CONSTRUCTION AND TESTING OF TYPE II AASHTO GIRDERS USING SELF-CONSOLIDATING CONCRETE

T. Labonte, Graduate Research Assistant, University of Florida, Gainesville, FL
H. R. Hamilton, Assoc. Prof., University of Florida, Gainesville, FL
M. H. Ansley, Structures Research Laboratory, Florida Department of Transportation, Tallahassee, FL
C. A. Ishee, State Materials Office, Florida Department of Transportation, Gainesville, FL

ABSTRACT

Self-consolidating concrete (SCC) has become a popular alternative for commercial building products in Florida. In response to producer requests to use SCC, FDOT initiated a study in which full-scale precast, pretensioned AASHTO Type II beams were constructed with SCC and tested to destruction. The study involved the development of several SCC trial mix designs in conjunction with the participating precast producer. These trial mixes included extensive plastic property testing of the SCC trial mixes. Three beams were then constructed using SCC, and three beams using a conventional FDOT approved mix. The major tasks included performing plastic and hardened property tests using mix samples, constructing SCC beams without vibrating, determining the prestress transfer length, monitoring the camber, and finally testing the beams in flexure and shear. The results from trial mix designs, transfer length, and camber tests are presented.

KEYWORDS: Prestressed, Concrete, Precast, Self-consolidating, Type II beam, bridge.

INTRODUCTION

Self-consolidating concrete (SCC) is a highly workable, non-segregating concrete that does not require mechanical vibration for consolidation. SCC evolved out of admixture technology for under-water concrete in Japan in the 1980's and the desire to make the casting process more efficient due to a low skilled labor supply.[1] Several European countries adopted the use of SCC starting in the early 1990's, and have successfully constructed many bridges, buildings, and other concrete structures using SCC. In the United States, SCC is currently being used mainly in the precast industry for the construction of non-critical structural components and other products that are not highly stressed elements of major concrete structures. Several pedestrian bridges have been constructed with SCC in the US, and there have been successful applications of SCC in building construction.

SCC can flow to fill areas around dense reinforcement and through thin openings under its own weight without voids, segregation or bleed.[2] Additional advantages include eliminating mechanical vibration, reducing the occurrence of voids, improving formed surface finishes, reducing finishing time, improving labor force efficiency, and improving working conditions and safety. The workability of SCC is higher than the highest class of workability associated with normal high-performance concrete typically used in precast concrete fabrication plants.[2] Standards currently being developed define a concrete mix as being SCC when the mix meets quantifiable workability criteria based on its confined flowability, passing ability, and resistance to segregation. The unique criteria checks have required the development of several new plastic property tests that are applicable only for SCC.

In general, the available research suggests that the mechanical properties of SCC are comparable to those of standard mixes. Khayat, Manai, and Trudel[3] reported on the in-place mechanical properties of walls cast with SCC. The SCC cores from the five-foot high SCC walls had an approximately 10% lower compressive strength than the standard cylinders. This group found insignificant differences between cores from the top and bottom of the SCC walls, with differences limited to 8%.

Sonebi, Tamimi, and Bartos[4] tested the structural performance of 8 inch, by 12 inch, by 12.5 foot beams. The variations of the concrete properties along the SCC beams were found to be insignificant. The SCC performed slightly better than the standard concrete in terms of the in-place compressive strengths as a percentage of the 28-day cylinder strengths, with the SCC being in the range of 80% to 100%, and the standard concrete being in the range of 75% to 80%. The SCC beams also performed slightly better in terms of cracking. The standard concrete beams had more and wider cracks than the SCC beams, but this can be partially attributed to the SCC having a 10% higher compressive strength. Also, the ultimate moment capacities of the SCC beams were similar to the control beams, although the SCC cylinder strengths were higher.

In Florida, the precast industry has requested that the Florida Department of Transportation (FDOT) consider the use of SCC in constructing bridge components. This paper presents some of the results of this study. Full scale AASHTO Type II beams were constructed and tested. The major tasks included performing plastic and hardened property tests using mix samples, constructing SCC beams without vibrating, determining the prestress transfer lengths, monitoring the camber of each beam, and finally testing the beams in flexure and shear. The results of this study, along with other testing, will be used by the FDOT to potentially approve SCC for bridge construction.

This research had a number of objectives from both the materials and structural perspective. The materials testing aspect includes both fresh properties and mechanical properties. In addition, durability testing is currently being conducted to determine the long-term efficacy of SCC concrete. This paper reports the design and construction of the beams along with the results of the fresh properties, mechanical, and limited durability testing. Additionally, transfer length and camber testing results are reported. Structural testing will be reported in a future publication.

