Analysis of Data from State Reports

EARL C. SUTHERLAND, Bureau of Public Roads

THE several experimental pavements for this investigation were constructed in 1940 and 1941. The pavements in Kentucky, Michigan and Minnesota are described in Proceedings, Highway Research Board, Vol. 20 (1940) and those in Oregon and Missouri in Vol. 21 (1941). The California pavement was described in the 5-year progress report published in 1945 with progress reports of the investigations in the other five states (1). A complete report of the study of the structural efficiency of transverse joints of the weakened-plane type made by the Bureau of Public Roads as a part of this investigation was also included in this same publication (1, 2).

A comparative analysis of the data contained in the six state, 5-year progress reports was published in 1946 (3).

Each of the pavements contained what might be called basic sections which were of essentially the same design in all of the states. Several states also incorporated in their pavements additional designs that are of interest, but do not lend themselves to comparative study. In this summary study only the data obtained from the studies of the basic sections will be included.

The spacing of the expansion and contraction joints in these pavements is shown in Table 1. It will be observed that the majority of the sections are of plain concrete and have contraction joints at intervals of 15 to 25 feet, the spacing in the different pavements being that favored by the respective states. The most important variable in this investigation is the spacing of the expansion joints and as the table shows this varies from an interval of 120 feet to no expansion joints in a mile of pavement.

Further data pertaining to the structural design of these pavements are given in Table 2 and it will be noted that in some details there are a number of differences in the designs of the pavements of the different states. For example, California used a redwood board expansion joint filler while the remainder of the states used preformed bituminous fiber and Missouri used the Translode base load transfer device while the remainder of the states used plain dowels. Also, the amount of expansion space was held constant for the various expansion joint spacings in the pavements of all of the states except Michigan. In this state the amount of expansion space was increased as the distance between the expansion joints was increased. In the more important details the designs of the pavements of the different states are, however, very similar.

In Table 3 are shown the length of the several pavements, the period of construction, the methods used in curing each and the time at which the basic set of measurements were made for determining the joint width changes. It will be noted that (1) with the exception of the California pavement and part of that in Michigan all were laid during the summer months, (2) methods used in curing the pavements varied widely, (3) the time at which the basic joint-width measurements were obtained ranged from immediately after the concrete had taken its initial set to several months after the pavement was laid.

Since the construction of these experimental pavements all of the states have made measurements and observations of the following: (1) daily and seasonal variations in temperature, (2) daily, seasonal and progressive or permanent changes in the widths of the expansion and contraction joints, (3) measurements of faulting at the joints, (4) pumping and (5) the general condition of the pavement.

After the publication of the 5-year reports the schedule of daily and seasonal joint width measurements was greatly reduced but other measurements and observations, including permanent joint width measurements, were continued.

A summary of the traffic data for the several pavements during the first 10 years of their life is shown in Table 4. It will be observed that there has been a moderate amount of heavy truck traffic on the Oregon pavement, but that the amount of truck traffic on the other pavements has been relatively light with the possible exception of the California pavement. The amount of traffic of all types is, however, increasing on all of the pavements.

TABLE 1

SPACING OF EXPANSION AND CONTRACTION JOINTS IN DIFFERENT SECTIONS OF PAVEMENTS

Section No.	Spacing of Joints		Reinforcement
	Expansion	Contraction	
	feet	feet	lb. per 100 sq. ft.
1	1 mile (approx.)	15 to 30[a]	None
2	800	15 to 30	None
3	400	15 to 30	None
4	120 to 125	15 to 30	None
5	120 to 125	15 to 30	None
6	120	120[b]	60 or 70
7	120 to 125	15 to 30	None

[a] The spacing was generally the same throughout the length of the respective projects but varied between the different states.
[b] 60-foot joint spacing.

Expansion Joints Closed Progressively

In Figure 1 is shown a comparison of the annual and progressive changes in the widths of the expansion joints in the non-reinforced sections. The annual joint-width changes are indicated by the length of the stippled bars and were computed from data obtained in the winter and summer of each year. Since the data for each annual cycle are plotted with respect to the same basic set of measurements, taken at the time indicated in Table 3, the position of the bars indicates the progressive or permanent changes in widths of the joints. It was not always possible to make measurements at the joints under extreme conditions so that the annual width changes presented are not necessarily the maximum for the yearly cycle. This same limitation also had an influence on the indicated progressive changes in width.

