

FINAL REPORT ON MICHIGAN
EXPERIMENTAL TRANSVERSE JOINT PROJECT

LAST COPY
DO NOT REMOVE FROM LIBRARY



MICHIGAN DEPARTMENT OF STATE HIGHWAYS

FINAL REPORT ON MICHIGAN
EXPERIMENTAL TRANSVERSE JOINT PROJECT

J. E. Simonsen

Research Laboratory Division
Office of Testing and Research
Research Project 60 F-58
Research Report No. R-634

State of Michigan
Department of State Highways
Lansing, September 1967

INFORMATION RETRIEVAL DATA

REFERENCE: Simonsen, J. E. Final Report on Michigan's Experimental Transverse Joint Project. Michigan Department of State Highways Research Report No. R-634. August 1967. Research Project 60 F-58.

ABSTRACT: An experimental pavement, constructed in 1962, incorporated five shapes of joint seal grooves (1- by 1-in., 3/4- by 3/4-in., 1/2- by 1/2-in., 3/8- by 1/2-in. and 1/2- by 2-in.), four joint groove construction methods (sawed with and without filler, and temporary styrofoam and bituminous fillers), and three different pavement slab lengths (99, 71, and 57 ft). The project failed to reveal which combination of groove size and joint spacing would give the most effective seal, but did demonstrate that the hot-poured rubber-asphalt sealer used had insufficient adhesion capability to maintain a satisfactory seal for an extended period of time. Premolded bituminous strips, styrofoam fillers, Unitubes, and initial 1/8- by 2-in. sawcut provided effective initial crack control. Structural quality of joint grooves was improved by sawing. Formed grooves spalled about 40-percent more than sawed grooves. Unitubes were found to rust away below the seals allowing the seals to loosen and be pulled out by traffic.

KEY WORDS: joint sealers, joints, sawed joint, joint fillers, transverse joints, grooves.

CONTENTS

	<u>Page</u>
INTRODUCTION	1
Instrumentation, Measurements, and Observations.	7
DISCUSSION OF RESULTS AND PERFORMANCE	9
Temperature	9
Joint Width Variations	11
Joint Seal Performance	14
Discussion of Results for Each Winter's Survey	18
Joint Spalling	25
Pavement Surface Roughness	25
Transverse Slab Cracks.	27
SUMMARY	28
CONCLUSIONS	30
REFERENCES	30

FINAL REPORT ON MICHIGAN EXPERIMENTAL TRANSVERSE JOINT PROJECT

In order to prevent random tension cracks, the common practice has been to provide transverse joints in rigid pavements at predetermined intervals. A transverse joint, however, is a point of structural weakness in the pavement. The degree of such weakness is related to slab length, joint construction methods, and joint seal quality. In Michigan, a 99-ft slab length with load transfer had been standard from 1946 to 1963. Construction has generally involved a 1/2-in. wide by 2-in. deep joint groove. Since about 1954 until 1965, this joint groove had been formed by inserting a premolded styrofoam filler in a manually formed channel in the plastic concrete, with subsequent hand finishing over the filler. In addition to serving as a groove form, the filler also establishes a plane of weakness for controlled cracking. Observations of performance of various liquid sealers under service conditions have shown that an adequate sealer, capable of performing satisfactorily for several years for joint width movements as experienced with 99-ft slab lengths, is yet to be developed.

In 1959, Professor Egon Tons of Massachusetts Institute of Technology attacked the problem of joint seal performance on the basis of theoretical strains induced in joint seal material due to various changes in joint opening, and width and depth of the joint groove.⁽¹⁾ After determining these strains theoretically, he verified them by laboratory experiments.

The accepted relationships between strain and joint opening, and between strain and groove width, were verified by Tons as follows:

1. Figure 1 shows that in a joint seal groove 1/2-in. wide and 1/2-in. deep, filled flush with joint seal, strain is maximum along the parabolic "curve in" line formed by the upper and lower surface of the sealer as the joint opening increases. With a 1/4-in. opening, the strain is 60 percent, and when the opening is 1/2-in. --about the average opening at 10 F for 99-ft slabs--strain is about twice as great, or 120 percent.

2. In Figure 2, groove width varies, and the accompanying joint seal strain is shown for a joint groove of 1/2-in. depth, as the joint width is increased by 3/4 in. This indicates that the narrower the groove, the greater the strain in the seal material.

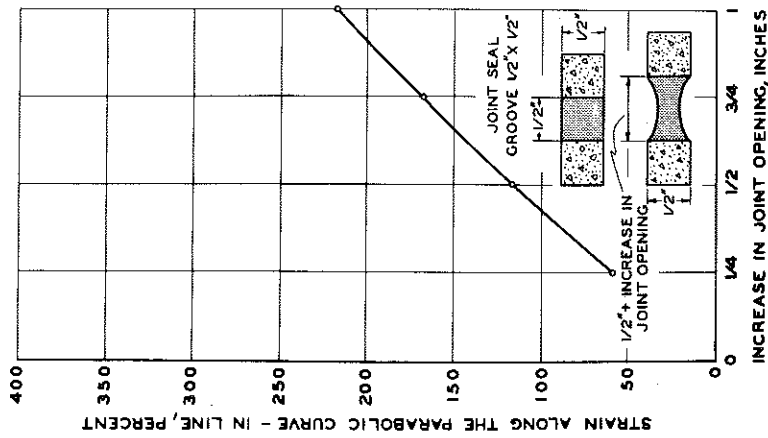


Figure 1. Relationship of strain in joint seal and increased joint opening.

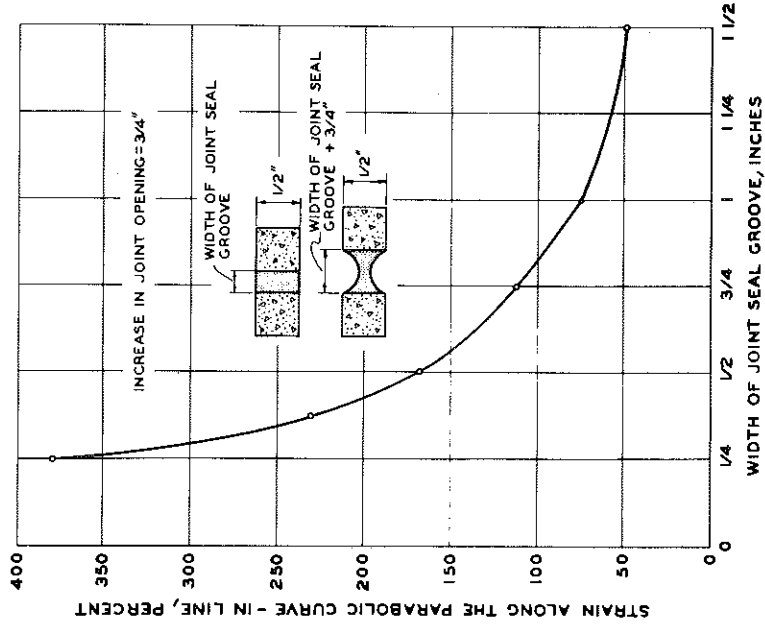


Figure 2. Relationship of strain in joint seal and width of joint groove.

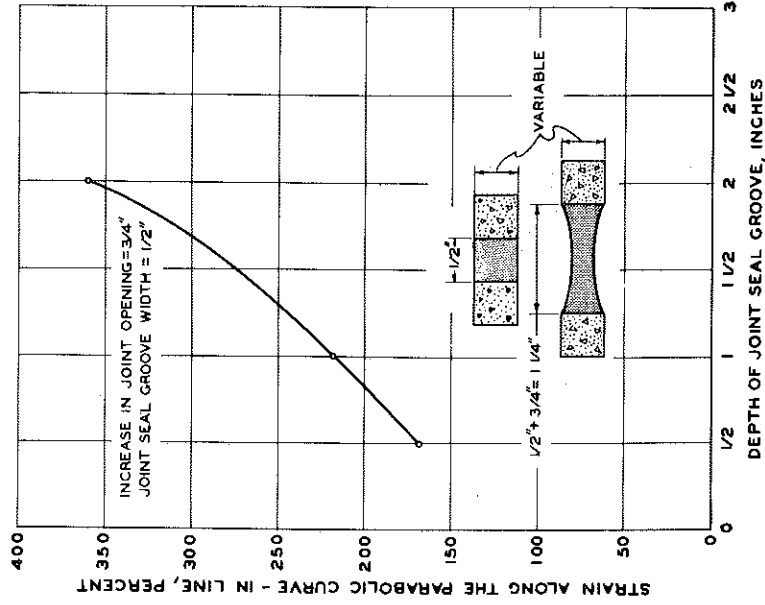


Figure 3. Relationship of strain in joint seal and depth of joint groove.

There was, however, a third relationship investigated by Tons, with a resulting reversal, rather than verification, of a common assumption. It had been generally assumed that, other things being equal, the deeper the joint groove and the greater the volume of joint sealing material, the smaller the strain in the seal for a given increase in joint opening. Tons showed this assumption to be incorrect, both in theory and in laboratory experiments, and that the reverse was true.

3. Figure 3 shows that for a joint seal groove width of 1/2 in. with an increase in joint opening of 3/4 in., joint seal strain increased with groove depth.

Tons concluded that for like conditions, the greater the minimum width of the joint, and the shallower the joint seal depth, the less the sealer will be strained for the same percentage of joint opening.

In the summer of 1962, the Michigan Department of State Highways, with the approval and cooperation of the Bureau of Public Roads, constructed an experimental pavement incorporating five various shapes of joint seal grooves, four different joint forming methods, and three different slab lengths.

The project purpose and scope of the field evaluation program were discussed in the Department's Research Report No. R-368⁽²⁾ and are reiterated here. Briefly, the project was undertaken for the purpose of evaluating the performance of hot-poured liquid sealant in relation to slab joint spacing and joint groove size, and to evaluate crack control of various methods used to construct a plane of weakness at the joint locations.

Joints were spaced at 57 ft 3 in., 71 ft 2 in., and 99 ft 0 in. Groove sizes were 3/8 by 1/2 in., 1/2 by 1/2 in., 3/4 by 3/4 in., 1 by 1 in., and 1/2 by 2 in. Plane of weakness construction methods included, installing temporary 1/2- by 2-in. styrofoam filler, installing 1/4- by 2-in. pre-molded fiber filler, sawing 1/8- by 2-in. grooves and installing "Unitubes." The field evaluation program consisted of:

1. Determining construction feasibility of various methods used in making the joints.
2. Annual survey of pavement cracking.
3. Semi-annual evaluation of sealer performance including:
 - a. Adhesion characteristics,
 - b. Cohesion characteristics,
 - c. Infiltration of foreign material in the joints,
 - d. Joint groove spalling.
4. Semi-annual measurements of joint width variation.
5. Semi-annual measurements of surface roughness.

Construction and instrumentation of the experimental pavement were reported in detail in Research Report No. R-428. ⁽³⁾ Based on observations during construction, no random cracking at or between joints was reported, indicating that the four different methods used to construct the plane of weakness were all satisfactory. It should be mentioned, however, that the absence of random cracking in sections where initial crack control was established by sawing a 1/8- by 2-in. deep plane of weakness may partially be due to the prevalence of exceptionally favorable curing conditions. In most cases, the days were partly cloudy and humid, with moderate velocity winds and an average recorded daily temperature variation of 22 degrees. Thus, shrinkage and temperature induced stresses were of insufficient magnitude to cause random cracking before the plane of weakness could be sawed.

