17-Year Report on the Owensboro-Hartford Cooperative Investigation of Joint Spacing in Concrete Pavements

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In 1940 the Kentucky Department of Highways constructed an investigational concrete pavement. This project was one of a group of six built in cooperation with the Bureau of Public Roads by the states of Minnesota, California, Kentucky, Michigan, Missouri, and Oregon to study and evaluate the performance of such pavements over a period of years.

The 6.27-mi Kentucky project was constructed in Daviess County beginning approximately 6 mi south of Owensboro on US 231 (formerly Ky. Route 71).

The present report is a 17-year performance survey which includes data obtained on the project through 1958. Subgrade, traffic, riding quality, and over-all condition data are provided.

On the whole, the pavement of uniform 7-in. cross-section had the poorest performance record of all the pavement in the project. Of the other sections, which are all of 9-7-9-in. cross-section, the pavement with alternating expansion and contraction joints every 60 ft and with 70 lb of reinforcement had the poorest performance record.

The results obtained from this project, representing specific aggregate and specific construction methods, permit the following important conclusions:

1. Expansion joints more than 400 ft apart are of little benefit and are probably detrimental.
2. Contraction joints, for best performance, should be closely spaced (20 to 30 ft apart).
3. Dowel bars for load transfer at contraction joints are of questionable value except in the case of joints that open considerably and remain open, thus being deprived of any advantage that might be gained through interfacial pressure and aggregate interlock.
4. The thickened edge pavement section is superior to that of uniform 7-in. thickness.

• IN 1940 the Kentucky Department of Highways constructed an experimental concrete pavement which was one of a group of six built in cooperation with the U.S. Bureau of Public Roads by the states of Minnesota, California, Kentucky, Michigan, Missouri, and Oregon. The purpose of these projects was to study and evaluate the performance of such pavements over a period of years with specific regard to types of joints and spacings. The Kentucky project, consisting of 6.27 mi, was constructed in Daviess County, beginning approximately 6 mi south of Owensboro on US 231 (formerly Ky. Route 71).

This report is a continuation of the 1940 joint-spacing and pavement-performance study. A complete discussion of the original scope, purpose, and early performance of this project has been given in previous reports (*1, 2, 3, 4*).

The present report is essentially a 17-year performance report, but includes some data obtained through 1958. Subgrade, traffic, riding quality, and over-all condition data are provided.

DESIGN FACTORS

The investigation pavement (20 ft wide) was constructed with the features, design and arrangement given in Table 1. It is composed of seven sections with variables prescribed in the general test program and an added section designated as "Standard," representing the design used by Kentucky at that time. The Standard Section, for the most part, was constructed over poorly drained land which has proven undesirable for experimental pavements.

The spacing of expansion joints in different sections varied from 60 ft to 5,000 ft, with contraction joint spacing of 20 ft. Two exceptions were Section 6, where the joint interval was 60 ft with alternating contraction and expansion joints, and the Standard Section, where the joint interval was 30 ft with expansion joints every 120 ft.

Expansion joints were constructed to accommodate a 1-in. width of premolded bituminous fiber filler; contraction joints were of the weakened-plane type with a premolded bituminous fiber filler.

Where dowel bars were installed for load transfer, they were preassembled in a metal support designed to hold the bars rigidly in proper spacing and alignment. Dowels were ¾-in. plain round bars 24 in. long, spaced 12 in. center to center. In sections where wire mesh reinforcing was installed, the initial pour of concrete was struck off 2 in. below grade to permit placing of the mesh.

Soil Conditions

The major part of the project lies on general upland terrain where the soils are predominantly wind-blown silt and fine sand. Underlying these materials is a shale formation which is below subgrade elevation in nearly every case. Soils throughout the project were predominantly HRB A-4 or approximately A-4-6 materials. Generally speaking, they were of a fine sand or silty texture with the clay content lower than 20 percent in all but a few cases. Tests were made on samples representing material at subgrade level regardless of cut or fill. Residual soils, having a greater percentage of finer particles, entered the subgrade from below at a few locations. This affected the plasticity relationships, which are only slightly typical of sorted and wind-blown materials. Tests of soil samples show that in the Standard Section there was a slightly greater percentage of fine sand; in the "repeat" (or R) sections there was a slight tendency toward reduction in silt and sand and an increase in finer particles.

In the determination of moisture-den-

TABLE 1
DESIGN OF EXPERIMENTAL JOINT SECTIONS

Section				Expansion Joints		Contraction Joints	
No.[1]	Length (ft)	Design (in.)	Wire Mesh Reinf.	Spacing (ft)	Load Transfer	Spacing (ft)	Load Transfer
7	1250	7-7-7	None	120	None	20	None
6	1500	9-7-9	70 lb	60[2]	Dowels	60[2]	Dowels
5	1500	9-7-9	None	120	Dowels	20	Dowels
4	1500	9-7-9	None	120	Dowels	20	None
3	2500	9-7-9	None	400	Dowels	20	None
2	3000	9-7-9	None	800	Dowels	20	None
1	5000	9-7-9	None	None	None	20	None
Std.	7000	9-7-9	44 lb	120	Dowels	30	Dowels
2R	2500	9-7-9	None	800	Dowels	20	None
3R	2500	9-7-9	None	400	Dowels	20	None
4R	1500	9-7-9	None	120	Dowels	20	None
5R	1500	9-7-9	None	120	Dowels	20	Dowels
6R	1500	9-7-9	70 lb	60[2]	Dowels	60[2]	Dowels
7R	1200	7-7-7	None	120	None	20	None

[1] R = Repeat sections; Section 1 not repeated.
[2] Alternating expansion and contraction joints.

sity relations for compaction control, the samples were divided into six different groups according to their common characteristics, and standard Proctor tests were run. Differences among the compaction curves were slight and the average density and optimum moisture content were chosen for use in construction of the subgrade. All embankments were constructed in successive 12-in. thick horizontal layers, with each layer compacted with a sheepsfoot roller.

Examination of the construction records for subgrade descriptions disclosed that in the repeat sections and the Standard Section the subgrade was frequently found to be soft and spongy. Also, that in the initial sections, 1 through 7, the subgrade was found to be consistently firm and uniform. Taking these differences into account, it appears that the performance of the repeat sections, 2R through 7R, and the Standard Section might be erratic because of varying soil conditions.

