Laboratory Research on Pavements Continuously Reinforced With Welded Wire Fabric

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Since February 1955, research has been conducted at the Structural Engineering Laboratory of the School of Civil Engineering, Purdue University, on reinforced concrete pavements using welded wire fabric as the principal reinforcement. The final techniques as used in the laboratory are presented.

The specimens chosen were 28 ft long by 3 ft wide by 8 in. thick. The reinforcement consisted of either 6 x 12, 0/3; 6 x 12, 00000/0; or 4 x 12, 00000/0 welded wire fabric. The specimens were cast in a portable form in which the amount of steel, the location of the steel, and the depth of slab could be varied. Each of the specimens was fabricated with weakened planes such that the slabs would crack at definite locations in the testing region of the slab. This permitted measurement of strains in the fabric at these predetermined cracks.

The slabs were tested on an elastic subgrade having a subgrade modulus of approximately 160 pci, although the subgrade modulus could be varied within reasonable limits. The slab specimens were loaded with vertical static loads to simulate traffic loads and horizontal loads to simulate stresses induced by temperature changes. Electric SR-4 strain gages were placed at various locations on the fabric to determine the stresses in the fabric. Vertical deflections of the slabs were obtained by use of Federal dial indicators, and crack widths or surface strains in the concrete were obtained by use of a Whittemore strain gage.

● RECENT years have brought an increased amount of interest in trying to determine engineering facts about concrete pavements in order that these facts might be incorporated in design criteria for such slabs. Reinforced concrete pavements are an answer to the search for a more efficient highway pavement; but the behavior of these pavements, with all of the variables involved, is still not fully understood. At the 1958 Highway Research Board Annual Meeting, various papers pertaining to continuously reinforced pavements were presented (1, 2, 3, 4). In previous sessions the condition of the experimental section of continuously reinforced highway in Indiana has been reported (5). Also at the 1958 meeting, a paper was presented on a theoretical "Analysis of Special Problems in Continuously Reinforced Concrete Pavements" (6). It can readily be seen that there is indeed a great amount of interest shown in the use of continuous reinforcement in concrete pavements. In each case, the experimental work reported involved field tests on sections of pavements continuously reinforced with either welded wire fabric or deformed bars.

Various state highway departments have conducted research on pavement slabs. Other organizations such as the Bureau of Public Roads, Highway Research Board, Portland Cement Association, American Concrete Institute, and many individuals have conducted research hoping to improve present design concepts.

In recent years the American Iron and Steel Institute organized a Committee on Welded Wire Fabric Reinforcement Research. The committee consisted of individuals who had varying interests, and it soon became apparent to certain members of the committee that there was a definite need for some basic research on concrete pavements in which some of the variables could be isolated, controlled, and studied. C.A. Willson, Research Engineer for the American Iron and Steel Institute, the late Wayne Woolley, Highway Engineer for Republic Steel, K.B. Woods, Head of the School of Civil Engineering, Purdue University, and several members of the committee were interested in a laboratory research program on pavement slabs and arranged for a meeting at Purdue to discuss the possibilities of starting such a research program. As a consequence of this initial meeting, the Committee on Welded Wire Fabric Reinforcement Research and the Purdue University School of Civil Engineering initiated a research program in 1955.

This laboratory research program has been continued since that time and a number of the variables involved in the design of concrete pavement slabs continuously reinforced with welded wire fabric have been studied. This investigation has been supplemented by a theoretical analysis (7) of continuously reinforced pavement slabs sponsored by the Indiana Joint Highway Research Project. Also, another committee of the Institute has sponsored a laboratory program to study the use of deformed bars as a continuous reinforcement in concrete pavements (8).

