INDICATIONS AT THE PRESENT TIME

Based on the service performance of this pavement and the experimental data secured to date, the indications at the present time are as follows:

1. Expansion joints do not appear to be necessary; in fact, their omission appears to be beneficial in preventing the development of undesirably wide openings in adjacent contraction joints.

2. Short panels, on the order of 15 ft. long, are desirable because they provide (1) a reduction in the width of individual joint openings, (2) a reduction in pavement roughness, (3) a reduction in warping stresses, and (4) a reduction in intermediate cracking.

3. The 7-in. uniform section and the 9-6-9-in. thickened-edge type, appear to be equally satisfactory so far as performance on this project is concerned

4. Load transfer dowels do not appear to be necessary in dummy-type contraction joints spaced at relatively short intervals where expansion joints are omitted. This is equally true of both types of pavement section, the thickened-edge as well as the uniform depth section.

5. There appears to be no advantage in the use of a reinforced design involving relatively long reinforced panels in comparison with a non-reinforced short panel design. Furthermore, such a design has certain physical disadvantages in service performance due to greater changes in joint openings

6 Contraction joints spaced at intervals greater than 15 ft. are very difficult to maintain in a sealed condition when the usual types of asphaltic sealing materials are used. Certain rubber-base materials are more successful, but these decrease in effectiveness as the panel length is increased.

7. Metallic water seals (copper) of several different designs have not proved effective on this project

8. The need for non-extrusive joint fillers increases as the interval between expansion joints is increased

INVESTIGATIONAL CONCRETE PAVEMENT IN MISSOURI

By F. V. Reagel, *Engineer of Materials, Missouri State Highway Department*

The Missouri project was described at the Twenty-first Annual Meeting of the Highway Research Board (1941)[1] and the proposed measurements and observations outlined. Following is a brief report covering the period from the date of construction, June 1941, through August 1944, adding some descriptive details omitted from the original report and giving a summary of the cross-joint measurements and the condition surveys.

CLIMATE

The climatic environment of this project is typical for northern Missouri Figure 1 shows the monthly average of the daily maximum and minimum temperatures for ten years from 1934 to 1943 inclusive; and also the 56-yr. average rainfall by months. It is worthy of note that there are no months of the year in which the average daily maximum temperature is below the freezing point, but there are four months when the average daily minimum temperature falls below this point. Such a condition results in a pavement being subjected to a large number of cycles of freezing and thawing

TRAFFIC

Volume of traffic on the project for the years 1941, 1942, and 1943 is shown as follows The figures were obtained by taking weighted averages of traffic counts at three stations One station was near the south end, one was near the center, and one was about three miles north of the north end of the project.

[1] F. V. Reagel, Investigational Concrete Pavement in Missouri, *Proceedings*, Highway Research Board, Vol. 21, p 150 (1941)

	Daily Weighted Average for Length of Project		
	1941	1942	1943
Cars	613	464	413
Trucks	148	141	131
Total	761	605	544

It is estimated that the traffic density indicated by this table is only about 60 per cent of normal peacetime traffic on this project.

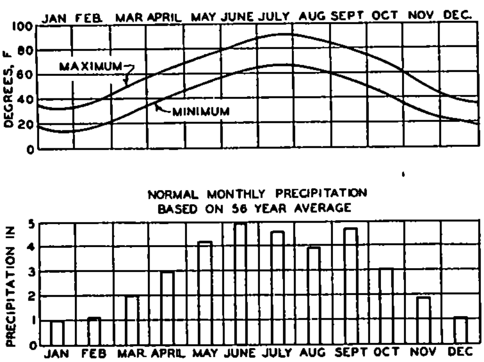

Figure 1. Daily Maximum and Minimum Air Temperatures Based on Monthly Averages for the 10-Year Period, 1934 Through 1943 Inclusive.

outline, tested in the laboratory at 28 days. The strengths in compression of many of the specimens were beyond the capacity of the testing machine. For this reason the compression tests show only that the concrete strength was greater than the values shown The flexural strength is about that which would be expected of the concrete used, and indicates that the concrete was relatively similar in all test sections. Only two sections (Nos 6 and 11 M) differ by more than 50 psi from the average for all sections.

