nels through which water can easily reach the subgrade, and in this way may eventually contribute to pumping, there is no evidence to indicate that they were caused by pumping or are pumping at the present time.

*Conclusions*—The experimental pavement is not old enough to justify a definite conclusion as to its ultimate performance but, based on its present behavior, it would appear that continuously reinforced concrete pavements properly designed and constructed for their environments would give good performance. In view of the high steel stresses measured in 0.7 percent steel, it may be necessary to provide more steel than was indicated by earlier experiments. It also may be found that continuous reinforcement, while it may be a factor in controlling pumping, cannot by itself economically solve this problem and, therefore, it may be necessary on future experiments to revise the design accordingly. Perhaps, overall performance would be improved by a combination of continuous reinforcement and a thin granular sub-base. These possibilities should be studied in other projects.

In the final analysis the criterion by which this type of construction is judged will be an economic one. Whether pavements of this type are practical will depend on their original cost, service life and the cost of maintenance. In other words, will it give more and improved service for the money expended than other types of pavement.

A study of the contract unit prices for the experimental pavement and the adjacent standard pavement, built under the same contract, shows that the contractor bid approximately the same unit price for the 7-in. pavement with 0.7 percent steel, the 8-in. pavement with 0.5 percent steel, and the standard 10-in. mesh reinforced pavement with 6-in. granular sub-base. Neither the experimental nor the standard pavement has required much maintenance to date and, of course, no estimate can be made at this time of the probable service life of the various test sections of continuously reinforced pavement. It appears that further study and additional experimental projects will be required before the question of economics can be answered.

# REPORT ON EXPERIMENT WITH CONTINUOUS REINFORCEMENT IN CONCRETE PAVEMENT—NEW JERSEY

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## SYNOPSIS

This paper reports the observed behavior and performance of two sections of continuously-reinforced concrete pavement constructed in New Jersey in 1947. These sections, which are each approximately one mile long, carry relatively heavy truck traffic. Some of the significant observations are as follows:

1. Both sections undergo an annual over-all change in length of approximately 2 in.
2. Except for minor movements limited to a few hundredths of an inch, all interior points located more than 700 ft. from the ends of the sections have undergone no longitudinal changes in position—that is, in each section there is an extensive central region which has remained essentially at constant length.
3. Except for distances ranging from 64 ft. to 177 ft. at their ends, both sections now contain hundreds of transverse cracks spaced from less than 6 in. to approximately 20 ft. apart. All of these cracks are essentially at right angles to the pavement. There has been no apparent longitudinal cracking.
4. There is a closer spacing of the cracks in the section containing the higher percentage of steel.
5. The cracks have almost doubled in number during the past three years.
6. The crack widths in both sections are extremely variable.
7. The maximum measured width of crack (at gauge plugs) is .03 in.

8. There has been no failure of the steel at any of the cracks and (or) construction joints, nor any faulting at these points.

9. The laps in the steel have had no apparent effect on the location and (or) widths of the cracks.

10. The maximum measured opening of the construction joints is .041 in.

11. Rather serious cracking has occurred, over a distance of from 6 to 10 ft., immediately adjacent to several of the construction joints, but only on the northerly side of the joint—the direction of construction being from south to north.

12. Very serious breakage has occurred at a localized point in the central region of the section containing the lower percentage of steel, within an area 8 ft. square, which will soon require major repairs.

13. Although, in the main, these sections are still in what might be regarded as very good condition, there appears to be an excessive amount of spalling and ravelling at a number of the cracks in the outside lanes—this apparently being largely due to the concentration of heavy traffic on these lanes.

During the fall of 1947 two sections of continuously-reinforced concrete pavement were constructed in New Jersey, each section being approximately one mile in length. Although a detailed preliminary report on the design and construction of these sections is presented in *Proceedings*, Highway Research Board, Vol. 27, 33–42 (1947), it appears desirable to include certain pertinent information concerning them in this report.

These sections are located in the northbound roadway of Route 25, between Hightstown and Cranbury. In this location Route 25 is a divided highway. The northerly section, which is separated from the southerly section by a series of slabs and a bridge, is 5430 ft. long, of 8-in. uniform thickness, and contains 0.90 percent of longitudinal reinforcing steel. The southerly section is 5130 ft. long, of 10-in. uniform thickness, and contains 0.72 percent of longitudinal reinforcing steel. Both sections have an over-all width of 24 ft., and consist of two 12-ft. lanes, constructed independently. The longitudinal joint between lanes is of the tongue-and-groove butt type. Because tie bars were omitted, each lane is more or less free to undergo longitudinal movement without restraint from the adjacent lane.

The reinforcing steel in both sections consists of a double line of welded wire fabric, in the form of mats 16.25 ft. long, installed by the strike-off method. The longitudinal members are of $\frac{3}{8}$-in. cold-drawn wire spaced 3 in. c. to c. Cross-sectionally, there are 94 of these members per lane. The transverse members are of No. 5 cold-drawn wire, spaced 12.2 in. c. to c.

The plans and specifications for this project called for the installation of deformed bars of various sizes. However, due to a steel shortage the contractor was permitted to substitute wire fabric.

Because of its possible effect on the results, it appears important to mention that the welded wire fabric was manufactured very shortly before use and that, in consequence, it was practically free from rust at the time of its arrival on the project. Between that time and its actual installation most of the steel did acquire a film of rust. However, because of its superficial thickness, it appears highly problematical whether the rust actually had any material effect on increasing the bond.

The pavement immediately adjacent to the ends of both sections consists of a series of 56-ft. slabs, the joints at the ends being the standard type of dowelled expansion joints employed in New Jersey—the only significant difference being that $\frac{1}{2}$-in. cork filler was installed in the joints at the ends of the 8-in. section, whereas $\frac{3}{4}$-in. cypress was installed at the ends of the 10-in. section.

The 8-in. section was constructed on 14 in. of high-quality granular sub-base material. The 10-in. section (and all other pavement incidental to the project) was constructed on 12 in. of the same kind of material. The underlying native soil is of a type that, under the truck traffic conditions prevailing in this location, is highly susceptible to pumping.

A typical cross section of the pavement and incidental construction details are shown in Figure 1.

The outstanding features of this design are:

1. The installation of a substantially greater

amount of longitudinal reinforcing steel than installed in pavements of conventional design.

2. The continuation of the reinforcing steel through the construction joints that occur between the portions of pavement constructed from day to day.

3. The complete omission of intermediate transverse joints of any kind other than the construction joints previously mentioned.

It is the function of the reinforcing steel to compel the occurrence of transverse cracks at very close intervals, but, at the same time, to prevent these cracks from opening to any detrimental extent.

*Traffic*—Because of the important influence of traffic on the performance of any pavement, it is necessary to point out that the test sections referred to in this report are subjected to a relatively large amount of heavy truck traffic. The type of heavy-trucking unit that predominates is the tractor-semitrailer combination which, as of the present (Dec. 1950), may legally have, in New Jersey, a gross weight of 60,000 lbs., and a single axle load exceeding 30,000 lbs.—the latter depending upon tire size. Based on 1950 counts, approximately 1,750 of these units pass over both sections daily.

As is usual on divided highways, almost all of the trucks travel on the outside lanes. These lanes are consequently subjected to a much more damaging type of traffic than the inside lanes, which is reflected in their present condition.

A general view of the 8-in. section is shown in Figure 2. The heavier travel on the outside lane is apparent from the greater amount of oil stain on that lane.

A detailed analysis of the traffic in this location is given in Table 1. This table includes traffic data for both 1947 and 1950. It will be noted that during this 3-yr. period the amount of truck traffic has almost doubled.

*Pertinent Observations*—Before proceeding with the details of this report it appears desirable to point out the following:

1. With respect to their over-all changes in length, it is important to appreciate that there is a considerable difference in the behavior of these sections as compared with a slab of conventional length. More particularly, in the case of the conventional slab the contraction or expansion of the slab, as the case may be, results in a movement of all portions of the slab towards or away from a point at its center. These test sections do not behave in this manner. Actually, in each section, which, for purposes of discussion, may be considered to have a length of 5000 ft., there is a central region approximately 3500 ft. in length which remains essentially at constant length at all times—the only portions of the sections that undergo appreciable changes in length being the end portions. In effect, this central region is part of a pavement of infinite length.

