VDOT APPLICATIONS OF HPC WITH LIGHTWEIGHT OR SCC

Celik Ozyildirim, PhD, PE, Virginia Transportation Research Council, VA

ABSTRACT

Virginia Department of Transportation (VDOT) is developing and using high-performance concrete (HPC) for cost-effective structures. As a part of this program, lightweight concrete (LWC) and self-consolidating concrete (SCC) were prepared in precast and prestressed concrete applications. Prior to the construction of a LWHPC structure, test beams were made. The results indicated the viability of using LWC with high strength and low permeability in prestressed bridge beams. For SCC, initially a precast arch bridge and prestressed Bulb-T test beams with SCC were cast. SCC in the arch bridge had satisfactory strength and permeability. The two Bulb-T beams with SCC were delivered to the FHWA structures laboratory for testing. One of the two beams has already been tested and gave satisfactory results.

Keywords: High-performance Concrete, Lightweight Concrete, Self-consolidating Concrete, Strength, Permeability, Beams, Bulb-T Beams, Transfer Length, Prestress Loss, Arch Bridge.

INTRODUCTION

The Virginia Department of Transportation continues to strive to develop high-performance concretes (HPC) that extend the service life of structures. Low permeability has been the cornerstone of the HPC in structural applications. Preventing harmful solutions from entering and deteriorating concrete has been possible through the use of supplementary cementitious materials. Concrete strengths as high as 10,000 psi have been used successfully in beams, although 8,000 psi strengths are more common[1,2]. Higher design strengths are used if they are economical. Extending HPC developmental work to lightweight (LW) concrete has resulted not only in improved durability and longevity, but has also made it possible to span longer distances and reduce foundation loads. Lightweight concrete has the advantage of internal curing for continuation of hydration and control of cracking, as well as a more continuous and improved contact zone between the aggregate and the paste. However, lightweight concrete has the disadvantage of low modulus and high creep, which leads to larger loss of prestress in bridge beams.

Another feature of HPC is its high workability. Self-consolidating concrete (SCC) exemplifies high flowability in a very effective way. SCC can flow into the formwork and encapsulate the reinforcement without any mechanical consolidation. SCC can be very useful for constructing prestressed Bulb-T beams with many strands in the bottom flange, as well as arch bridges and other structural elements with thin walls and heavy reinforcement. Advantages of SCC include fast construction, lower labor costs, less noise, a smooth surface, and improved strength. Some of the drawbacks are the possibility of an inadequate air void system, high shrinkage, and segregation. SCC is a value-added product that requires special attention to the mix design and production. In concretes with high flow rates, segregation is a real risk. Therefore, means to reduce segregation in SCC must be inherent to the mix design. Typically, a high amount of fine material, better shape and grading of aggregates, and a reduced amount of coarse aggregate with smaller maximum size aggregate may be used to minimize segregation. If segregation is still an issue, viscosity modifying admixtures can be added.

PURPOSE AND SCOPE

This paper summarizes early VDOT work in precast and prestressed concrete plants with lightweight concrete and SCC with normal weight aggregates. Lightweight HPC was used in a bridge structure with AASHTO beams. SCC was first used in an arch bridge and then in Bulb-T beams.

Prior to the construction of the lightweight bridge beams, test beams were made and tested to ensure that the desired material properties are achieved and the satisfactory structural behavior is obtained. Similarly SCC test beams have been cast before the planned use of SCC in bridge structures. Beams are tested at the FHWA structures laboratory to ensure that satisfactory material and structural behavior are attained.

LIGHTWEIGHT CONCRETE

VDOT placed the first LWHPC beam in a bridge located east of Richmond, which was opened to traffic in 2001[3]. It has three simple spans made continuous for live load with pier diaphragms and a continuous deck. The fifteen AASHTO Type IV beams used are each 84-ft long, with a minimum 28-day compressive strength of 8,000 psi and a maximum permeability of 1,500 coulombs. The deck is also LWHPC. It has a 28-day strength requirement of 4,000 psi and a maximum permeability of 2,500 coulombs. To ensure that the specified beam strength and permeability can be achieved and that the structural behavior is acceptable, concrete specimens and test beams were cast and tested. The mixture proportions of the test beams are given in Table 1. The lightweight coarse aggregate was ¾ in to No. 4 expanded slate with an absorption of 5 percent, a relative density of 1.47, and a bulk density of 49 lb/ft^3. The fine aggregate was natural sand with an absorption of 1.4 percent, a relative density of 2.61, and a fineness modulus of 2.60. The admixtures were a commercially available air-entraining admixture (AEA); a vinsol rosin complying with the requirements of ASTM C 260; a water-reducing admixture (WRA); a lignin complying with the requirements of ASTM C 494, Type A; and a high-range water-reducing admixture (HRWRA), which is a polycarboxylate complying with the requirements of ASTM C 494, Type F.

