



## Fiber Reinforcement in Prestressed Concrete Beams: Summary

Prestressed concrete I-beams are used extensively as the primary superstructure elements in Texas highway bridges. A commonly observed problem in these beams is the appearance of end zone cracking due to the prestress forces, hydration of concrete, shrinkage and temperature variation, as shown in Fig. 1. TxDOT provides a large quantity of transverse steel reinforcement (4.2 % by volume) in the end zone (Fig. 2) to control this cracking. Even with such a high percentage of reinforcing steel, cracks continue to occur at the end zone and the problem persists.

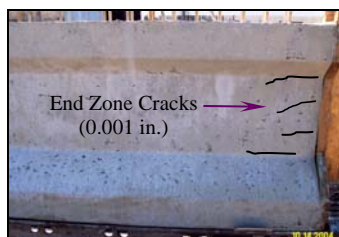


Fig. 1 End Zone Cracking in a Prestressed I-Beam



Fig. 2 End Zone Reinforcement in a Prestressed I-Beam

In addition to giving the appearance of structural dis-

stress, excessive crack widths can lead to the corrosion of reinforcement and the shortening of service life of bridges.

### What We Did ...

The research described in this report was targeted to develop a workable steel fiber reinforced concrete mix that would be capable of not only replacing partially/completely the dense reinforcement but also eliminating cracking in the end zone. The research was divided into three phases:

**Phase One** consisted of developing a TxDOT traditional mix, modified to incorporate steel fibers (TTFRC) and Self-Consolidating Fiber Reinforced Concrete (SCFRC). Four TTFRC and three SCFRC mixes with two different types and variable amounts of hook-ended steel fibers were tested for their workability and hardened properties. The two fibers RC80/60BN (L=2.4 in.) and ZP305 (L=1.2 in.) had an aspect ratio of 80 and 55, respectively. Fig. 3 shows various tests such as slump flow, VSI rating, V-funnel and J-ring conducted at the precast plant, to obtain the flowability, stability, filling ability and passing ability of SCFRC mixes, respectively.

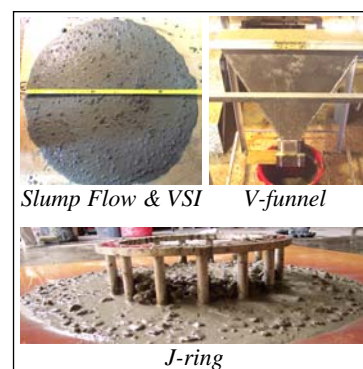


Fig. 3 Various Workability Tests of SCFRC Mixes

Tests of hardened properties for all the mixes, such as compressive, split tensile, flexural and average residual strengths, were carried out at different ages of concrete. Based on their performance in the workability and hardened properties tests, suitable TTFRC and SCFRC mixes with optimum fiber contents were selected to cast full-scale beams. Demonstration of casting a plexi-glass end zone model of a typical I-beam using SCFRC mix was conducted in the Texas-SCC Workshop at the University of Houston (Fig. 4).



Fig. 4 SCFRC-Demonstration



**Phase Two** dealt with the casting of seven 25-ft.-long, (AASHTO Type-A) I-beams using pre-selected TTFRC and SCFRC mixes along with the initial monitoring of beam end zones. Two control beams (B1 and B6) using TxDOT Traditional Concrete mix (TTC1) and Self-Consolidating Concrete mix (SCC2-3) were cast with 4.2 % and 1 % traditional transverse steel reinforcement at north and south ends of the beams, respectively. Beams B2 (Fig. 5) and B3 used TTC1 mix with steel fibers-TTFRC1 (1 % by vol. ZP305) and TTFRC3 (0.5 % by vol. RC80/60BN), respectively. Beam B0 was cast with TTFRC4 mix (1.5 % by vol. ZP305) and had absolutely no transverse/end zone steel reinforcement. SCFRC1 (0.5 % by vol. RC80/60BN) and SCFRC3 (1 % by vol. ZP305) mix were used to cast beams B4 and B5, respectively. 1 % and 0.42 % of traditional transverse steel reinforcement was used at the north and south ends of beams B2 to B5, respectively. Conventionally used equipment and techniques were applied for mixing, transporting, placing and steam curing the beams at the precast plant.



Fig. 5 Casting of I-Beam-B2

Strain gauges were installed at critical positions on the rebars of beams B1 to B5 to measure the rebar strains during steam curing and release of prestress force. A

total of 55 temperature loggers were placed in beams B1 to B6, to continuously record the concrete temperatures during hydration.

**Phase Three** consisted of load testing the seven beams till failure. Four hydraulic actuators mounted on a loading frame (Fig. 6), capable of applying a total vertical force of 1037 kip, were utilized to apply load on the top flange of the simply supported beams (Fig. 6.)

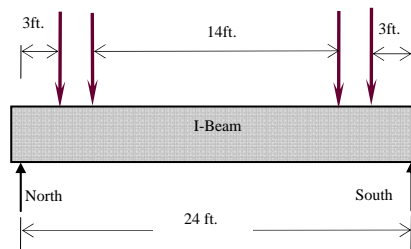


Fig. 6 Test Setup

During the load tests, beam deflections were measured at critical locations using Linear Voltage Displacement Transducers (LVDTs) and rebar strains were recorded with the help of strain gauges and LVDTs. Two 500 kip capacity load cells measured the shear force at both ends of the beam. It was possible to obtain post-peak shear force-deflection curves by controlling the actuators in displacement control mode. Shear crack widths were continuously measured with hand-held microscopes.

