Investigational Concrete Pavement in Oregon

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● THE section of pavement covered by this report is one of the six sections in six states built under cooperative agreements with the Bureau of Public Roads in 1940 and 1941. Two progress reports have previously been made.[1, 2] In these previous reports the location and details of construction were described in detail. For convenience the data are repeated here.

The Lombard Street-Killingsworth Street Section of the Northeast Portland Secondary Highway is located on a high river bench sloping slightly and evenly toward the north. The highway follows along the bench at practically a level grade with generally a light cut on the south and a low fill on the north. At only two places do the fills or cuts on center line exceed 4 feet in depth. At these two points small drainage courses are crossed with a maximum fill depth of 22 feet. The embankment was placed in 6-inch layers and compacted with hauling equipment. The grading was done in 1939 and had practically two years to settle before the pavement was placed in 1941.

The soil over the entire project is classified as A-4. It had a liquid limit of from 23 to 27 and a plasticity index of zero except for two sections where the plasticity index was 3. The soil analysis given in Table 1 is representative of the soil over the entire project.

The details of the project followed the outline specified by the Bureau of Public Roads[3] for the investigation except that their Section No. 2 was omitted. The dimensions of the sections and the type of pavement and joint treatment are given in Table 2.

The Lombard Street-Killingsworth Street Section had other advantages that influenced the selection. It is partly within the City of Portland and serves as a by-pass route for US 30 traffic from the east. It carries a relatively heavy volume of travel and the percentage of heavy trucks is greater than on most sections of highway. The average daily traffic for the ten-year period from 1941 to 1950, inclusive, is shown in Table 3.

The project was set up primarily to observe the effect of expansion joint spacing on the movements of expansion and contraction joints. The joints were built with and without loadtransfer devices with the expectation that an indication of the value of such devices might be observed.

Present Condition of the Pavement

The pavement after ten years of service is in excellent condition. This is true of all six of the test sections. The general excellence of the pavement makes it difficult, if not impossible, to compare the relative merit of the different joint and load-transfer arrangements. Except for the two crossings of minor drainage, no unequal settlement has occurred. At these two points a small amount of settlement has taken place, but without breakage of the pavement slabs. There are nine cracks in the entire length. In all cases the cracks are across one lane only and stop at the longitudinal joint. No specific cause can be assigned to any of these cracks. There seems to be no relationship between the position of the cracks and the distance between expansion joints or to the load transfer at the joints.

Photographs of one of these cracks were taken in 1943, when it was first observed, in 1945, and again in 1950. Figure No. 1 shows the development in eight years.

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

[2] G.S. Paxson, "Investigational Concrete Pavement in Oregon," Highway Research Board Report No. 3B, 1945.

[3] E.F. Kelley, "History and Scope of Cooperative Studies of Joint Spacing in Concrete Pavements," Proceedings, Highway Research Board, Vol. 20, P. 333.

TABLE 1

SOIL ANALYSIS

	%		%
F.M.E.	20	Larger than 2.0mm.	0.0
C.M.E.	9	Coarse sand, 2.0 to 0.25 mm.	9.8
L.L.	24	Fine sand, 0.25 to 0.05 mm.	36.7
P.L.	0	Silt, 0.05 to 0.005 mm.	37.4
P.I.	0	Clay, smaller than 0.005 mm.	6.1
S.L.	0	Colloids, smaller than 0.001 mm.	5.3
L.S.	0		
S.G.	2.63	Group A-4	

The spalling at the contraction joint corners has not significantly increased in the six years since the previous report was made. This spalling is certainly caused by improper placing of the elastic material in the upper part of the contraction joint. This spalling is only on the surface and does not affect the lower two thirds of the pavement slab.

Width Change of Joints

Section No. 1 is a mile in length without expansion joints, so that expansion of the concrete can only be accommodated by slab movement at the two ends of the section. Section No. 3 is 2,430 feet in length but is divided by expansion joints into six subsections, each 405 feet in length. Sections No. 4, 5, 6 and 7 are 1,200 feet in length, each divided into 10 subsections 120 feet in length. In all sections except No. 6, the reinforced section, contraction joints are at 15-foot intervals. In Section No. 6 each 120-foot subsection has a contraction joint at its mid-length dividing it into two 60-foot panels.