The initial 1/8- by 2-in. deep sawcut was made between 6 to 24 hr after pouring without excessive ravelling. Except at 15 joints, larger aggregate particles were displaced from the joint locations by lowering the 5/16-in. wide mechanically vibrated steel T-bar of the Unitube installation machine into the plastic concrete to a depth of 2-1/2 in. This operation was performed to facilitate sawing and was done after the final machine finishing of the pavement surface. Any surface roughness remaining after the T-bar was retracted was smoothed away during hand finishing operations. By treating the joint locations in this manner, it was possible to form the plane of weakness by sawing with carborundum blades. At the 15 joint locations where displacement of larger aggregate particles was omitted, diamond blades were required to saw the weakness plane. No problems were encountered in sawing the various sized joint groove widths.

Data obtained on regular scheduled surveys pertaining to joint spalling, transverse cracking and surface roughness, and joint seal performance data from a special survey conducted February 10, 1964, were presented in an interim progress report (Research Report No. R-452). ⁽⁴⁾ As a result of the data revealed in this interim report, Michigan's slab length was changed from 99 ft to 71 ft 2 in. and sawed joints were specified on some new construction projects. Excerpts of data and discussions from these earlier reports pertinent to the understanding of the performance results are included in this final report.

The test area, Construction Projects EBI 33084, C5 RN (Federal Project EI 96-3(17)157) and C7 RN, (Federal Project EI 96-3(18)63) and EBI 33085, C1 RN, (Federal Project EI 96-3(18)16.3) consists of an 11.6 mi portion of I 96, located between Meridian Road and Wallace Road in Ingham County (Fig. 4). It included both the eastbound roadway (Sta. 468+15 to

1085+00) and the westbound roadway (Sta. 467+90 to 1085+00) each containing two 12-ft reinforced concrete lanes of 9-in. uniform thickness. Load transfer is provided at transverse joints by means of 1-1/4-in. diam bars, 18-in. long and spaced at 12-in. centers, and a non-metallic base plate was installed at each joint. In pavement poured after September 10, 1-in. wide expansion joints were placed at approximately 400-ft intervals. Transverse tie bars, consisting of No. 4 deformed bars, 30-in. long, were spaced at 40-in. centers across the longitudinal joint between the two 12-ft lanes. This joint was sawed 1/8-in. wide by 2-in. deep and sealed before traffic was permitted on the slab.

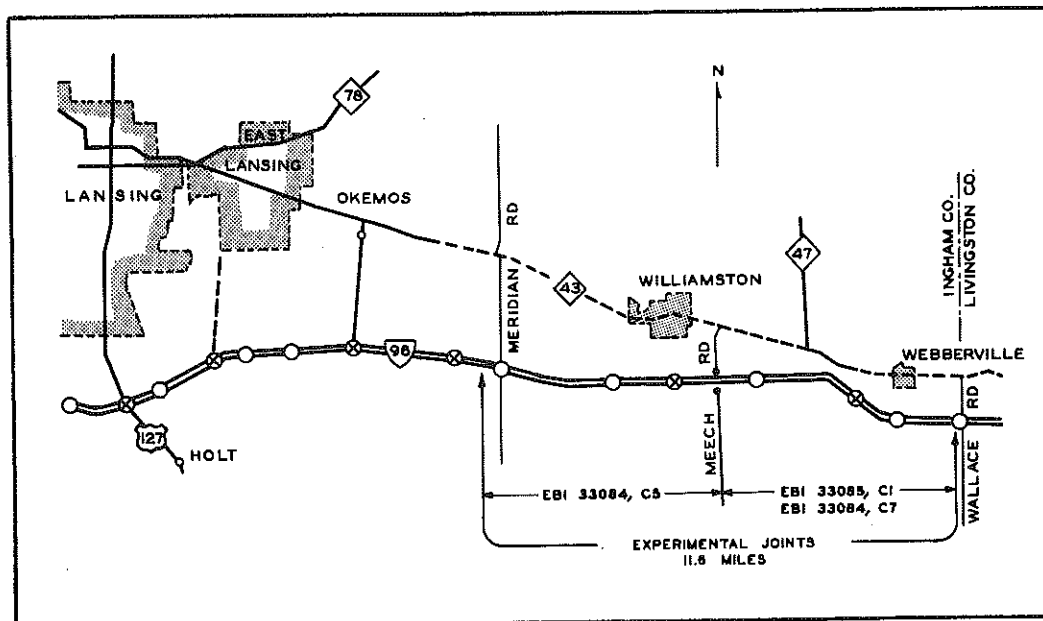


Figure 4. Location of experimental pavement joints southeast of Lansing.

The experimental pavement was divided into 18 test sections. The location, forming method, groove size, and spacing of the transverse joints of each section are given in Table 1.

As shown in Table 1, the five groove sizes are: 1/2 by 1/2 in., 3/4 by 3/4 in., 1 by 1 in., 1/2 by 2 in., and 3/8 by 1/2 in. The four types of joint forming methods were:

1. Unitube: a metal device (called "Unitube," a proprietary product of the Middlestat Corp., of Baltimore, Md.) was embedded transversely near the pavement surface, and subsequently treated to provide a joint groove for sealing material.

TABLE 1
DESCRIPTION OF FIELD INSTALLATIONS
Sections 1E-9E: Eastbound Roadway
Sections 0W-8W: Westbound Roadway

Section	Stationing	Joint Forming Method	Joint Groove, in.	Joint Spacing
1E	468+15 to 509+68	Sawed (without Filler Strip)*	1 by 1	99 ft 0 in.
2E	509+68 to 552+20	Sawed (without Filler Strip)*	3/4 by 3/4	99 ft 0 in.
3E	552+20 to 594+23	Sawed (without Filler Strip)*	1/2 by 1/2	99 ft 0 in.
4E	594+23 to 634+77	Sawed (without Filler Strip)*	3/4 by 3/4	71 ft 2 in.
5E	634+77 to 676+76	Sawed (without Filler Strip)*	1/2 by 1/2	71 ft 2 in.
6E	677+21 to 720+30	Styrofoam	1/2 by 2	99 ft 0 in.
7E	720+30 to 747+73	Sawed (without Filler Strip)*	3/4 by 3/4	57 ft 3 in.
8E	747+73 to 775+70	Sawed (without Filler Strip)*	1/2 by 1/2	57 ft 3 in.
9E	775+70 to 1085+00	Unitube	3/8 by 1/2	57 ft 3 in.
0W	776+23 to 1085+00	Unitube	3/8 by 1/2	57 ft 3 in.
1W	747+79 to 776+23	Sawed (with Filler Strip)**	1/2 by 1/2	71 ft 2 in.
2W	717+06 to 747+79	Sawed (with Filler Strip)**	3/4 by 3/4	71 ft 2 in.
3W	676+45 to 717+06	Styrofoam	1/2 by 2	99 ft 0 in.
4W	634+92 to 676+01	Sawed (with Filler Strip)**	1 by 1	99 ft 0 in.
5W	594+44 to 634+92	Sawed (with Filler Strip)**	3/4 by 3/4	99 ft 0 in.
6W	552+06 to 595+44	Sawed (with Filler Strip)**	1/2 by 1/2	99 ft 0 in.
7W	510+15 to 552+06	Sawed (with Filler Strip)**	3/4 by 3/4	57 ft 3 in.
8W	467+90 to 510+15	Sawed (with Filler Strip)**	1/2 by 1/2	57 ft 3 in.

* 1/8 by 2 in. plane of weakness sawcut, and sawed joint groove.

** 1/4 by 2 in. filler strip, and sawed joint groove.

2. Sawed with Filler Strip: a 1/4- by 2-in. premolded bituminous, fiber filler strip was embedded during construction, with the filler removed to the specified groove depth when the joint groove was cut after the pavement had cured.

3. Sawed without filler strip: a 1/8- by 2-in. plane of weakness was sawcut within 24 hr. after pouring, and the joint grooves cut after curing.

4. Styrofoam: 1/2- by 2-in. styrofoam strips were embedded during construction and subsequently removed to provide a joint groove for the sealer. This method was standard Departmental practice at the time the test road was built.

All joint grooves and immediate pavement surfaces were cleaned by sandblasting, and any loose material accumulated in the grooves was removed by a jet of compressed air just prior to sealing. A hot-poured, rubber-asphalt type joint sealing compound was used to seal all transverse joints. No attempt was made to prevent bonding of the sealer to the bottom surface of the grooves.

The three slab lengths were 99 ft 0 in., 71 ft 2 in., and 57 ft 3 in. Two types of welded wire mesh were used as reinforcement. One type, providing a steel percentage of 0.10, was installed in the Unitube sections (0W and 9E) which contained only 57-ft 3-in. slabs. In the remaining sections, in which all three slab lengths were represented, the provided steel percentage was 0.16. The reinforcement was placed 3 in. below the surface.

Instrumentation, Measurements, and Observations

A general plan and instrumentation layout of the test project are shown in Figure 5. In 14 test sections, 10 consecutive joints were instrumented with gage plugs for joint width readings. In the remaining 4 sections, more than 10 joints were equipped with gage plugs, because the instrumented portion contained either construction joints or expansion joints. Although readings were taken at all joints, data on these joint types and joints adjacent to expansion joints were excluded during data reduction. The gage plugs are 2-in. long by 1/4-in. diam stainless steel countersunk-head rivets with machined conical holes in the rivet head. Three sets of plugs were placed in the concrete at each joint, 12 in. from the pavement edge in the traffic and passing lane, and 12 in. from the longitudinal joint centerline in the traffic lane. Each set was placed symmetrically about the transverse joint centerline approximately 8 in. apart.

A temperature well for mid-depth slab temperature was formed in the slab at each set of instrumented joints. It consisted of a 3/8-in. diam hole containing 1 in. of liquid mercury and sealed with a brass plug and cap screw.

A Starret Vernier Caliper with a 0.001 in. resolution was used for joint plug measurements. To obtain joint width changes, the initial distance between plugs was measured before any movement at the joints had occurred. To determine sealer extension, the distance between plugs was measured just before the joints were sealed. A third set of plug readings was taken two weeks before the pavement was opened to traffic. Thereafter, measurements were made in the summer and winter of each year.

The concrete and air temperature at each of the 18 test sections were recorded when joint width measurements were taken. In addition, monthly temperature records were received from a local United States Weather Bureau Station.

In conjunction with joint and temperature readings, the performance of the sealer and joint grooves was observed. Evaluation of sealer performance consisted of detailed visual inspection of each instrumented joint in

each of the 18 test sections. Four basic sealer properties were checked; physical condition, adhesion failure, cohesion failure, and dirt infiltration. The physical condition of the sealer was rated in terms of its ductility (resilient, plastic, or hard) and surface appearance (normal, wrinkled, cracked, or checked). The length and depth of adhesion failures along the leading and trailing joint edges were estimated independently by two observers and the average results recorded. In the same manner, length and depth of cohesion failures near the joint edges and in the sealer interior were obtained. Infiltration of dirt was checked either as none, between joint faces and sealer, in cracks, mixed into sealer, or inclusion of dirt caused by folding of the seal's center. A photographic record of sealer conditions was maintained for the duration of the study.

Information on the extent of joint spalling was obtained by estimating the length and width of spalls along the leading and trailing joint edges. The location of the spalls with respect to the pavement edge and, where possible, the depth of spalls were also noted.

Initial surface roughness was measured with the Department's roughometer two weeks before the pavement was opened to traffic. Six more measurements were made: one in 1963, two in 1964 and 1965, and one in 1966. A condition survey on transverse slab cracking was made each year.

It was originally intended to schedule yearly traffic surveys at the test site. However, since pavement evaluation is based primarily on comparative performance of the various test sections, and the traffic volume being practically the same throughout the entire project length, cancellation of these surveys was considered justifiable.

