of the asphalt concrete. Transverse cracks also occur in PCCP but are more often caused by live load stresses combined with uneven base support.

Triple Axle Load. The total load transmitted to the road by three consecutive axles whose centers may be included between parallel vertical planes spaced more than 40 inches and not more than 96 inches apart, extending across the full width of the vehicle.

Weaken Plane Joint. Commonly called a contraction joint, a joint normally placed at recurrent intervals in a rigid slab to control transverse cracking.

Weathering. Gradual degradation of asphalt concrete due to oxidation and hardening, especially of the surface layer resulting in transverse cracking and surface raveling.

Wearing Course. See Surface Course.

Appendix B

RAINFALL INTENSITY CHARTS

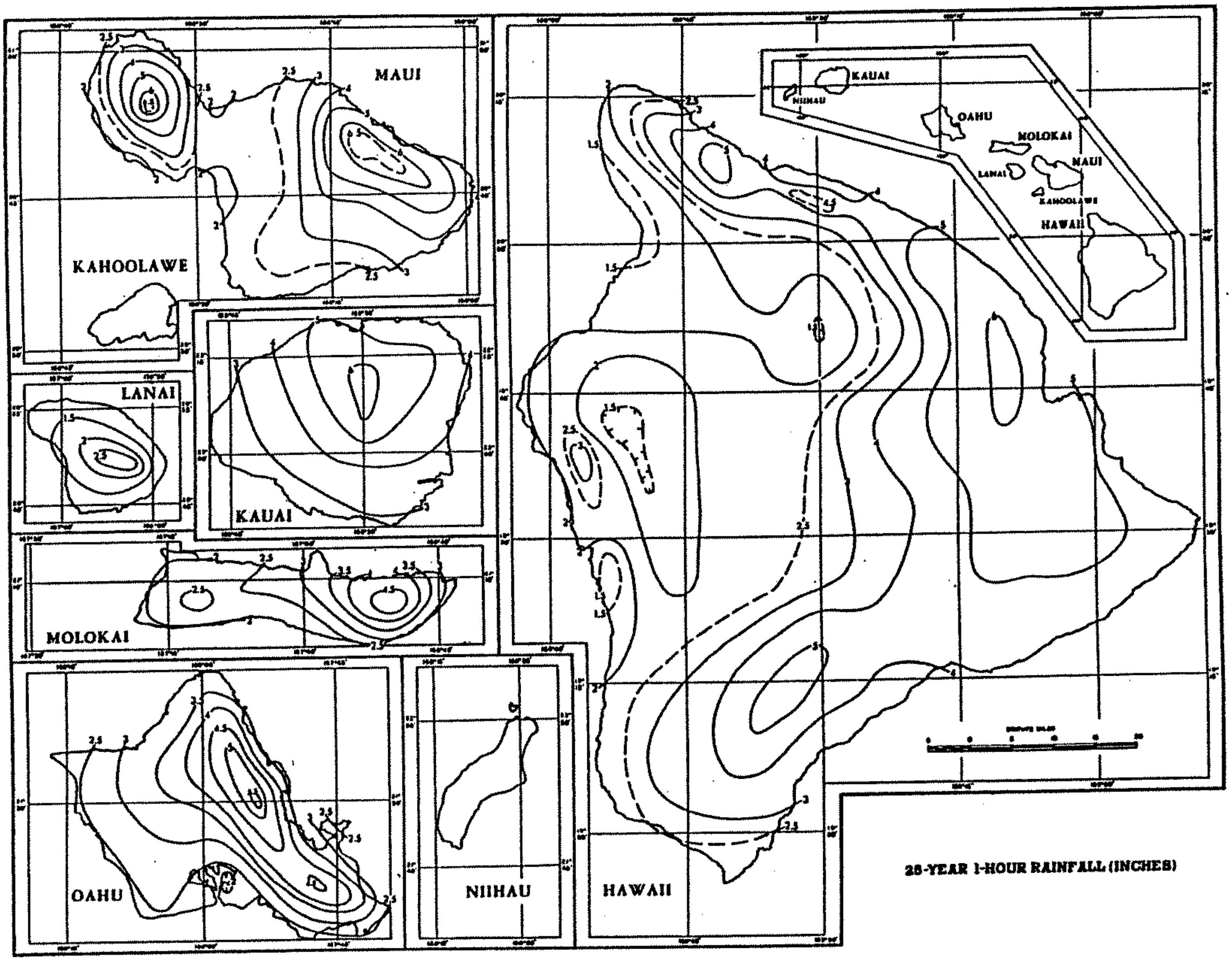


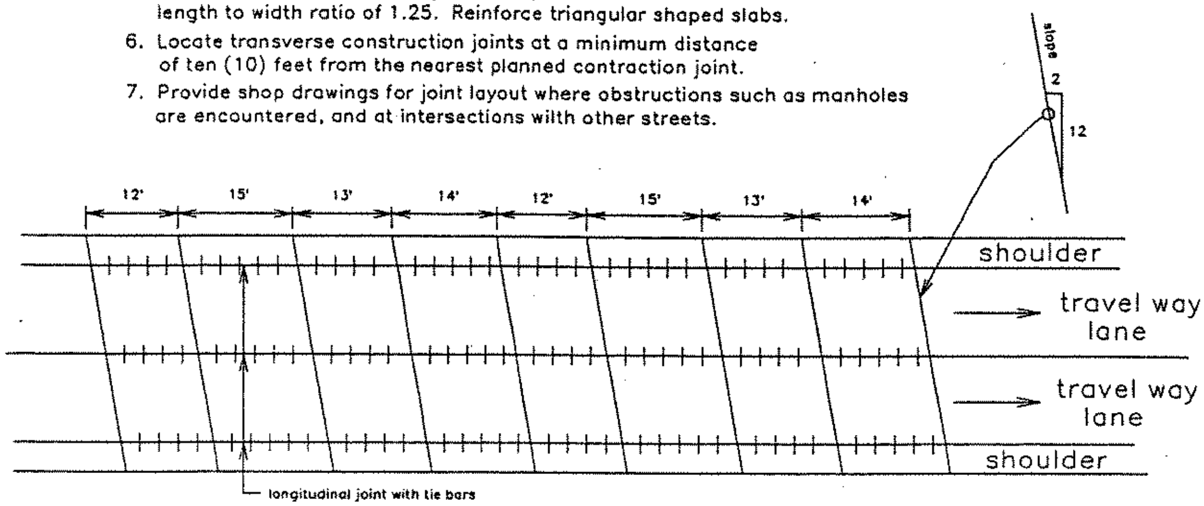
FIGURE 19.—25-yr. 1-hr. rainfall (in.)

Appendix C

JOINT DETAILS FOR PCC PAVEMENTS

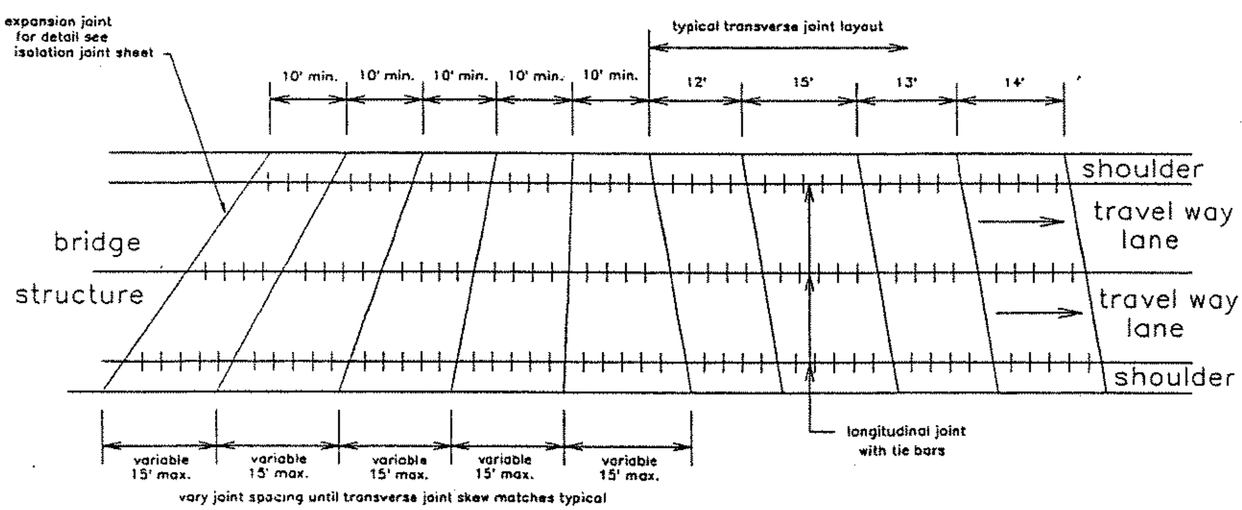
Notes:

1. The dimensions shown are for a 12 foot wide travel way lane width. For other lane widths adjust the transverse joint spacing to obtain a length to width ratio of not greater than 1.25 for the travel way lane slabs.
2. Skew the typical transverse joint with a 2 foot offset counter clockwise from a perpendicular to the edge of pavement for every 12 feet along that perpendicular.
3. Space transverse joint at successive intervals of 12', 15', 13', and 14' in the direction of travel. Repeat for the remaining joints.
4. For travelway lanes, reinforce odd shaped slabs and slabs with mismatched joints. Odd shaped slabs are slabs with length to width ratios greater than 1.25, and triangular and other nonsquare shaped slabs.
5. For the shoulder, reinforcing is not required for slabs that exceed the length to width ratio of 1.25. Reinforce triangular shaped slabs.
6. Locate transverse construction joints at a minimum distance of ten (10) feet from the nearest planned contraction joint.
7. Provide shop drawings for joint layout where obstructions such as manholes are encountered, and at intersections wilth other streets.



Typical Transverse Joint Layout

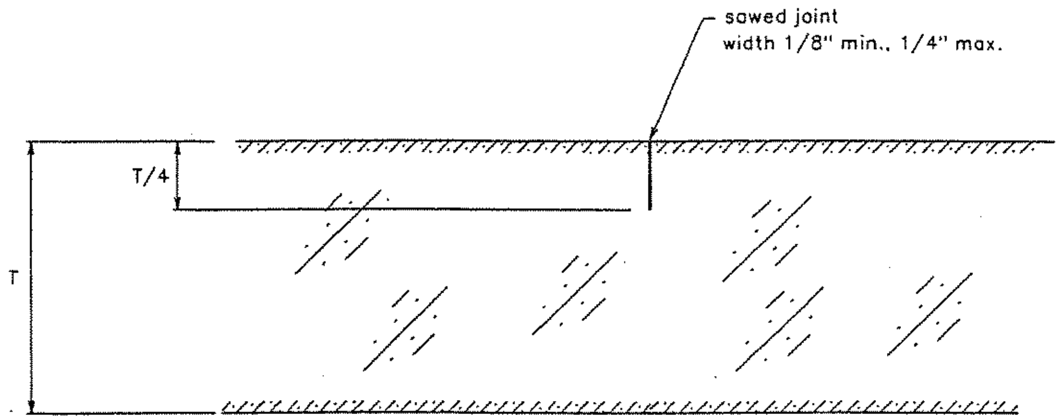
not to scale



Transverse Joint Transition
Odd Skew to Typical Skew

not to scale

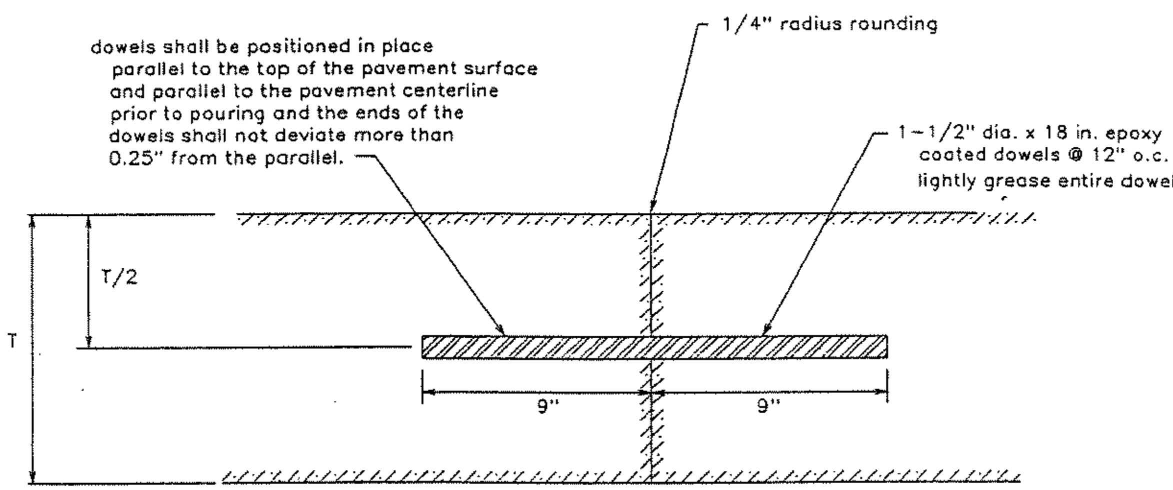
kuijp_nd.dw2



Transverse Contraction Joint

not to scale

note: epoxy coated dowels shall conform to AASHTO M284/M 284M-95, Grade 40.



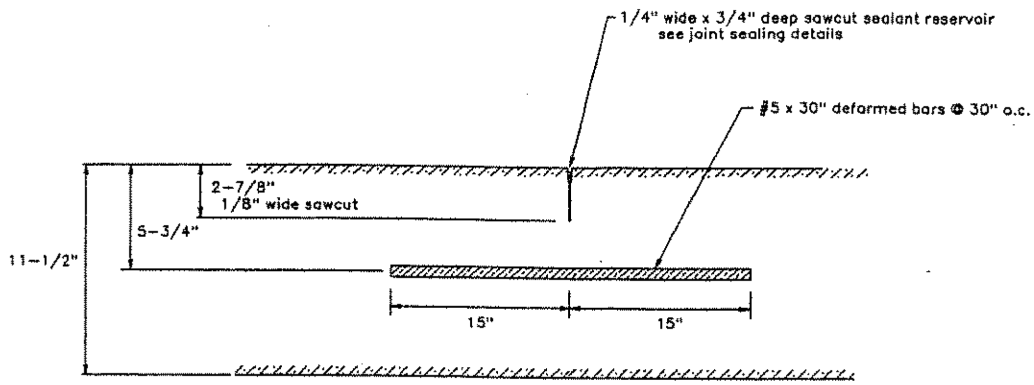
Transverse Construction Joint at Planned Joints

not to scale

manl_tjt.dw2
layers 1,2,3,5

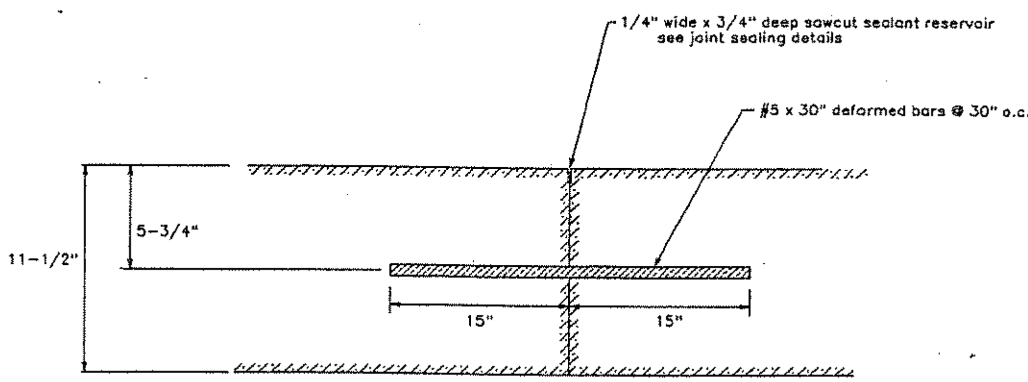
note: 1. minimum distance tiebars are to be located from a transverse joint is 15 inches. tiebars closer to the transverse joint can with joint movement.

2. epoxy coated dowels shall conform to AASHTO M284/M 284/M-95, Grade 40.