Measuring stations were installed at each end, at the mid-point, and at the quarter points of Section No. 1; at each end and at the mid-point of two of the subsections of Section No. 3; at each end of five of the subsections in Sections No. 4,5,6 and 7. Gauge points were placed to measure the change in width of all expansion joints in the selected subsections listed above. Gauge points were also placed at selected contraction joints in Sections No. 1 and No. 3 and at all contraction joints in two subsections of Sections No. 4, 5, and 7 and at the single contraction joint in each of the five subsections of Section No. 6.

TABLE 2

ARRANGEMENT OF EXPERIMENTAL SECTIONS

Section No.	Length	Thickness	Metal Reinforcement	Expansion Joints Spacing	Expansion Joints Load Transfer	Contraction Joints Spacing	Contraction Joints Load Transfer
	(feet)	(inches)		(feet)		(feet)	
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	0-7-9	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	1,260	8 uniform	None	120	None	15	None

The measuring stations at the section ends are not affected by pavement movement and provide means by which the total elongation of the subsections can be determined. The gross elongation of the subsections is also represented by the closure of the ex-

1943 1945 1950

Figure 1

pansion joints. In Figure No. 2 is shown the gross elongation or expansion joint closure of the six sections. An interesting feature of these graphs is the similarity of the five unreinforced sections both as to pattern and amount of closure. The expansion joints, all of which were originally 0.75 inch in width, have closed up until now after ten years of service they are practically half their original width. The closure of the joints at each end of the mile-long section is no greater than the closure at the ends of the 120-foot sections.

The rate of closure for all unreinforced sections was rapid in the first year and a half and then decreased. The closing of the expansion joints has continued during the entire ten-year period, however, and there is no indication that equilibrium will be established short of complete closure.

The reinforced section, No. 6, presents a slightly different pattern. After the first year and a half until 1949, the joint movement repeated itself with but little variation other than that due to the temperature at the particular day on which the measurement was taken. During the last two years additional joint closure has occurred. It is probable that the joints will eventually close as is indicated for the joints in the unreinforced sections.

TABLE 3

TRAFFIC DATA-LOMBARD-KILLINGSWORTH SECTION

			Daily Truck Traffic			
	Total Daily Traffic		Average		Maximum	
Year	Average	Maximum	Light	Heavy	Light	Heavy
1941	3810	6400	169	220	231	316
1942	4170	6210	184	262	263	390
1943	4200	5660	205	277	277	385
1944	3865	4830	212	290	256	357
1945	4440	5550	257	341	299	418
1946	5210	7720	276	411	358	521
1947	5770	8760	294	368	370	490
1948	6345	10780	324	339	510	510
1949	7150	12155	361	379	571	574
1950	7300	11750	406	439	510	580
10-yr.-averages of all	5226	7981	269	332	364	454

The joint closure at present is about half that of the unreinforced sections of the same length, but the seasonal variations are greater. This is to be expected because of the contraction joint arrangement. There is only one contraction joint in each subsection in the reinforced section, while there are seven such joints in the unreinforced

