Fifteen-Year Report on Experimental Concrete Pavement Project in Oregon

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The Lombard Street-Killingsworth Street section of the Northeast Portland Secondary Highway was paved with concrete in 1941. The pavement was an experimental project in which facilities were provided for measuring changes in expansion and contraction joint openings and for comparing the performance of the joints in sections varying from 120 ft to 1 mi in length between joints. Some joints, both expansion and contraction, had load-transfer dowels and some were without dowels. Two sections of reinforced concrete were included. Measurements of joint opening were made at least twice each year for 10 years and final sets of measurements were made at midsummer and midwinter of 1956 when the pavement was 15 years old.

Each lane of the pavement has been subjected to approximately 20,000,000 vehicle loadings in its 15-yr life. The only evidence of serious deterioration is longitudinal cracking at 40 percent of the expansion joints and at 5 percent of the contraction joints. Longitudinal cracking was also more than twice as prevalent at the contraction joint adjacent to an expansion joint as at the interior contraction joints. Indications are that the wider the joint opening the greater the tendency to crack. The conclusion is reached that the cracking is probably due to the heavy loading and lack of load transfer across the joint. There is no evidence of distress due to lack of expansion room in the interior of the mile-long section and the conclusion is reached that, under conditions existing in western Oregon, expansion joints can be eliminated.

● IN 1940 AND 1941 six states, of which Oregon was one, built experimental sections of concrete pavement. Preliminary reports were made in the Highway Research Board Proceedings of 1940 and 1941.[1] Complete reports on the earlier years of service were presented at the Highway Research Board meeting in 1945 and published as Research Report No. 3-B. Again in 1950 and 1951, reports on the ten years of service were made and published as Research Report No. 17-B. The principal purpose of these experimental projects was to study the effect of expansion-joint spacing and of dowels at both expansion and contraction joints. Data were also gathered on faulting, temperature and shrinkage effects, and on cracking.

No resurfacing has been necessary on this experimental section and the points set for measuring the joint movements are still accessible. Measurements of joint movement were made in July 1956 and again in January 1957 to give a record of their action after 15 years of service.

A short review of the construction features may be of interest. The project is the Lombard Street-Killingsworth Street section of the Northeast Portland Secondary Highway which serves the industrial district of northeast Portland. The section is on a well-drained bench which slopes toward the north. The grade line is practically level and the maximum fill or cut does not exceed 5 ft. The soil in the subgrade is quite uniform and is classed as A-4. Embankment was placed in 6-in. layers and compacted by hauling equipment. Settlement was allowed during a winter before the base and pavement were placed. The base consisted of 4 in. of 3- to 0-in. bank-run gravel with a leveling course of ¾- to 0-in. crushed gravel varying in thickness from nothing up to 2 in. The concrete

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

pavement was the thickened-edge section (9, 7, 9 in.), except for two sections, each 1,200 ft in length, designated 7W and 7E, which were of 8-in. uniform thickness. The same mix proportions of 1 part cement, 1.75 parts sand, and 3.56 parts coarse aggregate as dry-rodded volume were used for the entire section. This resulted in a cement content of 1.46 bbl per cu yd. The average modulus of rupture of the concrete was 580 psi in 28 days, measured by the standard beam test (three-point loading). The concrete aggregate was from a source that has never produced concrete showing any indication of reactivity. Macadam shoulders 8 ft wide, with 8 in. of 3- to 0-in. bank-run gravel and 3 in. of crushed rock were used. These shoulders were not oiled or paved.

For convenience, Table 1, showing the details of the six sections in the project, is repeated from previous reports.

