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Joint Design Methods Developed For The NYS Pavement Design Manual

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JOINT DESIGN METHODS DEVELOPED FOR THE NYS PAVEMENT DESIGN MANUAL

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16. Abstract

This report summarizes pavement joint design details developed for the New York State Pavement Design Manual. It describes the principles on which the design methods were based and the processes by which they were developed. Included are descriptions of design procedures for slab length, dowel bars, and tiebars. For slab length, the ratio of slab length (L) to radius of relative stiffness (l) is the basis for design. Dowel design uses a mechanistic-empirical model. Tiebar design is based on the strength of the reinforcing steel and drag forces on the slab. Tables and figures produced for these design procedures are included.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

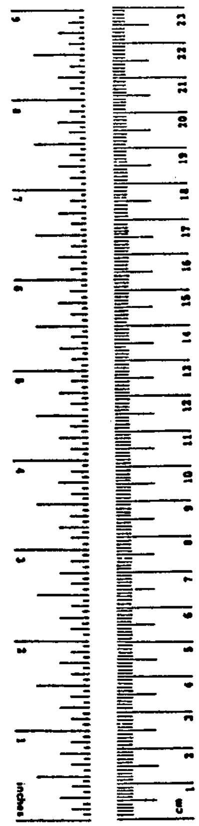
Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

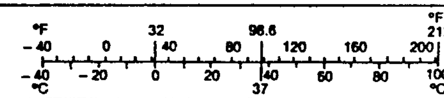
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

CONTENTS

INTRODUCTION

This report was prepared at the request of the Soil Mechanics Bureau to detail the joint design procedures used for the Corning Bypass and in development of the Department's Pavement Design Manual for New and Reconstructed Pavements (1). The intent is to explain these design methods and the principles on which they are based.

The Design Manual is being developed to adapt the 1986 AASHTO Pavement Design Guide (2) for use by New York State. This consists of adopting sections of the Guide determined to be sufficient, modifying those considered inapplicable or inappropriate, and adding material where significant items are not covered. It has been agreed that a more rational method of joint design is needed in New York, and the methods described here have been developed for that purpose.

Joint design in pavement structures involves two separate and independent procedures, for transverse and longitudinal joints. Transverse joint design also involves slab lengths and dowel bars, and longitudinal joint design includes tiebars. (Longitudinal joint spacing is normally set as a single lane width, and spacing thus is predetermined).

SLAB LENGTH DESIGN

Slab length in jointed plain concrete pavement (JPCP) is critical for crack control. JPCP design is based on the interaction between slab length, thickness, and stiffness, and the stiffness of slab support. The objective in selecting slab length is to minimize the potential for transverse cracking due to traffic and temperature, by providing desired performance at the lowest cost. This is done by considering two factors: 1) minimum initial cost (that is, to consume the minimum initial effort [man-hours], and use as little material as possible), and 2) minimal maintenance during the design life.

The design problem is to determine what slab length will provide the optimum combination of these two factors. In this process, some facts about shorter and longer slabs must be noted:

1. Shorter slabs increase the number of joints needed in the pavement, and thus more joint material and man-hours are required in initial construction.

2. The more numerous the joints, the greater is the amount of routine maintenance. Joint seals must be checked regularly and damaged seals repaired or replaced, which also increases material cost. However,

slab movement due to temperature differential is reduced, and potential for joint seal failure is thus also reduced.

3. The longer the slab, the greater are the number and severity of possible transverse cracks due to shrinkage, temperature differential, and traffic loading. Thus, if the same level of reliability is desired, thicker slabs are required.

As can be seen, a rational procedure is necessary to select a slab length that optimizes the advantages from shorter and longer slabs. Thus, very short slabs are economically unacceptable because of the large number of joints required, and longer-slab benefits are offset by the increased potential for transverse cracking. Transverse cracking potential has been found to depend on the following variables: slab length, slab thickness, modulus of subgrade reaction (k), and slab stiffness (3,4). The combination of slab thickness and modulus of subgrade reaction results in many different stress conditions for slabs. In general, the thicker the slab, the greater are the stresses due to temperature -- this effect is either increased or decreased depending on the modulus of subgrade reaction. The softer the subgrade, the lower is the k-value, and the more the subgrade will conform to the shape of the deformed slab with fewer resulting gaps. The greater the slab area that is supported, the lower is the likelihood that cracking will occur.