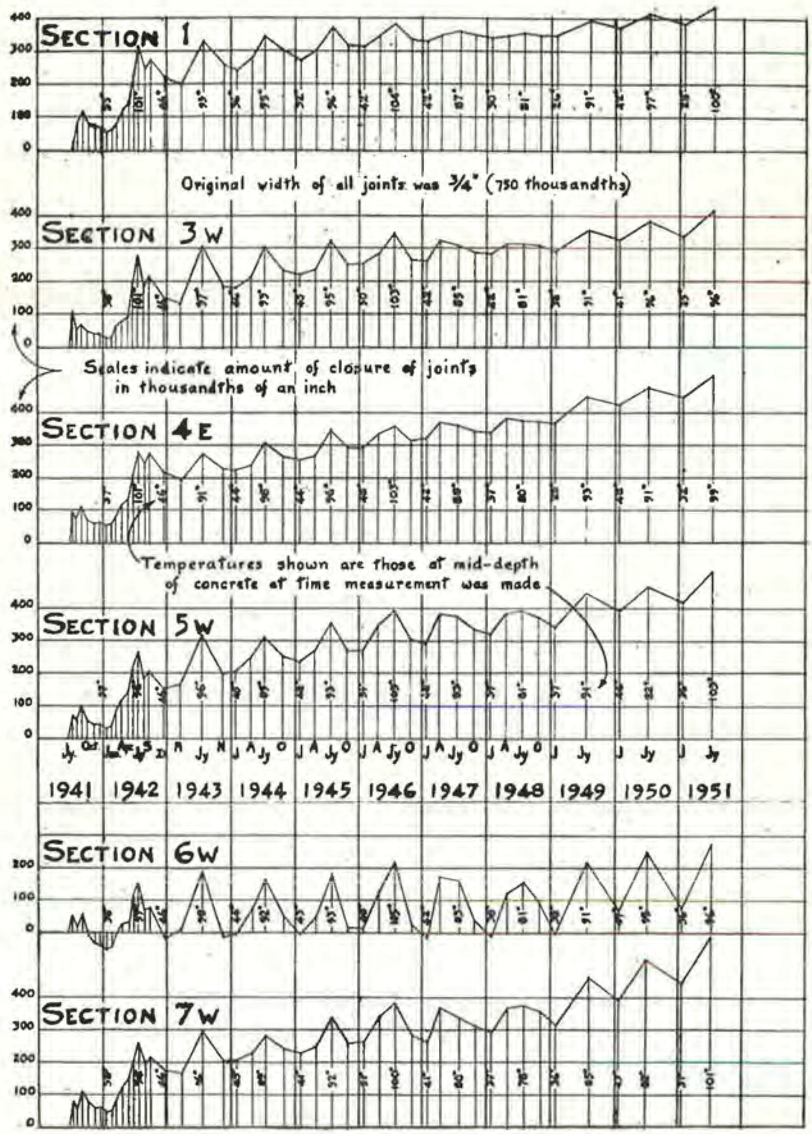

Figure 2. Lombard-Killingsworth pavement. Closure of expansion joints.

sections. Each contraction joint, by its failure to completely close during high temperatures, adds to the expansion joint closure. The seasonal movement after the first few years is principally affected by the action of the end slabs, which are 60 feet in length for the reinforced section and only 15 feet in length for the unreinforced sections.

It was expected that the subgrade drag would prevent the opening of the contraction joints in the central portion of the mile-long section. This effect has been relatively slight. Figure No. 3 shows the openings of the contraction joints in the five unreinforced test sections at the winter measurement when the joints are in their widest open position. The measurements shown are the average of the 1948 to 1950 readings. It will be noted that except for the end joints the openings of the joints in the mile-long section are approximately uniform. The opening of the joints in it, however, are much less than in the shorter sections.