DISCUSSION OF RESULTS AND PERFORMANCE

Temperature

The individual concrete and air temperature readings recorded at each test section were averaged to obtain representative temperatures for the survey date. Their relationship is shown in Figure 6. With the exception of the November 1962 reading, the air temperature was from 3 to 11 degrees lower than the concrete temperature. The monthly maximum-minimum, and average monthly air temperature variations for the locality are shown in Figure 7. Because the minimum temperatures to which the seals were subjected in the winter months were well below the survey temperatures, sealer failure observed at these inspections does not necessarily reflect extreme conditions.

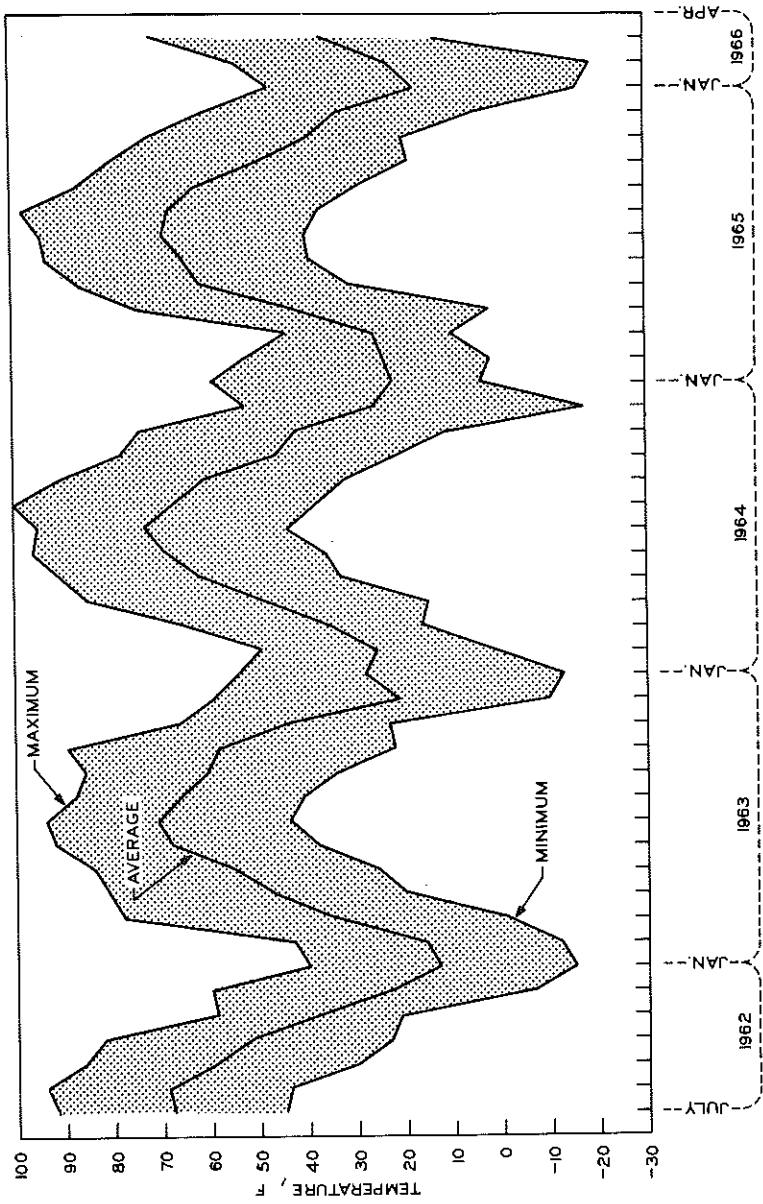


Figure 7. Monthly air temperature variation.

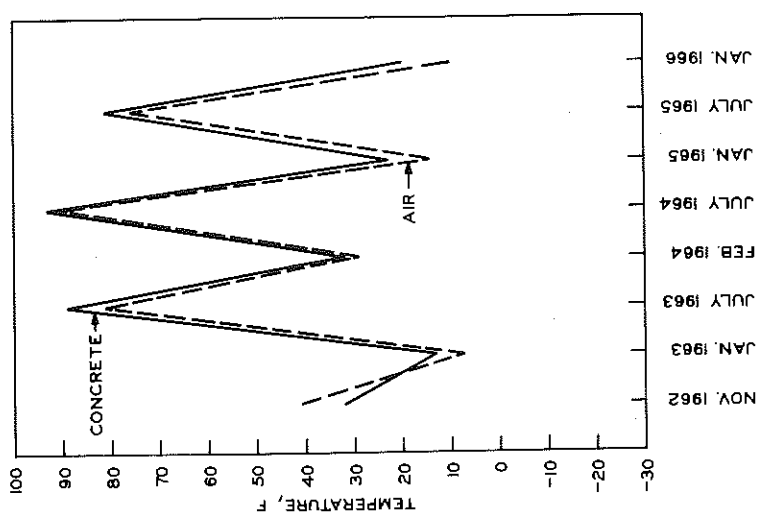


Figure 6. Average concrete and air temperatures at times of surveys.

Joint Width Variations

The set of measuring plugs installed near the center line of the 24-ft pavement was included in the joint instrumentation program for the purpose of determining if joint movements at this point differs from that measured near the pavement edge. To determine whether or not there was any difference in joint movement at the two locations, the data on joint width variation were subjected to a statistical analysis of covariance. Results of this test indicated that no difference in these measurement positions could be detected at the 95-percent probability level.

Summer and winter data on joint width changes in the three slab length groups were plotted with the joint opening as the dependent variable, and air temperature as the independent variable. The line of regression relating these two variables was obtained by the statistical method of least squares. Figure 8 shows the data for 99-, 71-, and 57-ft slab lengths. For high temperatures, beyond the range represented by the data included in these graphs, the regression equations have no meaning and zero joint opening should be assumed. Each point on the graphs represents the mean joint opening change based on all measurements taken in one section at a particular date and temperature. On each graph, the standard error of estimate and the correlation coefficient are given. The standard errors of estimate for 99-, 71-, and 57-ft slabs were 0.072, 0.056, and 0.036, respectively, which means that 68 percent of estimated joint openings for a given temperature could be expected to be within the standard error shown. The correlation coefficient for joint opening and temperature was -0.88 for 99-ft slabs, -0.87 for 71-ft slabs, and -0.91 for 57-ft slabs, where 0 signifies no correlation and -1 signifies perfect correlation between increasing joint opening and decreasing temperature.

Since the magnitude of the joint opening is dependent on the initial pour temperature, (as shown by the separation of regression lines for selected pour temperature in Figure 9) it was decided to include it as an independent variable in a multiple correlation solution for estimating joint opening values. Other independent variables were slab length and air temperature as determined at the time of joint measurement.

While the results are encouraging from a statistical point of view, the range covered by the data for each independent variable should be borne in mind. The eighteen pour temperatures for the sections considered ranged from 54.8 to 88.7 degrees and averaged 72.1 degrees and, of course, only

