DESIGN AND CONSTRUCTION OF CONCRETE PAVEMENTS

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INTRODUCTION

Modern concrete pavements are built using one of four jointing/reinforcement designs: (1) plain concrete without reinforcement and without added load transfer at joints (PC); (2) plain concrete without reinforcement but with dowels at joints (PD); (3) reinforced doweled concrete, that is, with both slab reinforcement and doweled joints (RD); and (4) concrete continuously reinforced longitudinally with no joints (CRC).

In 1975 the Portland Cement Association, under the sponsorship of the Federal Highway Administration, undertook a study of concrete pavement design and construction in the United States to determine regional uses and preferences and to evaluate performance. A questionnaire to all state highway or transportation departments gathered information on designs and specifications in use. The first part of this paper is a discussion of these data.

Initial construction cost data for the four concrete pavement design alternatives were obtained from state highway agencies. Construction costs were also received from ten paving contractors by means of bid requests on a hypothetical project containing identical pavement items. An analysis of these costs from areas throughout the United States and the cost effectiveness of the various designs when maintenance is considered are covered in the second part of this paper.

The third part of the paper deals with the field survey portion of the study, which gathered and evaluated data on pavement performance and distress manifestations associated with each design. Eighty-five concrete pavement projects were surveyed in seven states. Design details and maintenance information, as available, were collected for survey projects. Major problem areas noted in the survey for each pavement design type are summarized and recommended corrective designs and construction techniques are presented.

DESIGN DETAILS AND PRACTICES

Design details and practices for rigid pavements were obtained from 47 design agencies by questionnaire in 1975. The responses were categorized by region and analyzed for similarities and variances of details and practices within a region.

Description of Regions

Based on climatic considerations including temperature, rainfall, snowfall, and subgrade freezing, the United States was divided into five geographic regions. (Fig. 1)

Region 1 covers 7 states in the northeastern United States. It is characterized by humid cold winters and warm wet summers. Normal winter temperature is 15°-30° F., normal summer range is 65°-70° F. Rainfall is 38-42 in. per year, snowfall 40-100 in. per year. Soil normally freezes 18 in. to 3 ft and design freezing index ranges from 500 to 2,500 degree-days.

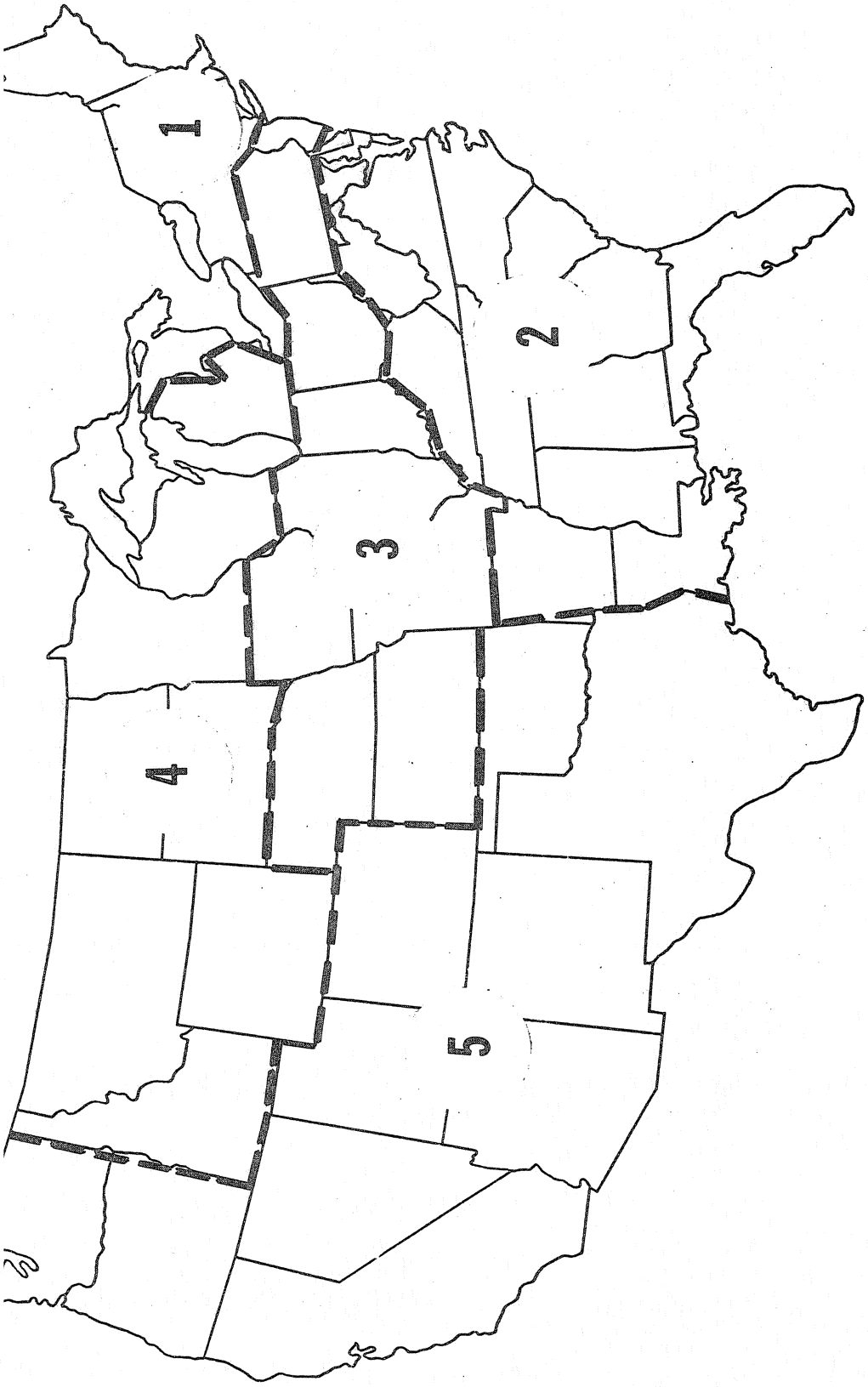


FIG. 1. ENVIRONMENTAL REGIONS

Region 2 covers 15 states made up of the southeastern continental United States and Hawaii. This region is characterized by a humid, hot, long summer and mild winter. Normal winter temperature is 35°-55° F, normal summer range is 70°-80° F. Rainfall is 48-55 in. per year, snowfall less than 10 in. per year. Frost is mostly rare and design freezing index is less than 500 degree-days.

Region 3 covers 9 states in the middle eastern United States. It has hot summers and cold winters. Normal winter temperature is 20°-35°F, normal summer temperature is 70°-75° F. Rainfall is 20-40 in. per year, snowfall is 15-40 in. per year. Soil normally freezes 6 in. to 3 ft and design freezing index ranges from 300 to 1,750 degree-days.

Region 4 covers 8 states in the middle northern United States. It has short mild summers and cold winters. Temperatures normally range from 5° to 20° F in winter and from 55° to 70° F in summer. Rainfall is 20-30 in. per year, snowfall 50-100 in. per year. Soil usually freezes 3-6 ft and design freezing index ranges from 750 to 3,500 degree-days.

Region 5 includes 6 states in the southwestern United States and 4 northwestern states. Hot summers and mild winters are the norm. Normal winter temperature range is 15°-55° F, normal summer range is 55°-85° F. While temperatures and precipitation vary considerably, the region is considered to be reasonably uniform from the standpoint of pavement design requirements.

Distribution of Design Types

The frequency of use of each type of pavement for Interstate and major expressways is presented in Fig. 2. Plain concrete pavements are specified or permitted by 20 states, plain doweled concrete by 13 states, conventionally reinforced concrete by 21 states, and continuously reinforced concrete pavements by 23 states for Interstate and major expressways.

Plain pavements are the only design used in many of the states in Region 5. Exceptions are the continuous design used exclusively in Oregon and the reinforced designs used in Oklahoma and Texas.

Plain pavements are used exclusively in the western states of Region 4 and reinforced pavements in the eastern states of this region. Both conventional and continuous designs are used.

Plain and reinforced designs are used in Regions 1, 2, and 3. In Region 1 plain doweled design is indicated for Maine and New York. Conventionally reinforced design is used in New York, Massachusetts, and Connecticut. The latter also has a continuous design. The other states in Region 1 do not build concrete pavements except for occasional experimental designs.

Plain pavements are the exclusive design for four states in Region 2. Continuously reinforced designs are used in 11 states, with Mississippi using it exclusively. Conventionally reinforced pavements are used in seven states of Region 2.

Conventionally reinforced pavements are used exclusively in Ohio, Missouri, and New Jersey in Region 3. Most of the states allow either conventional or continuously reinforced designs. The plain design is used in Nebraska, Iowa, Indiana, and Kansas.

Thickness Design Methods Used

Numerous procedures are available for the thickness design and analysis of concrete

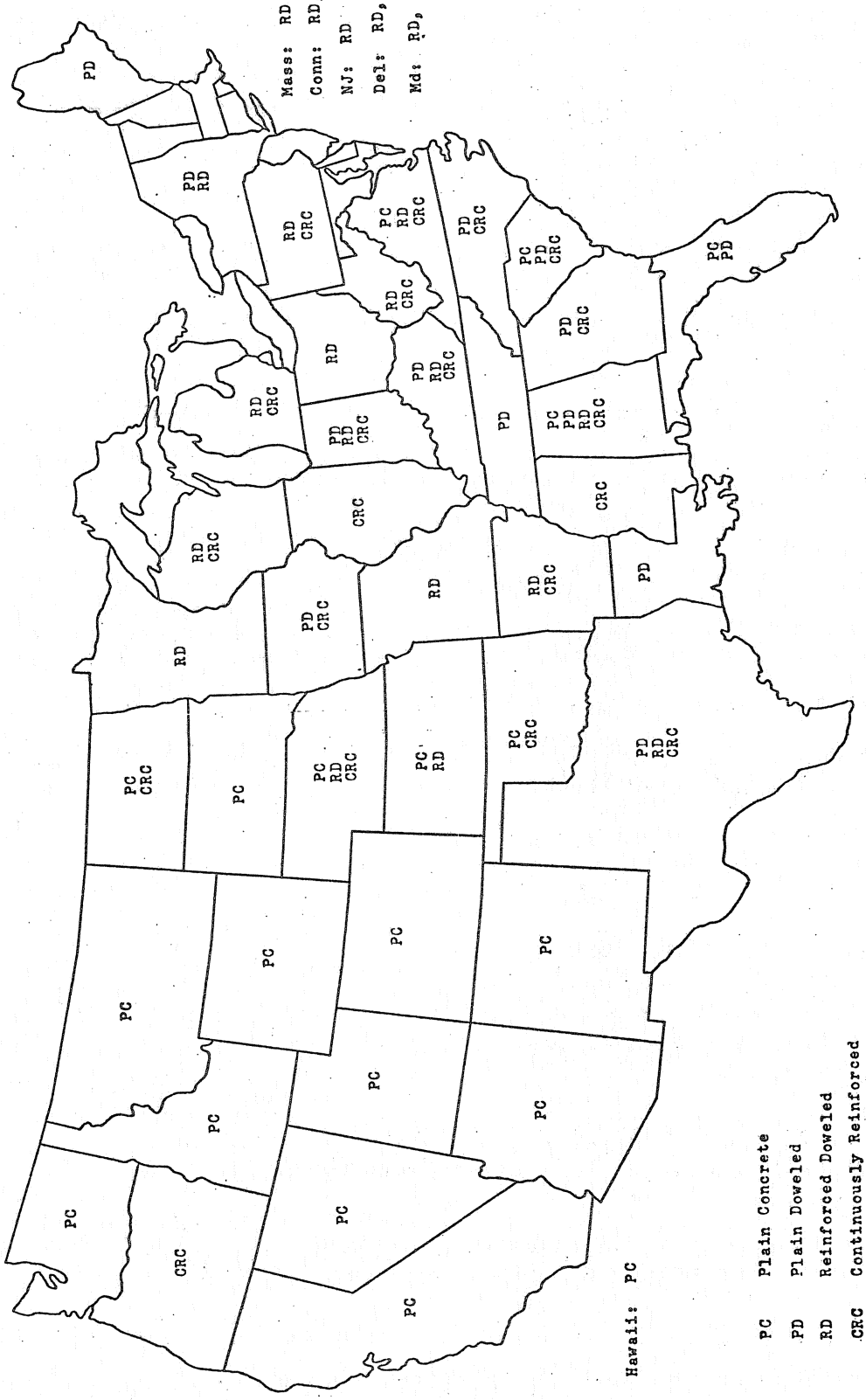


FIG. 2. PAVEMENT TYPES USED BY STATES

pavements. Two methods are extensively used.

The AASHTO design method is based on empirical relationships derived from the AASHO Road Test. These are supplemented by theory and by data developed from current practices of highway construction agencies. The design philosophy is based on the pavement serviceability.

The PCA design method is based on the flexural stress and flexural strength relationship of the concrete with the intent of keeping load stresses within safe limits.

The frequency of use of these design methods is summarized in Table 1. The AASHTO thickness design method is used by 21 states and the PCA method by 12 states. Four states use either method. The remaining states use other methods of design. The AASHTO method is generally used in the southern and eastern areas of the United States and the PCA method finds application in the northwest.

Plain Concrete Pavements With and Without Dowels

A primary difference in designs for plain concrete pavements among the states is the requirement for mechanical load transfer at joints. The data in Fig. 2 indicate that 17 states use a plain undoweled design only, 10 states use only a design with dowels, and three states have designs for both. Round steel bars are generally used for load transfer at the joints. Dimensions and spacing for dowels are given in Table 2. Dowel bar practices in most cases conform to the minimum design requirements proposed by AASHTO. Only eight states use 1-in.-diameter dowel bars, and dowel length of less than 18 in. is used by only six states. Only three states used a dowel spacing greater than 12 in.

Joints spaced at uniform intervals between 14 and 30 ft are used in 17 states for Interstate and major expressways, and in 20 states for primary highways. A random spacing pattern is specified by 15 states for Interstate and major expressways, and by 10 states for primary highways. Random skewed spacings are used primarily in the states west of Minnesota and Iowa. A joint spacing of 20 ft predominates east of those states. Frequency of use of some joint spacing patterns is summarized in Table 3. The most frequently recommended joint spacings are 20 ft for regular spacing and the pattern of 13-19-18-12 ft for random repeated spacing.

Variations in slab thickness and requirement for load transfer device in relation to joint spacing are summarized in Table 4. The data indicate that for undoweled plain concrete pavements, slab thickness varies from 8 to 13 in. for Interstate and major expressways. Most of the Interstate and major expressway designs for 8-in.-thick plain pavements were reported for states located west of North Dakota and Kansas. The plain doweled pavement thicknesses were generally 9 in. or more. Only Louisiana reported a range of 8 to 10 in. and Indiana a range of 10 to 13 in. The data indicate that in most cases the thickness of plain pavement slab for primary highways is 1 in. less than for Interstate and major expressways.

Examination of the data reveals that random, skewed joint spacing is used in states requiring the thinner plain pavement designs and that dowels are used with the heavier pavements favored in Regions 1 and 2 and also in Indiana and Texas.

Transverse contraction joint dimensions vary considerably among the states. The data show that depth of contraction joints is generally D/4. Prevailing practice for some of Regions 2 and 5 designs indicates a lesser depth of sawing or insert for some of the plain pavements. In the majority of states, joints are formed by sawing. The width of groove varies between 1/8 in. and 3/8 in.