It will be observed that there is a general tendency for the expansion joints to close with time and that the annual change in width of the joints is as a general rule greater during the early life of the pavement than later. The annual changes in width of the joints, shown in this figure, are caused by the combined effect of the annual moisture and temperature changes of the concrete and the progressive change in width of the joint. The change in width caused by the annual moisture and temperature change of the concrete would be expected to be approximately the same each year, but the annual progressive change in width becomes smaller with time. For example, assume that a plain concrete pavement with expansion joints and closely spaced contraction joints is laid during the spring at a reasonably low temperature. As the temperature rises seasonally the pavement will expand, causing the slab units to be shifted over the subgrade toward the expansion joints which results in a progressive closure of those joints. As the temperature of the pavement drops seasonally the slab units will not be shifted

TABLE 2

DESIGN DATA ON THE EXPERIMENTAL PAVEMENT INCLUDED IN THE COMPARATIVE STUDY

State	Cross section	Expansion Joints			Contraction Joints		Reinforced section[a]	
		Width	Filler	Load transfer	Type	Load transfer	Panel length	Weight of reinforcement
	in.	in.					feet	lb. per 100 sq. ft.
Mich.	9-7-9	1[b]	Preformed bituminous fiber	Dowels	Flexplane ribbon	Dowels	60[c]	60
Minn.	9-6-9 7 unif.	1	Preformed bituminous fiber or granulated cork	Dowels except as noted[d]	Grooved, copper water seals and latex-oil mixture in majority	No dowels except as noted[e]	60	
Mo.	9-7-9 9.8-7.8-9.8	1	Preformed bituminous fiber	Translode base	Grooved, pressure injected Tarvia XC	Dowels	60	70
Ky.	9-7-9 7 unif.	1	Dowels	Dowels except as noted[d]	Bituminous fiber strip (sealed)	Dowels	60	70
Calif.	9-7-9 8 unif.	¾	Redwood strips	Dowels	Grooved, poured blended asphalt	Dowels	60	70
Ore.	9-7-9 8 unif.	¾	Preformed bituminous fiber	Dowels	Asphalt impregnated felt strip	Dowels	60	

[a] 120-ft. spacing of expansion joints.
[b] Either 1, 2, or 3 one-inch wide joints, depending on length of subsection.
[c] Divided by dummy joint with reinforcement continuous through joint.
[d] No dowels in uniform-thickness section. This section has expansion joints at 120-ft. intervals.
[e] Dowels in reinforced section and in either one or two of the sections having expansion joints at 120-ft. intervals.

