steel-fiber-reinforced concrete

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Steel-fiber-reinforced concrete was used as a bridge deck overlay in Pennsylvania. This paper discusses the mixing and placing of that overlay on a single-span, continuous-truss bridge. Aside from a delay caused by the necessity for emergency bridge repair elsewhere, problems in placing the overlay included formation of wire balls in the concrete, nonuniformity of concrete loads delivered, and erratic strength test results. It is recommended that, on the steel-fiber-reinforced project to be undertaken by Pennsylvania, control sections be provided to afford more meaningful evaluations of concrete performance.

•Steel-fiber-reinforced concrete is a system wherein steel wires or fibers having a diameter of 0.010 to 0.025 inch and a length of ½ to 2 inches are incorporated into a conventional cement concrete mixture. The system provides many advantages over conventional concrete and promises to provide a solution to concrete pavement and bridge deck overlay problems. Steel-fiber-reinforced concrete has been used on a number of installations throughout the country on airport runways, arterials, and bridge deck surfaces.

It has been reported that the addition of steel fibers to concrete increases the flexural strength from two to three times and more than doubles the compressive strength. The impact resistance is nearly three times higher, the concrete is twice as abrasion-resistant, and spalling resistance is several times greater. The advantages of steel-fiber-reinforced concrete are its (a) much greater resistance to cracking, (b) superior resistance to thermal shock, (c) ability to provide design strength with thinner sections, which results in material savings, (d) elimination of conventional reinforcing with associated labor, and (e) lower maintenance requirement and longer life. The resistance to salt scaling is supposedly equal to that of conventional concrete. Rusting of the steel wire does not present any structural problems, and it should not adversely affect the surface appearance.

This report covers the first of two proposed research projects in Pennsylvania using steel-fiber-reinforced concrete. The purpose of the study is to evaluate the mixing and placing characteristics of the fiber-reinforced concrete and to observe the long-range performance of the system as a bridge deck surface overlay. The structure covered in this report is the bridge on LR-250 in New Cumberland over the Yellow Breeches Creek at the York and Cumberland County line. The other structure, proposed for the 1973 construction season, will be in Allegheny County.

THE STRUCTURE

The structure on LR-250 was built in 1936 as a single-span, continuous-truss bridge. It is 154 feet long and 44 feet wide including 2-ft right and left drain gutters. The reinforced concrete deck was a two-course single slab member consisting of a 7½-in. bottom course and a 2½-in. wearing course fixed to riveted plate end dams.

The concrete deck surface had previously been covered with a plant-mixed bituminous wearing surface that, in recent years, had required frequent patching. Deterioration of the wearing surface had progressed to the extent that surface cracks and pot holes were prevalent, and the riding surface was significantly impaired.

CONSTRUCTION DETAILS

Because of the nature of the contract, field inspection was required by district construction forces. It was understood, as a result of the preconstruction meeting, that the project should be governed by the applicable PennDOT specification requirements. The delineation of control in the field however was uncertain as the job progressed and, because of this, control was not so good as it should have been.

The project was designed in close cooperation with personnel from the Battelle Development Corporation and the U.S. Steel Corporation. These personnel were also present during the mixing and placing operations to provide guidance and assistance. The steel fibers for the project were provided, at no cost to the department, jointly by Battelle and U.S. Steel. Mix design data are given in Table 1.

The project was awarded, and preparation work began during the week of August 7, 1972. Preparation consisted of stripping the bituminous material from the concrete deck and removing any weak, unsound, or deteriorated concrete from the deck surface as specified in the contract. It was only during this process that the wearing course on the old deck surface became apparent. Arrangements were made with the contractor to remove the entire concrete wearing surface from the deck. At this time, an emergency arose: Bridge repair work was necessary on two major arteries. The contractor was asked to cease further deck preparation activities and to immediately place the fiber-reinforced concrete overlay. At this time approximately 50 percent of the wearing surface had been removed (Figs. 1 and 2).

On August 25, a 2-in.-thick, single-slab member was placed between the 2-ft gutters over the unstripped area, and an average of 6⅛ inches was placed over the stripped areas because of the removal of deteriorated concrete in the bottom course.