A two-step rational procedure to determine slab length is as follows:

STEP 1: Selection of L/l ratio

First, the radius of relative stiffness (3) of the slab as defined by Westergaard is determined:

$$l = \frac{1}{12}\left(\frac{Eh^3}{12(1-\mu^2)k}\right)^{\frac{1}{4}} \qquad (1)$$

where l = radius of relative stiffness (ft.),

E = modulus of elasticity of the slab (psi),

h = slab thickness (in.),

μ = Poisson's ratio of the slab, and

k = modulus of subgrade reaction (pci).

The following are the values normally used in the NYS Design Manual:

$E = 3.6 \times 10^6$ psi, and

$\mu = 0.15$

The k-value depends upon several factors, among which are subgrade resilient modulus, subbase material, and depth of bedrock. The k-value thus depends on the design location. Slab thickness is determined from the 1986 AASHTO Guide for Design of Pavement Structures (2) and the k-value.

The following ratios of L/l are recommended to minimize the potential of transverse cracking:

Base Type	Maximum L/l Ratio
Cement-stabilized aggregate or lean concrete	5.0
Asphalt-treated	5.5
Granular, no base	6.0

These limits will reduce the maximum transverse tensile stresses at the longitudinal joints -- that is, provide for crack control due to shrinkage, temperature differential, and traffic loading.

STEP 2: Slab Length

Once the thickness and base material type are known, slab length can be determined using the maximum L/l ratio from Step 1:

$$L/l = \text{maximum value} \tag{2}$$

$$L/l = 5.0$$

$$l = 2.49 \text{ (using Eq. 1)}$$

$$L = 5.0 \times 2.49$$

$$L = 12.46 \approx 12$$

Tables 1, 2, and 3 were compiled by performing this computation for different slab thicknesses and k-values. All values were rounded to the shorter length -- for example, 15.3 ft = 15 ft. This is necessary for construction purposes and adds additional conservatism to the design. The final step was to compare this design with current New York State practice and to develop a modified slab length design procedure.

Suitability of these criteria was compared with established performance of rigid pavements in New York. Since 20-ft PCC slabs on granular bases had performed adequately, the criteria to minimize the potential for transverse cracking were adjusted to reflect New York's experience. The L/l ratio for a 9-in. 20-ft slab on a granular base was calculated and used as the acceptable criterion. Since the new practice includes asphalt-treated and lean-concrete bases, their effects on slab length had to be included. To account for effect of the base on slab length design criteria, new L/l ratios were calculated based on the same

Table 1. Maximum slab length (ft) for cement-treated or lean-concrete bases.

	k, pci			
h, in.	200	300	400	500
9	13	12	11	10
10	15	13	12	11
11	16	14	13	12
12	17	15	14	13

Table 2. Maximum slab length (ft) for asphalt-treated base.

	k, pci			
h, in.	200	300	400	500
9	15	13	12	12
10	16	14	13	13
11	17	16	15	13
12	18	16	15	15

Table 3. Maximum slab length (ft) for granular base or no base.

	k, pci			
h, in.	200	300	400	500
9	16	15	13	13
10	18	16	15	14
11	19	17	16	15
12	20	18	17	16

Table 4. Slab length.

	L, ft	
h, in.	Asphalt-Treated Base	Lean Concrete Base
9	17	15
10	18	16
11	19	17
12	20	18

Table 5. Dowel bar design for tied PCC shoulders.

ESALs, millions	Dowel Bar No.
0 to 15	9
15 to 50	10
50 to 80	12
Over 80	12

reliability as the current practice, but with different base types. For the asphalt-treated base the L/l ratio was found to be 6.8, and for the lean-concrete base the L/l ratio was found to be 6.1. Slab lengths for different k-values were then determined based on these L/l ratios, and slab length was plotted versus slab thickness (Fig. 1). The recommended values for slab length are given in Table 4. Since Table 4 is based on current practice, it should be used for slab length design until more data can be collected to determine if shorter slabs are required.

DOWEL BAR DESIGN

In New York State it has been proved that use of dowels is essential in retarding faulting when PCC pavement is subjected to heavy traffic loading (5). Dowels transfer loads applied by traffic from one slab to the next, and minimize vertical deflection at the joint. Insufficient joint load transfer increases the potential for faulting and pumping by magnifying vertical deflections.

