# Ten-Year Report on Experimental Continuously-Reinforced Concrete Pavements in New Jersey

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This paper reports on the behavior and performance of two experimental sections of continuously-reinforced concrete pavement constructed in New Jersey in 1947. These sections, each approximately 1 mi long, have been subjected to relatively heavy truck traffic.

The northerly section is of 8-in. uniform thickness, and contains 0.90 percent of longitudinal reinforcing steel. The southerly section is of 10-in. uniform thickness, and contains 0.72 percent of longitudinal steel. In both sections the steel consists of a double line of welded wire fabric.

The paper includes data relative to the recorded changes in length, crack pattern, crack width, behavior of the terminal joints, and the effect of these sections on the adjacent concrete pavement. It also describes the defects which have developed, and compares the performance and cost of these sections with that of the standard design of reinforced concrete pavement constructed on the same route.

●THE FOLLOWING constitutes a report on two experimental sections of continuously-reinforced concrete pavement constructed in New Jersey during the fall of 1947. Two previous reports have been published (1, 2). Although complete details concerning the design, construction and materials may be found in the first report (1), it appears desirable to include certain of this information in this report.

In particular, both sections are located in the northbound roadway of Route 130, in the vicinity of Hightstown, N. J., and were constructed in connection with a project known as Route 25, Sections 25C and 22D. Traffic is one-directional on these sections; northbound only.

The southerly section, which is separated from the northerly section by a series of slabs and a bridge, is 5,130 ft long, of 10-in. uniform thickness, and contains 0.72 percent of longitudinal steel. The outside (travel) lane was constructed during the period September 8-16. During this period the air temperatures, midnight to midnight, ranged from a minimum of 60 F to a maximum of 89 F. The inside (passing) lane was constructed during the period September 23-30, the air temperatures ranging from 36 F to 70 F.

The northerly section is 5,430 ft long, of 8-in. uniform thickness, and contains 0.90 percent of longitudinal steel. The outside lane was constructed during the period October 3-10, the air temperatures ranging from 43 F to 78 F. The inside lane was constructed during the period October 14-20, the air temperatures ranging from 49 F to 79 F.

Both sections have an over-all width of 24 ft, and consist of two 12-ft lanes, constructed independently. The longitudinal joint between the lanes is of the tongue-and-groove type, without tie bars. Because of this absence of tie bars, each lane has been more or less free to expand and contract independently.

The reinforcing steel in both sections consists of a double line of welded wire fabric, in the form of mats 16 ft 3 in. long, installed by the strike-off method. The plans called for the upper line of steel to be 2 in. below the top of the pavement, and for the lower line to be 3 in. above the bottom, in both sections. A 15-in. lap was employed, except on the resumption of work at the construction joints, where a 4-ft lap was employed. During the first four days work the top mats were installed directly above the bottom mats. In the remainder of the work, however, in order to avoid laps in both mats at the same points, the top mats were installed approximately 4 ft to the rear of the bottom mats.

The longitudinal members consist of cold-drawn wire, 3/8 in. in diameter, spaced 3 in. c. to c. Cross-sectionally, there are 94 of these members per lane. The transverse members consist of No. 5 cold-drawn wire, spaced 12.2 in. c. to c. Tests made on representative samples indicated that the longitudinal members had an average ultimate tensile strength of 84,600 psi.

The mats were manufactured shortly before use, so were practically free from rust at the time of their arrival on the project. Between that time and their installation, however, most of the mats did acquire a film of rust, but of only superficial thickness. Whether or not this practically unrusted condition had any material effect on decreasing the bond is highly problematical; but on the basis of cores recently obtained at a number of the cracks, it appears doubtful.

The pavement immediately adjacent to the ends of both sections consists of 10-in. uniform-thickness reinforced concrete, and the terminal joints at the ends of both sections are ordinary dowelled expansion joints. All of these terminal joints are basically the same, except that 3/4-in. wood filler (cypress) was installed at the ends of the 10-in. section, whereas 1/2-in. cork filler was installed at the ends of the 8-in. section.

Both sections were constructed on a layer of high-quality granular subbase material, the thickness of this layer being 12 in. in the case of the 10-in. section ( and also in connection with the conventional concrete pavement incidental to the project) and 14 in. in the case of the 8-in. section. The underlying subgrade soil is of a type that, under the truck traffic at this location, is highly susceptible to pumping.

Figure 1 shows typical cross-sections and incidental construction details.

## CONCRETE DATA

Cement: Lehigh, air-entraining.

Fine aggregate: River glacial sand, and quartz sand.

Coarse aggregate: Diabase trap rock, graded 2¼ in. down.

Proportions (by wt): 1:1.7 5:3.50.

Average slump: 4 in. (high slump specified to facilitate embedment of reinforcing steel.)

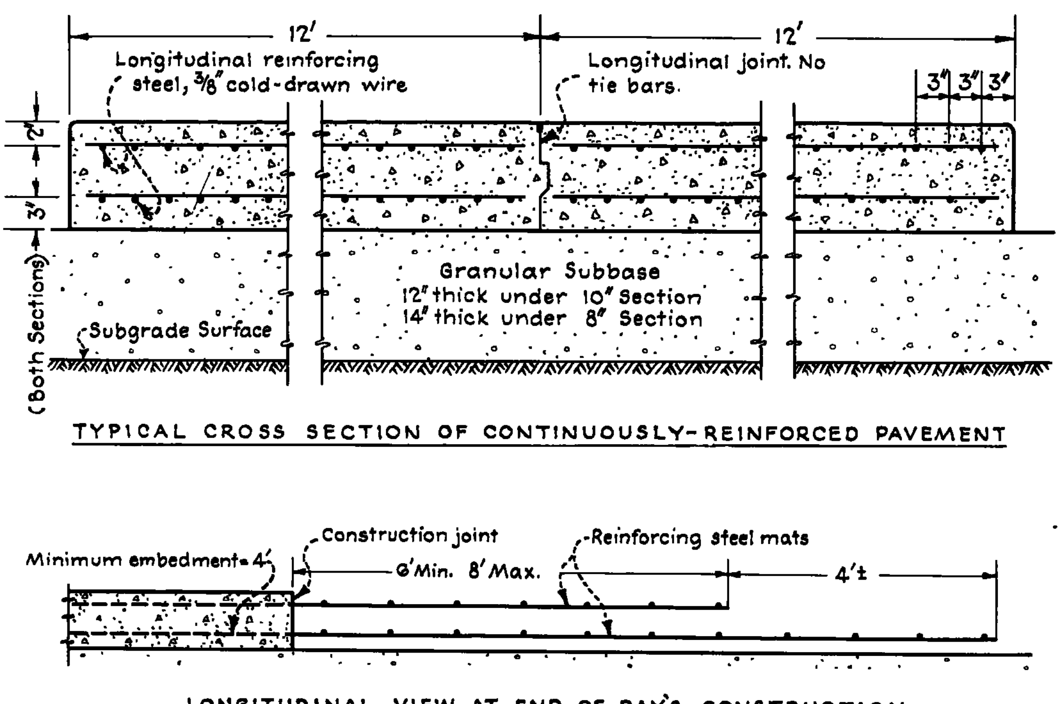


Figure 1.

Curing: "Colorless" membrane spray.

Based on 1957 cores, the concrete has an average compressive strength of about 7,000 psi.

## TEMPERATURE CHANGES

Long-term observations indicate that the concrete pavements on this project have undergone an annual change in temperature ranging from a minimum of about 15 F to a maximum of about 110 F, as recorded, by means of temperature wells, midway between the top and bottom.

## TRAFFIC

Because of the important influence of traffic on the performance of any pavement, it is necessary to point out that Route 130 is the major north-south trucking route in New Jersey and that, as a result, these sections have carried a considerable amount of heavy truck traffic. The type of heavy-trucking unit which predominates in this area is the tractor-semitrailer combination, which in New Jersey may legally have a single-axle load of 22,400 lb and a tandem-axle load of 32,000 lb, plus a 5 percent tolerance above these limits. From 1947 through 1957 approximately 1,600 vehicles of this type traveled over these sections daily.

Of importance is the fact that a recent visual count showed that about 95 percent of the tractor-semitrailers travel in the outside lanes, which appears to be more or less typical of the divided highways in New Jersey. On this basis, the outside lanes of both sections have thus far carried approximately 5,000,000 vehicles of this type. A breakdown of the average daily axle loads induced by these vehicles is given in Table 1. Figure 2 is a general view of the 8-in. section, the heavier travel in the outside lane being apparent from the greater amount of oil and grease stain on that lane.

## BASIC FEATURES

The basic features of a continuously-reinforced concrete pavement are as follows:

1. Installation of a substantially greater amount of longitudinal reinforcing steel than installed in pavements of conventional design.
2. Continuation of the reinforcing steel through the construction joints between the portions of pavement constructed from day to day.
3. Complete omission of transverse joints of any kind, other than the construction joints previously mentioned.

Initially, the function of the reinforcing steel is to induce the occurrence of transverse cracks at relatively close intervals. Subsequently, its function is to prevent these cracks from opening to any detrimental extent, and the success or failure of the pavement depends primarily on the ability of the steel to do so.

TABLE 1

AVERAGE DAILY AXLE LOADS
(Tractor-Semitrailers Only)

| Load (lb) | Number of Single Axles 1950 | Single Axles 1956 | Tandem Axles 1950 | Tandem Axles 1956 |
|---|---|---|---|---|
| Total, all weights | 4,660 | 3,717 | 560 | 1,053 |
| 16,000 and over | 1,980 | 1,270 | 524 | 926 |
| 20,000 and over | 1,020 | 648 | 490 | 871 |
| 22,000 and over | 515 | 458 | 438 | 791 |
| 24,000 and over | 276 | 229 | 393 | 749 |
| 28,000 and over | 50 | 38 | 257 | 551 |
| 32,000 and over | 8 | 0 | 92 | 320 |
| 36,000 and over | 0 | 0 | 6 | 65 |
| 40,000 and over | 0 | 0 | 0 | 8 |
| 44,000 and over | 0 | 0 | 0 | 0 |

## LONGITUDINAL MOVEMENTS, 10-INCH SECTION

During construction, to determine periodically the magnitude of the longitudinal changes in position at various locations, monumented transverse reference lines were installed at (a) the ends of the sections, (b) points 200, 500, 700, 900, 1,400 and 2,000 ft from the ends, and (c) points midway between the ends. At the time of initial set of the concrete, brass plugs having well-defined center points were installed in the pavement, as precisely as possible on the reference lines.

Subsequently, measurement has involved setting a transit on a given reference line and measuring the offset of the pavement plug, from the reference line, with an engineer's scale. From a purely scientific standpoint this method might not be as precise as desired. But in view of the care exercised in taking these measurements, it is doubted whether the maximum error exceeds 0.04 in. A few of the reference-line monuments have been destroyed by roadside developments, but most of the important monuments are still intact.

The changes in longitudinal position recorded at various points in the 10-in. section are shown in Table 2, which also shows the changes in width recorded at the terminal joints,

In view of the erratic nature of certain of these changes, it is necessary to point out that:

1. Owing to the variations in weather conditions from day to day, certain portions of this section were necessarily constructed at somewhat different temperatures than other portions. When the pavement eventually attained a more or less uniform temperature throughout, this variation in "as-constructed" temperature probably resulted in the development of a differential internal stress condition, which in turn possibly resulted in some longitudinal rearrangement of the various portions of the section. This may account for the small, erratic changes in position recorded at the points within the central region.

2. As will be noted, on January 29, 1948, due to inward movements at the ends

Figure 2. Eight-inch section looking north.

ranging from 0.64 in. to 1.00 in., the terminal joints had undergone an opening ranging from 0.67 in. to 1.18 in. This large amount of opening resulted in complete failure of the joint sealer and, in turn, infiltration of considerable quantities of sand and gravel into the terminal joints. With yearly repetitions of this cycle there has been a further infiltration of solid material. There has also been a progressive loss in the thickness of the joint filler, which now appears to have been compressed to the point of refusal. For these reasons it appears that at present there is far greater restraint to the expansion of this section than existed originally.

3. In May 1949 a localized area in the outside lane, approximately 1,430 ft from the south end, began to undergo failure. In December 1951 the failure had progressed to the point where it became necessary to remove the damaged concrete. This work, which also involved removal of the reinforcing steel, resulted in (a) creation of an open space about 7 ft wide for the full width of the lane, and (b) creation of two free ends. As a temporary measure the space was filled with crushed stone topped with bituminous material. In October 1954 these materials were removed and replaced with concrete, which was securely joined with the existing concrete by means of the reinforcing steel. In conjunction with this work a dowelled expansion joint with 3/4-in. bituminized-fiber filler was installed at the center of the repaired area.

In May 1949, in view of the probability of complete failure at this point, a supplementary reference line was installed 20 ft to the north (shown in Table 2 as 1,450 ft from the south end).

It is apparent that, owing to this occurrence and the work performed the outside lane has been divided into two sections 1,430 and 3,700 ft long. The inside lane, however, is still intact. In any event, this constitutes the reason for the considerable difference in movement recorded since 1949 for the inside and outside lanes in the vicinity of this area.

The maximum inward and outward movements, and the total range of movement, recorded at the ends of this section are as follows:

| Lane | Movement of 10-in. Section (in.) | | | | | |
|---|---|---|---|---|---|---|
| | South End | | | North End | | |
| | Max. Inward | Max. Outward | Total Range | Max. Inward | Max. Outward | Total Range |
| Inside | 0.68 | 0.29 | 0.97 | 0.72 | 0.23 | 0.95 |
| Outside | 0.96 | 0 | 0.96 | 1.00 | 0.03 | 1.03 |

The maximum recorded over-all changes in length of the inside and outside lanes of this section have been, respectively, 1.92 and 1.99 in.

Certain data worthy of note in Table 2 are as follows:

1. All of the terminal joints have undergone an appreciable increase in width, but the amount varies from joint to joint. The greatest increase has occurred at the joint at the north end of the outside lane, which on June 20, 1957, was 1.05 in. wider than at the time of construction, despite a 92 F pavement temperature. There appears to be little doubt that these increases have been due primarily to the infiltration of solid materials into these joints while in an open condition during cold weather.

2. On November 29, 1950, the north end of the outside lane was 0.62 in. south of its as-constructed position. This was also the case on June 20, 1957, despite a 53 F higher pavement temperature. It consequently appears that in this location the outside lane is now being prevented from expanding normally, owing to the impacted condition of the end joint, plus refusal of the adjacent pavement to be displaced.