TABLE 1. DESIGN METHODS

Interstate And Major Expressways + (Primary Highways)

Design Methods	No. of States					
	Region 1	Region 2	Region 3	Region 4	Region 5	Total U.S.
AASHTO	2 (-)	7 (6)	4 (4)	3 (4)	5 (3)	21 (17)
PCA	- (-)	3 (3)	1 (1)	3 (4)	5 (2)	12 (10)
AASHTO and/or PCA	- (-)	2 (1)	- (-)	2 (-)	- (-)	4 (1)
Others	1 (2)	1 (1)	4 (4)	- (-)	- (-)	6 (7)
Not Reported	- (-)	2 (2)	- (-)	- (-)	- (-)	2 (2)

TABLE 2 - DOWEL DIMENSIONS AND SPACING

Region	Length	Spacing	No. of States Specifying Diameter				
			1"	1-1/8"	1-1/4"	D/8	Other
1	16 18	12 12		1 2		1	*
2	15 16 18 18 19	12 12 12 15 12	 2 1 	 1 1 	1 4 1	 1 1 	
3	16-3/4 18	12 12	 2	 	1** 8	 	
4	18	12	2		4		
5	12 18 18 20	12 12 18 12	 1 	 	1 1 1	 	

*I-beam 1½ x 16 in. is alternate in one state
**Monel metal clad

TABLE 3. JOINT SPACING FOR INTERSTATE AND MAJOR EXPRESSWAYS + (PRIMARY HIGHWAYS)

Joint Spacing, ft		Number of States					
		Region 1	Region 2	Region 3	Region 4	Region 5	Total U.S.
Regular Joint Spacing	14				1 (1)		1 (1)
	15			1 (1)		2 (1)	3 (2)
	17			- (1)			- (1)
	18		1 (1)	- (1)	1 (1)	1 (1)	3 (4)
	20	2 (1)	4 (5)	2 (2)	- (2)		8 (10)
	25		2 (1)				2 (1)
	30		1 (1)	- (1)			1 (2)
Random Joint Spacing	13-19-18-12		1 (-)	1 (1)	3 (3)	3 (1)	8 (5)
	12-13-17-18		1 (1)				1 (1)
	18-19-23-25		1 (-)				1 (-)
	12-13-18-19			1 (1)			1 (1)
	13-15-17-16				1 (1)		1 (1)
	13-15-17					1 (1)	1 (1)
	13-18-17-16					1 (-)	1 (-)
	10-14-13-9					1 (1)	1 (1)

TABLE 4. SLAB THICKNESS

Interstate and Major Expressways and (Primary Highways)

	Joint Spacing, ft.	Region 1		Region 2		Region 3		Region 4		Region 5	
		Undoweled	Doweled	Undoweled	Doweled	Undoweled	Doweled	Undoweled	Doweled	Undoweled	Doweled
Regular Joint Spacing	14							9 (8)			
	15					9 (9)					9-10 (8-9)
	17					(8-9)					
	18				9-10 (9)	(9)		9 (8)			8 (8)
	20		9-10 (9)	10 (8-9-10)	8-9-10-11 (8-9-10)	(7-8-9-13)	10-13 (8-9-10-12)	(7-8-9)			
	25			8-10	9-10 (9)						
	30				10 (10)	(7-8)					
Random Joint Spacing	13-19-18-12			9		(9-12)	10-13	8-9½ (7-7½-8)	8 (8)	7.9-8-9.6 (7.2-9)	8
	12-13-17-18			(1-10)	11 (9-10)						
	18-19-23-25				10						
	12-13-18-19					10 (8)					
	13-15-17-12							8 (7-8)			
	13-15-17									8-13 (8-13)	
	13-18-17-12									9-10	
	10-14-13-9									9 (9)	

Longitudinal joint depth was D/4 or greater for the majority of pavements in all regions. Depth of sawing or insert of less than D/4 was noted for five states. For three of the five states the depth meets D/4 criteria for the thinner, but not the thicker designs. These longitudinal joint details for plain pavements apply also to conventional and continuously reinforced designs.

Expansion joint practices in the various states are shown by region in Table 5. The data show usage of this type joint adjacent to structures.

State practices in subbase designs for concrete pavement is shown in Fig. 3. Both granular and stabilized subbases are specified under plain pavements (Table 6). Two states specify untreated subbase, 12 states permit either untreated or stabilized subbases, and 15 states specify stabilized subbases. Requirements for type and depth of each class of subbase are also summarized in Table 6. Thickness of untreated or stabilized subbase ranges from 3 to 12 in. Thickness of cement-treated or asphalt-treated subbase ranged from 3 to 8 in. A 2-in. asphaltic concrete subbase is also permitted. Combinations of granular material and cement-treated or asphalt-treated subbase with total depth ranging from 4 to 11.4 in. are also specified. The thickness of subbase for both Interstate and primary highways is generally the same.

Reinforced Doweled Concrete Pavements

Conventionally reinforced concrete pavements are permitted or specified in 21 states. They are used in the area to the east of the Dakotas, Colorado, and New Mexico.

Reinforcement requirements in relation to slab length and thickness are summarized in Table 7. The data indicate that joint spacing ranges from 25 ft to 80 ft. A slab thickness of 9 or 10 in. is generally required. Reinforcement requirements range from 44 to 79.7 lb per 100 sq ft. Generally, the amount of reinforcement increases as joint spacing increases.

Joints are formed by sawing in most states. The data indicate (Table 8) that the width of sawed grooves varies from 1/8 to 3/4 in. However, there is no correlation between width of sawed groove and slab length. The depth of sawed groove varies from 2 to 3-1/4 in. Provisions for sealant reservoir dimensions are made in the specifications of 13 states. Fourteen design agencies permit use of preformed joint sealers.

Steel dowel bars are used as load transfer devices with all RD designs. Dowel dimensions are given in Table 2. Diameters of dowel bars vary from 1 to 1-1/4 in., length from 16 to 20 in., and spacing from 12 to 15 in.

The frequency of specifying each type of subbase in combination with reinforced doweled pavements is summarized in Table 9. Eleven states specify untreated subbase, 5 states permit either untreated or stabilized subbase, and 4 states specify stabilized subbases.

Requirements for type and depth of each class of subbase are given in Table 9. The data show that the thickness of untreated subbase ranges from 3 to 12 in. The thickness of cement-treated or bituminous-treated subbase ranges from 3 to 8 in. Stabilization by cement or asphalt is specified; no other stabilization is permitted. The data also indicate that subbase thickness for both Interstate and primary highways is generally the same.

Continuously Reinforced Concrete Pavements

Continuously reinforced concrete pavements are permitted or specified by 23 states.

The frequency of specifying a given slab thickness is summarized in Table 10. The

TABLE 5. PREFORMED EXPANSION JOINTS

Interstate and Major Expressways and (Primary Highways)

Number of Joints	Region 1		Region 2		Region 3		Region 4		Region 5	
	Width, in.	Spacing, ft.	Width, in.	Spacing, ft.	Width, in.	Spacing, ft.	Width, in.	Spacing, ft.	Width, in.	Spacing ft.
1			1 (1)		2 (2)				1½	
1					4					
1					4½±½					
1					48 (48)					
2			3/4 (3/4)	30 (30)	2	25			3/4	40
2									1	40
3			3/4 (3/4)	(45-61.5) (45)			1	39.5	3½	32
3			1 (1)	15-20-25 40.5-50 (15-20-25-40.5)			1	350		
4							3/4 (3/4)	40 (40)		
4							1	350		

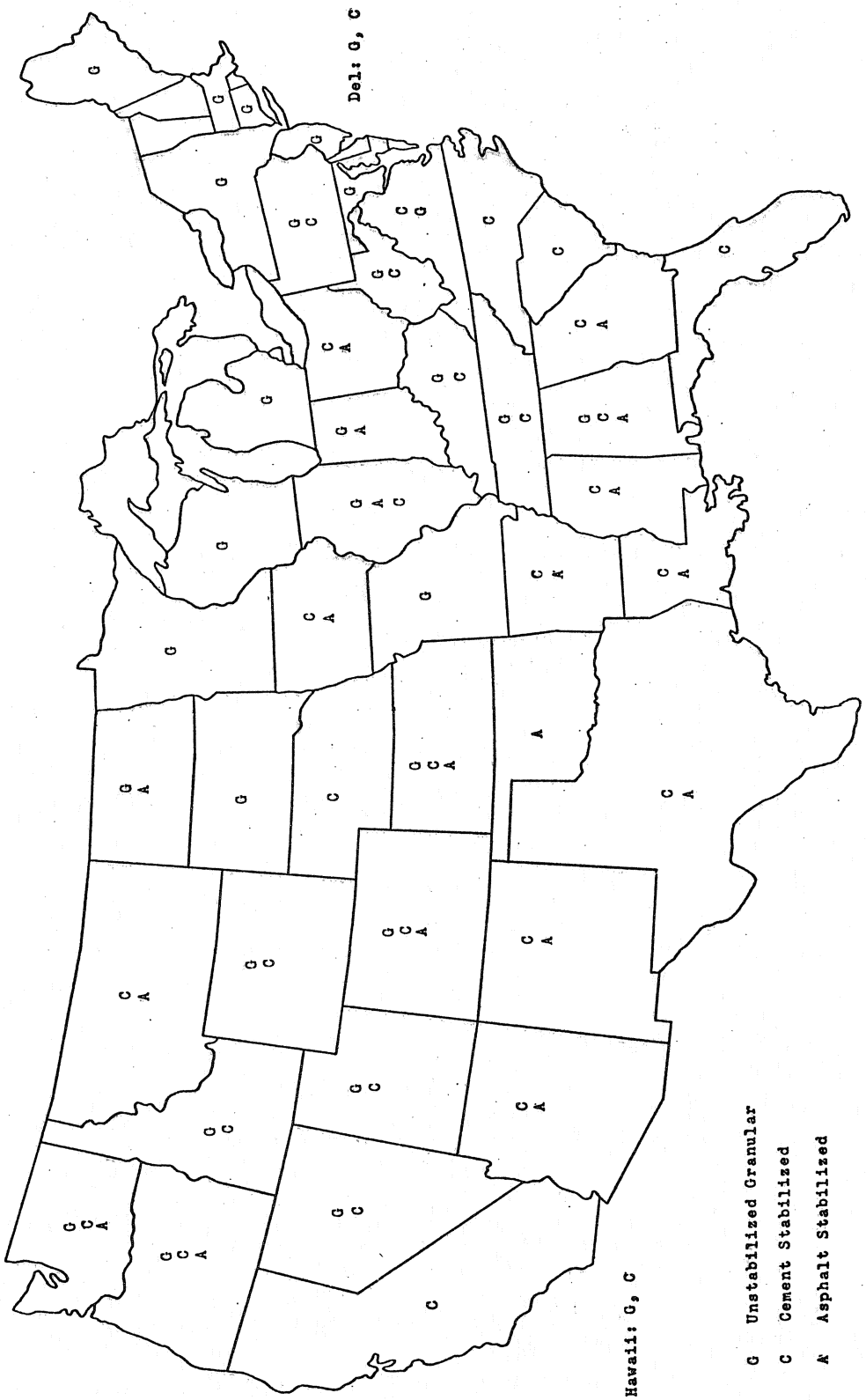


FIG. 3. SUBBASE TYPES USED BY STATES

TABLE 6. SUBBASES USED WITH PC AND PD PAVEMENTS

SUBBASE TYPE

Interstate and Major Expressways

Subbase Type	Number of States					Total U.S.
	Region 1	Region 2	Region 3	Region 4	Region 5	
Granular-Untreated	2	-	-	-	-	2
Granular or Stabilized	-	3	2	3	4	12
Stabilized, Asphalt or Cement	-	6	2	2	5	15

SUBBASE THICKNESS

Interstate and Major Expressways and (Primary Highways)

Subbase Type	Thickness, in.				
	Region 1	Region 2	Region 3	Region 4	Region 5
Granular/Untreated	3-4-12 (12)	5-6 (4-5-6)	6 (4-6)	4-6 (2-6-9)	4-6-12 (6-12)
Cement treated		4-5-6 (5-6)	3-4 (3-4)	4-4.8-6 (4-4.8-6)	4-6-8 (4-6)
Bituminous treated			4 (4)	4.8 (4.8)	3-4-6-8 (3-4-6)
Lime stabilized		12 (12)		3 (3)	
Asphaltic concrete				2	
Cement treated/ bituminous top		3/1-5/1 (3/1-5/1)			
Granular/ bituminous top		5/1			
Granular/cement treated top					4/4-6/5.4 (6/5.4)

TABLE 7. REINFORCEMENT PRACTICES

Interstate and Major Expressways and (Primary Highways)

Joint Spacing, ft.	Region 1		Region 2		Region 3		Region 4		Region 5	
	Thick-ness, in.	Reinforce-ment, lb./ 100 sq.ft.	Thick-ness, in.	Reinforce-ment, lb./ 100 sq.ft.	Thick-ness, in.	Reinforce-ment, lb./ 100 sq.ft.	Thick-ness, in.	Reinforce-ment, lb./ 100 sq.ft.	Thick-ness, in.	Reinforce-ment, lb./ 100 sq.ft.
25			10 (8)	44 (44)						
27*							9-10 (8-9)	47-51 (47-51)		
39			9 (9)	44 (44)						
40	9 (8)	52.4 (52.4)	9 (8-9)	53-60 (53-60)	10-13 (8-9-10-12)	54 (54)				
45			10 (8-9-10)	54-59 (54-59)						
46.5					8-9-10 (8-9-10)	44-54 (44-54)				
50			10 (9)	59 (59)	(10)	(54)				
60									10	66.3
61.5			9 (9)	61 (61)	8-9-10 (8-9-10)	61 (61)				
63	9 (9)	59.5 (59.5)								
70							9-10 (9)	74.5 (74.5)		
78.1					9	79.7				
80							9-10 (8-9)	69 (69)		

*Skewed 2 ft. in 12 ft.

TABLE 8. GROOVE DIMENSIONS*

Interstate and Major Expressways and (Primary Highways)

Joint Spacing, Ft.	Region 1		Region 2		Region 3		Region 4		Region 5	
	Width, in.	Depth, in.	Width, in.	Depth, in.	Width, in.	Depth, in.	Width, in.	Depth, in.	Width, in.	Depth, in.
25			1/8-⅛ (1/8-⅛)	2 (2)						
27*							1/8 (1/8)	2-2½ (2)		
39			3/8 (3/8)	2⅛ (2⅛)						
40	3/8 (3/8)	2-3/4 (2⅛)	⅛-5/8 (⅛-5/8)	2-2⅛ (2-2⅛)	⅛-⅛ for top 1/8 for bottom (⅛)	2-2⅛-3⅛ (1.6-1.8-2.3)				
45			⅛ (⅛)	2-2½ (2-2¼)						
46.5					3/8 (3/8)	2-2⅛-2½ (2-2⅛-2½)				
50			1/8-⅛ (1/8-⅛)	2 (2)	(1/8)	(2-3/4)				
60									3/8-3/4✓	2½
61.5			⅛ (⅛)	2⅛ (2⅛)	3/8 (3/8)	2-2⅛-2½ (2-2⅛-2½)				
63	5/8+ (5/8)	2+ (2)								
70							½ (½)	2½ (2½)		
78.1					3/4 (3/4)	? ?				
80							⅛ (⅛)	2 (2)		

* Joints are formed by sawing unless otherwise indicated
\+ Joints are formed by sawing or forming
✓ Joints are formed by forming only

TABLE 9 SUBBASES USED WITH RD PAVEMENTS

SUBBASE TYPE

Interstate and Major Expressways and (Primary Highways)

Subbase Type	Number of States					
	Region 1	Region 2	Region 3	Region 4	Region 5	Total U.S.
Granular/Untreated	2 (2)	3 (4)	3 (4)	3 (3)		11 (13)
Untreated or Stabilized		3 (2)	2 (1)			5 (3)
Stabilized (All types)		1 (1)	2 (3)		1 (-)	4 (4)
Cement Treated			1 (2)			1 (2)
Cement or Bituminous Treated		1 (1)	1 (1)		1 (-)	3 (2)

SUBBASE THICKNESS

Interstate and Major Expressways and (Primary Highways)

Subbase Type	Thickness, in.				
	Region 1	Region 2	Region 3	Region 4	Region 5
Granular/Untreated	6-10-12 (6-10-12)	5-6 (4-6)	4-6-8-12 (4-6-8-12)	4-6-9-10 (4-6-9-10)	
Cement Treated		4-6 (4-6)	3-5-6 (3-4)		4-8 (-)
Bituminous Treated		4-6 (4-6)	4 (4)		4-8 (-)

majority of states require one of three thicknesses - 8 in., 8-1/2 in., or 9 in.

The percentage of longitudinal steel specified in relation to slab thickness is shown in Table 11. Longitudinal steel percentage varies between 0.5 and 0.7 with the majority of states specifying 0.6. Less than 0.57% steel is permitted only for pavements in Region 5.

Terminal joint design practices include anchor lugs and use of a concrete sleeper slab with a wide-flange steel beam set into it. The frequency of specifying the type of terminal anchor is summarized in Table 12. Ten states specify steel beam and sleeper slabs, 5 states specify concrete lugs, and 5 states permit either type. A regional pattern was not discernible from the data.

The frequency of specifying each type of subbase with CRC is summarized in Table 13. Five states specify untreated subbase, 3 states permit either treated or stabilized subbase. Requirements for type and thickness of each class of subbase are also in Table 13. The thickness of untreated subbase ranges from 4 to 12 in., asphalt or cement-treated subbase from 3 to 8 in., lime-stabilized subbase is 4 in., asphaltic concrete subbase 2 in., and the maximum total thickness of combined asphalt treated and untreated or cement-treated subbase is 6 in. The data indicate that the thickness of subbase for primary highways is generally less than for Interstate and major expressways.