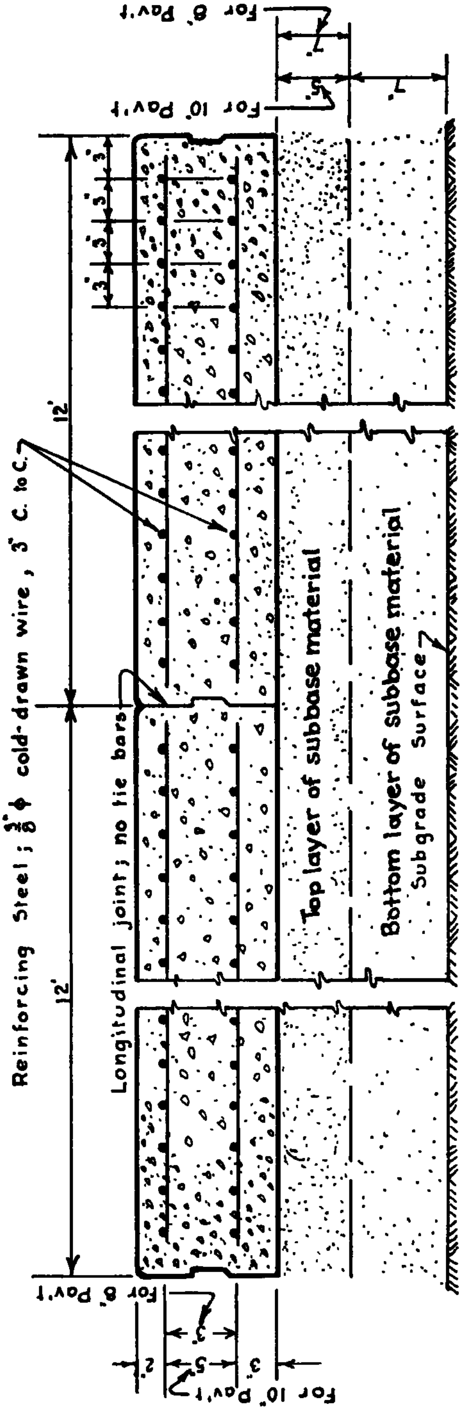
2. The over-all changes in length are considerably less than they would be if the sections were uncracked and free to change in length without material restraint. If, on a proportionate basis, they were to undergo the same seasonal over-all length-changes as ordinary 100-ft. slabs (in New Jersey) they would be approximately 26 in. shorter in midwinter than in midsummer, which is far from being the case.

3. Aside from the tension due to shrinkage resulting from moisture-loss, the tension developed in the central region is primarily a function of the difference between the "as constructed" temperature of the pavement and subsequent lower temperatures. For example, if the pavement were constructed at 90 degrees the tensile stresses developed by a lowering in temperature to 30 degrees would be much higher than if the pavement were constructed at 50 degrees.

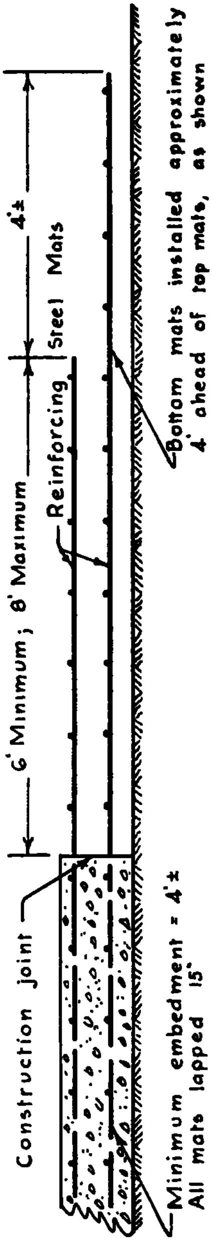
4. The various portions of the sections constructed from day to day were necessarily constructed under somewhat different temperature conditions. This may account to some extent for the erratic behavior observed.

5. During their 3 years of service, the sections have been exposed to only one winter that might be regarded as severe (1947–48), the minimum recorded pavement temperature being 25 deg. on Jan. 26, 1948. The winters of 1948–49 and 1949–50 were very much warmer than normal, with the pavement temperature averaging well above 32 deg., and little or no freezing of the sub-grade at any time.

*Longitudinal Movements*—During construce tion, in order to subsequently determinthe magnitude of the longitudinal changes in position of the ends of the sections, and of




TYPICAL TRANSVERSE SECTION THROUGH
CONTINUOUSLY-REINFORCED CONCRETE PAVEMENT




TYPICAL LONGITUDINAL VIEW
AT END OF DAY'S CONSTRUCTION

Figure 1

various interior points, transverse reference lines were established. These lines, which are perpetuated by cast-in-place concrete monuments, are located at: (1) the ends of the sections; (2) points 200, 500, 700, 900, 1400 and 2000 ft. from the ends; and (3) at points equidistant from the ends. At the time of initial set, brass plugs having well defined center points were installed in the pavement, as precisely as possible on the reference lines. The monument points are also defined by the same type of plug. Measurements are taken by means of a transit set over the monuments, and an engineer's scale. From a purely scientific standpoint, this method of measurement is probably not as precise as might be desired. On the other hand, considering the cost of installing more precise means, and the small margin of error (probably not exceeding 0.04 in.), this method appears sufficiently exact for all practical purposes—especially when it is appreciated that if the sections were free to expand and contract, even the points 1000 ft. from the ends would undergo a seasonal change in position of at least 7 in.

Unfortunately, it has not been possible to take measurements at all of the reference lines as often as desired. However, the significant results of those measurements which have been taken are shown in Tables 2, 3, 4, and 5. In explanation of these tabulations, the figures and arrows indicate the amounts and directions, on the dates shown, that the various points in the sections differed from their original positions. For example, with reference to Table 5, on Jan. 29, 1948 the plug at the northerly end of the 10-in. section was 1.00 in. south of its original position. This, incidentally, is the maximum change thus far measured at any point. The maximum over-all changes in length thus far measured *at the reference lines* are as follows:

*8-in. Section*

| *Inside Lane* | *Outside Lane* |
|---|---|
| 1.22 in. | 1.24 in. |

*10-in. Section*

| *Inside Lane* | *Outside Lane* |
|---|---|
| 1.79 in. | 1.86 in |

Since it might be inferred from the foregoing that the over-all length-changes have been greater in the 10-in. section, it is necessary to point out that, in the main, this difference is due to the fact that the figures shown for the 10-in. section include the results of measurements taken on Jan. 29, 1948, during very cold weather, whereas measurements could not be taken on the 8-in. section on that date because of severe ice conditions. Actually, based on the end joint measurements, which were taken much more frequently, both sections undergo essentially the same over-all seasonal length-changes of approximately 2 in.

As will be noted, all points in the central regions of the sections have remained essentially in their original positions, despite large seasonal changes in pavement temperature. This being the case, it is apparent that the over-all length-changes of the sections are due exclusively to the expansion and contraction of some 500 to 1000 ft. of pavement at the ends—the central regions between these limits remaining at all times essentially at constant length.

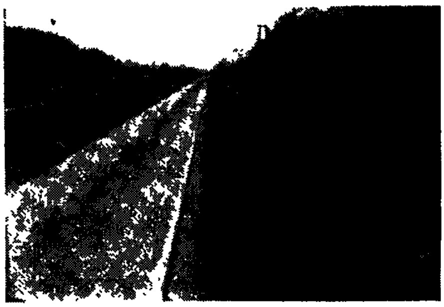


Figure 2

In view of the method of measurement, there may be some question as to whether the small changes in position shown for the interior points have actually occurred. It is believed, however, that, on the average, these figures are fairly accurate. Furthermore, considering that the various portions of these sections were constructed at different times, under somewhat different temperature conditions, it seems possible that as the section as a whole approaches a uniform temperature, different magnitudes of stress are developed in the various portions which, in time, tend to become equalized by a small amount of interior rearrangement. Variations in the cracking may also be responsible. For these reasons it was decided to include the figures.

