EXPERIMENTS WITH CONTINUOUS REINFORCEMENT IN CONCRETE PAVEMENTS

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(Abstract)[1]

In the fall of 1938, the Public Roads Administration and the Indiana State Highway Commission started the construction of a number of experimental sections of reinforced concrete pavement as a part of a regular Federal Aid project. The object of these experiments was to investigate more thoroughly the possibilities of longitudinal steel reinforcement as a means for increasing slab lengths, thus decreasing the number of joints required, but at the same time achieving the control over warping made possible by the short slabs. The sections were constructed on a heavily traveled transcontinental highway west of Indianapolis, which was particularly suitable because of a fairly uniform subgrade and the absence of steep grades and sharp curves. The maximum grade is 2.95 per cent and the maximum curve is 0 deg. 11.5 min.

Three types of steel reinforcing were installed in the test sections, welded fabric, intermediate grade billet steel, and rail steel. Each slab is 10 ft. wide, and of a length to produce a range of maximum stress in the steel due to subgrade resistance as the pavement expands and contracts. For practical reasons, the standard pavement cross section used by the State of Indiana was adopted. This is a 9-7-9 thickened edge section, 20 ft. wide using a deformed metal tongue-and-groove type longitudinal joint with ⅝-in. diameter tie bars spaced at 60-in. intervals.

The minimum amount of steel used corresponded to the 32-lb. welded wire fabric which is about as light as is used in pavements today. This consisted of No. 6 wire spaced at 6-in. centers longitudinally and 12-in. centers transversely. This represents about 22 lb. of longitudinal steel per 100 sq. ft. of pavement. The heaviest section of welded reinforcement was about 132 lb. of longitudinal reinforcement per 100 sq. ft. of pavement surface. The longitudinal steel was No. 4-0 wire placed 4-in. on centers, and the transverse steel was No. 3 wire, placed 12-in. on centers. The slab lengths for each of the six amounts of reinforcement used were varied so as to produce maximum stresses in the longitudinal steel of 25,000, 35,000, 45,000, and 55,000 lb. per sq. in.

Five amounts of billet steel reinforcing were used, varying from 33 to 534 lb. of longitudinal reinforcement per 100 sq. ft. of pavement surface. The lightest section consisted of ¼-in. round deformed bars set at 6-in. centers, with ¼-in. transverse bars set at 12-in. centers. The heaviest section used 1-in. round deformed bars set at 6-in. centers with ½-in. transverse bars at 24-in. centers. Slab lengths varying from 20 to 1,080 ft. were used to produce stresses of 15,000, 25,000, 35,000, and 45,000 lb. per sq. in. in each of the five quantities of reinforcement.

Five amounts of rail steel bar rein-

[1] Presented at the Nineteenth Annual Meeting, Highway Research Board (1939), Published in full in *Public Roads*, Jan. 1940, Vol. 20, No. 11.

forcement were also used in quantities and arrangements similar to that described for the billet steel. Slab lengths were such as to stress the steel to 25,000, 35,000, 45,000, and 55,000 lb. per sq. in. for each of the five reinforcement designs.

Three types of expansion joints were used because of the wide range of section lengths. For slabs of intermediate length, a type I joint was used, which is similar to the expansion joint used at bridge approaches. Essentially, it consists of two 2-in. angles and a cover plate. The angles are anchored in opposite sides of the joint, while the cover plate is rigidly attached to one angle and held to the angle on the opposite side of the joint by a keyway system that permits sliding of the plate. The joint is designed to permit 1½-in. movement in either direction.

Type II joint is merely two of the type I joints spaced 10 ft. apart, which permits a larger affective opening, and is used where two of the longer sections are joined.

Type III joint is the conventional dowel type with ¾-in. plain round bars spaced 12 in. apart.

Both conventional and submerged type of weakened-plane joints were used. The submerged joints were placed on the subgrade so that the top of the impregnated fiber strip was uniformly 4½ in. below the top surface of the pavement. A copper seal was placed at the top of the strip to provide a water-tight seal. Dowel shear bars were used at one-half the submerged joints placed. The conventional type of surface weakened-plane joint was made with a T-bar on which was mounted a vibrator, necessitated by the fact that the concrete was placed by the vibratory method, and was quite stiff.

Four 500-ft. sections were constructed for investigating special joint designs and methods of reinforcing. Using 91- and 45-lb. welded fabric reinforcing on both submerged and surface type weakened-plane joints, the bond between the steel and concrete was broken for 18-in. on each side of the joint, and the transverse steel eliminated. The object of this design is to eliminate as far as possible, warping stresses in pavements. Breaking of the bond between steel and concrete permits warping to take place more freely, because when warping occurs, a greater length of steel is available to provide the necessary elongation without the development of excessively high stresses in the steel.

