

Pavement Analysis and Design

TE-503 A/TE-503

Lecture-5
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DTEM

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION

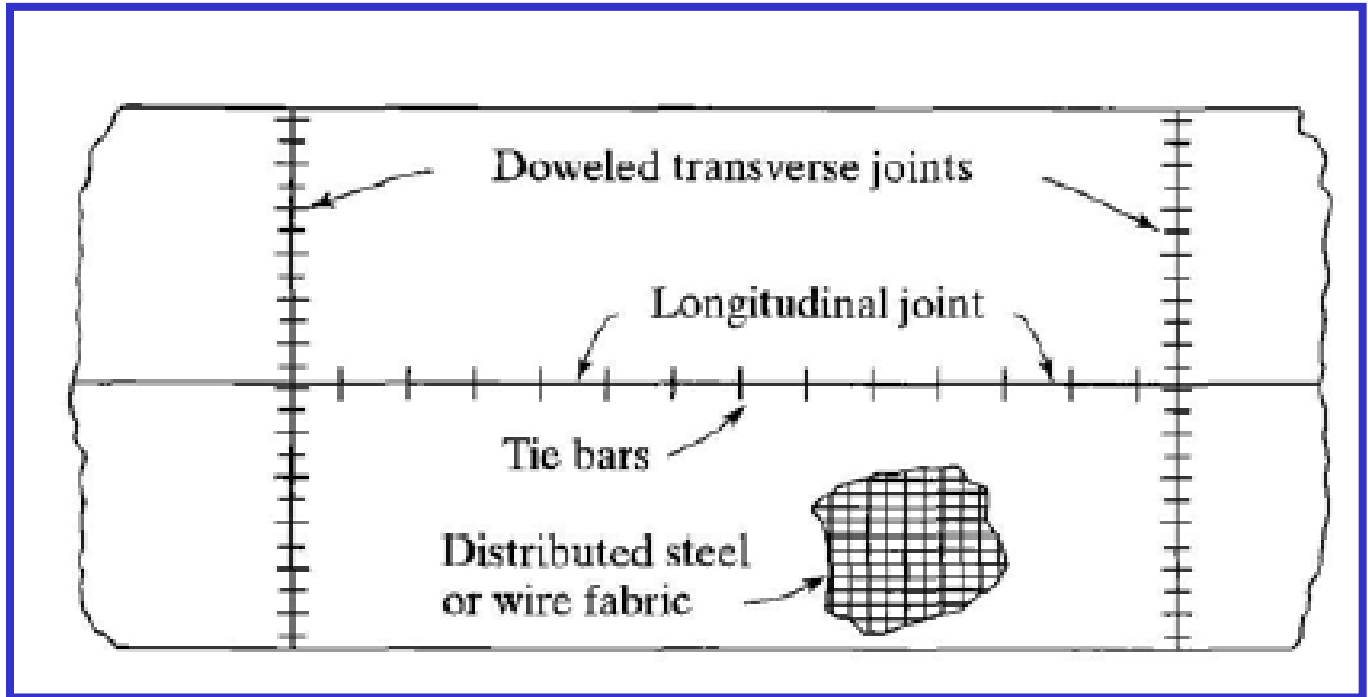
The friction between a concrete slab and its foundation causes tensile stresses in the concrete, in the steel reinforcements, if any, and in the tie bars.

For plain concrete pavements, the spacing between contraction joints must be so chosen that the stresses due to friction will not cause the concrete to crack.

For longer joint spacings, steel reinforcements must be provided to take care of the stresses caused by friction. The number of tie bars required is also controlled by the friction. Figure shows the arrangement of joints and steel in concrete pavements.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION



Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Effect of Volume Change on Concrete

The volume change caused by the variation of temperature and moisture has two important effects on concrete.

First, it induces tensile stresses and causes the concrete to crack.

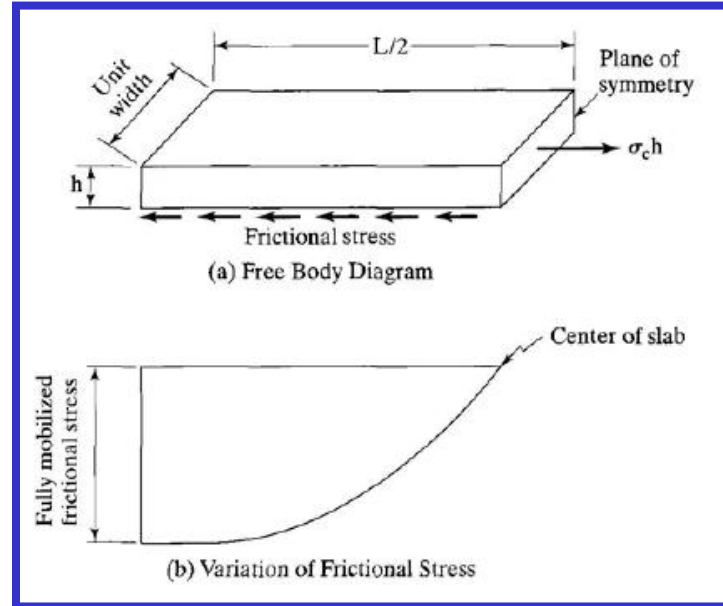
Second, it causes the joint to open and decreases the efficiency of load transfer.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Effect of Volume Change on Concrete Concrete Stress

Figure shows a concrete pavement subject to a decrease in temperature. Due to symmetry, the slab tends to move from both ends toward the center, but the subgrade prevents it from moving; thus, frictional stresses are developed between the slab and the subgrade.

The amount of friction depends on the relative movement, being zero at the center where no movement occurs and maximum at some distance from the center where the movement is fully mobilized, as shown in Figure.



Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Effect of Volume Change on Concrete

Concrete Stress

For practical purposes, an average coefficient of friction f_a may be assumed. The tensile stress in the concrete is greatest at the center and can be determined by equating the frictional force per unit width of slab, $\gamma_c h L f_a / 2$, to the tensile force $\sigma_c h$, as shown in Figure:

$$\sigma_c = \gamma_c L f_a / 2$$

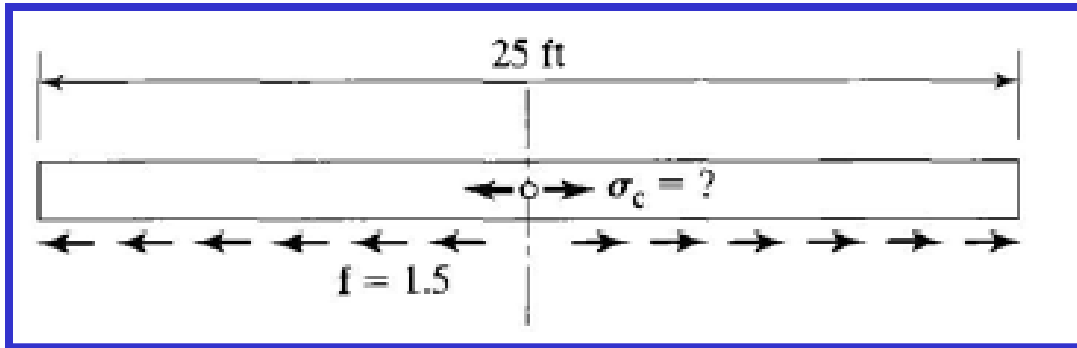
in which σ_c is the stress in the concrete, γ_c is the unit weight of the concrete, L is the length of the slab, and f_a is the average coefficient of friction between slab and subgrade, usually taken as 1.5. Equation implies that the stress in the concrete due to friction is independent of the slab thickness.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Effect of Volume Change on Concrete

Concrete Stress-Numerical problem

Given a concrete pavement with a joint spacing of 25 ft and a coefficient of friction of 1.5, as shown. Determine the stress in concrete due to friction.



$$\gamma_c = 150 \text{ pcf} = 150/12^3 = 0.0868 \text{ pci}$$

$$L = 25 \text{ ft} = 25 \times 12 = 300 \text{ in.}$$

$$f_a = 1.5$$

$$\sigma_c = \gamma_c L f_a / 2 = 0.0868 \times 300 \times 1.5 / 2 = 19.5 \text{ psi}$$

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION

Joint Opening

The spacing of joints in plain concrete pavements depends more on the shrinkage characteristics of the concrete rather than on the stress in the concrete.