Dowels at all joints were ¾-in. plain round, 24 in. long. At expansion joints the outside dowel is 6 in. from the pavement edge and the spacing is 12 in. At contraction joints the outside dowel is 7½ in. from the pavement edge and the spacing is 15 in. All dowel bars have a "slip sleeve" at one end allowing movement of at least ¾ in. All dowel bars are painted with red lead and just before the concrete was placed the bars were coated with a petroleum oil having a viscosity rating of 50 (S.A.E.). The expansion joint dowels were held in place by metal dowel-bar holders while the concrete was being placed. Dowel bars at contraction joints were placed in the soft concrete immediately after the first passage of the strike-off screed by a device that presumably insured that they were placed as called for. All dowels were at mid-depth of the slab. The tie bars at the longitudinal joint between lanes were ½- by 36-in. square deformed bars at 3 ft-6 in. centers. A tongue-and-groove joint 2½ in. by ½ in. at mid-depth was used.

Sections 6W and 6E, the reinforced sections, were reinforced with wire mesh having No. 1 wire at 6-in. centers longitudinally and No. 1 wire at 12-in. centers transversely. The mesh was placed 2 in. below the pavement surface. The percentage of longitudinal steel is 0.12.

Figure 1 shows the average closure of the expansion joints in each section for the first 10 years (during which measurements were made semi-annually or more often) and including the 15-yr measurements. The latest measurements indicate the average annual rate of closure for the period from 10 to 15 years is approximately equal to the rate existing for the period from 2 to 10 years for all sections except Section 7W. A change in rate of closure for this section was inevitable since the original joint width of ¾-in. would have been exceeded had the former rate continued during the past five years. In July 1956, the average closure for the five expansion joints in this section was 0.660 in. and the maximum was 0.709 in. These values indicate an average remaining opening of about ³⁄₃₂ in. and a minimum of about ¹⁄₃₂ in.; however, it is likely that aggregate particles from adjacent slabs are now in contact at some joints, thereby increasing the resistance to further closure. It seems probable that within a few years the expansion joints in this section will cease to serve their intended function entirely. The situation prevailing in Section 1 will then exist; that is, all joints will act as contraction joints. In the center of the mile-long Section 1, very little, if any, relief for

TABLE 1

ARRANGEMENT OF EXPERIMENTAL SECTIONS

Section No.	Length (ft)	Thickness (in.)	Metal Reinforcement	Expansion Joints: Spacing (ft)	Expansion Joints: Load Transfer	Contraction Joints: Spacing (ft)	Contraction Joints: Load Transfer
1	5,280	9-7-9	None	At ends	Dowels	15	None
3W	2,430	9-7-9	None	405	Dowels	15	None
3E	2,430	9-7-9	None	405	Dowels	15	None
4W	1,200	9-7-9	None	120	Dowels	15	None
4E	1,200	9-7-9	None	120	Dowels	15	None
5W	1,200	9-7-9	None	120	Dowels	15	Dowels
5E	1,200	9-7-9	None	120	Dowels	15	Dowels
6W	1,200	9-7-9	Mesh	120	Dowels	60	Dowels
6E	1,200	9-7-9	Mesh	120	Dowels	60	Dowels
7W	1,200	8 uniform	None	120	None	15	None
7E	1,200	8 uniform	None	120	None	15	None