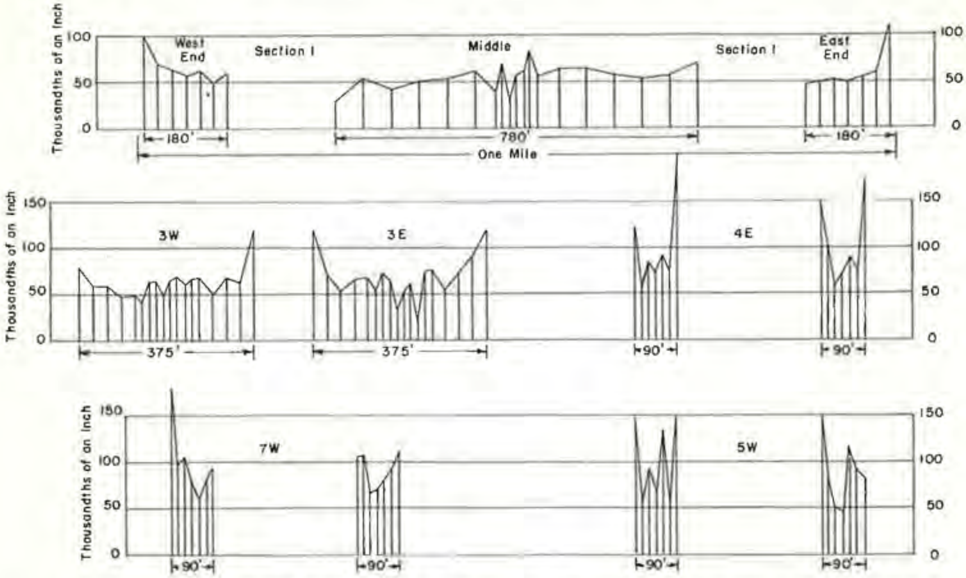

Figure 3. Lombard-Killingsworth pavement. Relative openings of contraction joints. Plotted values show the opening in thousandths of an inch of each contraction joint, as indicated by the mean of the three winter readings of 1948, 1949 and 1950, Average temperature of concrete at the times measurements were made, 37° F.

In Figure No. 4 are shown the average width of openings of the contraction joints in each of the six sections. The width of opening in the five unreinforced sections has remained practically constant since 1946. The width is less in the long sections, Sections No. 1 and No. 3, than in the 120-foot sections.

The movement at the single contraction joint at the mid-point of the 120-foot subsections of Section 6 is of considerable interest. The graph in Figure No. 4 shows the average movement of the five contraction joints measured in this section. The opening of these joints is approximately double that of the joints between the slabs of the other sections having 15-foot spacing of contraction joints. The seasonal movement between summer and winter conditions is also about double the movement between the 15-foot slabs. The joint widths are still increasing after ten years of service.

It will be noted that the openings of contraction joints during cold weather are in the range of 0.07 inch in Sections 1 and 3 and in general approach 0.10 inch in the 120-foot sections. In Section 6 with the 60-foot spacing between contraction joints the openings in the winter season are approximately 0.20, and even in summer the openings are more than 0.10. Sutherland and Cashell in their work on the "Structural Efficiency of Transverse Weakened-Plane Joints"[4] found that, "It must be concluded that aggregate interlock cannot be depended upon to give effective stress control throughout the full yearly temperature cycle in pavements with contraction joint spacings such that the joints can open an amount greater than approximately. 0.04 inch. The contraction joint measurements on this Oregon project show that even in the middle of the mile-long section the openings greatly

[4] "Structural Efficiency of Transverse Weakened-Plane Joints," Highway Research Board Report 3B, 1945.

exceed this figure. The almost complete absence of faulting and pumping and the general excellence of the pavement must be attributed to other causes than load transference across the joints, probably to the excellent base of gravel under the slabs.

It is probable that the width of contraction joint openings in the Oregon project is not typical of pavements in general. It will be noted later in this report that a slight shrinkage of the concrete has taken place rather than a growth as is usual in most concretes. Apparently the openings of the joints in the central portions of the larger sections is due to this shrinkage rather than to movement along the subgrade. It is