The formation of wire balls in the concrete, which is a constant problem with transit mixers, was minimized by batching the fine and coarse aggregates, then adding the steel fibers, 70 percent of the mixing water, and the cement, and then adding the remaining water. The fibers were delivered in 20-lb boxes and were manually spread and separated on a conveyor belt charging into the truck mixer.

The first transit mixer arrived at the job site at 9:30 a.m. The weather was sunny, the ambient temperature was 72 F, and the relative humidity was 82 percent. A total of 79 cubic yards was delivered to the job site; the hauling distance was 3 miles. With the exception of the first load, the capacity of the transit mixers was restricted to 6 cubic yards.

The prepared surface had been wet sufficiently, and a neat cement slurry was applied immediately before the fiber-reinforced concrete was placed (Figs. 3 and 4). The finishing equipment consisted of a strike-off unit and a trailing bridge unit that supported

Table 1. Concrete mix design.

Item	Amount
Ingredients/yd^3 batch	
Cement, lb	752
Water, lb	368
Air entrainer (6.5 percent), oz	5
Retarder, oz	24
Aggregate, lb	
Fine[a]	1,870[b]
Coarse[c]	610[b]
Fibers	200
Aggregate, percentage by volume	
Fine	74.0
Coarse	23.3
Fibers	2.7
Fibers/yd^3, percent	1.52
Slump, in.	3.25
Weight, lb/ft^3	140.72

[a] Fines modulus = 2.90.
[b] Saturated, surface dry.
[c] 100 percent passing ½-in. sieve.

Figure 1. Bridge deck with concrete removed.

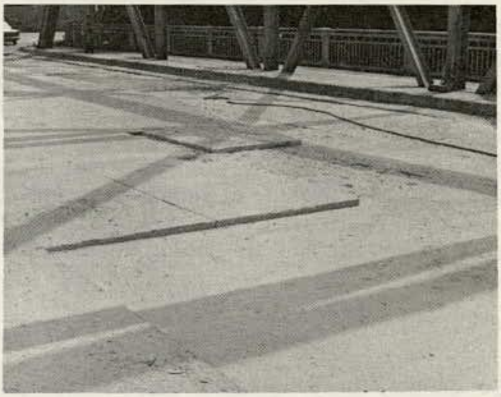


Figure 2. Deck layout.

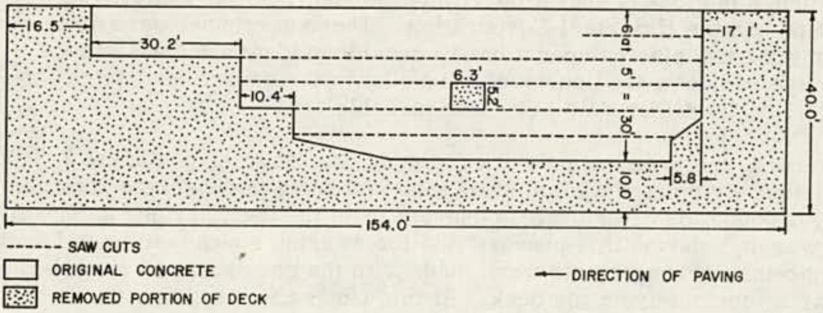


Figure 3. Cement slurry and finishing machine.

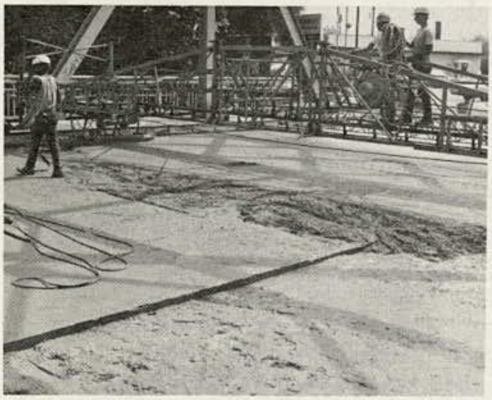


Figure 4. Steel-fiber-reinforced concrete.