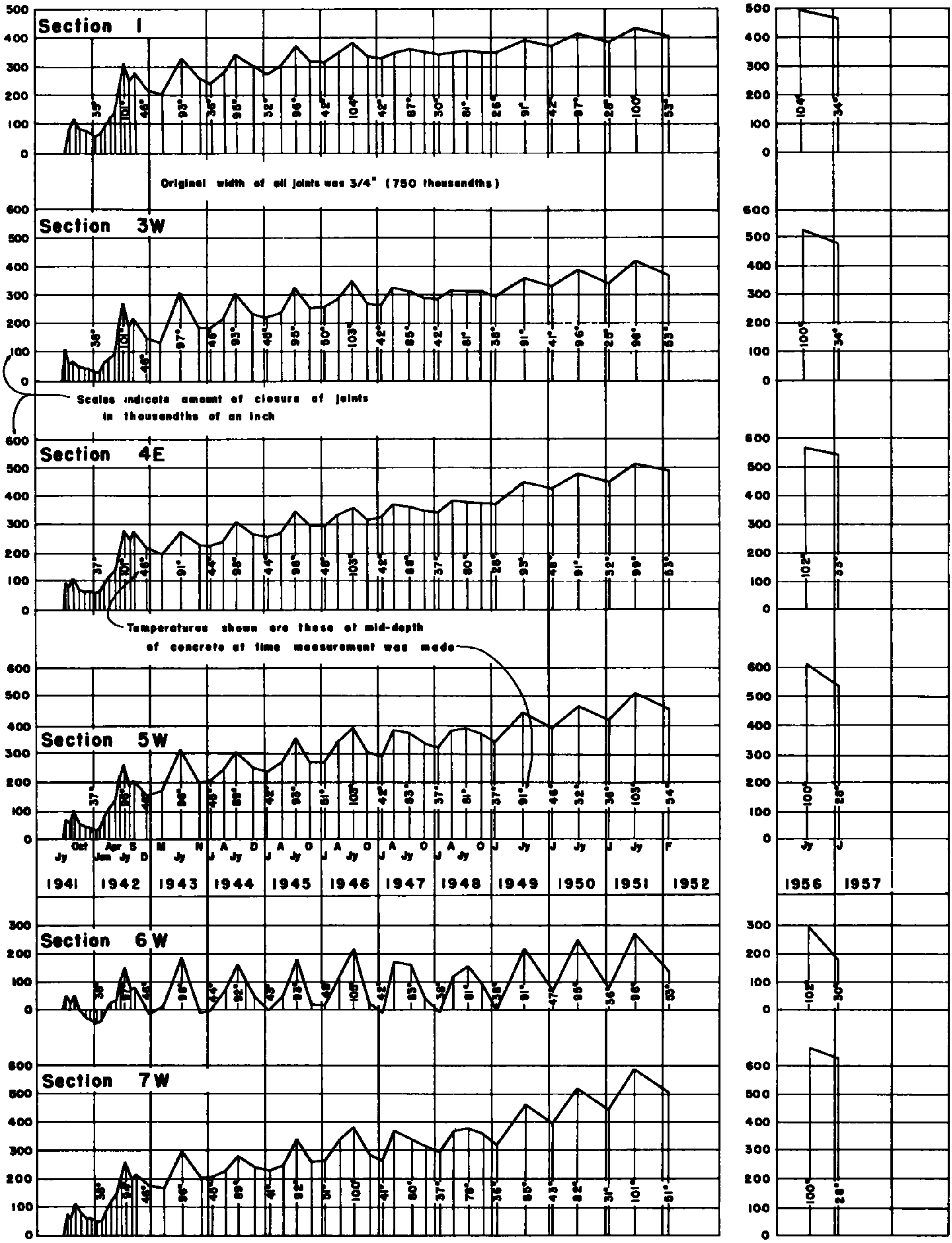

Figure 1. Closure of expansion joints.

the contraction joints will be provided by the expansion joints at each end. There is no indication of any distress in the center of this section that could be attributed to compression and it seems reasonable that no such distress should be anticipated in other sections in which the expansion joints are closer together.

