3.3 RIGID PAVEMENT JOINT DESIGN

This section covers the design considerations for the different types of joints in portland cement concrete pavements. A joint faulting check is made after the required slab thickness is determined as described in Section 3.2.2.

3.3.1 Joint Types (no change)

3.3.2 Joint Geometry and Load Transfer

The joint geometry is considered in terms of the spacing, load transfer, and general layout.

Joint Spacing. In general, the spacing of both transverse and longitudinal contraction joints depends on local conditions of materials and environment, whereas expansion and construction joints are primarily dependent on layout and construction capabilities. For contraction joints, the spacing required to prevent intermediate cracking decreases as the thermal coefficient, positive temperature gradient, or base frictional resistance increases, and the spacing increases as the concrete tensile strength increases. Spacing is also related to the slab thickness and the joint sealant capabilities.

Determination of the required slab thickness includes an input for joint spacing. As joint spacing increases, stresses due to thermal curling and moisture warping increase. For JPCP and JRCP, the following recommendations are made.

JPCP (short-jointed plain concrete): Transverse cracking must be controlled. Increased joint spacing requires increased slab thickness, especially for stiffer bases and subgrades. The joint spacing interacts with slab thickness, base stiffness, subgrade stiffness (k-value), and also with the effective temperature gradient, which is location-dependent. Thus, there are tradeoffs between all of these variables that should be considered when selecting a design joint spacing. As a rough guide, the joint spacing (in feet) for plain concrete pavements should not exceed twice the slab thickness (in inches). For example, the maximum joint spacing for an 8-in [203-mm] slab is 16 ft [4.9 m]. For treated bases and stiff subgrades, this general guide may produce too long a joint spacing. Also, as a general guideline, the ratio of slab width to length should not exceed 1.25.

JRCP (long-jointed reinforced concrete): Transverse cracking is an expected occurrence and steel reinforcement is provided to hold the cracks tight. For JRCP, the designer should input a joint (crack) spacing of 30 ft [9.1 m] for thickness design purposes only.

For both JPCP and JRCP, local performance data are valuable for helping to establish a joint spacing that will control cracking. Local experience must be tempered since a change in any of several concrete properties or construction methods (e.g., a change in coarse aggregate type), may have a significant impact on the concrete thermal coefficient and, consequently, the acceptable joint spacing.

The use of expansion joints is generally minimized on a project due to cost, complexity, and performance problems. They are used at structures where pavement types change (e.g., CRCP to jointed), with prestressed pavements, and at intersections.

The spacing between construction joints is generally dictated by field placement and equipment capabilities. Longitudinal construction joints should be placed at lane edges to maximize pavement smoothness and minimize load transfer problems. Transverse construction joints occur at the end of a day's placement or in connection with equipment breakdowns.

Joint Load Transfer. Because the joints of the AASHO Road Test pavements were adequately doweled, no significant faulting occurred during the 2 years of the experiment. If the joints had not been properly doweled, substantial faulting would have occurred, which would have greatly changed the rigid pavement performance model.

Faulting is one of the most important distresses affecting rideability and serviceability. A pavement that faults significantly will have reduced serviceability and carry fewer traffic loads to terminal serviceability than a pavement of the same cross section that does not fault. Thus, joints must be prevented from significant faulting through good joint load transfer and spacing design, base design, and subdrainage design.

The procedure to check the adequacy of the proposed joint load transfer design consists of the following steps:

1. Determine the required slab thickness as described previously (including, if the pavement will be undoweled, the check to compare midslab loading stress to joint loading stress).

2. Predict the mean joint faulting using the appropriate model for doweled or undoweled pavements.

3. Compare the predicted mean faulting to the critical faulting level recommended to prevent faulting from contributing significantly to serviceability loss. If the predicted mean faulting exceeds the critical level, the joint load transfer design should be modified.

Step 1. Determine the Required Slab Thickness. For undoweled pavement, the check for cracking due to joint loading is conducted as well. The joint design features may be modified if necessary and a redesign made to achieve an acceptable joint design to prevent cracking.

Step 2. Predict the Mean Joint Faulting Over the Design Life using the faulting prediction models given below.

Faulting Model for Doweled Joints:

$$FaultD = CESAL^{0.25} * [0.0628 - 0.0628 * C_d + 0.3673*10^{-8} * Bstress^2 + 0.4116 * 10^{-5} * Jtspace^2 + 0.7466*10^{-9} * FI^2 * Precip^{0.5} - 0.009503 * Basetype - 0.01917 * Widenlane + 0.0009217 * Age] \quad [52]$$

where FaultD = mean transverse doweled joint faulting, inches
CESAL = cumulative equivalent 18-kip [80-kN] single-axle loads, millions

C_d = modified AASHTO drainage coefficient:

Edge Drains	Precip. Level	Fine-Grained Subgrade		Coarse-Grained Subgrade	
		Nonpermeable Base	Permeable Base	Nonpermeable Base	Permeable Base
No	Wet	0.70-0.90	0.85-0.95	0.75-0.95	0.90-1.00
	Dry	0.90-1.10	0.95-1.05	0.90-1.15	1.00-1.10
Yes	Wet	0.75-0.95	1.00-1.10	0.90-1.10	1.05-1.15
	Dry	0.95-1.15	1.10-1.20	1.10-1.20	1.15-1.20