CONCRETE PAVEMENT COSTS RELATED TO DESIGN

The cost effectiveness of the pavement designs is determined by initial construction costs and maintenance expenditures. Initial construction costs were obtained from questionnaire responses from departments of transportation in the continental United States and also from cost estimates for four designs submitted to paving contractors. Maintenance expenditures were collected, as available, as part of the field survey. Maintenance cost data for individual construction projects are severely limited in availability. Records are often not kept at all or costs are not assigned to particular pavement projects. Limited data were obtained from three states and these are used for an analysis of maintenance costs in the study. However, the analysis suffers from the unavailability of consistent data.

Unit price maintenance data were obtained from maintenance contractors, departments of transportation, and toll highway authorities. These were used along with estimates of maintenance work to arrive at a maintenance cost for different work items and to discuss the cost impact of various design details.

Initial Costs

Concrete pavement costs were obtained from state DOT's by questionnaire. The considerable scatter of prices is due to regional influences and to local factors such as haul distances, cost of materials, and size of job.

Bid prices for the different pavement designs were solicited from contractors to obtain a better estimate of the costs of each design without the variables of time or job conditions affecting the analysis. All contractors were supplied with identical bid sheets of materials and were provided with the same job and site conditions. The contractor's responses were of course restricted to their areas of experience.

Square-yard costs for the various designs as submitted by contractors are tabulated by region in Table 14. Bids from two contractors in Region 3 were consistently higher than all others.

Average costs for 9-in-thick pavements are shown in Table 15 with a cost comparison

TABLE 10. SLAB THICKNESS

Interstate and Major Expressways and (Primary Highways)

Thickness, in.	Number of States					
	Region 1	Region 2	Region 3	Region 4	Region 5	Total U.S.
8	1 (-)	5 (4)	2 (1)	2 (1)	2	12 (6)
8½		1 (1)				1 (1)
9		3	1			4
8-9		2 (2)	2 (1)		1	5 (3)
8-9-10				1		1

TABLE 11. STEEL PERCENTAGE

Interstate and Major Expressways and (Primary Highways)

Slab Thickness, in.	Steel Percentage				
	Region 1	Region 2	Region 3	Region 4	Region 5
8	0.62	0.6-0.62-0.7 (0.57-0.6-0.64-0.7)	0.6-0.65-0.7 (0.6-0.7)	0.6-0.61-0.7 (0.61)	0.5-0.6-0.61
8½		0.6 (0.6)			
9		0.6-0.68-0.7 (0.57-0.6-0.64)	0.6-0.7 (0.7)	0.7	0.5-0.6
10				0.7	

TABLE 12. TERMINAL ANCHORS

Interstate and Major Expressways and (Primary Highways)

Type of Anchors	Number of States					
	Region 1	Region 2	Region 3	Region 4	Region 5	Total U.S.
Concrete Lugs		3 (1)	2 (1)			5 (2)
Steel Beam/ Sleeper Slab	1	6 (5)	2		1	10 (5)
Concrete Lugs or Steel Beam/ Sleeper Slab		2 (1)		1 (1)	2	5 (2)
None				1		1
Not reported			1 (1)	1		2 (1)

TABLE 13. SUBBASES USED WITH CRC PAVEMENTS

SUBBASE TYPE

Interstate and Major Expressways and (Primary Highways)

Subbase Type		Number of States					
		Region 1	Region 2	Region 3	Region 4	Region 5	Total U.S.
Granular/Untreated		1	2 (2)	-	2 (1)		5 (3)
Untreated or Stabilized		-	1 (1)	1		1	3 (1)
Stabilized (all types)		-	8 (4)	4 (2)	1	1	14 (6)
Type of Stabilization	Cement Treated		4 (1)	1			5 (1)
	Bituminous Treated		-	1 (1)			1 (1)
	Cement or Bituminous Treated		2 (2)	1		1	4 (2)
	Cement, Bituminous or Lime Stabilized		-	1 (1)			1 (1)
	Asphaltic Concrete		-		1		1
	Bituminous top over Cement Treated		1 (1)				1 (1)
	Bituminous top over Cement Treated or Untreated		1				1
Not specified						1	1

SUBBASE THICKNESS

Interstate and Major Expressways and (Primary Highways)

Subbase Type	Thickness, in.				
	Region 1	Region 2	Region 3	Region 4	Region 5
Granular/Untreated	6-10 (-)	4-5-6 (4-6)	8-12 (-)	6-9-10 (6-9)	4-8 (-)
Cement Treated		4-5-6-7 (4-6)	3-4-5-7 (4)		4-6-8 (-)
Bituminous Treated		4-6 (4-6)	4 (4)		4-6-8 (-)
Lime Stabilized			4 (4)		
Asphaltic Concrete				2 (-)	
Cement Treated/ Bituminous Top		3/1-5/1 (3/1)			
Granular/ Bituminous Top		5/1 (-)			

of the different designs. The least costly pavement was the 9-in.-thick plain pavement with randomly spaced skewed joints. The plain doweled pavement with 20-ft joint spacing cost 19% more than the plain pavement; conventionally reinforced pavement cost 28% more, and continuously reinforced pavements 54% more costly.

One mile of a two-lane-wide plain doweled pavement costs about $129,000. An extra $10,000 would be required to construct a conventionally reinforced pavement and an additional $39,000 would be required for a continuously reinforced pavement. Some of the design details involved and their impact on cost effectiveness follow.

Dowels:

From Table 14, the average increase in 9-in.-pavement costs when dowels were added was $1.43 a square yard. This difference was obtained from bid prices for an average skewed joint spacing of 15.5 ft for the undoweled pavement and 20-ft joint spacing for the doweled pavement. The average cost of dowels as shown in Table 16 was $1.17 per square yard. The remaining cost difference of $0.26 per square yard was due to additional finishing as well as overhead and profit.

The benefit of dowels was demonstrated in the performance of the pavements inspected in the field survey portion of the project. It should also be remembered that if dowels are omitted, pavement thickness might be increased by about 2 in. As seen in Table 16, the average cost of $1.17 per square yard for dowels is about equal to 2 in. of concrete. As it is not known what pavement thickness increase is necessary to obtain performance equal to that of doweled sections, the use of dowels is a safe precaution. But thicker pavements, wider pavements, paved concrete shoulders, and stabilized subbases should be considered as alternatives on the basis of economics when the benefits of these factors can be established.

Costs quoted for dowels include the cost of dowel-basket supporting units. This cost might be reduced by the use of automatic dowel placing machines as practiced in some parts of the country.

Joint Spacing:

For plain pavements, joints are spaced to control transverse cracking. Spacing varies from 15 to 30 ft depending on type of aggregate, climate, and prior experience. However, as joint spacing increases aggregate interlock decreases and there is an increase in risk of panel cracking. Based on these considerations, maximum joint spacing for plain pavements should be considered 20 ft.

For reinforced pavements, joint spacing varies from 30 to 100 ft. As joint spacing increases, the amount of distributed steel in the pavement is increased. Thus, as joint spacing increases, the cost of distributed steel increases. However, dowel costs are reduced because the number of joints decreases with increased spacing. Based on contractor-supplied unit prices for sawing, mesh, dowels, and joint sealants, a joint cost versus joint spacing analysis was made. This analysis shows (Fig. 4) that on a cost basis the optimum joint spacing for reinforced doweled pavements is between 40 and 50 ft. As maintenance costs generally increase with increased joint spacing, the selection of 40-ft joint spacing for mesh-dowel reinforced pavements appears warranted.

Steel Reinforcement:

Costs increase with an increase in the amount of steel required by the designs. Considering equal thickness pavements of PD, RD, and CRC designs as equal in load-carrying capacity, increased cost factors of 8% for RD and 30% for CRC occur over the PD design. Average costs of steel items in each of these designs are shown in Table 16.

TABLE 14 - CONCRETE PAVEMENT CONSTRUCTION COSTS FROM CONTRACTORS
(dollars per square yard)

CONTRACTOR	7	5	10	2	6	4	3	1	8	9	Average
REGION		2			3		4		5		
DESIGN											
1. 9 in. PC with skewed jts 13, 19, 18, 12	7.77	7.97	6.14	7.21	8.35	9.82	7.96	7.40	8.06	6.41	7.71
2. 9 in. PD with 20 ft joint spacing	8.37	9.07	7.25	8.23	10.08	11.26	8.67	8.68	10.64	-	9.14
3. 9 in. RD with 50 ft joint spacing	8.75	9.41	-	8.80	10.97	11.80	9.87	9.31	-	-	9.84
4. 9 in. CRC with transverse steel	10.99	10.94	-	12.56	12.73	13.89	11.04	10.77	12.31	-	11.90
5. 9 in. CRC without transverse steel	10.32	10.76	-	10.99	12.21	13.26	10.86	-	11.95	-	11.48
6. 8 in. CRC with transverse steel	10.00	10.07	8.73	11.59	11.62	12.67	10.24	9.64	11.27	-	10.65
7. 8 in. CRC without transverse steel	9.38	9.89	-	10.02	11.10	12.05	10.09	-	10.91	-	10.48
8. Granular subbase (6 in.)	1.50	2.50	-	2.12	-	1.45	1.70	1.52	2.04	-	1.83
9. Cement treated subbase (6 in.)	2.90	2.28	-	3.40	-	3.60*	-	2.21	2.90	2.16	2.64
10. Bituminous treated subbase (6 in.)	2.55	5.77	-	-	-	3.35*	-	2.27	4.17	-	3.69

*4 in.

TABLE 15 - COST COMPARISON OF DESIGNS FOR 9-IN. THICK PAVEMENTS

Design	Average Cost (dollars per square yard)	Cost Ratio	
		Compared to PC	Compared to PD
PC	7.71	1.00	0.84
PD	9.14	1.19	1.00
RD	9.84	1.28	1.08
CRC*	11.90	1.54	1.30

*with transverse steel

TABLE 16 - COST OF EMBEDDED ITEMS AND ADDITIONAL CONCRETE
(dollars per square yard)

Item	Region				Average
	2	3	4	5	
Tiebars	0.03	0.04	0.03	0.03	0.03
Dowels (9" PD @ 20')	0.91	1.26	0.61	1.70	1.17
Dowels	0.36	0.50	0.24	0.41	0.41
Mesh reinforcement (9" RD @ 50')	0.97	1.29	1.60	1.05	1.21
CRC Reinforcement (9" CRC with trans. steel)	3.31	4.47	3.18	3.52	3.78
Concrete per inch (above 8" thickness)	0.52	0.63	0.51	0.58	0.57

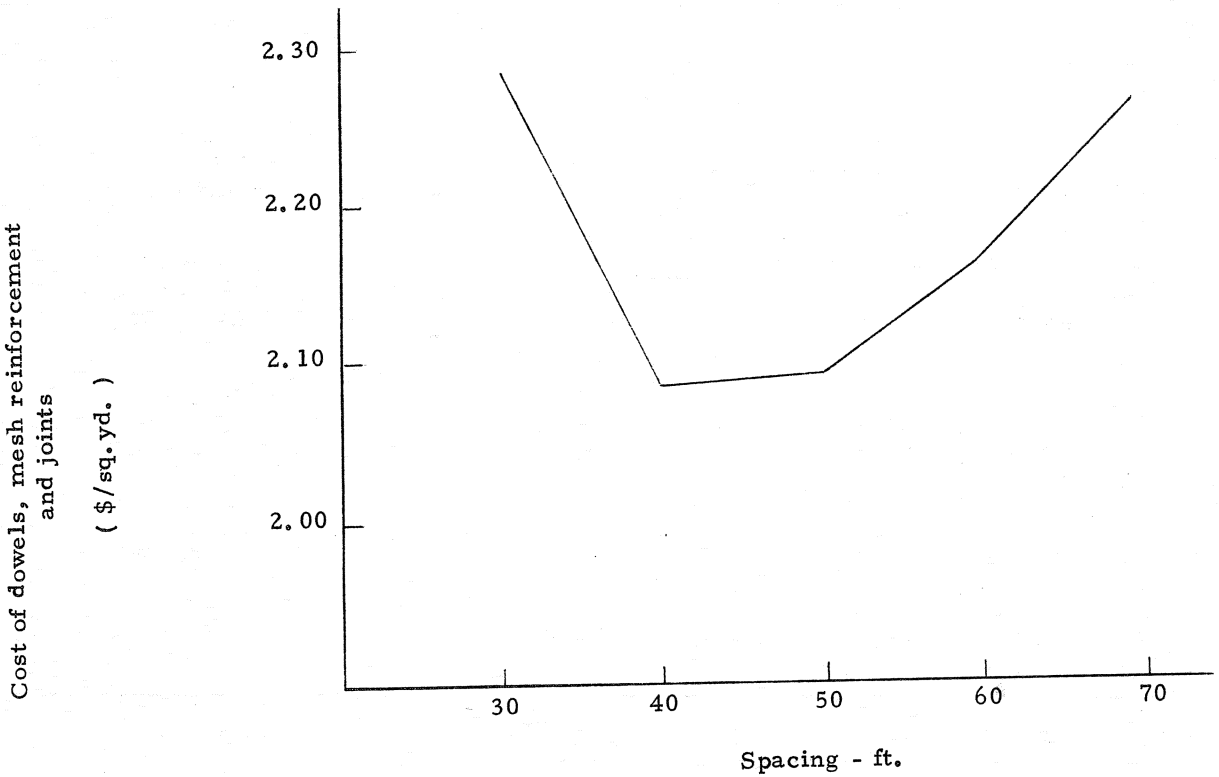


FIG. 4. OPTIMUM JOINT SPACING - RD PAVEMENT

Transverse Reinforcement in CRC:

Continuously reinforced pavements have been constructed with and without transverse steel. The lack of transverse steel, however, was not observed to be detrimental to pavement performance. Table 14 shows an average cost reduction of $0.42 per square yard where transverse steel is omitted from a 9-in. CRC pavement.

Tiebars:

Costs of tiebars are summarized in Table 16. Savings due to elimination of tiebars in longitudinal joints average only 3¢ per square yard. The absence of tiebars allows the otherwise tightly held longitudinal joint to open and may let water flow down below the pavement. This could contribute to much more costly maintenance than the savings gained by omitting the tiebars.

Joint Sealant:

The need for a high-type joint sealant becomes more acute with the greater joint movements associated with longer joint spacing. The average additional cost due to substitution of premolded joint sealant for hot liquid poured sealant in an RD pavement with 40-ft joint spacing was determined to be about 17¢ per square yard. Choice of a premolded sealant for 40-ft-long joint spacings is justified for sites where joint-opening fluctuations would exceed the extensibility of high-type liquid joint sealants.

Subbases:

Subbase costs per square yard for 6-in.-thick construction are listed in Table 14. Prices for granular subbases are generally much lower than those for stabilized subbases. A price advantage for cement-stabilized subbases over bituminous-stabilized subbases was noted in the average of all bids. The reverse was noted for two contractors' bids. Justification for use of stabilized subbases is the increased load-carrying capability of the total pavement system.

Maintenance Costs

Roadway maintenance costs were obtained for a total of 35 Wisconsin, Iowa and Oklahoma survey projects. Yearly maintenance expenditures were obtained for the entire life of Wisconsin RD and CRC designs. The data for Iowa PD, RD, and CRC pavements covered only the period from 1969 to 1974. Oklahoma maintenance data were available for only two 12-month periods: 1971-1972 and 1974-1975.

Maintenance costs reported by the three states were adjusted by a noncompounded factor of 7% per year to bring costs of prior years in line with 1975 costs. For example, 1967 maintenance expenditures were multiplied by a factor of 1.56 and 1970 expenditures by a factor of 1.35. The inflation-adjusted maintenance expenditures were plotted against pavement age. Graphs of these data showed considerable scatter in the expenditures at various pavement ages.

Thus, even though a considerable body of maintenance data was collected, it was insufficient for estimating maintenance costs with any degree of confidence. A far greater number of projects for each design in each state or region, would be required to determine reliable maintenance expenditure trends.

Consideration was also given to weighing the influence of truck traffic on maintenance expenditures. Plots of ratios of maintenance expenditures to truck traffic versus pavement age showed as much scatter as the expenditure versus age plot.