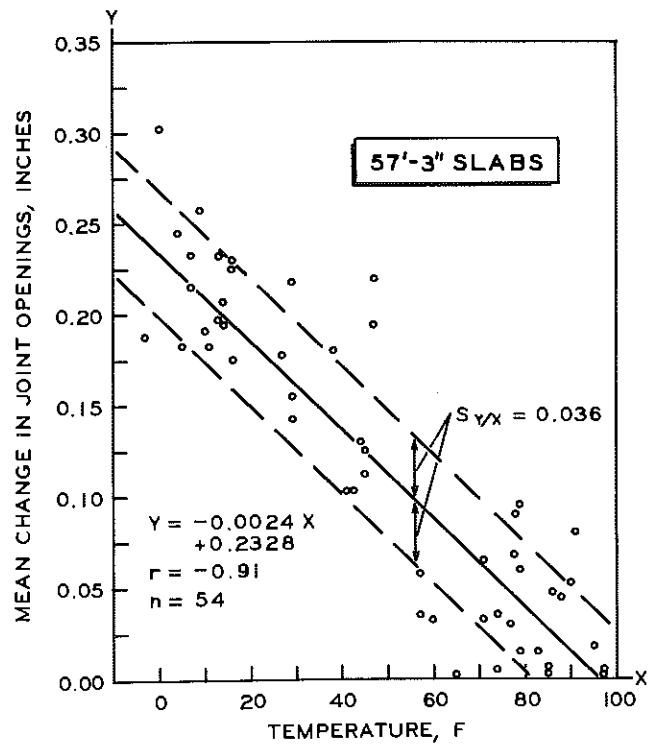
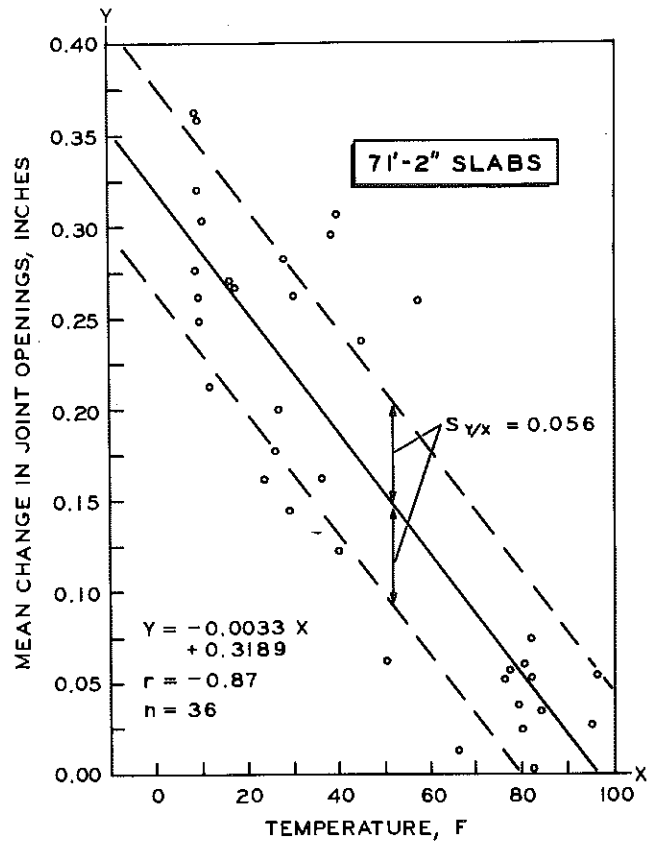
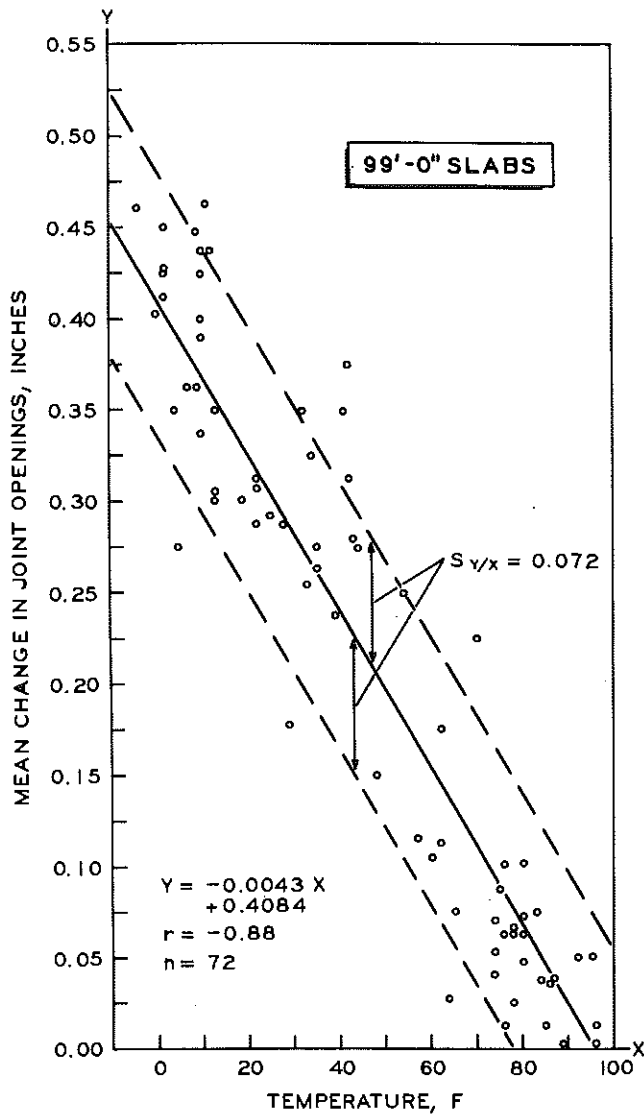
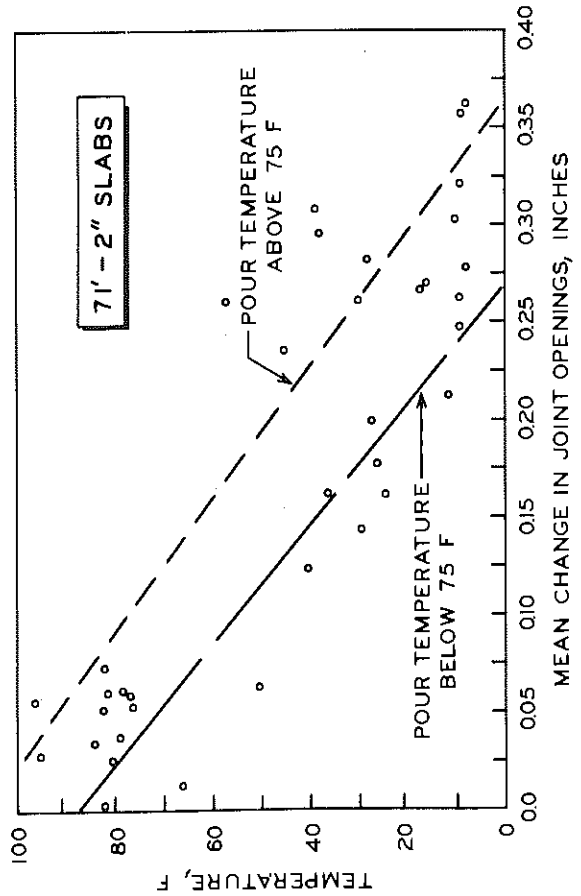
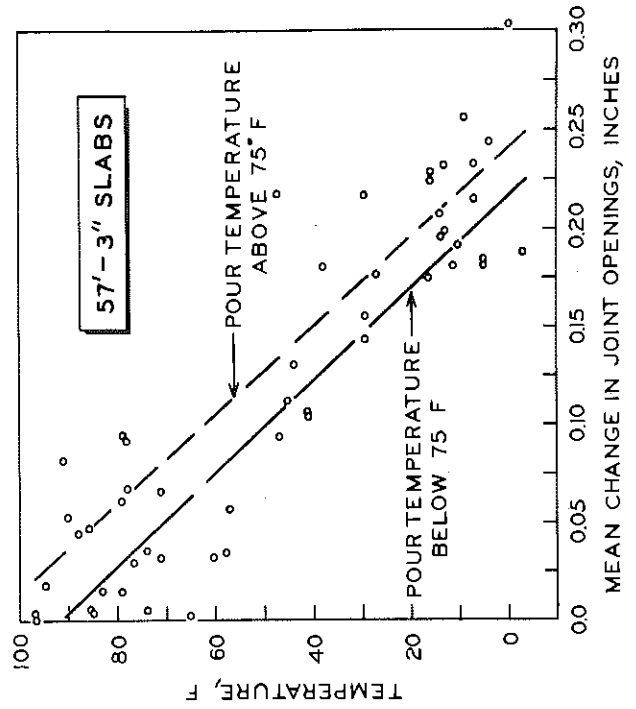
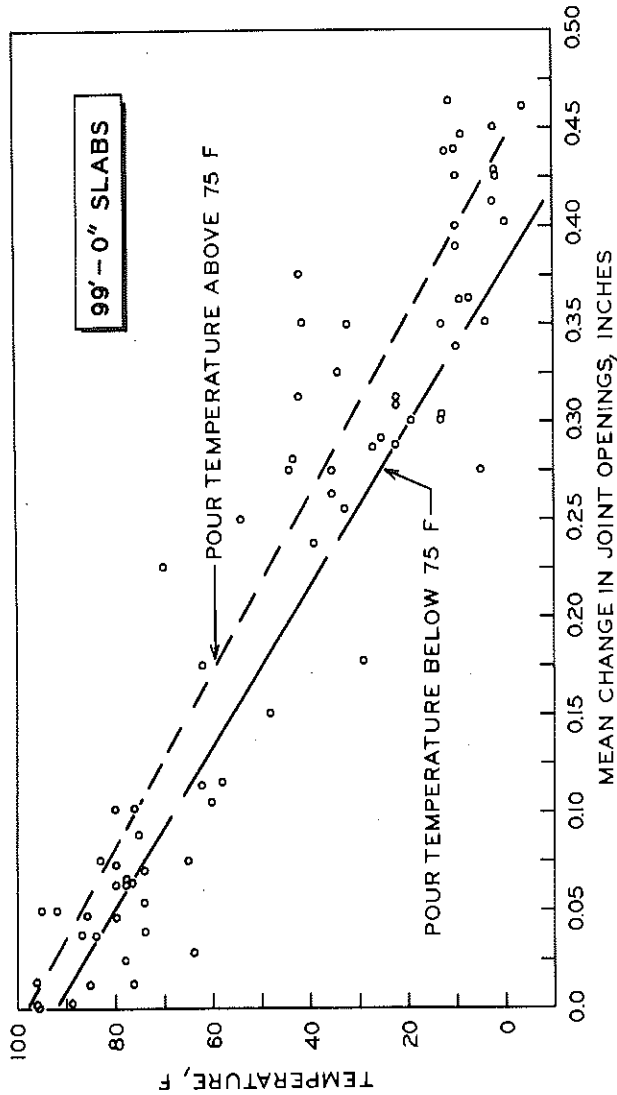


Figure 8. Relationship of air temperature and mean change in joint opening.

Figure 9. Effect of pavement pour temperature on joint opening.



the three slab lengths were available for consideration. The estimating equation obtained is as follows:

$$a = 0.002 l + 0.003 T_o - 0.004 T_i - 0.002$$

where:

a = joint opening (in.)	T_o = pour temperature (air, F)
l = slab length (ft)	T_i = measured temperature (air, F)

The standard error of estimate and the multiple correlation coefficient were 0.050 and 0.930 respectively.

Note that the multiple correlation standard error of estimate is less than that of two of the three, two-variable correlations (joint opening versus measure temperature). This reduction is desirable and is to be expected if the contribution of pour temperature to total variation is substantial.

For certain combinations of slab length, pour temperature, and measuring temperature, the joint opening obtained by using the estimating equation may be negative in value. This would indicate that zero joint opening occurs at a lower temperature than the temperature for which the joint opening is estimated.

Joint Seal Performance

From the semi-annual inspections of the joint seals, it is evident that the sealer's physical condition, surface appearance, and conditions that promote infiltration of dirt into the joint grooves or seals, are markedly different in the winter than in the summer. Observations on each of these factors and the sealer cohesion and adhesion failure are summarized as follows:

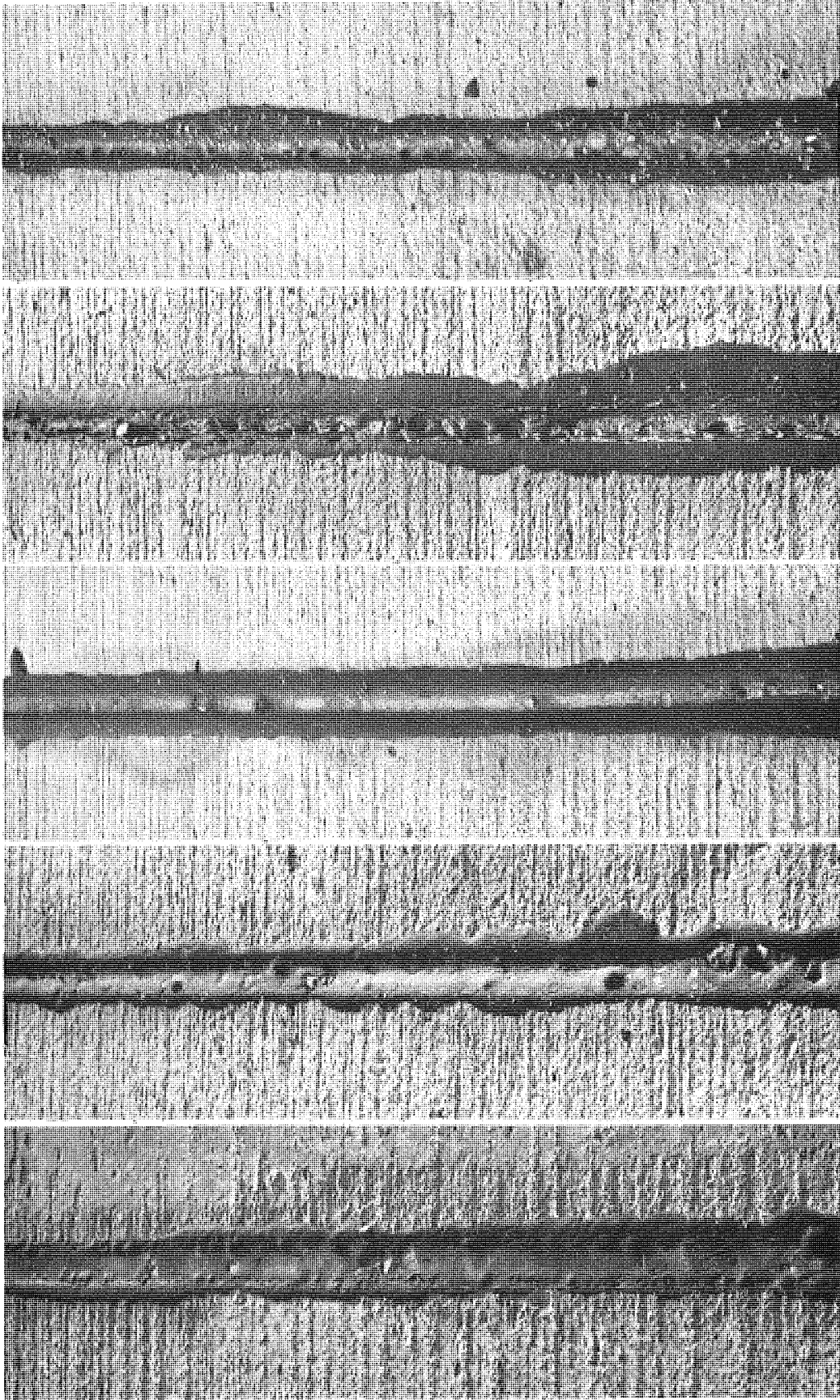
1. Physical condition: In all cases, the sealer was rated as hard at the time of inspection in winter, and it appeared that as sealer hardness increased its ductility and adhesion properties decreased. Since the greatest sealer extensions occur in winter, hardening of the sealer takes place at the most inopportune time. During summer, the sealer ductility was much better and all seals were rated as plastic. As the concrete slabs expanded, the sealer was extruded above the pavement surface, the amount depending on the width of the joint when sealed. The sealer was sufficiently soft to flow onto the immediate pavement.