TRIAL MIX DESIGN AND TESTING

An FDOT class VI mix with a target concrete strength of 8,500 psi was used as a template for the development of two pairs of "standard" concrete mixes and SCC mixes, respectively. This work was conducted by the FDOT State Materials Research Office. The trial mixes were batched and tested to determine the optimum mix design and determine if any adjustments to the relative constituent quantities were necessary. The relative quantities of cement, fly ash, and water were the same for each pair of mix designs (Table 1).

Table 1. Trial Mix Designs

Constituents*	**Description**	**Pair A**		**Pair B***	
		Control	SCC	Control	SCC
Standard Constituents		(lbs/cy)	(lbs/cy)	(lbs/cy)	(lbs/cy)
Cement	Lehigh Type I/II	686	686	752	752
Fly ash	ISG Class F	154	154	168	168
Coarse aggregate	Tarmac #67	1725	1400	1307	1307
Fine aggregate	Florida Rock silica sand	1047	1400	1414	1414
Water	Local	252	252	258	258
Admixtures		(oz/cy)	(oz/cy)	(oz/cy)	(oz/cy)
Air entraining agent	MBVR-S	5.0	1.7	1.8	1.8
Set retarding water reducer	Pozzolith 100 XR	25.2	12.6	13.8	13.8
High range water reducer	Glenium 3200 HES	25.2	73.5	62.1**	64.4

*Mix design selected for verification mix and to construct beam
**Final mix used 27.6 oz/cy in a single dose

The plastic property testing included unit weight, slump, spread, J-Ring, and L-Box tests. The hardened property testing included compressive and tensile strength tests at different concrete ages. The results from the trial mix property testing are shown in Table 2. After conducting the plastic and hardened property tests, it was determined that mix design Pair B would be used for the verification batch with the necessary modification to the amount of high-range water reducing (HRWR) admixture due to the original incremental additions.

Table 2. Trial Mix Fresh Properties

	Pair A		**Pair B**	
Plastic properties	Control	SCC	Control	SCC
Unit weight	138.5 pcf	142.5 pcf	145.8 pcf	146.6 pcf
Air content	5.50%	4.25%	2.50%	2.25%
Temperature	73°F	74°F	74°F*	73°F
Workability	5.3-in. slump	26.8-in. spread	5.0-in. slump	27.5-in. spread
Workability T-20	N/A	3.7 sec	N/A	13.2 sec
J-ring spread	N/A	21.5”	N/A	23.5”
J-ring T-20	N/A	15.2 sec	N/A	40.3 sec
J-ring H1/H2	N/A	5.8 in./4.3 in.	N/A	6.0 in./4.3 in.
L-box T-200	N/A	2.4 sec	N/A	6.0 sec
L-box T-400	N/A	5.8 sec	N/A	14.1 sec
L-box H1/H2	N/A	5.3 in./3.5 in.	N/A	5.3 in./3.3 in.

*Approximate value

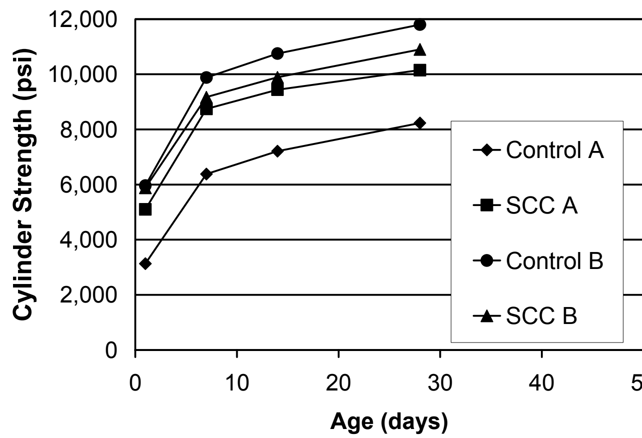


Figure 1. Trial mix average cylinder strength comparison

Table 3. Trial tensile strength using split cylinder (psi)

Day (Test)	**Pair A**		**Pair B**	
	Control	SCC	Control	SCC
28 (tensile*)	705	835	860	815

To achieve the targeted plastic properties for the mixes, it was necessary to add multiple dosages of HRWR to the Pair A SCC mix and the Pair B control mix with the total dosage equal to that indicated in Table 1. The admixture supplier indicated that a smaller quantity added in a single dose would have the same effect. Consequently, it was decided to use the mix design for pair B with a smaller HRWR dosage for the control mix.