3. In certain locations the longitudinal movements of the inside lane have differed appreciably from those of the outside lane, especially at (a) the ends of the section and for several hundred feet adjacent thereto, and at (b) the failure in the outside lane and for several hundred feet on each side of this failure. Inasmuch as these differential movements have necessarily involved slippage between the lanes, along the longitudinal joint,

TABL

10" SE

LONGITUDINAL MOVEMENTS AT TRANSVERSE REFERENCE

| Date | Slab Temp | Lane | End Joint | ← South |  |  |  |  |  | Distance |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | 0 | 200 | 500 | 700 | 900 | 1400 | 1450 |
| As Constructed | Var | Both | 0 | 0 | 0 | 0 | 0 | 0 | 0 | — |
| Nov. 13, 1947 | 46° | Inside | + .28 | .30 → | .08 → | .01 → | — | — | — | — |
|  |  | Outside | + .52 | .42 → | .10 → | .01 → | — | — | — | — |
| Jan 29, 1948 | 35° | Inside | + .67 | .64 → | — | .12 → | — | — | — | — |
|  |  | Outside | + .98 | .89 → | — | .10 → | — | — | — | — |
| July 20, " | 91° | Inside | + .22 | ← .20 | ← .05 | .07 → | .03 → | ← .04 | .03 → | — |
|  |  | Outside | + .09 | .06 → | .10 → | .07 → | — | .03 → | .07 → | — |
| Dec. 27, " | 28° | Inside | + .70 | — | — | — | — | — | — | — |
|  |  | Outside | +1.00 | — | — | — | — | — | — | — |
| June 24, 1949 | 99° | Inside | + .01 | ← .17 | — | — | — | — | — | — |
|  |  | Outside | + 38 | .22 → | — | — | — | — | — | — |
| Jan. 23, 1950 | 41° | Inside | + .69 | .41 → | .17 → | .08 → | — | .01 → | 0 | — |
|  |  | Outside | + .96 | .70 → | .34 — | .09 → | — | 01 → | 03 → | — |
| Oct 6, " | 69° | Inside | + .47 | .09 → | 0 | 0 | — | ← .02 | .02 → | — |
|  |  | Outside | + .77 | 43 → | .21 → | .02 → | — | .06 → | 06 → | — |
| Nov. 29, " | 39° | Inside | + .86 | 43 → | .10 → | — | .06 → | — | — | — |
|  |  | Outside | +1.07 | .73 → | .28 → | — | — | — | — | — |
| July 12, 1951 | 88° | Inside | + .26 | ← .19 | ← .04 | .08 → | .08 → | ← .02 | .02 → | — |
|  |  | Outside | + 71 | .32 → | 27 → | .12 → | — | .09 → | .18 → | ← .1 |
| Feb. 1, 1952 | 34° | Inside | +1.01 | .68 → | — | — | — | — | .08 → | — |
|  |  | Outside | +1.22 | .96 → | — | — | — | — | ← .12 | .80 → |
| June 10, " | 90° | Inside | + .36 | ← .12 | ← .04 | .08 → | .07 → | 0 | .04 → | — |
|  |  | Outside | + .76 | .37 → | .24 → | .12 → | — | .13 → | .63 → | ← .8 |
| June 5, 1953 | 84° | Inside | + .40 | — | — | — | — | — | — | — |
|  |  | Outside | + .78 | — | — | — | — | — | — | — |
| Oct. 24, 1955 | 71° | Inside | + .70 | ← .06 | — | — | — | — | — | — |
|  |  | Outside | + .90 | .42 → | — | — | — | — | — | — |
| Jan. 31, 1956 | 40° | Inside | +1.27 | — | — | — | — | — | — | — |
|  |  | Outside | +1.35 | — | — | — | — | — | — | — |
| Oct. 5, " | 70° | Inside | + .77 | ← .04 | ← .04 | .12 → | .06 → | 0 | ← .02 | — |
|  |  | Outside | +1 01 | .36 → | .22 → | .16 → | — | 36 → | .89 → | ← 1.0 |
| Feb 25, 1957 | 50° | Inside | +1.12 | .34 → | — | 06 → | .02 → | 0 | ← .04 | — |
|  |  | Outside | +1.26 | .71 → | — | .20 → | — | .29 → | .29 → | ← .4 |
| June 20, " | 92° | Inside | + .53 | ← .29 | ← .17 | 0 | .04 → | ← .02 | .04 → | — |
|  |  | Outside | + .90 | .34 → | .22 → | .18 → | — | 35 → | 1.10 → | ← 1.0 |

[1] See text.
[2] Actual width of joint space at end joints is obtained by adding 0.50 to changes shown.
[3] Reference line destroyed.

it is speculative whether the installation of tie bars would have proved beneficial, detrimental, or of no apparent consequence.

The movements at the points 1,400 and 1,450 ft from the south end in the outside lane are of particular interest, because these points are immediately south and north, respectively, of the failure which occurred in this lane. As will be noted, on June 20, 1957, these points were 2.19 in. closer together than they were originally. It will also be noted that for a distance of at least 550 ft both north and south of the point of failure the outside lane has undergone an appreciable movement toward the point of failure. Presumably this indicates two things—that this lane has tended to undergo an increase in length, and that there have been times when this lane has been under considerable compression.

## LONGITUDINAL MOVEMENTS, 8-INCH SECTION

The changes in longitudinal position recorded at various points in the 8-in. section are shown in Table 3, which also shows the changes in width recorded at the terminal joints.

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ION

.INES, AND CHANGES IN WIDTH OF END JOINTS (in.)

| from End (feet) | | | | | | | | North → | End Joint |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 2565 | 2000 | 1400 | 900 | 700 | 500 | 200 | 0 | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| — | — | — | — | — | .08 → | .05 → | ← .10 | ← .29 | +.30 |
| — | — | — | — | — | .06 → | .09 → | ← .10 | ← .43 | +.52 |
| — | — | — | — | — | — | — | ← .40 | ← .72 | +.88 |
| — | — | — | — | — | — | — | ← .47 | ← 1.00 | +1.18 |
| ← .01 | 0 | .03 → | 0 | .04 → | .10 → | * | 0 | .23 → | -.18 |
| 0 | .02 → | .03 → | .04 → | .03 → | .09 → | * | ← .05 | .03 → | +.02 |
| — | — | — | — | — | — | — | — | — | +.83 |
| — | — | — | — | — | — | — | — | — | +1.08 |
| — | — | — | — | — | — | — | — | — | -.02 |
| — | — | — | — | — | — | — | — | — | -.30 |
| 0 | ← .05 | * | * | .09 → | .15 → | — | ← .12 | ← .30 | +.65 |
| .03 → | 0 | * | * | .08 → | .13 → | — | ← .22 | ← .58 | +1.01 |
| ← .03 | ← .02 | — | — | .10 → | .08 → | — | ← .01 | .08 → | +.28 |
| 0 | 0 | — | — | .10 → | .05 → | — | ← .12 | ← .21 | +.68 |
| — | — | — | — | — | — | — | ← .08 | ← .33 | +.75 |
| — | — | — | — | — | — | — | ← .18 | ← .62 | +1.16 |
| .02 → | 0 | — | — | .10 → | * | — | .08 → | .20 → | +.16 |
| .05 → | .04 → | — | — | .10 → | * | — | ← .09 | ← .14 | +.63 |
| — | — | — | — | — | — | — | — | ← .54 | +.90 |
| — | — | — | — | — | — | — | — | ← .85 | +1.34 |
| ← .02 | ← .03 | — | — | .05 → | — | — | ← .02 | 10 → | +.29 |
| 0 | 0 | — | — | .06 → | — | — | ← .18 | ← .28 | +.91 |
| — | — | — | — | — | — | — | — | — | +.37 |
| — | — | — | — | — | — | — | — | — | +.86 |
| — | — | — | — | — | — | — | — | ← .16 | +.45 |
| — | — | — | — | — | — | — | — | ← 54 | +1.01 |
| — | — | — | — | — | — | — | — | — | +.07 |
| — | — | — | — | — | — | — | — | — | +1.51 |
| 0 | ← .02 | — | — | 13 → | — | — | ← .12 | ← .11 | +.37 |
| ← .25 | ← .02 | — | — | .14 → | — | — | ← .35 | ← .59 | +1.05 |
| — | — | — | — | .10 → | — | — | ← .26 | ← .39 | +.73 |
| — | — | — | — | .12 → | — | — | ← .46 | ← .84 | +1.32 |
| 0 | ← .10 | — | — | .16 → | — | — | ← .05 | ← .05 | +.30 |
| ← .23 | ← .10 | — | — | .18 → | — | — | ← .31 | ← .62 | +1.05 |

As in the case of the 10-in. section, in considering the changes shown in Table 3 it is necessary to bear in mind (a) the variations in as-constructed temperature from day to day, and (b) the infiltration of large amounts of sand and gravel into the terminal joints. In addition, there have been two serious failures in the outside lane. The first of these failures, 569 ft from the north end, became evident in the spring of 1951; the second, 372 ft from the north end, in the spring of 1952.

In October 1954 the damaged concrete in these areas was removed and replaced with new concrete. In conjunction with this work a dowelled expansion joint with 3/4-in. bituminized-fiber filler was installed at the center of each of these areas. Consequently, since October 1954 the outside lane has consisted of three independent sections (from south to north, 4,861, 197, and 372 ft long). The inside lane, however, is still intact.

The maximum inward and outward movements, and the total range of movement, recorded at the ends of this section are as follows:

TABLE 3

8" SECTION

LONGITUDINAL MOVEMENTS AT TRANSVERSE REFERENCE LINES, AND CHANGES IN WIDTH OF END JOINTS (in.)

| Date | Slab Temp | Lane | End Joint | ← South 0 | 200 | 500 | 700 | 900 | 1400 | Distance from End (feet) 2000 | 2715 | 2000 | 1400 | 900 | 700 | 500 | 200 | North → 0 | End Joint |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| As constructed | Var | Both | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nov 13, 1947 | 46° | Inside | + 33 | 22 → | 02 → | — | — | — | — | — | — | — | — | — | — | — | ← 02 | ← 24 | + 28 |
| | | Outside | + 30 | 23 → | 0 | — | — | — | — | — | — | — | — | — | — | — | 0 | ← 25 | +.22 |
| Feb 1, 1948 | – | Inside | + 97 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | +.86 |
| | | Outside | + 94 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | +.87 |
| July 22, " | 83° | Inside | – 06 | ← 20 | ← 09 | 07 → | 03 → | 04 → | 04 → | .03 → | 0 | 03 → | 04 → | .02 → | 0 | 0 | 11 → | 20 → | – 10 |
| | | Outside | – 01 | ← .13 | ← 06 | 03 → | .03 → | 05 → | 0 | ← 03 | ← 02 | 03 → | 02 → | ← 01 | 02 → | 0 | 08 → | 21 → | – 06 |
| Dec 27, " | 28° | Inside | + .88 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | +.80 |
| | | Outside | + 93 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | +.89 |
| June 24, 1949 | 99° | Inside | – 04 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | – 20 |
| | | Outside | + 09 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | + 02 |
| Jan 26, 1950 | 53° | Inside | + 52 | 17 → | .06 → | .02 → | ← .01 | .10 → | 01 → | 01 → | 02 → | .04 → | .04 → | 04 → | 0 | 05 → | ← 10 | ← .23 | +.47 |
| | | Outside | + 68 | 27 → | 07 → | 04 → | 0 | .11 → | 02 → | 0 | ← .02 | 04 → | .03 → | .01 → | 02 → | 07 → | ← .05 | ← .26 | +.67 |
| Oct 10, " | 73° | Inside | + 47 | .04 → | 02 → | * | 0 | 04 → | 07 → | 04 → | 0 | 07 → | 10 → | .12 → | ← .02 | .08 → | 17 → | .17 → | + 07 |
| | | Outside | + .62 | 12 → | 0 | * | 0 | 04 → | 02 → | ← 03 | 0 | 07 → | 10 → | 10 → | 01 → | .07 → | 20 → | 15 → | + 46 |
| Nov 29, " | 40° | Inside | + .88 | .32 → | 04 → | — | 03 → | — | — | — | — | — | — | — | ← 04 | — | 06 → | ← 19 | +.51 |
| | | Outside | +1.00 | 37 → | 07 → | — | 04 → | — | — | — | — | — | — | — | 0 | — | 04 → | ← .17 | + .87 |
| July 31, 1951 | 88° | Inside | + .47 | ← .13 | ← 19 | — | .08 → | 08 → | 07 → | 10 → | 03 → | 03 → | 0 | 02 → | 0 | 10 → | 25 → | .35 → | – 15 |
| | | Outside | + .67 | ← 02 | ← 12 | — | 09 → | 10 → | 02 → | 0 | 01 → | 02 → | 0 | ← 01 | 03 → | .06 → | 22 → | 32 → | + 35 |
| Feb. 20, 1952 | 44° | Inside | +1.12 | .45 → | .16 → | — | 05 → | 05 → | 08 → | .10 → | 03 → | 03 → | .03 → | .03 → | ← .05 | 02 → | ← 03 | ← 28 | + 50 |
| | | Outside | +1.24 | 51 → | .16 → | — | 08 → | .06 → | 03 → | .02 → | .01 → | 03 → | .05 → | .01 → | 0 | .07 → | ← .01 | ← 22 | + .90 |
| June 3, " | 88° | Inside | + .68 | ← .13 | ← 12 | — | ← 02 | .03 → | 06 → | 04 → | ← .02 | 03 → | 0 | 04 → | ← 01 | .05 → | 23 → | 30 → | + 05 |
| | | Outside | +1.01 | .04 → | ← 02 | — | 0 | 05 → | 02 → | ← 05 | ← .03 | 03 → | .02 → | 01 → | 05 → | 10 → | 22 → | 26 → | + .55 |
| June 5, 1953 | 84° | Inside | + 75 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | + .28 |
| | | Outside | +1.12 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | + 65 |
| Oct 24, 1955 | 71° | Inside | +1 16 | ← .06 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | | Outside | +1.60 | .08 → | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Jan 31, 1956 | 40° | Inside | +1 60 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | +1.22 |
| | | Outside | +1 98 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | +1 28 |
| Oct. 10, " | 61° | Inside | +1 18 | ← .06 | ← 14 | — | ← .01 | .10 → | 10 → | 05 → | 02 → | 02 → | 02 → | 0 | ← 02 | .10 → | 17 → | .16 → | + .97 |
| | | Outside | +1 76 | .12 → | ← 04 | — | 0 | .10 → | .04 → | 01 → | ← 01 | 01 → | 04 → | 06 → | 18 → | .10 → | 11 → | .13 → | +1.13 |
| Feb 25, 1957 | 52° | Inside | +1 40 | 22 → | — | — | 02 → | 10 → | — | — | — | — | — | 10 → | ← 04 | .02 → | — | ← 07 | +1 20 |
| | | Outside | +1 95 | 34 → | — | — | 04 → | .10 → | — | — | — | — | — | 13 → | .06 → | .10 → | — | 04 → | +1 24 |
| June 20, " | 94° | Inside | + 68 | ← 49 | ← 33 | — | ← 01 | 08 → | 04 → | .01 → | .10 → | 07 → | 01 → | 07 → | 11 → | .12 → | 32 → | 44 → | + .67 |
| | | Outside | +1 61 | ← 08 | ← .16 | — | 01 → | .10 → | ← 02 | ← 01 | 05 → | 08 → | 01 → | 18 → | 29 → | 14 → | .14 → | 29 → | +.93 |

[1] See text.

[2] Actual width of joint space at end joints is obtained by adding 0.50 to changes shown.

[3] Reference line destroyed

| Lane | Movement of 8-in. Section (in.) | | | | | |
|---|---|---|---|---|---|---|
| | South End | | | North End | | |
| | Max. Inward | Max. Outward | Total Range | Max. Inward | Max. Outward | Total Range |
| Inside | 0.45 | 0.49 | 0.94 | 0.28 | 0.44 | 0.72 |
| Outside | 0.51 | 0.13 | 0.64 | 0.26 | 0.32 | 0.58 |

The maximum over-all recorded changes in length of the inside and outside lanes of this section have been, respectively, 1.66 and 1.22 in.

Certain data worthy of note in Table 3 are as follows:

1. All terminal joints have undergone an appreciable increase in width. As in the case of the 10-in. section, there appears to be little doubt that these increases have been due primarily to infiltration of solid materials into these joints while in an open condition during cold weather.