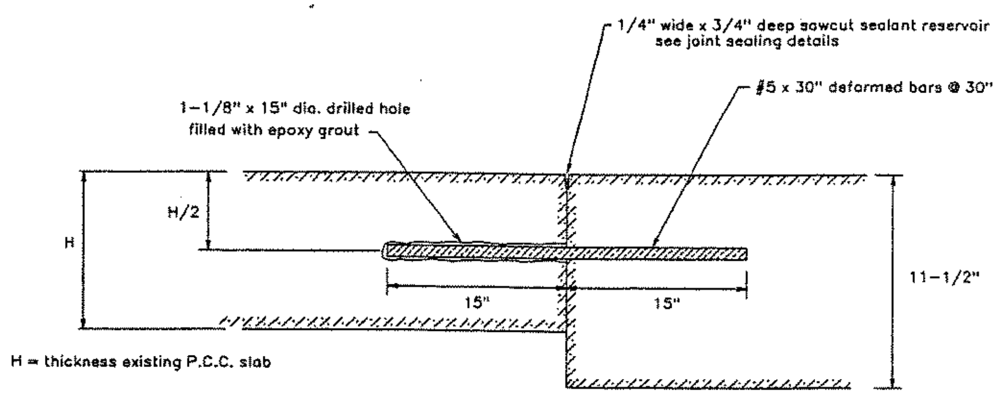
Longitudinal Contraction Joint

not to scale



Longitudinal Construction Joint

not to scale

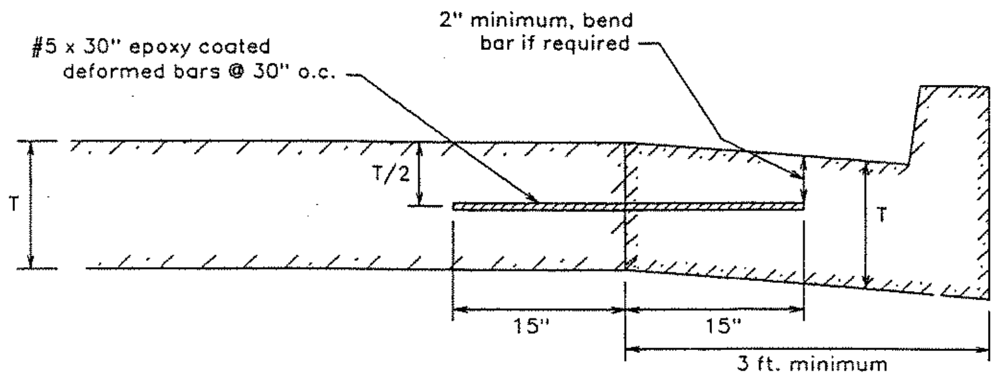


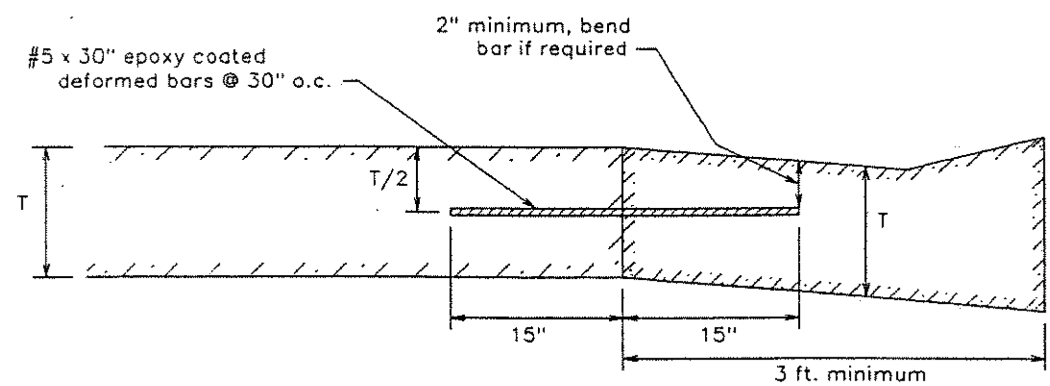
Longitudinal Construction Joint at Existing P.C.C. Pavement