Table 5 was developed using a mechanistic-empirical approach with a fatigue model that relates pavement performance to a mechanistic parameter -- maximum concrete bearing stress. The faulting model was formulated using data from the AASHTO Road Test databases developed by ERES Consultants, Inc., of Champaign, Ill. for FHWA and COPES (6,7,8):

$$\text{Fault} = \text{ESALs}^{a}(b\sigma^{c}_{max}+dk^{e}+f) \quad (3)$$

where Fault = mean transverse joint faulting (in.),

ESALs = cumulative 18-kip equivalent-single-axle loads (millions),

σ_{max} = maximum concrete bearing stress (ksi), and

k = modulus of subgrade reaction (pci).

The estimated coefficients in Eq. 3 are as follows:

a = 0.6

b = 0.00334

c = 2

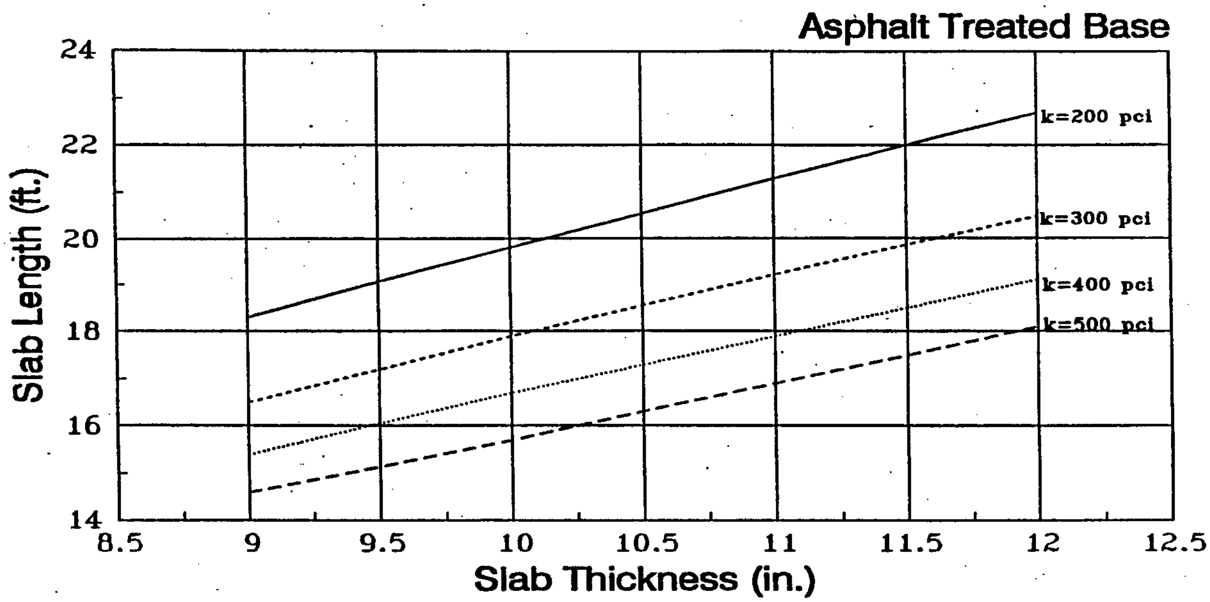
d = 60.228

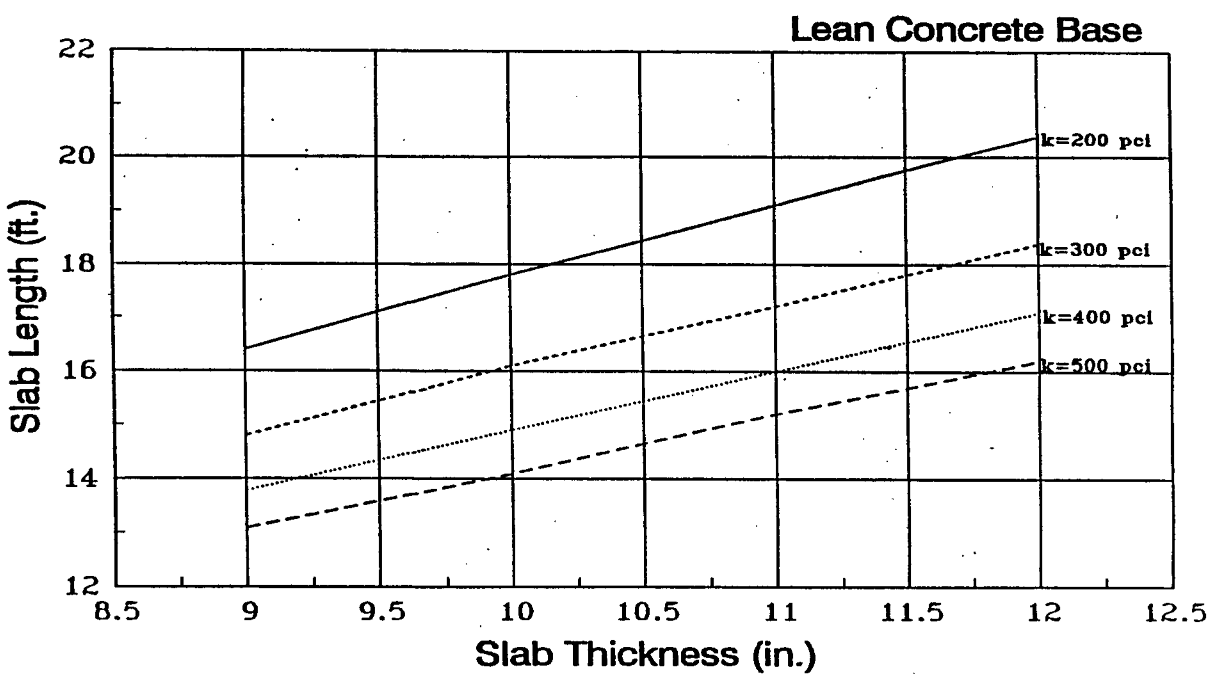
e = -1.809

f = -0.0074.

Concrete bearing stresses depend on dowel diameter, elastic modulus of the concrete, and applied load. Since E_c and the applied load are fixed in this

Figure 1. Slab length vs. slab thickness for two base types.





analysis, σ_{max} becomes a function of dowel bar diameter (d) and thus can be computed for different dowel bar diameters. Using the minimum cross-sections specified in the Design Manual (1), and the 1986 AASHTO design method (2), the total numbers of ESALs to failure were calculated for various PCC thicknesses. To optimize the benefit of using PCC pavements, only tied PCC shoulders were considered in this analysis. Edge stress, which is used to calculate the number of cycles to failure, is reduced due to shear transfer across the longitudinal joint to the tied shoulder. There is no such shear transfer with AC shoulders. Consequently, any PCC pavement with tied shoulders will be subjected to