2. The greatest increase in width has occurred at the joint at the south end of the outside lane, which on June 20, 1957, was 1.61 in. wider than at the time of construction, despite a 94F pavement temperature. Conditions at this joint on August 7, 1957, are shown in Figure 3, a portion of the joint space having been cleaned out. As will be noted, the joint space was found to be completely filled with infiltrated sand and gravel, in combination with the cork filler, which had become compressed to the point of refusal. These infiltrated materials were in a highly compacted condition.

3. Corresponding with the behavior of the 10-in. section, the longitudinal movements

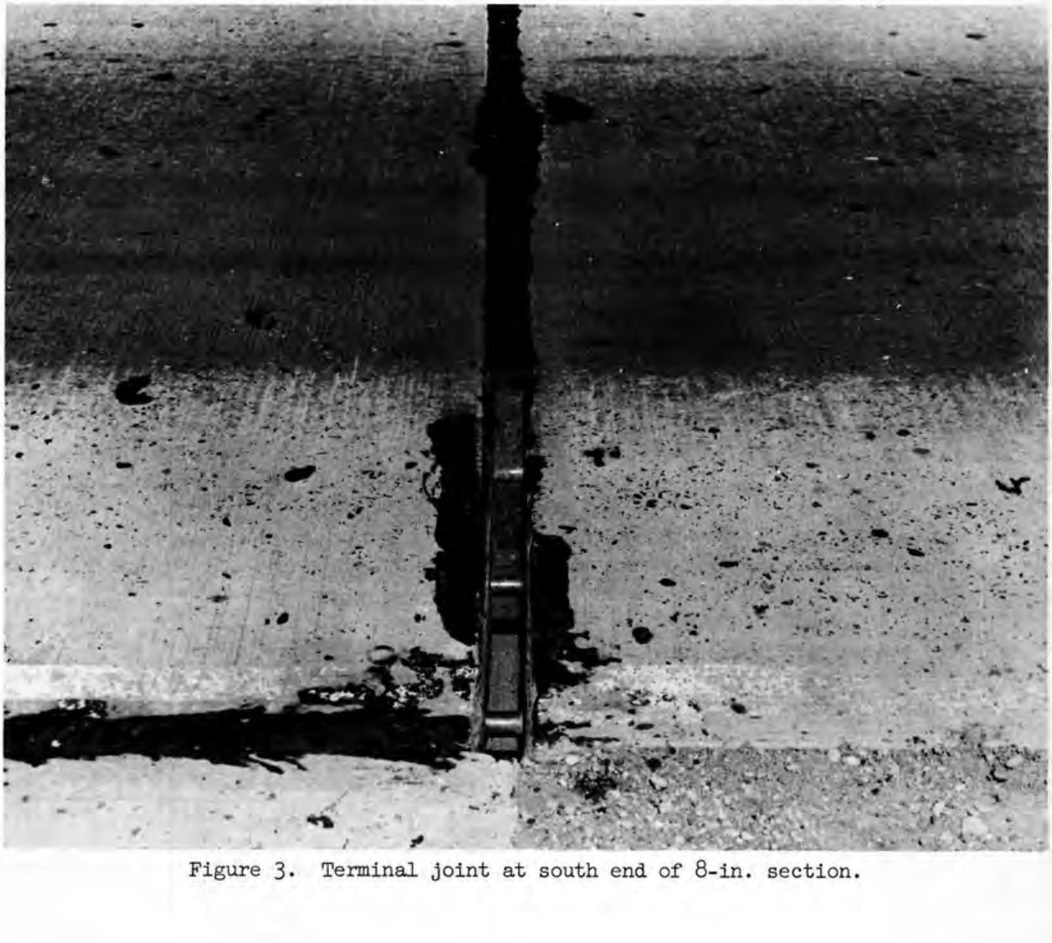
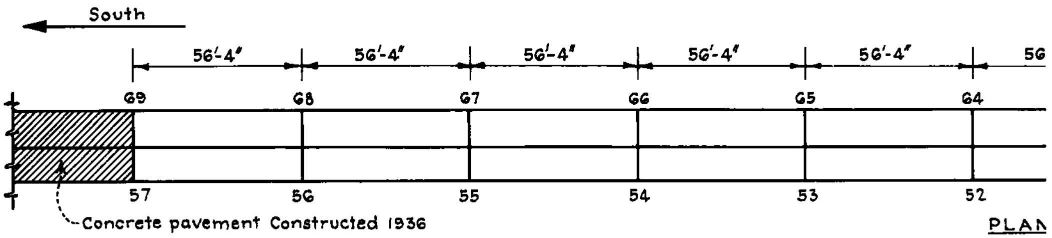


Figure 3. Terminal joint at south end of 8-in. section.




CHANGES IN JOINT

| Date | Slab Temp | Inside Lane | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | G9 | G8 | G7 | G6 | G5 | G4 | G3 | 12 |
| | | No filler | ¾" Wood | ¾" Wood | ¾" Wood | ¾" Wood | ¾" Wood | ¾" Wood | ¾" Wood |
| As Constructed | Var | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jan 24, 1948 | 35° | + 11 | + 11 | +.12 | +.12 | +.10 | +.10 | +.11 | +.16 |
| May 10, " | 78° | + 09 | -.08 | -.02 | -.03 | - 02 | - 02 | -.04 | +.01 |
| July 15, " | 92° | +.04 | -.26 | -.08 | - 08 | - 07 | -.07 | - 09 | - 11 |
| Aug 27, " | 100° | +.09 | -.50 | -.10 | -.10 | -.08 | -.09 | -.10 | -.15 |
| Dec 27, " | 28° | - | - | - | - | - | - | - | - |
| Oct 10, 1950 | 78° | +.30 | - 32 | - 04 | -.04 | -.05 | - 05 | -.08 | - 27 |
| Feb 5, 1951 | 35° | - | - | - | - | - | + 06 | +.03 | -.14 |
| Oct 29, " | 65° | +.38 | -.31 | -.01 | -.01 | +.01 | -.01 | -.06 | -.24 |
| June 10, 1952 | 93° | +.38 | -.42 | -.10 | -.10 | - 07 | -.11 | -.16 | - 37 |
| June 5, 1953 | 84° | +.42 | -.44 | -.11 | -.11 | -.08 | -.14 | -.20 | - 38 |
| Jan 31, 1956 | 39° | +.56 | -.35 | 0 | +.01 | +.04 | -.05 | -.15 | - 25 |
| Dec 28, " | 38° | +.60 | -.39 | -.01 | -.02 | +.02 | - 07 | -.17 | - 27 |
| June 21, 1957 | 94° | + 50 | -.51 | - 16 | -.20 | -.14 | -.21 | -.30 | -.42 |
| | | | | | | | | | |
| | | | | | | | | | |
| June 21, 1957 compared with July 15, 1948 | | +.46 | -.25 | -.08 | -.12 | - 07 | -.14 | -.21 | -.31 |

Figure 4. Pavement adjacent to south end of

of the inside lane in certain locations have differed appreciably from those of the outside lane.

## EFFECT ON ADJACENT PAVEMENT

Figures 4 to 7 show the pavement adjacent to the ends of the sections, and the engineer's stations of the ends. They also show the recorded changes in width of (a) the joints in this pavement, and (b) the terminal joints.

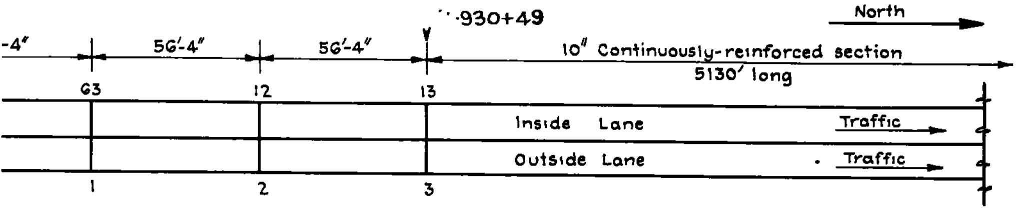
It will be seen that in conjunction with the increase in width of the terminal joints there has been, with certain exceptions, a decrease in the width of the expansion joints in the adjacent pavement. Analysis of the reference-line and joint-width measurements has shown that these sections have exerted pressure on the adjacent pavement, and that this pressure has caused the adjacent pavement to be displaced in various amounts.

During the summer of 1957 the displacements that had taken place in connection with the slabs immediately adjacent to the ends of these sections were approximately as follows:

| Lane | Outward Displacement of Adjacent Slabs (in.) | | | |
|---|---|---|---|---|
| | 10-Inch Section | | 8-Inch Section | |
| | South End | North End | South End | North End |
| Inside | 0.82 | 0.25 | 1.17 | 1.11 |
| Outside | 0.56 | 0.43 | 1.69 | 1.22 |

It will be noted that:

1. The displacements have been extremely variable, the range being from 0.25 to 1.69 in.




WIDTH (Inches)

| 13 | 57 | 56 | 55 | 54 | 53 | 52 | 1 | 2 | 3 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Outside Lane | | | | | | | | | |
| 13 | 57 | 56 | 55 | 54 | 53 | 52 | 1 | 2 | 3 | ← Joint Number |
| 3/4" Wood | No filler | 3/4" Wood | 3/4" Wood | 1" Wood | 3/4" Wood | 3/4" Wood | 3/4" Wood | 3/4" Wood | 3/4" Wood | ← Joint Filler |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| +.67 | + 17 | +.08 | +.13 | +.11 | + 10 | +.11 | +.19 | +.22 | + 98 | |
| +.03 | +.07 | -.06 | -.02 | - 02 | -.01 | -.03 | +.06 | + 07 | +.41 | |
| - 22 | + 06 | -.22 | -.10 | -.09 | -.06 | -.10 | + 01 | -.02 | +.09 | |
| - 26 | + 06 | -.26 | -.13 | -.11 | - 08 | -.12 | 0 | -.05 | +.06 | |
| +.70 | - | - | - | - | - | +.14 | +.22 | +.23 | +1.00 | |
| +.33 | +.19 | -.22 | -.01 | -.08 | 0 | -.09 | +.04 | -.10 | +.67 | |
| + 87 | - | - | - | - | - | +.02 | +.15 | +.01 | +1.16 | |
| + 07 | +.18 | -.20 | -.06 | -.05 | +.04 | -.06 | +.07 | -.07 | +.84 | |
| +.36 | +.13 | -.30 | -.14 | -.14 | +.04 | - 19 | -.03 | -.19 | +.76 | |
| +.40 | +.14 | -.31 | -.14 | - 13 | -.04 | -.21 | -.04 | -.21 | +.78 | |
| +1.27 | +.16 | -.18 | 0 | -.01 | +.08 | -.05 | +.07 | -.13 | +1.35 | |
| +1.15 | + 18 | -.21 | -.02 | -.02 | +.07 | -.07 | +.06 | -.15 | +1.26 | |
| +.52 | +.09 | - 35 | -.16 | -.17 | -.07 | -.25 | -.09 | -.28 | +.89 | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| +.74 | +.03 | -.13 | -.06 | - 08 | -.01 | -.15 | -.10 | -.26 | +.80 | |

10-in. continuously-reinforced section.

2. The least displacement has occurred at the north end of the inside lane of the 10-in. section.

3. The displacements in connection with the 8-in. section have been considerably greater than in connection with the 10-in. section.

This erratic behavior has apparently been due to the influence of several factors, as follows:

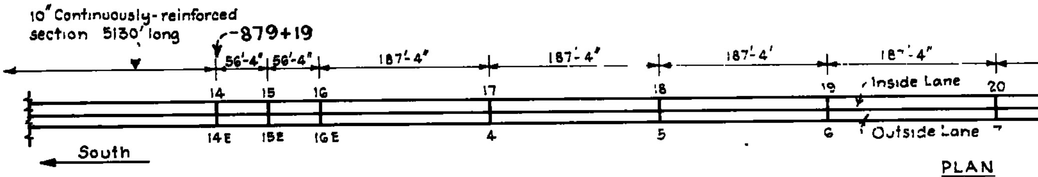
1. Differences in the as-constructed temperatures of the lanes.

2. Differences in the amount of solid material which has accumulated in the terminal joints.

3. Wood joint filler was used in connection with the pavement adjacent to the 10-in. section, whereas cork filler was used in the pavement adjacent to the 8-in. section. Of these two materials, wood offers far more resistance to compression, therefore the pavement adjacent to the 10-in. section has offered considerably more resistance to displacement.

With reference to the relatively small displacement of the slabs immediately adjacent to the north end of the 10-in. section, it is to be noted that the adjacent pavement consists of two 56-ft slabs, which are in turn followed by eight 187-ft slabs, in each lane. And from the tabulation in Figure 5 it will be noted that the joints between the 187-ft slabs have undergone an increase in width and that, conversely, the joints between the 56-ft slabs, both north and south of the 187-ft slabs, have undergone a decrease in width.

From this it is apparent that this series of 187-ft slabs has tended to undergo an increase in length; which, in fact, has actually occurred. At the north, this action has resulted in movement of the 56-ft slabs and the approach slabs, toward the bridge over




PLAN

CHANGES IN JOINT

| Date | Slab Temp | Inside Lane | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 54W | 53W | 52W |
| | | 3/4" W | 3/4 W | 3/4" W | 3/4" W | 3/4" W | 3/4" W | 3/4" W | 3/4" W | 3/4" W | 3/4" W | 1/2" C | 1" C | 1" C | 1" C |
| As Constructed | Var | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jan 26, 1948 | 24° | +.89 | +.15 | +.32 | +.42 | - 52 | +.45 | +.49 | + 57 | +.47 | + 56 | +.13 | + 07 | + 10 | + 12 |
| Aug 27, " | 100° | - 20 | - 20 | -.26 | - 20 | - 16 | -.20 | - 12 | -.12 | -.06 | - 14 | - 32 | - 21 | - 19 | -.17 |
| Dec 27, " | 34° | +.79 | +.06 | + 26 | + 41 | +.53 | + 40 | +.50 | +.53 | + 54 | + 51 | + 12 | -.03 | + 07 | +.10 |
| June 24, 1949 | 99° | -.02 | - 35 | -.29 | -.14 | -.11 | -.14 | -.08 | - 01 | -.05 | - 13 | - 32 | -.32 | -.19 | -.17 |
| Jan 20, 1950 | 38° | +.69 | -.18 | + 13 | + 33 | + 39 | +.29 | +.38 | +.42 | +.44 | + 37 | + 06 | - 10 | +.01 | + 06 |
| Oct. 10, " | 78° | + 23 | -.35 | -.12 | -.01 | +.03 | -.02 | + 05 | + 11 | +.10 | +.02 | -.17 | - 23 | -.11 | - 07 |
| Feb 5, 1951 | 38° | +.84 | - 23 | +.14 | +.32 | + 40 | +.30 | + 39 | + 42 | +.44 | + 37 | +.05 | -.11 | 0 | +.04 |
| Oct 29 " | 65° | + 36 | -.32 | - 02 | +.14 | +.15 | +.10 | +.18 | +.25 | +.23 | + 16 | -.04 | -.21 | -.07 | -.03 |
| July 15, 1952 | 95° | + 26 | - 42 | - 13 | - 01 | - 07 | -.08 | + 01 | +.12 | + 05 | - 01 | - 18 | - 47 | -.22 | -.20 |
| June 6, 1953 | 84° | + 37 | -.39 | - 05 | +.05 | 0 | - 02 | +.06 | + 17 | + 12 | +.09 | -.07 | -.44 | - 21 | - 16 |
| Jan 31, 1956 | 39° | + 97 | - 25 | + 21 | + 38 | +.41 | + 31 | + 42 | + 49 | +.46 | + 52 | +.36 | -.31 | -.22 | -.04 |
| Dec. 28, 1956 | 38° | +.80 | -.27 | + 21 | +.38 | +.37 | +.29 | +.38 | + 46 | +.47 | +.51 | + 38 | -.33 | -.26 | -.0[illegible] |
| June 12, 1957 | 89° | + 35 | - 38 | +.03 | + 13 | +.06 | +.04 | + 10 | + 20 | + 22 | +.20 | + 13 | -.47 | - 40 | -.24 |
| June 19, " | 104° | +.29 | - 40 | + 01 | + 11 | +.02 | + 02 | +.07 | +.17 | +.19 | +.16 | + 11 | - 47 | - 43 | -.28 |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| June 19, 1957 compared with Aug 27, 1948 | | +.49 | - 20 | + 27 | + 31 | +.18 | +.22 | +.19 | +.29 | + 25 | +.30 | + 43 | - 16 | -.24 | -.11 |

Figure 5. Pavement adjacent to north end of

Rocky Brook, and at the south it has resulted in development of pressure against the 10-in. section.