MEASURED JOINT MOVEMENTS

As directed in the original outline, measurements were made at selected joints in each test section of the change in joint opening due to·

(1) The daily temperature cycle from minimum.
(2) The seasonal variation in temperature and moisture content of the concrete.
(3) The growth of the pavement caused by continued hydration, infiltration of foreign material into contraction joints, etc

TABLE 1
CONCRETE STRENGTH AT 28 DAYS (LB PER SQ. IN)

	Section Number										
	1	2	3	5	6	6M	7	7M	8M	10M	11M
In Flexure											
Original Sections	720	725	750	789	833	775	775	739	736	735	655
Repeat Sections		695	765	692	695		781	751	760		
In Compression											
Original Sections	5,291[a]	5,246[a]	5,408[a]	5,374[a]	5,382[a]	5,316[a]	5,398[a]	5,337[a]	5,380[a]	5,288[a]	5,004[a]
Repeat Sections		5,205[a]	5,418[a]	5,350[a]	4,906[a]		5,126[a]	5,385[a]	5,412[a]		

[a] Compressive Resistance of some specimens was beyond capacity of testing machine

CONCRETE

Concrete proportions of 1:2.1:4 15 by weight of Type 1 Cement, Missouri River Sand, and crushed limestone, with approximately 6 gal of water per sack of cement were used on the entire project The slump varied from ½ in to 1½in but most of the concrete was poured at a 1 in slump Table 1 shows the strengths of the concrete on the various test sections, as indicated by tests on specimens fabricated in the field and, subsequent to curing as directed in the P R A.

Movements were measured at joints located at different points throughout each section Study of the movements at these individual joints reveals that there is no consistent relationship

(a) in the case of contraction joints, between the magnitudes of the movement and the proximities of the contraction joints to either expansion joints or the ends of the section; and

(b) in the case of expansion joints, between the magnitudes of the movements and the locations of the joints in the section. This being the case, in the interest of brevity, only the tables and graphs of the average movements at all joints of similar type in each section are presented in this report

Even the average joint movements on supposedly similar sections are not always consistent. The inconsistencies, no doubt, were caused by various unmeasured influences which probably varied in degree of effect from section to section, and even joint to joint. Among the more obvious of these are the following:

(1) Temperature and moisture curling of the slab at the joints, and the degree of restraint offered by the joints to this action
(2) Variation in subgrade friction
(3) Variation in moisture content of the slab
(4) Variation in joint movements which took place between the time of setting of the concrete and the time of making the datum measurements at the joints.

Despite the inconsistencies certain trends in the measurements are evident.

DAILY JOINT MOVEMENTS

Average daily movements at joints are shown in Table 2

Contraction Joints. The daily movement at contraction joints in sections with 25 ft. contraction joint spacing was not appreciably influenced by reducing expansion joint spacing from somewhat over a mile to 120 ft. On the other hand, with the longer (60 ft) contraction joint spacing, the same change in expansion joint spacing resulted in a smaller movement at the contraction joints.

With constant expansion joint spacing (120 ft. to 125 ft), the contraction joints at the longer spacing (60 ft.) moved about 50 per cent more than those at the shorter 25-ft spacing.

Expansion Joints. Daily apparent movements at expansion joints were of the order of magnitude of two to three times those at

TABLE 2
DAILY AND RESIDUAL CHANGES IN JOINT OPENINGS[a]