not to scale

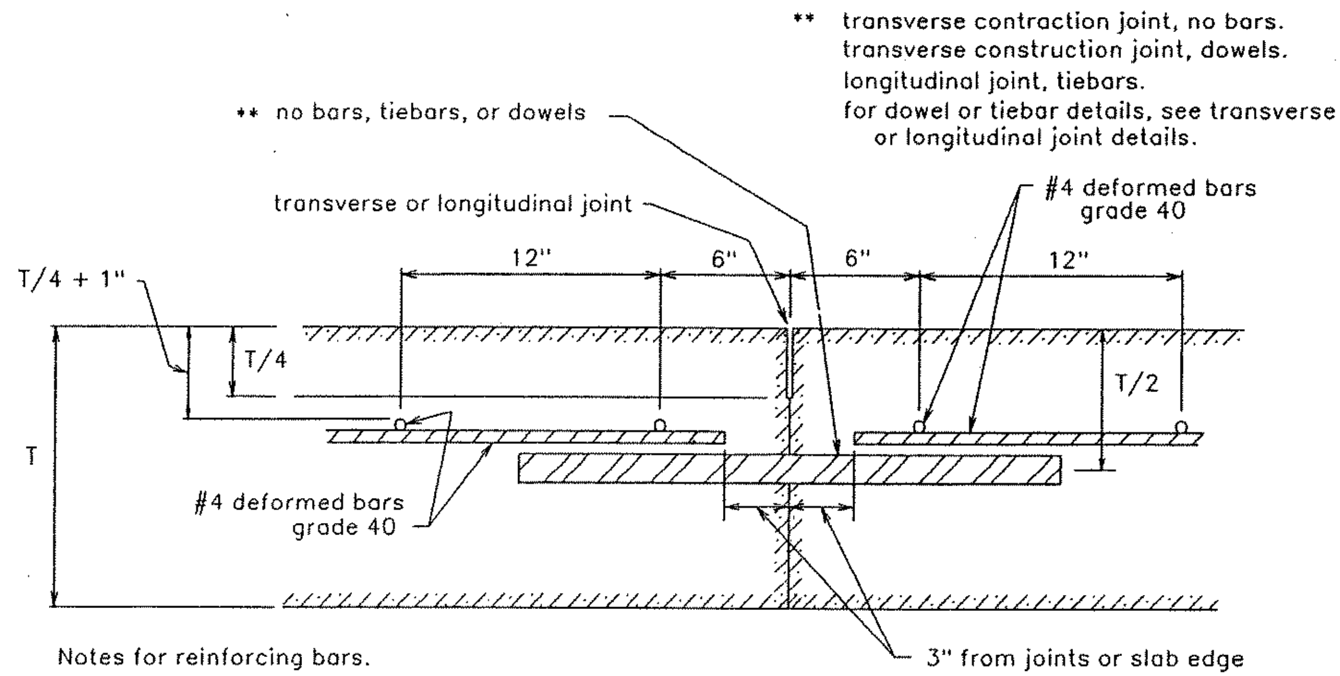
notes

1. for transverse joints location in gutter, match transverse joint and skew of adjacent lane or shouder.
2. epoxy coated bars shall conform to AASHTO M/284/M 284/M–95, Grade 40





guidelines for tieing lane or shoulder to curbs and gutters



Notes for reinforcing bars.

1. orient bars parallel to the transverse and longitudinal joints
2. one (1) bar in each foot of transverse and longitudinal length
3. terminate reinforcing bars 3" from joints or edge of slab.
4. adjust placement of reinforcing bars to avoid interfering with the movement of the dowels.

reinforcement typical section

manl_rnf.dw2
layer 2

ISOLATION JOINTS

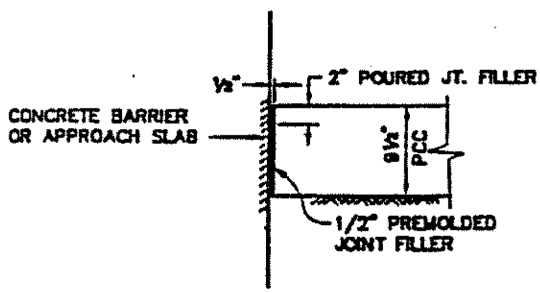
Notes:

1. Install isolation joints to allow the slab to move independently of objects that will not move evenly with the slab to minimize stress in the slab.