The hardened concrete properties are summarized in Table 2. At 28 days or at one year the specified 8,000 psi compressive strength was not achieved. The permeability values were marginal or below the 1,500 coulombs. The elastic moduli were below 3 million psi. The low strengths were attributed to high air and water contents in the mixtures.

Table 1. Mixture Proportions of Test and Bridge Beams in lb/yd^3

Material	Test Beams	Bridge Beams
PC	451	451
Slag	301	301
Water	250	255
w/cm	0.33	0.34
NW FA	1419	541
LW FA	----	390
NW CA	----	605
LW CA	800	696
Air	5.5 ± 1.5%	5.5 ± 1.5%
WR (fl oz)	----	22
WR+R (fl oz)	23	----
HRWRA (fl oz)	56	56
AEA (fl oz)	12	12
Calcium nitrite (gal)	----	3

Table 2. Properties of Hardened Concrete for Test Beams

Test	Age	LW1	LW2	LW3
Compressive Strength (psi)	1d (TMC)	6130	5430	----
	1d	5080	4210	5040
	28d	6660	6320	6140
	1 year	6930	6990	7030
Flexural Strength (psi)	28d	600	520	490
Permeability (coulombs)	28d	1110	1507	1454
Elastic Modulus (E+06 psi)	28d	2.95	2.78	2.72

The test beams indicated that the prestress force at 270 days was 65% of the ultimate strength, with a jacking stress of 76% of the ultimate strength. The actual transfer and the development lengths were less than the theoretical values. The actual compressive strains measured at the level of the bottom strands were less than that estimated by the PCI and ACI models as shown in Figure 1[4].

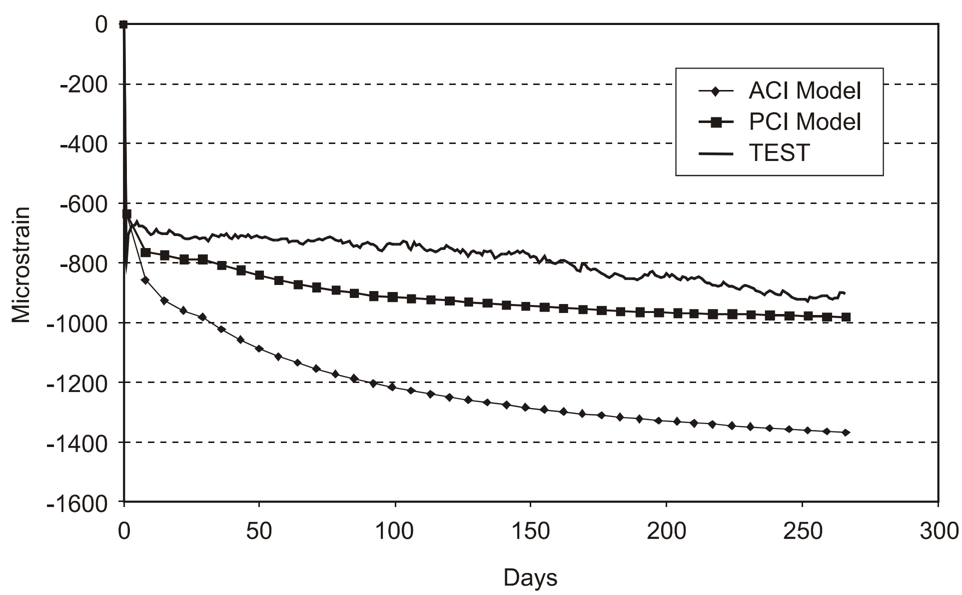

Fig. 1 Concrete strains over time for the LWHPC test beams.

The mixture proportions for the bridge beams are given in Table 1. The same materials used in the test beams were used in the bridge beams; however, proportions of aggregates were different and natural coarse aggregate and lightweight sand, which had an absorption of 5 percent and a relative density of 1.88, were also added to the mixtures. These changes were made to ensure that the 8,000 psi strengths were achieved in bridge beams, since this specified strength was not attained in the test beams. This modified mixture was used at the plant previously and had developed 8,000 psi. In addition to AEA, WR+R, and a HRWRA, calcium nitrite (30% solids) was used in bridge beams to help improve the strength. The hardened concrete properties are summarized in Table 3.