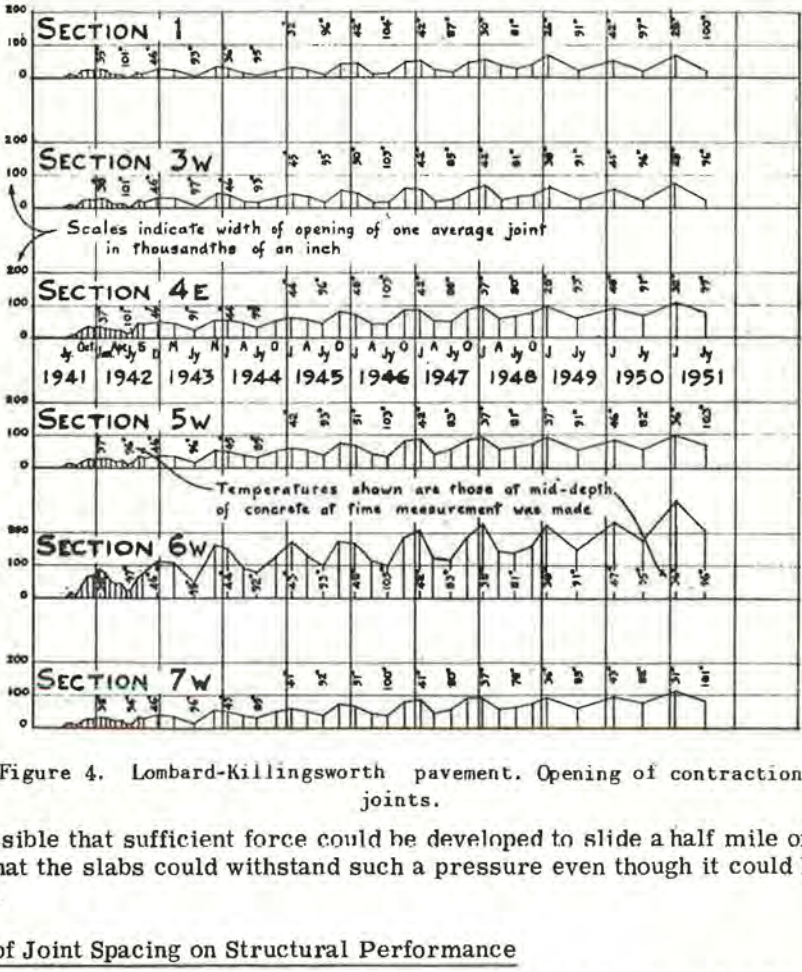

Figure 4. Lombard-Killingsworth pavement. Opening of contraction joints.

hardly possible that sufficient force could be developed to slide a half mile of pavement slab nor that the slabs could withstand such a pressure even though it could have been developed.

Influence of Joint Spacing on Structural Performance

There is no evidence that the joint spacing has had any effect on the structural performance or the riding quality of the pavement. As stated earlier, all of the sections are in such excellent condition that no significant differences can be detected. In 1941, 1944 and again in 1950, a graphic record of surface irregularity was made. These records were made on the same sections each year and as nearly as possible along the same line. A print of the three records is shown in Figure No. 6. There seems to be no significant change from 1944 to 1950. In each of these two later records the effect of the joints is more pronounced than in the 1941 record.

Faulting and Pumping

There has been no pumping on this project. Bronze pins were set in the pavement slabs on each side of a large number of expansion joints and contraction joints. The elevations of these points were determined at the time the pavement was opened to traffic and again in 1950. The greatest settlement observed at any point was 0.039 foot. The greatest differential movement between two adjacent points was 0.014 foot. This happened at three points at a contraction joint in Section No.5 where dowels were placed across the crack and at an expansion joint and a contraction joint in Section No.7 where no dowels were used. The average and maximum differential movement at all expansion and contraction joints is shown in Table 4. Neither the length of section between expansion joints nor the use of dowels seems to have had