PURPOSE AND SCOPE OF RESEARCH

The objectives of this research were to determine by laboratory means the following:

1. The relationship between the percentage and position of continuous steel reinforcement and the formation, spacing, and widths of cracks in reinforced concrete pavement slabs of determined thickness, caused by stresses induced by temperature, curing shrinkage, and live loads.
2. The relationships of stresses and deflections to percentage and position of steel in concrete pavements continuously reinforced with welded wire fabric, resting on subgrades of various stiffnesses, and subjected to various combinations of live loads and simulated temperature changes.

Thus, the controlled variables included in the experiments were percentage of longitudinal reinforcement, position of reinforcement, subgrade modulus, range of simulated temperature drop after casting of the concrete (longitudinal forces) and magnitude and position of simulated wheel loads. The dependent variables which were measured during the experiments were strains in the welded wire fabric steel at and adjacent to preformed cracks, concrete surface strains and crack widths, and vertical deflections of the slabs.

EXPERIMENTAL SPECIMENS AND APPARATUS

In designing the experiments, several items concerning the test specimens and the test apparatus received consideration.

Size of Specimen

The specimens used in each phase of this research work reported to date have been of the same size. The concrete slabs were 28 ft long, 3 ft wide, and 8 in. thick. Since it was not intended to simulate any of the effects of lateral stresses such as warping and curling of the slab, specimens 3 ft in width were chosen. This width provided enough contact surface for application of the vertical loads and permitted lateral distribution of the loads. The length of slab was limited to 28 ft to permit use of the facilities which were already available in the Structural Laboratory. This provided adequate length for a reasonable portion of each slab (middle 10 ft) to simulate, under the test conditions described later, the fully restrained area of a continuously reinforced pavement and to furnish sufficient measured data. Furthermore, in this length of continuously reinforced pavement slab, a definite crack pattern could form to predict the patterns which would occur in the field. An initial depth of 8 in. was chosen to conform with the actual depth used by some states in their present pavement design standards.

Concrete Specifications

The specifications for the concrete were established to conform to average present-day highway requirements. Due to the size of the specimens, it was appropriate to obtain the concrete from a local ready-mix plant. The concrete furnished was to meet the following minimum requirements:

1.	Twenty-eight day ultimate compressive strength	4,000 psi
2.	Maximum size aggregate	1½ in.
3.	Slump	2 to 4 in.
4.	Air entrainment	3 to 6 percent

Upon delivery of the concrete to the laboratory, slump and air entrainment tests were immediately made to see if the specifications were satisfied. Three 6-in. diameter cylinders 12 in. long were cast to determine the compressive strength, and three 6- by 6- by 16-in. were poured to determine the flexural strength of the concrete.

Steel Reinforcement

The specifications for the reinforcement steel used in the laboratory specimens were as follows:

1. The steel was to meet the standard specification for cold drawn steel wire for concrete reinforcement as specified in ASTM Specification A82-34.
2. The welded steel wire fabric was to meet the specifications for welded steel wire fabric as specified in ASTM Specification A185-54T.
3. The welded wire fabric was to be chosen from sizes that are available commercially.

The welded wire fabrics used were 6 x 12 - 0/3, 6x12 - 00000/0, and 4x12 - 00000/0. Standard tension tests were performed on individual wires both between and across the welds to determine the ultimate strength and the modulus of elasticity of the fabric used in the experiments. The ultimate strength of the welds was determined by means of the Wire Reinforcement Institute Weld Tester.