lower stress levels than one without them, and the number of applications to failure thus will increase. After computing σ_{max} and number of ESALs, and with a given k-value, faulting was predicted using the fatigue model in Eq. 3. Since for joint design the lower the k-value, the more conservative is the design, the k-value used in the FAULT model was taken as a "worst case" -- 200 pci with a treated permeable base. The recommended values in Table 5 were then determined using a failure criterion of 1/16-in. fault, Eq. 3 (which relates a predicted fault to dowel size), and fatigue loadings in terms of ESALs as just determined. The final two stipulations -- 1) that dowels must be spaced every 12 in. ± 1/2 in. on center, with the first and last dowels placed 6 in. from the pavement edge (as used in computing bearing stresses), and 2) that the dowels be epoxy-coated -- are required by the Standard Specifications (Items 502-3.08 and 705-15, respectively).

TIEBAR DESIGN

Tiebars are deformed steel bars used along longitudinal joints to connect one lane to another lane or to a shoulder. They are designed to overcome the tensile forces associated with subgrade drag, but not as load-transfer devices. The first step in designing tiebars is to determine the area of steel (A_s) required per foot of slab length to resist subgrade drag forces:

$$A_s = D_{fe} fWh/12f_s \tag{4}$$

where A_s = area of steel (in^2./ft),

D_{fe} = distance to the closest free edge (ft),

h = pavement depth (in.),

W = weight of the concrete (pcf),

f = coefficient of resistance, and

f_s = allowable stress in the steel (psi), taken as 2/3 of yield strength.

Once the steel required is determined, tiebar spacing for different bar sizes can be computed as follows:

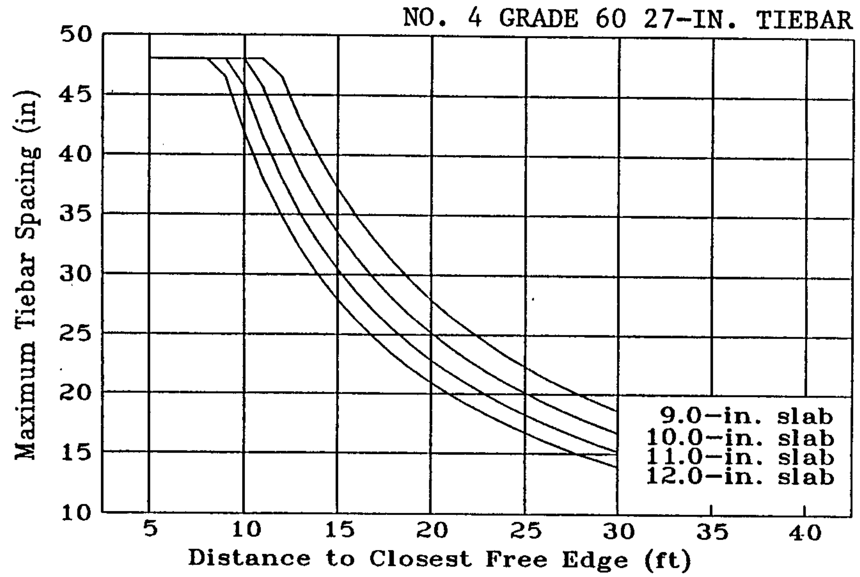
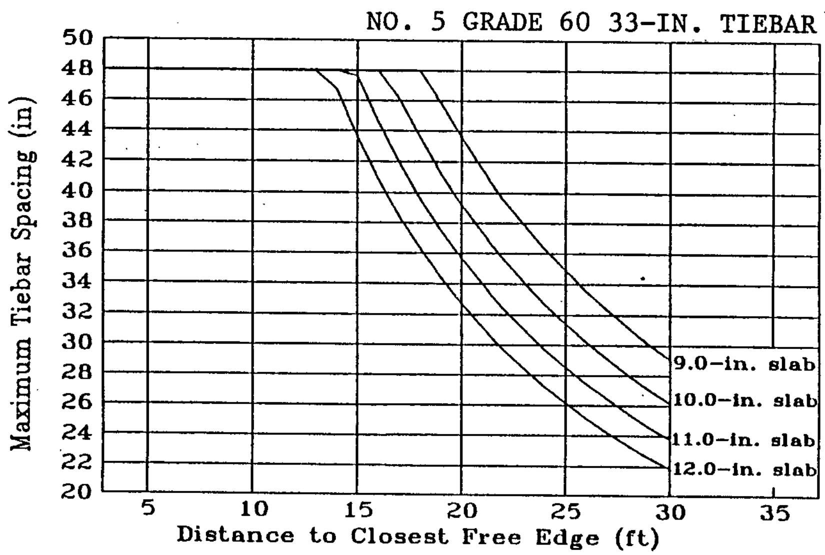
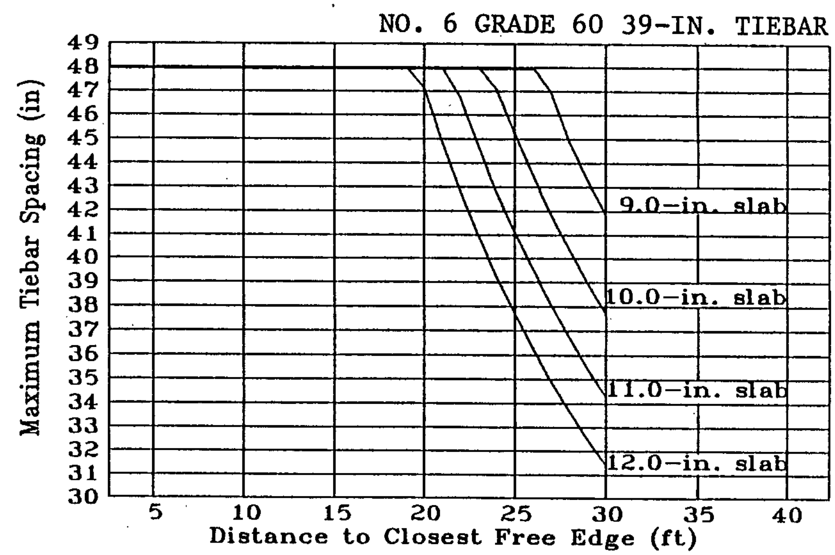


Figure 2. Tiebar spacing for three bar sizes vs. distance to closest free edge.





$$d = 12A_b/A_s \tag{5}$$

where d = tiebar spacing (in.), and

A_b = area of the bar to be used (in^2.).

A_s was determined for pavements of different thicknesses and Grade 60 steel. Figure 2 was developed to compute tiebar spacing, given tiebar diameter (the figures were created by plotting d versus A_s for different tiebar diameters).