Because of the length of the project, it was necessary to let the construction in two contracts. While slightly different methods were used by the two contractors, it is felt that the effects of these differences will be negligible. Both contractors used surface vibration to ensure consolidation of the concrete, particularly in sections containing a large amount of steel. The quantity of materials used per batch on the two contracts was slightly different. One contract used crushed stone for all coarse aggregate and the other used gravel for the smaller sized coarse aggregate and crushed stone for the larger. Large sized coarse aggregate ranged from ½ to 2½ in., and the small-sized from No. 4 to 1½ in.

In constructing the sections, the paver was operated outside the forms, which allowed placing the bar mat reinforcement some distance ahead of the mixer. This type reinforcing was supported on the subgrade by chairs attached to the transverse bars by welding. The welded fabric reinforcement was placed by the strike-off method at a depth of 2½ in. from the top of the pavement. After placing the welded fabric, the top section of the pavement was poured. The concrete was cured with wet burlap until the next morning when the burlap was removed and the pavement covered with wet straw for seven days.

Because of the amount of work involved in detailed observations of the entire experimental section, it was decided that the entire pavement would be given a general condition survey once a year, and that detailed observations would be concentrated on a selected number of representative sections. These sections fall in three groups, heavily reinforced pavement, medium reinforced, and welded fabric reinforcement. The sections selected eliminate as far as possible all variables except the amount of reinforcement.

The intensive schedule of observations which is to be made on the selected sections include (1) a detailed crack survey in which a special effort will be made to find all cracks, however fine; (2) precise level measurements made on the surface of one lane of pavement; and (3) measurements of horizontal movements at the joints in the longitudinal direction of the pavement. These detailed studies are to be made three times a year, in the fall, winter and spring. Annual observations to be made over the entire length of pavement include (1) a general crack survey; (2) measurements of horizontal movements at the joints in the longitudinal direction of the pavement; and (3) general observations of the condition of the pavement.

A number of special studies are also contemplated. These include the determination of the movements of the ends of the slabs between extreme summer and winter conditions, in other words, the maximum annual change in length of various length slabs; determination of the daily movements at the ends of certain selected slabs, which will be taken on days when large temperature variations are expected and measurement of the absolute movements at the two ends, center, and quarter points of the longest slabs.

The experimental pavement was approximately one year old in October 1939. Approximately 1½ mi. had been under traffic for a period of about one year, while the remaining 4½ mi. had been in service for about six months. A large number of fine transverse cracks have occurred in the central portion of the long, heavily reinforced sections. In the long sections containing the ¾- and the 1-in. diameter longitudinal bars, the distance between the cracks is frequently less than 3 ft. There is an appreciable number of these cracks in the longer sections containing the ½-in. diameter longitudinal bars, but relatively few in the shorter sections reinforced with this amount of steel. For the sections containing the smaller amounts of reinforcement, in general the number of transverse cracks which have occurred is related more directly with the length of the sections than it is with the amount of longitudinal reinforcement. There is practically no cracking in any of the sections less than approximately 150 ft. long, regardless of the amount of reinforcement.

Typical cracks appearing in the heavily reinforced sections are not apparent except on close examination, and are very similar to those that occurred very early in the life of the heavily reinforced sections of the Columbia Pike experimental pavement.[2] Those cracks have remained closed and no serious spalling or disintegration has occurred in their vicinity. It seems unlikely, therefore, that these fine cracks in the heavily reinforced sections of this pavement will ever cause serious damage.

The sections in which the weakened-plane joints were placed at intervals of 10 ft. are in excellent condition. These sections are 500 ft. long and the steel reinforcement is continuous through the joints. Two of the sections are reinforced with a 91-lb. and two with a 45-lb.

[2] J. T. Pauls, "Reinforcing and the subgrade as Factors in the Design of Concrete Pavements," *Public Roads,* Vol. 5, No. 8.

welded fabric. The bond is broken between the steel and concrete for a distance of 36-in. at each joint.

Cracks have occurred in the surface of the pavement over all except one of the submerged weakened-plane joints. The high stressing of the steel and the breaking of the bond at the joints has allowed these joints to open an appreciable amount. The typical crack over one of these joints is quite irregular and meandering.

The weakened plane joints of the conventional type, which were formed by placing grooves in the top surface of the pavement, all appear to be in excellent condition. The manner in which the seal has been maintained at these joints is especially impressive. The tight seal can undoubtedly be attributed to the fact that the short slab lengths and the continuous steel through the joints have reduced to a very small amount the changes in width of the joints caused by the expansion and contraction of the pavement.