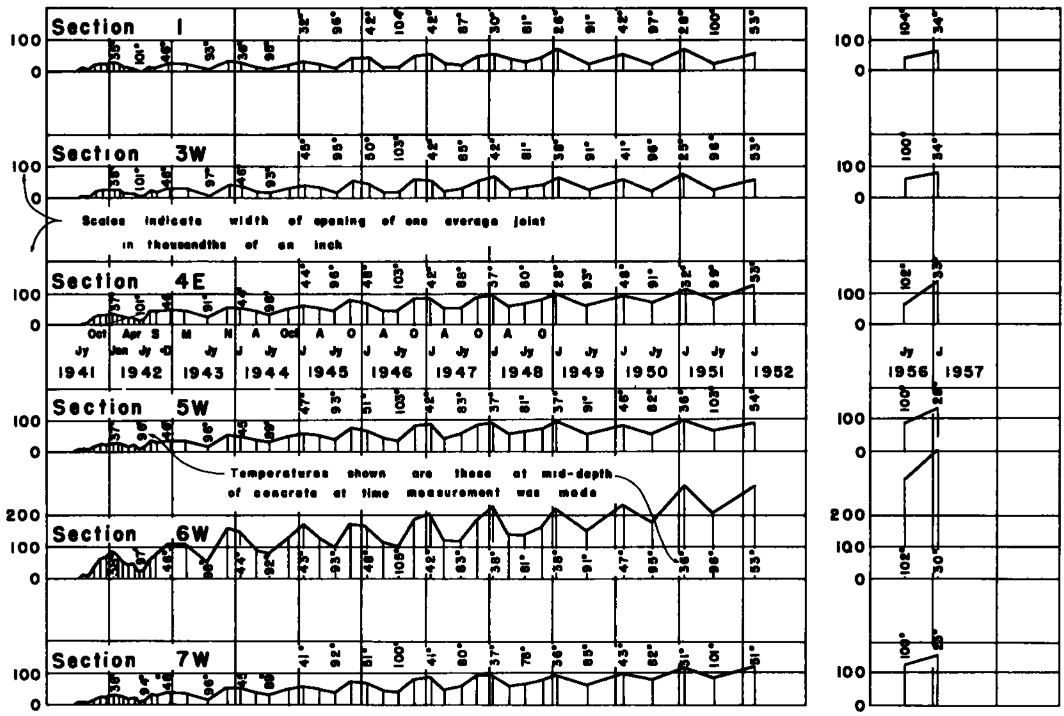

Figure 2. Opening of contraction joints.

Figure 2 shows the average opening of.contraction joints within each section at the various times measurements were made. The joints were measured during each of the first 10 years and again after 15 years of service. These joints do not show the significant change prevailing in the expansion joints; however, a comparison of July measurements for the years 1951 and 1956 shows the joints generally did not close as completely in the latter year as in the former. Although the reason for this is not known, the most plausible explanation is that incompressible particles get into the joints during cool periods, thus preventing their closure at higher temperatures. Prevention of thermal expansion naturally causes compressive stresses in the slab; however, there is little likelihood that these stresses would reach the ultimate strength of the concrete even though all expansion were prevented.

The condition of the pavement is good for one that has been heavily traveled for 15 years with little or no maintenance. However, a survey of the condition of the pavement made in February 1957 revealed numerous cracks not in existence five years ago. There are about 100 slabs having longitudinal cracks varying from short hairline cracks to those extending the full panel length and having spalled edges. Most of these cracks occur in pairs, one on each side of a joint. Usually the lateral offset between cracks at the joint varies from 0 to 1 ft. About 40 percent of these cracks meet at an expansion joint, whereas only 8 percent of the total number of joints are expansion joints.

A study of the location of these cracks with reference to the type of joint at which they occur shows trends that may shed some light on their cause. The data are shown in Table 2.

There are 104 expansion joints in the project and there is longitudinal cracking present at 40 of them. This is 38.5 percent of the total number of joints. In the two No. 7 sections, which do not have dowels at the expansion joints, 10 of the 22 joints show cracking. This is a slightly higher percentage than for the doweled joints but not enough higher to be significant. It should be noted that neither of the joints at the ends of Section 1 are cracked.