Subgrade

The slabs were tested on an elastic subgrade. Tests were to be made on several slabs resting on subgrades having the same modulus. It was anticipated that the use of a soil subgrade would introduce a variable subgrade modulus due to changing moisture content and progressive compaction during the series of tests. A subgrade was needed that would have a constant modulus during the period of the test (2 yr or more), and which would be reproducible, or very nearly so, at any future date. The Firestone Industrial Products Co. fabricated a small test slab of rubber 41 in. wide, 66 in. long, and 5 in. thick for preliminary testing. This subgrade specimen was made up of ten pads 41 in. by 33 in. by 1 in. stacked and glued brick fashion to alternate the joints. This specimen of rubber was subjected to a plate loading test and was found to have an average subgrade modulus of 175 pci. This subgrade modulus would represent a soil having medium plasticity, soft plastic clays having a modulus of approximately 50 pci while densely graded non-plastic sandy gravels may have a modulus of 500 or more (9). As a result of this preliminary test on the rubber subgrade, sixty pads 41 in. by 33 in. by 1 in. were purchased with the request that the rubber be made slightly more flexible than that of the trial rubber slab, to be nearly the middle range of soils of medium plasticity. The pads were stacked on the floor brick fashion in five layers, left unglued, and the resulting subgrade modulus was 155 pci. Leaving the pads unglued has the advantage that it provides greater flexibility for the laying out of future subgrades of different dimensions, patterns and moduli. As an example, such a laid-up subgrade 3 in. thick has a modulus of 440 pci.

Preformed Cracks

A survey of the literature pertaining to continuously reinforced pavements showed that the spacing of cracks developed in service varied, from approximately 2 to 15 ft depending on the amount of reinforcement, thickness of slab, distance from a formed joint at the end of a test strip, and other factors. A crack spacing of 5 ft was thought to be fairly representative of the average condition in the central portion of a continuously reinforced pavement; hence, three transverse cracks were performed — one at the the center of the slab and one 5 ft from the center on each side. The primary purpose of preforming these cracks was to insure that strain gages would be installed on the steel reinforcement at cracked sections.

The cracks were formed using 18-gage sheet metal strips 3 in. wide and 4 ft 6 in. long placed through vertical slots in the side boards of the form to span the form just under the longitudinal reinforcement. Two small pieces of plywood nailed to the bottom of the form on each side of the metal were used to keep it from deflecting to any great extent when the concrete was poured (Fig. 1).

Form for Test Slab

The form consisted of three plywood carts each 8 ft long and one cart 4 ft long resting on truck casters. The four carts assembled end-to-end with side and end boards in place provided a clear space 28 ft by 3 ft by 8 in. Holes were drilled in the end and side boards of the forms to receive the longitudinal reinforcement and the transverse bars. Slots were cut in the sides of the form to hold the sheet metal used to preform the partial cracks in the slabs (Fig. 2).

Preparation for Pouring

The steel reinforcement was installed in a single layer with the sheets lap-spliced at the two outermost preformed cracks, except in slab 1 where one lap was formed just beyond one of the cracks. An extra short length of fabric of the same size as the main reinforcement was installed at each end of the slab to provide adequate strength in fittings for applying longitudinal forces to the reinforcement. These extra sheets were offset laterally a distance of a half space and were turned over so that all of the longitudinal steel at the slab end was in the same plane.

Twelve No. 4 transverse bars were placed in the slab on 2-ft 6-in. centers. These bars served three purposes:

1. By means of threads and nuts on the ends of the bars, they tied the side boards of the form together, thus restraining the sides against spreading.