Notes:
1. Fine subgrade = A-1 through A-3 classes;
   Coarse subgrade = A-4 through A-8 classes.
2. Permeable Base = k = 1000 ft/day (305 m/day) or uniformity coefficient (C_u) ≤ 6.
3. Wet climate = Precipitation > 25 in/year (635 mm/year);
   Dry climate = Precipitation ≤ 25 in/year (635 mm/year).
4. Select midpoint of range and use other drainage features (adequacy of cross slopes, depth of ditches, presence of daylighting, relative drainability of base course, bathtub design, etc.) to adjust upward or downward.

BSTRESS = maximum concrete bearing stress from closed-form equation, psi:

$$BSTRESS = f_d \, P \, T \left[\frac{K_d \, (2 + BETA * OPENING)}{4 \, E_s \, I \, BETA^3} \right] \quad [53]$$

$$BETA = \sqrt[4]{\frac{K_d \, DOWEL}{4 \, E_s \, I}} \quad [54]$$

f_d = distribution factor = $2 * 12 / (\ell + 12)$

ℓ = radius of relative stiffness, inches

I = moment of inertia of dowel bar cross section, in^4:

$$I = 0.25 \pi \left(\frac{DOWEL}{2} \right)^4 \qquad [55]$$

P = applied wheel load, set to 9000 lbf [40 kN]

T = percent transferred load, set to 0.45

K_d = modulus of dowel support, set to 1,500,000 psi/in [405 MPa/mm]

BETA = relative stiffness of the dowel-concrete system

DOWEL = dowel diameter, inches

E_s = modulus of elasticity of the dowel bar, psi

k = modulus of subgrade reaction, psi/in

OPENING = average transverse joint opening, inches:

$$OPENING = 12 * CON * Jtspace * \left(\frac{ALPHA * TRANGE}{2 + e} \right) \qquad [56]$$

Jtspace = average transverse joint spacing, ft

CON = adjustment factor due to base/slab frictional restraint:

= 0.65 if stabilized base

= 0.80 if aggregate base or lean concrete base with bond breaker

ALPHA = PCC thermal expansion coefficient, set to 0.000006/°F [0.000003/°C]

TRANGE = annual temperature range, °F

e = PCC drying shrinkage coefficient, set to 0.00015 strain

FI = mean annual freezing index, Fahrenheit degree-days

Precip = mean annual precipitation, inches

Basetype = 0 for unstabilized base, 1 for stabilized base

Widenlane = 0 if not widened, 1 if widened

Age = pavement age, years

Faulting Model for Undoweled Joints:

$$FautND = CESAL^{0.25} * [0.2347 - 0.1516 * C_d - 0.000250 * Slabthick^2/Jtspace^{0.25} -0.0155 * Basetype + 0.7784*10^{-7} * FI^{1.5} * Precip^{0.25} -0.002478 * Days90^{0.5} - 0.0415 * Widenlane] \quad [57]$$

where FaultND = mean transverse undoweled joint faulting, inches

Days90 = number of days with maximum temperature above 90°F [32.2°C]

and all other variables are as defined for FaultD.

Tables 25, 26, and 27 were developed as examples using the above equations to show the faulting predictions for pavements with and without dowel bars, for the design parameters shown.

Table 25. Mean joint faulting predictions for doweled jointed plain concrete pavement using Equation 52.

ESALs, millions	Granular Base			Treated Base		
	Dowel Diameter 1.00 in	Dowel Diameter 1.25 in	Dowel Diameter 1.50 in	Dowel Diameter 1.00 in	Dowel Diameter 1.25 in	Dowel Diameter 1.50 in
1	0.03	0.01	0.01	0.02	0.00	0.00
2.5	0.04	0.02	0.01	0.03	0.01	0.00
5	0.05	0.03	0.02	0.04	0.01	0.00
10	0.07	0.04	0.03	0.05	0.02	0.01
20	0.10	0.07	0.06	0.08	0.05	0.04
30	0.13	0.10	0.08	0.11	0.07	0.06
40	0.16	0.13	0.11	0.14	0.10	0.09
50	0.20	0.16	0.14	0.17	0.13	0.12
75	0.29	0.24	0.23	0.26	0.22	0.20
100	0.38	0.33	0.32	0.35	0.30	0.29

Values shown in table are mean predicted joint faulting, inches [1 in = 25.4 mm]

Joint spacing = 15 ft [4.6 m]
k-value = 100 psi/in [27 kPa/mm]
Precipitation = 30 in/year [762 mm/year]
FI = 200°F [93.3°C]-days
Lane not widened

Slab thickness = 9 in [229 mm]
E = 4,000,000 psi [27,580 MPa]
TRANGE = 85°F [29.4°C] (July max - January min)
E_s = 29,000,000 psi [200,000 MPa]
Age = ESALs in millions

Table 26. Mean joint faulting predictions for doweled jointed reinforced concrete pavement using Equation 52.

