Spacing of Undoweled Joints in Plain Concrete Pavement

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In 1955 the Iowa State Highway Commission constructed approximately 16 mi of experimental portland cement concrete pavement containing sections without contraction joints and sections in which the joints were sawed at 20, 50 or 80 ft. None of the joints were doweled. Approximately half of the joints were left unsealed.

After 8 yr of service the pavement test sections have an average slab length of from 19 to 37 ft. Faulting of at least $1/16$ in. is evident at 70 percent of the joints spaced at 20 ft. The incidence of faulting is greater for the joints spaced at 50 and 80 ft. Measurements made in April 1964 revealed that more than 92 percent of the joints were open at least $1/16$ in. more than their original sawed width of $1/8$ in. The effect of joint sealing was not conclusive, but it appears that the seal may have been useful in keeping debris out of the joints spaced at 20 ft.

•HUNDREDS OF MILES of portland cement concrete pavement have been constructed in Iowa during the past 40 yr, and during that time there have been numerous changes in the thinking of design engineers regarding the use and design of joints. Ten years ago the Iowa State Highway Commission adopted a tentative policy of sawing undoweled contraction joints at 20-ft intervals, while omitting expansion joints except at bridge approaches. This policy has been continued to the present in the construction of almost all concrete pavement on primary highways in Iowa.

When 20-ft joint spacing was adopted, the Commission was aware of the good past performance of some Iowa pavements having joint spacing greater than 20 ft, as well as that of some pavements containing no contraction joints. This recognition led to further investigation of joint spacing. The formal investigation was confined largely to one 16-mi experimental project containing sections without contraction joints and sections in which the joint spacing was 20, 50 or 80 ft. Approximately half of the joints in each section were filled with an asphalt-rubber sealer; the others were left unsealed.

The objectives of the experimental joint construction were to examine the performance of a plain concrete pavement as it may be influenced by the distance between undoweled contraction joints and to compare the performance of sealed and unsealed joints.

The experimental pavement was constructed in 1955. This report contains observations and data obtained during the past 8 yr of pavement service.

PROJECT DESCRIPTION

Correct evaluation of the observations and measurements presented in this report requires preliminary consideration of the pavement materials, construction procedures, and the traffic to which the pavement has been subjected.

Location

The pavement containing the experimental joint spacing is located just west of Des Moines in central Iowa along approximately 16 mi of US 6. This section of US 6 is currently part of the connecting link between two completed portions of Interstate 80.

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The area has a well-developed erosional topography with broad flat valleys and rolling-to-hilly upland divides. The general location of the project is shown in Figure 1.

Subgrade

A considerable amount of subgrade preparation was undertaken before paving, including the placing of from 3 to 12 in. of reclaimed road surfacing or select glacial clay. Reclaimed road surfacing was used to top off the subgrade, and did not constitute a subbase. The various subgrade materials are distributed throughout the project approximately as follows: reclaimed road surfacing, 24 percent; select glacial clay, A-6 (11) to A-7-6 (16), 63 percent; alluvial silty clay, A-7-6 (14-18), 7 percent; and loess silty clay, A-7-6 (11-14), 6 percent.

Reclaimed road surfacing as used in Iowa is generally a gravelly sandy loam falling in the A-4 (0) to A-4 (2) groups.

Pavement Design

The pavement is 24 ft wide with a 10-9 ½-10 in. cross-section. The only reinforcement is ½-in. by 3-ft tie bars, spaced at 30-in. centers, across the longitudinal joint. The only experimental features are the transverse joint spacing and joint sealing. The experimental sections are given in Table 1. All the sections have earth shoulders.

Materials

The aggregate used in the concrete pavement was washed sand and gravel in the ratio of 45 percent sand and 55 percent gravel. The cement was Type I, furnished by two manufacturers. The cement content of the mix was 6.4 sk/cu yd. Air entrainment in the range of 4 to 6 percent was obtained by means of an admixture.

Construction

The pavement was cured with wet burlap for at least 20 hr, after which a clear wax-base curing compound was applied. All contraction joints were sawed, with every fourth joint in the 20-ft sections and all joints in the 50- and 80-ft sections done during the first 24 hr. The remaining joints in the 20-ft sections were sawed within 72 hr. The saw cuts were ⅛ in. wide by 1 ½ in. deep.