Figure 5. Finishing operation.

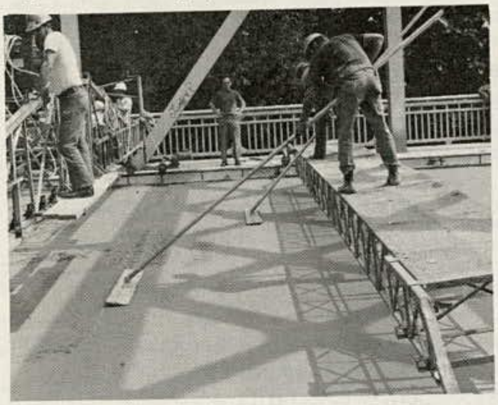


Table 2. Results of slump and air tests.

Test	Plant High	Plant Low	Plant Avg	Jobsite High	Jobsite Low	Jobsite Avg
Slump, in.	6½	3¼	4½	6.0	3¼	4¼
Entrained air, percent	8.0	4.8	6.4	7.4	4.8	6.5

Table 3. Strength test results.

Age (days)	Compressive Wet-Cured	Compressive Dry-Cured	Flexural Wet-Cured	Flexural Dry-Cured
3		2,891[a]		
4		3,970[b]		
7	2,617	2,476	520	879
8		5,217[b]		
14	4,333	3,360		
21			667	1,022
28		4,881		798[b]

[a] Avg of three tests. [b] Avg of two tests.

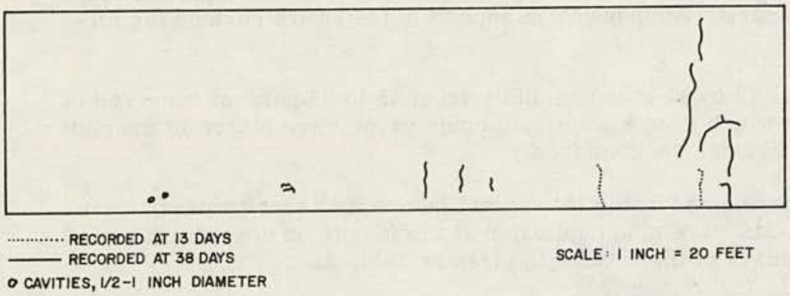
Table 4. Linear traverse data.

Item	Quantity
Specific surface, in.^{2}/in.^{3}	0.571
Spacing factor, in.	0.009
Total traverse length, in.	80.00
Entrained air[a], percent	4.65
Entrapped air, percent	0.55
Total air, percent	5.20
Avg fiber spacing, in.	0.88

Note: Coarse aggregate was carbonate with narrow gradation, no cracking, and good bond. The cement paste was glassy and had no internal cracking, no fine or coarse aggregate pullout, and good paste quality.

[a] Entrained air considered adequate.

Figure 6. Crack patterns.



the hand finishers (Fig. 5). Both units rode a tube rail located in the gutter area. The mechanical efficiency of the finishing units left something to be desired.

The concrete was discharged directly from the transit mixers onto the existing deck surface ahead of the strike-off unit. Hand finishing was accomplished with aluminum floats and straightedges; a bristled broom was used for the final transverse textured finish. Curing was achieved by hand spraying a white-pigmented liquid curing compound.

Although a design slump of 3¼ inches was specified, the actual slump varied from a low of 3½ to a high of 5¾ inches; the average of 13 truck loads was 4¼ inches.

The first batch of concrete mixed at the plant contained excessive water, which was corrected by the addition of another yard of ingredients. Tests at the jobsite produced a 4-in. slump and an air content of 7 percent, but the consistency during discharge varied considerably. Additional, intermittent charges of water were not uncommon, and water was sprayed on the concrete during finishing because of poor workability.

The third load was excessively wet throughout its discharge. Slump and air tests were omitted. Although the latter portion of the fourth batch was extremely wet and variations in consistency continued from truck to truck and within a single batch, there was an improvement in consistency and desired slumps in the remaining nine truckloads. Steel fiber balls, measuring from 1 to 3 inches in diameter, occurred frequently, but, because the batch plant had a limited supply of steel fibers, it was necessary to use all concrete as delivered. These balls were removed from the concrete wherever they were visible.