Longer joint spacings cause the joint to open wider and decrease the efficiency of load transfer. The opening of a joint can be computed approximately by (Darter and Barenberg, 1977):

$$\Delta L = C L (\alpha_t \Delta T + \varepsilon)$$

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Joint Opening $\Delta L = C L (\alpha_t \Delta T + \varepsilon)$

in which ΔL is the joint opening caused by temperature change and drying shrinkage of concrete;

α_t is the coefficient of thermal expansion of concrete, generally 5 to $6 \times 10^{-6} / ^\circ\text{F}$ (9 to $10.8 \times 10^{-6} / ^\circ\text{C}$);

ε is the drying shrinkage coefficient of concrete, approximately 0.5 to 2.5×10^{-4} ;

L is the joint spacing or slab length;

ΔT is the temperature range, which is the temperature at placement minus the lowest mean monthly temperature; and

C is the adjustment factor due to slab-subbase friction, 0.65 for stabilized base and 0.8 for granular subbase.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Joint Opening-Numerical problem
Given $\Delta T = 60^\circ\text{F}$, $\alpha_t = 5.5 \times 10^{-6}/^\circ\text{F}$, $\varepsilon = 1.0 \times 10^{-4}$, $C = 0.65$ and the allowable joint openings for undoweled and doweled joints are 0.05 and 0.25 in. respectively, determine the maximum allowable joint spacing.

$$\Delta L = C L (\alpha_t \Delta T + \varepsilon)$$

$$L = \Delta L / C (\alpha_t \Delta T + \varepsilon)$$

For undoweled joints:

$$L = \Delta L / C (\alpha_t \Delta T + \varepsilon) = 0.05 / 0.65 (5.5 \times 10^{-6} \times 60 + 1.0 \times 10^{-4}) = 178.9 \text{ in} = 14.9 \text{ ft}$$

For doweled joints:

$$L = \Delta L / C (\alpha_t \Delta T + \varepsilon) = 0.25 / 0.65 (5.5 \times 10^{-6} \times 60 + 1.0 \times 10^{-4}) = 892.9 \text{ in} = 74.4 \text{ ft}$$

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress

Steel is used in concrete pavements as reinforcements, tie bars and dowel bars.

The design of longitudinal and transverse reinforcements and of the tie bars across longitudinal joints is based on the stresses due to friction.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress Reinforcements

Wire fabric or bar mats may be used in concrete slabs for control of temperature cracking. These reinforcements do not increase the structural capacity of the slab but are used for two purposes:

- To increase the joint spacing and**
- To tie the cracked concrete together and maintain load transfers through aggregate interlock.**

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress Reinforcements

$$\sigma_c = \gamma_c L f_a / 2$$

When steel reinforcements are used, it is assumed that all tensile stresses are taken by the steel alone, so $\sigma_c h$ must be replaced by $A_s f_s$ and above equation becomes:

$$A_s = \gamma_c h L f_a / 2 f_s$$

in which A_s is the area of steel required per unit width and f_s is the allowable stress in steel. This equation indicates that the amount of steel required is proportional to the length of slab.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress

Reinforcements

The steel is usually placed at the mid depth of the slab and discontinued at the joint.

The amount of steel obtained from above equation is at the center of the slab and can be reduced toward the end.

However, in actual practice the same amount of steel is used throughout the length of the slab.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress

Reinforcements

Table 4.1 gives the allowable stress for different types and grades of steel. The allowable stress is generally taken as two-thirds of the yield strength.

TABLE 4.1 Yield Strength and Allowable Stress for Steel

Type and grade of steel	Yield strength (psi)	Allowable stress (psi)
Billet steel, intermediate grade	40,000	27,000
Rail steel or hard grade of billet steel	50,000	33,000
Rail steel, special grade	60,000	40,000
Billet steel, 60,000 psi minimum yield	60,000	40,000
Cold drawn wire (smooth)	65,000	43,000
Cold drawn wire (deformed)	70,000	46,000

Note. 1 psi = 6.9 kPa.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress Reinforcements

TABLE 4.2 Weights and Dimensions of Standard Reinforcing Bars

Bar size designation	Weight (lb/ft)	Nominal dimensions, round sections		
		Diameter (in.)	Cross-sectional area (in. ²)	Perimeter (in.)
No. 3	0.376	0.375	0.11	1.178
No. 4	0.668	0.500	0.20	1.571
No. 5	1.043	0.625	0.31	1.963
No. 6	1.502	0.750	0.44	2.356
No. 7	2.044	0.875	0.60	2.749
No. 8	2.670	1.000	0.79	3.142
No. 9	3.400	1.128	1.00	3.544
No. 10	4.303	1.270	1.27	3.990
No. 11	5.313	1.410	1.56	4.430

Note. 1 in. = 25.4 mm, 1 lb = 4.45 N, 1 ft = 0.305 m.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress Reinforcements

TABLE 4.3 Weights and Dimensions of Welded Wire Fabric

Wire size no.		Diameter (in.)	Weight lb/ft	Cross-sectional area (in. ² /ft) center-to-center spacing (in.)						
Smooth	Deformed			2	3	4	6	8	10	12
W31	D31	0.628	1.054	1.86	1.24	.93	.62	.465	.372	.31
W30	D30	0.618	1.020	1.80	1.20	.90	.60	.45	.36	.30
W28	D28	0.597	.952	1.68	1.12	.84	.56	.42	.336	.28
W26	D26	0.575	.934	1.56	1.04	.78	.52	.39	.312	.26
W24	D24	0.553	.816	1.44	.96	.72	.48	.36	.288	.24
W22	D22	0.529	.748	1.32	.88	.66	.44	.33	.264	.22
W20	D20	0.504	.680	1.20	.80	.60	.40	.30	.24	.20
W18	D18	0.478	.612	1.08	.72	.54	.36	.27	.216	.18
W16	D16	0.451	.544	.96	.64	.48	.32	.24	.192	.16
W14	D14	0.422	.476	.84	.56	.42	.28	.21	.168	.14
W12	D12	0.390	.408	.72	.48	.36	.24	.18	.144	.12
W11	D11	0.374	.374	.66	.44	.33	.22	.165	.132	.11

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress-Reinforcements

TABLE 4.3 Weights and Dimensions of Welded Wire Fabric

Wire size no.		Diameter (in.)	Weight lb/ft	Cross-sectional area (in. ² /ft) center-to-center spacing (in.)						
Smooth	Deformed			2	3	4	6	8	10	12
W10.5		0.366	.357	.63	.42	.315	.21	.157	.126	.105
W10	D10	0.356	.340	.60	.40	.30	.20	.15	.12	.10
W9.5		0.348	.323	.57	.38	.285	.19	.142	.114	.095
W9	D9	0.338	.306	.54	.36	.27	.18	.135	.108	.09
W8.5		0.329	.289	.51	.34	.255	.17	.127	.102	.085
W8	D8	0.319	.272	.48	.32	.24	.16	.12	.096	.08
W7.5		0.309	.255	.45	.30	.225	.15	.112	.09	.075
W7	D7	0.298	.238	.42	.28	.21	.14	.105	.084	.07
W6.5		0.288	.221	.39	.26	.195	.13	.097	.078	.065
W6	D6	0.276	.204	.36	.24	.18	.12	.09	.072	.06
W5.5		0.264	.187	.33	.22	.165	.11	.082	.066	.055
W5	D5	0.252	.170	.30	.20	.15	.10	.075	.06	.05
W4.5		0.240	.153	.27	.18	.135	.09	.067	.054	.045
W4	D4	0.225	.136	.24	.16	.12	.08	.06	.048	.04

Note. Wire sizes other than those listed above may be produced provided the quantity required is sufficient to justify manufacture.
1 in. = 25.4 mm, 1 lb = 4.45 N, 1 ft = 0.305 m.