Pavement construction began July 12, 1955, and was completed October 22, 1955. Table 1 gives the maximum and minimum temperatures for the days each section was paved.

Traffic

When the pavement was constructed in 1955, it was part of Iowa 90, and the traffic count was less than 2,000 veh/day. Later it was designated US 6 and became the connecting link between completed portions of Interstate 80. This resulted in a considerable increase in traffic, with an especially significant increase in tractor-truck combinations. The traffic data are as follows:

Year	Total Vehicles	Single-Unit Trucks	Tractor-Truck Combinations
1955	1,720	—	—
1959	2,250	352	244
1962	3,775	330	515
1964	4,870	430	664

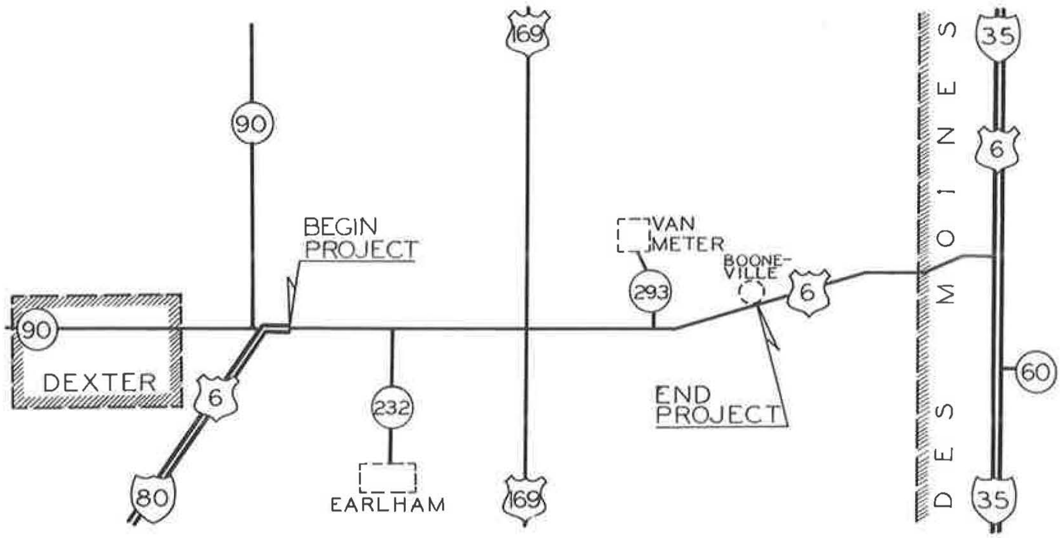

Figure 1. General location of experimental sections.

TABLE 1

EXPERIMENTAL JOINT SECTIONS

Sect. No.	Sect. Length (ft)	Joint Spacing (ft)	Joint Sealed or Open	Date Paved (1955)	Max. Temp. (° F)	Min. Temp. (° F)
1	3,200	None		7/15-27	99	64
2	2,700	None		8/17-19	98	66
3	7,434	None		10/3-10	80	37
4	2,636	None		10/10-11	80	53
5	1,137	None		7/12-13	93	66
6	4,040	20	S	7/29-30	103	76
7	1,345	20	S	8/16-17	97	66
8	5,400	20	S	10/15-19	70	30
9	3,664	20	O	8/2-8	95	62
10	1,370	20	O	8/15-16	93	61
11	5,300	20	O	10/11-15	80	30
12	4,047	50	S	8/9-11	86	58
13	3,512	50	S	8/27-31	99	52
14	1,335	50	S	8/15	93	61
15	4,673	50	S	9/22-28	78	46
16	558	50	O	8/12	85	58
17	1,350	50	O	8/13	85	57
18	5,300	50	O	10/19-22	72	36
19	2,161	80	S	8/26	99	72
20	1,270	80	S	10/1	69	41
21	682	80	S	9/20-22	80	54
22	4,601	80	S	9/8-13	99	43
23	5,922	80	O	8/20-25	97	60
24	1,526	80	O	10/1	69	41
25	5,275	80	O	9/13-20	96	56

OBSERVATIONS AND MEASUREMENTS

Annual Condition Survey

A condition survey of the pavement has been made each year beginning in November 1955. The locations of all cracks were recorded along with notes concerning the general condition of the joints and cracks. Blow-ups and evidence of pumping were also noted. Information from these surveys is given in Table 2.