PRA Section Number	Slab Length	Expansion Joint Spacing	Load Transfer @		Reinforcement	Pavement Cross Section	Average Daily Change in Joint Openings[b]			Residual Change in Joint Openings[c]					
			Contraction Jts	Expansion Jts			Contraction Jts	Expansion Jts	Avg Temp Change	Contraction Joints			Expansion Joints		
										Aug '42	Aug '43	Aug '44	Aug '42	Aug '43	Aug '44
	ft	ft				in									
1	25	No Exp Joints	None		None	9-7-9	23		27	+1	+12	0			
2 & 2R	25	800	None	Translode	None	9-7-9	26	44	22	+13	+14	+8	-307	-333	-337
3 & 3R	25	400	None	Translode	None	9-7-9	22	40	22	+23	+19	+13	-202[d]	NR	-276[d]
5 & 5R	25	125	Dowels	Translode	None	9-7-9	21	63	20	+14	+23	+26	-203	-229	-375
6 & 6R	60	120	Dowels	Translode	70-lb mesh	9-7-9	30	89	24	+66	+63	+72	-101	-157	-172
6M & 6MR	60	120	Dowels	Translode	43-lb mesh	9-7-9	33	92	26	+66	+85	+148	-35	-121	-103
7 & 7R	25	125	None	None	None	7-in Unif	24	77	25	+39	+56	+54	-206	-293	-316
7M & 7MR	25	125	Dowels	Translode	None	10-8-10[e]	20	67	23	+40	+41	+42	-124	-201	-235
8M & 8MR	60	No Exp Joints	Dowels		43-lb mesh	9-7-9	42		25	+25	+29	+29			
10 M	25	125	None	None	None	8-in Unif	19	71	24	+59	+82	+80	-217	-284	-299
11 M	25	125	None	None	None	9-in Unif	25	60	23	+49	+66	+61	-229	-322	-354

[a] In thousandths of an inch
[b] Each tabular figure is the average of the daily measurements made on the four days having the greatest temperature range from minimum to maximum
[c] Each tabular figure is the cumulative change in joint opening from the base measurement made in August, 1941 Plus values indicate joint opening and minus values joint closure
[d] No reading on August, 1941, so used 7-22-41 as base measurement
NR = No reading
[e] Actually 9 8-7 8-9 8