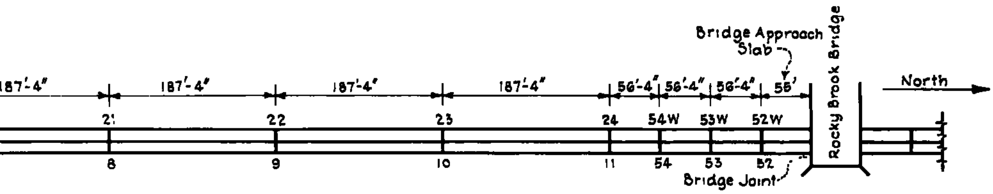
As previously indicated, the largest amount of displacement (1.69 in.) has occurred in connection with the slab adjacent to the south end of the outside lane of the 8-in. section. As shown in Figure 6, this displacement has resulted in considerable closure of Joints 26, 27, and 28, immediately to the south. It has also resulted in about 1 in. of closure of the joint adjacent to the bridge over Rocky Brook. It will also be noted that a similar action has taken place in the inside lane, but to a lesser degree. It therefore is apparent that all of the pavement adjacent to the south end of the 8-in. section has been moved an appreciable amount toward this bridge. And from the data shown in Figure 7 it is apparent that a similar displacement has taken place in connection with the pavement adjacent to the north end.

## CONDITION OF PAVEMENT AT ENDS

As measured from the ends, the end portions of the sections are still (1957) uncracked for distances ranging from 64 to 177 ft. The uncracked distances for all lanes are as follows:

| Lane | Uncracked Distance (ft) | | | |
|---|---|---|---|---|
| | 10-Inch Section | | 8-Inch Section | |
| | South End | North End | South End | North End |
| Inside | 161 | 167 | 152 | 109 |
| Outside | 88[1] | 177 | 64 | 114 |

[1] Through core hole.




WIDTH (Inches)

| | Outside Lane | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Br Jt. | 14E | 15E | 16E | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 54 | 53 | 52 | Br Jt |
| 2"C | 3/4"W | 3/4"W | 3/4"W | 3/4"W | 3/4"W | 3/4"W | 3/4"W | 3/4"W | 3/4"W | 3/4"W | 1/2"C | 1"C | 1"C | 1"C | 2"C |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| +.09 | +1.20 | +.12 | +.27 | +.61 | +.81 | +.59 | +.61 | +.66 | +.62 | +.80 | +.25 | +.14 | +.19 | +.20 | +.09 |
| -.10 | -.01 | -.18 | -.25 | -.13 | 0 | -.09 | -.12 | -.15 | -.13 | -.01 | -.19 | -.25 | -.14 | -.03 | -.10 |
| +.10 | +1.03 | +.07 | +.24 | +.56 | +.76 | +.60 | +.55 | +.57 | +.57 | +.73 | +.27 | +.02 | +.14 | +.23 | +.11 |
| -.10 | +.30 | -.39 | -.24 | -.09 | +.06 | +.06 | -.04 | +.01 | -.19 | -.03 | -.04 | -.37 | -.14 | -.03 | -.10 |
| +.08 | +1.05 | -.23 | +.14 | +.45 | +.59 | +.54 | +.44 | +.49 | +.38 | +.56 | +.32 | -.16 | +.07 | +.20 | +.08 |
| -.02 | +.64 | -.39 | -.09 | +.12 | +.24 | +.29 | +.18 | +.21 | +.02 | +.18 | +.22 | -.40 | -.08 | +.07 | -.03 |
| +.09 | +1.27 | -.28 | +.15 | +.44 | +.61 | +.57 | +.48 | +.53 | +.38 | +.57 | +.42 | -.29 | +.02 | +.17 | +.09 |
| +.02 | +.80 | -.36 | +.02 | +.24 | +.39 | +.39 | +.31 | +.33 | +.18 | +.36 | +.41 | -.41 | -.14 | +.06 | +.01 |
| -.16 | +.77 | -.44 | -.05 | +.15 | +.31 | +.32 | +.22 | +.24 | +.07 | +.29 | +.39 | -.53 | -.35 | -.27 | -.22 |
| -.16 | +.86 | -.42 | +.01 | +.22 | +.37 | +.37 | +.28 | +.29 | +.12 | +.40 | +.53 | -.48 | -.32 | -.28 | -.26 |
| -.05 | +1.51 | -.32 | +.26 | +.53 | +.69 | +.65 | +.60 | +.59 | +.51 | +.93 | +1.08 | -.29 | -.20 | -.22 | -.62 |
| -.09 | +1.38 | -.34 | +.26 | +.53 | +.67 | +.65 | +.58 | +.57 | +.50 | +.93 | +1.19 | -.27 | -.20 | -.20 | -.84 |
| -.30 | +1.07 | -.44 | +.12 | +.31 | +.48 | +.41 | +.34 | +.34 | +.23 | +.65 | +.98 | -.38 | -.34 | -.34 | -1.13 |
| -.37 | +1.04 | -.45 | +.10 | +.29 | +.47 | +.39 | +.32 | +.32 | +.21 | +.62 | +.96 | -.40 | -.35 | -.36 | -1.19 |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| -.27 | +1.05 | -.27 | +.35 | +.42 | +.47 | +.48 | +.44 | +.47 | +.34 | +.63 | +1.15 | -.15 | -.21 | -.33 | -1.09 |

← Joint Number
← Joint Filler

Note
W denotes wood filler
C denotes cork filler

10-in. continuously-reinforced section.

## CRACKS

The central regions of both sections now contain a large number of transverse cracks. Many of these cracks occurred immediately after construction—within a matter of days—and practically all of the remainder occurred within the next three years.

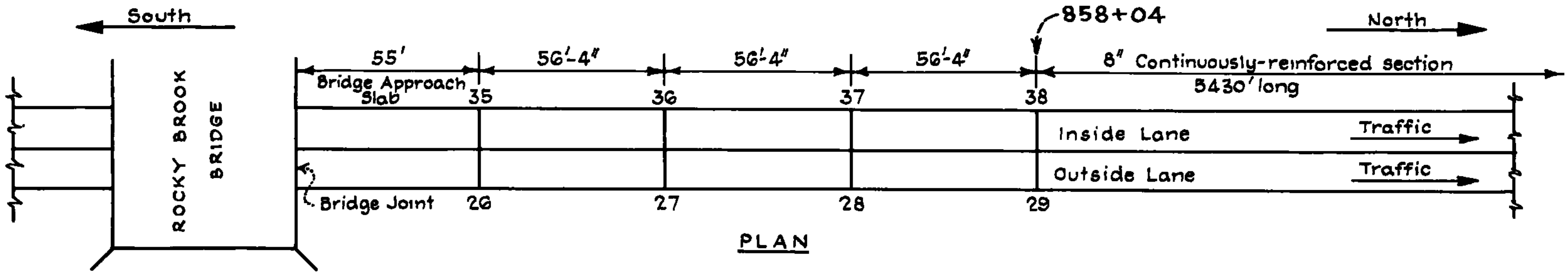
The cracks are of an extremely erratic nature. For example, there are the following types of cracks:

1. Cracks which extend across the full width of the lane.
2. Cracks which originate at an edge, but which become progressively narrower and terminate at some indefinite distance from the opposite edge.
3. Cracks which originate at an edge as a single crack, but which become divided into two cracks, which may or may not extend to the opposite edge.
4. Cracks which originate and terminate within the lane, without extending to either edge.

Although there are other variations in the cracking, these examples will serve to make two things apparent, as follows:

1. It is not possible to establish a true average crack interval, as would be the case if all the cracks were single cracks extending the full width of the lane.
2. It is not possible to establish a true average width of crack, considering, for example, that there are a great many cracks which fall in categories 2 and 3, previously described.

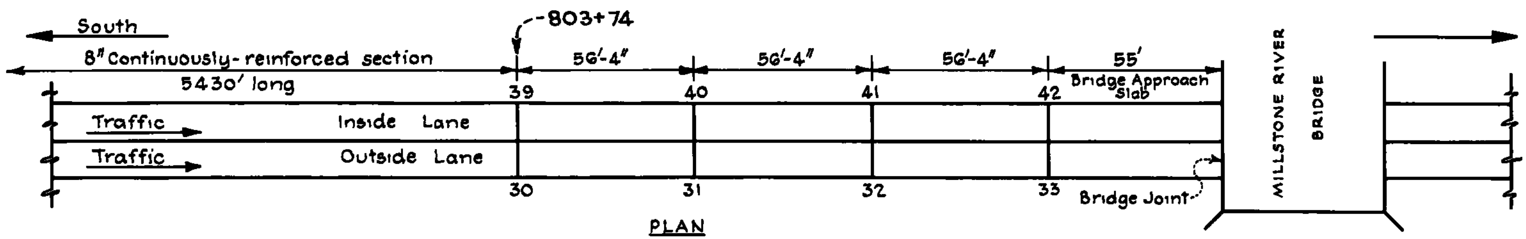
But despite these difficulties, and in order to obtain at least some idea as to the average crack interval, crack surveys were made of a full day's work in each lane of




CHANGES IN JOINT WIDTH (Inches)

| Date | Slab Temp. | Inside Lane | | | | | Outside Lane | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ← Joint Number | | Br. Jt. | 35 | 36 | 37 | 38 | Br. Jt. | 26 | 27 | 28 | 29 |
| ← Joint Filler | | 2" Cork | 1" Cork | 1" Cork | 1" Cork | 1/2" Cork | 2" Cork | 1" Cork | 1" Cork | 1" Cork | 1/2" Cork |
| As Constructed | Var. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jan 30, 1948 | 28° | +.09 | +.21 | +.19 | +.16 | +.78 | +.08 | +.22 | +.17 | +.12 | +.89 |
| July 15, " | 93° | -.16 | -.02 | -.04 | -.21 | -.14 | -.18 | -.02 | -.07 | -.32 | -.06 |
| June 24, 1949 | 99° | -.19 | +.03 | -.07 | -.35 | -.04 | -.22 | -.03 | -.10 | -.52 | +.09 |
| Oct. 10, 1950 | 78° | -.09 | +.06 | -.03 | -.43 | +.42 | -.14 | +.09 | -.10 | -.58 | +.59 |
| Feb. 5, 1951 | 40° | +.02 | +.17 | +.08 | -.29 | +.96 | -.02 | +.19 | 0 | -.44 | +1.07 |
| Oct. 29, " | 64° | -.07 | +.11 | -.05 | -.49 | +.76 | -.11 | +.13 | -.24 | -.51 | +.91 |
| July 15, 1952 | 103° | -.34 | -.07 | -.32 | -.66 | +.61 | -.38 | -.22 | -.46 | -.59 | +.96 |
| June 6, 1953 | 88° | -.31 | -.01 | -.30 | -.64 | +.75 | -.35 | -.20 | - 46 | -.55 | +1.12 |
| Oct. 24, 1955 | 69° | -.32 | +.10 | -.35 | -.50 | +1.15 | -.57 | -.20 | - 41 | -.45 | +1.60 |
| Jan 31, 1956 | 39° | -.23 | +.15 | -.28 | -.52 | +1.60 | -.47 | -.13 | -.36 | -.37 | +1.98 |
| Dec 28, " | 38° | -.30 | +.16 | -.31 | -.53 | +1.49 | -.63 | -.14 | -.36 | -.39 | +2.03 |
| June 21, 1957 | 102° | - 67 | 0 | -.46 | -.67 | +.67 | -1.09 | -.30 | -.50 | -.53 | +1.60 |

Figure 6. Pavement adjacent to south end of 8-in. continuously-reinforced section.




PLAN

CHANGES IN JOINT WIDTH (Inches)

| Date | Slab Temp. | Inside Lane | | | | | Outside Lane | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 39 | 40 | 41 | 42 | Br Jt | 30 | 31 | 32 | 33 | Br. Jt | ← Joint Number |
| | | 1/2" Cork | 1" Cork | 1" Cork | 1" Cork | 2" Cork | 1/2" Cork | 1" Cork | 1" Cork | 1" Cork | 2" Cork | ← Joint Filler |
| As constructed | Var. | 0 | 0 | 0 | 0 | – | 0 | 0 | 0 | 0 | – | |
| Jan 30, 1948 | 28° | +.82 | +.16 | +.22 | +.23 | – | +.83 | +.13 | +.21 | +.17 | – | |
| May 10, " | 77° | + 06 | -.01 | -.01 | +.05 | 0 | +.05 | -.04 | +.02 | -.01 | 0 | |
| Aug. 27, " | 100° | -.19 | -.25 | -.08 | +.01 | +.05 | -.15 | -.37 | -.11 | -.04 | +.04 | |
| Dec 27, " | 28° | +.80 | +.06 | +.17 | +.26 | +.15 | +.89 | -.03 | +.18 | +.22 | +.14 | |
| Oct. 10, 1950 | 78° | +.01 | -.18 | -.04 | +.07 | +.02 | +.41 | -.39 | -.25 | +.04 | -.01 | |
| Feb. 5, 1951 | 40° | +.57 | -.06 | + 07 | +.19 | +.08 | +.90 | -.28 | + 13 | +.16 | +.08 | |
| Oct. 29, " | 64° | +.18 | -.14 | +.02 | +.12 | +.02 | +.61 | - 37 | -.26 | +.09 | +.02 | |
| June 12, 1952 | 95° | +.05 | -.39 | -.12 | -.05 | -.15 | +.55 | -.50 | -.44 | -.15 | -.15 | |
| July 15, " | 103° | +.02 | -.45 | -.17 | -.09 | +.20 | +.50 | -.51 | -.48 | -.24 | -.21 | |
| June 6, 1953 | 94° | +.28 | - 47 | -.17 | -.07 | -.18 | +.65 | -.44 | -.47 | -.29 | -.19 | |
| Nov 23, 1954 | 47° | +.91 | -.42 | -.08 | + 08 | -.03 | +1 20 | -.26 | -.38 | -.23 | -.10 | |
| Jan 31, 1956 | 39° | +1.22 | -.41 | -.15 | -.01 | -.06 | +1.28 | -.23 | -.38 | -.24 | -.14 | |
| Dec. 28, " | 38° | +1.28 | -.42 | -.18 | -.10 | -.10 | +1.34 | -.19 | -.37 | -.27 | -.23 | |
| June 21, 1957 | 102° | +.66 | -.57 | - 34 | -.48 | - 45 | +.93 | - 31 | -.52 | -.44 | -.61 | |
| June 21,1957 compared with Aug 27,1948 | | +.85 | -.32 | -.26 | -.49 | -.40 | +1.08 | +.06 | -.41 | -.40 | -.57 | |

Figure 7. Pavement adjacent to north end of 8-in. continuously-reinforced section.

each section, the only cracks recorded being those which appeared to be clearly defined structural cracks adjacent to the longitudinal joint. The results of these surveys are as follows:

AVERAGE CRACK INTERVAL (ft)

| Date | 8-Inch Section | | 10-Inch Section | |
|---|---|---|---|---|
| | Inside Lane | Outside Lane | Inside Lane | Outside Lane |
| | Sta. 814+62-828+46 | Sta. 839+65-849+34 | Sta. 915+23-922+43 | Sta. 905+18-914+10 |
| Nov. 1947 | 7.7 | 6.6 | 10.7 | 6.2 |
| Oct. 1950 | 3.9 | 3.5 | 6.2 | 4.0 |
| Aug. 1957 | 3.7 | 3.5 | 6.2 | 3.9 |

It will be noted that:

1. In October 1950, after three years of service, there were nearly twice as many cracks as in November 1947.
2. There has been only a slight increase in the number of cracks during the past seven years.