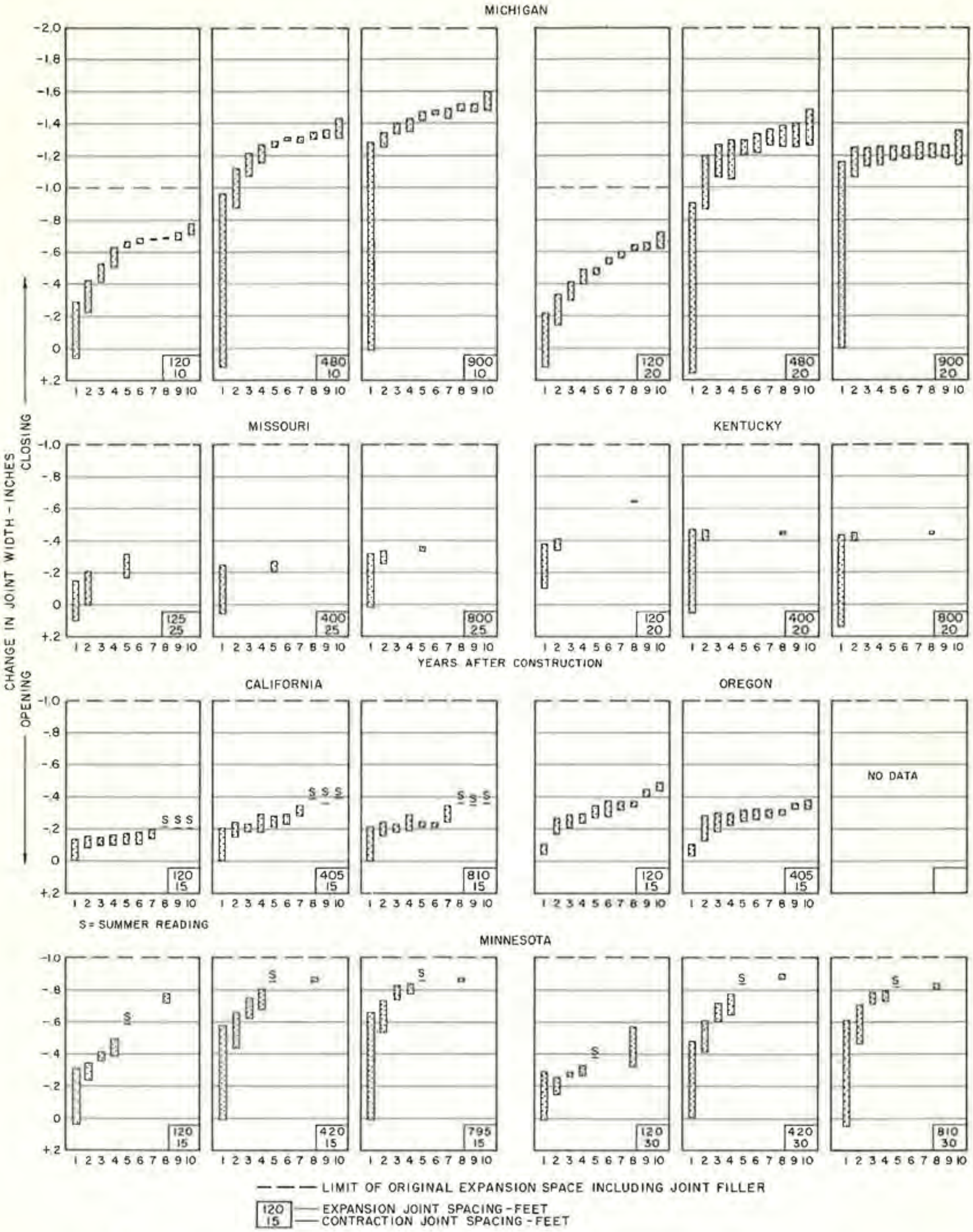

Figure 1. Annual and progressive changes in the width of expansion joints - non-reinforced sections.

over the subgrade, but will expand and contract about their own centers. After the first year there should be little or no progressive closure of the expansion joints resulting purely from temperature changes, but if foreign material infiltrates the contraction joints closure of the expansion joints will continue.

The data from the different states are in general agreement in showing that (1) there is a general tendency for the expansion joints to close with time, (2) the magnitude of

TABLE 3

CONSTRUCTION DATA ON THE EXPERIMENTAL PAVEMENTS

State	Length mi.	Time of laying concrete Year	Month	Method of curing	Time of basic measurements at joints
Michigan	10.7	1940	July 31 to Oct. 25	Burlap and straw for a total of 7 days	Immediately after completion of each section
Minnesota	8.1	1940	Aug. 6 to Sept. 20	Impermeable fiber filled paper for 72 hr.	Early in Oct. 1940
Missouri	7.0	1941	June to early Aug.	Transparent membrane sprayed on pavement	August 1941
Kentucky	6.3	1940	July 8 to Aug. 16	Burlap and Sisalkraft paper for a total of 4 days	Nov. 27, 1940
California	5.7	1941	Sept. 20 to Oct. 29	Moist earth for 8 days	Feb. 1942
Oregon	3.8	1941	June 10 to July 7	Wet cotton mats for 72 hr.	Immediately after concrete had taken initial set

the permanent closure of expansion joints appears to increase with an increase in the spacing, but the influence of spacing is small for intervals greater than approximately 400 feet and (3) the amount of closure increases with the amount of expansion space.