The specified strengths were about 8,000 psi at 28 days. The one-year permeability values were either low or very low. The elastic modulus was about 3 million psi. The bridge beams have been monitored continuously, and this LWHPC structure is in excellent condition.

Table 3. Properties of Hardened Concrete for Bridge Beams

Test	Age	B1	B2
Compressive Strength (psi)	1d (TMC)	4320	4370
	1d	4800	4640
	28d	8310	7900
	1 year	7740	7550
Flexural Strength (psi)	28d	695	580
Permeability (Coulombs)	1 year	1034	799
Elastic Modulus (E+06 psi)	28d	2.91	3.04

The success of the 2001 LWHPC structure has opened more possibilities with LWHPC. In two long bridges planned at West Point, Virginia, LWHPC will be used in areas with poor soil conditions to reduce foundation loads. One of the bridges is on Route 33 over the Mattaponi River. This bridge is 3,454 ft long, and 2,195 ft of the superstructure will be constructed with LWHPC. The span lengths are 136 ft in the simple span bulb-T units that are continuous for live load, and 200 ft and 240 ft in the continuous spliced bulb-T units. The spliced girder units have 160-ft long drop-in beams spliced to haunched girder segments over the piers. These girders are based on a 95.5 in bulb-T section. The specified 28-day compressive strength is 8,000 psi with a maximum permeability of 1,500 coulombs. The second LWHPC bridge to be constructed is again on Rte 33, but over the Pamunkey River. It will be longer than the Mattaponi, crossing at 5,354 ft and with 2,169 ft of LWHPC superstructure. The typical LWHPC spans are 145 ft, with 200 ft and 240 ft spans in the spliced girder units. The lightweight concrete will be tested in the laboratory, and bridge beams will be instrumented and monitored to evaluate their long-term performance. The bridge over the Mattaponi River was advertised in early 2004, and the contractor was selected. The bridge over the Pamunkey River will be advertised in September 2004.

SELF-CONSOLIDATING CONCRETE

The first application of SCC for VDOT was in an arch bridge that carries traffic in a residential area[5]. This arch bridge is comprised of 25 arches placed side by side to span 30 ft across a small creek. Each segment was an ellipsoidal arch measuring 7.5-ft wide and 10-in thick with two mats of reinforcement. The specified 28-day strength was 5,000 psi. Each arch segment was cast on its side in the precast plant with one person directing the bucket to one end of the section. The concrete spread from the point of pour to a distance greater than 40 ft without requiring any manual labor for consolidation. The finished product had smooth surfaces. The mixture proportions are given in Table 4.

Type II cement and slag were used. The strength and permeability data summarized in Table 5 indicate satisfactory strengths and low permeability. The average strengths were in excess of 7600 psi, and the permeability was lower than 1800 coulombs. The concretes contained slag and a polycarboxylate based high-range water-reducing admixture (HRWRA). Use of high amounts of HRWRA affected the air-void system, and large bubbles were found during the petrographic analysis. Freeze-thaw resistance was poor even though the total air contents were within the specifications. Later, more batches were made either with a different formulation of the HRWRA, or with the same HRWRA but with more air-entraining admixture. Satisfactory durability was obtained.

Table 4. Mixture Proportions of Arch Bridge and Bulb-T Beams in lb/yd^3

Material	Arch Bridge	Bulb-T
Cement	488	480
Slag	262	320
Fine aggregate	1451	1430
Coarse aggregate	1451	1430
Water	279	267
w/cm	0.37	0.33
Air (%)	5.5 ± 1.5	5.5 ± 1.5

The hardened concrete properties for the arch bridge are given in Table 5. The elements were precast but not steam cured. In two of the batches the specimens were rodded to determine if the concrete was self-consolidating. Similar values were obtained between concretes with and without rodding indicating that concretes were self-consolidating. The permeability values were low or very low.

Table 5 Properties of Concrete Used in the Arch Bridge

SCC	Batch	Strength (psi)				Perm
		1 d	7 d	28 d	28 d, R[a]	(Coul)
Slag	1	3380	6160	7610	-	815
	2	-	6490	7300	-	882
	3	-	6600	7270	-	1002
	4	3040	5740	7720	7870	1690
	5	2720	5620	7630	8180	1758

[a] Rodded.