It also will be apparent from the foregoing tabulation that a substantially greater crack interval was recorded in the inside lane of the 10-in. section than in any of the other lanes. In view of this inconsistency, and doubt as to whether the 6.2-ft recorded interval was representative of the entire lane, a survey was made in September 1957 of three day's work in this lane, among them being the day's work included in the original survey. In this case, however, owing to the hazard involved in taking measurements along the longitudinal joint, the cracks along the westerly edge were recorded. In the day's work originally surveyed, the crack interval was found to be 5.5 feet, and in the two additional day's work the interval was 4.5 and 4.2 ft.

Perhaps about the best that can be said is that in all of the lanes the interval averages from about 3½ to 4½ ft, and ranges from as little as 6 in. to as much as 20 ft.

The present typical crack pattern in the 8-in. section is shown in Figure 8, the cracks in the outside lane having been traced with yellow keel, for photographic reasons. This pattern is also typical of the 10-in. section. It will be noted that there are dark streaks across the lanes, expecially across the inside lane. These streaks, which are about 4 in. wide and dark grey in color, are coincident with the cracks. Apparently they are due to the exudation of a substance derived from the concrete during wet weather, but the nature of this substance is not known.

The variable spacing of the cracks is shown in Figure 9, the lane in the foreground being the outside lane of the 10-in. section approximately 1,800 ft from the north end.

## CRACK WIDTHS

During construction, at 12 locations within the central regions brass gage plugs were installed to provide continuing means of determining the amount of crack opening. These plugs, averaging 10 in. apart, were installed while the concrete was still plastic, along lines parallel with the longitudinal axis of the pavement. As many as 60 consecutive plugs were installed in some locations. The distances between these plugs were measured to the nearest 0.001 in. The initial measurements were taken on the day of construction, just as soon as the concrete had definitely hardened, and before any apparent cracking.

Results of the measurements taken from time to time in connection with the gage plugs installed in the 8-in. and 10-in. sections are summarized, respectively, in Tables 4 and 5. With reference to these tables, it is necessary to point out that:

1. The crack widths shown are based on the increase in distance recorded between the plugs. The actual crack width, however, may be slightly greater, as the concrete


Figure 8. Typical crack pattern, 8-in. section.

Figure 9. Variable crack spacing, 10-in. section.

TABLE 4

CRACK WIDTH DATA 8" SECTION

| Location and Incidental Data | | July 1948 | Aug. 1948 | Oct. 1950 | Dec 1950 | July 1951 | Nov-Dec 1951 | June 1952 | Mar. 1953 | Sept 1954 | Jan 1956 | Mar 1957 | June 1957 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 847+50 to 847+95 Inside Lane 49 Spaces @ 10" Const.- Oct. 16, 1947 | Slab Temp | — | — | 75° | 31° | 102° | 48° | 95° | 38° | — | — | 43° | 101° |
| | № Cracks | — | — | 7 | 7 | 7 | 7 | 7 | 7 | — | — | 7 | 7 |
| | Av Spacing | — | — | 5.8' | 5.8' | 5.8' | 5.8' | 5.8' | 5.8' | — | — | 5.8' | 5.8' |
| | Av. Width | — | — | .009" | .009" | .010" | .013" | .011" | .011" | — | — | .010" | .010" |
| | Max Width | — | — | .011" | .011" | .011" | .015" | .013" | .014" | — | — | .012" | .012" |
| 820+52 to 820+84 Outside Lane 38 Spaces @ 10" Const.- Oct. 9, 1947 | Slab Temp | 90° | — | 69° | 31° | 87° | 48° | 95° | — | — | — | 43° | 106° |
| | № Cracks | 7 | — | 9 | 9 | 9 | 9 | 9 | — | — | — | 9 | 9 |
| | Av. Spacing | 4.5' | — | 3.5' | 3.5' | 3.5' | 3.5' | 3.5' | — | — | — | 3.5' | 3.5' |
| | Av. Width | .002" | — | .007" | .007" | .007" | .008" | .007" | — | — | — | .006" | .006" |
| | Max. Width | .004" | — | .014" | .012" | .012" | .013" | .012" | — | — | — | .011" | .011" |
| 831+40 to 831+80 Outside Lane 49 Spaces @ 10" Const.- Oct. 8, 1947 | Slab Temp. | — | — | 69° | 31° | 86° | 48° | 94° | 38° | — | — | 43° | 105° |
| | № Cracks | — | — | 4 | 4 | 4 | 4 | 4 | 4 | — | — | 4 | 4 |
| | Av Spacing | — | — | 10.2' | 10.2' | 10.2' | 10.2' | 10.2' | 10.2' | — | — | 10.2' | 10.2' |
| | Av Width | — | — | .014" | .016" | .015" | .016" | .015" | .015" | — | — | .015" | .015" |
| | Max Width | — | — | .018" | .020" | .019" | .020" | .019" | .019" | — | — | .020" | .020" |
| 835+00 to 835+20 Outside Lane 23 Spaces @ 10" Const.- Oct. 7, 1949 | Slab Temp. | 90° | — | 75° | 31° | 84° | 54° | 94° | — | — | — | 42° | 105° |
| | № Cracks | 4 | — | 6 | 7 | 7 | 7 | 7 | — | — | — | 7 | 7 |
| | Av Spacing | 4.8' | — | 3.2' | 2.7' | 2.7' | 2.7' | 2.7' | — | — | — | 2.7' | 2.7' |
| | Av Width | .006" | — | .010" | .012" | .010" | .011" | .010" | — | — | — | .010" | .010" |
| | Max. Width | .008" | — | .017" | .020" | .019" | .020" | .019" | — | — | — | .019" | .020" |
| 848+00 to 848+50 Outside Lane 60 Spaces @ 10" Const.- Oct. 6, 1947 | Slab Temp | — | 101° | 75 | 31° | 102° | 54° | 94° | — | 82° | 42° | 43° | 100° |
| | № Cracks | — | 17 | 21 | 21 | 21 | 21 | 21 | — | 21 | 21 | 21 | 21 |
| | Av. Spacing | — | 2.9' | 2.4' | 2.4' | 2.4' | 2.4' | 2.4' | — | 2.4' | 2.4' | 2.4' | 2.4' |
| | Av. Width | — | .001" | .006" | .007" | .006" | .008" | .007" | — | .006 | .006" | .006" | .005" |
| | Max. Width | — | .003" | .011" | .012" | .011" | .012" | .012" | — | .011" | .011" | .011" | .010" |

TABLE 5

CRACK WIDTH DATA 10" SECTION

| Location and Incidental Data | | Nov. 1947 | Oct.-Nov. 1950 | Dec. 1950 | July 1951 | Nov.-Dec 1951 | March 1952 | June 10 1952 | June 27 1952 | March 1953 | Sept 1954 | March 1957 | June 1957 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 894+78 to 895+00 | Slab Temp | — | 72° | 32° | 94° | 48° | — | 93° | 100° | — | — | 43° | 95° |
| Inside Lane | Nº Cracks | — | 5 | 5 | 5 | 5 | — | 5 | 5 | — | — | 5 | 5 |
| 26 Spaces @ 10′ | Av. Spacing | — | 4.3′ | 4.3′ | 4.3′ | 4.3′ | — | 4.3′ | 4.3′ | — | — | 4.3′ | 4.3′ |
| Const.- Sept 29, 1947 | Av Width | — | .010″ | .013″ | .011″ | .013″ | — | .011″ | .010″ | — | — | .012″ | .012″ |
| | Max Width | — | .018″ | .022″ | .019″ | .022″ | — | .020″ | .020″ | — | — | .020″ | .020″ |
| 910+00 to 910+50 | Slab Temp. | 52° | 76° | 30° | 92° | 47° | — | 93° | — | 38° | — | 43° | 94° |
| Inside Lane | Nº Cracks | 5 | 8 | 9 | 9 | 9 | — | 9 | — | 9 | — | 9 | 9 |
| 60 Spaces @ 10′ | Av. Spacing | 10.0′ | 6.2′ | 5.6′ | 5.6′ | 5.6′ | — | 5.6′ | — | 5.6′ | — | 5.6′ | 5.6′ |
| Const.- Sept. 26, 1947 | Av Width | .008″ | .010″ | .013″ | .010″ | .012″ | — | .010″ | — | .011″ | — | .011″ | .010″ |
| | Max. Width | 012″ | .017″ | .023″ | .021″ | .022″ | — | .019″ | — | 020″ | — | .021″ | .021″ |
| 921+11 to 921+61 | Slab Temp | 52° | 69° | — | 94° | 55° | — | 88° | 100° | — | — | 43° | 92° |
| Inside Lane | Nº Cracks | 4 | 10 | — | 10 | 10 | — | 10 | 10 | — | — | 10 | 10 |
| 60 Spaces @ 10′ | Av Spacing | 12.5′ | 5.0′ | — | 5.0′ | 5.0′ | — | 5.0′ | 5.0′ | — | — | 5.0′ | 5.0′ |
| Const.- Sept. 24, 1947 | Av. Width | .005″ | .007″ | — | .008″ | .010″ | — | .008″ | .008″ | — | — | .008″ | 010″ |
| | Max. Width | .008″ | .015″ | — | .016″ | .021″ | — | .018″ | .017″ | — | — | .018″ | .020″ |
| 886+62 to 886+92 | Slab Temp | — | 73° | — | 94° | 34° | — | 93° | 100° | — | — | 43° | 96° |
| Outside Lane | Nº Cracks | — | 8 | — | 8 | 8 | — | 8 | 8 | — | — | 8 | 8 |
| 43 Spaces @ 10′ | Av Spacing | — | 4.5′ | — | 4.5′ | 4.5′ | — | 4.5′ | 4.5′ | — | — | 4.5′ | 4.5′ |
| Const.- Sept. 16, 1947 | Av. Width | — | .013″ | — | .014″ | .018″ | — | .014″ | .014″ | — | — | .016″ | .016″ |
| | Max. Width | — | .019″ | — | .019″ | .022″ | — | .018″ | .018″ | — | — | .020″ | 019″ |
| 910+25 to 910+50 | Slab Temp | 52° | 70° | 30° | — | 47° | 38° | 93° | — | — | — | 41° | 94° |
| Outside Lane | Nº Cracks | 4 | 6 | 6 | — | 6 | 6 | 6 | — | — | — | 6 | 6 |
| 30 Spaces @ 10′ | Av Spacing | 6.2′ | 4.2′ | 4.2′ | — | 4.2′ | 4.2′ | 4.2′ | — | — | — | 4.2′ | 4.2′ |
| Const - Sept. 11, 1947 | Av Width | .015″ | .016″ | .020″ | — | .020″ | .021″ | .018″ | — | — | — | .022″ | .023″ |
| | Max. Width | .020″ | .025″ | .029″ | — | .027″ | .028″ | .027″ | — | — | — | .029″ | .030″ |
| 921+25 to 921+50 | Slab Temp | 52° | 77° | 32° | — | 55° | — | 88° | — | — | 84° | 43° | 94° |
| Outside Lane | Nº Cracks | 4 | 8 | 8 | — | 8 | — | 8 | — | — | 8 | 9 | 9 |
| 30 Spaces @ 10′ | Av. Spacing | 6.2′ | 3.1′ | 3.1′ | — | 3.1′ | — | 3.1′ | — | — | 3.1′ | 2.8′ | 2.8′ |
| Const - Sept 10, 1947 | Av. Width | .008″ | .008″ | .012″ | — | .010″ | — | 009″ | — | — | 011″ | .010″ | .010″ |
| | Max. Width | .011″ | .015″ | .018″ | — | .018″ | — | .016″ | — | — | .017″ | .017″ | .017″ |
| 925+34 to 925+50 | Slab Temp | 70° | 77° | 30° | 95° | 40° | — | 88° | — | — | 82° | 43° | 94° |
| Outside Lane | Nº Cracks | 2 | 4 | 4 | 4 | 4 | — | 4 | — | — | 4 | 4 | 4 |
| 19 Spaces @ 10′ | Av Spacing | 7.9′ | 3.9′ | 3.9′ | 3.9′ | 3.9′ | — | 3.9′ | — | — | 3.9′ | 3.9′ | 3.9′ |
| Const.- Sept. 9, 1947 | Av Width | .008″ | .009″ | .013″ | .010″ | .013″ | — | .010″ | — | — | .013″ | .012″ | .014″ |
| | Max. Width | .013″ | .014″ | .017″ | .014″ | .018″ | — | .015″ | — | — | .018″ | .017″ | .017″ |

between the plugs is susceptible to a slight reduction in length.

2. As will be brought out later, the widths shown are indicative only of the crack widths at the pavement surface, and are by no means necessarily indicative of the widths of these cracks below the surface.

From Tables 4 and 5 it will be apparent that:

1. The greatest increase in crack width occurred during very early life.
2. The increase in crack width during the past seven years has been practically nil.
3. The seasonal variation in crack width has been very small.
4. The cracks have never returned to zero width, nor ever approached doing so, even during periods of high temperature.

Measurements taken at the crack plugs in March 1957 and again in June 1957 showed that the decrease in crack width during this period was practically nil, despite an increase in pavement temperature of more than 50 F. In view of this finding it was decided to install plugs at a number of the wider cracks in both sections, inasmuch as there were many cracks which appeared to be considerably wider than those in connection with the plugs originally installed. Therefore, plugs were installed at about 60 of the wider cracks, and the original measurements were taken in July 1957, the pavement temperature being 102 F at the time. Subsequent measurements taken in December 1957, when the pavement temperature was 60 F lower, showed that:

1. The cracks in the 8-in. section had undergone an average opening of only 0.0010 in., the maximum opening being 0.0023 in.
2. The cracks in the 10-in. section had undergone an average opening of only 0.0015 in., the maximum opening being 0.0029 in.

It was also decided to core-drill the pavement at a few of the wider cracks, to determine whether the failure to undergo closure during hot weather had been due to the accumulation of incompressible material in the cracks. Accordingly, four 6-in. diameter cores were obtained, two from each section. Quite unexpectedly it was found that in all cases the cracks were much narrower in the lower two-thirds of the pavement than at the surface, and of only microscopic width in the lower third. In view of this finding, 12 additional cores were obtained, five from the 10-in. section and seven from the 8-in. section. In nine of these cores the cracks were essentially the same as in the first four cores. In the remaining three cores, however, which were obtained at appreciable localized settlements, a crack of hair-line width extended clear through to the bottom.