Data include performance factors and information concerning the initial sections, the Standard Section, and the repeat sections. Evaluations are made separately for the initial sections, and for the Standard and repeat sections. Where trends found by comparing initial sections are not validated by trends found in the repeat sections, variance in subgrade appears to be the cause. However, the performance of the repeat sections, with two exceptions, generally bears out the performance of the initial sections.

Physical Properties of Concrete

The constituents of the concrete used in this project were fine and coarse aggregates dredged from the Boone Bar in the Ohio River about 8 mi upstream from Owensboro, and a single brand of Type I portland cement.

The average 28-day compressive strength for 68 specimens, representing one cylinder for each 500 ft of pavement, was 4,910 psi. Maximum and minimum strengths were 6,200 and 3,890 psi, respectively, and 71 percent of the strengths were within 10 percent of the average strength. The average modulus of rupture for 42 beams was 1,000 psi at 28 days. Maximum and minimum values were 1,200 and 815 psi, respectively, with 77 percent of the strengths falling within 10 percent of the average.

The 34 core specimens, one for each 1,000 ft of pavement, varied in age from 41 to 80 days and had an average compressive strength of 4,855 psi. Maximum and minimum strengths were 6,735 and 3,245, respectively, and 47 percent of the strengths were within 10 percent of the average.

Climate

Climatological data were obtained from the U.S. Weather Bureau's special observer station ½ mi west of Owensboro in Daviess County. These data (Table 2) represent the average temperature and precipitation for each month of the year.

As is typical of Kentucky, there was frequent freezing and thawing within a normal winter. However, few severe changes in temperature occurred. Past calculations (*5*) based on air temperatures at a station in the central part of the state show that the temperature drops below freezing about 55 times in a representative year.

Mean annual precipitation for the 18-year period at Owensboro was 44.9 in. This is generally representative of the entire state.

Traffic

The average daily traffic, by number and type, for each year throughout the life of the project is given in Table 3. The traffic is moderate and has increased gradually throughout the life of the project. Average daily traffic in 1940 was 675 vehicles, in 1950 it was 1,400 vehicles, and in 1958 it had increased to 3,000 vehicles. In other words, traffic volume doubled during the first 10-year period and has more than doubled during the succeeding 8 years. The number of trucks for each of the three years has increased at a rapid rate. Trucks represent 27.5

TABLE 2

TEMPERATURE AND PRECIPITATION DATA, JULY 1940 TO JULY 1958[1]

Month	Temperature (°F)					Precipitation (in.)	
	Avg.	Avg. Max.	Abs. Max.	Avg. Min.	Abs. Min.	Avg.	Snowfall, Avg.
Dec.	37	56	72	20	−6	3.3	1.4
Jan.	35	53	76	17	−15	4.4	3.7
Feb.	38	56	73	18	−21	3.9	2.2
Winter	37	55	76	18	−21	3.9	7.3
Mar.	47	65	85	29	0	5.0	1.8
Apr.	57	77	90	38	25	4.2	0.0
May	66	84	95	48	33	3.5	0.0
Spring	57	75	95	38	0	4.2	1.8
June	75	92	107	58	42	3.8	0.0
July	78	94	106	61	44	3.2	0.0
Aug.	77	94	105	59	42	3.2	0.0
Summer	77	93	107	59	42	3.4	0.0
Sept.	68	89	104	50	32	3.2	0.0
Oct.	60	80	95	38	21	2.1	0.0
Nov.	46	66	85	26	−7	4.1	0.4
Fall	58	78	104	38	−7	3.1	0.4
Annual	57	76	107	39	−21	43.9	9.5

[1] From Special Observer Station, U.S. Weather Bureau, ½ mi west of Owensboro, Daviess County, Ky.

percent of the total traffic in the 1958 survey.

This evaluation depends in large measure on the amount and type of traffic which the pavement has withstood. Therefore, the fact that traffic has been only moderate is a prime consideration.

JOINT WIDTHS AND PAVEMENT ELEVATIONS

A representative number of joints was selected in each initial section for daily, seasonal, and permanent width measurements. Brass inserts were installed on each side of the joints selected for caliper measurements. Table 4 gives the number and type of joints measured in each section.

Also, a representative number of joints was selected in each section for periodic elevation measurements, steel points being set on each side of the joints. The first column of Table 6 gives the number of these joints. Points were also placed at some of the midpoints in order to measure warping.

TABLE 3

AVERAGE DAILY TRAFFIC

Year	ADT	Pass. Car	Light Trucks, Under 1.5 T	Med. Trucks, 1.5-5 T	Tractor-Semi Over 5 T	Buses
1940	675	511	150	0	6	8
1941	840	584	237	0	8	11
1942	649	207	413	4	8	17
1943	648	264	300	64	11	9
1944	700	290	325	63	12	10
1945	750	360	333	29	16	12
1946	1003	590	363	7	28	15
1947	1068	670	300	61	22	15
1948	1140	675	282	149	18	16
1949	1066	681	194	175	2	14
1950	1400	895	255	230	3	18
1951	1700	1233	221	181	49	16
1952	1850	1342	241	196	53	18
1953	1900	1378	247	202	55	18
1954	1950	1415	253	207	56	19
1955	2000	1451	260	212	57	20
1956	2200	1596	286	234	63	21
1957	2400	1740	311	255	69	23
1958	3000	2177	389	319	86	29

Daily Measurements

The average daily change in joint width for each section is given in Figure 1. Daily movements of the expansion joints within each section were somewhat erratic and varied greatly among the sec-

TABLE 4

NUMBER OF JOINTS SELECTED FOR WIDTH MEASUREMENTS

Section No.	Joint Width Measurements					
	Daily		Seasonal		Permanent	
	Exp.	Contr.	Exp.	Contr.	Exp.	Contr.
7	2	5	4	10	2	5
6	3	2	6	5	4	3
5	2	5	4	10	2	5
4	0[1]	0[1]	4	10	0[1]	0[1]
3	2	5	3	10	0	7
2	2	8	2	20	2	14
1	0[2]	8	0[2]	21	0[2]	7
Std.	3	6	5	24	3	6

[1] No measurement schedule.
[2] No expansion joints in section.