The magnitude of the progressive expansion joint closure varies considerably between the pavements of the different states. These differences are probably caused by a combination of several factors. For example, the amount of expansion joint closure would be expected to be greater in a pavement which took its final set at a relatively low temperature than in one which took its final set at a high temperature. Also, the amount of expansion joint closure is influenced by the resistance offered to closure by the expansion joint. In this connection the redwood expansion joint filler used in the California pavement offered more resistance to closure than the plastic fillers used in the other states. Also, it is probable that the Translode load transfer devices used in the Missouri pavement offered more resistance to closure than the plain dowels used in the other states.

Other factors which may have had some influence on the amount of expansion joint closure which developed at the expansion joints of the pavements of the different states are (1) amount of available expansion space, (2) climatic differences and (3) differences in the amount of infiltration and, therefore, opening which developed in the intermediate contraction joints.

Contraction Joints Opened Progressively

The annual and progressive changes in widths that occurred in the contraction joints of the nonreinforced sections are shown comparatively in Figure 2. These width changes are with respect to the basic set of measurements made at the time indicated in Table 3 and are averages for a number of joints in the central parts of the sections some distance from the expansion joints. The differences in the positions of the annual joint-width change bars with respect to their base line, in the different states, is explained by the fact that the basic measurements were made at different temperature conditions and at different times with respect to cracking of the weakened-plane joints.