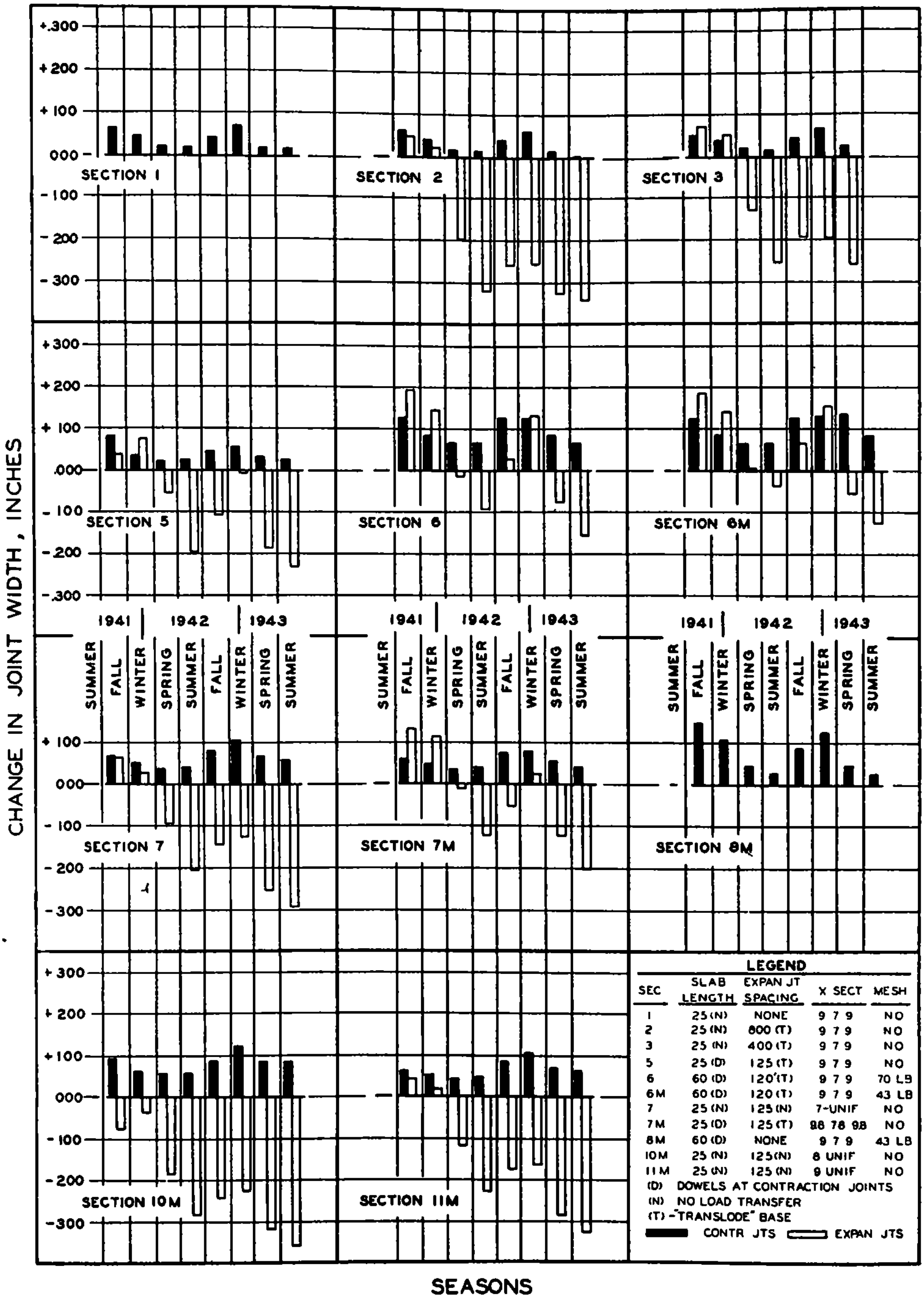

Figure 2. Seasonal Changes in Joint Openings, Datum Measurement as of August, 1941

the contraction joints in the same section The reason for this is not readily apparent. Of the possible causes considered, the only ones which are not invalidated by results of this particular investigation are. (1) that temperature warping was restrained at the contraction joints but not at the expansion joints; and (2) that during expansion of the pavement, the contraction joints were translated longitudinally and then during periods of pavement contraction, they at least partially returned to their original position by elastic rebound of the subgrade.

For the sections with contraction joint spacing of 25 ft., there was little difference in the movements at the expansion joints spaced at 800 ft and 400 ft but reduction in expansion joint spacing to 125 ft resulted in about 50 per cent greater movement at each expansion joint.

Daily movements at expansion joints were somewhat greater in sections with the longer contraction joint spacings. For the sections with 60-ft contraction joint spacing and 120-ft expansion joint spacing, the movements were about 20 per cent greater than in sections with contraction joints spaced 25 ft. and expansion joint spacing of 125 ft.

SEASONAL JOINT MOVEMENTS

In Figure 2, the seasonal changes in width (movements) of expansion and contraction joints are shown for each test section of one cycle

Contraction Joints For the contraction joints, the relative movements from one season to another are about the same regardless of spacing of either contraction or expansion joints, however, the maximum movements from summer to winter and vice versa, are greater for the contraction joints in sections having the longer contraction joint spacings (It should be noted that all the sections having longer spacings are reinforced with mesh.)

Expansion Joints For the unreinforced sections with contraction joint spacing of 25 ft., the maximum movement at the expansion joints from summer to winter and vice versa, increases somewhat with increase in expansion joint spacing, movements at joints spaced at 800 ft. being about 45 per cent greater than at joints spaced at 125 ft

Increasing contraction joint spacing from 25 to 60 ft. (and reinforcing with mesh) has little effect on the seasonal movement at expansion joints spaced at 125 ft

Apparently the load transfer devices used in most of the expansion joints did not affect the seasonal movements at the joints This is indicated by the fact that the maximum seasonal movements, at the joints of three sections from which the devices were omitted were about the same as in comparable sections containing these devices.

RESIDUAL CHANGE IN JOINT OPENINGS

Contraction Joints There is fairly definite indication that thus far there has been a