To date, neither section appears to have

TABLE 1
TRUCK WEIGHTS AND AXLE LOAD DATA
ROUTE 25 AT CRANBURY—NORTHBOUND TRAFFIC (ANNUAL DAILY AVERAGE)

| Gross Weights | | | | |
|---|---|---|---|---|
| | 1947 | 1950 | | |
| | Number of Trucks | Number of Trucks | Number of Tractor-Semitrailers | |
| | | | 2-S-1 [1] | 2-S-2 [2] |
| Total | 1420 | 2500 | 1182 | 560 |
| 5 tons and over | 1310 | 2200 | 1182 | 560 |
| 10 " " " | 1050 | 1930 | 1140 | 560 |
| 15 " " " | 755 | 1555 | 955 | 536 |
| 20 " " " | 530 | 1185 | 670 | 496 |
| 25 " " " | 232 | 695 | 314 | 378 |
| 30 " " " | 78 | 136 | 82 | 54 |
| 35 " " " | 25 | 0 | 0 | 0 |

| Axle Loads | | | | |
|---|---|---|---|---|
| | 1947 | 1950 | | |
| | Number of Single Axles [3] | Number of Single Axles [3] | Tractor-Semitrailers | |
| | | | Number of Single Axles | Number of Tandem Axles |
| Total | 4000 | 7400 | 4660 | 560 |
| 4000 pounds and over | 3740 | 6890 | 4600 | 560 |
| 8000 " " " | 2162 | 4630 | 3140 | 560 |
| 12000 " " " | 1608 | 3525 | 2440 | 536 |
| 16000 " " " | 1220 | 2295 | 1980 | 524 |
| 18000 " " " | — | 1490 | 1405 | 508 |
| 20000 " " " | 721 | 1050 | 1020 | 490 |
| 22400 " " " | — | 533 | 515 | 438 |
| 24000 " " " | 195 | 276 | 276 | 393 |
| 28000 " " " | 48 | 50 | 50 | 257 |
| 32000 " " " | 10 | 8 | 8 | 92 |
| 36000 " " " | 0 | 0 | 0 | 6 |
| 40000 " " " | | | | 0 |

Notes:
1. 2-S-1 denotes a 2-axle tractor, 1-axle semitrailer combination.
2. 2-S-2 denotes a 2-axle tractor, 2-axle semitrailer combination.
3. Also includes the individual axles of tandem axles.

Average daily northbound traffic, all vehicles, in 1947 = 3650
" " " " " " in 1950 = 6800

TABLE 2
LONGITUDINAL MOVEMENTS AT TRANSVERSE REFERENCE LINES

## Inside Lane of 8" Section
Constructed Oct. 1947

| Date | Slab Temp | ← South | | | | | | Distance from End (in feet) | | | | | | | | North → |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 200 | 500 | 700 | 900 | 1400 | 2000 | 2715 | 2000 | 1400 | 900 | 700 | 500 | 200 | 0 |
| Nov. 13, 1947 | 46° | → .22" | → .02" | — | — | — | — | — | — | — | — | — | — | — | ← .02" | ← .24" |
| July 22, 1948 | 83° | ← .20" | ← .09" | → 07" | → .03" | → .04" | → .04" | → .03" | 0 | → 03" | → .04" | → 02" | 0 | 0 | → .11" | → .20" |
| Jan. 23, 1950 | 41° | → .31" | → .06" | → .02" | ← .01" | → .10" | → .07" | → 07" | — | — | — | — | — | — | — | — |
| Jan 26, 1950 | 53° | → .17" | — | — | — | — | — | — | → 02" | → 04" | → .04" | → 04" | 0 | → 05" | ← .10" | ← .23" |
| Oct. 10, 1950 | 73° | → .04" | → .02" | — | 0 | → .04" | → .07" | → .04" | 0 | → 07" | → 10" | → .12" | ← .02" | → 08" | → .17" | → .17" |
| Nov 29, 1950 | 40° | → .32" | → .04" | — | → .03" | — | — | — | — | — | — | — | ← .04" | — | → 06" | ← .19" |

TABLE 3
LONGITUDINAL MOVEMENTS AT TRANSVERSE REFERENCE LINES

## Outside Lane of 8" Section
Constructed Oct 1947

| Date | Slab Temp | ← South | | | | | | Distance from End (in feet) | | | | | | | | North → |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 200 | 500 | 700 | 900 | 1400 | 2000 | 2715 | 2000 | 1400 | 900 | 700 | 500 | 200 | 0 |
| Nov. 13, 1947 | 46° | → .28" | 0 | — | — | — | — | — | — | — | — | — | — | — | 0" | ← .25" |
| July 22, 1948 | 83° | ← .13" | ← 06" | → .08" | → .03" | → 05" | 0 | ← 03" | ← 02" | → 03" | → 02" | ← .01" | → .02" | 0 | → .08" | → .21" |
| Jan 23, 1950 | 41° | → 38" | → 07" | → .04" | 0 | → .11" | → 02" | 0 | — | — | — | — | — | — | — | — |
| Jan 26, 1950 | 53° | → 27" | — | — | — | — | — | — | ← .02" | → .04" | → 03" | → 01" | → .02" | → .07" | ← .05" | ← .26" |
| Oct 10, 1950 | 73° | → 12" | 0 | — | 0 | → .04" | → 02" | ← 03" | 0 | → 07" | → 10" | → 10" | → .01" | → 07" | → .20" | → 15" |
| Nov 29, 1950 | 40° | → 37" | → 07" | — | → .04" | — | — | — | — | — | — | — | 0 | — | → .04" | ← .17" |

TABLE 4
LONGITUDINAL MOVEMENTS AT TRANSVERSE REFERENCE LINES

## Inside Lane of 10" Section
Constructed Sept. 1947

| Date | Slab Temp | ← South | | | | | | Distance from End (in feet) | | | | | | | | North → |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 200 | 500 | 700 | 900 | 1400 | 2000 | 2565 | 2000 | 1400 | 900 | 700 | 500 | 200 | 0 |
| Nov 13, 1947 | 46° | → .30" | → 08" | → 01" | — | — | — | — | — | — | — | — | → .08" | → 05" | ← 10" | ← .29" |
| Jan 29, 1948 | 35° | → 64" | — | → 12" | — | — | — | — | — | — | — | — | — | — | ← 40" | ← 72" |
| July 20, 1948 | 91° | ← 20" | ← 05" | → 07" | → 03" | ← 04" | → 03" | ← 01" | 0 | → 03" | 0 | → 04" | → .10" | — | 0 | → 23" |
| Jan 23, 1950 | 41° | → 41" | → 17" | → 08" | — | → 01" | 0 | 0 | ← 05" | — | — | → .09" | → 15" | — | ← 12" | ← 32" |
| Oct. 6, 1950 | 69° | → .09" | 0 | 0 | — | ← 02" | → .02" | ← 03" | ← 02" | — | — | → 10" | → 08" | — | ← 01" | → 08" |
| Nov. 29, 1950 | 39° | → .40" | → .10" | — | → .06" | — | — | — | — | — | — | — | — | — | ← 08" | ← 33" |

TABLE 5

LONGITUDINAL MOVEMENTS AT TRANSVERSE REFERENCE LINES

## Outside Lane of 10″ Section

Constructed Sept 1947

| Date | Slab Temp | ← South 0 | 200 | 500 | 700 | 900 | 1400 | 2000 | 2565 | 2000 | 1400 | 900 | 700 | 500 | 200 | North → 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Distance from End (in feet) | | | | | | | | | | | | | | |
| Nov 13, 1947 | 46° | → .42″ | → 10″ | → 01″ | – | – | – | – | – | – | – | – | → 06″ | → 09′ | ← 10″ | ← 43″ |
| Jan 29, 1948 | 35° | → 89″ | – | → 10″ | – | – | – | – | – | – | – | – | – | – | ← .47″ | ← 100″ |
| July 20, 1948 | 91° | → 06″ | → 10″ | → 07″ | – | → 03″ | → 07″ | 0 | → 02″ | → .03″ | → .04″ | → 03″ | → .09″ | – | ← 05″ | → .03″ |
| Jan 23, 1950 | 41° | → .70″ | → 34″ | → 09″ | – | → 10″ | → 03′ | → 03″ | 0 | – | – | → .08″ | → 13″ | – | ← 22″ | ← 58″ |
| Oct 6, 1950 | 69° | → 43′ | → 21″ | → 02″ | – | → .06″ | → 06″ | 0 | 0 | – | – | → 10″ | → 05″ | – | ← .12″ | ← .21″ |
| Nov 29, 1950 | 39° | → 69″ | → 28″ | – | – | – | – | – | – | – | – | – | – | – | ← 18″ | ← .62″ |