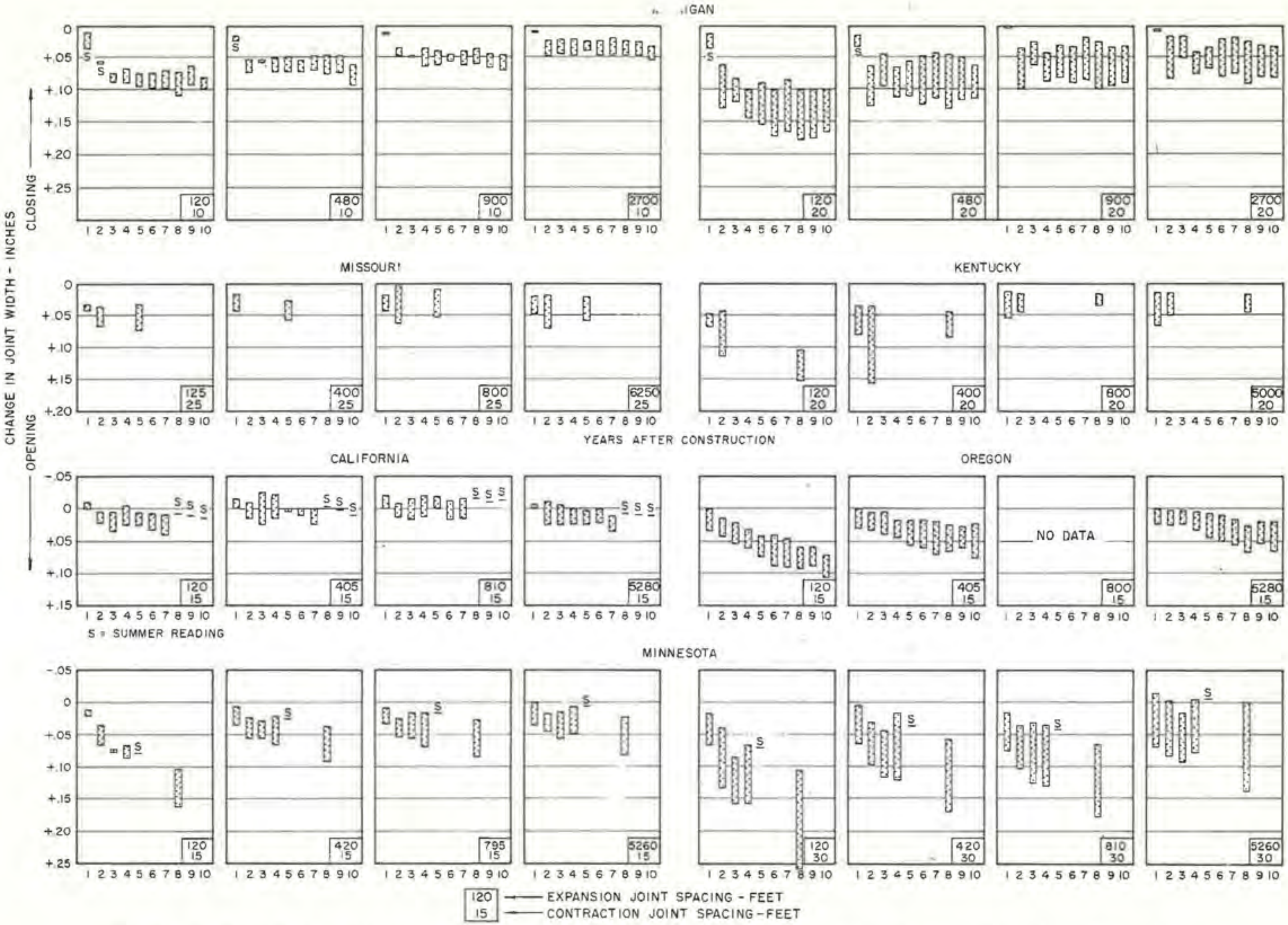

Figure 2. Annual and progressive changes in the width of contraction joints - non-reinforced sections.