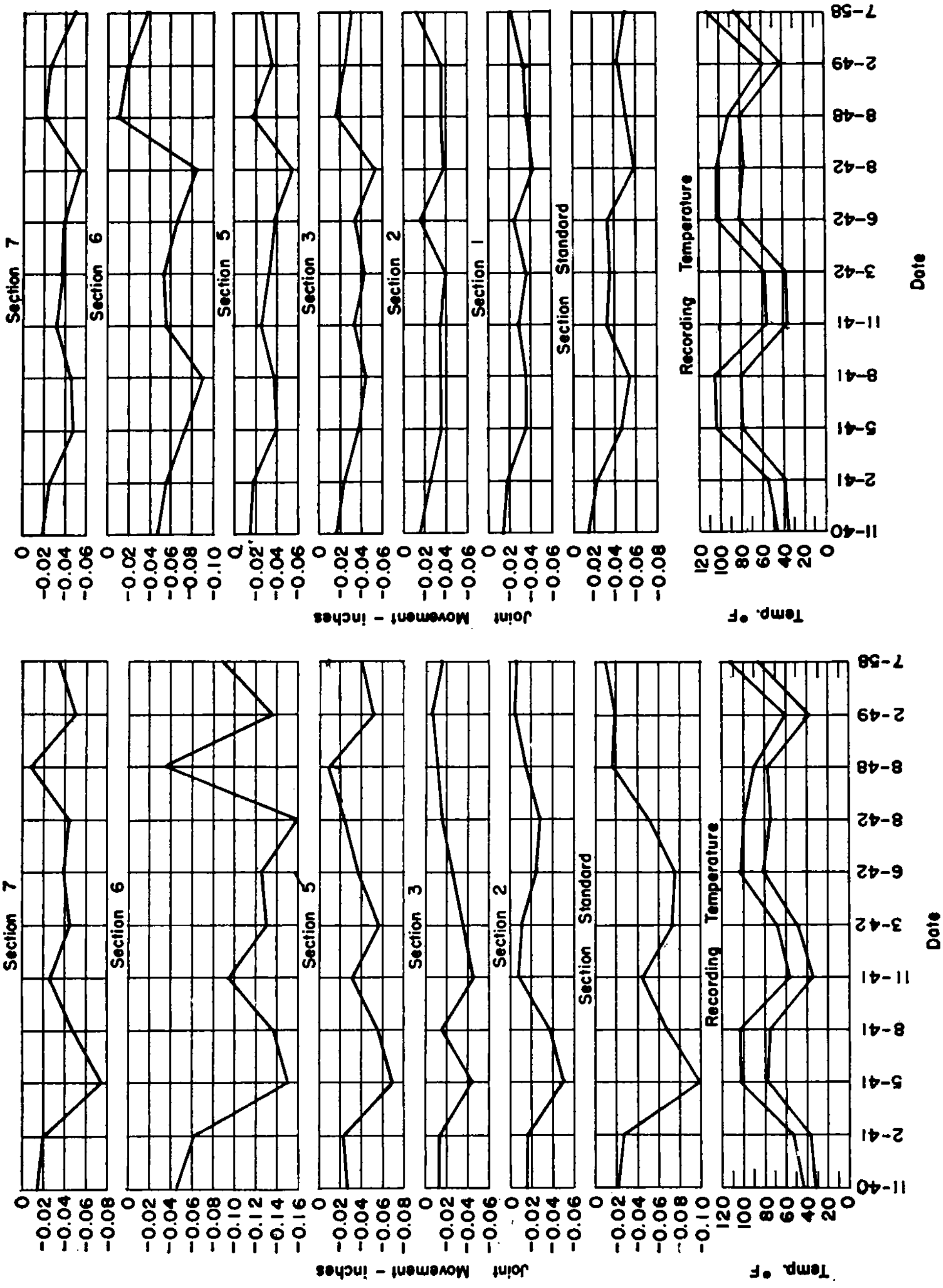

Figure 1. Average daily width change: expansion joints, left; contraction joints, right.

tions. The unit change (total closure converted to closure per 10 F temperature increase per 20 ft of pavement) in widths of the contraction joints was relatively uniform, regardless of section or date of measurement. In sections having 120-ft intervals between expansion joints, there was greater movement in expansion joints than contraction joints. However, the opposite was true where this interval was 400 ft or greater. This suggests that the sections with the longer joint interval reached a permanent set in expansion joint closure. The joints spaced at long intervals showed practically no seasonal changes, whereas the joints spaced at shorter intervals showed considerable change.

The 60-ft spacing in Section 6 and the 30-ft spacing in the Standard Section, both of which are greater than in any of the other sections, showed the least unit change in width of the contraction joints. Section 6 showed less unit change than the Standard Section. However, Section 6 had the most transverse cracks, and it is probable that much of the movement was taken up by them.

Seasonal Measurements

The average seasonal joint width change for each section is given in Figure 2. Expansion joints in Sections 2 and 3 reached a "closed set" at an early age and remained closed thereafter. Section 6 was the most variable in this respect.

Contraction joints in Sections 1 and 2 almost invariably regained their original widths at summer temperatures. The contraction joints in Section 6 showed the greatest tendency to open and remain open regardless of season. After the first year, the seasonal width change for all joints of a given type in each section has been somewhat uniform.

Permanent Measurements

The average permanent change in joint widths for each section is given in Figure 3. Section 2 showed practically no permanent change in joint widths for either expansion or contraction joints beyond the initial set. Contraction joints showed little change in Sections 1, 3, and 5. No permanent measurements were scheduled for Section 4, and those taken for Section 6 were too erratic for evaluation. Expansion joints in Section 7 and the Standard Section showed a slight increase in the amount of closure each year, whereas contraction joints in these sections have gradually opened.

Change in Elevation

Table 5 gives the percent of joints faulted within each section on specific dates. Variations in pavement elevations and the extent to which faulting has occurred are given in Table 6.

Original pavement elevations, to 0.005 ft, were established in September 1940 by means of a standard level. Subsequent elevation measurements were taken in March 1942, July 1944, August 1948, February 1949, and July 1958. Measurements and observations during this period suggest that changes in elevation of the joints do not particularly reflect or indicate structural failure of the concrete. The maximum variation in adjacent slab elevations in all the sections was 0.42 in. Generally, the variation was less than 0.24 in.

Pavement Condition

Surveys were conducted and reported twice yearly between 1940 and 1945, between 1948 and 1950, and once in 1958. Generally, service characteristics of the pavement have been considered satisfactory from the standpoint of existing traffic, and particularly so with respect to initial design expectations.