TABLE 6

## End Joints - 8″ Section

Changes in Width

| Date | Weather | Slab Temp | South End Inside Lane | South End Outside Lane | North End Inside Lane | North End Outside Lane |
|---|---|---|---|---|---|---|
| Oct. 3, 1947 | | 85°± | | 0 500″* | | |
| Oct 10, 1947 | | 80°± | | | | 0.500* |
| Oct 14, 1947 | | 68°± | 0.500″* | | | |
| Oct 20, 1947 | | 75°± | · | | 0.500″* | |
| Nov 15, 1947 | Cloudy | 44° | 0 892″ | 0 863″ | 0.838″ | 0 840″ |
| Jan 20, 1948 | Sunny | 26° | 1.405″ | 1 381″ | 1.321″ | 1 331″ |
| Feb. 11, 1948 | Cloudy | 26° | 1.467″ | 1 443″ | 1.360″ | 1 382″ |
| May 10, 1948 | Sunny | 77° | 0 580″ | 0.593″ | 0.558″ | 0 550″ |
| July 15, 1948 | ″ | 92° | 0 363″ | 0.438″ | 0.329″ | 0 369″ |
| Aug 31, 1948 | ″ | 92° | 0.356″ | 0.421″ | 0.338″ | 0 366″ |
| Dec 27, 1948 | ″ | 28° | 1.375″ | 1.426″ | 1.303″ | 1 389″ |
| June 24, 1949 | ″ | 99° | 0.462″ | 0 593″ | 0 305′ | 0 517″ |
| Feb. 27, 1950 | ″ | 31° | 1.322″ | 1 440″ | 1.147″ | 1 344″ |
| Oct 10, 1950 | ″ | 78° | 0 968″ | 1 124″ | 0 570″ | 0 955″ |
| Dec. 28, ″ | ″ | 29° | 1.636″ | 1 732″ | 1.240″ | 1.581″ |

* Indicates "As Constructed" Width

undergone any permanent increase or decrease in over-all length.

*Periodic Changes in Width of End Joints*—As mentioned previously, the joints at the ends of both sections are dowelled expansion joints of the type standard in New Jersey, and the pavement adjacent to the ends consists of a series of 56-ft. slabs. The joints between these slabs also are expansion joints. During construction, gauge plugs were installed at all joints. The initial measurements were taken

just as soon as the concrete had hardened sufficiently to hold the plugs securely in place.

The most significant results of the measurements taken at the end joints are shown in Tables 6 and 7. Because of the way the data are presented, it appears desirable to mention again that ½-in. cork filler was installed in the joints at the ends of the 8-in. section, and ¾-in. cypress filler was installed at the ends of the 10-in. section. The "as constructed" width of the joint space was, therefore, .500 in. at the ends of the 8-in. section and .750 in. at the ends of the 10-in. section. As determined by the gauge plug measurements, the figures shown in these tabulations are the actual widths of the joint spaces at various times.

It is of particular interest to note that, in general, these joints have undergone an increase in width. For example, in Table 7, it will be noted that on May 10, 1948 and Oct. 10, 1950 the pavement temperature was within one degree of being the same, but that on Oct. 10, 1950 the joints at the ends of the 10-in. section were, on the average, approximately ¼ in. wider. With reference to the widths shown for the 8-in. section, it will be noted that, with but one exception, the joints at the ends of this section have also undergone an increase in width. Taking into account both sections, the greatest increase (more than ½ in.) has taken place at the joint at the south end of the outside lane of the 8-in. section.

A careful study of the data has disclosed that these increases in joint width are not due to a shortening of the sections, but, instead, to a longitudinal displacement of one or more of the 56-ft. slabs adjacent to the ends. An analysis of the reference-line and joint-width measurements taken at the southerly end of the outside lane of the 8-in. section, and of the pavement adjacent to this end, has shown that the 56-ft. slab immediately adjacent to the end is now approximately .60 in. south of its "as constructed" position. The position of the next 56-ft. slab has, however, remained essentially unchanged. This displacement of

TABLE 7

END JOINTS – 10" SECTION
CHANGES IN WIDTH

| Date | Weather | Slab Temp | South End | | North End | |
|---|---|---|---|---|---|---|
| | | | Inside Lane | Outside Lane | Inside Lane | Outside Lane |
| Sept 8, 1947 | | 106°± | | 0.750"* | | |
| Sept. 16, 1947 | | 80°± | | | | 0.750"* |
| Sept 23, 1947 | | 75°± | 0.750"* | | | |
| Sept. 30, 1947 | | 70°± | | | 0.750"* | |
| Nov. 15, 1947 | Cloudy | 44° | 1.059" | 1.302" | 1.095" | 1.310" |
| Jan 20, 1948 | Sunny | 26° | 1.496" | 1.804" | 1.603" | 1.901" |
| Feb. 11, 1948 | Cloudy | 26° | 1.536" | 1.843" | 1.681" | 1.972" |
| May 10, 1948 | Sunny | 77° | 0.783" | 1.164" | 0.805" | 1.092" |
| July 15, 1948 | " | 92° | 0.528" | 0.841" | 0.566" | 0.770" |
| Aug. 31, 1948 | " | 92° | 0.537" | 0.858" | 0.584" | 0.769" |
| Dec. 27, 1948 | " | 28° | 1.450" | 1.753" | 1.580" | 1.833" |
| June 24, 1949 | " | 99° | 0.744" | 1.131" | 0.729" | 1.050" |
| Feb 27, 1950 | " | 31° | 1.535" | 1.807" | 1.587" | 1986" |
| Oct. 10, 1950 | " | 78° | 1.077" | 1.425" | 0981" | 1.388" |
| Dec. 28, " | " | 29° | 1.808" | 1.985" | 1.755" | 2.171" |

* Indicates "As Constructed" Width

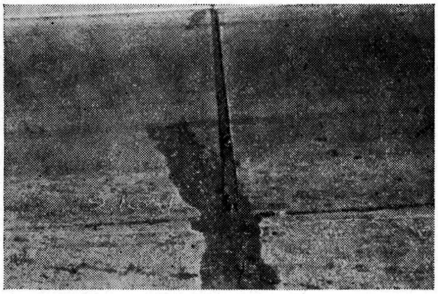


**Figure 3**

extent this process will continue remains to be seen. Despite these infiltrated conditions there has, however, been no apparent breakage of the concrete at any of the end joints. A picture of the joint at the north end of the outside lane of the 10-in. section, taken Nov. 1950, is shown in Figure 3.

*Condition of Pavement at Ends*—As measured from the ends, the end portions of the sections are uncracked for distances ranging from 64

TABLE 8
AVERAGE CRACK INTERVAL (FEET)

| Date | 8" Section | | 10" Section | |
|---|---|---|---|---|
| | Inside Lane 815+46-828+46 | Outside Lane 840+34-849+34 | Inside Lane 915+43-922+43 | Outside Lane 906+10-914+10 |
| Nov. 1947 | 7.7' | 6.6' | 10.7' | 6.2' |
| Oct. 1950 | 3.9' | 3.5' | 6.2' | 4.0' |

the first slab has been reflected in a permanent closure of approximately .60 in. of the expansion joint between the first and second slab—1 in. cork filler having been installed in the joints between the 56-ft. slabs.

Although a detailed analysis has not been made in the remaining instances, it is clearly evident from even a superficial examination of the data that one or more of the 56-ft. slabs adjacent to the ends of both sections has moved away from the sections to a greater or lesser extent—which, of course, is reflected in a corresponding amount of increased opening of the end joints.

A careful inspection of the end joints has disclosed that this displacement is due principally to the infiltration of large amounts of incompressible sandy materials into the end joints. In view of the large amounts that these joints open during cold weather, such infiltration is practically unpreventable. These materials have, in turn, resulted in the compression of the filler to the point where it resists any further compression, at least at some of the joints. This combination of infiltrated materials and compressed filler has naturally prevented the normal closure of the end joints during warm weather, with the result that the adjacent slabs have been pushed outward to new locations. To what

to 177 ft. The uncracked distances for all lanes are as follows:

*8-in. Section*

| *Inside Lane* | *Outside Lane* |
|---|---|
| North end: 109 ft. | North end: 114 ft. |
| South end: 64 ft. | South end: 64 ft. |

*10-in. Section*

| *Inside Lane* | *Outside Lane* |
|---|---|
| North end: 167 ft. | North end: 177 ft. |
| South end: 161 ft. | South end: 64 ft.[a] |

[a] Through core hole

*Cracks*—The central regions of both sections now contain a very large number of transverse cracks. However, to a somewhat lesser degree, this condition has existed almost from the time of construction, there having been the development of a great many cracks within a matter of days.