Figure 3 shows physical interpretations of these variables. To use Figure 2 (depending on the bar size selected), enter the figure from the distance D_{fe}. (D_{fe} for the shoulder tiebar would be A or D, and D_{fe} for the center joint tiebar would be A+B or C+D; in both cases the lower value controls.) Vertical placement of the tiebars should be at mid-depth of the pavement. All tiebars must be epoxy-coated in accordance with Standard Specifications Item 705-14.

CONCLUSIONS

Joint design takes into consideration factors that will make the pavement cost-effective, while not directly examining cost. Optimum design provides longest service with minimum maintenance and materials. This report details procedures used to accomplish this objective, and has given the principles and methods by which a joint design was developed. Further references are provided which describe the basis for development of the joint design.

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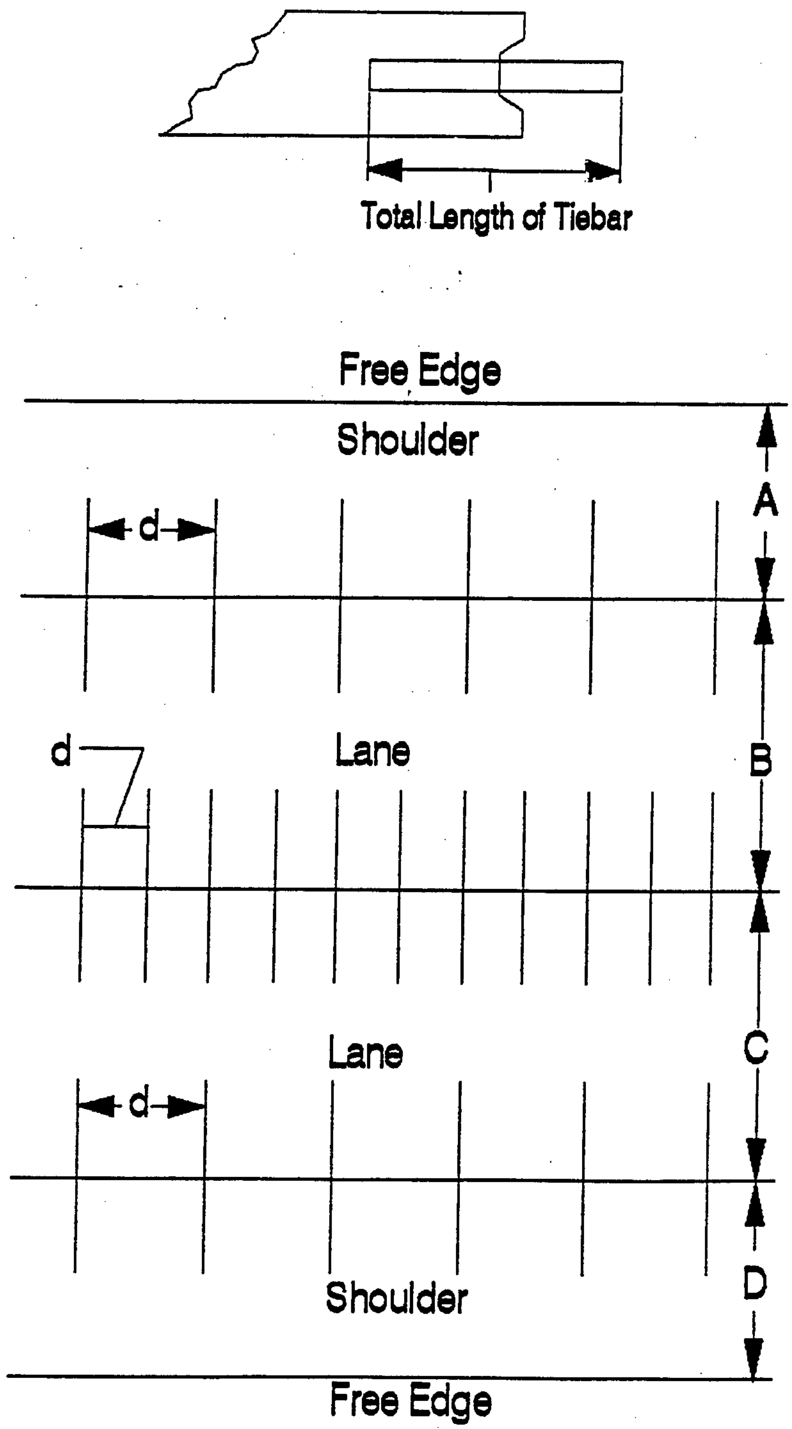
Figure 3. Slab cross-section and tiebar variables.



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