Source. After WRI (1975).

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress

Reinforcements

Table 4.2 shows the weight and dimensions of reinforcing bars and Table 4.3 shows those of welded wire fabric.

Welded wire fabric is prefabricated reinforcement consisting of parallel series of high-strength, cold-drawn wires welded together in square or rectangular grids. The spacings and sizes of wires are identified by "style." A typical style designation is 6x12-W8xW6, in which the spacing of longitudinal wires is 6 in. (152 mm), the spacing of transverse wires is 12 in. (305 mm), the size of longitudinal wire is W8 with a cross-sectional area of 0.08 in². (51.6 mm²) and the size of transverse wires is W6 with a cross sectional area of 0.06 in². (38.7 mm²).

The typical style with deformed welded wire fabric is 6x12-D8xD6.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress-Reinforcements

The following standard practices on wire sizes, spacings, laps and clearances are recommended by the Wire Reinforcement Institute (WRI, 1975):

1. Because the fabric is subjected to bending stresses as well as tensile stresses at cracks, neither the longitudinal nor the transverse wires should be less than W4 or D4.
2. To provide generous opening between wires to permit placement and vibration of concrete, the minimum spacing between wires should not be less than 4 in. (102 mm). The maximum spacing should not be greater than 12 in. (305 mm) between longitudinal wires and 24 in. (610 mm) between transverse wires.
3. Because the dimensions of a concrete slab are usually greater than those of the welded wire fabric, the fabric should be installed with end and side laps. The end lap should be about 30 times the longitudinal wire diameter but not less than 12 in. (305 mm). The side laps should be about 20 times the transverse wire diameter but not less than 6 in. (152 mm).
4. The fabric should extend to about 2 in. (51 mm) but not more than 6 in. (152 mm) from the slab edges. The depth from the top of slab should not be less than 2.5 in. (64 mm) or more than mid depth.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress-Reinforcements-Numerical problem

Reinforcements-Numerical problem

Determine the wire fabric required for a two-lane concrete pavement, 8 in. thick, 60 ft long and 24 ft wide, with a longitudinal joint at the center, as shown.

Solution:

$$\gamma_c = 150 \text{ pcf} = 150/12^3 = 0.0868 \text{ pci}$$

$$L = 60 \text{ ft} = 60 \times 12 = 720 \text{ in.}$$

$$W = 24 \text{ ft} = 24 \times 12 = 288 \text{ in.}$$

$$h = 8 \text{ in.}$$

$$f_a = 1.5$$

$$f_s = 43,000 \text{ psi}$$

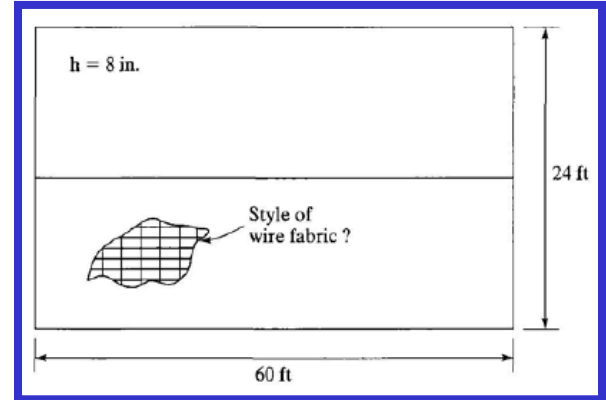
Longitudinal steel:

$$A_s = \gamma_c h L f_a / 2 f_s = 0.0868 \times 8 \times 720 \times 1.5 / (2 \times 43,000) \\ = 0.00872 \text{ in}^2/\text{in.} = 0.105 \text{ in}^2/\text{ft.}$$

Transverse steel:

$$A_s = \gamma_c h L f_a / 2 f_s = 0.0868 \times 8 \times 288 \times 1.5 / (2 \times 43,000) \\ = 0.00349 \text{ in}^2/\text{in.} = 0.042 \text{ in}^2/\text{ft.}$$

From Table 4.3 use 6x12-W5.5xW4.5 with steel area 0.11 in²/ft. for longitudinal wires and 0.045 in²/ft. for transverse wires.



Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress-Reinforcements

TABLE 4.3 Weights and Dimensions of Welded Wire Fabric

Wire size no.		Diameter (in.)	Weight lb/ft	Cross-sectional area (in. ² /ft) center-to-center spacing (in.)						
Smooth	Deformed			2	3	4	6	8	10	12
W10.5		0.366	.357	.63	.42	.315	.21	.157	.126	.105
W10	D10	0.356	.340	.60	.40	.30	.20	.15	.12	.10
W9.5		0.348	.323	.57	.38	.285	.19	.142	.114	.095
W9	D9	0.338	.306	.54	.36	.27	.18	.135	.108	.09
W8.5		0.329	.289	.51	.34	.255	.17	.127	.102	.085
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W6.5		0.288	.221	.39	.26	.195	.13	.097	.078	.065
W6	D6	0.276	.204	.36	.24	.18	.12	.09	.072	.06
W5.5		0.264	.187	.33	.22	.165	.11	.082	.066	.055
W5	D5	0.252	.170	.30	.20	.15	.10	.075	.06	.05
W4.5		0.240	.153	.27	.18	.135	.09	.067	.054	.045
W4	D4	0.225	.136	.24	.16	.12	.08	.06	.048	.04

Note. Wire sizes other than those listed above may be produced provided the quantity required is sufficient to justify manufacture.
1 in. = 25.4 mm, 1 lb = 4.45 N, 1 ft = 0.305 m.

Source. After WRI (1975).

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress

Tie bars

$$A_s = \gamma_c h L f_a / 2 f_s$$

Tie bars are placed along the longitudinal joint to tie the two slabs together so that the joint will be tightly closed and the load transfer across the joint can be ensured. The amount of steel required for tie bars can be determined in the same way as the longitudinal or transverse reinforcements by slightly modifying the above equation:

$$A_s = \gamma_c h L' f_a / f_s$$

in which A_s is the area of steel required per unit length of slab and L' is the distance from the longitudinal joint to the free edge where no tie bars exist.

For two or three lane highways, L' is the lane width. If tie bars are used in all three longitudinal joints of a four-lane highway, L' is equal to the lane width for the two outer joints and twice the lane width for the inner joint.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress

Tie bars

The length of tie bars is governed by the allowable bond stress. For deformed bars, an allowable bond stress of 350 psi may be assumed. The length of bar should be based on the full strength of the bar, namely,

$$t = 2[A_1 f_s / \mu \Sigma_o]$$

in which t is the length of the tie bar, μ is the allowable bond stress, A_1 is the area of one bar and Σ_o is the bar perimeter.

For a given bar diameter d , $A_1 = \pi d^2 / 4$ and $\Sigma_o = \pi d$, the above equation can be written as

$$t = 0.5[f_s d / \mu]$$

Then length t should be increased by 3 in. for misalignment.