The cracks are of an extremely erratic nature. Some typical examples are as follows:

(a) Cracks that extend across the full width of the lane.

(b) Cracks that originate at an edge, but which progressively become narrower and terminate at some indefinite distance from the opposite edge.

(c) Cracks that 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.

(d) Cracks that originate and terminate within the lane, without extending to either edge.

Although there are other variations in the cracking, which almost defy description, these examples will nevertheless serve to make apparent two things—namely:

1. That 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. That it is not possible to establish a true average width of crack—considering, for example, that there are a great many cracks that fall in categories (b) and (c), previously described.

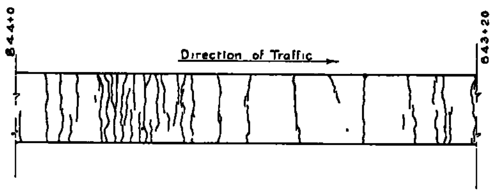



**Figure 4. Crack Pattern—8-in. Section—Inside Lane—Nov. 1950.**

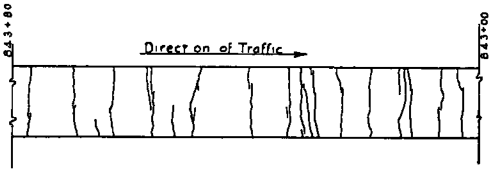



**Figure 5. Crack Pattern—8-in. Section—Outside Lane—Nov. 1950.**

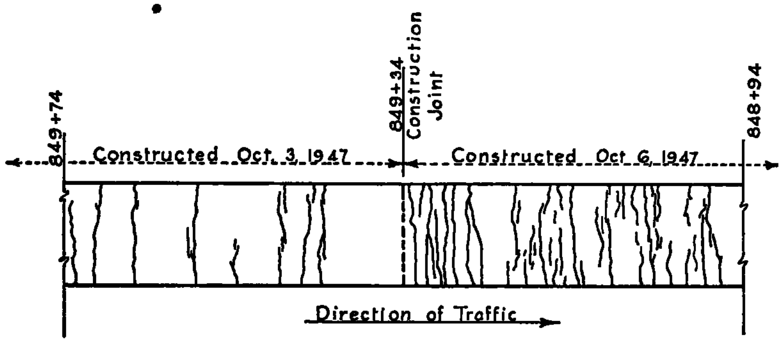



**Figure 6. Crack Pattern—8-in. Section—Outside Lane—Nov. 1950**

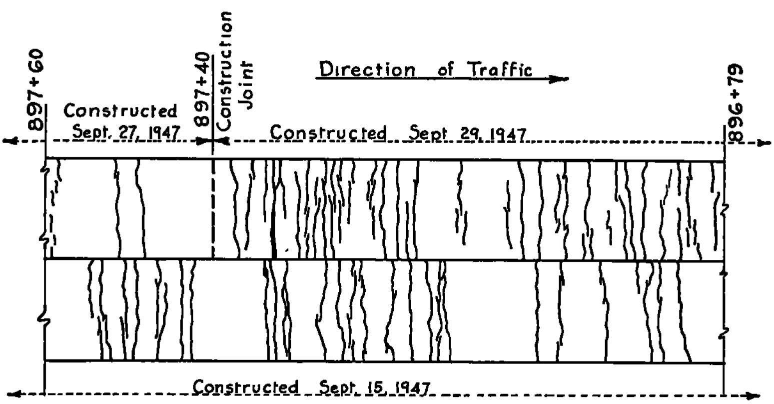



**Figure 7. Crack Pattern—10-in. Section—Nov. 1950**

Bearing these difficulties in mind, the tabulation shown in Table 8 nevertheless was prepared. This tabulation, which is at least indicative of the average crack interval, and of the increase in cracking during the 3 years of service, is based on crack surveys made of a full day's work in each lane of each section—the only cracks recorded being those clearly defined structural cracks that were apparent in the pavement adjacent to the longitudinal joint. It will be noted that:

(a) The number of cracks has almost doubled during the past 3 years.

(b) On the average, the cracks are spaced at somewhat closer intervals in the outside lanes than in the inside lanes—the greatest difference being in the 10-in. section.

(c) On the average, the cracks are more closely spaced in the 8-in. section than in the 10-in. section.

In addition to their erratic characteristics, the cracks are far from being uniformly spaced. Actually, the spacing ranges from less than 6 in. to approximately 20 ft. There are, however, only six locations in the central regions where the spacing exceeds 12 ft.

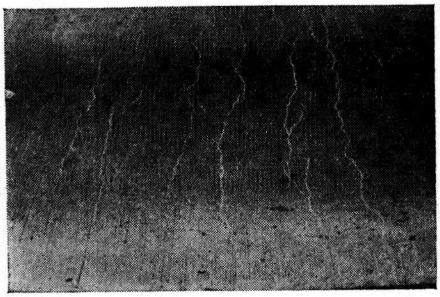


**Figure 8**

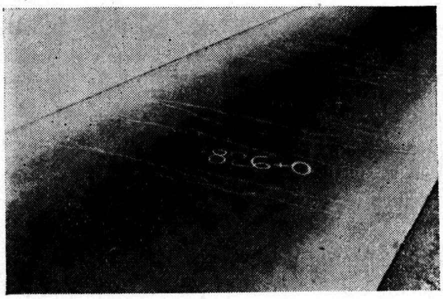


**Figure 9**


**Figure 10**

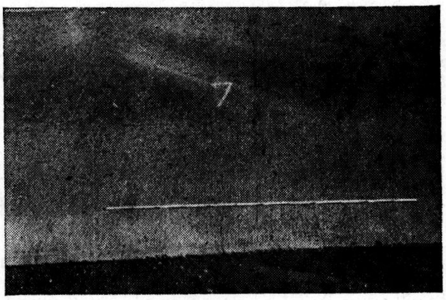



**Figure 11**

In order that this report would show the true nature of the cracking, detailed crack surveys were made in four locations. The crack patterns in these locations are shown in Figures 4, 5, 6 and 7. Figures 8 to 11 are pictures of various typical crack patterns. Of particular interest is the cracking shown in Figure 11, which is in the inside lane of the 10-in. section, at station 897 + 33. As will be noted, the most prominent crack in evidence extends clear across the lane. This crack is of variable width, being much wider at the longitudinal joint than at the shoulder edge seen in the foreground. This variation in width is compensated for, in the vicinity of the shoulder, by the shorter and narrower cracks on each side of the crack in question.

Variations in the widths of cracks throughout their lengths, as a result of the influence of other cracks nearby, are evident in numerous locations. Furthermore, the very considerable number of cracks which originate at an edge, but which do not extend clear across the lane, are obviously of variable width.

*Crack Widths*—During construction, at 12 locations within the central regions of the

sections, brass gauge plugs were installed to provide means of taking precise measurements from time to time of the amounts the cracks are open. 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 intermediate distances between these plugs were measured to the nearest .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.

As may be inferred from the foregoing, the cracks which now pass between these plugs are of variable widths. The results of the gauge-plug measurements taken periodically in four of these locations are shown in Tables 9 and 10. With reference to these tabulations, it will be noted that:

(a) In general, the cracks are somewhat wider in the 10-in. section than in the 8-in. section.

(b) The maximum measured width of crack in the 10-in. section is .030 in.