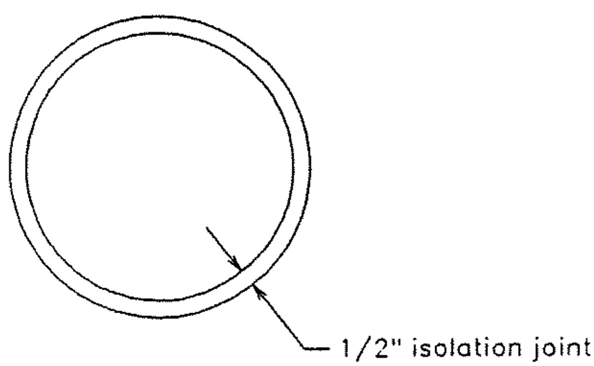
2. Minimize the amount of openings within the slab to minimize the areas from which cracking can occur. Listed below are considerations that can minimize cracking from openings in the slab.

   - Install reinforcing bars at the corners as shown below.
   - Use circular openings.
   - Install the openings along a joint.

3. Locate openings in the slab that require access in a manner that minimizes the number of travelway lanes that need to be shut down when accessing the openings.



EXPANSION JOINT DETAIL



CIRCULAR OPENING

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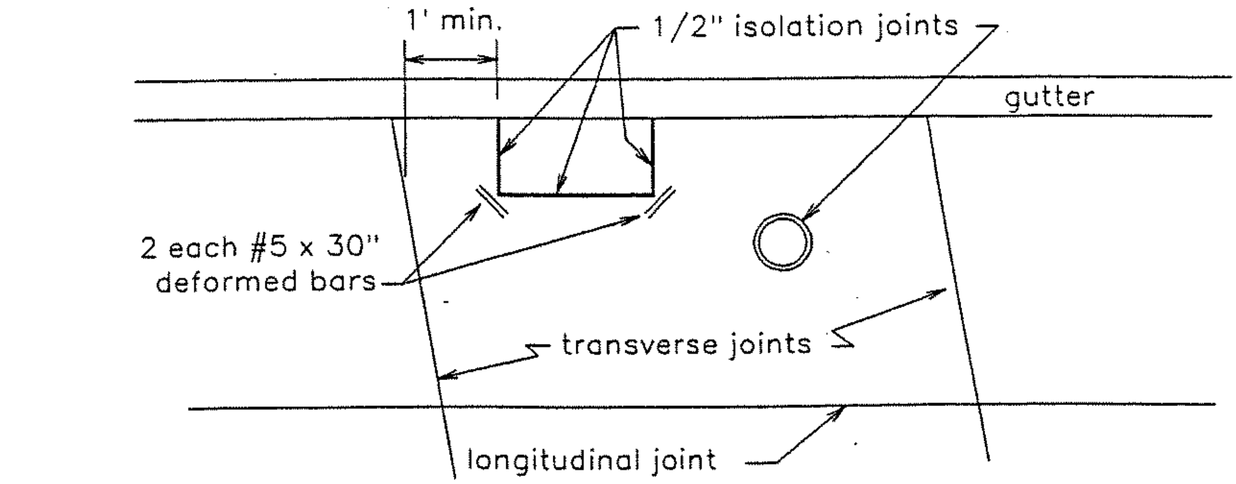
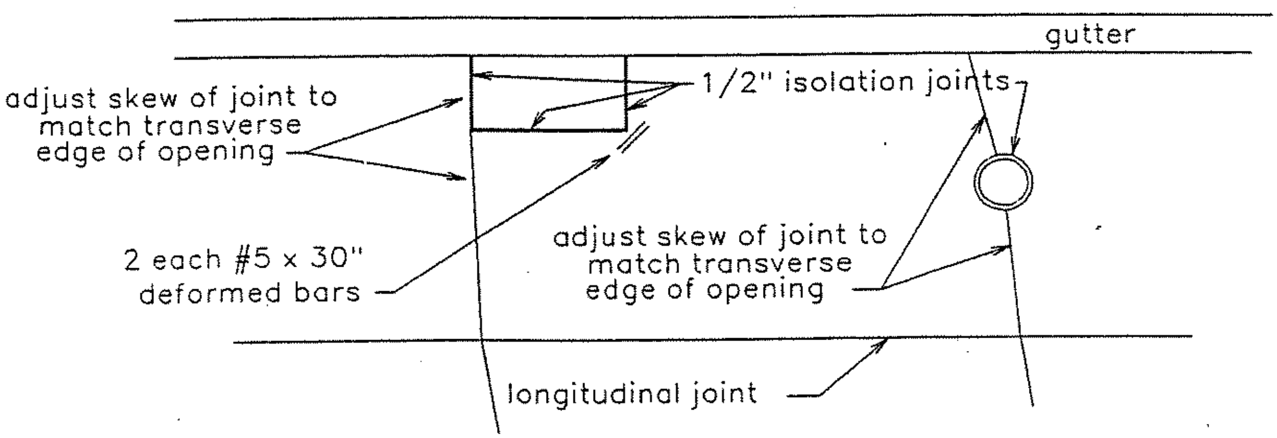
cont'd ISOLATION JOINTS