The success of the arch bridge prompted the fabrication of two Bulb-T test beams 45-in deep and 60-ft long. The test beams were monitored during construction, and concrete samples were cast to ensure that beams with SCC could be made without segregation or the need for mechanical vibration. The mixture proportions are given in Table 4. Type III cement and slag were used. Air entraining admixture, a polycarboxylate based HRWRA, and low amount of (1 fl.oz/cwt) an acrylic-based viscosity-modifying admixture were used. The SCC leveled itself and did not need any surface finishing. The hardened properties are summarized in Table 6 indicating that the minimum 28-day specified strength of 8,000 psi and the maximum permeability of 1,500 coulombs were met. Similar strengths between rodded and unrodded specimens indicated that the concrete was self-consolidating. A composite deck using regular bridge deck concrete was placed on the beams. The deck concrete was vibrated.

Table 6. Properties of SCC used in Bulb-T Beams

Properties at 28 days	B1	B2	B2 Rodded
Compressive strength (psi)	8340	8800	8520
Permeability (coulomb)	750	533	664

Measurements at the plant indicated that the transfer length of the prestress strands was shorter than that given by the AASHTO equation. A typical transfer length data is shown in Figure 2.

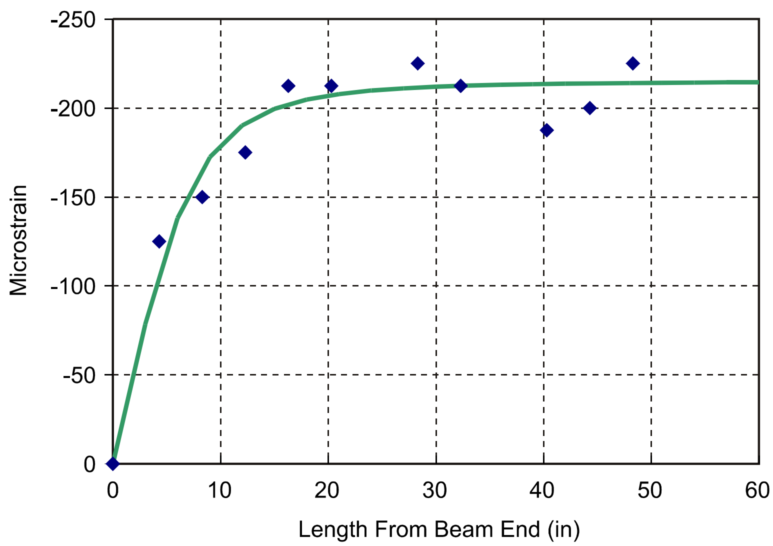

Fig. 2 Transfer length for one end of Beam 1.

The beams were then shipped to the FHWA structures laboratory for testing. One of the beams has been tested as of August 2004, and the other beam will be tested soon. In the first test, the beam was loaded to simultaneous nominal flexural and shear capacity. This loading caused a shear induced tension failure in web as the moment capacity of the beam was reached. Uncracked and post-cracked shear capacity were of similar magnitude for this test beam. The average compressive strength of the concrete specimens during testing was 9,580 psi and the splitting tensile strength 820 psi. The structural test indicated that the beam had the flexural and shear capacity expected from theoretical calculations. The calculations also indicated that the tensile capacity of the beam was 5.3 times the square root of the compressive strength. This reasonable value confirms acceptable performance. The other end of the first beam was loaded near the support in an attempt to force a strand development failure. The strands were well bonded to the concrete near the beam end, and strand slip was minimal. The beam failed by web compression failure. The second test beam will also be tested to flexural and shear failure, but the load points will be varied from those used for the first test beam. The overall goal is to permit the use of SCC in VDOT structures provided that the test results are predictable by calculation.

SUMMARY

VDOT has used LWHPC in beams with strengths exceeding 8,000 psi and low permeability successfully in a bridge structure. More work with LWHPC is planned.

SCC was successfully used in an arch bridge and in two 60-ft-long Bulb-T beams with high strength and low permeability. Testing of one of the beams was completed, and the other beam will be tested soon. The testing of the first beam indicated that the beam had the flexural and shear capacity expected from the theoretical calculations. Also, the strands were well-bonded to the concrete, and slip was minimal.

ACKNOWLEDGMENTS

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