TABLE 9

8" SECTION; INSIDE LANE; 847+50-847+95
Laid Oct. 15, 1947; 49-10" Spaces; Sunny
Slab temperature at initial reading = 70°±

| Date | Slab Temp. | Nº Cracks | Crack Width | |
|---|---|---|---|---|
| | | | Maximum | Average |
| Nov. 14, 1947 | 51° | 4 | .010" | .008" |
| Feb. 24, 1948 | 45° | 6 | .008" | .007" |
| Jan. 19, 1950 | 35° | 7 | .012" | .010" |
| Jan. 20, 1950 | 30° | 7 | .013" | .011" |
| Feb. 27, 1950 | 36° | 7 | .013" | .011" |
| Oct. 3, 1950 | 84° | 7 | .012" | .010" |
| Nov 6, 1950 | 75° | 7 | .011" | .010" |
| | | | | |

8" SECTION; OUTSIDE LANE; 831+40-831+80
Laid Oct 7, 1947; 49-10" Spaces; Sunny
Slab temperature at initial reading = 75°±

| Date | Slab Temp | Nº Cracks | Crack Width | |
|---|---|---|---|---|
| | | | Maximum | Average |
| Nov 14, 1947 | 51° | 3 | .011" | .010" |
| Feb. 24, 1948 | 45° | 3 | .010" | .008" |
| Jan 19, 1950 | 35° | 4 | .018" | .014" |
| Oct 4, 1950 | 69° | 4 | .018" | .014" |
| Nov. 14, 1950 | 56° | 4 | 019" | .014" |
| Nov 30, 1950 | 44° | 4 | 019" | .015" |
| | | | | |

TABLE 10

10" SECTION; INSIDE LANE; 910+00-910+50
Laid Sept. 26, 1947; 60-10" Spaces; Sunny
Slab temperature at initial reading = 76°±

| Date | Slab Temp. | Nº Cracks | Crack Width | |
|---|---|---|---|---|
| | | | Maximum | Average |
| Nov 13, 1947 | 52° | 5 | 012" | .008" |
| Jan 15, 1948 | 30° | 6 | .016" | .012" |
| Feb. 10, 1948 | 26° | 7 | .022" | .011" |
| Feb. 24, 1948 | 46° | 7 | .011" | .006" |
| Jan 20, 1950 | 30° | 8 | 024" | .014" |
| Oct. 3, 1950 | 80° | 8 | 016" | .011" |
| Dec 1, 1950 | 45° | 8 | .023" | .013" |
| | | | | |

10" SECTION; OUTSIDE LANE; 910+25-910+50
Laid Sept. 11, 1947; 30-10" Spaces; Sunny
Slab temperature at initial reading = 105°±

| Date | Slab Temp | Nº Cracks | Crack Width | |
|---|---|---|---|---|
| | | | Maximum | Average |
| Nov. 13, 1947 | 52° | 4 | .020" | .015" |
| Feb. 10, 1948 | 26° | 5 | .028" | .016" |
| Feb. 24, 1948 | 46° | 5 | .019" | .012" |
| Jan 19, 1950 | 36° | 6 | 029" | 020" |
| Feb. 27, 1950 | 31° | 6 | .030" | .021" |
| Oct 3, 1950 | 80° | 6 | .026" | .015" |
| Oct 18, 1950 | 70° | 6 | .025" | .016" |
| | | | | |

(c) The maximum measured width of crack in the 8-in. section is .019 in.

It should be borne in mind that the crack widths shown in these tabulations are based exclusively on the measurements taken at the gauge plugs. Actually there are some cracks in other locations, outside the limits of the gauge plugs, which, on the basis of their appearance, exceed to some extent the maximum widths shown, but for which no precise means of measurement has been available.

Because of changes in the temperature and

moisture content of the pavement, the cracks are almost constantly changing in width. The maximum widths exist only during that brief period in midwinter when the pavement is at its lowest temperature. Conversely, the minimum widths exist only during that period in the summer when high pavement temperature and moisture content, acting jointly, have their greatest expansive effect. The results of certain very precise measurements indicate, however, that even during periods of high pavement temperature the cracks do not return to zero width. This, in fact, is evident from the data given in Tables 9 and 10. There is also an indication that, with the elapse of time, there is a tendency for the cracks to remain more open during the summer. Whether this residual opening is due to the accumulation of incompressible material in the crack spaces, shrinkage, plastic flow, or other causes remains unknown.

In giving consideration to the opening of the cracks, it is apparent that since the central regions of the sections are, in effect, part of a pavement of infinite length, any such opening must be compensated for by an equivalent amount of shortening of the uncracked portions of the pavement included between the cracks. Both this and the tendency for the cracks to remain open even during warm weather have been confirmed by actual measurement. For example, on July 31, 1950, measurements were taken at a series of 20-in. gauge plugs installed, during construction, at 100-ft. intervals along the center line of the outside lane of the 8-in. section. When these measurements were taken, the pavement temperature was 95 degrees. Taking into consideration only the 34 pairs of plugs in the central region, the following conditions obtained:

There were one or more transverse cracks passing between 13 of the 34 pairs of plugs. At these 13 locations, the plugs were an average of .0051 in. farther apart than at the time of construction, whereas, the 21 pairs of plugs between which no cracking had occurred were an average of .0028 in. closer together.

Measurements were again taken at these plugs on Dec. 1, 1950, the pavement temperature being 46 degrees. As compared with the measurements taken on July 31, the following changes had occurred:

The plugs between which cracking had occurred were an average of .0013 in. farther apart, whereas, the plugs between which no cracking had occurred were an average of .0011 in. closer together.

Since it might be inferred from the foregoing that the average increase in crack width between these dates, for a drop in pavement temperature of 49 deg. was only .0013 in., it appears necessary to point out that the actual increase was more nearly .0024 in. This is explained by the fact that the plug measurements merely show the amount of change in distance that has taken place between the plugs themselves, which amount is not truly indicative of the increase in crack width because there is also an actual shortening of the concrete between the plugs. In order to obtain the actual increase (more nearly), the amount of shortening must be added to the increase in the distance between plugs.

To date, there has been no apparent failure of the reinforcing steel at any of the cracks, nor has there been any longitudinal cracking. The laps in the reinforcing steel have had no apparent effect on the location and (or) the widths of the cracks.

*Conditions at Cracks*—With the exception of certain locations to be considered later, no deterioration susceptible to evaluation on a quantitative basis has as yet occurred at the cracks. On the other hand, there are a considerable number of cracks at which a small amount of spalling has occurred—this being much more pronounced in the outside lanes. This condition is also somewhat more pronounced in the 10-in. section—possibly because the cracks in this section are somewhat wider. The cracks in the inside lanes of both sections are still comparatively free from spalling, the indications being that this is a form of deterioration that is accelerated by the action of heavy traffic.

Typical spalled cracks are shown in Figures 12 and 13. Of particular interest and significance is the crack shown in Figure 12, which is typical of many other cracks. It will be noted that at certain points this crack becomes divided into two cracks which form small islands. In the course of time, especially under the action of heavy traffic, these islands tend to shatter and become dislodged, leaving holes in the surface. The extent to which this form of deterioration will progress remains

unknown—but the indications are that it will progress. Actually, the division of the cracks in such a way as to form small islands susceptible to being shattered and broken out may constitute one of the most serious objections to this design. Whether or not this is preventable by the installation of a larger amount of steel, or steel of a different design, is not known.

Although there is apparently no pumping at any of the cracks (perhaps because of the granular sub-base) it has been observed that following a rain there is, at some of the wider cracks, the exudation of a small amount of water containing a whitish material in suspension. This is shown in Figure 16. This material appears to be derived from the concrete itself, possibly as a result of abrasion or some form of break-down at the crack.

Thus far there has been no apparent faulting at any of the cracks.

*Construction Joints* — Except for a small amount of minor spalling at a few of the construction joints, the pavement immediately adjacent to these joints is still in very good condition. There furthermore has been no apparent faulting at any of these joints. The maximum opening thus far measured is .041 in.

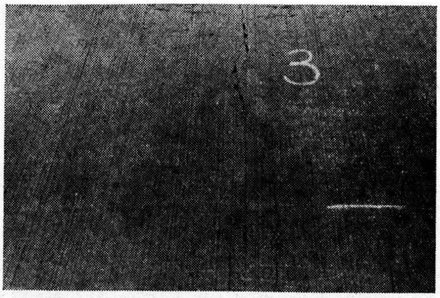



**Figure 12**

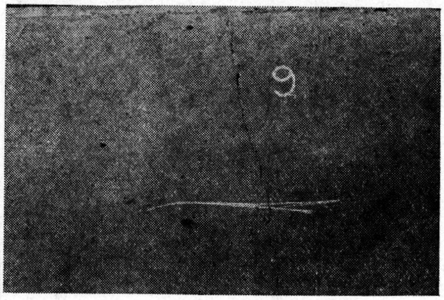



**Figure 13**

Rather serious cracking has, however, occurred in the immediate vicinity of several of these joints, over a distance of from 6 to 10 feet, but only on the northerly side of the joint—the direction of construction being from south to north. The most serious cracking of this kind is adjacent to a joint in the outside lane of the 8-in. section, at 849 + 34, between the pavement laid on Oct. 3 and Oct. 6. The pavement at this joint is shown in Figures 14 and 15, the cracks having been delineated by yellow keel. Figure 15 shows in greater detail the cracks just north of the joint, considerable ravelling being in evidence. The results of a detailed crack survey extending for 40 ft. on each side of this joint are shown in Figure 6. As will be noted, there is a very much closer spacing of the cracks on the north side. This crack pattern is typical of the cracking adjacent to a number of other construction joints, as will also be noted in Figure 7.