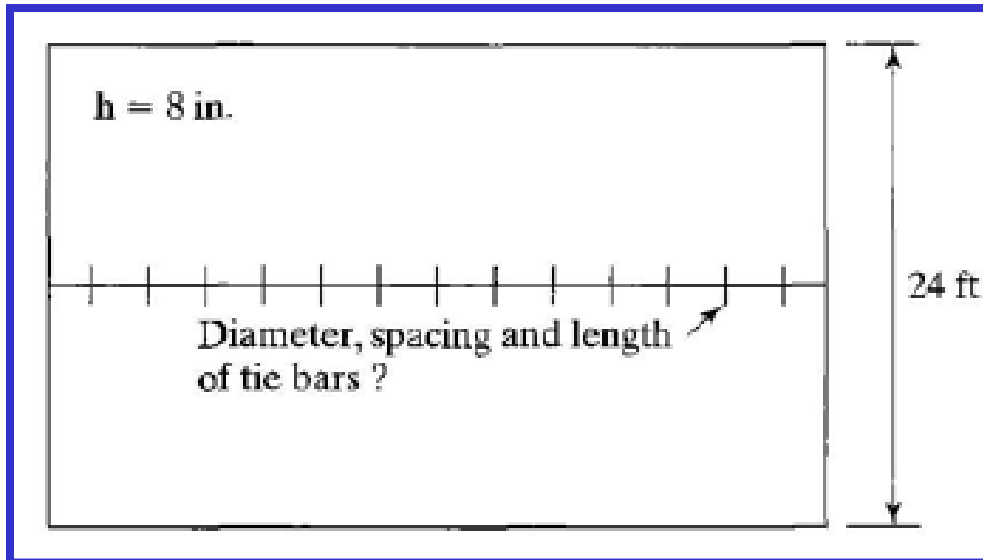
It should be noted that many agencies use a standard tie bar design to simplify the construction. Tie bars 0.5 in. (13 mm) in diameter by 36 in. (914 mm) long spaced at intervals of 30 to 40 in. (762 to 1016 mm) are most commonly used.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress

Tie bars-Numerical problem

For the pavement shown, determine the diameter, spacing and length of the tie bars required.



Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress

Tie bars-Numerical problem

Assume $f_s = 27,000$ for billet steel.

TABLE 4.1 Yield Strength and Allowable Stress for Steel

Type and grade of steel	Yield strength (psi)	Allowable stress (psi)
Billet steel, intermediate grade	40,000	27,000
Rail steel or hard grade of billet steel	50,000	33,000
Rail steel, special grade	60,000	40,000
Billet steel, 60,000 psi minimum yield	60,000	40,000
Cold drawn wire (smooth)	65,000	43,000
Cold drawn wire (deformed)	70,000	46,000

Note. 1 psi = 6.9 kPa.

With $L' = 12\text{ft} = 12 \times 12 = 144\text{ in.}$

$$A_s = \gamma_c h L' f_a / f_s = 0.0868 \times 8 \times 144 \times 1.5 / 27,000 = 0.00556\text{ in}^2/\text{in.}$$

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress

Tie bars-Numerical problem

Use No. 4 bars. Area of one bar= 0.2 in^2 .

Spacing= $0.2 \text{ in}^2 / 0.00556 \text{ in}^2/\text{in} = 36 \text{ in}$.

Bar size designation	Weight (lb/ft)	Nominal dimensions, round sections		
		Diameter (in.)	Cross-sectional area (in. ²)	Perimeter (in.)
No. 3	0.376	0.375	0.11	1.178
No. 4	0.668	0.500	0.20	1.571
No. 5	1.043	0.625	0.31	1.963
No. 6	1.502	0.750	0.44	2.356
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Note. 1 in. = 25.4 mm, 1 lb = 4.45 N, 1 ft = 0.305 m.

Stresses and Deflections in Rigid Pavements

STRESSES DUE TO FRICTION-Steel stress

Tie bars-Numerical problem

Assume $\mu=350$ psi

$$t = 0.5[f_s d / \mu] = 0.5[27,000 \times 0.5 / 350] = 19.3 \text{ in.}$$

Add 3 in.

$$t = 19.3 + 3 = 22.3 \text{ in. Say 24 in.}$$

The design selected is No. 4 deformed bars, 24 in. long and 3 ft on centers.

Stresses and Deflections in Rigid Pavements

Design of dowels

Dowel bars are usually used across a transverse joint to transfer the loads to the adjoining slab.

The stress and deflection at the joint are much smaller when the loads are carried by two slabs, instead of by one slab alone.

The use of dowels can minimize faulting and pumping which has been considered by the Portland Cement Association (PCA, 1984) as a factor for thickness design.

Stresses and Deflections in Rigid Pavements

Design of dowels-Allowable Bearing Stress

Because concrete is much weaker than steel, the size and spacing of dowels required are governed by the bearing stress between dowel and concrete.

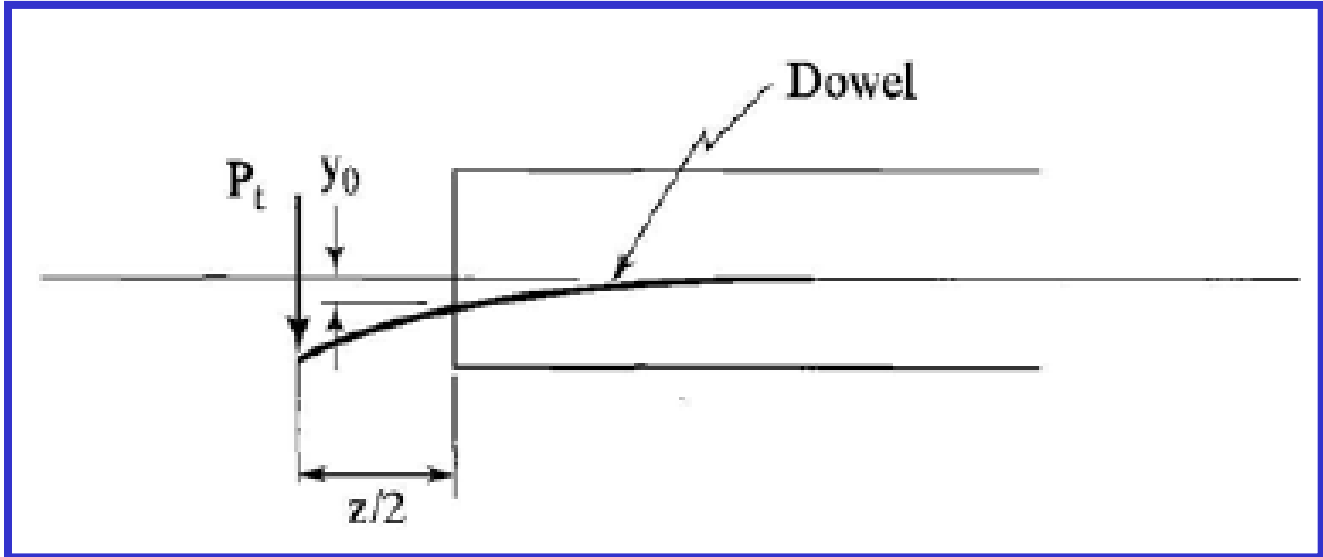
The allowable bearing stress can be determined by (American Concrete Institute, 1956):

$$f_b = \left(\frac{4 - d}{3} \right) f'_c$$

in which f_b is the allowable bearing stress in psi, d is the dowel diameter in inches and f'_c is the ultimate compressive strength of concrete.

Stresses and Deflections in Rigid Pavements

Design of dowels-Bearing stress on one dowel



Stresses and Deflections in Rigid Pavements

Design of dowels-Bearing stress on one dowel

If the load applied to one dowel is known, the maximum bearing stress can be determined theoretically by assuming the dowel to be a beam and the concrete to be a Winkler foundation. Using the original solution by Timoshenko, Friberg (1940) indicated that the maximum deformation of concrete under the dowel, as shown by y_0 in Figure, can be expressed by

$$y_0 = \frac{P_t(2 + \beta z)}{4\beta^3 E_d I_d}$$

in which

y_0 is the deformation of the dowel at the face of the joint,

P_t is the load on one dowel,

z is the joint width,

E_d is Young's modulus of the dowel,

I_d is the moment of inertia of the dowel and

β is the relative stiffness of a dowel embedded in concrete.