Faulting and Pumping

Faulting, although not infrequent, exists in such magnitude as to defer any particular emphasis on relative merits of design or imply definite association with particular construction features. Additionally, neither the presence of expansion joints, nor their spacing as compared with contraction joints, had any meas-

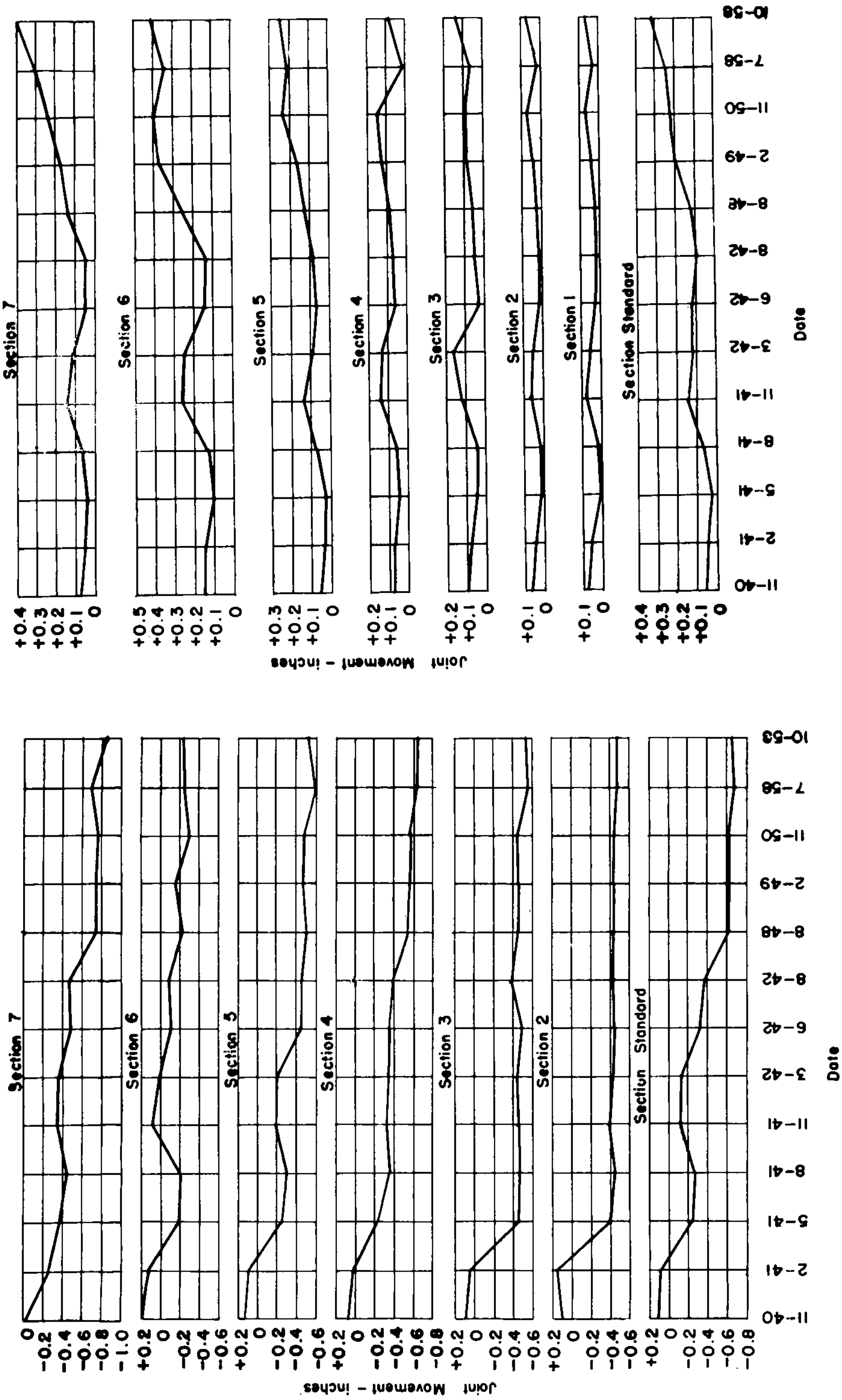

Figure 2. Average seasonal width change: expansion joints, left; contraction joints, right.

