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DEVELOPMENT OF CONTINUOUSLY REINFORCED CONCRETE
HIGHWAY PAVEMENTS IN THE UNITED STATES

by

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The first concrete pavements constructed in the United States consisted of concrete blocks approximately six feet square and six inches thick.

Success with these first experiments encouraged further research to develop a better design and to improve construction methods. Pavement block dimensions were increased and steel reinforcement was added for structural strength. Granular materials were used to support these larger slabs and to provide better drainage and insulation. Paving machinery was developed to speed up the paving operations. By 1935 a major portion of the new highways designed for heavy vehicular loading were of concrete slab construction.

During the past few years jointed pavement sections have increased in size until slabs ten inches thick, twelve feet wide

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and one hundred feet long are not uncommon. Various connecting devices installed between adjoining slabs and adjacent traffic lanes help facilitate load transfer and permit thermal expansion and contraction of the individual slabs.

While this form of pavement construction has proven quite successful, and at present is an accepted standard for highway pavements throughout the United States, it is not believed to be the optimum design for reinforced concrete pavements.

Highway engineers found that the random cracks which often occurred within the longer reinforced pavement slabs did not become a maintenance problem if adequate reinforcement had been used. While these cracks responded slightly to thermal expansion and contraction, they did not open to objectionable width during cold weather or fail under traffic loading.

This led to the theory that pavements with adequate continuous longitudinal steel reinforcement could be constructed without prepared joints. The concrete shrinkage and the temperature induced strains would cause very narrow transverse cracks to occur at frequent intervals but the steel reinforcement would maintain longitudinal continuity and limit the width of the cracks.

In theory, this type of construction results in a continuous semi-flexible slab, capable of withstanding normal climatic and vehicular loading conditions. The elimination of the often troublesome transverse joints reduces maintenance costs and provides
a smoother, safer riding surface for the motorist.

In September of 1938, near Stilesville, Indiana, several sections of continuously reinforced concrete pavements were constructed. This experimental project, under the supervision of the Indiana State Highway Department and the U. S. Bureau of Public Roads, was planned to investigate a large number of design variables. Several sizes and types of longitudinal steel reinforcements were used in 9-7-9-inch thickened-edge pavements 20 feet wide with a total length of three miles. The quantity of reinforcement was varied in selected sections to comprise from 0.07 to 1.82 percent of the cross-sectional area. All of the pavement was placed on compacted native soil without the use of a special base course. Different types of contraction-expansion joints were installed at the ends of individual test sections in order to evaluate their comparative performance.

A complete record was maintained of the construction operations and provisions were made to permit the measurement of future dimensional changes in the pavement.

After twenty years of service, this heavily traveled four-lane pavement remains in good condition. Maintenance costs have been moderate and the quality of the riding surface is excellent, when compared with conventional jointed pavements of equal age and service.
The continued good performance of this first experimental pavement has been an important factor in maintaining interest in the use of continuous reinforcement as a means of building better highways.

During the period of World War II, research and construction of highways for civilian use dropped far behind the post-war needs. By 1946 most of the existing roads were in need of repair and the increased traffic indicated a definite need for improved highway design to meet the demands of modern vehicles.

In 1947, the states of Illinois and New Jersey each constructed experimental pavements using the continuous reinforcement design. Similar pavements were constructed in California in 1949 and in Texas in 1951.

Each of these test pavements was designed to take advantage of the information obtained from previous experiences. By 1956, when the state of Pennsylvania planned the construction of two experimental continuously reinforced pavements, many general design limitations had been established.

Most pavements containing less than 0.20% longitudinal steel reinforcement had developed wide cracks in cold weather. Under heavy traffic loads the steel at some of these cracks had failed within a few years, resulting in excessive pumping at the faulted joints. Where the reinforcement had been 1.0% or greater, the cracks were more numerous but had remained very narrow and
had not shown any evidence of progressive deterioration.

All of the expansion and contraction devices which were used had shown some degree of weakness. The conventional dowel type joints were unsatisfactory, failing to function properly when subjected to the greater end movements of long continuously reinforced pavement sections.

The optimum pavement thickness had not been fully established. It appeared that the percentage of steel reinforcement would be the major factor in the prevention of pavement damage at contraction cracks, even in pavements six or seven inches thick.

In planning the experiments in Pennsylvania, it was decided that, in addition to other measurements and observations, a thorough investigation would be made of the transverse cracking process and the effects of these cracks upon the steel and concrete in their immediate vicinity. The Fritz Engineering Laboratory at Lehigh University, under contracts with the United States Bureau of Public Roads, the Pennsylvania Department of Highways and the American Iron and Steel Institute was assigned this portion of the project.

The first continuously reinforced pavement in Pennsylvania was constructed on U. S. Route 111 between Harrisburg, Pa. and Baltimore, Md. in the fall of 1956. It consisted of four traffic lanes, each twelve feet wide, with a twenty foot wide median strip separating the North and South-bound double lanes. Each
nine-inch thick lane was constructed separately and was supported on a six-inch thick granular base course. The 0.48 percent longitudinal reinforcement was placed at pavement mid-depth and consisted of bar-mats sixteen feet long as shown in Fig. 1.