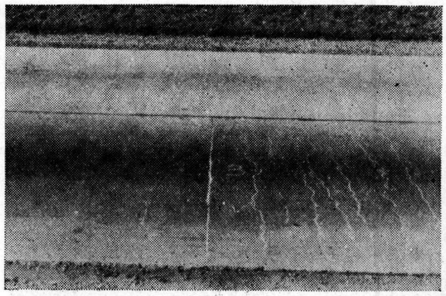


**Figure 14**

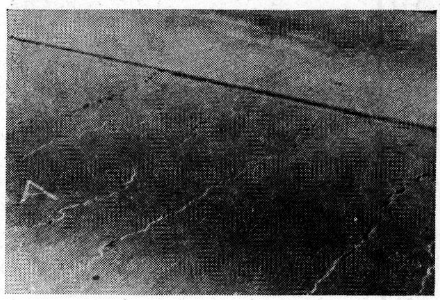



**Figure 15**

Of several possible causes, the indications are that this severe form of cracking is due to

the fastening together of the various portions of pavement constructed from day to day—that is, by means of the reinforcing steel continued through the construction joints. This method of construction naturally involves the attachment together of sections of pavement having, at the time of attachment, materially different tensile strengths. During early life, with a lowering in termperature and resulting tendency to contract, the stronger concrete apparently pulls the weaker concrete apart. This appears to be confirmed by the fact that, in general, this form of cracking is most pronounced adjacent to those joints at which construction was not resumed the following day. At the joint previously referred to, and at which the cracking is more serious than at any other joint, there was a 3-day delay in the construction.

**Figure 16. May 27, 1949**

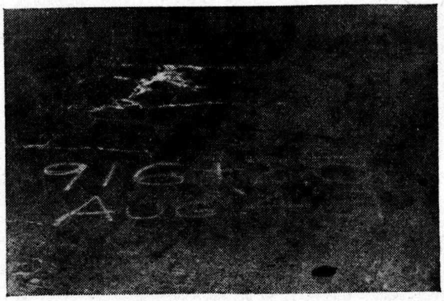


**Figure 17. August 16, 1949**

Since it might have had considerable influence on the development of this cracking, it appears desirable to mention that colorless membrane spray was used in the curing of all pavements constructed on this project. This material obviously has practically no insulating value. Had the method of curing been one that would have prevented a material lowering in pavement temperature until such time as the adjoining sections had more nearly attained equivalent strength the cracking might have been much less serious.

In any case, this development naturally raises the question of whether it is sound practice to attach together the sections of pavement constructed from day to day—bearing in mind the possibility of long delays due to equipment failures, rainy weather, etc., and the difficulty and cost of providing a type of insulation that would be sufficiently effective in the event of a large drop in temperature. Based on the behavior of these sections, the safer course would appear to be the installation of joints between each day's construction, despite the fact that this would largely defeat the main objective of the design—that is, a completely jointless pavement.

*Failed Area*—During very early life, rather severe cracking was observed at a point in the outside lane of the 10-inch section, approximately 1425 ft. from the southerly end. This cracking did not appear to become serious until the spring of 1949, at which time there were indications that there might soon be a break-up. Beginning in May 1949, pictures were taken periodically at this location in order to record pictorially the manner of failure. These pictures are shown in Figures 16 through 23.

As will be noted in Figure 19, on Sept. 15 the failure had advanced to the point where the upper 3 in. of concrete had become shattered and broken loose from the underlying concrete. On that date the shattered concrete was removed and replaced with cold-patch material. The conditions immediately prior to the placement of the cold-patch are shown in Figure 20. It will be noted that the failed area has progressively increased in size. At present (Dec. 1950) it is approximately 8 ft. square.

The concrete underlying the 3-in. thickness of cold-patch now appears to be shattered into pieces 2 ft. or less square—the effect being a mass of shattered concrete clinging to the reinforcing steel. With the passage of heavy trucks, considerable up and down movement is in evidence. During rainy weather, pumping

is also in evidence—the indications being that, owing to the large amount of surface water which reaches the subgrade through the shattered concrete, the finer particles of the subbase material are being pumped out.

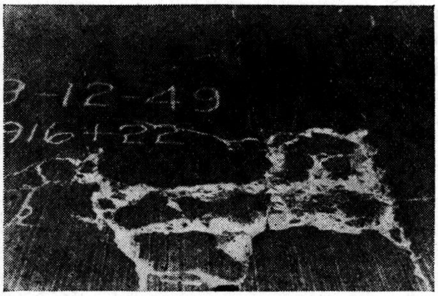


**Figure 18. September 12, 1949**

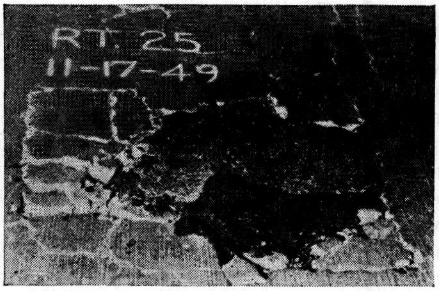



**Figure 21. November 17, 1949**

**Figure 19. September 15, 1949**

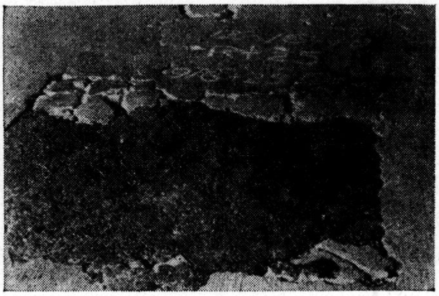


**Figure 22, December 16, 1949**

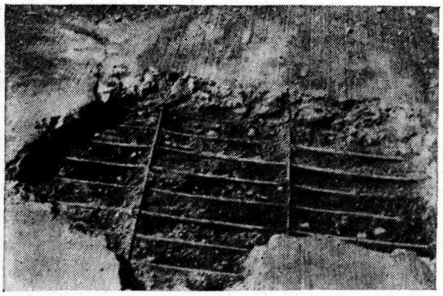


**Figure 20. September 15, 1949**

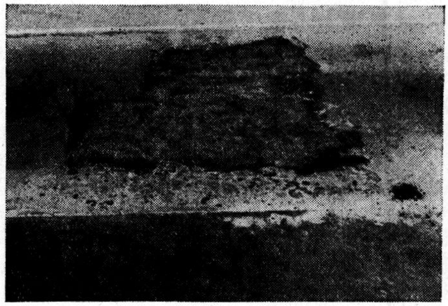


**Figure 23. December 7, 1950**

Thus far there does not appear to have been any material pulling-apart of the pavement at this point, but this appears imminent. With this probability in mind, transverse reference lines have been established on each side of the break. Actually, the deterioration has now advanced to the point where major repairs will soon be necessary. The only practical procedure appears to be the introduction of a joint, in conjunction with the replacement of the shattered concrete with new concrete.

The cause of this failure remains obscure. However, the indications are that the concrete at this point is of inferior quality, especially the layer between the upper and lower lines of reinforcing steel. The records kept during construction mention that, when placed, the concrete in this layer, at this particular point, was very "soupy", there being considerable free water on its surface after being struck off. When the upper 3 in. were removed this layer

was found to be soft and spongy. The batch from which it was derived may have been accidentally deficient in cement. There is, however, the possibility that the close spacing (3 in.) of the longitudinal members may have created a plane of separation.