Figure 10 shows one of the wider cracks in the outside lane of the 10-in. section, and the exposed shoulder edge of the pavement. It also shows the location of the core obtained at this crack.

In this instance the upper line of steel was found to be 6 in., instead of the specified 2 in., below the surface. This however, is apparently a localized condition, because it was not found to be anywhere near the same degree in connection with the other cores. At any rate, during the drilling operations the core broke in two at this line of steel, and there was a general breaking-up of the concrete for about the next inch. The lower 3 in. of the core remained intact, however, and in this portion the crack was of only microscopic width. From a careful inspection of the entire core it appears that this crack was of appreciable width clear down to the upper line of steel. It therefore seems that installing the steel a considerable distance below the surface might tend not only to promote wide cracks at the surface, but also to promote wide cracks of appreciable depth. Incidentally, measurements show that this crack is not at a hump in the grade line.

Several of these cores were subsequently sawed in two longitudinally to facilitate measuring the widths of the cracks at various levels below the pavement surface. The results of these measurements, which were taken by means of a 20-power scale microscope, are given in Table 6, which also shows the distance below the surface of the upper


Figure 10. Crack in 10-in. section, Sta. 927+81.

and lower lines of reinforcing steel. It must be appreciated, however, that owing to the irregular nature of these cracks, and the breaking-down of their edges, it is extremely difficult, if not impossible, to measure their true widths, and for this reason the figures shown are necessarily only approximate. It is believed, however, that the cracks are at least no wider than indicated.

Figure 11 shows a crack and the exposed edge of the pavement at 894+92 in the outside lane of the 10-in. section, the difference in crack width at the surface and in the lower portion of the pavement being clearly apparent.

The core (C-2) obtained at this crack is shown in Figure 12, the location of the steel

TABLE 6

WIDTH OF CRACKS AND LOCATION OF STEEL IN CORES (in.)

| Core No. | Section (in.) | Lane | Eng'rs. Sta. | Distance Below Surface: Crack-width Measurement[1] | | | | | | Steel | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 in. | 1 in. | 3 in. | 5 in. | 7 in. | 9 in. | Upper | Lower |
| 1 | 10 | Outside | 927+81 | - | - | - | - | .008 | .001 | 6.0 | 8.5 |
| 2 | 10 | Outside | 894+92 | .060 | .020 | .016 | .008 | .004 | M | 3.0 | 7.2 |
| 3 | 10 | Outside | 910+49 | .050 | .018 | .014 | .010 | .004 | M | 2.4 | 7.7 |
| 10 | 10 | Outside | 886+82 | .020 | M | M | M | M | M | 2.5 | 7.0 |
| 21 | 10 | Outside | 905+22 | .020 | .020 | .016 | .012 | .008 | .008 | 1.7 | 7.3 |
| 9 | 10 | Inside | 894+88 | .025 | .012 | M | M | M | M | 2.6 | 7.2 |
| 5 | 8 | Outside | 835+14 | .025 | .020 | .008 | .004 | M | - | 3.2 | 5.4 |
| 6 | 8 | Outside | 835+04 | .020 | .016 | .004 | M | M | - | 3.2 | 5.4 |
| 7 | 8 | Outside | 831+70 | .020 | .018 | .016 | .006 | M | - | 3.0 | 5.2 |
| 19 | 8 | Outside | 823+08 | .030 | .016 | .010 | .004 | M | - | 3.2 | 6.2 |
| 22 | 8 | Outside | 820+63 | .010 | .004 | .004 | .003 | M | - | 2.2 | 5.0 |
| 23 | 8 | Outside | 831+94 | .010 | .001 | M | M | M | - | 3.2 | 5.1 |

[1] M = crack of microscopic width.

being indicated by dashed lines. In this instance the crack occurred at a lap in the upper line of steel, and at a transverse member in the uppermost line.

Figure 13 shows a core (C-21) obtained at 905+22 in the outside lane of the 10-in. section. It will be noted that in this core the crack, although very narrow, is traceable clear to the bottom. There was a slight sag in the grade line where this core was obtained, and this may account for the more or less uniform crack width below the upper line of steel. As in the case of Core C-2, this crack also occurred at a transverse member in the upper line of steel. Apparently this is typical of a great many of the cracks.

It will also be noted that in this core the upper line of steel is only about $1\frac{1}{2}$ in. below the surface, and that to the right of the vertical crack there is a horizontal crack at the level of the steel. A careful investigation was made to determine whether this crack existed in the pavement or, on the other hand, was induced by the drilling operations. This involved wedging the core apart at the horizontal crack. This resulted in what appeared to be a new fracture, but there were some indications that there might have been a plane of weakness at this point.

The pavement itself was also carefully examined. In addition to a visual inspection, the pavement surface adjacent to the crack was tapped with a hammer. No evidence of a horizontal crack was found. But in view of this occurrence, plus the fact that the reinforcing steel showed some evidence of rusting at the crack, it appears that even though it may be advisable to install the steel above mid-depth, it is also advisable that it not be installed too close to the surface.

Figure 14 shows a core (C-9) obtained at a crack at 894+88 in the inside lane of the 10-in. section. Although this crack was about 0.025 in. wide at the surface, it was of only microscopic width throughout practically the entire depth of the pavement.

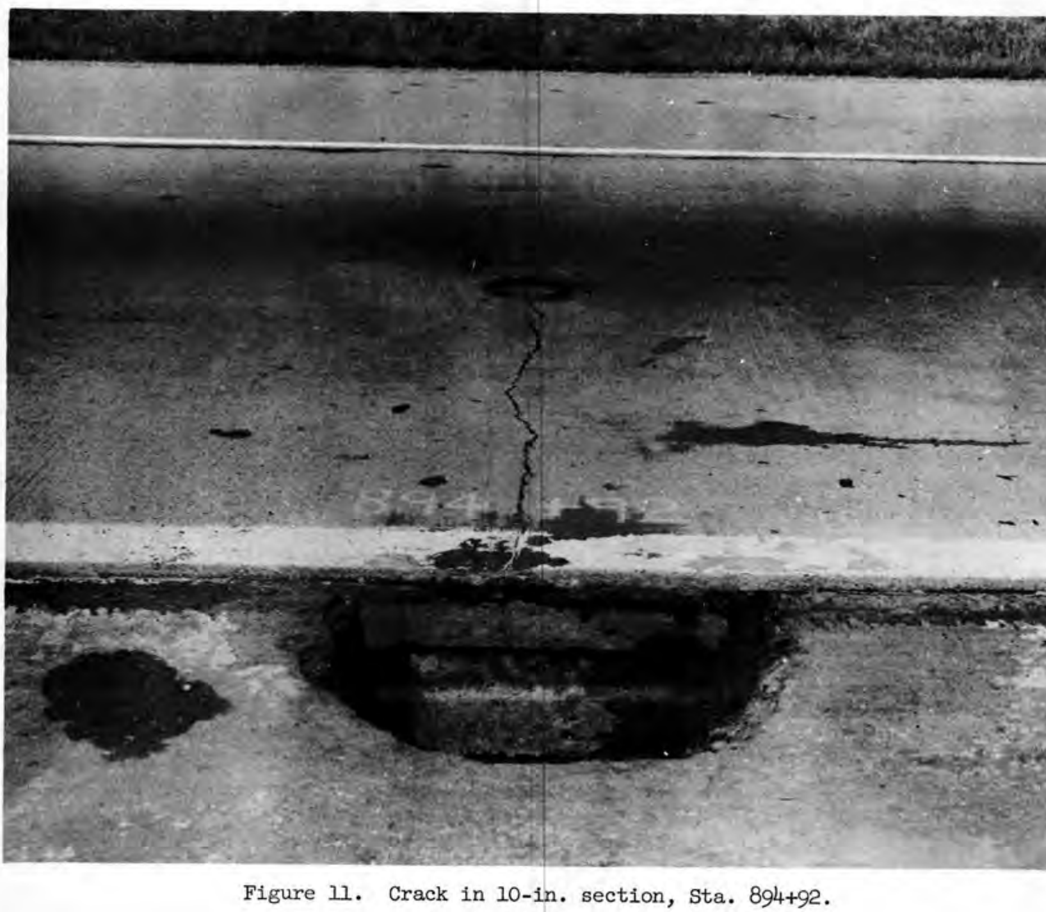


Figure 11. Crack in 10-in. section, Sta. 894+92.

Figure 15 shows a crack and the exposed pavement edge at 835+04.5 in the outside lane of the 8-in. section.

The core (C-6) obtained at this crack is shown in Figure 16, which also shows a thin slice of concrete sawed from the outer surface of the core. Oddly enough, despite the fact that there was no steel holding this slice together, it did not come apart at the crack. It was subsequently determined, however, that the slice was held together by about 2 in. of concrete near the bottom, notwithstanding the presence of a crack of microscopic width through this concrete.

Figure 17 shows a core (C-19) obtained at a ravelled crack at 823+08 in the outside lane of the 8-in. section, and also shows a thin slice of concrete sawed from the side of the core. In this instance the slice did come apart at the crack. Despite the extreme narrowness of this crack in the lower portion of the core, the cracked surfaces were discolored for the full depth of the pavement. Moreover, the crack contained what appeared to be very finely divided silty materials, from brown to almost black in color. Similar materials, incidentally, were found in all of the cracks examined.

Figure 18 shows a core (C-4) obtained at a badly ravelled crack, which had been sealed, about 4 ft north of a construction joint at 849+34 in the outside lane of the 8-in. section. This core broke in two during the drilling operations. As will be noted, the crack is quite wide in the upper third of the pavement (above the upper line of steel). In the lower two-thirds, however, the crack was found to be only about 0.01 in. wide. It is apparent that the conditions at this crack are none too good. In addition to rather serious ravelling at the pavement surface, appreciable rusting was found in connection with the lower line of steel, especially of the transverse member.


Figure 12. Core at crack in 10-in. section, Sta. 894+92.

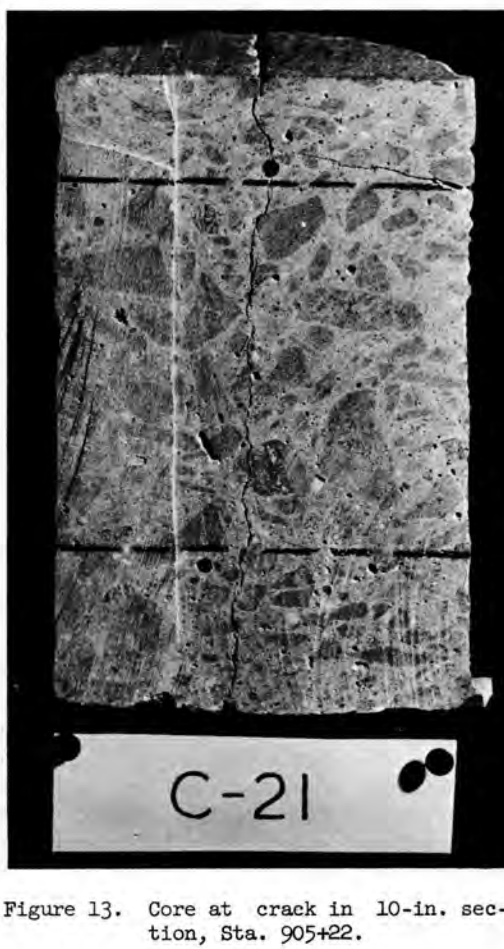



Figure 13. Core at crack in 10-in. section, Sta. 905+22.

The procurement of these cores has resulted in several very important findings, as follows:

1. The measurements at the crack plugs installed during construction are of very limited value, and are indicative only of the surface widths of the cracks.
2. From all indications, the cracks are much narrower in the lower portion of the pavement than they are at the surface. There may, of course, be exceptions. But in a total of 16 cores, no cracks exceeding about 0.015 in. in width were found at the bottom, even at appreciable localized settlements.
3. Owing to the marked difference in crack width from top to bottom, the surface appearance of the pavement, at least in general, is not indicative of its true structural condition.

Figure 14. Core at crack in 10-in. section, Sta. 894+88.

The reason for this difference in crack width is not known. A number of factors may, of course, be involved. However, differential shrinkage of the concrete, which might have been aggravated by the high slump employed, appears to be the most likely predominating cause.

With respect to these findings, it may be stated that because of the serious appearance of the cracks there had been speculation for a number of years as to how the outside lanes of these sections could possibly hold together under the heavy truck traffic they were carrying. Moreover, it was because of their "apparent" poor condition, and the fact that a serious failure had already occurred in the 10-in. section, that the long-term performance of the outside lanes was viewed with skepticism in the 1950 report. Whether or not the two additional failures that occurred a short time later in the 8-in. section justified this point of view is, of course, a matter of opinion. But it has nevertheless become apparent that the life expectancy of the continuously-reinforced pavements cannot be predicted solely on the basis of their surface appearance.

Incidentally, no faulting has been observed at any of the cracks.

## CONSTRUCTION JOINTS

In general, the pavement adjacent to the construction joints is still in good condition. Furthermore, there has been no apparent faulting at any of these joints. As of June 25, 1957, the recorded opening of the construction joints in the 10-in. section ranged from 0.004 to 0.045 in., and averages 0.015 in. In the 8-in. section the opening ranged from 0.002 to 0.011 in., and averaged 0.007 in.

Rather severe cracking has occurred, however, in the immediate vicinity of several of these joints, for a distance of 20 ft or more, but only on the northerly side. (Construction was from south to north.) The severity of this cracking is shown in Figure 19, the construction joint being about 3 ft to the left of the core hole. But despite what would appear to be the very poor condition of the pavement, no failures other than excessive ravelling at some of the cracks have occurred in any of these areas. As suggested previously, the reason for the absence of failure appears to be that the cracks are much narrower in the lower portion of the pavement than at the surface.

It is generally believed that the difference in cracking on one side of the joint, as compared with the other, has been due primarily to having attached together two sections of pavement which necessarily had, at the time of attachment, materially different tensile strengths.

## CHANGES IN ELEVATION

At certain locations, immediately after construction levels were taken at 5-ft intervals along the edges of the lanes, to determine the amount of subsequent change in elevation. Levels taken one year later indicated that, in general, the changes were limited to less than 1/4 in., but that there were a few localized areas in the outside lanes where, within a distance of about 30 ft, settlements of as much as 5/8 in. had occurred: a slight dip is felt in riding over these areas. A recent re-taking of some of these levels has indicated, however, that little change in elevation has taken place during the past nine years. Probably for this reason, there appears to have been no appreciable change in riding qualities since 1948.

It is to be pointed out, however, that because of the closely spaced cracks these sections appear to lack the longitudinal rigidity and load-distributing capacity of the standard reinforced concrete pavements, and are therefore more susceptible to the development of an undulating profile and localized settlements.

## FAILURES

As previously mentioned, in May 1949 a localized area in the outside lane of the 10-in. section approximately 1,430 ft from the south end began to undergo failure,


Figure 15. Crack in 8-in. section, Sta. 835+04.5.

this being evident from severe cracking and the exudation of a whitish-colored substance from the cracks during wet weather. Pictures were taken periodically in this location to obtain a photographic record of the failure as it progressed. Figure 20 shows this failure on November 17, 1949.

By the summer of 1951 the failure had advanced to the stage where the entire width of the lane had become involved. The conditions on August 23, 1951, are shown in Figure 21, at which time considerable buckling of both the pavement and the reinforcing steel had occurred.