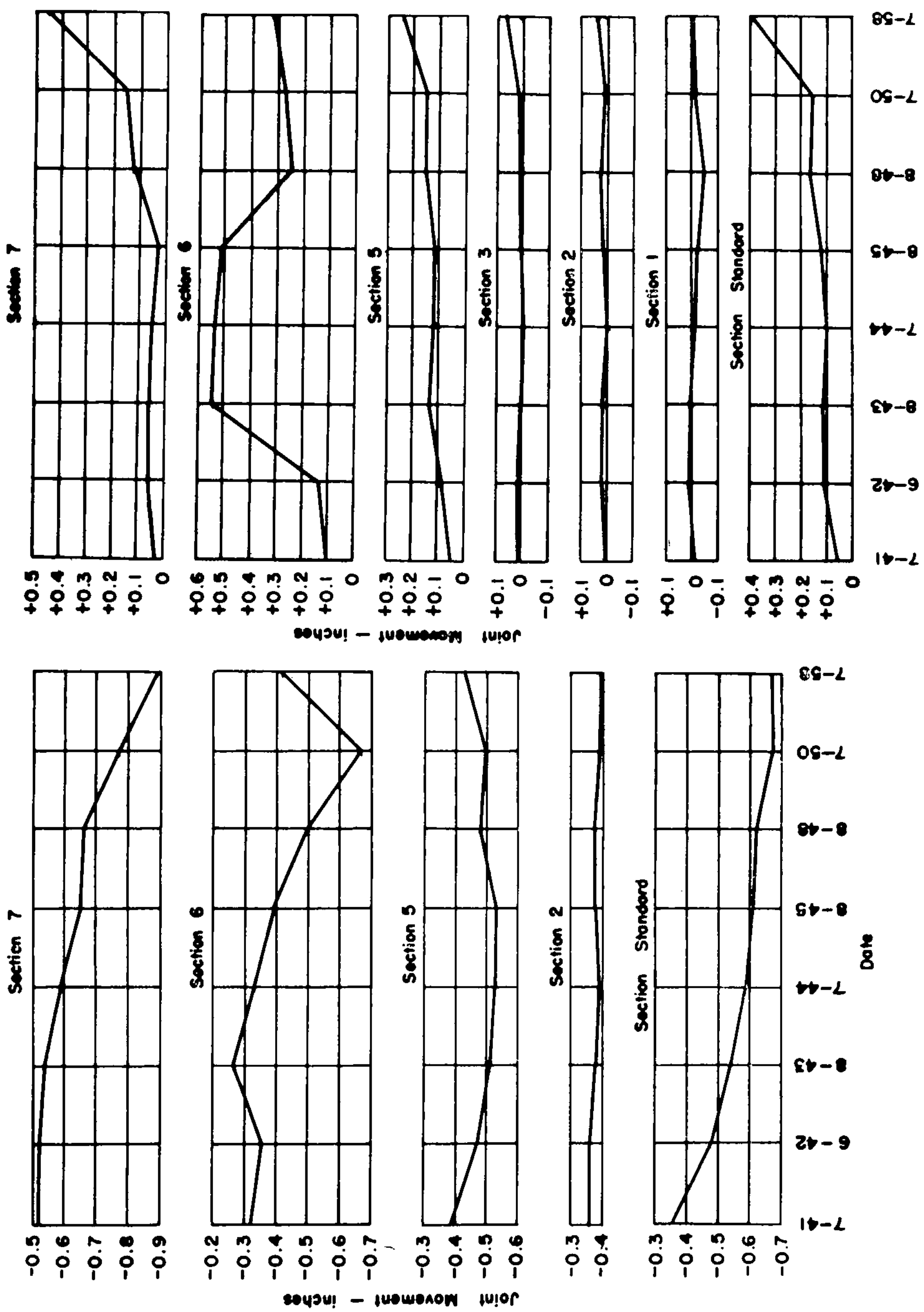

Figure 3. Average permanent width change: expansion joints, left; contraction joints, right.

TABLE 5

PERCENT OF TOTAL JOINTS FAULTING

Measurement Date	Amount of Faulting (%)						
	0 In.	0.06 In.	0.12 In.	0.18 In.	0.24 In.	0.36 In.	0.42 In.
Mar. 1942	53.10	41.09	5.81	0	0	0	0
July 1944	49.22	44.19	6.59	0	0	0	0
Aug. 1948	47.67	40.31	9.69	1.94	0.39	0	0
Feb. 1949	40.70	41.86	15.50	1.16	0.78	0	0
July 1958	22.48	41.09	25.97	5.04	4.26	0.77	0.39

urable effect on faulting or differentials in pavement elevations in adjacent slabs. Little or no significant evidence of pumping was observed to have occurred in any of the sections during the 17-year period.

Cracking, Corner Breaks, and Joint Deterioration

A summary of cracks in each section is given in Table 7. More transverse cracking has occurred in the initial test sections than in the corresponding repeat sections, whereas more longitudinal cracking has occurred in the repeat than in the initial sections. Corner breaks were somewhat equally distributed in both the initial and repeat sections except for Section 7, which showed more corner breaks than any other section, and Section 7R, which showed less than any of the other repeat sections.

TABLE 6

DIFFERENCE IN ELEVATION FROM ORIGINAL ELEVATIONS

Section No.[1]	Measurement Date	Charge in Elev. (in.)		No. Joints Faulting[2]			
		Max.	Avg.	0.12 In.	0.24 In.	0.36 In.	0.42 In.
7	Mar. 1942	0.36	0.17	1	0	0	0
(31)	July 1944	0.36	0.17	4	0	0	0
	Aug. 1948	0.66	0.33	6	0	0	0
	Feb. 1949	0.72	0.25	7	1	0	0
	July 1958	1.62	0.39	9	4	1	1
6	Mar. 1942	0.40	0.23	0	0	0	0
(11)	July 1944	0.48	0.25	0	0	0	0
	Aug. 1948	0.60	0.34	1	0	0	0
	Feb. 1949	0.72	0.29	2	1	0	0
	July 1958	0.84	0.50	3	0	0	0
5	Mar. 1942	0.48	0.27	0	0	0	0
(31)	July 1944	0.42	0.22	2	0	0	0
	Aug. 1948	1.14	0.90	3	0	0	0
	Feb. 1949	1.26	1.01	5	0	0	0
	July 1958	1.20	0.96	6	0	0	0
4	Mar. 1942	0.54	0.30	1	0	0	0
(31)	July 1944	0.84	0.23	2	0	0	0
	Aug. 1948	1.08	0.41	1	0	0	0
	Feb. 1949	0.96	0.32	3	0	0	0
	July 1958	1.08	0.19	6	0	1	0
3	Mar. 1942	0.66	0.40	5	0	0	0
(41)	July 1944	0.48	0.25	2	0	0	0
	Aug. 1948	0.90	0.46	5	0	0	0
	Feb. 1949	0.66	0.31	7	0	0	0
	July 1958	0.66	0.35	9	4	0	0
2	Mar. 1942	0.84	0.38	2	0	0	0
(41)	July 1944	0.72	0.25	4	0	0	0
	Aug. 1948	1.14	0.48	6	0	0	0
	Feb. 1949	0.66	0.16	8	0	0	0
	July 1958	1.62	0.96	15	1	0	0
1	Mar. 1942	0.90	0.53	2	0	0	0
(31)	July 1944	0.60	0.40	3	0	0	0
	Aug. 1948	0.96	0.70	0	1	0	0
	Feb. 1949	0.78	0.48	3	0	0	0
	July 1958	1.02	0.74	10	2	0	0
Std.	Mar. 1942	0.60	0.30	4	0	0	0
(41)	July 1944	0.60	0.24	0	0	0	0
	Aug. 1948	1.02	0.43	3	0	0	0
	Feb. 1949	0.78	0.32	5	0	0	0
	July 1958	0.96	0.30	9	0	0	0
Total	Mar. 1942	0.90	0.32	15	0	0	0
(258)	July 1944	0.84	0.25	17	0	0	0
	Aug. 1948	1.14	0.45	25	1	0	0
	Feb. 1949	1.26	0.39	40	2	0	0
	July 1958	1.62	0.55	67	11	2	1

[1] Number in parentheses is number of joints selected for periodic elevation measurements.
[2] 0.42 in. maximum faulting observed.