OPENINGS AWAY FROM JOINTS

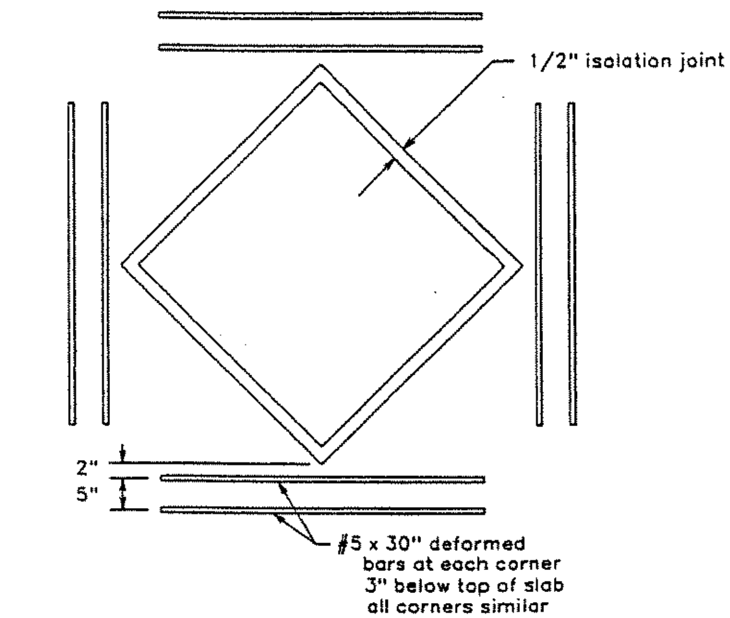


OPENINGS NEAR JOINTS

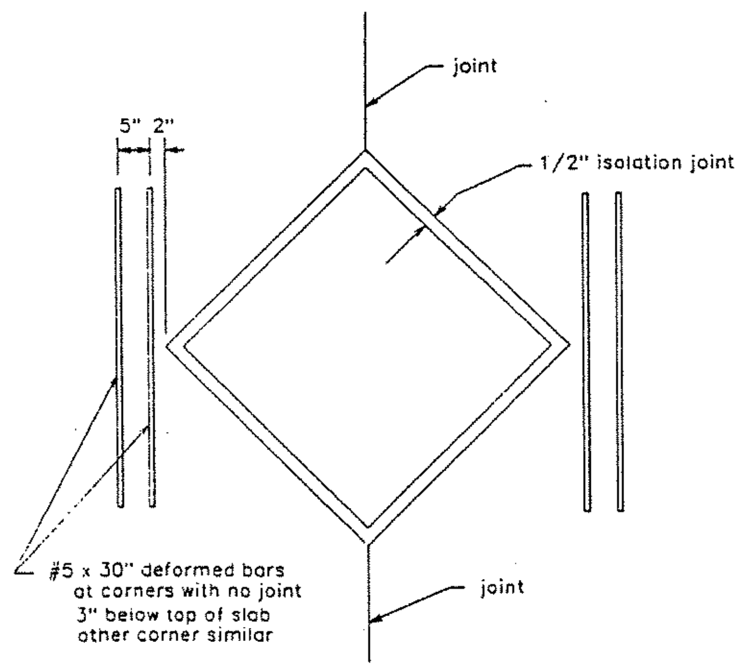
notes:

1. Locate openings along joints and configured to minimizes the amount of corners within the slab.
2. Avoid locating access openings along or near the longitudinal joints that seperate two travelway lanes.

Cont'd ISOLATION JOINTS



OPENINGS WITH CORNERS INSIDE SLAB



Avoid locating access openings along or near the longitudinal joints that separate two travelway lanes.

OPENINGS WITH CORNERS - CORNERS AT A JOINT

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