TABLE 17 - PAVEMENT MAINTENANCE COSTS
(dollars per square yard)

State	Design	Thickness (in.)	Initial Cost (1975)	Maintenance Cost	
				10 Year Cumulative	Percent of Initial Cost
Wisconsin	RD	9	8.81	0.55	6.2
Wisconsin	CRC	8	10.23	0.14	1.3
Iowa	PC	10	9.20	0.34	3.6
Iowa	RD	10	9.61	0.47	4.9
Iowa	CRC	8	11.95	0.78	6.5
Oklahoma	PC	9	7.28	0.55	7.5
Oklahoma	RD	9	9.23	0.38	4.1

Ten-year cumulative expenditures for maintenance were determined from the area under a curve drawn to include 90% of the data. The expenditures are listed in Table 17 along with the initial construction costs determined for each design on the basis of contractor unit prices. Maintenance costs for 10 years varied from 1.3% to 7.5% of the initial pavement cost. These low expenditures for maintenance indicate either that the pavements were relatively maintenance-free or that timely maintenance procedures are not always followed.

FIELD SURVEY - METHODS AND FINDINGS

Pavements in Iowa, Wisconsin, Pennsylvania, Georgia, Oklahoma, Texas, and California were included in the survey. Each of plain, conventionally reinforced, and continuously reinforced pavements were located in at least four of the seven states. California was the only state where only one design, plain concrete pavement, was surveyed. A total of 31 plain, 31 conventionally reinforced, and 23 continuously reinforced pavements were included in this study. Four plain doweled pavements located in Texas were included as part of the plain pavement total.

Within each state, projects were selected that were representative of quality of construction, traffic density, climatic exposure, and overall performance of that design and age group. Selection was made in cooperation with state highway department representatives. Most projects were on the Interstate System, although some were on primary highways carrying substantial truck traffic. Most of the pavements were between 5 and 12 years old. Some older pavements were included to provide data on effects of long-term traffic and environmental exposures.

Survey methods included an initial drive over the length of the project in both directions. General conditions, ridability rating, and type and number of distress manifestations were noted. A minimum of two 1,000 ft-long pavement segments from each project were selected randomly for condition survey. This consisted of a walking survey to map pavement distress and repair areas, and to record measurements of faults at joints and cracks. A photographic record was made of deterioration indicators and distress types, maintenance repairs, and general performance features.

Information on age, design details, construction methods, construction costs, maintenance history, traffic, climatic exposure, and performance rating was obtained for each project to the extent possible.

The range of pavement serviceability rating (PSR) varied from 2.3 to 4.6 for plain designs, with most of the ratings between 3.5 and 4.2. Average PSR for continuously reinforced pavements ranged from 3.9 to 4.6, and those for conventionally reinforced designs ranged from 3.2 to 4.6.

Average daily truck traffic varied from 280 to in excess of 8,000.

Trends between PSR and truck traffic, faulting, cracking, or other forms of distress were not discernible from plots of the data. Difficulties in correlation may be due to the relatively narrow distribution of PSR values and the age distribution of the majority of pavements in the survey.

Plain Concrete Pavements (PC)

The majority of plain pavements were from 5 to 12 years old. The PSR of most of these projects varied from 3.5 to 4.2 with an average daily truck traffic volume range of 280 to 5,600. Performance varied from good to very good even though faulting was noted for many pavements.

Plain pavement distress indicators included faulting at joints, slab cracking, spalling, patching of distressed portions of slabs, and shoulder defects.

Faulting was observed in varying degrees at most plain undoweled pavement joints. About 75% of the survey pavement projects had tolerable faulting and the remainder had moderate or severe faulting. The amount of Class 3 cracking was not extensive. Only about 5% of the projects had longitudinal or transverse cracking in excess of 6 ft per 1,000 sq ft of pavement surface. Measurable faulting was not observed for most of the cracks in plain pavements.

The surface area of spalls with plain pavements was generally small. About 30% of the 1,000-ft pavement sections had one or more spalled joints. However, only about 10% had more than 4 spalled joints. Patching was generally not extensive.

Pavement-shoulder edge joint defects were present on most study projects. Major defects associated with edge joint problems are loss of joint sealant, widening of the joint, longitudinal cracking of the bituminous shoulder, settlement of the shoulder relative to pavement edge, and pumping of fines from below the pavement and/or the shoulder. Water was observed to stand freely in the open edge joint for a considerable time after rainfall. Pavement edge joint distress was observed to be more prevalent near transverse contraction joints.

Plain Doweled Pavements (PD)

Four plain doweled projects were surveyed in Texas. They were 9 to 12 years old and 9 and 10 in. thick. Daily truck counts were as high as 1,350. PSR ranged from 3.8 to 4.2. There was no faulting of joints on these projects, and they manifested no distress of any kind. Pavement inspection indicated that maintenance work had not been required. However, this could not be confirmed because maintenance cost records were not available.

Reinforced Doweled Pavements (RD)

Conventionally reinforced pavements varied in age from 5 to 13 years. The PSR varied from 3.2 to 4.6 with an average daily truck traffic volume range of 550 to more than 8,000. Performance varied from good to very good even though a number of structural distress items were noted.

Spalling at doweled joints was observed for about 75% of the conventionally reinforced projects. The highest proportion of spalls at joints was noted for projects with 80-ft joint spacing.

Intermediate slab cracking in reinforced pavements is expected and designed for. Only cracks open wide enough to cause failure of the longitudinal reinforcing steel are significant. A considerable variation in the extent of intermediate slab cracking was observed. In one state, projects with narrow or no intermediate slab cracking were observed as well as projects with average cracking of 22.5 ft per 1,000 sq ft of pavement. In three states surveyed, many pavement panels did not show any intermediate slab cracking. Others showed narrow cracks, that is, less than 1/8 in. wide. Class 3 cracks were observed for some panels in 65% of conventionally reinforced pavements. There was little evidence that any of the cracks had been routed and/or sealed.

Longitudinal cracking was observed in nine of the 31 RD pavements. Class 3 longitudinal cracking was noted on four of these nine projects.

Blowups were observed for 20% of the conventionally reinforced projects. Each of these projects was 13 or more years old and had a joint spacing of 80 ft.

Pavement-shoulder edge joint problems were observed on many of the RD projects. The distress was similar to that described for plain pavement projects. With the RD design, shoulder depressions were noted both at the transverse joints and at panel mid-span locations.

Continuously Reinforced Pavements (CRC)

CRC pavements were generally 8 in. thick, had a PSR of 3.9 or better, and most were 5 to 12 years old. The average daily truck traffic varied from 685 to 7,425.

Cluster cracking was observed for 45% of the projects. Cluster cracks are a group of three or more transverse cracks spaced 18 in. or less apart. Frequency of such cracking for the projects varied from one cluster to more than five per 1,000 ft of two-lane pavement.

Cluster cracks were observed in combination with developing punchouts, with pumping, and with Y-cracking.

Alligator cracking and punchouts were observed for 25% of the projects. This type of distress occurred principally on projects in two states.

Spalls at cracks were noted for CRC pavements in three states. Of two contiguous projects on an Interstate route in one of these states, one showed a high incidence of spalling, while the other showed none. A difference in the type of coarse aggregate used in the concrete was reported as the only disparity in design or construction between the two projects. Severe spalling was observed on a second survey project in this state. On this project the spalling was reported to be due to overworking of the concrete during finishing operations. This was aggravated by a low cement factor. The low cement factor had been selected to provide closer crack spacing. The shallow spalls were observed to one side of the crack and on the same side of all cracks within an area but not throughout the project. They occurred more frequently in the passing lane than in the outer traffic lane. One investigator has reported that the position of the spall to one side of the crack depended on the direction of paving.

Blowups were noted on nonsurvey CRC projects in two states. They have also been reported for pavements in states other than those surveyed.

Pavement-shoulder joint problems were also prevalant on CRC projects. On a project in Oklahoma the edge joint was open more than 3/4 in. over a considerable length of the roadway. The unusually wide opening appeared to have resulted from lateral shifting of the pavement on a horizontal curve.

Depressions in the bituminous concrete shoulder were observed together with water and pumping action near cluster cracking and Y-cracking.

Subbases

Granular untreated, asphalt-stabilized, and cement-stabilized subbases were used under plain and reinforced pavements. Granular untreated materials included crushed limestone, slag, gravel, and sandstone. Bituminous materials included spray treatment of in-place granular materials, treated soil aggregate, hot-mix sand, and hot-mix bituminous concrete. Pavements on cement-treated and soil-cement subbases were also observed.

SIGNIFICANCE OF FINDINGS AND RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION

Major pavement distress areas due to either design or construction deficiencies were found to be

-faulting at joints of PC pavements
-joint sealant failure
-spalling at joints and cracks
-transverse cracking in RD pavements
-blowups in RD and CRC designs
-punchouts in CRC pavements
-pavement-shoulder edge joint distress with all designs

Faulting at Joints of PC Pavements

The basic cause of joint faulting is excessive deflections at the joints. Alleviation of this problem is primarily a matter of improving load transfer at joints. Experience with pavement evaluation has demonstrated that evenly distributed faulting of 3/32 in. or less is tolerable to ridability and performance. A sequence of a small number of joints faulted 1/4 in. or more will contribute to poor ridability.

There was zero faulting of joints on the four PD projects in Texas. Observations of pavements in 12 other states and Canadian provinces has also shown that the addition of dowels is effective in eliminating faulting at joints.

A total of 17 of 47 responding states have standards for plain pavement using dowels at the contraction joints for load transfer.

Faulting may also be reduced or its onset delayed by increasing pavement thickness. Thicker pavements reduce slab deflection. Several states have built experimental projects with thicknesses as great as 15 in. A number of experimental projects are now under study to further evaluate the effectiveness of PC pavement thicknesses in the range of 11 to 15 in. in reducing faulting.

The cost of additional thicknesses of the plain pavement designs can be extrapolated by adding the additional materials and jointing costs to the contractor bid prices for 9-in. pavement. On this basis, a 10-in. plain doweled pavement will cost about the same as a 12-in. -thick PC design.

Doweled transverse joints are recommended for plain pavements designed by conventional methods that will carry in excess of 300 trucks per day in both directions.

Joint Sealant Failure

Failures of joint sealants are generally due to deficiencies in design and selection of materials. Design deficiencies include inadequate geometry of the sealant reservoir and not taking into account changes in joint opening due to slab length and temperature changes. Material requirements often fail to specify a joint sealant with adequate extensibility to acccmmodate joint movement and adherence to the joint faces. Some failure can be laid to improper sealant installation, inadequate joint cleaning prior to sealing, etc.

Movements at joints were calculated for a range of temperature changes and panel lengths. A graph was prepared using a coefficient of contraction of 0.0000035 in.per inch and taking into account the resistance to sliding. Maximum panel lengths were determined by limiting movements at joints. Sealant extensibility, sealant reservoir geometry, and the range of temperature exposure were considered in the determination of

slab length and joint details.

Based on the information thus developed, joint spacing of 20-ft or less should be used with PC and PD designs. Reservoir width should be a minimum of 3/8 in. for 20-ft spacing and 1/4 in. for 15-ft spacing. Liquid sealants that fulfill the extensibility requirements for these shorter panels should be used.

Joint spacing of 40 ft or less should be used for RD pavements in combination with high-type two-component or single-component polymer-type liquid sealants or preformed compression seals. Joint reservoir width to receive the sealant should be determined on the basis of maximum temperature range and accompanying joint movement.

Spalling at Joints and Cracks

Spalling at joints is caused by failure of sealants with subsequent intrusion of incompressibles or by improperly placed dowel load-transfer devices. Failures observed in the field survey were associated with compression forces and incompressibles in poorly maintained joints and cracks. Failures due to dowel-associated problems were not observed.

Design and construction recommendations to prevent spalling at joints are the same as those presented for alleviating joint sealant failure: spacing joints within the suggested limits, attaining the proper shape factor for sealant reservoir, and correctly installing sealant material with a proven record of performance.

Transverse Slab Cracking

Intermediate slab cracking is anticipated for most reinforced doweled pavement designs. The function of the reinforcing steel is to hold the crack tight. Load transfer across the crack is provided by aggregate interlock. These tight cracks are not a problem to pavement performance. Many reinforced pavements inspected as part of the field survey and those observed by the authors on other occasions have intermediate slab cracking. Most of the cracks were tight and without spalls. Ridability was good and maintenance effort requirements at cracks were low.

While most reinforced pavement slabs crack at intermediate locations and are designed to do so, it was observed that many of the longer panels in service showed no cracking whatever. A substantial number of panels 61.5 ft and 76.5 ft long in projects surveyed in Regions 3 and 5 were completely free of cracks, even with 4,000 trucks per day on a 12-year-old Interstate project.

Where problems did occur with intermediate cracks, they were normally in reinforced, doweled pavements with 61.5 ft, 76.5 ft, and 80-ft long joint spacing. The cracks had opened, spalled, and faulted, The longitudinal steel reinforcement had failed at most of these wider cracks. Steel failure may be due to higher subgrade friction than used for design calculations, salt attack on exposed steel that reduced the steel cross section or increased deflections at the crack. Opening of the crack may also be due to malfunction of the dowels at the joint. Tensile stresses in the distributed steel reinforcement at the crack due to dowel seizure may exceed the yield strength.

Design of reinforced doweled slab lengths of 40 ft or less will normally correct the pavement distress due to opening of intermediate slab cracks. Economic advantages of an approximately 40-ft panel length were previously discussed.

The amount of steel specified by some states using long joint spacing designs may be insufficient when used in conjunction with modern stabilized subbases. A friction coefficient of 2 is generally used in the design of the reinforcing steel. Tests at the

Portland Cement Association laboratories have shown that friction values for stabilized bases can be considerably higher. Therefore, the design should provide for a bond breaker between concrete and subbase or the mesh should be designed on the basis of the combined thickness of slab and subbase.

Dowel seizure can be prevented by improving construction practices to assure dowel alignment. Use of coated dowels will help to prevent rusting and seizing of dowels. Use of automatic dowel placers to depress dowels into the fresh concrete will alleviate dowel assembly misalignment problems due to concrete placing procedures.

Blowups

Pavement blowups have been observed on reinforced doweled pavements with long joint spacings and on a few isolated continuously reinforced roadways. A combination of design deficiencies and maintenance omissions contribute to blowup distress; such as long joint spacing, inadequate sealant reservoir geometry, and inadequate sealant extensibility combined with a lack of timely maintenance in routing and resealing joints. Infiltration into cracks and joints at top, sides, and bottom of RD pavements result in nonuniform stresses that lead to crushing and buckling of the concrete at these locations. In CRC pavements, cluster cracks, high pavement deflections due to inadequate thickness, and weakened pavement support reduce continuity and thus the effective pavement cross section. Compressive stresses due to increased pavement temperature exceed the compressive strength of the reduced cross section and result in blowups.

Designs to overcome blowup failures of reinforced pavements are the same as those indicated for alleviating intermediate slab cracking. Joint spacing of 40 ft or less, improved sealant reservoir geometry, use of sealants with increased extensibility, and stabilized subbases and shoulders to prevent infiltration are recommended. Blowups in CRC pavements can be averted by increasing pavement thickness to reduce pavement deflections. Special care during construction may prevent cluster crack development near construction joints. Starting paving early in the morning, wetting the pavement for about 200 ft from the construction joint during early curing, and preventing exposure to large temperature drops for the first 48 hours are some of the suggested strategies to prevent tensile stresses prior to concrete strength development.

Punchouts in CRC Pavements

Punchouts in CRC pavements generally develop in areas that initially showed a combination of cluster cracking and weakening of the underlying subbase or subgrade. Reduced thickness designs, when compared with plain or reinforced pavements, allow greater deflections and contribute to the progress of deterioration.

Of the 23 states with CRC design standards, more than half specify 8-in. thickness for use on the Interstate System and major expressways. Five states use 8-in. or 9-in. thicknesses and only one a 10-in. thickness.

Increasing the thickness design of CRC pavements will reduce pavement deflections and considerably reduce the development of punchout failure. The thicker pavement will provide the additional stiffness required to bridge localized areas of subbase and subgrade weakness.

One state, Texas, has recently recommended a design change that would require the same thickness for CRC pavement designs as for doweled-joint pavements. This state has built a greater mileage of CRC pavement than any state, and it has a mild southern climate. The Texas experience bears out the concept that the basic design thickness required in a concrete pavement structure is not altered by the addition of steel.

Use of stabilized subbases built with sufficient beam strength and stability to reduce slab deflection can contribute significantly to preventing punchout distress. Construction control of embankment compaction and subbase placement is necessary. An adequate drainage system will help avert water-associated weakening of the pavement support structure.

Proper vibration of concrete and more attention to curing and temperature exposure of fresh concrete adjacent to transverse construction joints are also needed.