In December 1951 it became necessary to remove the damaged concrete. This work resulted in creation of an open space about 7 ft wide, for the full width of the lane. As a temporary measure, the space was filled with crushed stone topped with bituminous material.

In October 1954 this area was repaired with concrete, which involved replacement of 25 ft of the lane and installation of a dowelled expansion joint at the center of the repaired area. Figure 22 shows this area in August 1957. The black discoloration on the pavement adjacent to the joint is due to extrusion of a large quantity of joint-sealing compound which had been inadvertently poured into the joint space while in an open condition during cold weather.

Mention was also made previously of two similar failures which occurred in the outside lane of the 8-in. section. The first of these failures occurred at a point 569 ft from the north end, and first became apparent in May 1951. Conditions at this point

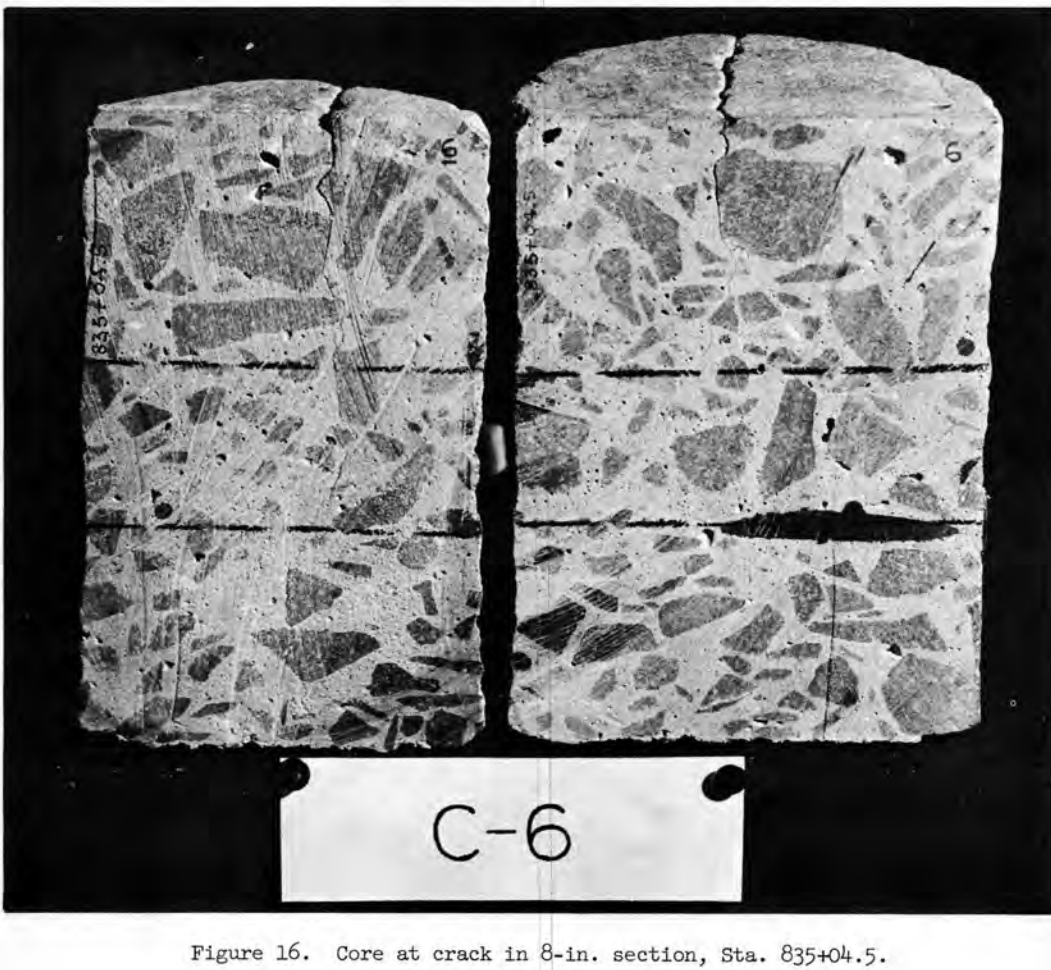



Figure 16. Core at crack in 8-in. section, Sta. 835+04.5.

six months later (November 27, 1951) are shown in Figure 23.

For the next three years the pavement was maintained in passable condition by periodically removing the ruptured concrete and replacing it with bituminous materials. In October 1954 this area was repaired with concrete, at which time a dowelled expansion joint was installed at the center of the repaired area.

The second failure occurred at a point 372 ft from the north end, and first became apparent in 1952. This failure was of the same nature as the one just described, and was also repaired with concrete in October 1954, in the same manner. Each of these repairs involved replacement of about 12 ft of the lane.

The cause of these three failures is unknown. However, there appear to be several possible causes: namely, (a) an excessively wet batch of concrete, (b) a batch of concrete deficient in cement, (c) poor consolidation of the concrete and resulting inadequate bond with the reinforcing steel, (d) a localized weakness in the subgrade, and/or (e) a horizontal plane of cleavage at the upper line of steel. In addition, a pavement of this design is under a high degree of tension in cold weather, at least during early life, and this tension may have been an important contributory cause.


Figure 17. Core at crack in 8-in. section, Sta. 823+08.


Figure 18. Core at crack near construction joint, 8-in. section.

There is also the fact that all of these failures occurred in the outside lanes and that no similar failures have occurred in the inside lanes. Presumably, therefore, the heavy truck traffic in the outside lanes played an important part in their occurrence. On the other hand, the absence of any further failures of this nature since 1952 seems to indicate quite definitely that there was some form of weakness at these failed areas which was not present elsewhere in the outside lanes. Whether or not there are similar weaknesses in the inside lanes, but which have not been brought to light owing to the relative absence of truck traffic in these lanes, is obviously not known.

In view of the indications that these failures may have been caused primarily by construction deficiencies of a type which usually have little or no apparent effect in connection with a conventional pavement, it appears that great care needs to be exercised in the construction of continuously-reinforced pavements.

During the past eight or nine years a progressive deterioration of the concrete has been taking place in a small area in the outside lane of the 8-in. section at a point about 490 ft from the south end. The present condition of this area is shown in Figure 24. Judging from the appearance of the surface, an excessively wet, stoney batch of concrete may have been placed at this point. Whether or not this deterioration will eventually advance to the point of serious structural failure remains to be seen.

In February 1957 a rupturing of the concrete was discovered adjacent to the terminal joint at the north end of the inside lane of the 10-in. section. At that time the rupturing was confined to the end of this section. During the following summer, however, rupturing also occurred in connection with the adjoining pavement. The present conditions are shown in Figure 25, the 10-in. section being to the left of the joint.

Investigations have shown that this rupturing has been due to the combined effects of (a) large seasonal changes in width of this joint and resulting infiltration of large amounts of sandy and gravelly materials, (b) compression of the wood joint filler to the point of refusal, and (c) resistance of the adjoining pavement to displacement. Although there have been no similar failures at any of the other terminal joints, this occurrence serves to illustrate the deficiencies of conventional expansion joints when used at the ends of continuously-reinforced pavements.

## RELATIVE CONDITION OF LANES

As previously mentioned, three serious failures requiring replacement of the concrete

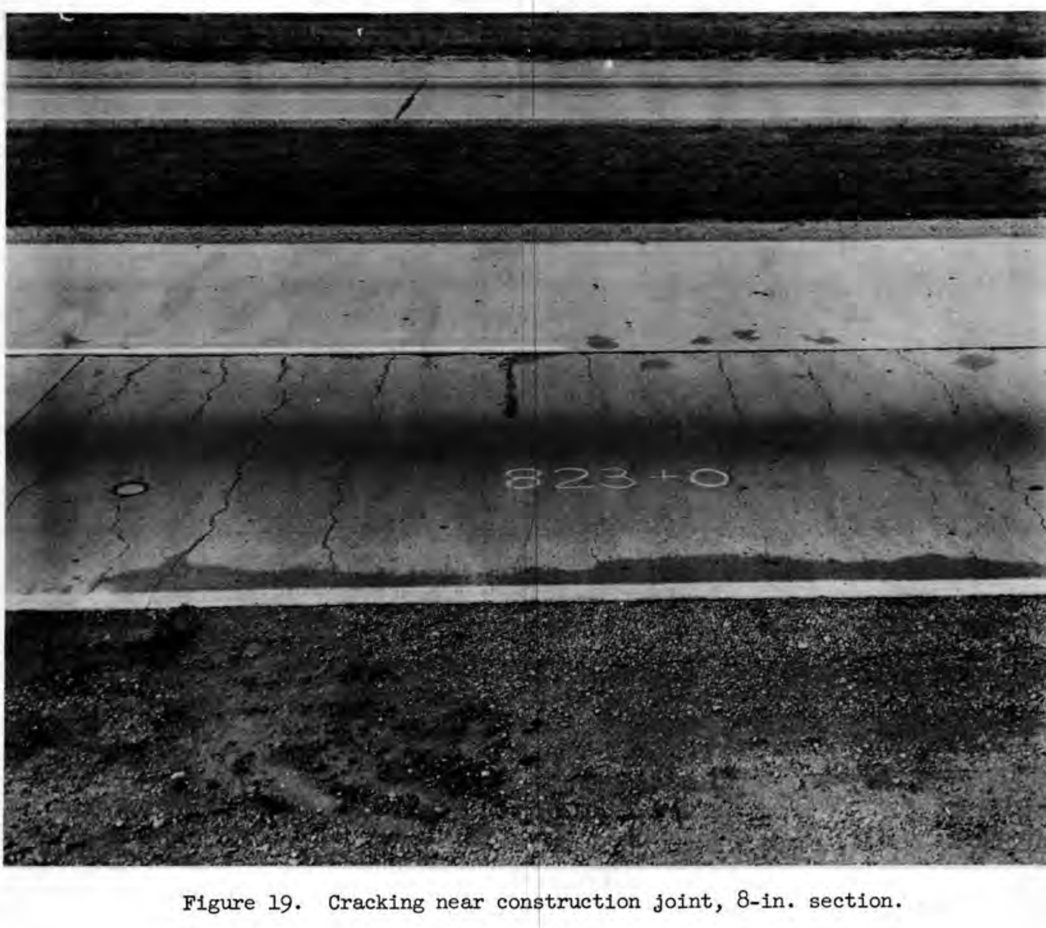



Figure 19. Cracking near construction joint, 8-in. section.

have occurred in the outside lanes, and a localized area in the outside lane of the 8-in. section is undergoing slow deterioration. In addition, there has been rather pronounced ravelling at some of the cracks in the outside lanes of both sections. Because of this ravelling, a few of these cracks have been poured with joint-sealing compound. The inside lanes, on the other hand, are still in first-class condition.

From the standpoint of riding qualities, the outside lanes have numerous undulations of noticeable magnitude, whereas the undulations in the inside lanes are much less frequent and much less pronounced.

Needless to say, the relative performance of these lanes serves to emphasize the fact that, as in the case of any pavement, the amount and kind of traffic a continuously-reinforced pavement is to carry must definitely be given serious consideration in the design.

## RELATIVE PERFORMANCE OF STANDARD PAVEMENT

In addition to these continuously-reinforced sections, this project included construction of 52 slabs (26 in each lane) containing New Jersey's standard amount of welded wire fabric (612-2/03). These slabs were of 10-in. uniform thickness, 56 ft long, and the joints used in connection therewith were dowelled expansion joints. With the exception of a few experimental joints, the dowels, which were installed 12 in. c. to c., consisted of $1\frac{1}{4}$-in. diameter cold-finished steel bars partly uncased in Monel tubing.

With the exception of a slight sag at one of the joints in the outside lane, and the rupturing previously described at the north end of the 10-in. section, all of these slabs are still in excellent condition and there has been no apparent faulting at any of the joints. Of these 52 slabs, 48 are still uncracked. To date this pavement has required no main-


Figure 20. Failure in 10-in. section, Nov. 17, 1949.

tenance whatever, other than periodic resealing of the joints.

One year after construction of this project a $2\frac{1}{2}$-mi section of concrete pavement was constructed immediately to the north by the same contractor, on the same route, and carrying the same traffic. This pavement was of 10-in. uniform-thickness reinforced concrete, on a 12-in. layer of bank-run gravel subbase. Dowelled expansion joints with 3/4-in. wood filler were installed at 78-ft intervals. The dowelling system was of the type previously described. This, essentially, has been the New Jersey standard design of heavy-duty reinforced concrete pavement since 1948.

All of this pavement is still in excellent condition. There has been no apparent faulting at any of the joints. In a total of 171 slabs in the outside lanes, 164 are still uncracked. Furthermore, there is only one transverse crack, of hair-line width, in each of the remaining seven slabs in this lane. All of the 169 slabs in the inside lane are still uncracked.

Other than periodic resealing of the joints (which would probably not have been necessary had they been sealed originally with the presently used type of rubber-asphalt compound), this pavement has required absolutely no maintenance whatever. Also, there are no indications of incipient failures of any kind, and despite the presence of expansion joints, the riding qualities of this pavement are in no apparent way inferior to the riding qualities of the continuously-reinforced sections probably owing to the care taken in the finishing and edging of the joints, and to adequate dowelling.

## RELATIVE COSTS

In the continuously-reinforced sections the cost of the reinforcing steel alone was \$2.78 per square yard of pavement. In consequence, the cost of the 10-in. section was approximately \$1.60 more per square yard than was paid in 1947 for the standard design of 10-in. reinforced pavement. Even the cost of the 8-in. section was approximately \$1.00 more per square yard than the 10-in. standard design. This higher cost would perhaps be of little importance were it reflected in superior performance, but to date there have been no apparent indications that this has been the case.

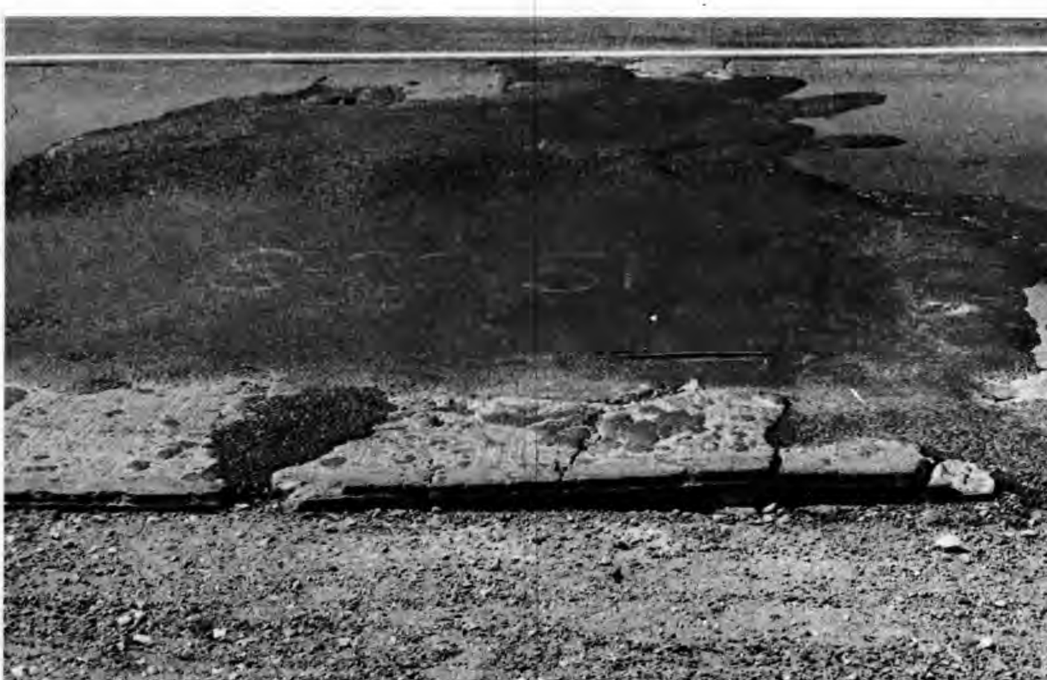


Figure 21. Failure in 10-in. section, Aug. 23, 1951.