Stresses and Deflections in Rigid Pavements

Design of dowels-Bearing stress on one dowel

Note that

$$I_d = \frac{1}{64} \pi d^4$$

$$\beta = \sqrt[4]{\frac{Kd}{4E_d I_d}}$$

in which K is the modulus of dowel support, which ranges from 300,000 to 1,500,000 pci, and d is the diameter of dowel.

Stresses and Deflections in Rigid Pavements

Design of dowels-Bearing stress on one dowel

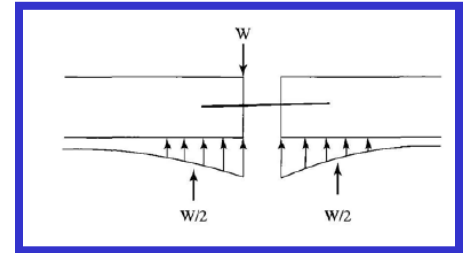
The bearing stress σ_b is proportional to the deformation:

$$\sigma_b = Ky_0 = \frac{KP_t(2 + \beta z)}{4\beta^3 E_d I_d}$$

The bearing stress obtained from this equation should compare with the allowable bearing stress. If the actual bearing stress is greater than allowable, then larger dowel bars or smaller dowel spacing should be used.

Stresses and Deflections in Rigid Pavements

Design of dowels-Dowel group action



When a load W is applied on one slab near the joint, as shown in Figure, part of the load will be transferred to the adjacent slab through the dowel group. If the dowels are 100% efficient, both slabs will deflect the same amount and the reactive forces under both slabs will be the same, each equal to $0.5W$, which is also the total shear force transferred by the dowel group.

If the dowels are less than 100% efficient, as in the case of old pavements where some dowels become loose, the reactive forces under the loaded slab will be greater than $0.5W$, while those under the unloaded slab will be smaller than $0.5W$. As a result, the total shear force on the dowels is smaller than $0.5W$. Therefore, the use of $0.5W$ for the design of dowels is more conservative.

Stresses and Deflections in Rigid Pavements

Design of dowels-Dowel group action

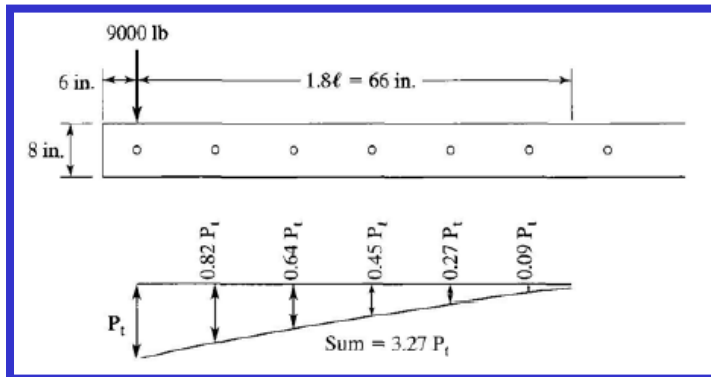
Based on Westergaard's solutions, Friberg (1940) found that the maximum negative moment for both interior and edge loadings occurs at a distance of $1.8e$ from the load, where e is the radius of relative stiffness.

When the moment is maximum, the shear force is equal to zero. It is therefore reasonable to assume that the shear in each dowel decreases inversely with the distance of the dowel from the point of loading, being maximum for the dowel under or nearest to the point of loading and zero at a distance of $1.8e$.

Stresses and Deflections in Rigid Pavements

Design of dowels-Numerical problem

Figure shows a concrete pavement 8 in. thick having a joint width of 0.2 in., a modulus of subgrade reaction of 100 pci and a modulus of dowel support of 1.5×10^6 pci. A load of 9000 lb is applied over the outermost dowel at a distance of 6 in. from the edge. The dowels are 3/4 in. in diameter and 12 in. on centers. Determine the maximum bearing stress between dowel and concrete.

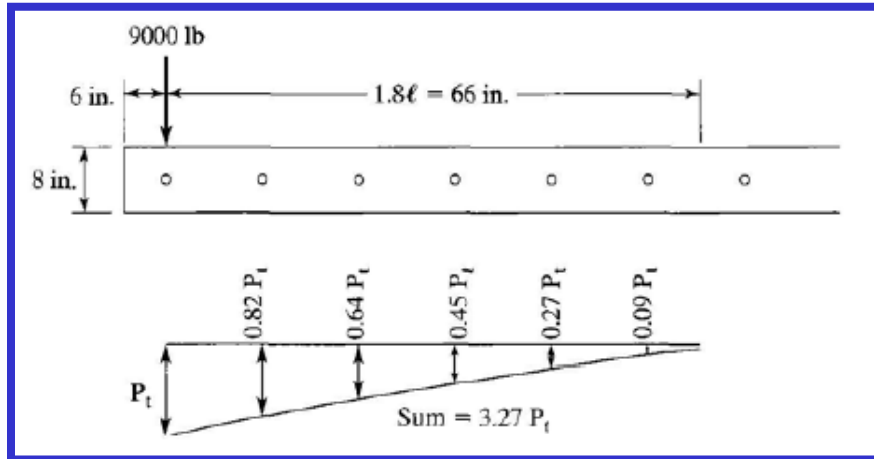


Stresses and Deflections in Rigid Pavements

Design of dowels-Numerical problem

$$\ell = \left[\frac{Eh^3}{12(1 - \nu^2)k} \right]^{0.25}$$

$$\ell = [4 \times 10^6 \times 512 / (12 \times 0.9775 \times 100)]^{0.25} = 36.35 \text{ in.}$$



$$y_i = (66 - x_i) / 66$$

Stresses and Deflections in Rigid Pavements

Design of dowels-Numerical problem

If the dowel directly under the load is subjected to a shear force P_t , the forces on the dowels within a distance of $1.8e$, or 66 in., can be determined by assuming a straight line variation, as shown in Figure.

The sum of the forces on all dowels is $3.27 P_t$, which must be equal to one-half of the applied load based on 100% joint efficiency, or $P_t = 4500/3.27 = 1,376$ lb.

Stresses and Deflections in Rigid Pavements

Design of dowels-Numerical problem

$$I_d = \frac{1}{64} \pi d^4$$

$$I_d = \pi (0.75)^4 / 64 = 0.0155 \text{ in.}^4$$

$$\beta = \sqrt[4]{\frac{Kd}{4E_d I_d}}$$

$$\beta = [1.5 \times 10^6 \times 0.75 / (4 \times 29 \times 10^6 \times 0.0155)]^{0.25} = 0.889 \text{ in.}$$

$$\sigma_b = K y_0 = \frac{K P_t (2 + \beta z)}{4 \beta^3 E_d I_d}$$

$$\sigma_b = 1.5 \times 10^6 \times 1376 (2 + 0.889 \times 0.2) / (4 \times 0.703 \times 29 \times 10^6 \times 0.0155) = 3556 \text{ psi}$$

Stresses and Deflections in Rigid Pavements

Design of dowels-Numerical problem

$$f_b = \left(\frac{4 - d}{3} \right) f'_c$$

$$f_b = (4 - 0.75) \times 3000/3 = 3250 \text{ psi}$$

Since $f_b < \sigma_b$

The design is not satisfactory.

Stresses and Deflections in Rigid Pavements

Design of joints

Joints should be provided in concrete pavements so that premature cracks due to temperature or moisture changes will not occur. There are four types of joints in common use :

- Contraction**
- Expansion**
- Construction**
- Longitudinal .**

Stresses and Deflections in Rigid Pavements

Design of joints-Contraction Joints

Contraction joints are transverse joints used to relieve tensile stresses. The spacing of joints should be based on local experience since a change in coarse aggregate types may have a significant effect on the concrete thermal coefficient and consequently the acceptable joint spacing.