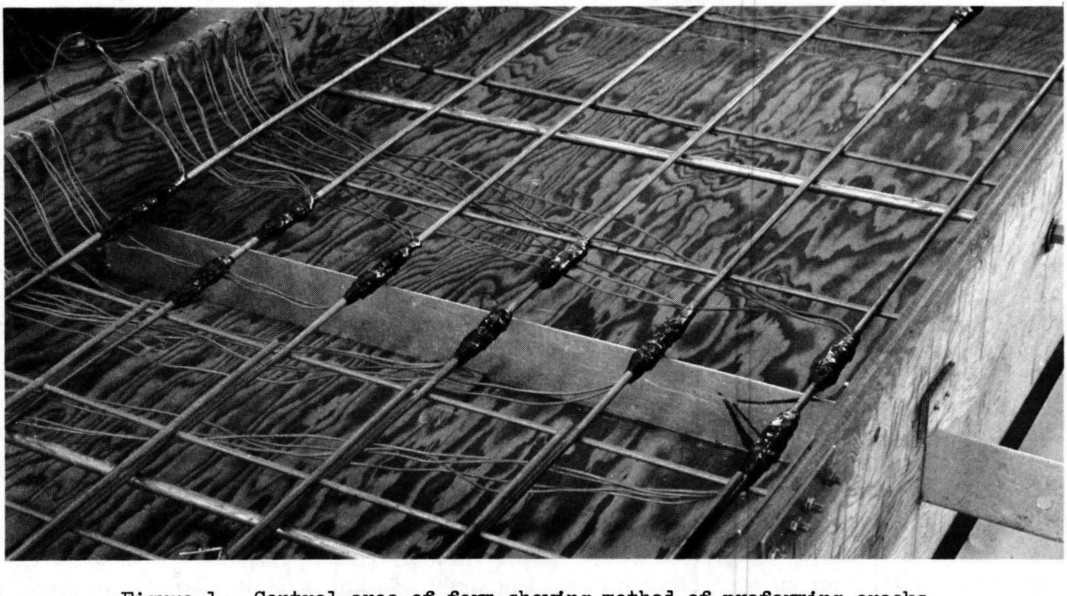

Figure 1. Central area of form showing method of preforming cracks.

2. They supported the longitudinal reinforcement in its correct position.
3. They served as lugs for the hangers used in lifting the slab from the form and lowering it onto the rubber.

The strain gage stations on the welded wire fabric were prepared by removing all rust and scale with emery cloth. The cleaned surface was roughened to insure a good base for the glue and then thoroughly cleaned with acetone. The gages were preformed to fit the fabric and were placed on the wire fabric at the preformed cracks and at several other gage locations between the cracks. Either two type A-7 or two type A-18 SR-4 electric strain gages were applied diametrically opposite one another, wired, and waterproofed at each of the predetermined gage stations. The fabric reinforcement was then placed in position and each sheet of fabric was tied to the transverse bars with soft wire. Two temperature compensation gages mounted on short pieces of reinforcement steel were placed in the form. The strain gage lead wires were carefully laid out to emerge from the form at the top edge near the middle of the test specimen.

The three pieces of oiled 18-gage sheet metal were placed through the sides of the forms at the location of the preformed cracks.

Pouring of Concrete

As mentioned before, the test slabs were poured using ready-mix concrete. The concrete was vibrated carefully to insure the filling of all spaces around reinforcement, strain gages, and lead wires. After striking off and before initial set had taken place, plugs for Whittemore strain gage readings were embedded in the top surface of the slab.

Curing of Concrete

Approximately 6 hr after completion of the pouring, two layers of wet burlap were placed on the slab and were covered with a heavy canvas tarpaulin. The burlap was kept continuously wet for three weeks after which the cover, the burlap bags, and the side and end boards of the form were removed (Fig. 3). The test cylinders and beams were cured in the same manner as the slabs and were tested at 28 days after casting.

Figure 2. Full-length view of form.

Positioning Slabs for Test

A system (Fig. 4) was devised whereby a test slab could be carefully transferred from the form to the rubber base. Eye-bolt hangers were hooked onto the projecting ends of the transverse bars in the test slab. The threaded upper ends of the hangers on each side of the slab were engaged by nuts and washers to a longitudinal timber beam which was supported in position parallel to the side of the slab by a steel framework over the slab. By tightening all of the nuts at the upper ends of the hangers, the slab was raised free of the form and suspended while the form was pulled out and the rubber subgrade was laid into position. The slab was then lowered into position by loosening all of the nuts evenly.

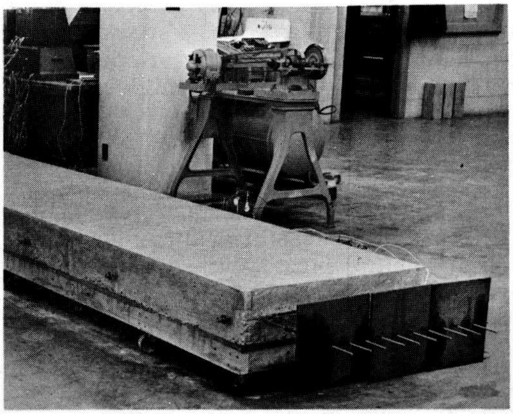

Figure 3. Slab at end of curing period.