Edge Joint Distress

Edge joint distress has no immediate effect on the roadway riding surface of concrete pavements; however, it contributes to inflow of water into transverse joint areas and below the pavement. Ultimately, it contributes to the rate of deterioration noted for many design-and construction-associated pavement problems. A dropoff of the shoulder from the pavement edge of greater than 2 in. was observed on many pavements. This can be a considerable safety problem.

A pavement-shoulder design is needed that will keep the longitudinal pavement edge joint closed. Safety considerations require that shoulder settlement be prevented. These goals can be accomplished by designs that use a tied concrete shoulder. The shoulder joint then remains tight and may prevent the inflow of water into the subbase; shoulder dropoff is eliminated; construction is simplified; and subgrade and subbase compaction under the shoulder is made less critical. An added structural benefit accrues from the support given the mainline pavement. Both edge stresses and deflections are significantly reduced.

The longitudinal joint can be formed in the same manner as a normal longitudinal centerline or construction joint.

A basic design change in mainline pavement width has been proposed by the Texas Highway Department. The new design is also aimed at reducing free-edge stresses and deflections of the outside (truck) lane. The lane is 14-1/2 ft wide rather than the conventional 12 ft. This moves heavy truck loads 2-1/2 ft farther away from the free edge of the pavement. This design may reduce or eliminate the detrimental effect of edge pumping and shoulder erosion.

Research efforts and experimental projects in the area of highway drainage in connection with edge joint problems are continuing. Much attention is given to draining water away from the pavement. Porous edge materials, porous surface courses, drainage blankets, underdrain systems, and different shoulder materials are experimental design alternatives.

Pumping and loss of support are associated with deflections due to moving loads, presence of water, and erodible materials. Design provisions to prevent each of the causes include increasing slab thickness, moving loads away from free edge by widening the pavement, and specifying nonerodible subbases and positive subbase and subgrade drainage.

Success with long-term performance of drainage designs has been very limited. This is due to intrusion of fines into the drainage structure, thus ultimately blocking the flow of water. None of the 47 design agencies responding to the design practices questionnaire used filter designs for the pavement drainage system. A filter design is recommended to assure long-term performance of the drainage system and ultimately the pavement structure.

COMMENTS AND CONCLUSIONS

In summary, the following areas of concrete pavement design and construction are considered to hold the greatest potential for improving pavement performance and economy:

Load transfer at joints. Use of dowels at joints is a proven method of increasing load transfer. They are needed in all jointed pavements where anticipated truck traffic is great enough to cause intolerable faulting during the life of the pavement. Factory-coated dowels have the greatest potential for trouble-free performance. Generally used dowel lengths of 15 in. to 18 in. may be greater than necessary with recommended 20-ft PD and 40-ft RD designs. A closer study of dowel embedment data on joints with small openings is needed. The original embedment research on which current practice is based was done 20 years ago on joints with openings of 3/4 in. It is possible that significant cost savings would be effected if dowel length could be reduced. Alternate spacing requirements to concentrate dowel location below the truck wheel paths should also be considered.

Short joint spacing. Pavements with properly designed thicknesses and 15-to 20-ft-long slabs do not crack transversely between joints. This design is therefore a means of averting the intermediate cracking problem. Minimum spacing keeps joint openings very narrow and improves continuity between adjacent panels. Joint performance is also improved, with a reduction in spalling and an elimination of blowups if slabs are kept short.

Joint reservoir and sealant shape factor. Experimental projects in several states have established that a depth-to-width ratio not to exceed 3 to 1 in the design of joint sealant reservoirs avoids overstressing that leads to sealant failure and prolongs joint life. This detail should be a part of every jointed pavement design.

Tiebars. Experience has shown that tiebars in longitudinal joints are effective in holding slabs in contact and in the same vertical plane. For their relatively low cost they are good insurance against faulting and the inflow of water through open joints between adjacent pavement slabs.

Concrete shoulders. Projects 9 to 11 years old in one state and projects of lesser age in other states have proved the effectiveness of tied concrete shoulders. With the rigid support of the tied shoulder, the potential for improved cross-surface drainage, for reduced water inflow at the joint, and for a stronger structural pavement system is substantial and could have a significant impact on concrete pavement performance.

Stabilized subbases. The advantages of stronger and more erosion-resistant subbases in reducing pavement deflections and migration of fines under the pavement were confirmed by the study. This was more evident with PC pavement than with RD and CRC designs.

Pavement thickness. Increasing pavement thickness is an established means of reducing deflections and improving performance. It was evident in the field survey and in observations of other pavements that deflections and resulting deterioration along the shoulder-roadway edge joint have been excessive. This was more apparent with CRC pavements, most of which were not more than 8 in. thick, and with 8-in. -thick plain pavements.

DESIGN AND CONSTRUCTION OF CONCRETE PAVEMENTS

A charted summary of concrete highway pavement practices in the United States as of 1975.

This information was compiled from data gathered from state highway departments as a part of a research project sponsored by the Federal Highway Administration.

PORTLAND CEMENT ASSOCIATION
5420 Old Orchard Road, Skokie, Illinois 60076

State	Interstate & Major Expressways*					
	Thickness of Pavement, in.				Shoulder	
	PC	PD	RD	CRC	Type	Thickness (B) in.
Ala.	10	9	9	8	Tied and tapered PCC, on crushed aggregate base	6, 4
Ariz.	8-13	-	-	-	AC, on granular base or full width PCC	(1)
Ark.	-	-	10	8	AC, on ATB or Tied PCC on ATB	(1)
Calif.	7.8-9.6	-	-	-	AC on aggregate base	-
Colo.	8	-	-	-	Hot mix, on granular &/or stabilized base	3, -
Conn.	-	-	9	8	Bituminous PCC, on stab. base (9)	3, 6
Del.	-	-	10	9	Hot mix, on crushed aggregate, or S/C	2, 7, 4
D.C.	(14)	(14)	9	-	--	-
Fla.	9	9	-	-	Types S-1 AC, over hot mix (20)	1, 5
Ga.	-	10, 11	-	9	Tied PCC	var.
Hawaii	9	-	-	-	Hot mix, on aggregate base, on aggregate subb.	2 1/2, 6 1/2, 10
Idaho	8	-	-	-	PCC, full width, full depth	-
Ill.	-	-	-	8-10	Bituminous aggregate mix	4
Ind.	-	10-13	10-13	8-9	Bituminous	5-7
Iowa	-	10	-	8	Tied PCC, ATB	6, 8
Kan.	9	-	9	-	Crushed limestone w/ $CaCl_2$ or Asphalt mix	(1)
Ky.	-	11	10	9	Bituminous surface, on full depth DGA	2, -
La.	-	10, 9, 8	-	-	Hot bituminous aggregate	(1)
Maine	-	9-10	-	-	Hot bituminous	3
Md.	-	-	9	8, 9	Dense graded sand agg. base, bituminous PCC	7, 3
Mass.	-	-	9	-	Bituminous PCC	-
Mich.	-	-	9, 10	8, 9	PCC or bituminous base plus surface	-
Minn.	-	-	10, 9 (19)	-	Hot mix, over gravel	2, -
Miss.	-	-	-	8	Double bituminous s.t.	-
Mo.	-	-	8, 9, 10	-	AC, over bit. base or PCC treated agg. ,type 4 agg.	2, 5, 5-7
Mont.	8	-	-	-	Hot mix, on crushed base	-
Neb.	10	-	8, 9, 10	8	Hot mix, on soil aggregate base	2, -
Nev.	8	-	-	-	Asphalt or PCC	-
N.J.	-	-	9	-	Bituminous PCC, on crushed stone base, on subbase	2, 7, 8-12
N.M.	8	(22)	-	-	Asphalt, untreated aggregate, plant mix seal coat	3, 4 1/2, 5/8
N.Y.	-	9	9	-	Hot mix or s.t.,on bit. stab. soil,or AC on subb.	1, 3, var.
N.C.	-	10	-	8 1/2	Asphalt, on full depth granular base	3, -
N.D.	9	-	-	8	Tied PCC	8 or 9
Ohio	-	-	10	-	Bituminous over aggregate	3, 6
Okla.	9	-	-	8	AC, on bituminous base	1 1/2, -
Ore.	-	-	-	8	AC, on treated base	4, -
Pa.	-	-	10	9	Bituminous PCC on subbase material	4, 4-6
S.C.	8-10	10	-	8-9	Hot mix, on CTB or ATB aggregate	1-1 1/2, 6
S.D.	9 1/2	-	-	-	--	-
Tenn.	-	9 or 10	-	-	Bituminous	-
Texas	-	10	10	8-9	--	-
Utah	9, 10	-	-	-	PCC	6
Va.	8-9	(14)	9	8	Bituminous PCC on gran. base	3, 12
Wash.	9	-	-	-	Hot mix, on base	2, var.
W.Va.	-	-	9	8	Macadam, on crushed aggregate base	3, -
Wis.	-	-	9-10	8	Bit. PCC, over gravel or crshd. stone base course	3, -
Wyo.	-	8	-	-	AT	(1)

* See list of abbreviations and notations following these tables

State	Primary Highways						Pavement Crown (C)	Subbase (A)			
	Thickness of Pavement, in.				Shoulder			Type			Thickness (B) in.
	PC	PD	RD	CRC	Type	Thickness (B) in.		Granular	GT	AT	
Ala.	10	9	9	8	Bituminous hot mix, crushed aggregate base	4, 5		✓	✓	✓	6
Ariz.	8-13	-	-	-	AC, on granular base or full width PCC	(1)			✓	✓	4-6, 6-12
Ark.	-	-	9-10	8	AC, on crushed stone base	1 1/2, -			✓	✓	4-6
Calif.	7.2-9	-	-	-	AC on aggregate base	-			✓		(2)
Colo.	-	-	-	-	--	-		(3)(6)	✓	✓	var.
Conn.	-	-	8	-	Bituminous PCC on stab. base (9)	3, 5		(8)			(10)
Del.	-	-	8, 9	8, 9	S.t. on well graded soil aggregate	-, 6		(3)	✓		6, 4
D.C.	-	-	8	-	--	-		(4)(8)			6
Fla.	9	9	-	-	Type S-1 AC, over hot mix	1, 5			✓		6
Ga.	-	9, 10	-	-	Tied PCC	var.			✓	(4)	(15)
Hawaii	-	-	-	-	--	-		(3)	✓		6, 4
Idaho	7-8	-	-	-	PCC, full width, full depth	-		(16)	✓		4
Ill.	-	-	8-10	8-10	Bituminous aggregate mix	4		(17)	✓		4
Ind.	-	9-12	8-12	8-9	Bituminous	5-7		(13)(18)		✓	6, 4
Iowa	7-10	8-10	-	-	Granular earth	6			✓	✓	4
Kan.	9	-	9	-	Crushed limestone w/ $CaCl_2$ or Asphalt mix	(1)		(4)(11)	✓	✓	4
Ky.	(64)	10, 9	9, 8	8	Bituminous seal, DGA	1, 11		(4)	✓		5-6, 4
La.	-	10, 9, 8	-	-	Hot bituminous aggregate	(1)			✓	AC	6, 4
Maine	-	-	-	-	--	-		(8)			3-4
Md.	-	-	9	8, 9	Dense graded sand aggregate base, bituminous PCC	7, 3		(3)			4 & 6
Mass.	-	-	-	-	--	-		(8)			12
Mich.	-	-	9	-	PCC or bituminous base plus surface	-		(5)(7)			4 & 10
Minn.	7, 8	-	9, 8 (19)	-	Hot mix, over gravel (20)	1 1/2, -		(4)			-
Miss.	-	-	-	8	Double bituminous s.t.	-			✓	✓	6, 4
Mo.	-	7, 8	8, 9, 10	-	AC, on bituminous base on type 1 or 2 aggregate	(1)		(18)			4
Mont.	7	-	-	-	Hot mix on crushed base	-	(21)		✓	✓	4.8
Neb.	8	-	8	-	Hot mix, on subgrade	5 or 6, -			✓		3
Nev.	-	-	-	-	--	-		✓	✓		6, 4
N.J.	-	-	9	-	Bituminous,on crushed stone base, on subbase	2, 7, 8-12		(4)(5)			8-12
N.M.	8	(22)	-	-	Asphalt, untreated aggregate, plant mix seal coat	3, 4 1/2, 5/8			✓	✓	4
N.Y.	-	9	9	-	Hot mix or s.t.,on bit. stab. soil,or AC on subb.	1, 3, var.		(3)(6)(8)			12
N.C.	-	10	-	8 1/2	Asphalt, on full depth granular base	3, -			✓		4
N.D.	8	-	-	-	Tied PCC, or total depth hot mix	8		(7)		(23)	3, 2
Ohio	8, 9	9	8, 9, 10	-	Bituminous over aggregate	3, 6			✓	✓	4
Okla.	8 or 9	-	-	-	AC, on bituminous base	1 1/2, -				✓	4
Ore.	-	-	-	-	--	-		✓	✓	✓	4-8, 6, 6
Pa.	-	-	9-10	-	Bituminous PCC on subbase material	4, 4-6		✓	✓		8-12, (24)
S.C.	-	-	-	-	--	-			✓		5-6
S.D.	7-8	-	-	-	--	-		(25)			3
Tenn.	-	9	-	-	Bituminous	-		(3)	✓		5
Texas	-	10	10	8-9	--	-			✓	✓	4-8
Utah	-	-	-	-	--	-		(8)	✓		4
Va.	8	-	8-9	-	Aggregate base	4-6		(3)(11)	✓		6
Wash.	9	-	-	-	Hot mix, on base	2, var.		(3)	✓	✓	4, 6, 6
W.Va.	-	-	9	-	Crushed aggregate	-		(6)(18)	(12)		6
Wis.	8-9	-	8-9	8	Gravel or crushed stone base course	-		(3)(18)			6-9
Wyo.	-	8	-	-	AT	(1)		✓	✓		4 & 6, 6

State	Longitudinal Joints											Transverse Joints	
	Construction Joints (D)			Centerline					Tiebars			Contraction Joints	
				Type			Dimensions (B)		Diameter in.	Length in.	Spacing in.	Spacing, ft. (A)	
	Keyed	Butt	Tied	Sawed	Formed	Insert	Width in.	Depth in.				PC	PD
Ala.	✓	✓	✓	✓			3/8	D/4	5/8	30	18-26	20	20
Ariz.		✓	✓	✓			1/8	2 (26)	1/2	24	30	13-15-17	-
Ark.	✓	x	x	✓		(28)	1/4	(27)	1/2	48	30	-	-
Calif.		✓		✓		✓	1/4, 0.013	2	1/2	22	24	13-19-18-12	-
Colo.	✓		✓	✓		✓	1/8-1/4, 0.01	1 1/4, 2	1/2-5/8	24	18	12-18-19-13	-
Conn.	+		+	✓		✓	3/8	(31)	(30)	30	30	-	-
Del.			x	✓			1/4	D/4+1/4	1/2	30	24	-	-
D.C.	✓		✓	✓	✓		1/8, 1/4	D/5, D/4	1/2	30	30-60	15 (14)	20 (14)
Fla.	✓		✓	✓		(28)	1/8	D/4-D/5	1/2	24	31	20	20
Ga.	+		+	✓		✓	1/4, 0.02	D/4	1/2	30	30	-	20
Hawaii						✓	N.R.	2	5/8	30	30	13-19-18-12	-
Idaho		✓	✓	(36)		✓	5/16, 0.01	2	1/2		30	13-15-17-12	-
Ill.	+		+	✓		✓	1/8, 0.01	D/4	(37)	30	30	-	-
Ind.	+		+	✓	✓		1/8, 1/8 or 1/4	D/4, D/4-1/2	5/8	36	36	-	20, 13-19-18-12
Iowa	✓		✓	✓			1/8	D/4	1/2	36	30	20	20
Kansas	+		+	✓			(39)	2 1/2	1/2	24	30	15	-
Ky.	+		+	✓		NP	1/8-1/4	D/4+1/4	1/2	30	30	12-13-17-18	12-13-17-18
La.		✓	✓		✓	✓	5/16, 0.03	3	1/2	24	24	-	20
Maine	✓		✓	✓	✓		1/4	D/4+1/2, 1	5/8	30	30	-	20
Md.	+		+	✓		✓	1/4, 7/16	(42), 2 1/4	5/8	48	48	-	-
Mass.	✓		✓	✓			1/4	2 1/2	5/8	30	48	-	-
Mich.		✓	✓	✓			1/8	2 1/2	5/8	30	40	-	-
Minn.	(45)	(45)	(45)	✓			1/8	(46)	(47)	(47)	30	20	-
Miss.	x		x			✓	0.008	2	1/2	30	36	-	-
Mo.	✓		✓	✓			1/8	D/4	5/8	30	30	-	30
Mont.	✓			✓		✓	1/4-3/8, -	2	1/2	36	30	13-19-18-12	-
Neb.	+		+	✓			1/8	(51)	5/8	30	48	12-13-18-19	-
Nev.		✓	✓	✓			1/4	2	1/2	22	30	13-19-18-12	-
N.J.	✓		✓	✓	✓		1/8-1/4, 1/4	2 3/4, 7/8	5/8	36	48	-	-
N.M.	✓		✓	✓			1/4	2	1/2	30	30	18	-
N.Y.	✓		✓	✓	✓		(54)	2	5/8	(55)	40	-	20
N.C.		+	+	✓	✓		1/4, 0.02	(56)	1/2	30	30	-	30
N.D.	+	+	+	✓		✓	1/8-1/4, 0.03	2 1/2, 3	5/8	30	48	14-18	-
Ohio	✓		✓	✓			1/8	D/3	5/8	30	30	17	18
Okla.	✓		+	✓			3/8	D/4	1/2	30	30	15	-
Ore.		x	(59)	✓			1/4	2	1/2	30	30	-	-
Pa.	+		+	✓			3/16	D/4+1/4	5/8	48	(60)	-	-
S.C.		+	+	✓		✓	1/8, 0.013	D/4	1/2	30	30	25	18-19-23-25
S.D.	✓		✓	✓			1/8	(61)	5/8	30	48	13-19-18-12	-
Tenn.		✓	✓	(62)		(62)	1/4, 0.01	D/4	1/2	24	30	-	(62)
Texas		+	+	✓			1/4	D/4	1/2	30	24-36	-	15
Utah	✓		✓	✓			1/8	2 1/4	5/8	30	36	13-18-17-12	-
Va.		+	+	✓		✓	1/8, 0.01	D/3, 2 1/2	5/8	30	40	20	-
Wash.		✓	✓	✓			1/8-1/4	D/4+1/2	1/2	24	36	10-14-13-9	-
W.Va.	+		+	✓		✓	1/4, 0.012	D/4, 2 1/2	(65)	(65)	(65)	-	-
Wis.		+	+	✓			1/8	1 1/2	1/2	24	36	-	-
Wyo.	✓		✓		✓	✓	1/8-3/16, 0.008	D/4, D/4, 2	1/2	24	30	-	18-19-13-12