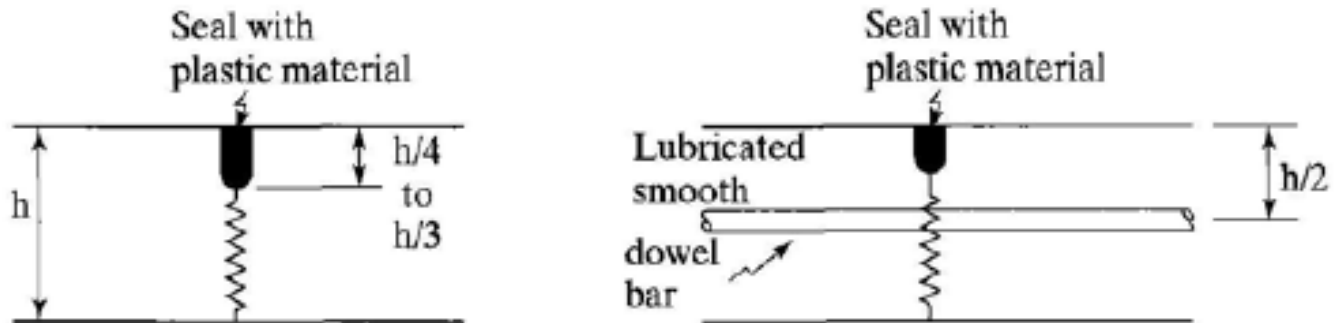
As a rough guide, the joint spacing in feet for plain concrete pavements should not greatly exceed twice the slab thickness in inches. For example, the maximum joint spacing for an 8-in slab is 16 ft.

Also, as a general guideline, the ratio of slab width to length should not exceed 1.25 (AASHTO, 1986).

Stresses and Deflections in Rigid Pavements

Design of joints- Contraction Joints

Figure shows typical contraction joints. In Figure (a), a dummy groove is formed by placing a metal strip on the fresh concrete, which is later removed or by sawing after the concrete is set. The groove is then sealed with a plastic material.

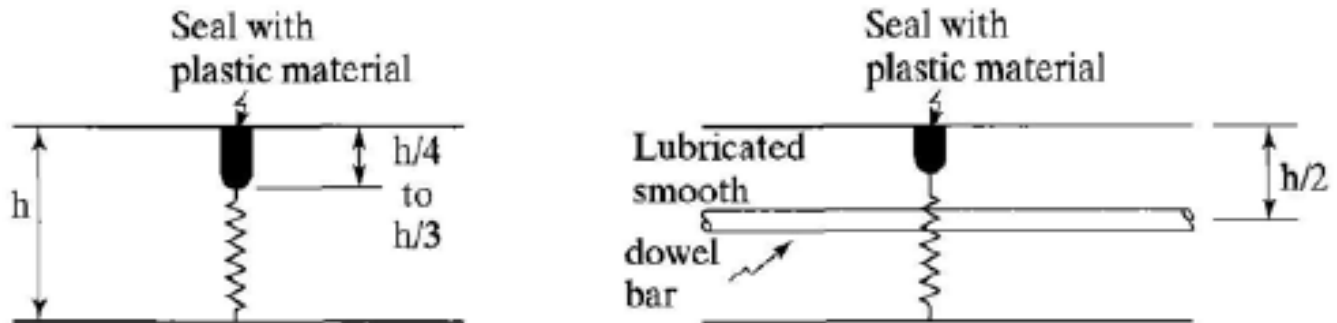


(a) Dummy Groove

Stresses and Deflections in Rigid Pavements

Design of joints- Contraction Joints

If the joint spacing is small, the load transfer across the joint can be achieved by the aggregate interlock and no dowels may be needed. However, dowels are needed if the joint spacing is large or if the short panels are located near the end of the pavement. In such cases, the joint may open up and the load transfer through aggregate interlock may be lost.

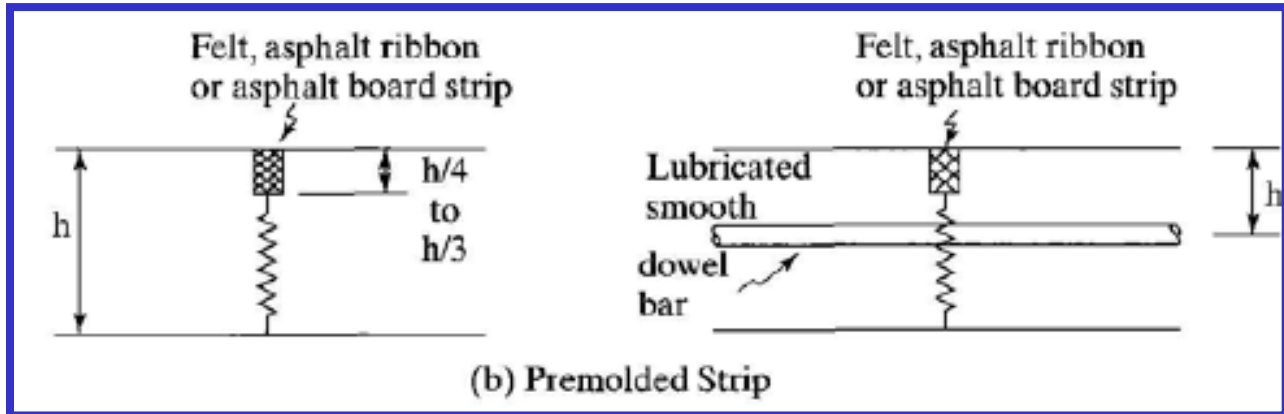


(a) Dummy Groove

Stresses and Deflections in Rigid Pavements

Design of joints- Contraction Joints

In lieu of a dummy groove, joints can be formed by placing a felt, asphalt ribbon, or asphalt board strip in the fresh concrete and leaving it there permanently, as shown in Figure (b).



Stresses and Deflections in Rigid Pavements

Design of joints-Contraction Joints

The sealant used in the joints must be capable of withstanding repeated extension and compression as the temperature and moisture in the slabs change.

Sealants can be classified as field molded and preformed.

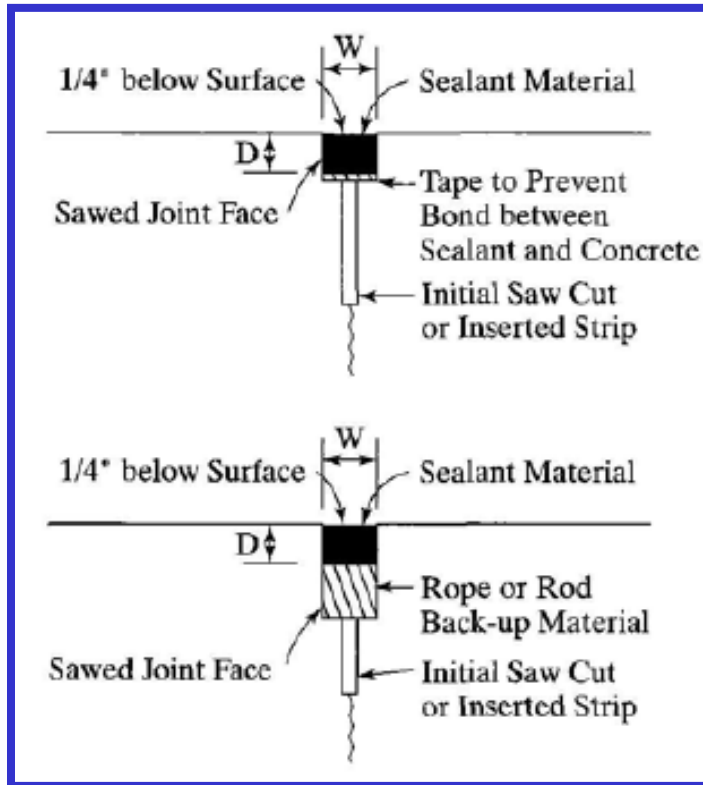
Field-molded sealants are those applied in liquid or semi-liquid form, and preformed sealants are shaped during manufacturing.