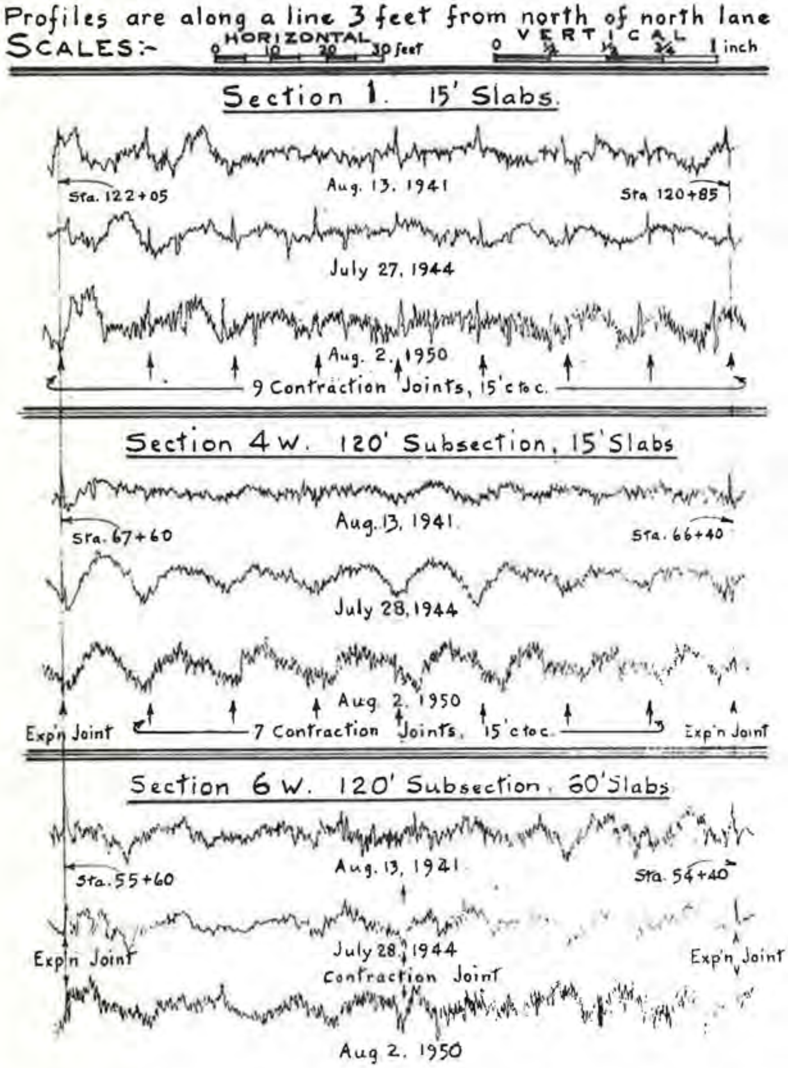

Figure 6. Lombard-Killingsworth pavement, Portland. Changes in surface irregularity at 3 and 9 years after construction.

any significant effect on the differential movement. The gravel base under the pavement probably accounts for the general excellence.

Relative Performance of Plain and Reinforced Concrete

This project did not give data that would warrant drawing conclusions as to the relative performance of the plain and reinforced sections. All sections are in approximately equal condition at the end of ten years of service. The closure of the

TABLE 4

DIFFERENTIAL MOVEMENT AT JOINTS

Section No.	Joint Type	Average	Maximum	Load Transfer
1	Contraction	0.005	0.012	No Dowels
3	Contraction	0.005	0.011	No Dowels
3	Expansion	0.003	0.005	Dowels
4	Contraction	0.005	0.010	No Dowels
4	Expansion	0.002	0.004	Dowels
5	Contraction	0.004	0.014	Dowels
5	Expansion	0.004	0.008	Dowels
6	Contraction	0.005	0.009	Dowels
6	Expansion	0.004	0.008	Dowels
7	Contraction	0.006	0.014	No Dowels
7	Expansion	0.007	0.014	No Dowels

expansion joints is less, and the opening of the contraction joints is greater in the reinforced sections than in the plain concrete sections. These differences have not appreciably affected the performance of the pavements. If any inference can be drawn it is that with a good subsoil and an adequate granular base reinforcing of concrete pavements is not necessary.

Structural Condition of Slab Corners

There have been no corner breaks, as the term is ordinarily used, in the Oregon project. In the Highway Research Report 3B, attention was called to the surface spalling at the corners due to faulty installation of the asphaltic filler in the contraction joints. This took place in the first few years of service and has not progressed further. The contraction joints were made by inserting a one-fourth inch by 2-inch strip of asphalt-impregnated felt into the upper surface of the pavement. This was