VERIFICATION MIX TESTING

Previous studies have shown that SCC plastic properties can change significantly depending on the mixing method. Consequently, a verification mix was conducted at the plant to ensure that the plastic properties remained unchanged when mixing was performed with a production mixer. The mix design for pair B from Table 1 was used to create full-size batches at the plant. This mix was also used for constructing the beams. The plastic property testing included slump, spread, J-ring, L-box, and V-funnel tests. A summary of the test results is shown in Table 4. The plastic properties were found to be comparable or better than the small mixes prepared initially.

Table 4. Verification Mix Plastic Properties

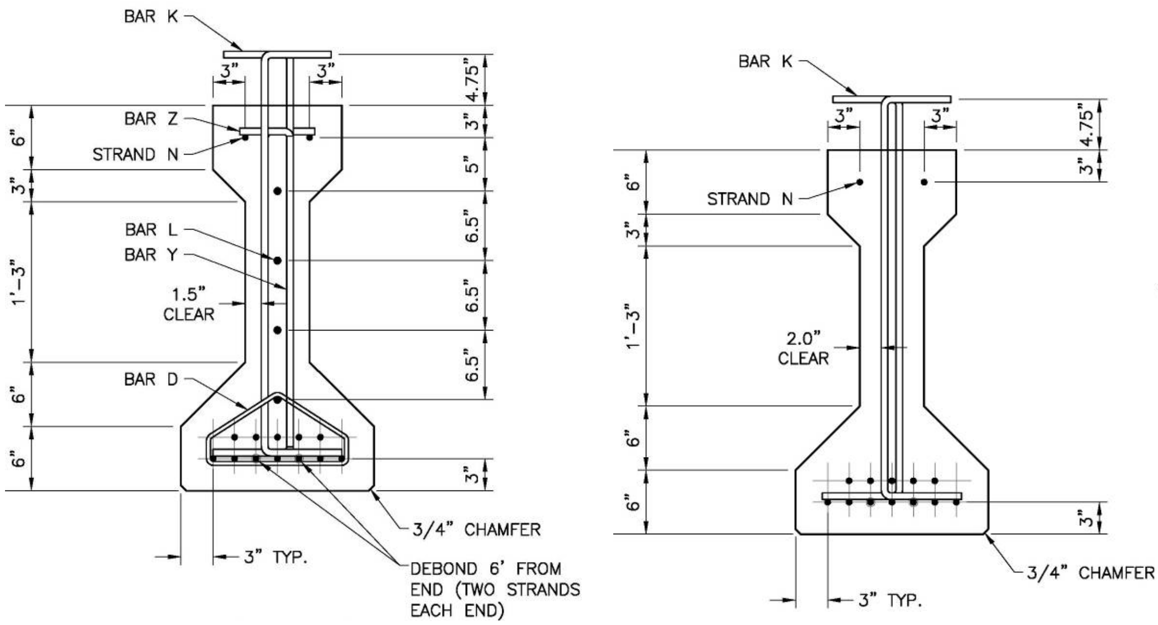
Test	Result
Control slump	7.2-in.
SCC spread	27.2-in.
SCC workability T-20	1.3 sec
SCC J-ring spread	28.0 in.
SCC J-ring T-20	1.3 sec
SCC J-ring H1/H2	5.75 in./5.5 in.
SCC L-box H1/H2	4.0 in./4.0 in.
SCC L-box T-200	0.5 sec
SCC L-box T-400	1.0 sec
SCC U-box H1/H2	13.75-in./14.0 in.
SCC V-funnel flow	2.0 sec

BEAM DESIGN

The objectives of the beam testing were to compare the transfer length, camber growth, and structural properties of the beams, specifically shear and flexure. Four of the beams (two SCC and two standard) were designed to be tested in flexure and shear with a composite cap to simulate the composite action of the bridge deck. Two (one SCC and one standard) were designed to be tested in shear without the benefit of the composite action from the deck. These specimens also had light shear reinforcement at the ends to determine the effect (if any) on the shear behavior.

The AASTHO Type II beam tendon size and configuration was designed to meet the requirements of AASHTO LRFD Bridge Design Specification for a fictitious bridge in which the beams were assumed to be spaced at 6-ft with a 40 ft span. The deck thickness was assumed to be 10 inches. Florida Department of Transportation (FDOT) software (LRFD P Beam Version 1.85) was used in the beam design.