Fault Measurements

When the condition survey was made in November 1963, all joints were measured to determine the amount of faulting. The measurements were made in both traffic lanes at about 3 ft from the edge of the pavement with the device shown in Figure 2. The measurements are summarized in Table 3.

Width of Crack and Joint Openings

In April 1964, measurements were made of the joint and crack openings in 13 of the 25 experimental sections. One measurement was made for each joint and crack at a point about 5 ft from the edge of the pavement. Pictures were taken of the joints and cracks, and the width of each opening was shown by the scale included in the picture. Figure 3 shows the equipment used in taking the pictures. Figure 4 is an example of the finished pictures. The data are presented in Table 4. A series of check measurements indicated that within the degree of the accuracy of the measurements no significant change in the joint openings occurred during the time required to take photographs of the joints.

Road Roughness

The Iowa State Highway Commission uses a BPR-type trailer for measuring the surface roughness of pavements. The roughness of the experimental pavement was measured shortly after completion of the pavement in 1955. It was determined with the same machine again in October 1963. Both sets of measurements are given in Table 5.

RESULTS

In planning this experiment it was assumed that the primary purpose of transverse joints in concrete pavements is to control the cracking which accompanies volumetric changes in concrete and which also results from combined warping and load stresses. It is recognized that the optimum distance between contraction joints depends on numerous factors, and is not the same for all pavements.

Slab Length

Figure 5 shows the changes in slab length which occurred in the experimental pavement. The numerical data for the curves are given in Table 2. The average slab length at the time of the last crack survey was from 19 to 37 ft. Therefore, the optimum joint spacing for this pavement lies within this range, provided the sole criterion is the duplication of the average slab length resulting from random cracking. The proper functioning of undoweled contraction joints, however, requires consideration of additional criteria.

Joint Faulting

Effective load transmission across a joint is highly desirable because it precludes formation of unprotected corners and because it prevents, or at least minimizes, differential movement of the slab ends. Such movement frequently results in permanently faulted joints and pumping of the underlying subbase or subgrade material.

Figure 6 summarizes the measurements of joint faulting. The curves show the percentage of joints at each spacing which have faulted by the indicated amount. Of the

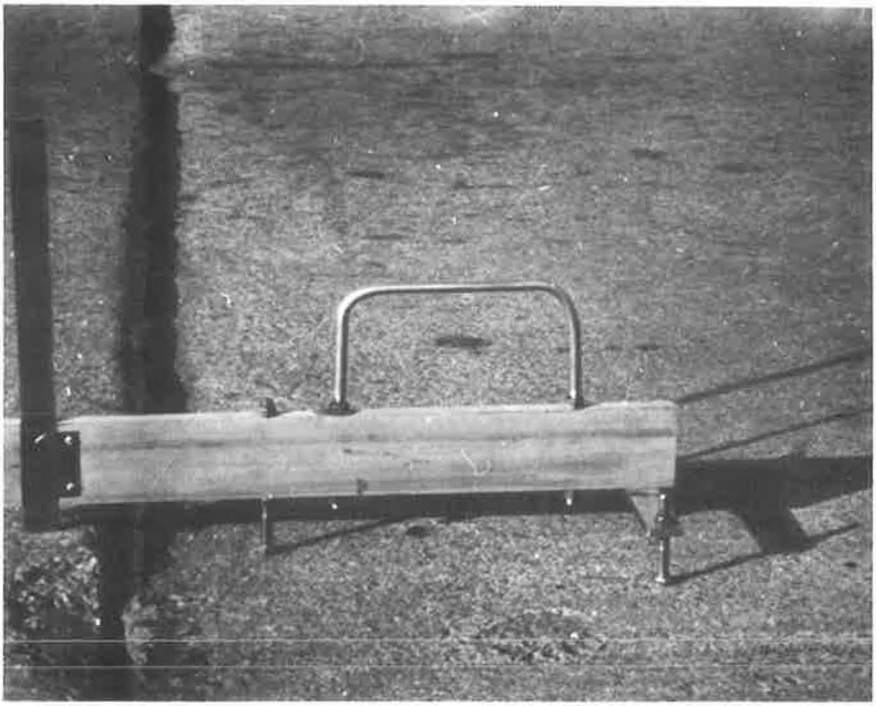

Figure 2. Measuring device for joint faulting.