EXPERIMENTAL PROCEDURES

Measurement of Vertical Deflection

On a line 5 in. in from one edge of the slab, nine 0.001-in. Federal dial indicators were suspended from a framework with the stems of each engaging a piece of sheet tin bonded to the surface of the concrete. These indicators were spaced at 20 in. on centers in the test area, with an indicator at each of the preformed cracks. The dials were used to measure the vertical deflections of the surface of the slab at these points, when the slab was subjected to the various combinations of loading. This arrangement of dial indicators is shown in Figure 5.

Measurement of Surface Strains and Crack Widths

In the test area, plugs were embedded in the surface of the concrete at 10-in. intervals on a line 8 in. in from one edge of the slab. Gage holes were drilled in these plugs and a 10-in. Whittemore strain gage was used (Fig. 6) to make surface strain and crack width measurements.

For an uncracked section, the unit strain was taken as the change in length between adjacent plugs divided by ten. When a cracked section occurred between two plugs, it was assumed that the total change in distance between plugs was due to the change in crack width.

Figure 4. Lowering of slab onto rubber base.

Determination of Stresses in Welded Wire Fabric

As mentioned previously, Electric SR-4 strain gages were used to determine the stresses set up in the welded wire fabric. Since the stresses in the longitudinal steel could be assumed to be primarily uniaxial, the strain readings obtained with the gages, when multiplied by the modulus of elasticity of the steel in the fabric gave the stresses in the wire fabric. Type A-7 and type A-18 paper backed constant wire gages having a resistance of 120 ohms and a gage factor of $1.9^{\pm}$ were used.

Two gages were used at each station. They were placed longitudinally on opposite sides of a wire, with the center of their gage filaments at the same cross-section but with their leads facing in opposite directions. The two gages were used to observe any bending or eccentric load effect.

Strain readings were taken with a Baldwin SR-4, type L, strain indicator.

Vertical Loading

The framing for application of the vertical loads to the slab consisted of a longitudinal beam supported above the longitudinal center line of the slab by 4 transverse bents spaced 6 ft on centers. Each bent was made up of a transverse beam clamped at its ends to vertical pipe posts which were threaded into floor inserts on each side of the slab. The longitudinal beam transmitted the reaction of the vertical load to the bents which in turn transmitted the vertical uplift to the floor inserts (Fig. 7).

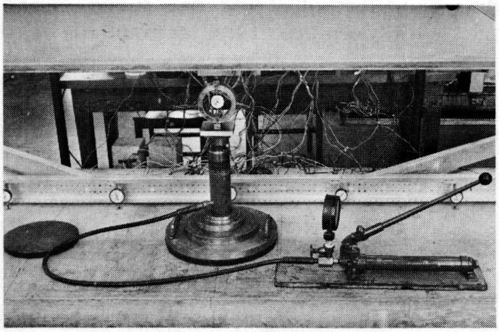

Figure 5. Vertical deflection and vertical loading apparatus.