The flexural test beams were tested with a composite concrete top flange to model the compression area provided by the bridge deck in actual service conditions. The top flange was constructed by FDOT Structures Laboratory personnel prior to testing using a Class II ready-mix concrete (*f'c* = 6,000psi). Minimal shear reinforcement was used in the shear test beams as shown in Figure 3.



(a) (b)

Figure 2. Prestressed beam design (a) end section (b) middle section

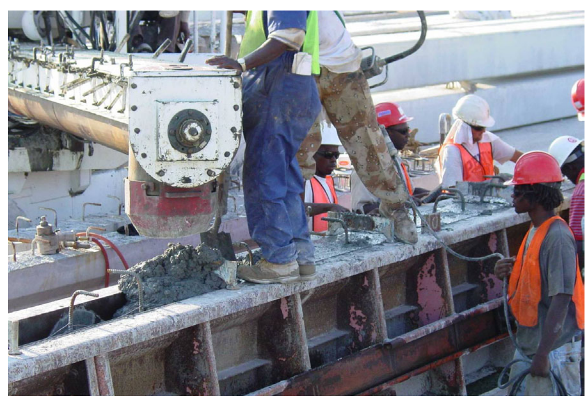
Figure 3. Stirrup and confinement reinforcement at end of non-capped shear beam

Figure 4. Stirrup and confinement reinforcement at end of capped flexure beam

BEAM CONSTRUCTION

Six 42-foot long AASHTO Type II beams were cast in a single day at the prestressed concrete plant in Jacksonville, FL. FDOT quality assurance personnel were present to ensure the beams were cast with the correct procedures and tolerances. To eliminate a vibration carry-over effect from the consolidation of the standard concrete due to the continuously connected forms, all standard concrete beams were cast and consolidated before the SCC beams were poured. No consolidation was utilized on the SCC beams (Figure 5). Fresh properties were also taken during the batching of the concrete for the beam construction. The results are shown in Table 5.

(a)



(b)

Figure 5. Concrete placement (a) SCC beam immediately after concrete placement (b) standard concrete mix during placement.

The SCC beams were poured in approximately 40% less time, and they required approximately 50% fewer workers than the control beams due to the increased flow rate of the concrete and the elimination of side mounted and internal vibrators. The elimination of the vibrators also caused a dramatic decrease in the noise level of the casting process, resulting in a more pleasing work environment. Having fewer workers on top of the SCC beams also increased the safety level.

Table 5. Beam Mix Plastic Properties

Test	Result
Control slump	4.7-in. slump
SCC spread	24.7-in.
SCC workability T-20	1.6 sec
SCC J-ring spread	25.3 in.
SCC J-ring T-20	2.4 sec
SCC J-ring H1/H2	5.75 in./5.25 in.
SCC L-box H1/H2	4.0 in./4.0 in.
SCC L-box T-200	0.5 sec
SCC L-box T-400	1.0 sec
SCC U-box H1/H2	13.0 in./14.0 in.
SCC V-funnel flow	1.9 sec

To ensure an adequate connection between each flexure beam and its top flange, the top surface was roughened (raked). Unlike the SCC beams, it was possible to roughen the control beams immediately after being poured. The SCC beams required approximately 1.5 hours set time for the paste to have sufficient stiffness to hold a roughened surface. As demonstrated by a greater amount of leakage of the concrete from the SCC beam forms than the control beam forms, it is necessary to have very tight forms with SCC construction. Additionally, there is a greater importance to grease all areas of the steel forms when using SCC, due to SCC causing a stronger bond between the beams and the forms requiring excessive force when removing the forms. The stronger bond is caused by the high flowability of SCC, enabling it to flow into very small surface irregularities of the forms. If forms are sufficiently oiled and the formwork is watertight, then the SCC will provide a better formed finish.

BEAM MIX TESTING

The beams were constructed using concrete mixed in the prestressing supplier's batch plant, as was done for the verification mix. A number of fresh properties tests were conducted on the beam mix. The hardened property tests included cylinder compressive strength, shrinkage, surface resistivity, and tensile strength. The results are shown in Figure 6 through Figure 8 and Table 6.