## What We Found ...

- (1) It was possible to produce TTFRC and SCFRC mixes with Texas conventional materials, equipment and techniques. The mixes showed satisfactory workability and were deemed suitable to cast the end regions of a prestressed I-beam.
- (2) Optimum steel fiber content was found to be governed by the workability criteria for both the TTFRC and SCFRC mixes. TTFRC3, TTFRC4, SCFRC1 and SCFRC3 mixes were found to have an optimum fiber content.
- (3) Tests of hardened properties confirmed the effectiveness of steel fibers in enhancing the tensile strength, flexural strength and ductility of concrete. On average, steel fiber increased the tensile strength of concrete by about 50 % in case of SCFRC and 25 % in case of TTFRC mixes.
- (4) Casting SCFRC mixes in beams was relatively easy. The SCFRC mixes were highly workable and demonstrated self-compactability without any signs of fiber blocking when placed in the beam form. SCFRC was observed to flow from one end of the beam to the other without losing its stability. Nevertheless, rapid casting of SCFRC mixes in the central portion of the beam caused air-pockets to form. The rate of casting of an SCFRC mix should be comparatively lower than that of the traditional concrete to avoid the formation of air-pockets in the beam. Another solution to avert the formation of air-pockets while using SCFRC mixes is to completely eliminate the transverse reinforcement in the beam. This would not only facilitate the unrestricted filling of SCFRC in the beam, but also increase the workability performance of SCFRC.



(5) The end region cracks appeared after about three months from casting in most of the beams. Hence, end zone cracking could be caused not only by the thermal and prestress forces, but also by the time-dependent effects of shrinkage. Most of the TTFRC and SCFRC beams had end zone crack widths much smaller than those of the control traditional beam. Moreover, beam B0 with TTFRC4 mix had no end region cracks, even when the beam had absolutely zero traditional transverse steel reinforcement. End zone cracks were also missing at the north end of beam B3. Hence, the steel fibers had performed quite effectively in controlling or completely eliminating the end zone cracks.

(6) Results showed that steel fibers have considerably reduced the tensile strains (i.e. also the stresses) in the rebars during the initial stage of concrete curing and prestress release in comparison with the non-fibrous traditional beam. This means that the steel fibers were able to take up the tensile stress developed in the concrete due to thermal and prestress loading, causing lower tensile strains in the rebars. Observations of rebar residual strains at 10 hours after prestress release showed that the residual strains were much lower in the case of the fibrous concrete beams than in case of the traditional non-fibrous beam.

(7) Temperature logger data revealed that the maximum thermal loading for the traditional beam was about 84 °F, much more than the value found in literature of 60 °F. SCC produced more thermal loading (120 °F) due to a higher cement content. Hence, it is prudent to incorporate steel fibers in

SCC mixes to counteract the thermal load in the matrix.

(8) Load tests of beams have shown that steel fibers were effective in increasing the shear strength and ductility of the beams. These tests have proved the ability of steel fibers to partially or completely replace traditional transverse steel reinforcement in the end region of the beams. Steel fibers were also helpful in increasing the flexural capacity of the beams. Most of the beams with steel fiber reinforced concrete were stiffer than the control beams with non-fibrous mix. Steel fibers were also found to alter the mode of failure from sudden brittle in the case of traditional non-fibrous beams, to a ductile mode, in TTFRC and SCFRC beams.

(9) Crack resistance of TTFRC and SCFRC beams was found to be better than that of the traditional control beams. Thus, steel fibers were very effective in controlling the shear crack width.

## **The Researchers Recommend ...**

The researchers have put forth the following design guidelines for engineers to aid them in designing, producing, testing and casting satisfactory steel fiber reinforced concrete mixes for the application in the end zones of prestressed concrete I-beams.

(1) TTFRC mix with satisfactory workability could be prepared by adding a maximum of 1.5 % by volume of ZP305 and not more than 0.5 % by volume of RC80/60BN steel fibers to the traditional TxDOT concrete mix, without modifying the prevalent mix design.

(2) SCFRC mix with satisfactory workability could be produced by adding a maximum of 1.0 % by volume of ZP305 and not more than 0.5 % by volume of RC80/60BN steel fibers to the SCC mix.

(3) To eliminate the end zone cracks and completely replace the traditional transverse steel reinforcement in the prestressed I-beam, the investigators advocate the use of TTFRC4 mix, i.e. TxDOT traditional concrete with 1.5 % by volume of short steel fibers (ZP305). TTFRC4 would also increase the crack resistance and ductility of the prestressed I-beam.

(4) SCFRC mixes with optimum fiber contents reduced the end zone crack widths considerably, but were not effective in eliminating them completely. Nevertheless, due to excessive shrinkage cracks, SCC without steel fibers would not be feasible to be used in the end zone.

With the above recommendations presented by the researchers, it would be possible to eliminate the problem of end zone cracking along with the complete/partial replacement of transverse steel reinforcement with the use of steel fiber reinforced concrete in the traditional prestressed TxDOT I-beams.



## For More Details ...

Visit the University of Houston website at <http://www.egr.uh.edu/structurallab/Final Report 0-4819.pdf> for the detailed report.

This research is documented in: [Report 0-4819-1, Fiber Reinforcement in Prestressed Concrete Beams.](#)

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