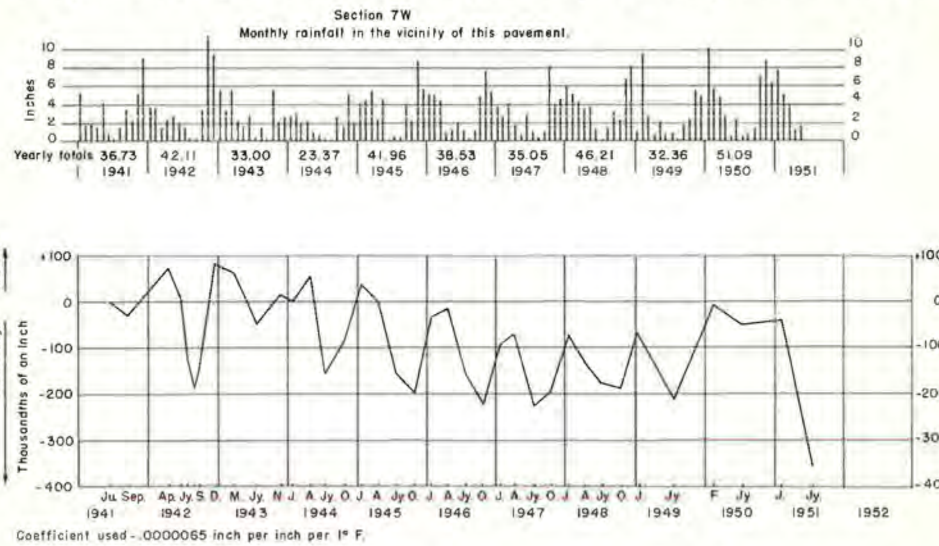

Figure 5. Lombard-Killingsworth pavement. Length changes in 120 feet corrected for a concrete temp. of 40° F.

done before the passage of the finishing machine, and in some cases the felt was pulled away from the side forms several inches leaving a small area at the edge of the pavement in direct bearing. As the slabs curled due to temperature change, these areas took the entire pressure and spalled for the depth of the felt strip. This is a surface defect and not a corner break due to load. It occurs in all sections regardless of joint spacing or load transfer devices.

Evidence of Slab Growth

There is apparently no slab growth in the sense of a swell of the concrete due to physical or chemical change in the concrete itself. There is some slight evidence that shrinkage has been taking place. The procedure used in measuring actual change in the length of concrete slabs does not allow for the separation of the length changes due to temperature, moisture content, elasticity and other external causes, from the internal changes usually classified as growth or shrinkage. Records of the gross length change in all sections have been kept. There is a remarkable similarity in the records for all sections. Figure No. 5 is the record for Section 7. The net change in length is the difference between the outward movement of the ends of the section and the contraction joint openings. In this figure the length changes have been corrected for temperature change. No correction has been attempted for other external causes. A bar graph showing rainfall is included in the figure. The change in net length follows the rainfall, being less in winter than in summer. In general the slope of the length change is down, indicating a slight tendency toward shrinkage.

SUMMARY

As an experimental project, the Lombard Street-Killingsworth Street Section has been a disappointment. The excellent quality of the soil and the adequate granular base have masked any differences in performance of the several subsections. All subsections, regardless of joint spacing, load transfer or other variables, have withstood ten years of heavy traffic without noticeable deterioration. A few conclusions can be drawn which are certainly applicable to this project and which can be extended to similar projects.

Expansion joints can be eliminated in pavements built from sound materials. There is no indication of any kind that a mile-long section without expansion joints has been injured in any way. When expansion joints are placed, they begin to close immediately after construction, and this closure has continued at a fairly even rate for ten years. It is probable that eventually expansion and contraction joints will be of approximately equal width.

All contraction joints, even in the mile-long section where restraint is a maximum, have opened enough so that aggregate interlock across the joints is not effective. With a yielding base, some load transfer device is probably advisable. In this particular project the quality of the base and subgrade is such that load transfer is apparently not necessary.

Even though the measurements show that the contraction joints cannot develop aggregate interlock, there is no indication of pumping or faulting at the joints. The traffic volume is great enough to have produced these effects if they are to occur. Their absence is undoubtedly due to the excellent subgrade and the adequate granular base. The durability of the pavement is evidence of the advisability of the use of granular bases where such use is economically feasible.

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