TABLE 7

CRACK SUMMARY BY TYPE PER SECTION

Section No.	Length (ft)	No. of Transverse Cracks		No. of Longitudinal Cracks		No. of Outside Corner Breaks		No. of Inside Corner Breaks		No. of Spalling Joints	
		Per Sect.	Per Mile	Per Sect.	Per Mile	Per Sect.	Per Mile	Per Sect.	Per Mile	Per Sect.	Per Mile
7	1250	25	105.5	17	71.7	11	46.4	12	50.6	11	46.5
6	1500	32	112.6	3	10.6	6	21.1	7	24.6	5	17.6
5	1500	15	52.8	5	17.6	4	14.1	2	7.0	2	7.0
4	1500	24	84.5	24	84.5	7	24.6	8	28.2	5	17.6
3	2500	4	8.4	6	12.7	4	8.4	3	6.3	5	10.6
2	3000	2	3.5	23	40.5	7	12.3	6	10.6	6	10.6
1	5000	20	21.2	19	20.1	7	7.4	5	5.3	5	5.3
Std.	7000	45	33.9	6	4.5	13	9.8	10	7.5	80	60.3
2R	2500	12	25.3	25	52.8	9	19.0	7	14.7	14	29.6
3R	2500	10	21.1	24	50.6	6	12.7	5	10.6	25	52.8
4R	1500	7	24.6	12	42.2	4	14.1	7	24.6	17	59.8
5R	1500	18	63.4	17	59.8	10	35.2	8	28.2	13	45.8
6R	1500	27	95.0	2	7.4	4	14.1	5	17.6	17	52.8
7R	1200	9	39.7	10	44.0	3	13.2	4	17.6	2	8.8

According to the soil descriptions given in this report, there may be significant differences in the subgrade on which the initial sections were constructed and the subgrade on which the repeat and Standard sections were constructed. The crack summary also points to some major variable other than the design variables. Therefore, it was necessary to evaluate the performances of the initial sections separately and look for verification of trends thus established in the repeat sections. It is believed that where there is a lack of agreement between performance factors for the initial and repeat sections, the information for the initial sections is more reliable. Also, there are more data on the initial sections available for evaluation.

Pavement Roughness

Pavement roughness measurements were made by recording the vertical accelerations imparted to a passenger in a 1957 Ford, driven at 55 mph (*6*). A CE recording oscillograph recorded the occurring phenomena on a strip chart (Fig. 4), which was analyzed to determine the over-all pavement roughness in terms of acceleration per second.

The area under the acceleration curve was measured with a compensating polar

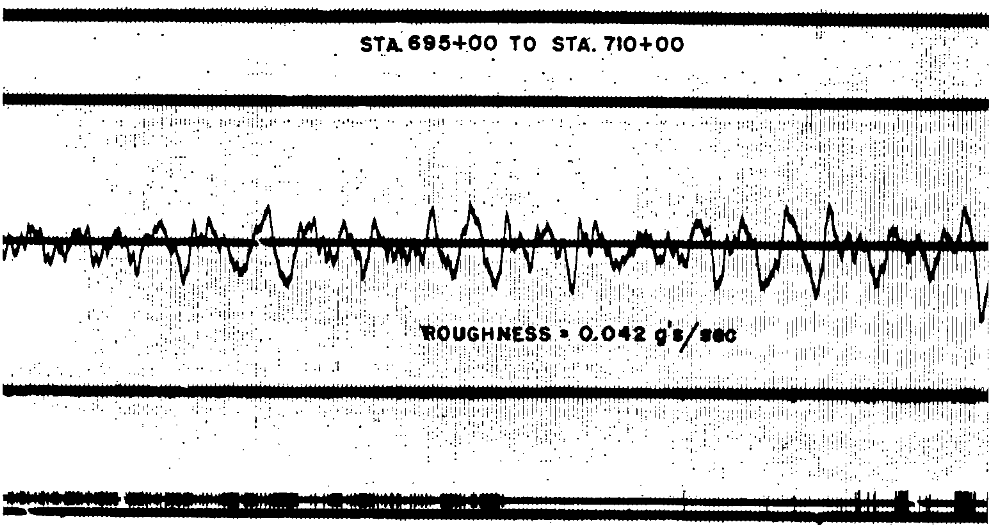

Figure 4. Road roughness chart recorded for Section 5R.

planimeter. Average acceleration was obtained by expressing the length of chart in terms of elapsed time, in seconds, and then dividing time into the area under the acceleration curve to obtain feet per second per second, or g's. The inverse of the frequency of the fluctuations divided into the average acceleration produced a mathematical parameter in terms of acceleration per second which was used as a basis for comparing sections of road. This parameter for each section is given in Table 8. The initial sections, ranked from smoothest to roughest, are: 5, 2, 6, 1, 3, Std., 7, and 4. The repeat sections, ranked from smoothest to roughest, are: 2R, 6R, 3R, 4R, 7R, and 5R. The smoother sections were generally those with dowels in the joints and those in which the expansion joints were widely spaced. Figures 5, 6, and 7 show some of the defects described.

TABLE 8

RIDING QUALITY OF TEST SECTIONS

Section	Riding Quality (g/sec)		
	North-bound	South-bound	Avg.
7	0.0317	0.0272	0.0294
6	0.0283	0.0230	0.0256
5	0.0246	0.0234	0.0240
4	0.0354	0.0275	0.0314
3	0.0285	0.0232	0.0258
2	0.0265	0.0229	0.0247
1	0.0279	0.0237	0.0258
Std.	0.0288	0.0275	0.0281
2R	0.0281	0.0300	0.0290
3R	0.0282	0.0320	0.0301
4R	0.0296	0.0338	0.0317
5R	0.0420	0.0470	0.0445
6R	0.0285	0.0308	0.0296
7R	0.0314	0.0335	0.0324

SUMMARY

The 1958 data bear out the trends noted in previously reported data (*4*). The several differences among the sections and the effect of different variables noted in 1950 are discussed.

Expansion Joints

1. With few exceptions, changes in joint widths were uniform for each type of joint within each section on each date. However, there were greater differences among the different sections, particularly

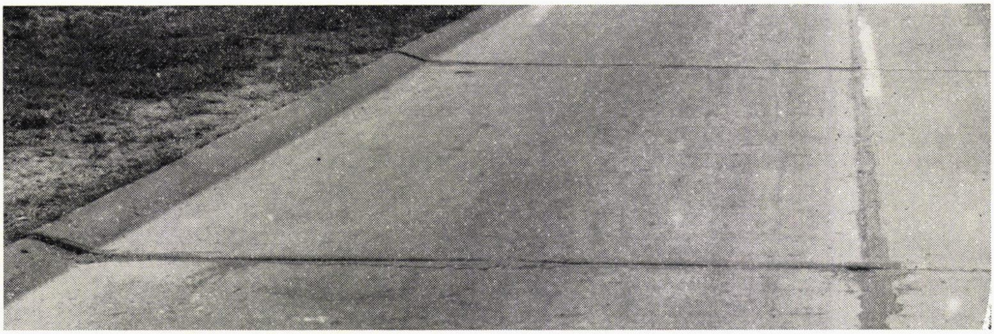

Figure 5. Faulted joints in Section 3.