In view of this development, it appears that in the continously-reinforced design serious thought needs to be given to the strength of the concrete, especially uniformity in strength, and also to the positioning and spacing of the reinforcing members. Bearing in mind that during cold weather very high tensile stresses are developed within the central regions, it appears that the concrete must be of very good quality or else it will break up into small pieces. Unfortunately, however, from an economic standpoint, the

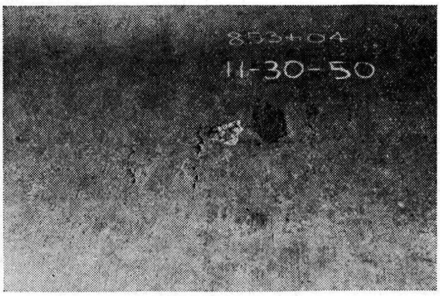



**Figure 24. November 30, 1950**

stronger the concrete the greater the amount of steel required to produce the desired results.

With the exception of the previously described severe cracking adjacent to some of the construction joints, there is at present only one other location which appears likely to undergo this form of failure. This is in the outside lane of the 8-in. section, 494 ft. from the southerly end. The present conditions at this point are shown in Figure 24. Except for a slow progressive enlargement of the cold-patched area, the conditions at this point have remained essentially unchanged during the past year.

*Changes in Elevation*—At certain locations, at the time of construction, levels were taken at 5-ft. intervals along both edges of the lanes, in order to determine the magnitude of subsequent changes in elevation. A recent re-taking of these levels indicates that, during the 3 years of service, changes in elevation have occurred, but that, on the average, they are limited to less than $\frac{1}{4}$ in. Except for a few very limited areas where the pavement is now from $\frac{1}{8}$ to $\frac{1}{4}$ in. above its "as constructed" grade, the pavement still is, in general, either at grade or below grade from $\frac{1}{8}$ to $\frac{1}{4}$ in., the latter condition predominating. There are, however, a few localized areas where, over a distance of some 50 ft., settlements of as much as $\frac{5}{8}$ in. have occurred. In driving over these areas a slight "dip" is felt.

On Feb. 2, 1948, after a period of subfreezing weather, levels were taken along both edges of the outside lane of the 10-in. section, between 893 + 53 and 899 + 03. These levels disclosed a differential heaving of the edges—the outside and inside edges having heaved, respectively, an average of .07 and .03 ft. The most pronounced differential existed between 895 + 53 and 897 + 03. Between these points, over the entire distance, the outside and inside edges averaged, respectively, .08 and .01 ft. above their original grade. A similar pronounced differential heaving between the edges of lanes has been recorded on other projects.

*Supplementary Experimental Pavement*—As a supplementary experiment, 16 slabs 187 ft. long were included in this project, 8 slabs in each lane. The transverse joints between the slabs are expansion joints of the dowelled type standard in New Jersey, with $\frac{3}{4}$-in. cypress filler. These slabs are continuous from expansion joint to expansion joint, with no intermediate joints of any kind. At each end, over a distance of 34 ft., the reinforcing steel consists of a single line of welded wire fabric, the longitudinal members being No. 00 gauge cold-drawn wire, 6 in. c. to c. In the central 119 ft. the steel consists of a single line of the same kind of wire fabric installed in the continuously-reinforced sections (0.36 percent).

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

| *Inside Lane* | *Outside Lane* |
|---|---|
| Four uncracked | Four uncracked |
| Two with one crack | Two with one crack |
| One with two cracks | One with four cracks |
| One with five cracks | One with five cracks |

These cracks are not concentrated within the central regions, but, instead, are located at various distances from the ends. Six of the 20

cracks are within 20 ft. from the ends. All of these cracks are very narrow, free from ravelling, and of no apparent structural significance. There are no longitudinal cracks.

Periodic measurements show that for a change in pavement temperature of 66 degrees, between winter and summer, the expansion joints between these slabs undergo an average change in width of .672 in.

There has been no pumping or faulting apparent at any of these joints, nor at other joints on the project. Except for the above-mentioned small amount of cracking these slabs, and all of the 56-ft. slabs, are still in excellent condition. Only four of the 56-ft. slabs, of which there are 54, are cracked (one crack in 3 slabs, 2 cracks in one slab).

*Concluding Remarks*—Although the future performance of these continuously-reinforced sections cannot, of course, be predicted, the following remarks nevertheless seem to be in order.

1. In terms of their riding qualities, and of what may be seen in driving over them at normal speeds, these sections, in the main, are still in excellent condition. Except for some small localized settlements, there have been no significant changes in elevation. On the other hand, if examined critically, the condition of the pavement, expecially that of the outside lanes, does not create a very favorable impression.
2. Many of the cracks appear to have opened too much to permit the pavement to have long-term serviceability.
3. The amount of ravelling at the cracks in the outside lanes appears to be excessive.
4. The crack pattern is such that it encourages ravelling.
5. The severe cracking that has developed adjacent to several of the construction joints suggests that it is not sound practice to connect together the various portions of pavement constructed from day to day.
6. The broken area in the outside lane of the 10-in. section suggests that any material lack of concrete strength at any given point is likely to result in serious failure at that point.
7. The present condition of the outside lanes suggests that the continuously-reinforced pavements on this project, despite the presence of a high-quality granular sub-base, are not capable of satisfactorily carrying, on a long-term basis, the type and volume of heavy truck traffic existing in this location.
8. It is the general impression of those who have examined these sections critically that, despite its lesser thickness, the 8-in. section is, on an over-all basis, in somewhat better condition than the 10-in. section. This is probably attributable to the higher percentage of steel and resulting narrower cracks.

It is obviously not known whether the results would have been materially different had the steel consisted of high-bond deformed bars of high tensile strength. Nevertheless, it is quite apparent from the behavior of these sections that a continuously-reinforced pavement is one that, in effect, tends to be self-destroying. As evidenced by the opening of the cracks, it is clear that during periods of cold weather very high tensile stresses are developed within the central regions. Inasmuch as the central regions are unable to relieve the tension by contracting, as occurs in the case of slabs of conventional length, it follows that the lower the temperature the higher the tension. As a matter of fact, cold weather appears to be the force or factor which tends most to destroy a pavement of this design.

There furthermore appear to be reasonable grounds for questioning whether a continuously-reinforced pavement has a structural strength equivalent to that of a pavement of conventional design—especially when it is considered that during the winter the pavement actually consists of a series of very short sections of concrete clinging to the reinforcing steel, similar to a venetian blind, and that these sections are separated from one another by open cracks. Under these conditions the pavement presumably has relatively little rigidity and/or load-distributing capacity in a longitudinal direction.

Because of the fact that continuously-reinforced pavements are susceptible to a very wide range of variation in design—that is, in regard to their thickness, and the amount, type, positioning and tensile strength of the reinforcing steel—they are consequently susceptible to a wide variation in behavior and performance. It is to be understood, therefore, that the preceding remarks are based exclusively on the observed performance of the New Jersey test sections, particularly as related to

the amount of steel in these sections. Clearly, if there were no economic limitations on the amount of reinforcing steel that could be installed, a very substantial design of continuously-reinforced pavement could undoubtedly be developed. But since the cost factor is obviously one that must be taken into account, the problem resolves itself into determining whether or not, from an economic as well as structural standpoint, a pavement of this design can compare favorably with a pavement of different design.

It is therefore pertinent to mention that, in our test sections, the reinforcing steel in itself cost $2.78 per sq. yd. of pavement. In consequence, the cost of the 10-in. section was approximately $1.60 more per sq. yd. than we paid at that time for our standard design of 10-in. reinforced pavement. Even the 8-in. section cost approximately $1.00 more per sq. yd. than our 10-in. standard design. This higher cost would perhaps be of little importance were it reflected in outstandingly superior performance. But the fact of the matter is that our standard reinforced pavements on the same route, of essentially the same age, on practically the same kind of subgrade material, and carrying the same traffic, are in excellent condition—being thus far almost entirely free from visible defects of any kind. Furthermore, despite the presence of expansion joints, the riding qualities of these pavements are essentially on a par with the continuously-reinforced sections—due to the care taken in finishing and edging of the joints, and to adequate dowelling.

In view of the foregoing, it appears that this design would stand the best chance of proving satisfactory in those parts of the country where the winters are relatively mild —especially if, in order to minimize the differential between the "as constructed" temperature and subsequent lower temperatures, construction were limited to the cooler seasons. Theoretically, any such reduction in differential would justify a reduction in the amount of steel required.

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