2. Surface appearance: Small shallow cracks, and wrinkles along the groove's edge parallel to the groove, were noted to be present in the sealer when inspected in cold weather. These surface features were somewhat more pronounced in the sections with narrow groove widths. The neck-down or curve-in portion of the seals was generally smooth, with the deepest curve-in occurring in narrow joint grooves. During the initial, and first winter survey, the surface contained air bubbles, resulting from air entrapped in grooves or material at the time of sealing. Small stones, spilled on the pavement during construction operations, were also present in the sealer. The surface appearance of typical seals in winter 1962 is shown in Figure 10. Cracks, wrinkles, air bubbles, and embedded foreign material present during winter, were obliterated by summer compression and extrusion of the sealer, the sealer surface appearing much smoother and cleaner (Fig. 11).

3. Dirt Infiltration: With exception of the first two surveys, when small stones were found embedded in the seals, the type of dirt entering the seals was of the sand-silt variety. This material collects in cracks, neck-downs, and in adhesion failures during winter, and enters the seal during the compression period in the summer. Since the surface features promoting dirt infiltration were absent in the summer, the only way that material could enter the seals during warm weather is through the surface by the kneading action of tires. Whether or not infiltration in this manner takes place was not established, but if it does occur the amount would appear to be negligible compared to the amount entering the seals in cold weather.

4. Sealer Cohesion and Adhesion Failure: Performance inspections of the seals revealed insignificant amounts of cohesion failure. The only seals in which this type of failure was noted, were those installed in the 1/2- by 2-in. styrofoam formed grooves. The failures were first noted in the winter of 1964 and had occurred in the center of the seals. Winter inspections in 1965 and 1966 revealed lesser amounts of cohesion failure, but increased length of adhesion failure, indicating that compression of the sealer in the summer healed the cohesion failures whereas the adhesion capability of the sealer decreased with time.

Before discussing the performance of the seals in terms of adhesion failure, two items should be mentioned which could affect this performance aspect of certain seals. First, the width of some sawed grooves was equal to the width of the saw blades because no adjustment in saw blade width was made when these grooves were sawed in joints which had already opened. Thus, when these joints are fully closed the groove shape factor, i. e., the depth to width ratio, would be slightly greater, which theoretically would



1-by 1-in. Groove
Sawed without Filler
99-ft 0-in. Slabs

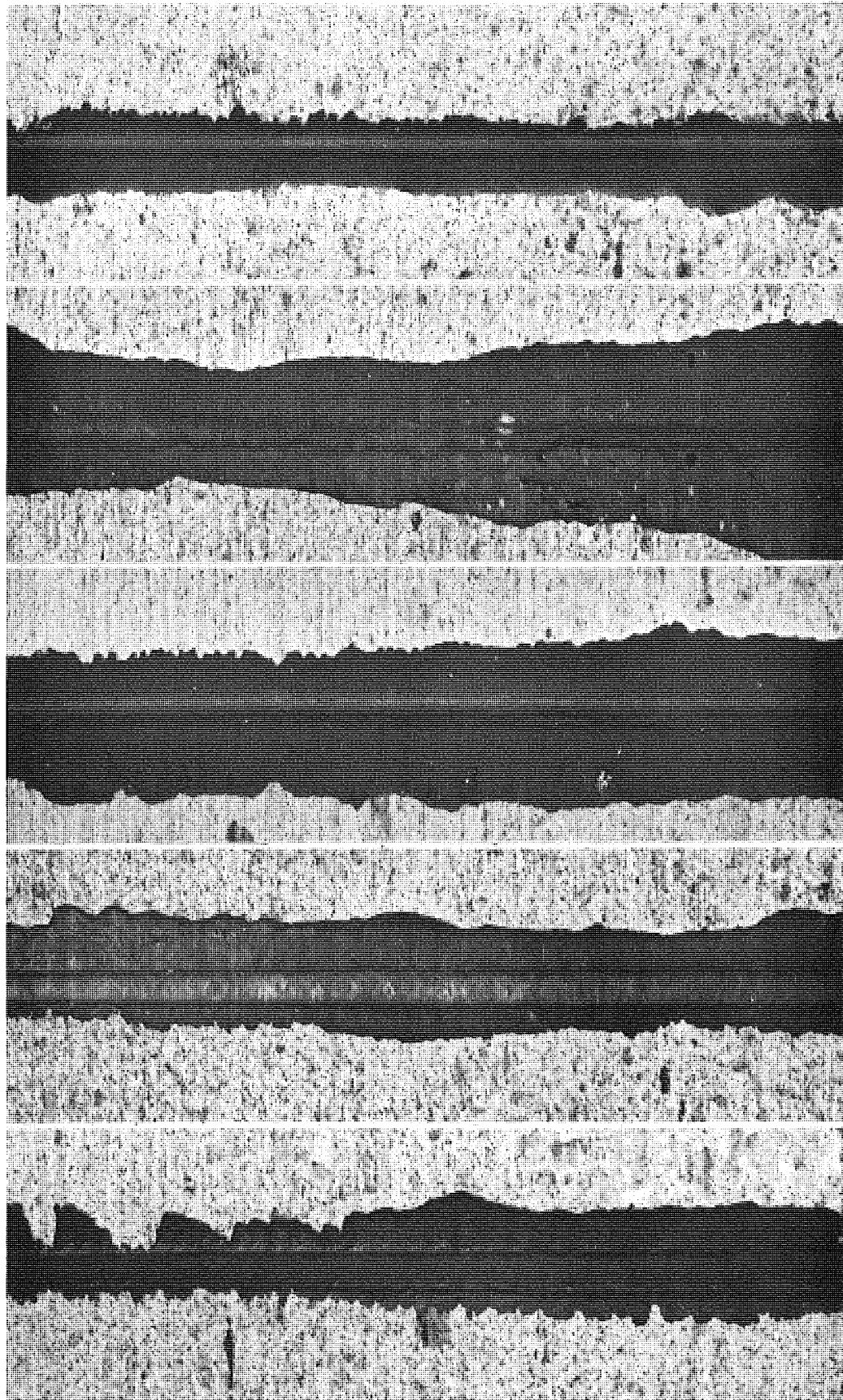
3/4-by 3/4-in. Groove
Sawed without Filler
71-ft 2-in. Slabs

1/2-by 1/2-in. Groove
Sawed with Filler
71-ft 2-in. Slabs

1/2-by 2-in. Groove
Formed with Styrofoam
99-ft 0-in. Slabs

3/8-by 1/2-in. Groove
Formed with Unitube
57-ft 3-in. Slabs

Figure 10. Typical surface condition in the fall after construction (November 1962). Note bubbles and embedded stones in the surface, and wrinkled condition of the sealer in the 1/2- by 2-in. groove.



1-by 1-in. Groove Sawn without Filler 99-ft 0-in. Slabs
 3/4-by 3/4-in. Groove Sawn without Filler 71-ft 2-in. Slabs
 1/2-by 1/2-in. Groove Sawn with Filler 71-ft 2-in. Slabs
 1/2-by 2-in. Groove Formed with Styrofoam 99-ft 0-in. Slabs
 3/8-by 1/2-in. Groove Formed with Unitube 57-ft 3-in. Slabs

Figure 11. Typical surface condition approximately one year after construction (July 1963). Stones and air bubbles observed in the sealer surface the previous fall are completely obliterated.

have an adverse effect on sealer performance. Second, in some grooves the seal was installed when the joints were open, which allowed the sealer to flow down into the plane of weakness crack. However, sealing grooves when they are wider than their nominal width should have a beneficial effect on the sealer performance until the joints have tightly closed. After that, any excess sealer would have been extruded from the joint and the volume and shape of the seal would be the same as if it had been installed before the joints had opened.

As the surface features observed in the winter were obliterated by compression of the seals in the summer, so were adhesion failures. Thus, none of the three summer inspections revealed any failures of this type. In July 1965, after approximately three years service, the joints were still effectively sealed. However, adhesion failures were readily noticeable in the winter, the amount and seriousness increasing with sealer age. Figure 12 shows the percent of adhesion failure per joint (based on a possible total length of failure of 288 in. per joint) for each winter survey in relation to slab length, groove size, construction method, and sealer extension. The lengths of sealer extensions shown for January 1963 (Fig. 12) are the extensions to which the seals have been subjected from the time of sealing to the date of survey, whereas the February 1964, January 1965, and January 1966, are the extensions from the previous summer to the following winter.

Discussion of Results for Each Winter's Survey

January 1963: Figure 12 shows the only seals that failed were those installed in the 1- by 1-in., 3/4- by 3/4-in., and 1/2- by 1/2-in. grooves, in the 99-ft slabs, and sawed without filler. Depth of failure was estimated to range from 1/16 to 1/8 in. The beginning of failures in these sections may be because these seals were subjected to the greatest amount of extension as compared to other seals in the 99-ft slab category, rather than due to groove geometry or construction method.

February 1964: Shallow adhesion failures, estimated to range from 1/8- to 1/4-in. deep, had occurred in seals in all test sections. The average percent of failure per joint in the 99-ft slab group ranged from less than one for the 1/2- by 2-in. styrofoam formed grooves, to 11 for the 3/4- by 3/4-in. grooves sawed without filler. For the same size grooves in the 99-ft slab category, those sawed with filler had less failure than those sawed without filler. In the 71-ft slab group, the seals in grooves sawed without filler had less failure than those where the bituminous filler was used to form the plane of weakness. The greatest failure (23 percent) and the least failure (0.3 percent) recorded during this inspection had occurred