The ambient temperature increased steadily during the day, and there were some lengthy delays between truckloads. The midday temperature reached a high of 92 F, the relative humidity was 47 percent, and there was a considerable amount of direct sunlight. At noontime, with less than one-third of the required concrete in place, a 1-hour delay between truckloads occurred. Concrete temperature during the placing period ranged from 85 to 98 degrees.

As concrete placement progressed, the existing surface was rewet, and the neat cement slurry was applied. Frequently, this appeared to be considerably thin-textured. The 684-yd^2 area was completed around 7:00 p.m.; the final surface texture appeared to be of fair quality. Additional curing compound was applied to the entire surface the following day.

Ambient temperatures from 73 to 90 F and humidity from 45 to 85 percent occurred on the following 3 days during which time 8 additional cubic yards were placed in the gutter areas, which completed the bridge deck surface.

Slump and air tests were performed at the batch plant before the transit mixers were dispatched, and the same tests were also duplicated at the jobsite on concrete sampled after final mixing. A summary of these tests is given in Table 2.

TEST RESULTS

One of the anticipated advantages of adding steel fibers to a conventional concrete mixture is the higher flexural and compressive strengths. Although higher-than-usual strength tests were achieved, these were not so great as anticipated. Although the slump and entrained air test results were generally favorable, the erratic strength test results given in Table 3 are disappointing and are perhaps indicative of the nonuniformity of the delivered concrete. Minimum PennDOT strength requirements are as follows:

Age (days)	Compressive Strength (psi)	Flexural Strength (psi)
3	3,000	550
28	3,750	660

The primary function of the steel fibers is to curb the development of cracks and to prevent the propagation of any microcracks that occur in the concrete matrix. It is therefore important that the steel fibers be added in sufficient quantity and in a manner designed to provide an average spacing of 0.5 inch or slightly less. A petrographic analysis was performed by PennDOT on samples obtained from a 28-day beam specimen. The fiber spacing and other relevant characteristics of the concrete are given in Table 4.

COST DATA

The contract was awarded at a bid price of $215.00 per cubic yard for in-place concrete (all preparation work included), which amounted to approximately $25.00 per square yard. Traffic control costs were assumed by the department and were not included in this price. As mentioned before, the steel fibers were donated to the project. The cost of the steel fibers would normally be expected to be about 18 to 25 cents per pound and this, in addition to a batching cost of approximately $3.00 per cubic yard (costs for this project), would run the cost of steel-fiber-reinforced concrete to twice that of conventional concrete. A uniform, 2-in.-thick, steel-fiber-reinforced concrete overlay (8-bag mix) could be placed for about $4.00 a square yard for material costs only.

Although steel-fiber-reinforced concrete will never approach the cost of a conventional mix, the increased use of this product together with research leading toward use of larger sized aggregate and less cement will contribute to lower unit costs.

RECENT INSPECTIONS

The condition of the project was observed at 7-, 30-, 60-, and 90-day intervals. As of this date, no major defects have developed; however, some cracks are evident as shown in Figure 6. Most of these have developed at areas where the concrete overlay varied abruptly in thickness from 2 to 5 inches or more because of the concrete removal pattern. These cracks measured from 0.01 to 0.03 inch in width and did not appear too severe at this time. The surface finish is generally smooth (little or no texture), and the riding quality is uneven.

CONCLUSIONS AND RECOMMENDATIONS

It is premature to make predictions on the ultimate performance of the fiber-reinforced concrete, particularly on the basis of this installation. It is certain, however, that the advantages of using steel-fiber-reinforced concrete will be evident in many areas of highway construction. The principal disadvantage is the cost, but this can be justified by reduced maintenance and longer service life.

The project selected for construction next season will be closely monitored to provide additional research data relative to the performance of this system.

Recommendations at this time are limited; however, it would be desirable in future installations to provide control sections using conventional concrete overlay methods or other overlay systems to provide a more meaningful evaluation.