ESALs, millions	Granular Base			Treated Base		
	Dowel Diameter 1.00 in	Dowel Diameter 1.25 in	Dowel Diameter 1.50 in	Dowel Diameter 1.00 in	Dowel Diameter 1.25 in	Dowel Diameter 1.50 in
1	0.04	0.02	0.02	0.03	0.01	0.01
2.5	0.05	0.03	0.02	0.04	0.02	0.01
5	0.06	0.04	0.03	0.05	0.02	0.02
10	0.08	0.05	0.04	0.07	0.04	0.03
20	0.12	0.08	0.07	0.10	0.06	0.05
30	0.15	0.12	0.10	0.13	0.09	0.08
40	0.19	0.15	0.13	0.16	0.12	0.11
50	0.22	0.18	0.16	0.20	0.15	0.14
75	0.31	0.27	0.25	0.28	0.24	0.22
100	0.41	0.36	0.34	0.38	0.33	0.31

Values shown in table are mean predicted joint faulting, inches [1 in = 25.4 mm]

Joint spacing = 45 ft [13.7 m]
k-value = 100 psi/in [27 kPa/mm]
Precipitation = 30 in/year [762 mm/yr]
FI = 200°C [93.3°C]-days
Lane not widened

Slab thickness = 9 in [229 mm]
E = 4,000,000 psi [27,580 MPa]
TRANGE = 85°F [29.4°C] (July max - January min)
E_s = 29,000,000 psi [200,000 MPa]
Age = ESALs in millions

Table 27. Mean joint faulting predictions for undoweled jointed plain concrete pavement using Equation 57.

ESAL, millions	$C_d = 0.80$		$C_d = 1.0$	
	Joint Spacing 15 ft	Joint Spacing 20 ft	Joint Spacing 15 ft	Joint Spacing 20 ft
1	0.09	0.09	0.05	0.05
2.5	0.12	0.12	0.06	0.06
5	0.14	0.14	0.08	0.08
10	0.16	0.17	0.09	0.09
20	0.20	0.20	0.11	0.11
30	0.22	0.23	0.12	0.12
40	0.23	0.23	0.13	0.13
50	0.25	0.25	0.13	0.14
75	0.27	0.27	0.15	0.15
100	0.29	0.29	0.16	0.16

Values shown in table are mean predicted joint faulting, inches [1 in = 25.4 mm]

Joint spacing = 15 or 20 ft [4.6 or 6.1 m]
Slab thickness = 9 in [229 mm]
Precipitation = 30 in/year [762 mm/year]
FI = 200°F [93.3°C]-days
Days90 = 20
Lane not widened

Step 3. Compare the Predicted Mean Faulting With the Recommended Maximum Critical Levels given in Table 28. If the predicted faulting is greater than the recommended level, an adjustment to the joint load transfer design should be made. Potential adjustments include use of dowels, or, if dowels already exist, an increase in the diameter; selection of a different base type and permeability; and/or a decrease in the joint spacing (for undoweled joints).

Slab thickness should not be increased in an effort to improve the joint load transfer design, because slab thickness has only a minimal effect on joint faulting. However, the slab design may need adjustment after the joint design is completed, especially if the joint spacing is reduced or the base type is changed to reduce expected faulting.

Table 28. Recommended critical mean joint faulting levels for design.

Joint Spacing	Critical Mean Joint Faulting
Less than 25 ft	0.06 in
Greater than 25 ft	0.13 in

1 ft = 0.305 m, 1 in = 25.4 mm

These critical levels were derived from analysis of extensive field data. The mean faulting was computed for pavements with a serviceability of 3.0 or less. For example, based upon data from many short-jointed JPCP sections, a mean joint faulting of 0.12 in [3 mm] corresponded to a serviceability index of 3.0 or less. For long-jointed JRCP, the mean faulting level was 0.26 in [6.6 mm]. The recommended critical levels for design were selected as 50 percent of these values in order to effectively exclude faulting as a significant contributor to serviceability loss.

Example check for joint faulting. Assume the same pavement defined in the previous examples. The pavement has a 16-ft [4.9-m] joint spacing, treated base, subdrains, and no dowel bars. A Freezing Index of 500°F [260°C]-days, an annual temperature range of 85°F [47.2°C], and an annual precipitation of 30 in [762 mm] are also assumed for the location. A slab thickness of 10.75 in [273 mm] was obtained for a design traffic of 20 million ESALs and 95 percent reliability. The mean predicted joint faulting of 0.13 in [3.3 mm] exceeds the recommended limit of 0.06 in [1.5 mm], and thus the joint design is inadequate. One possible design modification would be to specify 1.25-in-diameter [32-mm-diameter] dowels. The mean predicted joint faulting would then be 0.05 in [1.27 mm], which would be acceptable.

Joint Layout (no change)

Joint Dimensions (no change)

3.3.3 Joint Sealant Dimensions (no change)