Figure shows the design of joint sealant reservoir for field-molded sealants. To maintain an effective field-molded seal, the sealant reservoir must have the proper shape factor or depth to width ratio. The common practice is to have the ratio between 0.5 to 1.

Table 4.5 shows the reservoir dimensions for field-molded sealants, and Table 4.6 shows the joint and sealant widths for preformed seals as recommended by PCA (1975).

Stresses and Deflections in Rigid Pavements

Design of joints-**Contraction Joints**



Stresses and Deflections in Rigid Pavements

Design of joints-**Contraction Joints**

TABLE 4.5 Reservoir Dimensions for Field-Molded Sealants

Joint spacing (ft)	Reservoir width (in.)	Reservoir depth (in.)
15 or less	$\frac{1}{4}$	$\frac{1}{2}$ minimum
20	$\frac{3}{8}$	$\frac{1}{2}$ minimum
30	$\frac{1}{2}$	$\frac{1}{2}$ minimum
40	$\frac{5}{8}$	$\frac{1}{2}$ minimum

Note. 1 ft = 0.305 m, 1 in. = 25.4 mm.

Source. After PCA (1975).

Stresses and Deflections in Rigid Pavements

Design of joints-**Contraction Joints**

TABLE 4.6 Joint and Sealant Width for Preformed Seals

Joint spacing (ft)	Joint width (in.)	Sealant width (in.)
20 or less	$\frac{1}{4}$	$\frac{7}{16}$
30	$\frac{3}{8}$	$\frac{5}{8}$
40	$\frac{7}{16}$	$\frac{3}{4}$
50	$\frac{1}{2}$	$\frac{7}{8}$

Note. 1 ft = 0.305 m, 1 in. = 25.4 mm.

Source. After PCA (1975).

Stresses and Deflections in Rigid Pavements

Design of joints-Contraction Joints

The preformed sealant is the type most recommended to achieve long-term performance. Preformed sealants can do an excellent job of keeping out incompressibles over along period of time, but might not be completely water tight compared to the field-molded sealants.

The preformed sealants should be so designed that the seal will always be compressed at least 20% in the joint. The maximum allowable compression of the seal is 50%. Thus, the seal working range is 20 to 50% (Darter and Barenberg, 1977).

Stresses and Deflections in Rigid Pavements

Design of joints- Contraction Joints- Numerical problem

A concrete pavement 15 ft long is placed on a gravel subbase. If the joint width is 1 in., the design temperature range ΔT is 100°F , the coefficient of thermal expansion α_t is $5 \times 10^{-6}/^\circ\text{F}$ and the drying shrinkage coefficient ϵ is 1.0×10^{-4} , determine the width of preformed sealant required.

$$\Delta L = CL(\alpha_t \Delta T + \epsilon) = 0.65 \times 15 \times 12 (5 \times 10^{-6} \times 100 + 0.0001) = 0.07 \text{ in.}$$

Try 7/16 or 0.4375 in. sealant installed in summer, so the joint would not be further compressed.

Stresses and Deflections in Rigid Pavements

Design of joints-Contraction Joints-Numerical problem

Check maximum compression of sealant:

$$(0.4375-0.25)/0.4375=0.43 < 50\% \text{ OK.}$$

Check minimum compression of sealant:

$$(0.4375-0.25-0.07)/0.4375=0.27 > 20\%, \text{ OK.}$$

Therefore, the use of 7/16 in. sealant for a 1/4 in. joint is satisfactory, as shown in Table 4.6.

Stresses and Deflections in Rigid Pavements

Design of joints-**Contraction Joints-Numerical problem**

TABLE 4.6 Joint and Sealant Width for Preformed Seals

Joint spacing (ft)	Joint width (in.)	Sealant width (in.)
20 or less	$\frac{1}{4}$	$\frac{7}{16}$
30	$\frac{3}{8}$	$\frac{5}{8}$
40	$\frac{7}{16}$	$\frac{3}{4}$
50	$\frac{1}{2}$	$\frac{7}{8}$

Note. 1 ft = 0.305 m, 1 in. = 25.4 mm.

Source. After PCA (1975).

Stresses and Deflections in Rigid Pavements

Design of joints-Expansion Joints

Expansion joints are transverse joints for the relief of compressive stress. Because expansion joints are difficult to maintain and susceptible to pumping, they are no longer in use today except at the connection between pavement and structure.

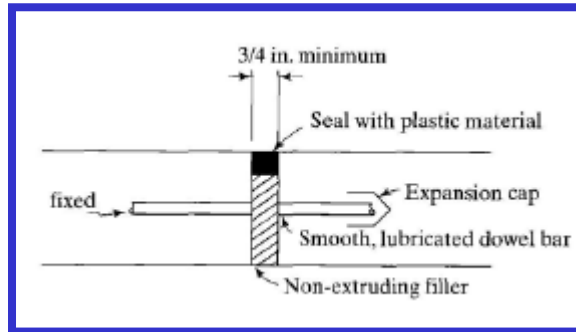
Experience has shown that the blowups of concrete pavements are related to a certain source and type of coarse aggregates. If proper precaution is exercised in selecting the aggregates, distress due to blow ups can be minimized.

The plastic flow of concrete can gradually relieve compressive stress, if any, so it is not necessary to install an expansion joint except at bridge ends.

Stresses and Deflections in Rigid Pavements

Design of joints-Expansion Joints

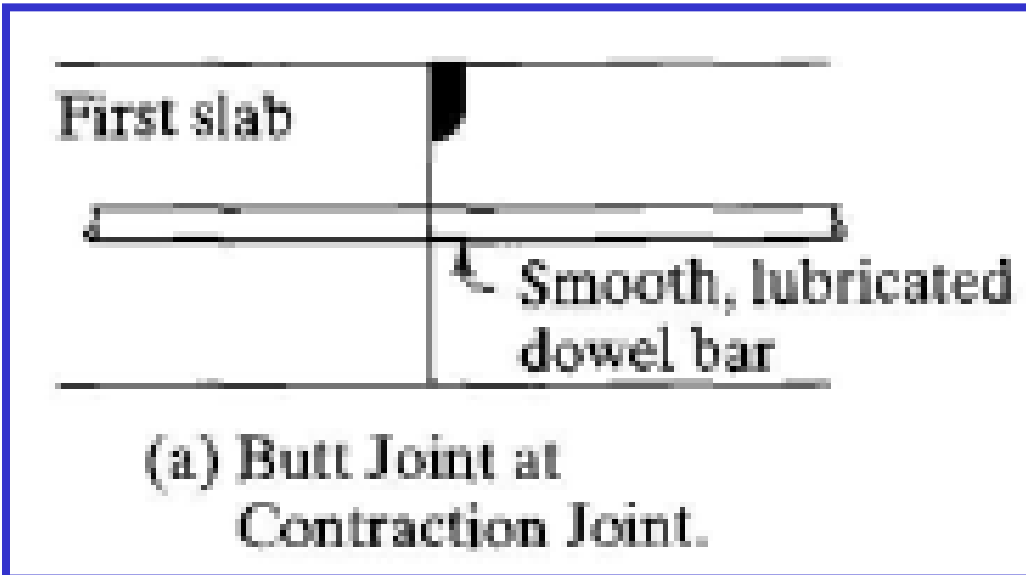
Figure shows a typical expansion joint. The minimum width of joint is $\frac{3}{4}$ in. (19 mm). Smooth dowel bars lubricated at least on one side must be used for load transfer. An expansion cap must be installed at the free end to provide space for dowel movements. Non-extruding fillers, including fibrous and bituminous materials or cork, must be placed in the joint and the top sealed with a plastic material.