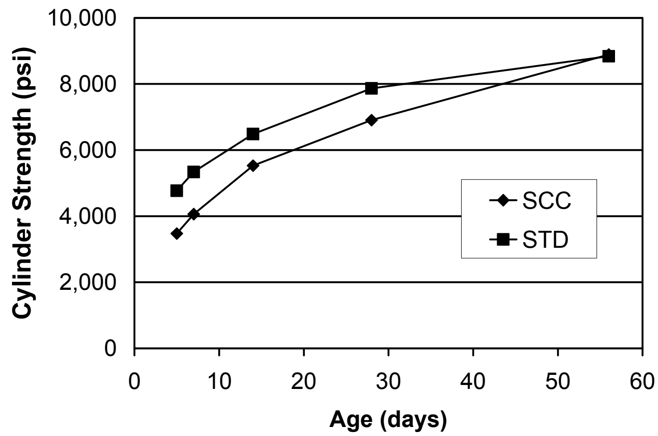


Figure 6 – Beam mix average cylinder strength comparison

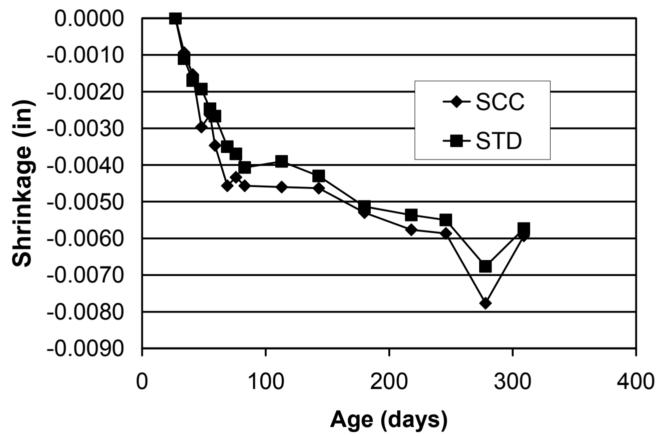


Figure 7 – Comparison of SCC and Standard mix shrinkage

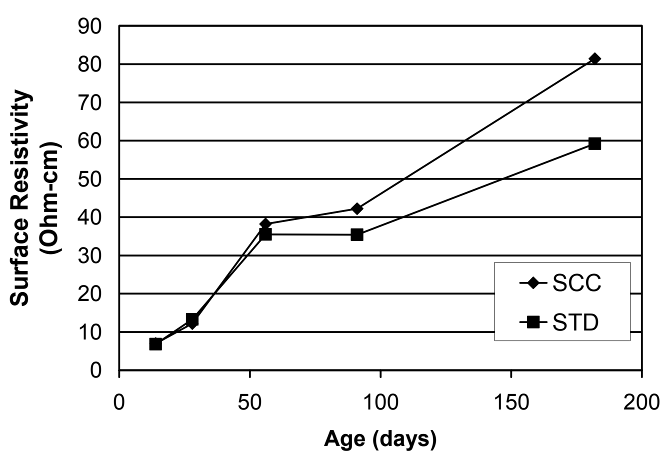


Figure 8 – Comparison of surface resistivity.

Table 6. 28-day tensile strength test comparison

Test	Average Tensile Strength (psi)	
	Standard	SCC
Split cylinder	813	712
Beam	898	859

PRESTRESS TRANSFER LENGTH

The beams were cast in a single line on a single casting bed. The transfer of prestress was accomplished by torch-cutting one strand at a time simultaneously between every other pair of beam ends and at each far end of the casting bed as shown in Figure 9. This pattern resulted in each beam having a cutting end and a free end. As other researchers have found, and as the results of the transfer length analysis shows, the transfer lengths are significantly larger at the cutting end.

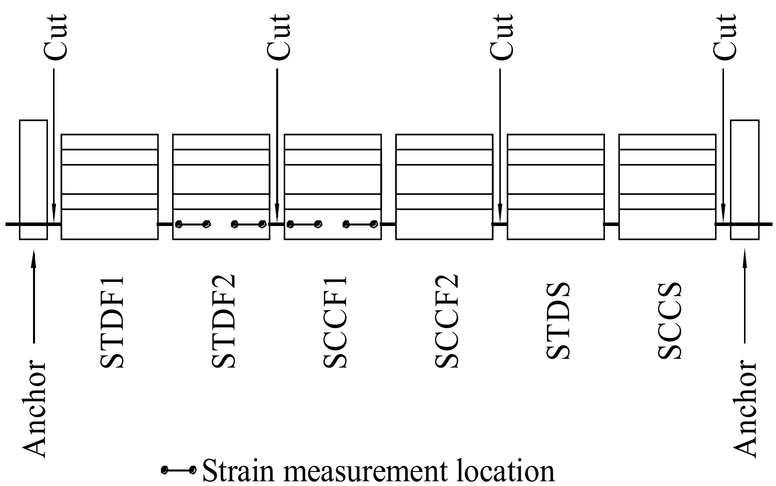


Figure 9. Specimen configuration in prestressing bed.