The vertical load was applied by means of a hydraulic jack. Its magnitude was determined with a proving ring placed between the the jack and the longitudinal beam. Three loading magnitudes of 5,000, 10,000, and 15,000 lb were applied. The largest of these loads compares closely to a wheel loading for the H20-S16-44 loading which is the present standard for design for bridges and larger than the wheel load for highway pavements. It was estimated that a 15,000-lb load on the 3-ft width of the test slab would produce maximum bending moments in the longitudinal direction of about the same magnitude as the maximum moments produced by a pair of 16,000-lb wheel loads on a 12-ft pavement slab. The 5,000-lb load was transmitted to the slab through a stack of circular steel plates of increasing size, of which the largest was 12 in. in diameter, and a piece of rubber of the same diameter located on the surface of the slab at the test position. The 10,000- and 15,000-lb loads were applied through a stack of plates, of which the largest was 18 in. in diameter, and a piece of rubber of the same diameter. The purpose of the rubber was to seat the plate on the slab surface, thus obtaining a more uniform application of load to more nearly simulate an actual tire load. These sizes conform sufficiently close to the equivalent contact areas of 12-, 16-, and 19-in. diameters, respectively for 5,000-, 10,000-, and 15,000-lb dual wheel loads as given in Concrete Pavement Design (9).

Figure 6. Measurements of surface strains and crack widths.

Longitudinal Loading

To simulate temperature stresses, tensile stresses were induced in the reinforced slab by applying longitudinal loads to the longitudinal wires which protruded 18 in. from each end of the slab. Each wire was threaded approximately 4 in. for loading purposes. Tension tests on similar threaded wires indicated an ultimate strength of threaded wires approximately 5/7 of the ultimate strength of unthreaded wires. Thus, in the case of 6 x 12 fabric, five longitudinal wires were added to the original six wires at the ends of the specimen.

A set of two beams was placed transverse to the slab at each end with the projecting wires passing between them. Plates and nuts were fitted on the threaded ends of the wires with the plates flush against the beams.

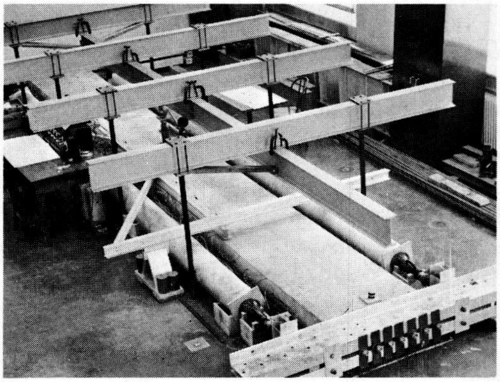

Figure 7. Framework for vertical loading.

Figure 8. Longitudinal load jack and cell.

Thus, when the beams were forced away from the slab in the longitudinal direction, a tensile load was applied to the wires which in turn transferred a portion of it to the concrete of the slab. The nuts were adjusted so that the longitudinal load was distributed as evenly as possible among the longitudinal wires. This distribution among the wires was facilitated by SR-4 strain gages mounted on the projecting wires between the threaded portion of the wires and the slab end (Fig. 7).

The longitudinal load was applied to the transverse beams by either screw jacks or hydraulic jacks placed on each side of the slab near each end. The jacks on each side of the slab worked against each other through pipe columns (Fig. 7). The applied load was measured by means of cylindrical load cells which were placed between the jacks and the transverse beams (Fig. 8). Small bearing beams placed between the load cells and the transverse beams served to distribute the load on the flanges of the transverse beams.

For the large longitudinal loads, four solid cylindrical steel load cells each having a cross-sectional area of 3.14 sq in. and a 4-in. length, were placed two at each end. For the small and medium loads, to obtain greater sensitivity, two of the solid load cells were replaced by hollow circular stainless steel load cells having a cross-sectional area of 1 sq in. and a 4-in. length.

Each load cell was constructed by placing four SR-4 strain gages on longitudinal elements at the quarter points of the circular cylinder. Two diametrically opposite gages were connected in series; the two pairs were then connected in parallel. The series connections eliminated the effect of any bending of the cylinder and the parallel connection of the pairs in series resulted in a resistance change of the connected four gages equal to that of a single gage on a perfect axially loaded cell. The load cells were calibrated in a 120,000-lb capacity Baldwin testing machine.

Many additional details concerning the design of the experiments as well as the design and operation of the test apparatus are given in reports written by Witzell (10) and Houmard (11). Results of the first phases of this research program are included in other papers (12, 13).

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