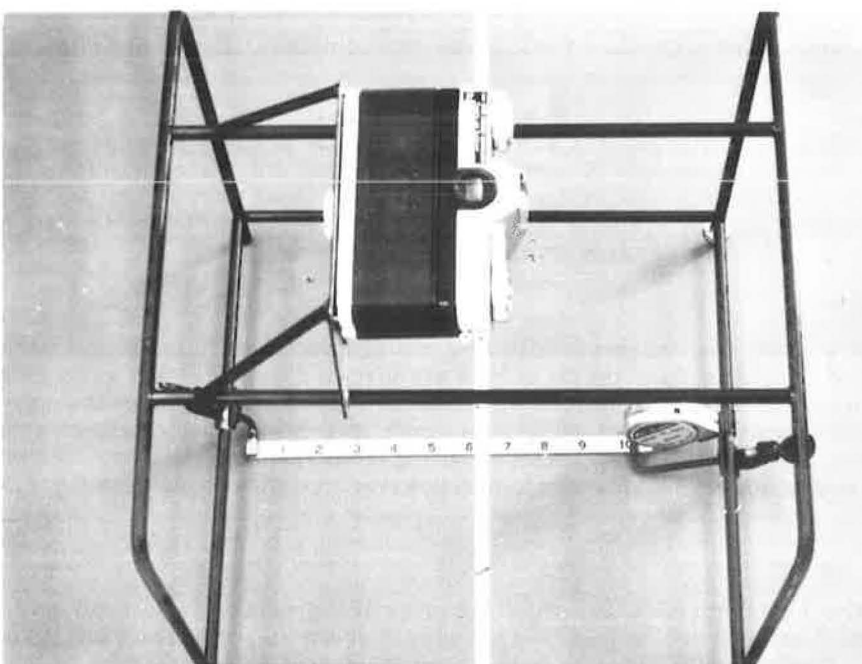

Figure 3. Equipment used to photograph joint and crack openings.

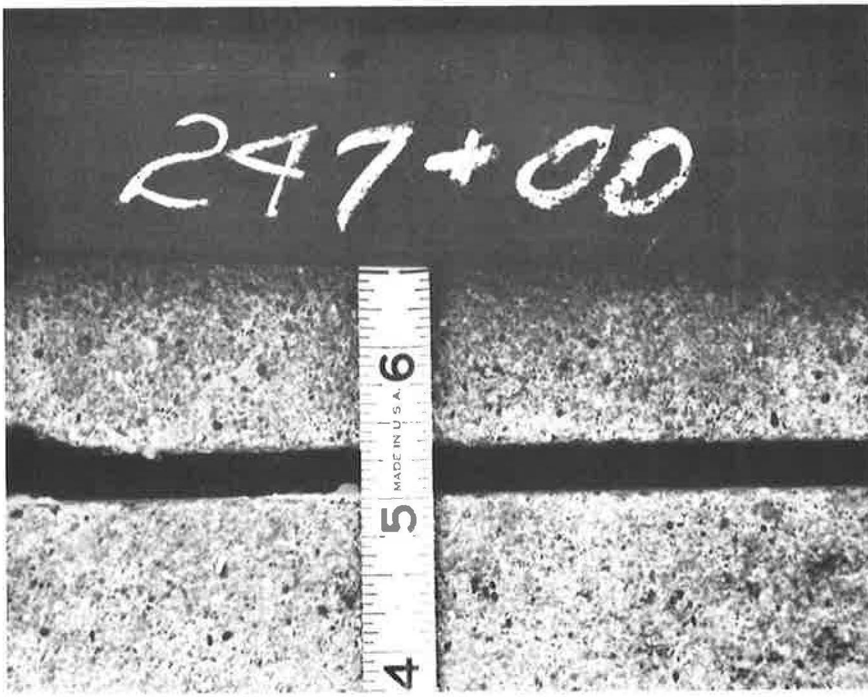

Figure 4. Example of type of photograph from which measurements of joint and crack openings were made.