State	Transverse Joints														
	Contraction Joints											Construction Joints (D)			
	Spacing, ft. (A)		Type				Dimensions (B)		Dowels						
		RD	Skewed (E)	Sawed	Formed	Insert	Width in.	Depth in.	Diameter in.	Length in.	Spacing in.	Keyed	Butt	Tied	Doweled
Ala.		39	No	✓			3/8	D/4	1 1/8	16	12		+	x	✓
Ariz.		-	Yes	✓	✓		1/8, 0.105	2 (26)	-	-	-		✓	✓	
Ark.		45	-	✓			1/4	2	1	18	15		+	(29)	✓
Calif.		-	Yes	✓		✓	1/4, 0.013	2	-	-	-	✓		✓	
Colo.		-	Yes	✓		✓	1/8-1/4, 0.01	1 1/4, 2	1 1/4	12	12		✓		✓
Conn.		40	-	✓			3/8	(31)	(32)	(32)	12		+	(29)	✓
Del.		45	-	✓			1/4	2 1/2	1 1/4	18	12			x	(33)
D.C.		40	-	✓	✓		1/4, 3/8	D/5, D/4	(34)	(34)	12	(35)	(35)	(35)	
Fla.		-	-	✓		(28)	3/8, 1/4	D/4	1	18	12		✓		✓
Ga.		-	-	✓			1/4	D/3.6	D/8	18	15		+	(29)	✓
Hawaii		-	Yes	✓			1/4	2 1/2	-	-	-		✓		✓
Idaho		-	Yes	✓		(36)	5/16, 0.01	D/4, 2 1/4	-	-	-		✓		✓
Ill.		50	-	✓			1/8	2 3/4	1 1/4	18	12		+	(29)	
Ind.		40	Yes	✓			(38)	D/4	1 1/4	18	12			(29)	
Iowa		-	No	✓			1/8	D/4 (142)	1 1/4	18	12		+	(29)	✓
Kansas		61.5	Yes	✓			3/8	(40)	1 1/4	18	12			✓	
Ky.		25, 50	Yes	✓	NP	NP	1/8-1/4	2	(41)	18	12	✓		✓	
La.		-	No			E	7/16	3	1 1/8	18	12		✓		(33)
Maine		-	No	✓			1/8	D/4	D/8	16	12	✓		✓	
Md.		40	No	✓			1/4	2	1 1/4	18	12			(29)	✓
Mass.		40	-	✓			3/8	2 1/4	1 1/8	16	12		✓	✓	
Mich.		70	No	✓			1/2	2 1/2	1 1/4	18	12		✓	(29)	✓
Minn.		27	Yes	✓			(44)	(43)	(48)	18	12	✓		✓	
Miss.		-	-				-	-	-	-	-		x	(29)	
Mo.		61.5	No	✓			3/8	D/4	(49)	18	12	✓		✓	
Mont.		-	Yes	✓			1/4-3/8	D/4	1	18	12	✓			(33)
Neb.		46.5	Yes	✓			3/8	D/4	(50)	18	12		+	(29)	✓
Nev.		-	Yes	✓			1/4	2	-	-	-	✓		✓	
N.J.		-	-				-	-	(52)	(52)	12				
N.M.		-	No	✓			1/4	D/4	1	18	18	✓	✓		
N.Y.		63	No	✓	✓		(53)	2	1 1/8	18	12		✓		✓
N.C.		-	No	✓			3/8	2 3/4	1 1/4	18	12		+	(29)	✓
N.D.		-	No	✓	✓	✓	7/32-1/4, 1/4, 1/4	(57)	1 1/4	18	12	✓	+	✓(29)	
Ohio		40	Yes	✓			1/4	(58)	1 1/4	18	12		✓		✓
Okla.		-	No	✓			3/8	D/4	1 1/4	18	12		+	(29)	✓
Ore.		-	-				-	-	-	-	-		x	(29)	
Pa.		46.5	No	✓			3/8	D/4	1 1/4	18	12		+	(29)	✓
S.C.		-	Yes	✓	✓	✓	1/8-1/4, 1/4, 1/4	D/4	1	18	12		+	(29)	✓
S.D.		-	Yes	✓			1/4	D/4	-	-	-			✓	
Tenn.		-	No	(62)		(62)	1/4, 0.01	D/4	1 1/4	15	12		✓		✓
Texas		60, 30	-	✓	✓		3/8, 3/4	D/4	1 1/4	20	12		+	(29)	✓
Utah		-	Yes	✓			1/8	2 1/4	-	-	-		✓	✓	
Va.		40	No	✓			5/8	D/4+1/4	1 1/4	18	12		+	(29)	✓
Wash.		-	Yes	✓	✓	✓	1/8-1/4, 1/8, 0.02	2	-	-	-		✓		✓
W.Va.		61.5	No	✓			1/4	D/4	1 1/4	19	12		+	x	✓
Wis.		80	-	✓			1/4	2	1 1/4	18	12		+	+	
Wyo.		-	Yes		✓	✓	1/8-3/16, 0.02	D/4, 2	-	-	-	✓		✓	

State	Joint Sealants Specified (F)			Reinforcement		Expansion Joints (A)(B)		
						Location		
	Hot-poured Elastic	Cold Application Type	Preformed Compression Seal	Conventional lbs/100 sq.ft.	Continuous % longitudinal	Bridge Ends or Approach	Other	Number
Ala.			✓	44.2	0.7	✓	-	3
Ariz.	SS-S-164			-	-	✓	-	(66)
Ark.	M-173	✓		59.0	0.6	✓	-	-
Calif.	(68)			-	-	(69)	-	1
Colo.	M-173	D-1850		-	-	✓	-	1
Conn.	M-173			52.4	0.62		(74)	
Del.	M-173		M-220	54.0	0.7	✓	-	1
D.C.	(73)		✓	51-54	-	✓	-	var.
Fla.	M-173		✓	-	-	✓	(74)	-
Ga.			✓	-	0.6	✓	-	2
Hawaii				-	-		-	1
Idaho	(68)			-	-	✓	-	1
Ill.	D-1190	D-1850	✓	54.0	0.6	✓	-	1
Ind.	M-173		✓	54.0	0.7	✓	-	1
Iowa	M-173			-	0.64	✓	-	(78)
Kansas	(79)		✓	61.0	-	✓	-	-
Ky.	✓		E	44, 59	0.7	✓	-	3
La.	✓		✓	-	-		(63)	-
Maine	SS-S-1401A			-	-	✓	-	1
Md.	✓	✓	✓	60.0	0.6		(72)	(81)
Mass.	✓		✓	-	-	✓	(74)	-
Mich.	SS-S-164	D-1850	✓	74.5	0.7	✓	-	3 or 4
Minn.	M-220-67		✓	(82)	-	✓	-	1
Miss.				-	0.6	✓	-	3
Mo.	D-1190			61.0	-	✓	(74)	2
Mont.	SS-S-164			51.0, 46.8 (19)	-	✓	-	2
Neb.	Neb. Spec.		(11)	44 & 54	0.6	✓	(74)	(84)
Nev.			✓	-	-		(63)	1
N.J.	(79)			79.7	-	✓	-	
N.M.	M-173	D-1850		-	-	✓	-	2
N.Y.			✓	59.5	-		(86)	2
N.C.			✓	-	0.6	✓	-	4, 3
N.D.	N.D. Spec.		M-220	58.0	0.6	✓	-	2, 3, 3
Ohio	M-173	✓	✓	54.0	0.6	✓	-	2, 1
Okla.		✓	✓	-	0.61	✓	-	1, 3
Ore.	-			-	0.6	✓	-	2
Pa.	(79)		✓	53.6	0.6	✓	-	1
S.C.	M-173			-	0.6 (89)	✓	-	3
S.D.	M-173		✓	-	-	✓	-	1
Tenn.	SS-S-164			-	-	✓	-	1
Texas	✓			66.3	0.5 or 0.6	✓	-	1
Utah	SS-S-164			-	-		(72)	2
Va.	M-173	VTM-34	D-142	53.0	0.6	✓	-	3
Wash.	M-173	D-1850		-	-	✓	-	2
W.Va.	M-173			61.0	0.62	✓	(74)	1, 3
Wis.	D-1190		✓	69.0	0.61	✓	-	4
Wyo.	M-173	M-173	M-173	-	-		(63)	-

State	Expansion Joints (A)(B)				CRC End Anchorage		Subbase Construction					
							Wire Control			Subbase used by construction Traffic		
	Width in.	Spacing (G) ft.	Doweled	Sleeper Slab	Type	Dimension ft. x ft.	yes	no	Opt.	yes	no	Other Subbase Control
Ala.	1	40.5	✓	✓	Lugs	2 x 4			✓	✓		depth
Ariz.	-	-	-	-	-	-	(91)	(91)		✓		blue tops
Ark.	(67)	-	✓	✓	-	-	✓				✓	-
Calif.	(70)	-	-	-	-	-			✓	✓		-
Colo.	3/4	-	-	-	-	-				✓		-
Conn.	3/4	-	(11)	(12)	-	-			✓	✓		prep. subbase
Del.	3/4	20		✓	-	-				(93)		offsets
D.C.	1/2, 3/4	350+	✓		-	-		✓			✓	-
Fla.	18 (76), 3/4	-		✓	-	-			✓		✓	template
Ga.	3/4	30	✓		Lugs	2 x 4	✓			✓		-
Hawaii	3/4	-			-	-	✓			✓		-
Idaho	1	20		✓	-	-	✓			✓		-
Ill.	4	-	(75)		3 Lugs	2 x 4			✓		✓	-
Ind.	48 (76)	-	-	-	-	-	✓			✓		-
Iowa	4 1/4±1/2	20-60 (71)			5 Lugs	(71)	✓				✓	auto. screed
Kansas	(80)	-			-	-	✓			✓		-
Ky.	1	25	(13)	(12)	-	-		N.S.			✓	-
La.	3/4	-		✓	-	-	✓			✓		-
Maine	(64)	(64)		✓	-	-	✓			✓		-
Md.	1	-	(11)	(12)	-	-			✓		✓	string
Mass.	-	-			-	-						-
Mich.	1	29 1/2, 15 1/2		✓	-	-			✓	✓		-
Minn.	4	-		✓	-	-			✓		✓	-
Miss.	1	15	✓		Lugs	2 x 3	✓			✓		-
Mo.	2	30 or 61.5		(83)	-	-		✓			✓	-
Mont.	2, 3/4	20	✓	✓	-	-			✓	✓		-
Neb.	(84)	(84)	✓	(85)	(81)	-	✓				✓	-
Nev.	1 1/2	-			-	-	✓			✓		-
N.J.	3/4	78 1/6	✓	-	-	-			✓	✓		-
N.M.	3/4	15+18	✓	-	-	-			✓	✓		prep. subg.
N.Y.	3/4	20, 63	✓	-	-	-	✓				✓	-
N.C.	1	(87), 20	✓	-	(81)	-	✓				✓	-
N.D.	1	14-18, 39.5	✓		-	-			✓		✓	straight-edge
Ohio	1	40	(11)	(12)	(81)	-		✓				-
Okla.	6, 3 1/2	-, 32	✓		-	-		✓		✓		-
Ore.	3/4 & 1	40	✓	(81)	2 Lugs	2 x 4	✓				✓	-
Pa.	(88), 1	-		✓	-	-			✓		✓	-
S.C.	1	50	✓		Lugs	2 x 3	✓				✓	-
S.D.	4	15		✓	-	-	✓					-
Tenn.	2	25			-	-	✓				✓	-
Texas	1 1/2	-		✓	-	-	✓			✓		prep. subg.
Utah	1 1/4	10 1/2	-	-	-	-		✓		✓		-
Va.	3/4, 1	40, 20	✓	(90)	3 Lugs	6 x 15			✓	✓		-
Wash.	1/2	-	-	-	-	-	✓			✓		-
W.Va.	48 (76), 3/4	61.5	(12)	(81)	-	-	✓					prep. subg.
Wis.	3/4	20, 40	✓	(12)	4 Lugs	2 x 4			✓	✓		red tops
Wyo.	3/4	-	✓		-	-			✓			-

State	Portland Cement Type Used	Aggregate			Admixture (Maybe Optional)		
		Coarse		Fine	Air-entraining Agent Specification (F)	Type	
		Maximum size in.	No. of separate Sizes	Fineness Modulus Max-Min (or variation)		Vinsol Resin	Other
Ala.	I, II, IP	2 1/2	1 or 2	3.0-2.3	M-154	✓	Fly ash
Ariz.	II	2	2	2.8	-	✓	
Ark.	I	< 1 1/2	2	-	M-154	✓	
Calif.	II modified	1 1/2-2 1/2	2-3	-	C-260		
Colo.	II	2 1/2	2	AASHTO M-6	M-194		
Conn.	I, II, III, IA, IIA, IS, IS-A	2, 1 1/4 (105)	2	0.2±	-	✓	
Del.	I	1 1/2	1	AASHTO M-6	var.		
D.C.	I & III	1 1/2	3	AASHTO M-6 ±0.2	-	✓	WR
Fla.	I, IP, II, III, IS	1 1/2	1	-	3 1/2		Retarder
Ga.	I	2, 1 1/2 (106)	1-2	3.5-2.0	-	✓	WR
Hawaii	I	1 1/2	2	3.0-2.7	N.R.		
Idaho	II - Low alkali	1 1/2	2	-	(63)		
Ill.	I	2 1/2	2	-	M-154		WR
Ind.	I or III	1 1/2	1	-	C-260		
Iowa	I	1 1/2	1	-	-	✓	
Kansas	II	3/4	-	-	-	✓	
Ky.	I	1 1/2	3	(107)	-	✓	
La.	I (B) or II (143)	2	1	-	C-125	✓	WR-retarder
Maine	I or II	2 1/2	1	3.1-2.3	M-154		
Md.	I or IA	1 1/2	1	-	M-154		
Mass.	-	-	-	-	-		
Mich.	IA	1	1	3.35-2.6	C-260		
Minn.	I, IA or IP	2	2	3.35-2.15	M-154		WR
Miss.	I	1 1/2-2	2	2.65-2.62	-		
Mo.	I	1 1/2	1 or 2	-	-	✓	
Mont.	II	1 1/2	2	2.5	M-154		WR
Neb.	I or II	1	1	4.2-3.0	M-154		
Nev.	II	1 1/2	2	±0.2	var.		
N.J.	II	1-2	1 or 2	3.1-2.3	-	✓	
N.M.	I, II, or III	2 1/4	2	NS	M-154		
N.Y.	I & II	1 1/2, 2 (111)	2, 3 (111)	3.49-2.15	C-260		
N.C.	I or II	1	1	-	(63)		Retarder
N.D.	I, IA or IS-A	1 1/2, 2	1, 2	3.2-2.4	M-154		
Ohio	I	1/2	3	-	-	✓	
Okla.	I	2 1/2	2	-	-		
Ore.	I or II	1 1/2	2	3.68-2.35	M-154		
Pa.	NB, NC, ND, IP (112)	-	-	3.15-2.3	-	✓	
S.C.	(113)	1 1/2	2	NR	-	✓	
S.D.	I	1	1	-	M-154		
Tenn.	I	1 1/2	2	-	-	✓	WR-accelerator
Texas	I	1 1/4	4	NS	C-260, C-494		
Utah	I or II	1 1/2	2	-	M-154		✓
Va.	II	1 1/2, 2	1, 2	-	M-154	✓	
Wash.	II	1 1/2	2	-	M-154		(63)
W.Va.	I, IS & IP	2, 1 1/2 or 1	3	-	-	✓	
Wis.	IA or I	(117)	2	0.2±	M-154, C-260		
Wyo.	II	1 1/2	2	AASHTO M-6	M-154		(119)