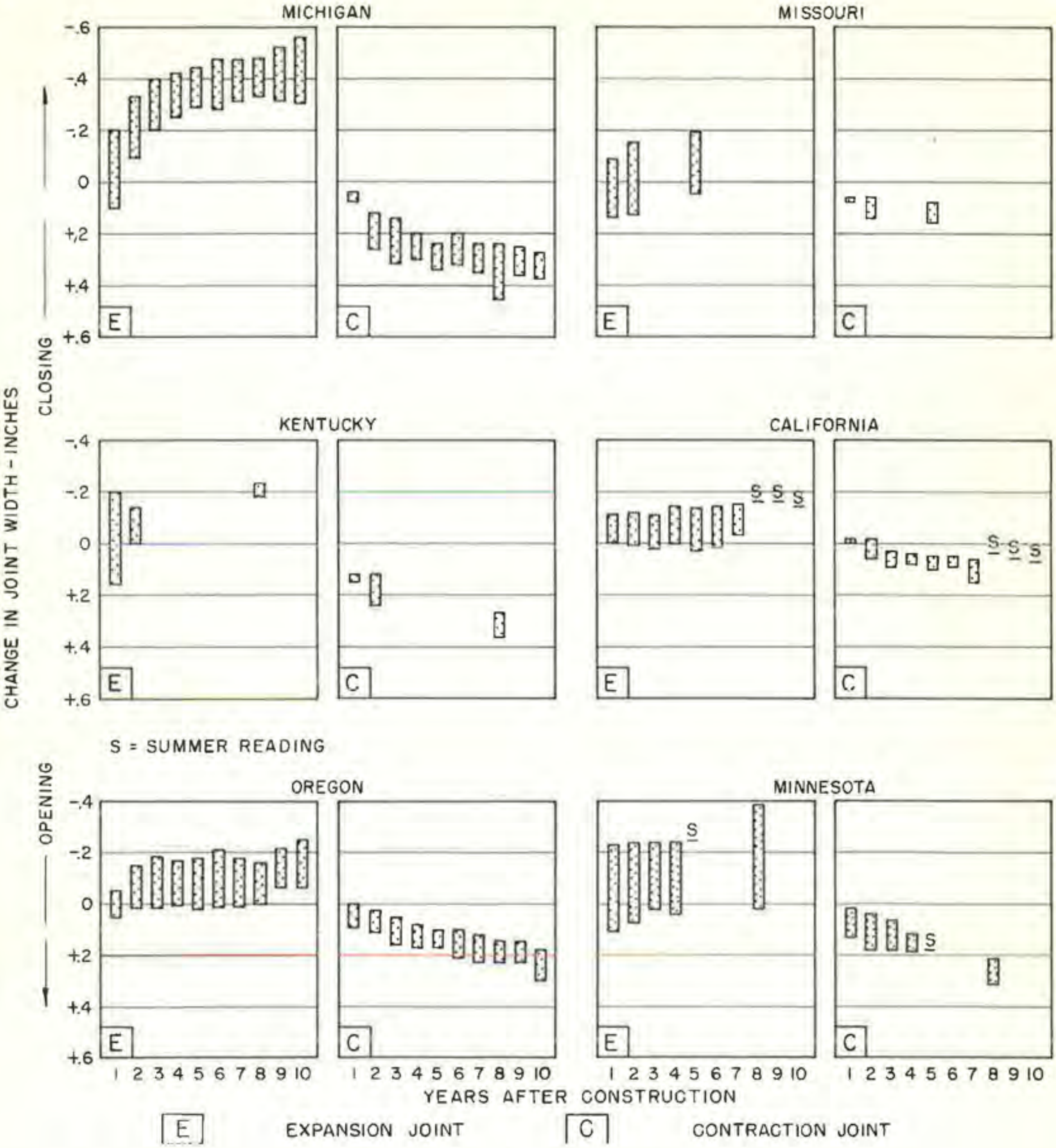

Figure 3. Annual and progressive changes in the width of expansion and contraction joints - reinforced sections.

As indicated in Table 3 the basic measurements, or those used for computing the subsequent changes in joint width, were made at the upper range in seasonal temperatures in Missouri and Oregon, at an intermediate range in Michigan and Minnesota and at a lower range in Kentucky and California.

Also the basic measurements were made immediately after the concrete had taken its initial set in the States of Michigan and Oregon and later after an undetermined number of joints had fractured in the remaining states. Thus, in the States of Michigan and Oregon the joint width changes shown are the total changes, but this is not necessarily true for the other states. At the end of the first year, the magnitude of the joint movements as related to the basic measurements indicated that practically all, if not all, of the joints had fractured.

There is a close relationship between the progressive closures which develop at the expansion joints of concrete pavements and the progressive openings which develop at the contraction joints. Actually the progressive or permanent closure of the expansion joints is essentially the accumulative progressive openings which developed at the intermediate contraction joints. Because of this interrelationship many of the factors mentioned earlier as influencing the progressive closing of the expansion joints apply equally to the progressive opening of the contraction joints.

It will be observed in Figure 2 that (1) the contraction joints opened progressively with time, the rate being greatest during the early life of the pavement, (2) the amount of progressive opening was greatest in the sections with the 120-foot expansion joint spacing, but did not increase appreciably with expansion joint spacing where the spacing was approximately 400 feet or greater and (3) the annual joint width change of the contraction joints increased with an increase in spacing of the contraction joints. (See Michigan and Minnesota data.)

The fact that the progressive changes in widths of the contraction joints varies between the different states is, as explained earlier, associated with the same factors that influenced the progressive movements at the expansion joints. These are (1) the temperature of the concrete in the different pavements at the time of initial set, (2) temperature conditions at the time that the basic measurements were made, (3) differences in the resistance offered to closure of the expansion joints by the load transfer devices and joint fillers, (4) amount of available expansion space and (5) amount of infiltration of foreign material which developed in the joints.

Movements at the Expansion and Contraction Joints of the Reinforced Sections

The annual and progressive changes in the widths of the expansion and contraction joints in the reinforced sections of the different pavements are shown in Figure 3. Excepting the Michigan pavement these sections are divided into 60-foot panels by alternate expansion and contraction joints, the steel being interrupted at the joints. The Michigan pavement differs from the others in that the 60-foot panels are divided at the center with a warping joint through which the steel is continous.

As in the plain concrete sections a progressive closing of the expansion joints and a progressive opening of the contraction joints has developed. Generally the annual changes in width of the expansion joints are greater than those of the contraction joints. Since the same type of load transfer devices were used in both expansion and contraction joints in all cases except the Missouri pavement, this behavior can hardly be attributed to differences in resistance offered by these devices. This same phenomenon was observed and studied in the Arlington investigation. It appears to be caused by a shifting of the slabs over the subgrade as the temperature of the slabs changes, causing a greater concentration of movement at the expansion than at the contraction joints. This is discussed at greater length in the report on the Arlington investigation (4).

The progressive and annual changes in widths of the joints vary among the different pavements and, except for magnitude, the variations are similar to those found in the plain concrete sections. The probable reasons for these variations have been mentioned in the discussion of the joint width changes for the plain concrete pavements.

A comparison of the maximum openings observed at the contraction joints separating the 60-foot panels of the 120-foot reinforced sections with maximum openings observed at the contraction joints separating the shorter panels of the 120-foot plain concrete sections is shown below:

State	Ratio of slab lengths [a]	Ratio of maximum contraction joint opening
Michigan	3: 1	2. 5: 1
Missouri	2. 4: 1	2. 3: 1
Kentucky	3: 1	2. 5: 1
California	4: 1	3. 8: 1
Oregon	4: 1	3: 1
Minnesota	4: 1	1. 9: 1

It is evident that while the openings of the contraction joints in the reinforced sections are larger than those in the plain concrete sections the differences are not, in all cases, proportional to the slab lengths.