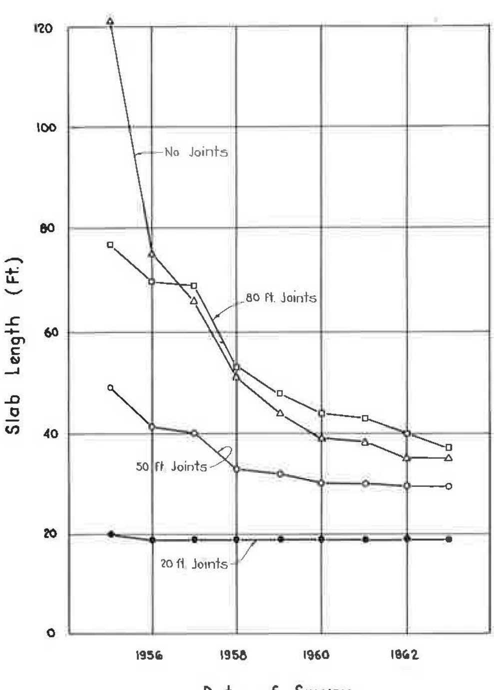

Figure 5. Change of slab length with time.

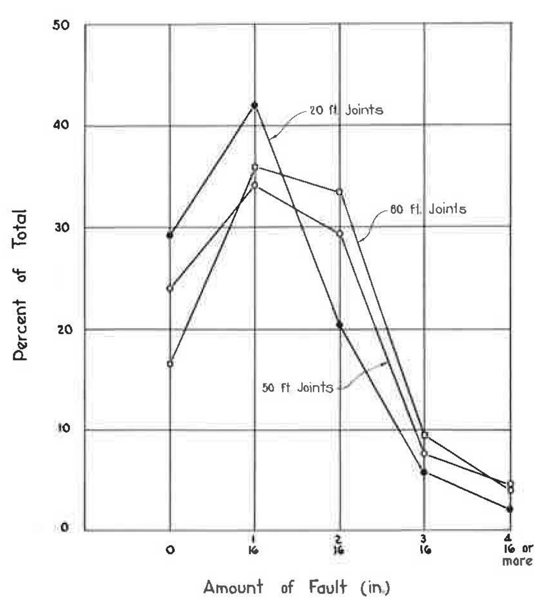

Figure 6. Relation of faulting to contraction joint spacing.

TABLE 2

SLAB LENGTH

Joint Spacing (ft)	No. of Sect.	Total Length (ft)	Avg. Length, Nov. or Dec. (ft)								
			1955	1956	1957	1958	1959	1960	1961	1962	1963
20	6	21,119	20	19	19	19	19	19	19	19	19
50	7	20,775	49	41	40	33	32	30	30	20	29
80	7	21,437	77	70	69	53	48	44	43	40	37
None	5	17,107	121	75	66	51	44	39	38	35	35

TABLE 3

JOINT FAULTING

Joint		Percent of Joints Faulted by:							
Spacing (ft)	Condition	None	$\frac{1}{16}$ In.	$\frac{2}{16}$ In.	$\frac{3}{16}$ In.	$\frac{4}{16}$ In.	$\frac{5}{16}$ In.	$\frac{6}{16}$ In.	$\frac{7}{16}$ In. or More
20	Sealed	24.3	40.1	25.4	7.5	2.0	0.5	0.2	0
20	Open	34.9	44.5	15.1	3.6	1.2	0.5	0.2	0.1
20	All	29.3	42.0	20.5	5.7	1.6	0.6	0.2	0.1
50	Sealed	25.2	36.0	26.0	7.3	3.6	1.4	0.2	0
50	Open	21.2	31.0	35.6	8.3	3.1	0.4	0.4	0
50	All	23.8	34.4	29.4	7.7	3.4	1.0	0.3	0
80	Sealed	14.7	45.5	35.8	2.5	0.5	0.5	0.5	0
80	Open	17.6	29.7	32.0	14.3	4.7	0.6	0	0.7
80	All	16.5	35.9	33.6	9.6	3.0	0.6	0.4	0.4

TABLE 4

JOINT AND CRACK OPENINGS

Crack or Joint Opening ($\frac{1}{16}$ in.)	Percent of Total						
	20-Ft Sections		50-Ft Sections		80-Ft Sections		No Joints
	Joints	Cracks	Joints	Cracks	Joints	Cracks	
1				52		65	7
2	8		4	26		33	33
3	37		31	18	9		11
4	30		22	4	19		30
5	9		16		12	2	
6	6		19		19		
7	3		6		19		7
8	2				17		4
9	2				5		
10	1						
11							
12	1		2				
13							
14	1						4
15							
16							4