TABLE 3
TRANSVERSE CRACKS AS OF AUGUST, 1944

Section Number	Station	Description of Transverse Cracks	1st Evidence of Crack	Latest Progression
1		No Cracks		
1a		No Cracks		
1b		No Cracks		
2		No Cracks		
3	226 + 36	20-ft Crack	Apr '44	Aug '44
5	232 + 65	10-ft Crack	Apr '44	Apr '44
6	242 + 97	7-ft Crack	Apr '44	Apr '44
	256 + 37	10-ft Crack	Nov '43	Nov '43
	256 + 43	10-ft Crack	Apr '44	Apr '44
6M		No Cracks		
7	291 + 40	7-ft Crack	Aug '44	Aug '44
7M	296 + 84	17-ft. Crack	Dec '41	Dec '41
	300 + 10	20-ft Crack	Nov '43	Nov '43
8M		No Cracks		
10M		No Cracks		
11M		No Cracks		
2R	406 + 08	20-ft Crack	Feb '42	Feb '42
	406 + 15	20-ft Crack	May '42	May '42
	414 + 88	10-ft Crack	Nov '43	Nov '43
3R		No Cracks		
5R	455 + 82	10-ft Crack	Mar '42	Mar '42
	457 + 33	10-ft Crack	July '41	Aug '43
	458 + 31	20-ft Crack	July '41	Aug '43
6R	475 + 70	20-ft Crack	Aug '43	Aug '43
	481 + 14	10-ft Crack	Aug '44	Aug '44
6MR	482 + 62	18-ft Crack	Aug '43	Aug '43
7R	498 + 64	10-ft Crack	Aug '43	Aug '43
7MR	512 + 59	20-ft. Crack	Aug '43	Aug '43
8MR	533 + 11	15-ft Crack	Sept. '41	Aug '42

progressive opening of the contraction joints in the sections having expansion joints at 120 and 125 ft The residual opening is considerably greater for the longer (60-ft.) contraction joint spacings.

Three years after construction the residual opening of contraction joints spaced at 25 ft. is indicated to be greater, the closer the expansion joint spacing However, the variation in this opening, between sections having the same joint spacings (contraction joints 25 ft and expansion joints 125 ft), is greater than between the sections having the same contraction joint spacing and expansion joint spacing varying from 120 to 800 ft , which, to put it mildly, throws some doubt on the validity of this indication.

Expansion Joints. There has been a progressive closing of the expansion joints as the pavement gets older. However, the magnitudes of the closure in the joints of the various sections at any particular time, are such that the spacing of expansion joints is indicated to have little effect on the amount of closure. On the other hand spacing of contraction joints had an effect. For expansion joint spacing of 120 ft , the residual joint closure is smaller with 60-ft. than with 25-ft contraction joint spacing.

CONDITION SURVEY

As a whole the pavement is in excellent condition. To date there is no evident difference between the conditions of the various test sections. Warping of most of the slabs has been so small as to be barely measurable, with negligible effects on the pavement riding qualities The maximum warping observed on any slab at any time measurements were made was 0.28 in. Joint faulting has not yet developed to any extent. The maximum observed faulting has been 0.25 in., but the great majority of the joints of all sections show less than 0.14 in. difference in elevation between the two sides of the joints.

There are no longitudinal cracks, except short checks, nor any corner-breaks in any of the test sections. Also the transverse cracking has been so slight in amount that no trends are evident Table 3 shows the location, description, date of initial observance and date of observance of latest progression of all transverse cracks.

All joints in general are in good condition; faulting is infrequent and slight, spalling is infrequent and generally confined to the lip curbs, condition of filler is good, and no joints evidence any "pumping" action thus far.

CONCLUSION

This pavement is as yet too young and has been subjected to too little traffic to indicate the relative merits of the various designs used.

INVESTIGATIONAL CONCRETE PAVEMENT IN OREGON

By G S. Paxon, *Bridge Engineer, Oregon State Highway Department*

This is the second progress report on the experimental concrete pavement project begun in 1941 under cooperative agreement with the Public Roads Administration. This project parallels similar projects in five other states. The object and scope of the project were given in detail in Mr. Kelley's report at the 1940 annual meeting of the Highway Research Board.[1] In general the program is designed to furnish information concerning the necessity for the spacing, the arrangement, and the type of transverse joints in concrete pavements.

In the first progress report, made at the 1941 annual meeting of the Highway Research Board,[2] construction details, instrumentation, and results of the subgrade soil survey were given. For convenient reference, Table 1 from the first progress report is repeated. This table gives the designation, pavement section, and joint spacings included in the project.

This project is now four years old and sufficient data have been gathered to show several interesting trends Whether the trends shown to date will continue over the life of the pavement or will reverse themselves can be told only after further observation.

[1] E. F. Kelley, "History and Scope of Co-operative Studies of Joint Spacing in Concrete Pavements," *Proceedings*, Highway Research Board, Vol. 20, p 333.

[2] G. S. Paxson, "Investigational Concrete Pavement in Oregon," *Proceedings*, Highway Research Board, Vol 21, p 147