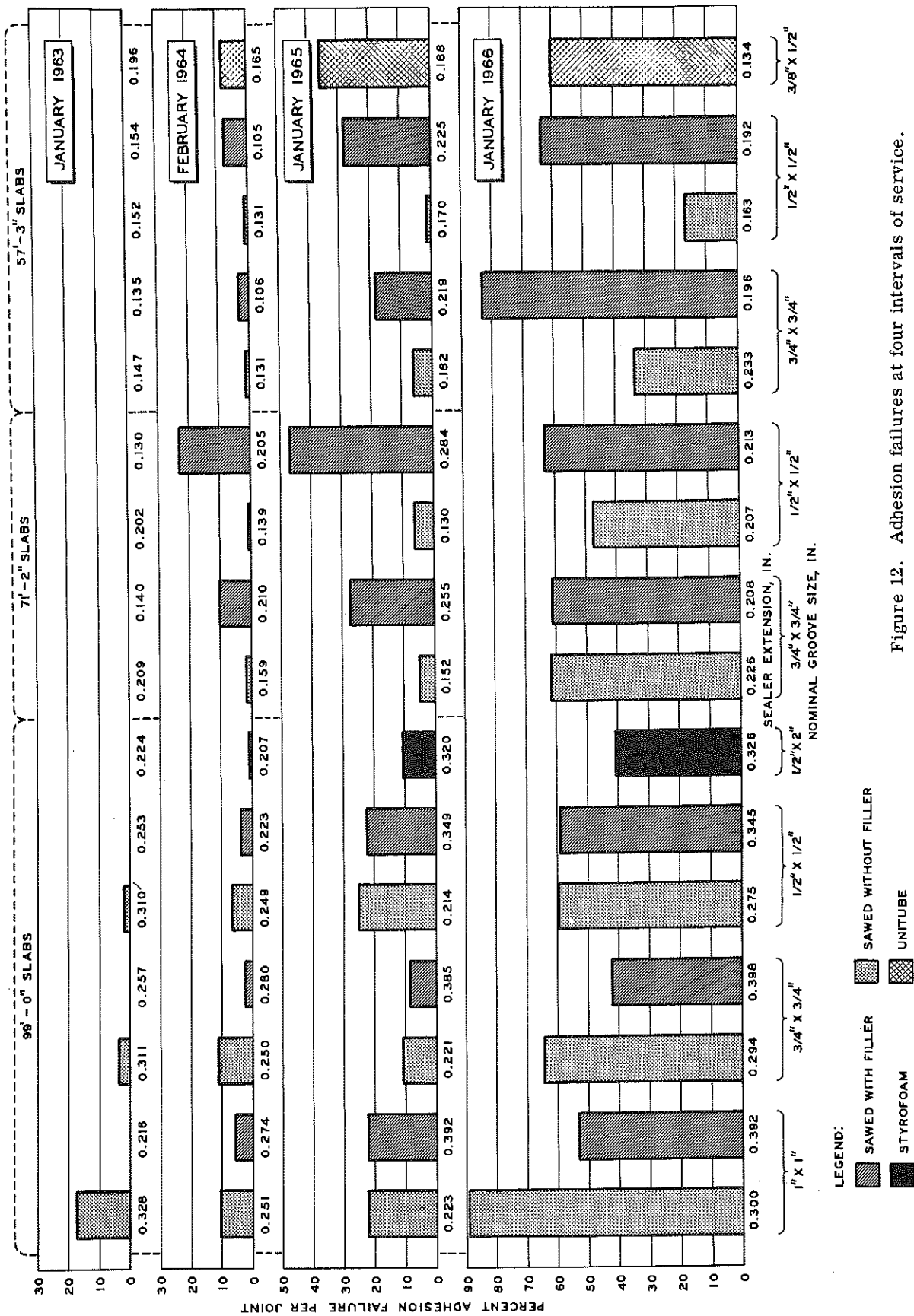


Figure 12. Adhesion failures at four intervals of service.

in the sections having 71-ft slabs. The seals placed in grooves sawed without filler performed better than those in grooves sawed with filler where the joint spacing was 57 ft. The seals in grooves formed by the Unitube method had the most failure in the 57-ft slab group. Only in sections with 71-ft slabs did the amount of failure correspond to the length of sealer extension. In the other two slab categories, the seal failure and extension relation was reversed with the exception of one section.

Since the depth of failure was judged to be no more than 1/4 in. in all cases, the seals apparently were still preventing infiltration of both liquid and solids into the joint itself. Thus, any of the combinations of groove size, slab length, and joint construction method would appear to result in satisfactory sealer performance for at least one year, although shallow adhesion failures may be expected. The reason for adhesion failure occurring in all slab categories is believed to be insufficient bond capability of the sealer, even for the sealer extensions experienced with the short slabs.

January 1965: By comparing the percent of failure shown in Figure 12 for February 1964 with that shown in January 1965, it can be seen that the order of sealer performance in the various test sections remained the same except that in the 99-ft slab group the performance of the seals in the 1/2- by 2-in. styrofoam formed grooves was surpassed by those in the 3/4- by 3/4-in. grooves sawed with filler. The percent of failure was more than double that recorded in 1964 for all sections but one (3/4- by 3/4-in. grooves; sawed without filler, with 99-ft slabs), which actually showed a small decrease in percent of failure. In all sections the maximum depth of failure was estimated to be 1/2 in. The 71- and 57-ft slab groups showed the largest amount of failure for those joints where the sealer extension was at maximum, the reverse being true for sections containing 99-ft slabs as shown in Figure 12.

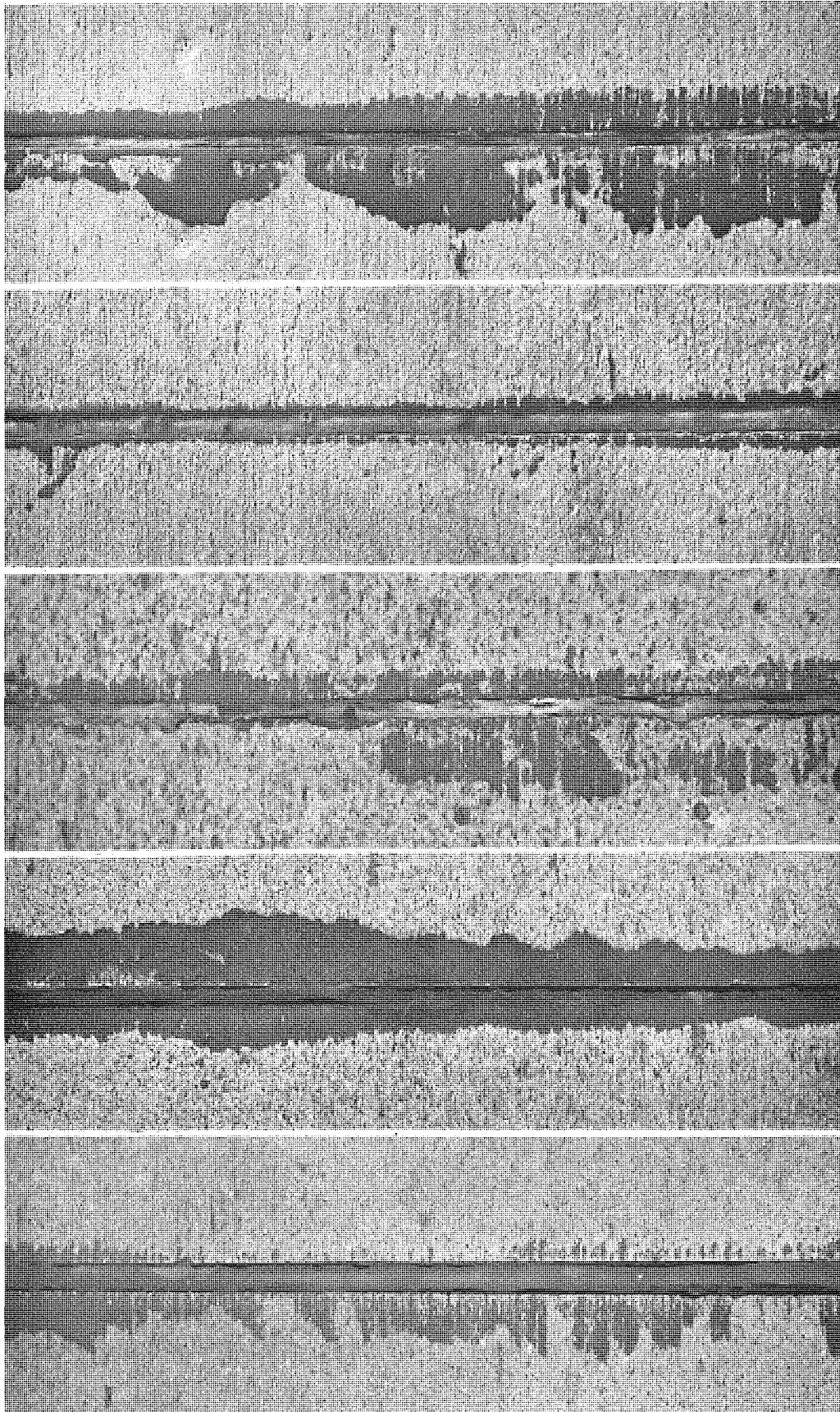
Based on the depth of failure, it appears that seals in 1/2-in. deep grooves fail to the bottom of the groove after about two years regardless of which of the three slab lengths are used, and whether the grooves are sawed or formed. Seals in the deeper grooves apparently were still effective in sealing out foreign material from the joints.

January 1966: Although the seals in none of the test sections had failed 100 percent, the loss of adhesion was now full depth. Based on slab length alone, the average failure was 52-, 58-, and 53-percent for the 99-, 71-, and 57-ft slab groups, respectively. In the 99-ft slab category the seals in the 1/2- by 2-in. styrofoam formed grooves were almost equal in performance to those in the 3/4- by 3/4-in. grooves sawed with filler. The greatest failure (90 percent) had occurred in the section where the grooves were

sawed without filler and were 1 by 1 in. in size. The performance of the seals in the remaining four sections in this slab group was approximately the same. The best performing seals (47-percent failure) in the 71-ft slab sections were those in the 1/2- by 1/2-in. grooves sawed without filler. In the other three sections with 71-ft joint spacing, the failures were close to 60 percent for each section. The most variation in seal failure among sections with the same slab length was found in the short slab group. Here, the least amount of failure was 17 percent and the most 83 percent. The seals in the section with 17-percent failure were placed in 1/2- by 1/2-in. grooves sawed without filler, and the grooves in which the seals had 82-percent failure were sawed with filler and the groove size was 3/4 by 3/4 in. Figure 13 illustrates adhesion failures observed in 1966.

Seals in the Unitube formed joint grooves showed 60-percent failure per joint. However, the January 1966 inspection revealed that the Unitube was rusting out, leaving the seals unsupported on the bottom. Consequently, where adhesion failure had occurred along both groove walls, the seals in many cases were pulled out by traffic, leaving the joint exposed to infiltration of liquid and solid material. Since there are more than 1,000 joints of this type, a larger sample (88 joints, as compared to the original 20) was selected for inspection by using statistical sampling procedures. This special survey was performed in March 1966, and revealed that an average of 10 in. of seal per joint was missing. In addition, an average of 35 in. of seal per joint was found to be either loose or settled into the groove indicating that the Unitube had rusted out below the seal. This failure type is illustrated in Figure 14.

One might assume that seals in a given groove size would perform in accordance with the amount of extension to which the seals are subjected. However, measurements of adhesion failure and sealer extension revealed that this was not necessarily true for the test joints. This would indicate that the adhesion capability of the sealer varies. Further evidence that variation in this sealer property existed, is the fact that a seal extended the same amount did not fail the full length of the joint. Since all seals generally showed good adhesion to the groove walls during the first winter, but failed in adhesion the following winter, it appears that the adhesion quality of the sealer decreases with time. Apparently, these observed variations in sealer adhesion quality obscured most of the beneficial influence of groove size, slab length, and joint construction method. Thus, conclusive evidence as to which combination of these three variables would give the most satisfactory sealer performance was not obtained. Rather, the results indicate that regardless of which combination of groove size,



1-by 1-in. Groove
Sawed without Filler
99-ft 0-in. Slabs

1/2-by 1/2-in. Groove
Sawed without Filler
99-ft 0-in. Slabs

1/2-by 2-in. Groove
Formed with Styrofoam
99-ft 0-in. Slabs

3/4-by 3/4-in. Groove
Sawed with Filler
57-ft 3-in. Slabs

1/2-by 1/2-in. Groove
Sawed with Filler
71-ft 2-in. Slabs

Figure 13. Appearance of adhesion failures after approximately four years of service (February 1966).