Stresses and Deflections in Rigid Pavements

Design of joints-Construction Joints

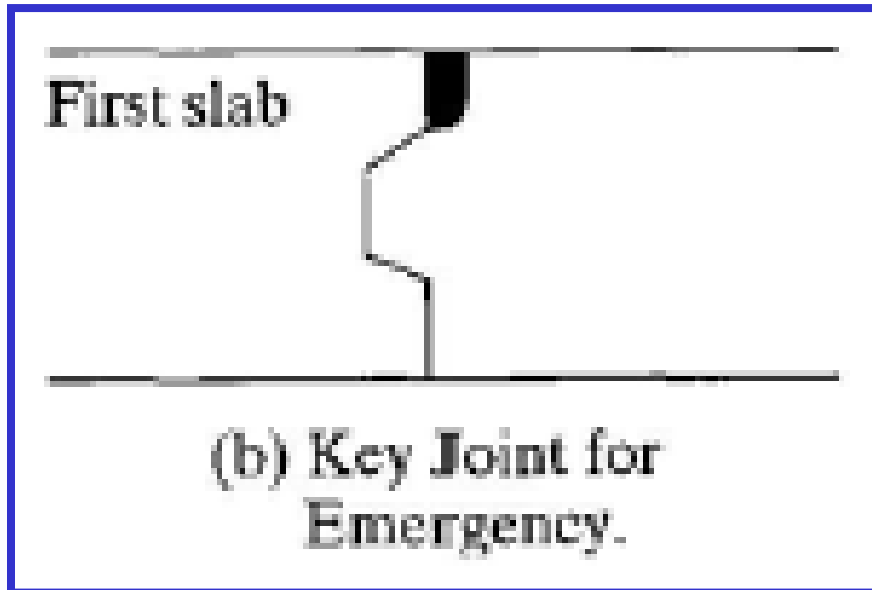
If at all possible, the transverse construction joint should be placed at the location of the contraction joint, as shown by the butt joint in Figure (a).



Stresses and Deflections in Rigid Pavements

Design of joints-Construction Joints

If the work must stop due to an emergency or machine breakdown, the key joint shown in Figure (b) may be used. This joint should be placed only in the middle third of a normal joint interval.



Stresses and Deflections in Rigid Pavements

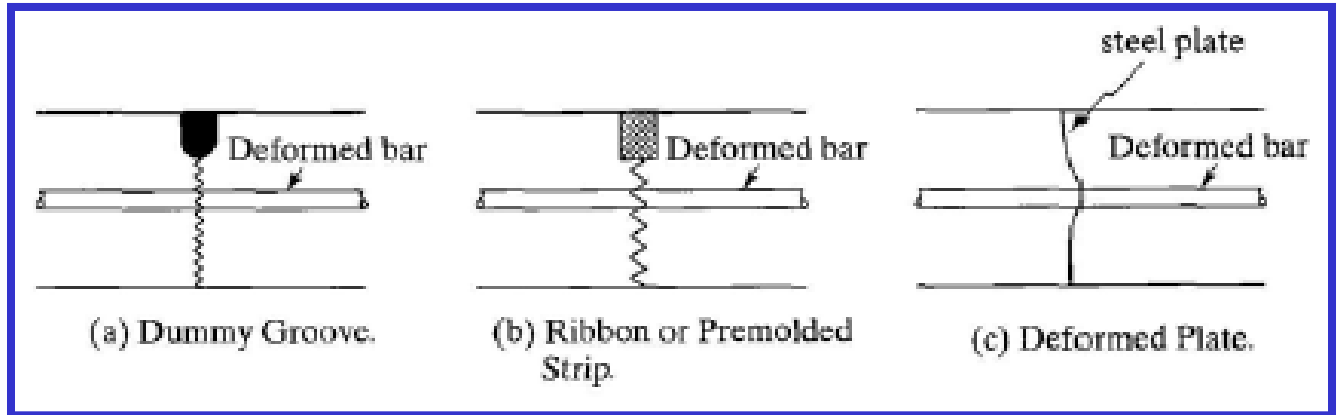
Design of joints-Longitudinal Joints

Longitudinal joints are used in highway pavements to relieve curling and warping stresses. Different types of longitudinal joints are used, depending on whether the construction is full width or lane-at-a-time.

In the full-width construction, as shown in Figure, the most convenient type is the dummy groove joint, in which tie bars are used to make certain that aggregate interlock is maintained. These bars may be shoved into the wet concrete before the final finishing and placement of the dummy groove. The joint can also be formed by inserting a premolded strip into the fresh concrete and leaving it there permanently as an integral part of the warping joint. Another method is to install deformed steel plates and tie bars at the center line before the pour of concrete.

Stresses and Deflections in Rigid Pavements

Design of joints-Longitudinal Joints



Stresses and Deflections in Rigid Pavements

Design of joints-Longitudinal Joints

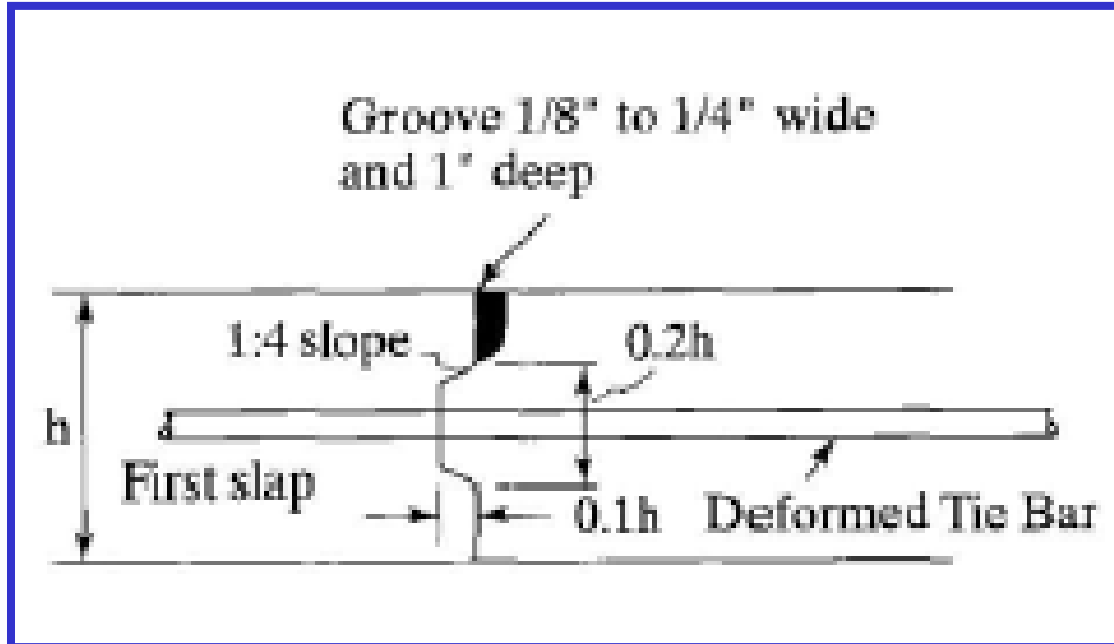
Lane-at-a-time construction is used when it is necessary to maintain traffic on the other lane. To insure load transfer, key joints are usually used, as shown in Figure.

In most cases, the keyed joints are tied together with tie bars. However, tie bars may be omitted if the longitudinal joint is at the interior of a multilane pavement and there is very little chance that the joint will be wide open.

Butt joints have also been used for lane-at-a-time construction. Current practice prefers the use of butt joints over keyed joints because keyed joints usually do not perform well due to the occurrence of cracks along the key.

Stresses and Deflections in Rigid Pavements

Design of joints-Longitudinal Joints



Assignment No. 3

Pavement Analysis and Design by Yang H. Huang

Chapter-4

Problems 4.1 to 4.14 (Pages 182-185)

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