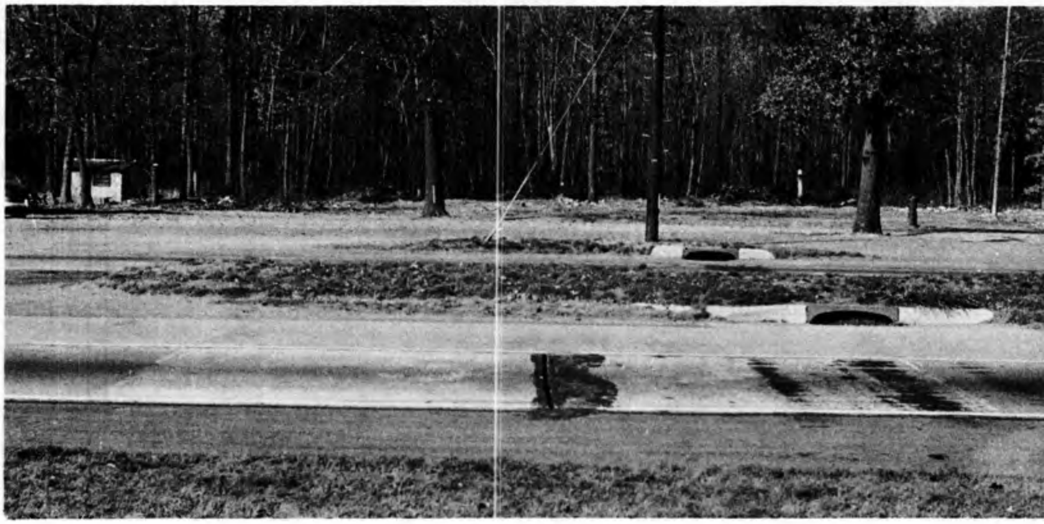


Figure 22. Repaired area, 10-in. section, August 1957.

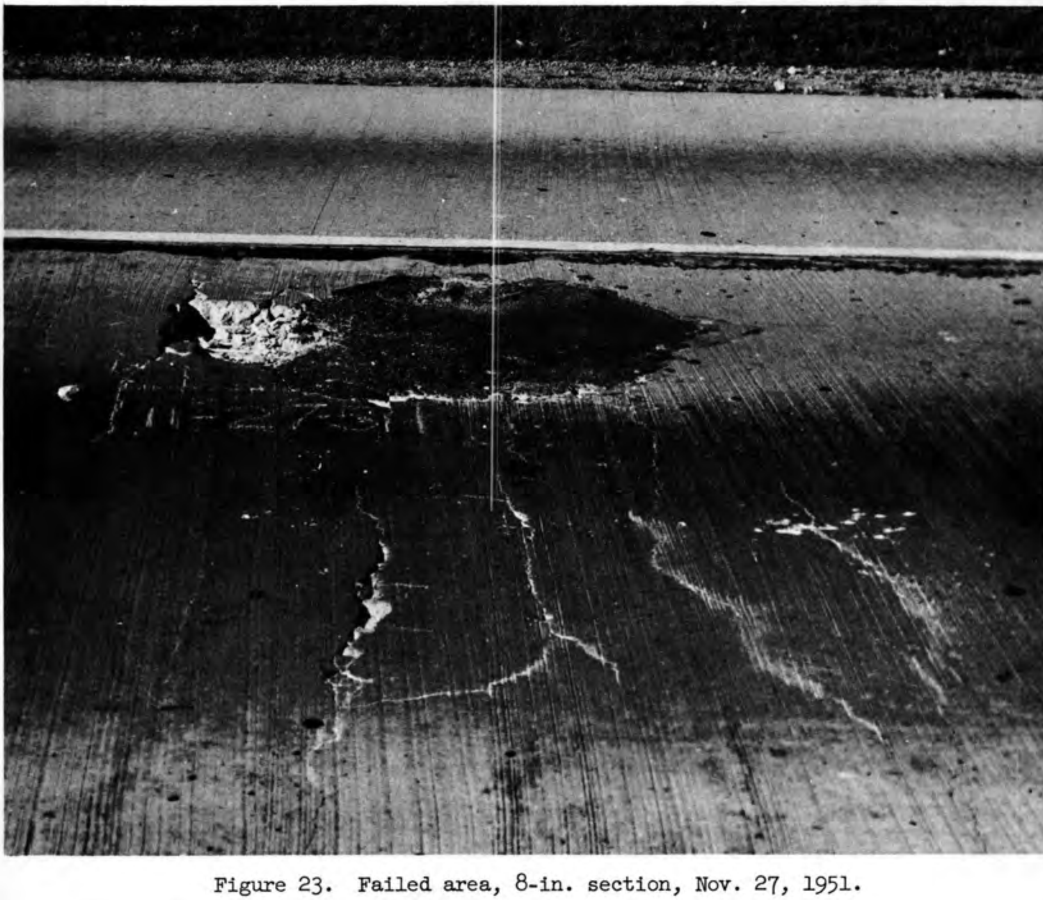


Figure 23. Failed area, 8-in. section, Nov. 27, 1951.

## SUPPLEMENTARY EXPERIMENTAL PAVEMENT

As shown in Figure 5, this project included an experimental section of pavement involving slabs 187 ft long. In the end portions of these slabs, for a distance of 34 ft, the reinforcing steel consisted of a single line of the standard type of welded wire fabric. In the remaining 119-ft central portions the steel consisted of a single line of the same kind of wire fabric installed in the continuously-reinforced sections (0.36 percent). The expansion joints between these slabs were of the dowelled type previously described.

With the exception of a corner spall about 6 in. square at the shoulder end of Joint 7, all of these slabs are still in very good condition, and there has been no apparent faulting at any of the joints.

With respect to transverse cracking, the present condition of these slabs is as follows:

| Inside lane | | Outside lane | |
|---|---|---|---|
| No. of Slabs | Cracks | No. of Slabs | Cracks |
| 6 | 0 | 4 | 0 |
| 1 | 1 | 3 | 1 |
| 1 | 2 | 1 | 2 |

The cracks are not concentrated within the central regions. On the contrary, five are within 26 ft of the ends, and only two are within the central regions. All of these

Figure 24. Deteriorating area, 8-in. section.

cracks are very narrow, free from ravelling, and of no apparent structural significance.

Inasmuch as this report lists fewer cracks in these slabs than listed in the 1950 report, it is necessary to state that the 1950 report included a number of cracks which, on the basis of a careful recent inspection, were actually very fine surface checks, whereas this report lists only clearly defined structural cracks.

As previously mentioned, the pavement involving these 187-ft slabs has undergone an over-all increase in length, although the exact amount is not known. But on the basis of reference-line measurements in the vicinity of Joints 10 and 23 at the north end, the inside lane at this point has moved northerly about 5/8 in., and the outside lane has moved northerly about 1 in. It is problematical, however, whether any appreciable outward movement has occurred at the south end, owing to the restraining effect of the 10-in. continuously-reinforced section.

This over-all increase in length is also indicated by the considerable increase in width that occurred at the joints between these slabs during the period August 27, 1948-June 19, 1957, and by the decrease in width of the joints in the adjoining pavement. (See lower line of figures "June 19, 1957, compared with August 27, 1948," in tabulation in Figure 5.)

It will also be noted that the joints between these slabs have undergone large seasonal changes in width. As a result, there has been infiltration of large amounts of solid material. Although this has not caused any apparent damage except the small spall at Joint 7, recent experience in other locations indicates that infiltration can be very harmful in connection with an extensive section of pavement in which the joints are spaced 100 ft or more apart. It is not considered advisable, therefore, to construct slabs of this length.

## SUMMARY

The more important results and observations in connection with these continuously-reinforced sections during the past ten years may be summarized as follows:

1. The maximum recorded over-all changes in length of the inside and outside lanes

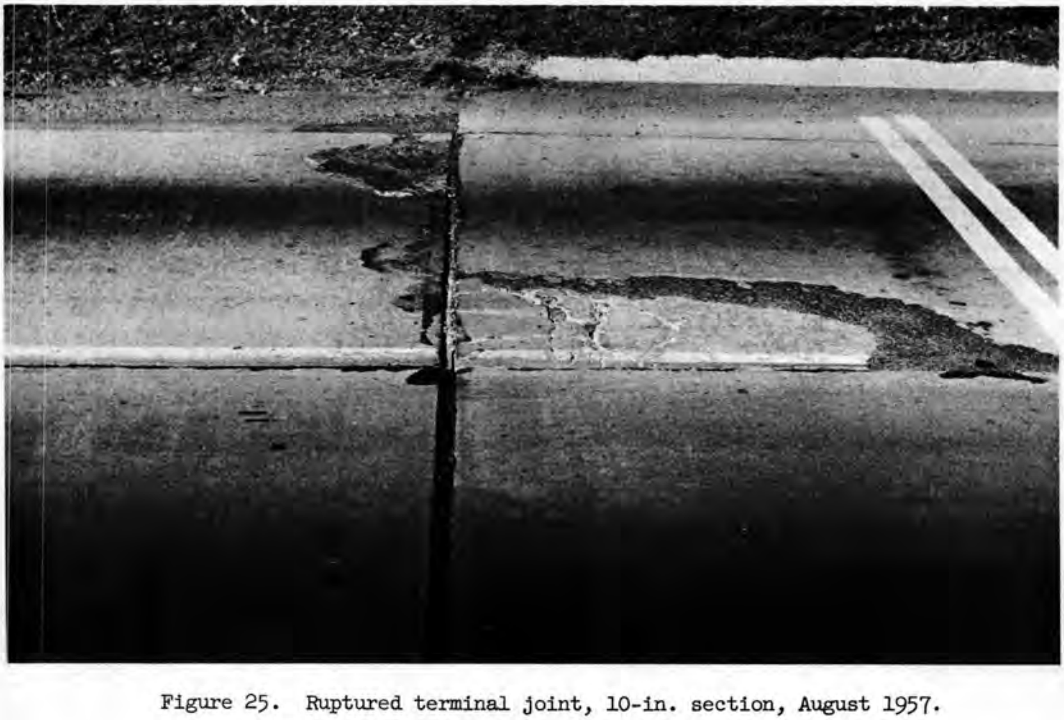


Figure 25. Ruptured terminal joint, 10-in. section, August 1957.

of the 8-in. section have been, respectively, 1.66 and 1.22 in. For the inside and outside lanes of the 10-in. section these changes have been, respectively, 1.92 and 1.99 in.

2. The 3,500-ft central regions of the inside lanes of both sections have remained essentially at constant length at all times. (This does not apply at present to the outside lanes, owing to certain failures in these lanes.)

3. Neither section has undergone any apparent permanent increase in length. There are indications, however, that there has been a tendency in this direction, which has been counteracted by the restraining effect of the adjacent pavement.

4. The terminal joints at the ends of both sections have undergone an appreciable increase in width, due to the infiltration of solid materials, but despite this increase there has been no apparent faulting at any of these joints.

5. In conjunction with the increase in width of the terminal joints, the slabs adjacent to the ends of both sections have been moved away from these sections, in amounts ranging from approximately 1/4 to 1¾ in.

6. The central regions of both sections have a large number of transverse cracks. These cracks are of an extremely erratic nature. Their spacing averages from about 3½ to 4½ ft, and ranges from as little as 6 in. to as much as 20 ft. Many of these cracks occurred immediately after construction (within a matter of days), and practically all of the remainder occurred within the next three years.

7. In the 12 locations where gage plugs were installed, the maximum recorded crack width has been 0.03 in. There are, however, other locations where the crack width at the surface is as much as 0.06 in.

8. Based on cores recently obtained at 16 cracks in the central regions, the cracks are much narrower in the lower two-thirds of the pavement than at the surface, even at localized settlements. There may, however, be exceptions, but these have not been found.

9. At some of the wider cracks where cores were obtained there was evidence of rusting of the reinforcing steel, but apparently not to a serious degree.

10. Owing to the variation in crack width from top to bottom, the surface appearance of the pavement, at least in the main, is not indicative of its true structural condition.

11. There has been no apparent faulting at any of the cracks.

12. In June 1957 the recorded opening of the construction joints in the 10-in. section ranged from 0.004 to 0.045 in., and averaged 0.015 in. In the 8-in. section the opening ranged from 0.002 to 0.011 in., and averaged 0.007 in.

13. There has been no apparent faulting at any of the construction joints.

14. Many closely-spaced ravelled cracks have occurred immediately north of several of the construction joints in both sections, but no structural failures have occurred in these areas.

15. With the exception of a few localized settlements and undulations in the outside lanes of both sections, the changes in profile which have developed since construction have not resulted in any noticeable impairment in riding qualities.

16. With the exception of serious rupturing at the terminal joint at the north end of the 10-in. section, the inside lanes of both sections are still in very good condition.

17. Three serious localized failures, which required removal and replacement of the damaged concrete, have occurred in the outside lanes; one in the 10-in. section and two in the 8-in. section. The cause of these failures is not known, but the indications are that they were caused primarily by a structural deficiency of some kind in these particular areas. However, the absence of any failures of this nature in the inside lanes would seem to indicate that heavy truck traffic also played an important part in their occurrence.

18. The standard expansion joints have not proved satisfactory as terminal joints.

19. The 16 supplementary 187-ft slabs constructed in conjunction with this project are still in very good condition, and ten of these slabs are still uncracked. There has been no faulting at any of the intermediate joints. However, owing to the large seasonal changes in joint width and resulting infiltration of large amounts of solid material, it does not appear advisable to construct slabs of this length.

## CONCLUSIONS

From the foregoing, it is apparent that:

1. Within five years after construction three serious failures occurred in the outside lanes of the continuously-reinforced sections. In addition to constituting a troublesome maintenance problem, these failures eventually required removal and replacement of the damaged concrete.
2. Owing to the close spacing of the transverse cracks, and as indicated by the localized settlements and undulations which have developed in the outside lanes, these sections apparently lack the longitudinal rigidity and load-distributing capacity exhibited by the standard reinforced concrete pavements.
3. The cost of these sections was substantially higher than that of the standard pavements constructed during the same period.
4. The standard pavements on the same route, of essentially the same age, and carrying the same traffic, are still in excellent condition and show no signs of incipient failure. In addition, they have first-class riding qualities.

For these reasons it is felt that, to date, the continuously-reinforced pavements have not proved superior, nor even equivalent, to the standard design of reinforced concrete pavement. Whether or not this will still be the case some years hence remains, of course, to be seen.

It is hoped, however, that this experience will in no way tend to discourage further investigations into the possibilities of this design. Certainly, the fact that a continuously-reinforced pavement constitutes, in effect, a continuous ribbon of concrete without joints of any kind is in itself a strong point in its favor. Furthermore, it is apparent that a pavement of this type is susceptible to a wide range of variation in design, such as in thickness, and in the amount, type, location and tensile strength of the reinforcing steel. Consequently, it is felt that no final conclusions relative thereto should be drawn on the basis of a single experiment, such as this one.

## ACKNOWLEDGMENTS

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