The second pavement was constructed in the summer of 1957 on U. S. Route 22 between Harrisburg, Pa. and New York City. The design was identical to that on Route 111, except that a pavement of seven, eight and nine inches thickness was constructed upon granular bases of three or six-inch thicknesses. Also a short section was reinforced with welded wire mesh instead of the conventional bar-mats.

Both experimental pavements were approximately two miles in length and were terminated at each end with finger-type bridge expansion joints which separated the experimental sections from the adjacent jointed pavements and permitted complete freedom of longitudinal movement at each end.

During construction, electrical gages were installed at selected locations to measure longitudinal strain in the steel reinforcing bars and in the concrete. (Fig. 2). Resistance wire temperature transducers were inserted in the sub-base, granular base course and concrete pavement to determine seasonal temperatures and vertical temperature gradations. Arrangements were made to enable the measurement of crack widths and pavement warping adjacent to the cracks. All electrical gage lead wires were
placed under the pavement and terminated at a junction box near the edge of the highway. Fig. 3.

To insure that cracks would occur at the exact locations of the instrument installations, transverse planes of weakness were induced in the pavement. This was accomplished by inserting a thin metal strip transversely across the lower pavement depth prior to the placing of the concrete. Fig. 4. Cracks developed at these artificial planes of weakness within 48 hours after construction.

Readings taken from the electrical and mechanical gages immediately after the test area was paved provided the basis for subsequent measurements.

During the first two days after construction and until the instigated crack had developed, measurements were taken every two hours. After this, measurements were taken weekly for a month and then only once each month until the present time. The schedule of monthly readings will probably continue for three years or until the pavement stabilizes and responds, within a predictable pattern, to yearly temperature cycles.

Although the magnitude of the periodic measurements varied at individual test sections, the general behavior pattern at all instigated cracks was very similar. Stresses in the pavement remained low during the first two days after construction. As the concrete began to cure and develop a stronger bond with the reinforcing steel, shrinkage stresses in the concrete were transferred
to the steel. Continuing shrinkage and daily temperature cycling produced sufficient tensile stress in the pavement to cause transverse cracks to form; first at the induced plane of weakness and later at random intervals throughout the length of the pavement. Colder winter temperatures caused these cracks to open wider and some new cracks to occur in the longer uncracked sections. After approximately one week, temperature became the major influence in the behavior of the pavement, with crack widths and strain in the reinforcing steel responding directly with changes in seasonal temperature. This very close relationship is graphically evident in Fig. 5.

After one year of service all of the experimental pavements in Pennsylvania are in very good condition. No longitudinal cracking has occurred, and the normal transverse cracks have not opened to excessive widths. The results of previous research combined with information obtained from the current field tests provide the basis for the following conclusions:

1. Continuous concrete pavements with 0.5% steel reinforcement develop a pattern of transverse cracks with average spacing of approximately fourteen feet. These cracks open to a maximum width of .03 inch when the air temperature is zero degrees Fahrenheit and close very tightly when the temperature reaches 80 degrees.

2. The crack pattern depends more upon the percentage of steel reinforcement than upon pavement thickness. There was no significant difference in the crack pattern or crack width in the
seven, eight and nine-inch pavements.

3. If less than 0.5% steel reinforcement is used, the distance between cracks will be greater and the crack openings proportionally wider as the amount of longitudinal reinforcement is reduced. Some yielding of the steel will occur at the cracks during cold weather and damage to the pavement may result from heavy traffic loads.

4. The results of field tests indicate that an eight-inch thick pavement with 0.7% longitudinal steel reinforcement may be the optimum practical pavement design; considering durability and economy. A three-inch thick granular base course on compacted, well drained native soil appears to offer a suitable foundation for this type of pavement.

5. Continuous pavement sections may be constructed to any desired length, but the continuity of the reinforcing steel must be carefully maintained throughout each section. When the continuity of the pavement must be interrupted, it is necessary to install an expansion joint capable of permitting two inches of movement at the free end.

6. Construction costs of continuously reinforced pavements compare favorably with those of conventional jointed designs. Lower maintenance costs throughout the life of these pavements, should give them a significant economic advantage.
It is believed that continuing research and development will establish continuous pavements as the accepted design for future highways.

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BAR-MAT REINFORCEMENT
(9 INCH PAVEMENT)

FIGURE NO. 1
GAGE POSITIONS IN TEST SECTION – YORK, PA.

FIGURE 2
Figure 3

Taking electrical gage readings at terminal box placed near edge of pavement.

Figure 4

Steel reinforcing mat in position, with transverse metal strip to cause crack at exact location of installed electrical gages.
FIGURE 5

Air Temperature vs. Days from Construction

Steel Strain at Crack (Average) vs. Days from Construction

Crack Width (Average) vs. Days from Construction

Steel Strain 2" from Crack (Average) vs. Days from Construction
Resistance wire strain gages were attached directly to the reinforcing steel and made water-proof by a coating of vulcanized rubber.

A general view of the paving operation.
Frequent testing of the concrete used in the pavement construction assured a uniform mixture of known properties.

Steel reinforcing mats were placed at the vertical center of the pavement between two separate layers of concrete.
Gage measurements were taken throughout the early curing period of the pavement.