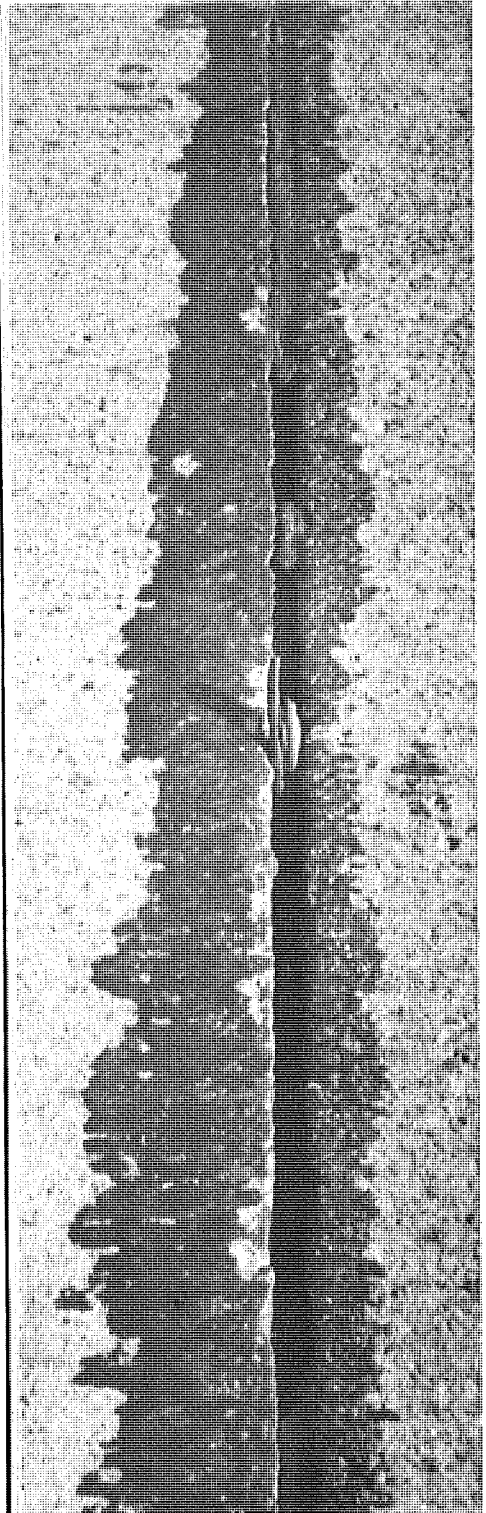
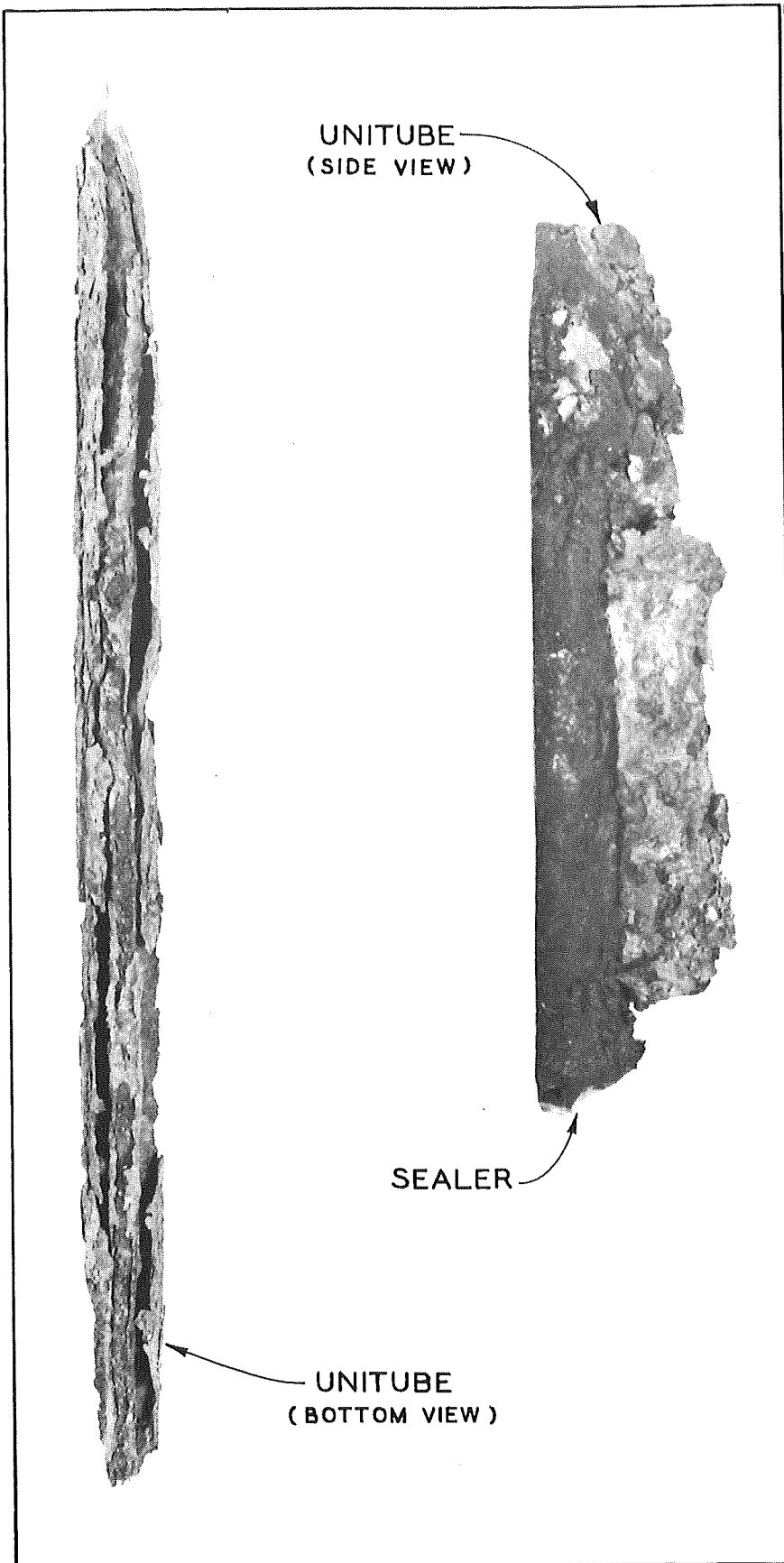


Figure 14. Rusted fragments of Unitube (left). Joint at right was found with portions of sealer and Unitube missing.

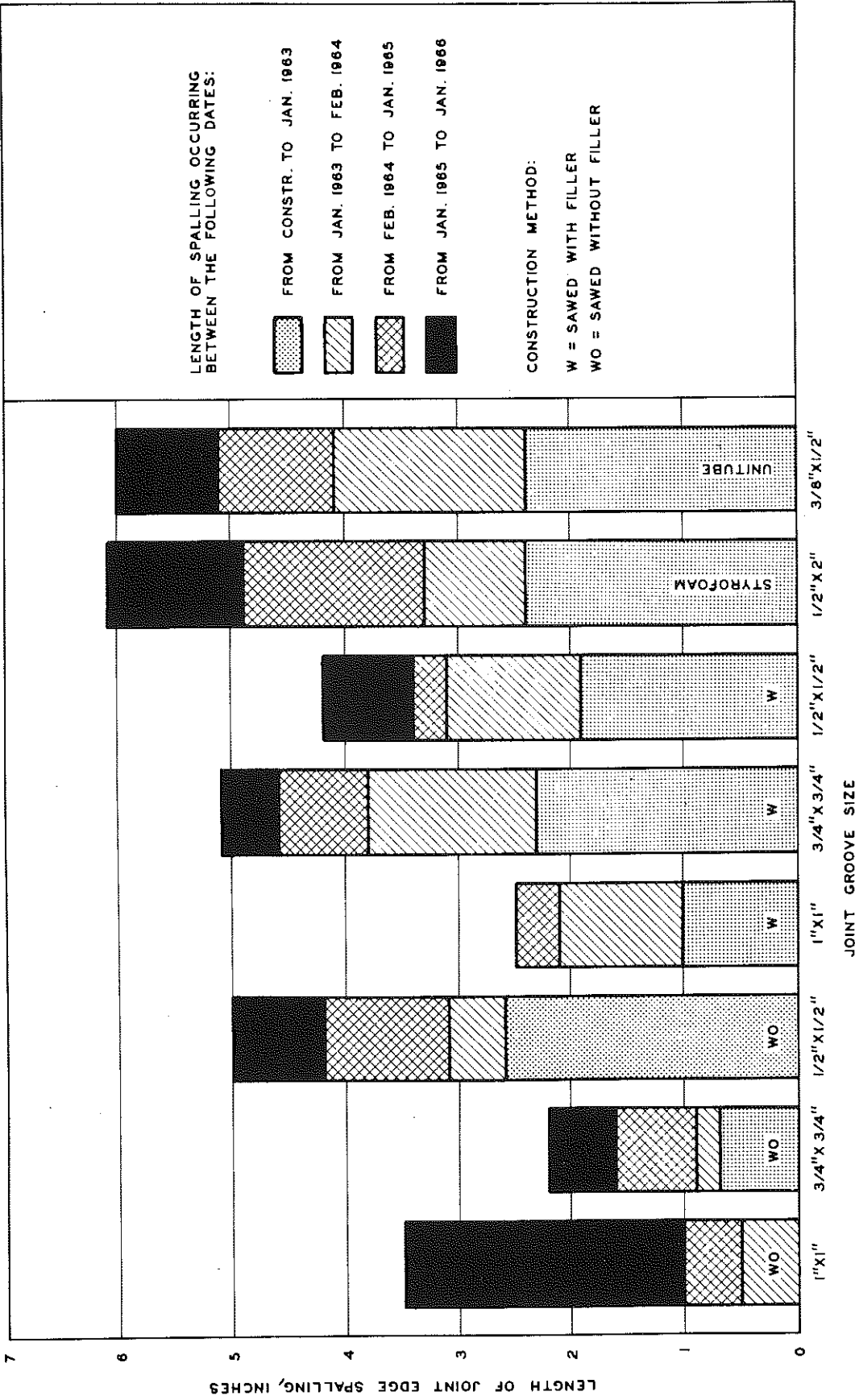


Figure 15. Cumulative length of spalling measured at four intervals of service, in relation to groove size and construction method.

slab length, and joint construction method was used, the type of seal employed appears to effectively prevent infiltration of foreign material into the joint itself for approximately two years only.

Joint Spalling

In evaluating this phase of joint performance the only variables considered were joint construction method and joint groove width. The influence of slab length on joint spalling is thought to be relatively minor and was excluded from this analysis. The cumulative amount of joint groove edge spalling is shown in Figure 15. The observed width of spalls ranged from 1/8 to 1/2 in., with the exception of corner spalls where the maximum width was about 3 in. Because most of the spalls were still in place at the time of inspection, it was difficult to obtain accurate depth measurements. However, no spalls were estimated to exceed 1 in. in depth.

In all cases the total amount of spalling on sawed joint grooves after slightly more than 3 years service was less than on grooves formed by either styrofoam or Unitube. In the sawed groove category, the wider joint grooves, in general, performed best. Sawing the grooves subsequent to forming or cutting of the plane-of-weakness probably absorbs or obliterates any small, initial spalls. Comparing the average total length of spalls on grooves sawed without filler (3.6 in. per joint) to that on grooves sawed with filler (3.9 in. per joint) shows that cutting or forming the plane-of-weakness has little influence on spalling.

The greatest amount of spalling occurred from the time of construction to one month after opening to traffic. Since then the average yearly increase has been about 0.7 in. per joint for sawed grooves and about 1.3 in. per joint for formed grooves. Comparing the amount of spalling on sawed grooves to that on styrofoam formed grooves (1/2- by 2-in. deep) revealed a 52-, 42-, and 26-percent reduction in spalling on 1- by 1-in., 3/4- by 3/4-in., and 1/2- by 1/2-in. sawed grooves, respectively. Spalling on Unitube formed joints was practically equal to that on styrofoam formed joints. Although sawing of joint grooves does not entirely solve the problem of groove edge spalling, it appears to reduce the amount of spalling considerably on grooves of the size considered here. It also appears that the yearly rate of spalling could be reduced by about 50 percent by use of sawing.

Pavement Surface Roughness

Because slab length, groove width, and joint construction method may, in general, have an adverse affect on surface roughness, the roughness

index for each experimental section was measured periodically. Table 2 gives the values for the initial roughness measurements before the pavement was put into service. Subsequent measurements showed little variation in the indices over the past three years.