The cracking at contraction joints is shown in Table 2 in two ways. In columns 6 and 7 the total number of joints and the number of cracked slabs at the joints are shown. In columns 9 and 10 only the joints immediately adjacent to an expansion joint are shown. It should be noted that, while 5 percent of the total number of joints show cracking, 12.9 percent of the joints next to an expansion joint show cracks. There were 14 joints immediately adjacent to expansion joints on which measurement of openings were made. The average opening of these 14 joints was 0.119 in. There were 83 other contraction joints where measurements were made. The average opening of these 83 joints was 0.056 in. Only 5 percent of the joints with an average opening of 0.056 in. cracked, while 12.9 percent of the joints with an average opening of 0.119 in. cracked. The detailed data give another comparison that may be pertinent. At the contraction joint where measurements were taken, the joints with cracked slabs have an average opening of 0.098 in., while the joints with uncracked slabs have an average opening of 0.061 in.

Another interesting comparison is the percentage of cracking in Section 5 where the contraction joints have dowels with the percentage of cracking in Sections 4 and 7 where dowels were not used. The three sections are identical in length and joint spacing. In Section 5 cracked slabs occurred at 4.5 percent of the joints, in Section 4 at 10.1 percent and in Section 7 at 3.8 percent. The percentage of cracking at the doweled joints is between the two undoweled sections.

Pavement behavior is a complex thing. It would be presumptuous to say that any one thing is the cause of the cracking of the slabs. The data given above do lend support to a few tentative conclusions. The most important observation is that the wider the opening at contraction joints, the more tendency to crack. The joints next to the expansion joints are open twice as far as the average of the interior joints and the percentage of cracking is more than twice as great. About 40 percent of the expansion joints show cracking and the width of opening, even after 15 years of service, is still greater than the opening at the contraction joints. There is no definite difference in the amount of cracking at doweled and undoweled joints at either expansion or contraction joints. It has been suggested that the longitudinal cracking at the joints is due to pressure. There is no evidence of pressure such as "blow ups" or spalling at the joint edges. The wider the joint opening, the greater the tendency for the slabs to crack. All of this points toward a lack of load transfer across the joint and over-stress at the slab edge as the major cause of the cracking. It also indicates that the dowels used were of little value in transferring the load.

There are only about 20 transverse cracks in the entire 3.75 mi of the project. The presence or absence of dowels or the distance between expansion joints does not appear to be related in any way to the transverse cracking. There is no transverse cracking in Sections 6, the reinforced sections. The average weight of traffic does have a great effect. All but three of the transverse cracks are in the westbound lanes where the greater number of heavy loads are carried. Gravel trucks making deliveries from quarries near the east end of the project are loaded when using the westbound lane and

TABLE 2

LOCATION AT LONGITUDINAL CRACKS

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Section No.	Dowels at Expansion Joints	Number of Joints	Joints Cracked	Dowels at Contraction Joints	Number of Joints	Joints Cracked	Percent Cracked	Joints Adjacent to Expansion Joint	Joints Cracked	Percent Cracked
1	Yes	2	0	No	351	15	4.3	2	0	0
3W	Yes	7	3	No	161	4	2.5	12	1	8.3
3E	Yes	7	3	No	161	11	6.8	12	4	33.3
4W	Yes	11	3	No	79	8	10.1	20	6	30.0
4E	Yes	11	3	No	79	8	10.1	20	6	30.0
5W	Yes	11	9	Yes	79	6	7.6	20	1	5.0
5E	Yes	11	1	Yes	79	1	1.3	20	0	0
6W	Yes	11	5	Yes	19	0	0	20	0	0
6E	Yes	11	4	Yes	19	0	0	20	0	0
7W	No	11	5	No	79	3	3.8	20	3	15.0
7E	No	11	5	No	83	3	3.8	20	3	15.0
Total		104	40		1,189	59	5.0	186	24	12.9

empty when returning over the eastbound lane. The same is true of livestock transports making deliveries to Portland from eastern Oregon.