Due to low early concrete strengths and scheduling conflicts, the prestress transfer was delayed until fifteen days after casting. The five-day cylinder compressive strengths from the precasting plant were 3170 psi for the control concrete and 3810 psi for the SCC. It is not known why the early strengths were low. Strain gauges were installed before the transfer of prestress on each end of one control beam and one SCC beam on the bottom flanges in order to measure the prestress transfer lengths (Figure 10).

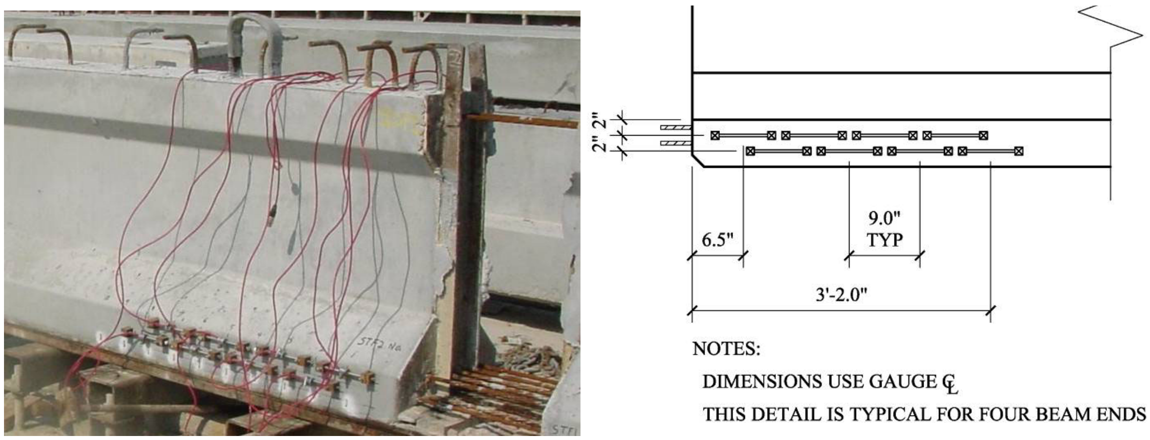


Figure 10. Transfer Length Instrumentation Setup

An analysis was performed on the strain data to determine where the strain transitions from increasing in the longitudinal direction to a constant value using the 95% AMS method.[6] The execution of the 95% AMS method was as follows:

1. Plot the strain profile.

2. Determine the AMS for the specimen by computing the numerical average of all the strains contained within the strain plateau of the fully effective prestress force.

3. Multiply the AMS by 0.95 and construct a line corresponding to this value.

4. Prestress transfer length is determined by the intersection of the 95% line with a best-fit line through 0,0 and the first two points of the strain profile.

This is a modified version of the 95% AMS method due to having slightly higher variations in the measured strains than others have found when determining transfer lengths and due to using fewer gauges than most transfer length measurements. The slightly higher variations were caused by using crack gauges and using multiple vertical placements of the gauges as shown in Figure 10. Also, it was necessary to change the vertical locations of the gauges from the planned positions in the field. The vertical placements of the gauges, therefore, were determined from photographs, which added some error to the measurements. After the vertical locations of the gauges were determined, the strain readings from each gauge were used to calculate the strains at the height of the strand centroid using the assumption that plain sections remain plane. The strains from the innermost gauges clearly within the fully effective prestress force were used to calculate the 95% AMS. The first two strain points and the origin were used for a linear best-fit line. In one case, only one gauge was within the transition region due to another gauge being nonfunctional, and therefore the intersection of the strain profile with the 95% AMS was used to determine the transfer length (Figure 14). The instrumentation and analysis methods used here are sufficient to compare the prestress transfer lengths of the SCC and control beams. The resulting profiles from the analysis are shown in Figure 11 through Figure 14.