State	Concrete Mix Requirement									
	Strength						Durability			Slump (maximum) in.
	Compressive		Flexural		Loading		Minimum Cement lbs/cu.yd.	Maximum Water cement ratio	Air content Limits, %	
	psi	days	psi	days	3rd pt.	Mid pt.				
Ala.	–	–	550	7		✓	var.	var.	5	1 1/2
Ariz.	2000	7	500	NS (102)		✓	564	0.53	4-7	3
Ark.	2000	28	–	–			560	0.5	3-7	2
Calif.	–	–	550	10 (102)		✓	var.	0.55-0.66	(103)	(104)
Colo.	N.R.		–	–			var.	0.45	4-7	1-2
Conn.	–	–	500	7 (102)	✓		592, 611 (105)	0.48, 0.53 (105)	4-6	3, 2 (105)
Del.	3500	28	–	–			564	0.53	4 1/2-7 1/2	1 1/2-4, 1-1 1/2 (105)
D.C.	3500	28	500	7	✓		564	0.5	6 1/2±1 1/2	–
Fla.	3000	28	500	28	✓		508	0.55	3-6	(63)
Ga.	3000	28	600	28	✓		517	0.53	2-6 1/2	2 1/2
Hawaii	–	–	–	–			564	0.55	2-3	3
Idaho	–	–	550	14	✓		564	0.49	6 1/2±1-1/2	–
Ill.	3500	14	650	14		✓	526	–	4-7	1 1/2
Ind.	–	–	550	14 (102)	✓		564	0.49	5-8	1 1/4-3
Iowa	–	–	500	7 (102)	✓		var.	0.49	6±1 1/2	2
Kansas	–	–	500	7		✓	601	0.49	4-8	1 1/2
Ky.	3500	28	550	7	✓		564	0.48	4-8	1 1/2
La.	3600	28	–	–			545	0.53 (144)	3-7	2 1/2
Maine	–	–	650 (108)	28	✓		var.	0.42	6±1 1/2	2
Md.	–	–	350 SpT	(102)			610	0.49	5-8	3, 2 (105)
Mass.	–	–	–	–			–	–	–	–
Mich.	3500	28	550, 650	7, 28		✓	564 (109)	–	5-8	3
Minn.	–	–	550	(102)		✓	530	0.46	4-7	2
Miss.	–	–	525-550, 700	7, 28	✓		545	0.55-0.65	3-6	1-2
Mo.	N.R.		–	–			var.	0.57	4-7	2 1/2
Mont.	2000, 3000	7, 28	500	28	✓		564	0.53	5±1	2
Neb.	2000, 3000	7, 28	550	7		✓	564	0.53	5-7 1/2	–
Nev.	–	–	640	28		✓	564	0.49	5+1	3
N.J.	4500	28	–	–			630	(110)	4 1/2-7 1/2	–
N.M.	–	–	–	–			564	0.53	4-7	2 1/2
N.Y.	–	–	–	–			590, 600 (111)	0.44, 0.41 (111)	5 1/2±1 1/2	2 1/2, 3 (111)
N.C.	–	–	550	14	✓		526	0.56	3 1/2-6 1/2	1 1/2
N.D.	3500	28	550	7 (102)	✓	✓	517	0.51	5-8	3
Ohio	–	–	600	5 (102)		✓	600	0.5	4-8	4
Okla.	3500	7	550, 650	7	✓	✓	564	0.53	5±2	3 1/2
Ore.	3300	28	525	28	✓		564	0.53	3-6	1-2
Pa.	3000, 3750	7, 28	550, 660	7, 28		✓	587	0.47	5±1 1/2	3
S.C.	–	–	550	14	✓		(114)	0.53	3 1/2-6	2
S.D.	–	–	–	–			526	–	3-7	(115)
Tenn.	3500	14	550	14	✓		526	0.47	3-8	1 1/2
Texas	–	–	(116)	7		✓	var.	0.55	5±1	3
Utah	3500	28	–	–			564	0.49	6±1	3
Va.	3000	28	650	28	✓		564	0.45	6±2	3
Wash.	–	–	585	(102)	✓		565	–	4 1/2-7	–
W.Va.	3000	28	500	28	✓		564	0.48	4 1/2-9 1/2	1-2 3/4
Wis.	–	–	–	–			565	0.53	4 1/2-7 1/2	(118)
Wyo.	–	–	580	28	✓		564	0.47	6±2	2

State	Vibration Equipment											
	Wire Control			Type			Frequency (B)	Coordinated with forward Speed		Mixing Time	Max. Concrete Mix Temp.	
	Yes	No	Opt.	Spud	Tube	Pan	rpm	Yes	No	secs	°F	
Ala.			✓			✓	3500	✓		M-157	-	
Ariz	✓			✓			4500			50-90	90	
Ark.			✓	✓	✓		7000, 5000	✓		60+	90	
Calif.			✓	✓			5000		✓	50	90	
Colo.			✓	✓	✓	✓	7000, 5000, 3500		✓	50-90	90	
Conn.	✓			(11)		(12)	-, 3500	(12)	(11)	60 (92)	90	
Del.	(12)	(11)		✓		✓	7000, 3500		✓	50-90	90	
D.C.		✓		✓			4500		✓	90	90	
Fla.			(94)	✓		✓	7000, 3500	✓		60	90	
Ga.			✓	✓	✓	✓	7000, 5000, 35000	✓		-	-	
Hawaii	✓			✓			10,000		✓	50	80-90	
Idaho	✓			✓		✓	(95), 3500	✓		50	-	
Ill.			✓	✓			7000		✓	50	(96)	
Ind.	✓			✓		✓	10000, 3500	✓		50	None	
Iowa	✓				✓	✓	3500		✓	60	-	
Kansas	✓			✓	✓	✓	7000, 5000, 3500		✓	50-90	-	
Ky.		NS			NS		NS	NS		60	60-80	
La.	✓			✓		✓	7000	✓		50	None	
Maine	✓			✓			7000	✓		90	None	
Md.	✓			✓			5000	✓		45, 75	90	
Mass.							-			-	-	
Mich.			✓	(12)			NS		✓	60, (145)	90	
Minn.			✓	✓		✓	3600-6000		✓	60	90	
Miss.		✓		✓			7000-9000	✓		50-90	None	
Mo.		✓		✓		✓	4500, 3600	✓		60	80	
Mont.	✓			✓	✓		7000		✓	60	90	
Neb.		✓		✓	✓	✓	7000, 5000, 3500		✓	60-90	-	
Nev.		✓		✓			5000	✓		50-90	90	
N.J.		✓					NS			60	None	
N.M.			✓	✓	✓	✓	7000, 5000, 3500	✓		50-90, 75-120	90	
N.Y.		✓		✓	✓	✓	7000, 5000, 3500		✓	90	-	
N.C.	✓			✓			7000	✓		60	None	
N.D.				✓	✓	✓	7000, 5000, 3500	✓		50+	90	
Ohio		✓		✓	✓		7000, 5000		✓	60	-	
Okla.	✓			✓	✓	✓	7000, 5000, 3500			90	90	
Ore.	✓			✓			NS		✓	50-90	80	
Pa.			✓	✓			6000		✓	50	90	
S.C.		✓		✓			7000		✓	90	None	
S.D.		✓		✓			7000		✓	60	90	
Tenn.	✓			✓			(92)	✓		60-90	100	
Texas	✓		(99)	✓			8000		✓	50-90	-	
Utah	✓			✓			9500		✓	45	90	
Va.			✓	✓			7000	✓		75+	90	
Wash.	✓			✓			5000	✓		50-90	None	
W.Va.		✓		✓		✓	5000, 3500	✓		(100)	90	
Wis.			✓	✓	✓	✓	7000, 5000, 4000	(92)		50-90	(101)	
Wyo.	✓			✓	✓	✓	7000, 5000, 3500	✓		50-90	80	

State	Slip-form			Surface Texture					Placing and Equipment (H)												
				Type			Direction		Automatic Dowel Placer			Mesh Placer			Reinforcement Depresser			Longitudinal Reinforcing Tubes		
	Yes	No	Opt.	Broom	Burlap Drag	Steel Tine	Longit.	Transv.	Yes	No	Opt.	Yes	No	Opt.	Yes	No	Opt.	Yes	No	Opt.
Ala.	✓				✓	E		✓	✓			✓			✓				✓	
Ariz	✓			✓	✓		✓			✓			✓			✓				
Ark.	✓				✓	✓		✓		✓				✓			✓			✓
Calif.			✓	Opt.	Opt.	Opt.	✓													
Colo.	✓			✓	✓			✓			✓									
Conn.	✓			✓	✓			✓		✓			✓		✓				✓	
Del.	(12)	(11)			✓	✓		✓		✓		✓				✓				
D.C.		✓		✓	✓			✓												
Fla.	✓					✓		✓	✓											
Ga.	✓					✓		✓			✓						✓			✓
Hawaii	✓					✓	✓													
Idaho	✓					✓		✓												
Ill.	✓				✓					✓				✓	✓			✓		
Ind.	✓				✓	✓		✓		✓			✓		✓			✓		
Iowa	✓			(97)	✓		✓			✓					✓			✓		
Kansas	✓				✓					✓			✓			✓			✓	
Ky.	✓				✓	✓		✓		✓			✓		✓				✓	
La.	✓					✓		✓	✓											
Maine	✓			✓		✓		✓		✓										
Md.	✓				✓				✓			✓					✓			✓
Mass.																				
Mich.	✓			✓		✓		✓		✓		✓			✓			✓		
Minn.	✓				✓	✓		✓		✓		✓			✓					
Miss.	✓				✓	✓		✓								✓			✓	
Mo.	✓					✓		✓	✓			✓			✓				✓	
Mont.	✓					✓		✓												
Neb.	✓				✓					✓				✓		✓			✓	
Nev.	✓			✓	✓		✓													
N.J.		✓		✓				✓		✓			✓		✓				✓	
N.M.	✓			✓	✓			✓		✓										
N.Y.	✓					✓		✓	✓		✓		✓							
N.C.	✓					✓		✓		✓					✓			✓		
N.D.	✓			Opt.	Opt.			✓				✓			✓			✓		
Ohio	✓			✓	✓	✓	✓			✓			✓			✓			✓	
Okla.	✓				✓	✓		✓												
Ore.	✓			✓		E		✓								✓			✓	
Pa.			✓	✓		✓	(98)	(98)		✓		✓			✓			✓		
S.C.	✓				✓	✓		✓	E						✓			✓		
S.D.	✓				✓															
Tenn.	✓				✓				✓											
Texas	✓				✓	E		E		✓			✓			✓		✓		
Utah	✓				✓															
Va.	(12)	(11)			✓	✓	✓			✓						✓		✓		
Wash.	✓			✓		✓		✓												
W.Va.	✓					✓	Opt.	Opt.		✓			✓		✓					✓
Wis.			✓	✓		E		✓		✓				✓			✓			✓
Wyo.	✓				✓					✓										

State	Method	Design Life, Years	Final Serviceability level psi	Concrete Working stress, psi	Equivalent axle load kips	Maximum single axle load, kips	Maximum tandem axle load, kips	K subgrade pci	
Ala.	AASHTO	20	2.5	514	18	18	32	100 (d)	
Ariz.	AASHTO	20	2.5	517.5	18	20	34	(120)	
Ark.	AASHTO	20	2.5	450	18	26	42	100-150 (a)	
Calif.	PCA-Mod.	20	None	(123)	-	18-35	32-55	80-300 (120)	
Colo.	PCA-Mod.	20	2.5	MR-550	-	20	36	var.	
Conn.	Based on experience; CRCP systems are experimental, standards not yet established								
Del.	AASHTO	20	(124)	490	18	-	-	(125)	
D.C.	AASHTO	30	-	488	18	-	-	150 (a)	
Fla.	ACI-Mod.	-	2.5	550	-	-	-	-	
Ga.	AASHTO	20	2.5	450-515	18	-	-	100-200 (a)	
Hawaii	PCA	20	None	600	-	36	50	85 (d)	
Idaho	PCA-Mod.	20	None	-	-	-	-	-	
Ill.	Illinois	20	(124)	-	18	-	-	(127)	
Ind.	AASHTO	30	2.5	450	18	18	32	-	
Iowa	PCA	20	2.5	540	-	24	50	100-200 (a)	
Kansas	Worley	20	2.5	225	-	18	-	100-700 (d)	
Ky.	(129)	20	2.5	450	-	-	-	-	
La.	LHD	-	-	-	-	-	-	-	
Maine	AASHTO	20	2.5	394-487	18	22	34	70 (d)	
Md.	PCA (130)	25	2.5	700	18	22.4	(131)	100-170 (d)	
Mich.	(132)	20	2.5	-	18	18	32	100 (a)	
Minn.	PCA, HB 35	35	2.5	400	-	30	52	150 or 300	
Miss.	BPR-ACI	25	(133)	-	18	-	-	-	
Mo.	MSHD	20	-	-	18	18	32	-	
Mont.	PCA	40	None	400	18	18	32	100 (a)	
Neb.	AASHTO	20	2.5	487	18	20	34	75-150 (a)	
Nev.	PCA	20	None	550	18	20	34	70 (d)	
N.J.	Experience	30	-	-	-	22.4	32	-	
N.M.	AASHTO	20	None	450+	18	21.6	34.3	(d)	
N.Y.	AASHTO	20	2.5	416	-	22.4	36	-	
N.C.	AASHTO	20	2.5	490	18	-	-	200 (a)	
N.D.	AASHTO	-	-	-	18	-	-	-	
Ohio	AASHTO	28	2.5	700	18	-	-	100 (a)	
Okla.	None	20	-	300	18	-	-	125 (a)	
Ore.	PCA-Mod.	20	2.5	525	18	-	-	(d)	
Penn.	AASHTO	20	2.5	412	18	22.4	36	(d)	
S.C.	AASHTO	20	2.5	412.5	18	-	-	100-300 (d)	
S.D.	AASHTO	-	-	412	18	20	24	var. (d)	
Tenn.	AASHTO	20	2.5	500	18	18	32	130-240 (d)	
Texas	AASHTO-Mod.	20	3.0	400-500	18	-	-	100 (a)	
Utah	AASHTO	20	2.5	490	18	20	36	-	
Va.	(137)	(138)	2.5	475	18 (12)	28 (139)	48 (139)	100 (a)	
Wash.	PCA-Mod.	25	-	-	10	24	46	(d)	
W.Va.	PCA (140)	20	-	300	-	18	32	var. (a)	
Wis.	(141)	20	2.5	490	18	19.5	32	100-300 (a)	
Wyo.	PCA-Mod.	20	-	-	18	22	50	var. (d)	