TABLE 2
ROUGHNESS DATA FOR EXPERIMENTAL SECTIONS

Slab Length	Joint Groove, in.	Joint Forming Method	Roughness, in./mi	
			As Measured	Weighted Arithmetic Mean
99 ft 0 in.	1/2 by 2	Styrofoam ⁽¹⁾	139	139
99 ft 0 in.	1 by 1	Sawed (without Filler Strip) ⁽²⁾	132	139
	1 by 1	Sawed (with Filler Strip) ⁽³⁾	143	
	3/4 by 3/4	Sawed (without Filler Strip) ⁽²⁾	139	
	3/4 by 3/4	Sawed (with Filler Strip) ⁽³⁾	143	
	1/2 by 1/2	Sawed (without Filler Strip) ⁽²⁾	142	
	1/2 by 1/2	Sawed (with Filler Strip) ⁽³⁾	136	
71 ft 2 in.	3/4 by 3/4	Sawed (without Filler Strip) ⁽²⁾	137	139
	3/4 by 3/4	Sawed (with Filler Strip) ⁽³⁾	143	
	1/2 by 1/2	Sawed (without Filler Strip) ⁽²⁾	132	
	1/2 by 1/2	Sawed (with Filler Strip) ⁽³⁾	150	
57 ft 3 in.	3/4 by 3/4	Sawed (without Filler Strip) ⁽²⁾	128	136
	3/4 by 3/4	Sawed (with Filler Strip) ⁽³⁾	135	
	1/2 by 1/2	Sawed (without Filler Strip) ⁽²⁾	133	
	1/2 by 1/2	Sawed (with Filler Strip) ⁽³⁾	140	
	3/8 by 1/2	Unitube	136	

(1) Standard Departmental pavement construction.

(2) 1/8- by 2-in. plane of weakness sawcut, and sawed joint groove.

(3) 1/4- by 2-in. filler strip, and sawed joint grooves.

The Research Laboratory, on the basis of roughness indices, classifies pavements into three riding quality categories: "good" (roughness range 0 to 130 in. per mi), "average" (131 to 174 in. per mi), and "poor" (175 or more in. per mi). According to this classification, all experimental sections are in the "average" category, with the exception of the section containing 57-ft 3-in. slab 3/4- by 3/4-in. groove, and joints constructed by sawing without filler strip, which is in the "good" category. The weighted arithmetic mean roughness index for 99-, 71-, and 57-ft slab lengths in the experimental sections was 139, 139, and 136, respectively, as compared to 139 for the standard constructed pavement section.

Since there is little variation in the roughness indices obtained for the various experimental sections, it appears that the three variables in the experimental pavement do not cause any significant change in the surface roughness.

Transverse Slab Cracks

Cracking caused by flexural stresses resulting primarily from a combination of loads and volume change restraint due to differential temperature and moisture conditions is almost certain to occur, except in slabs of short length. Once a slab has cracked, it is necessary to hold the fractured faces in intimate contact to maintain aggregate interlock and prevent intrusion of foreign material. If the unit weight of concrete and the subgrade friction are assumed constant and for given reinforcement bond and strength characteristics, the required steel percentage increases with slab length.

The portion of the experimental pavement constructed under contract EBI 33084, C5, contained 0.16 percent steel, which is the design requirement for 99-ft slabs. Although 71- and 57-ft slabs were also included in this part of the pavement, the same steel percentage as used with 99-ft slabs was maintained throughout to avoid using three types of reinforcement mats which would probably decrease the construction efficiency. Since the individual test sections were of relatively short length there would be little saved by decreasing the steel percentage in the shorter slabs. Test sections 9E and 0W (Contracts EBI 33084, C7 and 33085, C1, (Federal Project EI 96-3(18)163) Unitube Joints) were constructed with 57-ft slabs exclusively and contained 0.10 percent steel.

Yearly condition surveys were conducted to determine the effect of slab lengths on transverse cracking. The results of the 1966 winter survey are shown in Figure 16 in the form of frequency distribution curves for the percentage of slabs with 0 to 8 cracks per slab for the three different slab lengths containing 0.16 percent steel. The percentage of slabs with no cracks has decreased roughly 27, 40, and 36 percent for 57-, 71-, and 99-ft slabs, respectively, since the 1963 winter survey. A comparison of the percentages of slabs with no cracks in the passing lane with those in the traffic lane shows that a larger number of uncracked slabs are found in the passing lane, possibly because the largest number of heavy vehicles use the traffic lane. The average number of transverse cracks per slab were: 2.5, 1.5, and 0.6 in the traffic lane and 1.8, 0.5, and 0.4 in the passing lane for 99-, 71-, and 57-ft slabs, respectively. The average number of transverse cracks, considering the total slab width, were 2.2, 1.0, and 0.5 for the 99-, 71-, and 57-ft slab lengths, respectively.

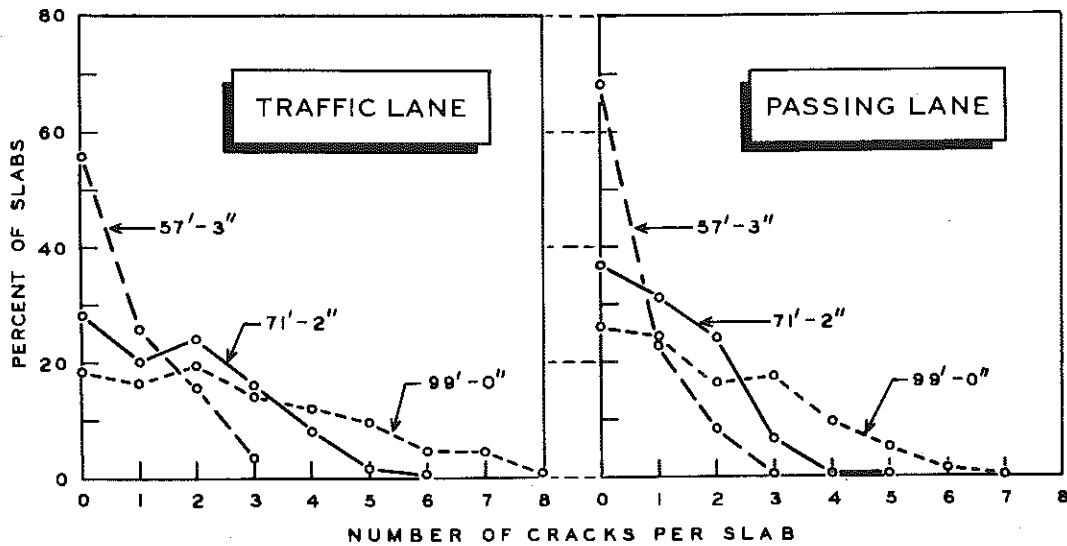


Figure 16. Frequency distribution curves for slab cracking.

SUMMARY

Since the construction of the experimental pavement, Michigan has made three design changes affecting joint performance. Two of these changes, reducing slab length from 99 to 71 ft and sawing joint grooves, were based on data published in an earlier report on performance of the experimental pavement. The third change, sealing the transverse contraction joints with preformed seals, was based on evaluations of hot-poured rubber-asphalt seals on this and other projects. It is believed the combined effect of these changes will considerably reduce the structural weakness of transverse contraction joints.

Based on the sealer evaluation data, there was no basic difference in the performance of the seal in the various test sections. Apparently this is because the bond between seal and concrete is not of sufficient strength to maintain an effective seal even for the smaller extensions experienced with the 57-ft slab lengths. As a result, no specific conclusions can be reached concerning comparable performance of the seals installed in various size grooves, constructed in different manners, and separated by different slab lengths. Several other factors related to the performance of the sealer are summarized as follows:

1. Only minute cohesion failure in the sealer was noted.
2. Seal failure in all cases occurred due to loss of adhesion to the concrete joint groove wall. The failures progressed in depth from year

to year resulting in full depth failure of seals in the 1/2-in. deep grooves after approximately two years of service. All seals had failed full depth at the time of the 3-year survey.

3. Seals subjected to the same amount of extension for their entire length lost adhesion to the groove wall intermittently along the joint. Based on the average length of failure of all joints, the failure observed at each of the four winter surveys was roughly three times greater than the preceding year's value.

4. The sealer hardened as the temperature decreased, which had an adverse effect on its bonding properties at a time when these characteristics are of utmost importance.

5. During periods of cold weather, foreign materials accumulated in the failure openings, in small cracks in the sealer surface, and in the necked-down portion of the seals. This material was then mixed into the sealer during closing of the joints in hot weather.

6. Loss of support under the seals in Unitube formed joints, due to rusting out of the tubes, was noted after three years and resulted in the seals being pulled out by traffic. Where this occurs the joints are exposed to serious infiltration of liquid and solid material.

Estimates of joint groove spalling revealed that sawed joint grooves spalled less than formed grooves. Three years after construction, sawed grooves had 42 percent less spalled length than styrofoam and Unitube formed grooves. Also, the yearly rate of spalling was reduced about 50 percent by use of sawing.

As expected, reduction in slab length reduced transverse slab cracking. The average number of transverse cracks per roadway slab four years after construction was 2.2, 1.0, and 0.5 for 99-, 71-, and 57-ft slabs, respectively. The passing lane contained a greater percentage of uncracked slabs in all three categories. On the average the number of transverse cracks per slab in the passing lane were 28-, 67-, and 33-percent less than in the traffic lane for the 99-, 71-, and 57-ft slabs, respectively.

Based on roughness indices, the use of shorter slabs and wider joint grooves had little effect on the initial pavement surface roughness, and periodic measurements during a three year period after construction showed no significant change in the surface roughness of, or between, the various test sections.

CONCLUSIONS

Although the experimental joint project failed to reveal which combination of groove size and joint spacing would give the most effective seal, the results have demonstrated that the hot-poured rubber-asphalt sealer used has insufficient adhesion capability to maintain a satisfactory seal for any extended period of time for the groove sizes and joint spacings considered in this study. The results indicate that in order to evaluate the effect of groove geometry on sealer performance much shorter joint spacing would be required.

The structural quality of joint grooves was improved by sawing, and initial crack control was maintained without difficulty in sections where a sawed plane of weakness was used. Depending on curing conditions, the initial sawcut can be made from 6 to 24 hr after pouring without excessive ravelling.

Installation of premolded bituminous strips or temporary styrofoam fillers at the joint locations provided effective initial crack control. Based on groove spalling, the grooves sawed over the bituminous filler were of the same structural quality as those where the groove was cut over the sawed plane of weakness. The joint grooves formed by removing the styrofoam filler crumpled at the edges and spalled on the average of 40 percent more than sawed grooves.

The use of Unitubes was an expedient way of establishing crack control, and crimping the tube resulted in neat looking joint grooves. However, the grooves spalled as much as the styrofoam formed grooves and rusting of the tubes below the seal resulted in loose seals being pulled out by traffic.

REFERENCES

1. Tons, Egon, "A Theoretical Approach to Design of a Road Joint Seal." Highway Research Board Bulletin 229, 1959, pp. 20-53.
2. Oehler, L. T., "Michigan's Test Road for Transverse Joints: I 96 from Meridian Road to Wallace Road." MDSH Report No. R-368 (November 1961).

3. Simonsen, J. E., "Construction of Michigan's Experimental Transverse Joint Project: I 96 from Meridian Road to Wallace Road." MDSH Research Report No. R-428 (January 1964).

4. Oehler, L. T., "Progress Report on the Experimental Transverse Joint Project: I 96 from Meridian Road to Wallace Road." MDSH Research Report No. R-452 (February 1964).