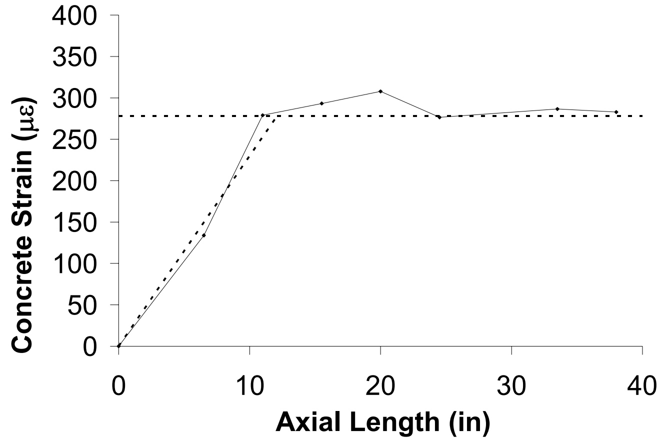


Figure 11. Transfer Length Determination Plot for STF2 North

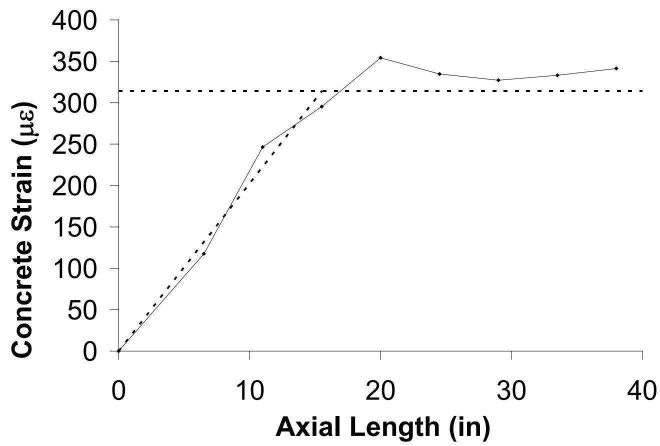


Figure 12. Transfer Length Determination Plot for STF2 South

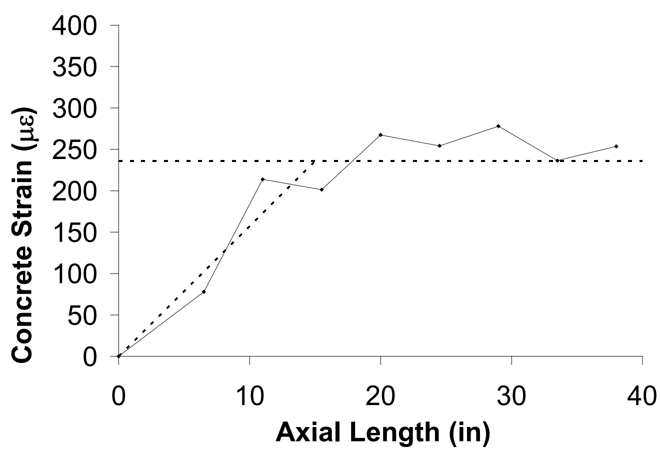


Figure 13. Transfer Length Determination Plot for SCF1 North

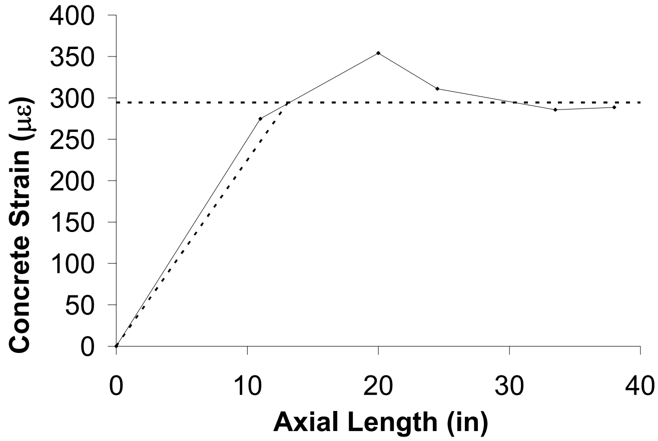


Figure 14. Transfer Length Determination Plot for SCF1 South

The results shown in Table 7 show that the transfer length for the control beam on the cutting end was 0.5 inches higher than the SCC beam, and the transfer length for the SCC beam on the free end was 0.9 inches higher than the control beam. The results show that there is an insignificant difference between the SCC and control beams with respect to prestress transfer lengths.