State	K on top of subbase, pci	E of concrete psi x 10^6	Drainage Design	Other Design Inputs
Ala.	-	3	below pavm't & shoulder	Subgrade CBR value
Ariz.	(121)	4.2	-	% of each truck type; 2-way ADT ÷ one way ADT
Ark.	-	-	(122)	---
Calif.	200 to 600 (a)	-	-	R value; Load Safety factor; MR; estimated axle load repetitions for 20 years.
Colo.	var.	-	No	Average daily truck traffic (20 years hence) - variable
Conn.				
Del.	300, 300 (105)	-	(126)	---
D.C.	-	4	No	---
Fla.	-	-	No	---
Ga.	200-450 (a)	3.5	(63)	95% truck lane distribution for 4 lanes, 60% for 6 lanes; Tied PCC shoulders to reduce longitudinal crack bituminous middle lane and shoulder and edge stresses
Hawaii	175 (d)	3.5	No	---
Idaho	-	-	No	Slip form beveled edges "Horizontal-Vertical" 2"-8"
Ill.	-	-	Shoulder only	Predicted design traffic ADT; % passenger cars; % single unit only, truck and buses; % multiple unit trucks
Ind.	-	4	No	---
Iowa	(128)	4	No	---
Kansas	-	3.5	(122)	25% impact, 0.15 Poisson's ratio;50% M.R.; 25 psi warping; unprotected corner
Ky.	-	-	below pavm't	---
La.	-	-	below pavm't	---
Maine	260 (d)	3.1	below pavm't & shoulder	---
Md.	130-200 (d)	-	below pavm't & shoulder	CBR's based on actual test results; equiv. 18K loads computed from compatible loadometer stations; PCA design less 1" for reinforced concrete (21)
Mich.	200 (a)	-	below pavm't & shoulder	---
Minn.	150 or 300 (a)	-	Yes	---
Miss.	-	-	No	---
Mo.	-	-	(5)	2-axle equivalent units 750+ for mesh-doweled pavements and 125+ for plain-doweled pavements
Mont.	300 (a) (134)	4.2	No	---
Neb.	175-250 (a)	4.2	No	---
Nev.	235 (d)	3.3	No	---
N.J.	-	3.9	transverse drain below pavm't	---
N.M.	(d)	4	No	---
N.Y.	200-300 (a)	-	(135)	---
N.C.	400 (a)	-	longitudinal drain at edge	---
N.D.	-	-	transverse drain	"Load limit" free system for Interstate Major Expressways and (a) competitive bid alternate (b) match existing city paving practice for primary highways
Ohio	300 (a)	4.2	No	---
Okla.	375 (a)	-	No	Climatic factor
Ore.	(d)	-	below pavm't & shoulder	---
Penn.	(a)	4.2	below pavm't & shoulder	Truck type distribution; lane distribution
S.C.	400 (a)	4	No	---
S.D.	-	-	No	---
Tenn.	-	4.2	(136)	---
Texas	100 (a)	4	No	Static load design strength: 300 psi (tensile)
Utah	-	-	below pavm't & shoulder	Modulus of subgrade reaction: 350 for CTB; MR: 650; % trucks in heaviest traveled lane
Va.	450 (a)	4	transverse drain below pavm't	Traffic study of each project, weight and truck % determined
Wash.	(d)	-	below pavm't & shoulder	Two-way ADT (average design for life); truck classifications % 2, 3, 3, 5, 6 axles, no lanes
W.Va.	var. (a)	4	Yes	Soil Frost classification and Design Freezing Index of the Corps of Engineers Procedure
Wis.	-	4.2	No	---
Wyo.	var. (d)	-	NS	Load safety factor; probability factor; allowable repetitions; MR; stress.

ABBREVIATIONS AND NOTES

(a)	Assumed
AC	Asphalt-concrete
Agg.	Aggregate
Asph.	Asphalt
AT	Asphalt treated
ATB	Asphalt treated base
Auto.	Automatic
Av.	Average
Bit.	Bituminous
CBR	California bearing ratio
CRC	Continuously reinforced concrete pavement
Crshd.	Crushed
CT	Cement treated
CTB	Cement treated base
D	Depth or thickness
(d)	Determined
Dash (-)	Indicates none or no information, or range if between numbers except for contraction joint spacing dash denotes sequence
DGA	Dense graded aggregate
Dia.	Diameter
Dr.	Drain
E	Experimental
Equiv.	Equivalent
Gran.	Granular
Longit.	Longitudinal
Max.	Maximum
Min.	Minimum
Mod.	Modified
NP	Not permitted
NR	Not required
NS	Not specified
Opt.	Optional
Pavm't.	Pavement
PC	Plain concrete pavement
PCC	Portland cement concrete
PD	Plain concrete pavement with dowels
Prep.	Prepared
Pt.	Point
RD	Mesh-dowel pavement
S/C	Soil cement
Shldr.	Shoulder
Spec.	Specification
SpT	Split-tensile
S.t.	Surface treated
Stab.	Stabilized
Subb.	Subbase
Subg.	Subgrade
Transv.	Transverse
Var.	Varies, variable
WR	Water reducer

Measures:

F	Degrees Fahrenheit
ft.	Feet
in.	Inches
lb/cu.yd.	Pound(s) per cubic yard
pci	Pound(s) per cubic inch
psi	Pound(s) per square inch
rpm	Revolutions per minute
secs.	Second(s)
sq.ft.	Square feet

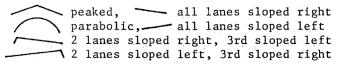
Footnotes:

(A) Applies to both Interstate-Major Expressways and Primary Highways

(B) In the order of type shown and offset by a comma

(C) In the order of Interstate-Major Expressways and Primary Highways if more than one type shown and offset by a comma

Transverse profiles are:



(D) For construction joints:

✓ for jointed pavements
x for CRC pavements
\+ for both CRC and jointed pavements

(E) Applies to PCC pavements only except for Indiana (PD), Minnesota (RD) and Wyoming (PD). 2 ft. in 12 ft. if yes.

(F) AASHTO specifications are designated as M; ASTM's, D; Federal, SS-S, and VTM is Virginia Test Method

(G) Or distance from ends

(H) Checked where applicable to pavement type

(I) Roadmeter

Numbered Notations:

(1) Slab plus subbase

(2) 5.4-in. CTB over 6-in. untreated aggregate.

(3) Crushed stone, or crushed rock, or gravel, or aggregate

(4) Dense graded aggregate, or sand, or crushed stone

(5) Open graded aggregate

(6) Slag

(7) Sand

(8) Gravel

(9) Stabilized with $CaCl_2$

(10) 6-in. fill (minimum); 10-in. cuts (minimum)

(11) Used in RD pavements only

(12) Used in CRC pavements only

(13) Used in all doweled pavements

(14) PCC base

(15) 5-in. of either subbase plus 1-in. AC

(16) When A-1 to A-3 inclusive, subgrade will exist, no CTB is provided

(17) Lime and fly ash

(18) Crushed limestone

(19) For urban and outstate, respectively

(20) Or 5-in. lime rock base plus 1-in. asphalt surface

(21) Center 6 ft. rounded

(22) Used for less than 24- ft. wide pavement

(23) Plant mix bituminous base

(24) 5-7-in. for CRC and 5-6-in. for RD

(25) Lime treated, 1 1/2-2 percent for granular, 4-6 percent for A-7-6 subgrade

(26) Except for the 13-in. thick pavements

(27) D/4-in. for CRC and 2-in. minimum for RD

(28) Insert sawed

(29) Add extra longitudinal steel for CRC pavements

(30) 5/8-in. dia. tiebar for RD of Interstate-Major Expressways and 1/2-in. dia. tiebar for RD of Primary Highways; 1-in. dia. x 36-in. long spaced at 18-in. for CRC pavements

(31) Depth = 2 3/4-in. for Interstate-Major Expressway pavements and 2 1/2-in. for Primary Highways

(32) I-beam: 1 1/2 x 16-in.; round: 1 1/8 x 18-in. (for Interstate-Major Expressways); and round: 1 x 18-in. (for Primary Highways)

(33) Dowels are used in both longitudinal and transverse construction joints of jointed pavements

(34) 1 1/8-in. dia. x 16-in. long dowels for Interstate-Major Expressways, and 1-in. dia. x 14-in. long for Primary Highways; 1 1/4-in. dia. x 18-in. long for PC based pavements

(35) Emergency only

(36) Transverse must be plastic insert if longitudinal is sawed

(37) 1/2-in. dia. for 8-in. and 9-in. thick pavements; 5/8-in. dia. for 10-in. thick pavements

(38) 1/4-in. width for the top 1-in., 1/8-in. width below that

(39) 1/4-in. wide for RD; 3/8-in. for PC

(40) 2 1/4-in. deep for RD; 2 1/2-in. deep for PC

(41) 1/8-in. dia. per 1-in. of pavement thickness

(42) 2 1/4-in. deep for 8-in. thick pavement; 2 1/2-in. for 9-in. pavement thickness

(43) 1 5/8-in. deep for 7-in. pavement thickness; 2-in. for 8-in. and 9-in. pavement and 2 1/2-in. for 10-in. pavement

(44) 1/8-in. wide plus reservoir

(45) Keyed if tied, butted if not tied, only 2 lanes tied

(46) 2 1/4-in. deep for 7 to 7 1/2-in. thick pavement, 1/4-in. deeper for each additional 1-in. thickness

(47) 1/2-in. dia. x 30-in. long tiebars for less than 8-in. thick pavement; 5/8-in. dia. x 30-in. long for 8-9 in. thick pavements; and 5/8-in. dia. x 36-in. long for 10-in. thick pavement.

(48) 1-in. dia. for 8-9-in. thick pavements; 1 1/4-in. dia. for 10-in. pavement

(49) 1 to 1 1/4-in. dia. for RD pavements; 1-in. dia. for PD

(50) 1-in. dia. for 8-in. thick pavements; 1 1/4-in. dia. for 9-10-in. thick pavement

(51) 2 1/8-in. deep for CRC; D/4-in. for RD & PC

(52) 1 1/4-in. dia. x 16 3/4-in. long stainless steel clad or monel

(53) 5/8-in. RD, varies for PD; formed type not allowed on PD

(54) For both sawed and formed type: 5/16-in. wide for RD, 1/8-in. wide for PD

(55) 15 in. ⊓-shaped bar

(56) For both sawed and formed type: 2 3/8-in. for CRC, and 2 3/4-in. for PD

(57) 2 1/4-in. deep for Interstate-Major Expressways; 2-in. for Primary Highways

(58) 2-in. for Interstate-Major Expressways; D/5-in. for Primary Highways

(59) Only when over untreated base

(60) Spacing: 48-in. for CRC; 50.7-in. for RD

(61) 2 1/2-in. for Interstate-Major Expressways; 1 1/2-in. - 2-in. for Primary Highways

(62) Joints sawed 25 ft. apart for crushed stone coarse aggregate base; plastic inserts used on crushed gravel coarse aggregate base 18 ft. apart

(63) As required/as approved

(64) As shown on plans

(65) 5/8-in. dia. x 48-in. long x 40-in. spacing for RD; 1/2-in. dia. x 30-in. long x 30-in. spacing for CRC

(66) Either 4-in. wide on base or 2-in. on sleeper and lugs

(67) 4-in. @ bridge end for RD pavements; 4-in. @ bridge approach slab, 3/4-in. @ 30 ft. and 60 ft., and WF beam @ 90 ft. for CRC pavements

(68) Sealants used where pavement is sanded or salted

(69) Between structure paving notch and approach slab

(70) Depends on movement rating and time of year concrete is placed

(71) Used on PD pavements only

(72) Terminals, approach slabs

(73) Types used: SS-S-164, TT-S-227 Type II

(74) Crossroads, ramps, R.R.-xing

(75) 2-in. doweled expansion joints for CRC

(76) Wide asphalt-treated on bituminous base pressure relief provided

(77) 1 1/2 ft. x 4 1/6 ft. @ 20 ft.

(78) 3 for PD; 1 for CRC

(79) Hot rubber asphalt

(80) 4-in. and 2-in. pressure relief joint (polyethylene plank)

(81) Wide flange: 12 x 58 beam

(82) 51.6 lb./100 sq. ft. for 10-in. thick pavements; 46.8 lb./100 sq. ft. for 9-in. thick pavement

(83) Compacted aggregate sill

(84) For CRC, RD and PC bridge: 2 @ 2-in. x 25 ft. or 1 @ 4-in. x 25 ft.; for RD, PC, R.R.-xing: 3 @ 1-in. spaced at 46 1/2 ft. on RD, and 45 ft. on PC

(85) Not for R.R.-xing of RD and PC

(86) 1st two joints before and after structure approach slab

(87) 2 @ 20 ft. or 2 @ 90 ft. for PD

(88) In RD, relief joints 4 ft. wide used at bridge approach slab when 200-400 ft. between bridges use one; if less than 200 ft. between bridges, use none.

(89) Transverse bars omitted when contractor options to use tube method of inserting longitudinal bars into slab

(90) Sleeper slab used with bituminous concrete (3 ft.) joint at structure on RD pavements

(91) Yes for CTB, no for aggregate base

(92) Per manufacturer's recommendation

(93) Controlled

(94) Not required if subbase trimmed with wire control

(95) 10,800 rpm @ 24-in.

(96) Not $<40^0$F in moderate weather; 50^0-90^0F in cold weather ($<40^0$F); not $>80^0$F when insulated forms are used

(97) Transverse brooming is required if desired texture cannot be obtained with a burlap drag

(98) Either direction could be used in broom surface texturing; transverse for steel tine

(99) For asphalt stabilized base

(100) For central mix: 50 sec. minimum if test performance of mixers are made; otherwise, 75 sec. minimum; for site mixers: 50-90 sec.; maximum mixing time equals minimum plus 60 sec.

(101) None specified except during cold weather (100^0F max.)

(102) To open traffic

(103) 6 ± 1/2 percent when specified for freeze-thaw areas; maximum of 4 percent without additional cement for optional use

(104) Kelly Ball penetration, 1 1/2-in. maximum

(105) For RD & CRC, respectively

(106) For PC & CRC, respectively

(107) Determined when source selected that meets percent passing 3/8 is approximately 100; #4 is approximately 85-100; #16 is approximately 40-80; #100 is approximately 0-5

(108) Maybe less with increased slab thickness

(109) Maybe less with fly ash or water reducer

(110) 0.44 with gravel; 0.47 with crushed stone

(111) Allowed and standard, respectively

(112) NB is normal strength non-air entraining portland blast furnace slag cement; NC is normal strength non-air entraining portland cement; and ND is high early strength non-air entraining portland cement

(113) Type I, IP for CRC pavements; IP for other pavements

(114) 489-517 lb/cu.yd. for CRC, 489 lb/cu.yd. for P, and 517 lb/cu.yd. for PD

(115) 2-in. for slipform; 1-3-in. for formed

(116) 575 psi for CRC, 650 psi for other pavements

(117) 100 percent pass 2-in., 90-100 percent pass 1 1/2-in.

(118) 2-in. for slipform; 3-in. for machine vibrator; 4-in. for hand vibration

(119) Type A, B, D (AASHTO M-194) chemical admixtures

(120) Determined by R value

(121) Determined by PCA relationship

(122) Transverse drain below pavement, longitudinal drain at edge

(123) Calculated from expected loading based on MR 550 psi

(124) 2.5 psi and 2.0 psi for Interstate-Major Expressways, and Primary Highways, respectively

(125) Correlated from soil test results

(126) 4-in. thick minimum below pavement and shoulder for CRC; 8-in. thick minimum for RD pavement

(127) Determined by CBR

(128) Add 30 to subgrade K (assumed)

(129) Conforms basically to PCA criterion and AASHTO Interim Guide

(130) Experience indicates 1-in. less than PCA design for RD

(131) 40 kips if spaced 48-in. or more between axle centerline; 36 kips for less than 48-in.

(132) PCA for CRC, AASHTO for other pavement types

(133) 2.5 psi for Interstate-Major expressways and 3.6 psi for Primary Highways

(134) On top of treated base

(135) Longitudinal drain on bathtub sections only, elsewhere daylight subbase

(136) Longitudinal drain at edge continuously through low shoulder

(137) AASHTO for CRC, PCA for RD, experience for plain base concrete

(138) 35 years for AASHTO-designed pavements; 25 years for PCA and experience-designed

(139) For RD & PC pavements

(140) With some modifications for CRC

(141) Emperical for CRC, AASHTO for RD, and AASHTO-PCA for PC

(142) For PC pavements only, saw depth are 1-in. 1 1/8-in., 1 1/4-in., 1 1/2-in., and 1 3/4-in. for 6-, 7-, 8-, 9-, and 10-in. thick pavements, respectively

(143) I(B) is La. designation for AASHTO Type I modified for a coarser grind (Turbidimeter values 2100 max.)

(144) Reduced 5 percent when WR is used, 10 percent when air entraining admixture is used

(145) 45 secs. with turbines