Most of the daily joint width measurements were made during the first five years

[a] Ratio of slab lengths in reinforced sections (60 ft.) to slab lengths in nonreinforced sections.

TABLE 4

SUMMARY OF TRAFFIC DATA FOR THE SEVERAL PAVEMENTS

	Average daily traffic									
	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
					Michigan					
Total traffic	1,590	829	578	733	803	1,204	1,176	1,361	1,472	
Light trucks	43	44	14	32	16	4	5	29	6	
Medium trucks	26	37	56	51	27	30	28	25	32	
Heavy trucks	43	12	13	5	5	7	18	5	5	
Trailer combinations	41	68	101	62	89	46	59	64	61	
					Missouri					
Total traffic	761	605	544			943	1,052	1,052		1,330
Light trucks	68	54	48			84	93	93		118
Single unit trucks	145	115	103			180	200	200		254
Trailer combinations	19	15	14			24	26	26		33
Buses	8	6	5			9	11	11		13
					Kentucky					
Total traffic	840	649	648	700	750	1,003	1,068	1,140	1,066	1,400
Light trucks	237	413	300	325	333	363	300	282	194	255
Medium trucks	0	4	64	63	29	7	61	149	175	230
Heavy trucks and trailer combinations	8	8	11	12	16	28	22	18	2	3
Buses	11	17	9	10	12	15	15	16	14	18
					California [a]					
Total traffic	1,850	1,550	1,420	1,670	1,720	2,300	2,450	2,770	3,120	3,240
Commercial vehicles	500	510	520	640	420	560	660	730	760	830
					Oregon					
Total traffic	3,810	4,170	4,200	3,865	4,440	5,210	5,770	6,345	7,150	7,300
Light trucks	169	184	205	212	257	276	294	324	361	406
Heavy trucks	220	262	277	290	341	411	368	339	379	439
					Minnesota					
Total traffic	572			602		682		1,274		1,580
Single unit trucks	84			160		126		144		251
Heavy trucks and trailer combinations	2			11		38		45		109
Buses	2			2		3		4		5

[a] For this state the number of vehicles indicated is for 16 hours.

and are published in the 5-year reports. For a discussion of the daily joint width changes the reader is referred to the 5-year progress reports and the comparative study of these reports referred to earlier.

Only a Moderate Amount of Faulting Has Developed

As indicated earlier in the discussion of Table 4 none of these pavements has carried more than a small to moderate amount of heavy truck traffic. Thus it would not be expected that serious pumping and faulting would develop. Furthermore, the pavements of California, Michigan and Oregon were laid either on granular subgrades or subbases which would be expected to control pumping.

The faulting data reported by the states are summarized for the expansion and contraction joints in Tables 5 and 6, respectively. It is apparent from Table 5 that mechanical load transfer devices have been very helpful in controlling faulting at expansion joints even on pavements with granular subbases.

The data pertaining to faulting at the contraction joints, Table 6, are inconclusive, due apparently to the small amount of faulting which has developed thus far in the contraction joints. The States of Missouri and Minnesota, however, made special studies, the data from which are not included in the above tabulation, but which show that mechanical load transfer is helpful in reducing faulting in contraction joints of pavements with closely spaced contraction joints and with expansion joints at intervals of approximately 120 feet.

With regard to pumping, three of the states report that none was observed while the remaining three do not mention it. Apparently no significant pumping has developed in any of the pavements.

The only reason for placing expansion joints in concrete pavements is to prevent structural damage caused by high compressive forces. In each of the six experimental pavements, under discussion, there is a one-mile section with contraction joints at intervals of 15 to 25 feet and no expansion joints. Also there are two sections in each pavement with contraction joints at the same intervals and expansion at intervals of approximately 800 feet.