Table 7. Prestress Transfer Lengths

Test	Beam End	End Condition	Transfer Length (in)
STDSF T1	STDF2 North	Free	12.1
STDSF T2	STDF2 South	Cutting	15.5
SCCSF T1	SCCF1 North	Cutting	15.0
SCCSF T2	SCCF1 South	Free	13.0

CAMBER MONITORING

The camber on each beam was monitored from transfer of prestress to approximately 200 days after casting. The concrete strengths at the time of prestress transfer and during the camber-monitoring period were similar, so it was expected that the camber values for all of the beams would be very close, assuming the SCC concrete would have the same camber characteristics as the control concrete. An analysis was performed to determine the predicted camber, which produced slightly higher values than the measured camber. It is expected that the predicted camber values, which are partly empirically based on a sooner transfer of prestress, are slightly higher than the measured values due to the 15-day period between beam construction and transfer of prestress. It is likely the delay of prestress caused the camber to be less than if a standard release age was used.

Figure 15. Camber monitoring of beams.

The camber values for all of the beams during the camber monitoring period are shown in Table 8. It can be seen in the plot of the camber values, shown in Figure 16, that the mean camber for the SCC beams nearly identically matched the mean camber for the control beams. The SCC beams exhibited slightly more camber variation than the control beams. This variation is minor and within acceptable limits of expected variation. It is concluded from this camber test program that no camber equation modifications are necessary for SCC construction using this mix design.

Table 8. Camber Monitoring

Beam	Day							
	0	50	77	84	99	112	172	188
SCS	0.31	0.53	0.81	0.80	0.81	0.80	0.81	0.88
SCF1	0.34	0.60	0.78	0.77	0.77	0.75	0.78	0.84
SCF2	0.41	0.60	0.78	0.77	0.78	0.77	0.80	0.84
STS	0.41	0.60	0.66	0.66	0.66	0.66	0.69	0.75
STF1	0.34	0.66	0.84	0.84	0.84	0.84	0.88	0.91
STF2	0.44	0.53	0.75	0.77	0.77	0.77	0.80	0.84
Theoretical	0.44	-	0.90	-	-	1.00	-	1.05

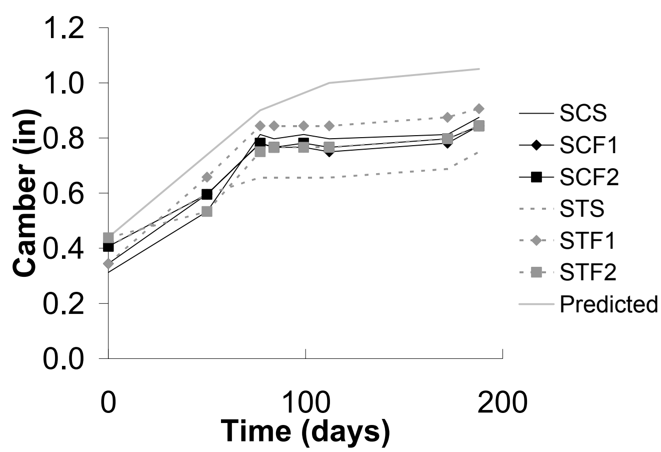


Figure 16. Camber versus Time

CONCLUSIONS

This testing program evaluated the mix design development and construction of AASHTO Type II girders using SCC. Plastic and hardened properties of mix samples were tested. The prestress transfer length on each end of one SCC beam and one standard beam were determined. The camber for the three SCC beams and the three standard beams were monitored for approximately 200 days after casting. The following can be concluded from this testing program:

- Obtaining the desired plastic properties of an SCC mix was a great deal more complicated than obtaining the desired plastic properties of a standard mix, and significant changes to the plastic properties of SCC were caused by minor changes in the mixing procedures and conditions, which indicates that quality control is much more critical with SCC.

- Using SCC resulted in a lower construction time, the labor efficiency was improved, and the noise level and the safety level of the work environment were improved.

- The hardened properties of the SCC sample testing were comparable with those of the standard samples.

- There was an insignificant difference between the SCC and control beams with respect to prestress transfer lengths.

- The mean camber of the SCC beams closely matched the mean camber of the standard beams, although there was slightly more variation with the camber of the SCC beams.

FUTURE WORK

This paper presented the mix design development, construction, materials testing, transfer length measurements, and camber monitoring of beams constructed with SCC concrete. Load testing on these specimens has been conducted and will be reported in the future.

ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank the Florida Department of Transportation Research Office for funding. In addition, we would like to thank FDOT State Materials Office for materials testing; and the FDOT Structures Laboratory (David Allen, Frank Cobb, Steve Eudy, Tony Johnston, Paul Tighe) for structural testing; Gate Concrete Products Company Jacksonville, FL and Jim Kunberger and Bruce Hunter for constructing the specimens; Eckart Buehler with Master Builders for technical assistance with the mix designs.

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