TABLE 5

ROAD ROUGHNESS

Joint		Roughness, 1955 (in./mi)		Roughness, 1963 (in./mi)	
Spacing (ft)	Condition	E. B'd.	W. B'd.	E. B'd.	W. B'd.
None	—	105	98	112	104
20	Open	107	109	118	118
20	Sealed	91	93	104	108
50	Open	106	102	115	119
50	Sealed	111	113	113	117
80	Open	114	112	117	120
80	Sealed	100	95	102	103

joints spaced at 20 ft, 29.3 percent have not faulted, or have faulted less than $\frac{1}{16}$ in. The corresponding figures for joints spaced at 50 and 80 ft are 23.8 and 16.5 percent. Thus it appears that the joints spaced at 20 ft have been least susceptible to faulting.

Pumping

This favorable view of 2-ft joints is somewhat distorted because most of the pumping observed throughout the project was in areas with 20-ft joint spacing. Pumping is evident at nine locations, of which seven are in 20-ft joint sections and two are in 50-ft joint sections. Pumping was first reported in 1961, approximately the time when heavy truck traffic began to increase substantially.

Width of Joint and Crack Openings

Load transmission across an undoweled joint in concrete pavement depends entirely on aggregate interlock. It has been estimated that aggregate interlock is effective across openings up to 0.037 in. wide (1). Measurements of joint openings in the experimental sections show that the percentage of joints open $\frac{3}{16}$ in. or more are as follows: 20-ft joint spacing, 92 percent; 50-ft joint spacing, 96 percent; and 80-ft joint spacing, 100 percent.

Since the joints were sawed $\frac{1}{8}$ in. wide, it appears reasonable to assume that by now aggregate interlock is effective at only a very few joints.

The measurements made in April 1964 are representative of joint and crack openings as they existed at that time. During the first few years many of the 50- and 80-ft joints were open $\frac{1}{2}$ in. or more. Some of the first cracks in the no-joint sections also opened as much as 2 in.

Joint Sealing

Approximately one-half of the joints were sealed at the time of construction; the others were left open. No maintenance was performed on the joints during the study period and consequently many of the joint seals are now in poor condition.

It is assumed that the purposes of a joint seal are to prevent the passage of surface water through the joint and to prevent the intrusion of debris between the slab ends. The value of joint sealing might be indicated by comparing the width of openings of sealed and unsealed joints. Such a comparison is given in Table 6.

The value of this comparison depends on the theory that the joint openings vary in width from time to time according to the temperature and moisture content of the concrete, and that debris between the slabs may prevent a joint from closing. Table 6 compares the sealed and unsealed joints on the basis of those open $\frac{3}{16}$ in. or less, since the initial sawed opening was $\frac{2}{16}$ in. This may be misleading in the case of joints spaced at 50 and 80 ft because these joints would tend to open wider than the 20-ft joints and also remain open wider even without being jammed with debris.

Blow-Ups

Seven blow-ups have occurred of which five were in sections without contraction joints. The other two occurred in a section with unsealed contraction joints spaced at 20 ft and a section with a spacing of 80 ft.

CONCLUSIONS

The following conclusions apply in particular to the experimental pavement discussed in this report.

1. If the purpose is simply to control the formation of transverse cracks, a joint spacing of from 19 to 37 ft may be adequate.
2. From measurements of joint openings it appears doubtful that aggregate interlock is maintained even by joints spaced at 20 ft.
3. On a percentage basis, the incident of faulting is less for the joints spaced at 20 ft than for those spaced at 40 or 80 ft. The magnitude of faulting is also least for the 20-ft joints.

TABLE 6

COMPARISON OF SEALED AND OPEN JOINTS

Spacing (ft)	Percent Open 3/16 In. or Less[a]	
	Open	Sealed
20	25	63
50	35	35
80	9	9

[a]Percent of total measured.

4. Initial sealing of the joints spaced at 20 ft may have been effective in preventing the intrusion of debris.

ACKNOWLEDGMENTS

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Annual condition surveys were conducted by the Des Moines Laboratory of the Iowa State Highway Commission.

REFERENCE

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