There was no transverse cracking in either of the reinforced sections nor was there any longitudinal cracking at any of the contraction joints even though the contraction joints are now open from 0.3 to 0.4 in. Longitudinal cracks occur at 9 of the 22 expansion joints. These expansion joints have closed from 0.2 to 0.3 in. from their original opening of 0.75 in. and are now but little wider than the contraction joints. Both types of joints have dowels. There is no apparent reason for the cracking at expansion joints and the complete absence of cracks at contraction joints. The absence of any transverse cracks indicates that the reinforcement used was adequate for 60-ft sections on the excellent base used in this project.

There has been considerable spalling at the corners of contraction joints. Most of these occurred in the first few years after the pavement was placed. The surface finish was done by a machine with an oscillating screed. This screed sometimes pulled the preformed mastic strip away from the side forms so that the concrete of the adjacent slabs was in direct contact. The pressure on this small area caused a surface spall as deep as the preformed strip and extending 6 to 8 in. along the edge of the slab.

After 15 years of service a careful inspection was made to locate and measure the amount of "faulting" or differential settlement of adjacent slabs. In one instance a fault of $^9/_{16}$ in. at the outer edge, tapering to 0 at the inner joint, was measured. This occurred in Section 5E at a doweled expansion joint. The corner of the slab is fractured on one side of the joint over a triangular area about 2 ft on a side. It is apparently due to faulty subgrade support. In no other case were faults exceeding $^1/_4$ in. detected and faults greater than $^1/_8$ in. were very infrequent. Since they were insignificant, no study was made to determine the relative amounts and numbers of faults at doweled and non-doweled joints.

An inspection of the project was made after a period of several weeks of heavy rainfall to observe the existence of any pumping action of the slabs. No pumping or rocking of the slabs under traffic was observed on the entire 3.75 mi of highway.

The average daily traffic on this section has increased steadily from a count of 3,800 in 1941 to 11,000 in 1956. Of this total of 11,000 vehicles, 870 are light trucks and 850 are heavy trucks. The daily traffic counts for the 15-yr period since the project was completed indicates each lane has been subjected to 20 million vehicle loadings. The deterioration of the pavement has been remarkably slight considering this heavy use.

SUMMARY

There has been so little damage to the pavement in this project that it is difficult to find any definite superiority of one section over another. All sections, regardless of joint spacing, load transfer devices, reinforcement, or pavement cross-section, have withstood 15 years of heavy traffic with only nominal deterioration. The only major indication of serious trouble is the occurrence of longitudinal cracks at some of the joints. Such cracking is not peculiar to this particular project as it has been observed in a number of other projects in other states. Generally it has been attributed to uneven pressure distribution at the joint caused by the infiltration of debris at the pavement edges.

The data from this project raise considerable question that the cracking should be attributed to pressure. The cracking was not apparent during the first 10 years of the pavement life. During this period the contraction joints were gradually opening and at some point the opening was sufficient so that aggregate interlock was lost. There would be no transfer of load across the joint; a free edge condition would exist. The edges of the joints would be the weakest element of the slab and, with the repeated heavy loading, cracking would result. This reasoning is supported by the large percentage of cracks at expansion joints where the openings are wider and there was no aggregate interlock.

If the assumption that load rather than pressure is the cause of cracking is accepted, it is evident that the dowels used in this project were of little value, especially at the

expansion joints where the opening is relatively wide. At the contraction joints where, in general, the opening is relatively small, no definite trend is shown by a comparison of Section 5 which has dowels with similar Sections 4 and 7 which do not have dowels.

There was almost a complete absence of faulting and pumping, undoubtedly due to the excellent subbase and base. The performance emphasizes the importance of adequate granular bases and the advisability of their use when economically available. Even with the excellent base there is indication that load transfer is needed at transverse joints. The dowels used were not adequate.

Expansion joints can be eliminated in pavements built from sound materials under climatic conditions existing in western Oregon. The opening of contraction joints in the sections with long spacing between expansion joints was less than on the shorter sections and less cracking occurred. The elimination of expansion joints should result in more economical construction and better performance in service.