Five of the states report no blow-ups in the ten-year reports while one, Minnesota, reports one. Thus it is strongly indicated that expansion joints, except in special locations, can be eliminated in plain concrete pavements of sound concrete which does not develop excessive permanent growth and with contraction joints at intervals of 15 to 25 feet. In this connection four of the states drew conclusions which, in effect, state that where the aggregates are of sound character expansion joints are not required in concrete pavements except at bridge approaches, intersections, etc. The other two states drew no conclusions, feeling that on the basis of developments in their pavements up to this time conclusions were not justified.

Only a nominal amount of cracking has developed in these pavements up to this time. The amount of transverse cracking appears to bear little or no relationship to the spacing of the expansion joints, but is of course directly related to the panel length. It is indicated that a panel length exceeding approximately 20 feet is too great to control cracking in plain concrete pavements.

All of the states express the opinion that the pavements should be observed for a greater length of time before drawing any conclusions concerning the relative merits of the plain and the reinforced sections.

TABLE 5

FAULTING AT EXPANSION JOINTS WHEN PAVEMENTS WERE APPROXIMATELY 10 YEARS OF AGE

Section No.	Spacing of joints		Type of load	Joints faulted		
	Expansion	Contraction	transfer	1/8"	1/8" to 1/4"	Over 1/4"
	feet	feet		%	%	%
			Michigan			
10 A-1	120	20	Dowels	5	0	0
10 A-2	120	15	Dowels	0	0	0
10 B-1	120	20	None	33	39	0
10 B-2	120	15	None	28	34	11
			Missouri			
5-a 5 R	125	25	Translode	95	5	0
6-a 6 R	120	60	Translode	94	6	0
7-a 7 R	125	25	None	76	17	7
			Oregon		inches	
5	120	15	Dowels		.048[a]	
6	120	60	Dowels		.048	
7	120	15	None		.084	

[a] Faulting values are averages for expansion joints.

TABLE 6

FAULTING AT CONTRACTION JOINTS WHEN PAVEMENTS WERE APPROXIMATELY 10 YEARS OF AGE

Section No.	Spacing of joints		Type of load	Joints faulted		
	Expansion	Contraction	transfer	1/8"	1/8" to 1/4"	Over 1/4"
	feet	feet		%	%	%
			Missouri			
1	None	25	None	93	6	-
2	800	25	None	91	8	-
3	400	25	None	91	8	-
5	125	25	Dowels	100	0	0
6	120	60	Dowels	100	0	0
7	125	25	None	86	10	4
			Oregon		inches	
1	None	15	None		.060[a]	
3	405	15	None		.060	
4	120	15	None		.060	
5	120	15	Dowels		.048	
6	120	60	Dowels		.060	
7	120	15	None		.072	
			Kentucky		percent	
1	None	20	None	-	10	-
2	800	20	None	-	20	-
3	400	20	None	-	17	-
4	120	20	None	-	10	-
5	120	20	Dowels	-	16	-
6	120	60	Dowels	-	27	-
7	120	20	None	-	26	-
			Minnesota		percent[b]	
1	5,280	20	None		4	
2	800	20	None		4	
3	400	20	None		4	
-	120	20	None		4	

[a] Faulting values are averages for contraction joints.
[b] Percent of joints faulted without reference to magnitude of faulting.

SUMMARY

This investigation was initiated in 1940 as a cooperative effort by six states and the Bureau of Public Roads to obtain information as to the need for expansion joints in concrete pavements. The experimental pavements constructed for this investigation were widely dispersed and covered a wide range in subgrade as well as climatic conditions.

It was found that in pavements with expansion joints spaced at what was considered to be a desirable interval and intermediate contraction joints at sufficiently close intervals to control transverse cracking there was a tendency for the expansion joints to close progressively and the contraction joints to open progressively with time. These movements progress rapidly during the early life of the pavement and within a few years are of sufficient magnitude to destroy aggregate interlock in contraction joints of the weakened plane type. Where the expansion joints were eliminated or widely spaced there has been little or no tendency for the contraction joints to open progressively.

On the basis of the 5-year progress reports the practice of many of the states with respect to expansion joints has changed. Today practically every state has eliminated expansion joints in nonreinforced concrete pavements except at structures and other special locations. This has resulted in pavements which offer greater resistance to pumping and faulting because of the better maintenance of aggregate interlock in the contraction joints.

References

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