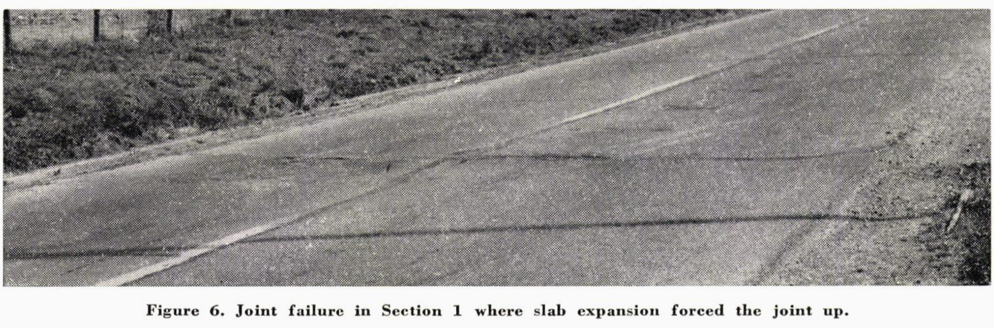

Figure 6. Joint failure in Section 1 where slab expansion forced the joint up.

for expansion joints as compared with contraction joints.

2. The expansion joints continued to close and retain an increasing amount of closed set. Only Section 5 (short slab lengths) and Section 6 (long slab lengths), both having expansion joints spaced every 120 ft, show any notable reversal of this tendency. However, closure has increased little during the past 10 years, which indicates that nearly maximum closure has been attained.

3. Expansion joint spacing has shown no appreciable effect on the tendency of these joints to assume and retain a closed set.

4. The influence of temperature on changes in width of expansion joints is greater when the spacing is relatively short (120 ft) than when it is 400 ft or greater.

5. The unit movement of expansion joints with changes in temperature has been generally greater than that of contraction joints in those sections having 120-ft intervals between expansion joints. The reverse was true where this interval is 400 ft or greater. In sections with the 120-ft spacing of the expansion joints, contraction joints opened more and tended to stay open more than in sections where the expansion joint interval was 400 ft or more.

6. In sections having longer spacings of expansion joints or having no expansion joints, there are fewer transverse cracks in slabs of equal length.

7. Expansion joint spacing, or even

Figure 7. Interior corner breaking in Section 3.

the existence of expansion joints, shows no measurable relationship to faulting or differences in slab elevations.

Contraction Joints

8. In the two sections where the contraction joint spacing was greater than 20 ft, the expansion joints show the greatest tendency to return to their original width with reduction in temperature. This was more pronounced in Section 6 than in the Standard Section.

9. The extent of opening of most contraction joints increased in approximate proportion to slab length. Joints in sections having the longest joint interval assumed and retained the largest opening, regardless of changes in temperature.

10. Pavement elevations show that the greater the slab length the greater the differences in elevation between the ends and centers of slabs. However, the average difference in elevation per foot of slab is about the same regardless of slab length. All sections had some warped slabs, but no general tendency toward warping was noted with increased age.

11. All sections had tilted slabs, but in Section 6 (60-ft slab length) there were fewer instances of tilted slabs to total number of slabs.

12. The survey has shown no definite relationship between contraction joint spacing and the development of cracks in pavement.

13. The data show no evidence that dowels resist the closure of expansion joints or the opening of contraction joints.

14. Interlock in contraction joints, where maintained, in the absence of load transfer, has tended to prevent cracks and corner breaks.

15. The sections having load transfer dowels in all joints generally have shown less faulting of the joints.

16. The high frequency of transverse cracks in Sections 6 and 6R indicates that the 70-lb mesh failed to prevent more cracking in slabs 60 ft in length than in slabs 20 ft in length, whereas the combination of 44-lb mesh and a 30-ft slab length in the Standard Section resulted in a transverse crack interval that is about the same as for sections with 20-ft slab lengths.

Pavement Section

17. Section 7, of uniform 7-in. cross-section, has shown more faulting and corner breaks than any of the other sections, and is one of the sections with the largest amount of transverse cracking. It appears that the excessive corner breaking, and perhaps the high frequency of transverse cracking, may be attributed to the lesser pavement cross-section. It also appears that the absence of load transfer devices in any of the joints contributed to the cracking and faulting.

Riding Quality

18. The whole test project is relatively smooth when compared with other pavements of similar age. Generally, the sections having load transfer devices or widely spaced expansion joints and no transfer devices in contraction joints showed better riding qualities.

General

In order better to describe the relative performance of the various sections, numerical ratings were given to the sections according to each performance factor. The initial sections, 1 through 7, have been treated as a group on the assumption that the subgrade conditions throughout these sections were uniform. Table 9 summarizes the ratings of the sections. Ratings were made according to the following factors: transverse cracks per mile, longitudinal cracks per mile, outside corner breaks per mile, inside corner breaks per mile, spalled joints per mile, road roughness indications for each section, percentage of joints faulted in each section, and the average faulted joints in each section. By assigning each section a rank according to each of these factors, sections were compared according to individual factors. By totaling these numerical ranks, a total performance rating was given to each section.

The repeat sections, 2R through 7R,

and the Standard Section have been treated as a separate group because, according to construction records, subgrade conditions during construction were not uniform within the sections or with respect to their companion sections in the first group.

On this basis (Table 9), Section 5 has the best over-all rating; and the remaining sections rated in declining order are: 1, 3, 2, 6, 4, and 7. Generally, the repeat sections bear out these performance ratings. It is obvious, however, that there is a discrepancy between the performance ratings of the initial and repeat sections. Section 5R, showing the poorest performance in the repeat group, has the best rating (Section 5) in the first group. Another discrepancy may be noted by comparing Section 7, which shows the poorest performance, with Section 7R, which shows moderate performance. With these two discrepancies in mind, the only assumption that can be made is that an extraneous factor affected performance of these companion sections more than the design variables. It appears that this factor was variation in subgrade. Section 5R, by visual examination, showed signs of poor drainage and excessive deterioration. Likewise, Section 7R shows moderate deterioration because of subgrade and drainage problems. By discounting Sections 5R and 7R, the ratings of the rest of the repeat sections generally check the ratings of the initial sections.

From the performance data in Table 9, the sections, from best to poorest, can be described as follows. The best section performance-wise is Section 5 (9-7-9 cross-section, 120-ft expansion joint spacing, 20-ft contraction joint spacing, and dowels in all the joints). Second in performance is Section 1 (also 9-7-9-in. pavement, but differs from Section 5 in that there are no expansion joints and no load transfer dowels). Next in performance is Section 3 (also 9-7-9-in. pavement with 20-ft contraction joint interval, but with 400-ft expansion joint interval and load transfer dowels only in the expansion joints). The only difference between Section 3 and Section 2, which is next in performance, is the 800-

TABLE 9

SUMMARY OF PERFORMANCE DATA AND SECTION PERFORMANCE RATINGS

Sect. No.	Cracks per Mile				Corner Breaks per Mile				Spalled Joints per Mile		Road Roughness per Sect.		Joints Faulted		Avg. Fault Displ.		Total Perf. Rating	
	Transverse		Long.		Outside		Inside											
	No.	Rank	No.	Rank	No.	Rank	No.	Rank	No.	Rank	Vol.	Rank	%	Rank	(in.)	Rank	Vol.	Rank
(a) Initial Sections																		
1	21.2	3	20.1	4	7.4	1	5.3	1	5.3	1	0.0258	4	38.7	5	0.14	3	22	2
2	3.5	1	40.5	5	12.3	3	10.6	4	10.6	3	0.0247	2	39.0	6	0.13	2	26	4
3	8.4	2	12.7	2	8.4	2	6.3	2	10.6	3	0.0258	4	31.7	4	0.16	5	24	3
4	84.5	5	84.5	7	24.6	6	28.2	6	17.6	4	0.0314	6	22.6	2	0.15	4	40	6
5	52.8	4	17.6	3	14.1	4	7.0	3	7.0	2	0.0240	1	19.4	1	0.12	1	19	1
6	112.6	7	10.6	1	21.1	5	24.6	5	17.6	4	0.0256	3	27.3	3	0.12	1	29	5
7	105.5	6	71.7	6	46.4	7	50.6	7	46.5	5	0.0294	5	48.4	7	0.19	6	49	7
(b) Standard and Repeat Sections																		
Std.	33.9	4	4.5	1	9.8	1	7.5	1	60.3	6	0.0281	1	—	—	—	—	14	1
2R	25.3	3	52.8	6	19.0	5	14.7	3	29.6	2	0.0290	2	—	—	—	—	21	3
3R	21.1	1	50.6	5	12.7	2	10.6	2	52.8	4	0.0301	4	—	—	—	—	18	2
4R	24.6	2	42.2	3	14.1	4	24.6	5	59.8	5	0.0317	5	—	—	—	—	24	5, 6
5R	63.4	6	59.8	7	35.2	6	28.2	6	45.8	3	0.0445	7	—	—	—	—	35	7
6R	95.0	7	7.4	2	14.1	4	17.6	4	52.8	4	0.0296	3	—	—	—	—	24	5, 6
7R	39.7	5	44.0	4	13.2	3	17.6	4	8.8	1	0.0324	6	—	—	—	—	23	4

ft expansion joint spacing in Section 2. Section 6, which is fifth in performance, is also a 9-7-9-in. pavement differing from the other sections in that it has a 60-ft joint spacing, expansion joints at 120-ft intervals, dowels in all joints, and 70-lb reinforcement throughout. Section 4, next to last in performance, has a 9-7-9-in. pavement section, expansion joints at 120-ft intervals, contraction joints at 20-ft intervals, and dowels only in the expansion joints. Last in performance is Section 7, which is the only 7-in. uniform pavement. It has a 120-ft expansion joint interval, a 20-ft contraction joint interval, and no load transfer dowels in any of the joints.

CONCLUSIONS

The following conclusions are based only on findings from the Owensboro-Hartford Road, which to date has not been subjected to a high enough concentration of commercial traffic to test all of the design variables in the sections.

From the foregoing performance factors, it appears that expansion joints spaced closer than 400 ft were detrimental to the performance of this pavement, and that the pavement would have performed as well or better without expansion joints. When expansion joints were spaced 400 ft or more, or excluded, it proved desirable to have contraction joints spaced 20 ft apart. Under these conditions, no excessive opening of the contraction joints was permitted and interfacial pressure and aggregate interlock appeared sufficient to transfer load.

Generally, the most satisfactory arrangement of joints in this project appeared to be the use of contraction joints at 20-ft intervals with expansion joints every 120 ft and load transfer dowels in all the joints. Another arrangement nearly as satisfactory as the foregoing was the use of contraction joints at 20-ft intervals, the elimination of expansion joints, and the elimination of load transfer dowels.

It was further apparent from the data that the sections with longer joint spacing and wire mesh reinforcement suffered more transverse cracking than the sections where joints were more closely spaced without reinforcement. Faulting of the cracks in reinforced and non-reinforced pavements was slight. Indications were that no advantage was gained from the use of wire mesh reinforcement on this project. However, it is recognized that if the test sections had been subjected to heavier traffic the faulting of the cracks in the non-reinforced sections might have been more pronounced than in the reinforced sections. Also apparent from the data was the inferiority of the 7-in. uniform thickness slab as compared to a 9-7-9-in. thickened edge slab.

REFERENCES

1. Kelley, E. F., "History and Scope of Co-operative Studies of Joint Spacing in Concrete Pavements." *HRB Proc.*, 20:333 (1940).
2. Thomas, T. R., "Investigational Concrete Pavement in Kentucky." HRB Research Report 3B, p. 28 (1945).
3. Collier, S. T., "Co-Operative Investigation of Joint Spacing in Concrete Pavements." Kentucky Dept. of Highways, Prog. Rep. No. 4, Proj. FA 125 F (2) S (July 1949) (Unpubl.).
4. Sawyer, D. H., "Report on Experimental Project in Kentucky." In "Joint Spacing in Concrete Pavements." HRB Research Report 17-B, p. 21 (1956).
5. Gregg, L. E., "Experiments with Air Entrainment in Cement Concrete," Univ. Kentucky Eng. Exp. Sta. Bull. No. 5 (Sept. 1947).
6. Gregg, L. E., and Foy, W. S., "Triaxial Acceleration Analysis Applied to Evaluation of Pavement Riding Qualities." *HRB Proc.*, 34:210 (1955).