LIGHTWEIGHT HPC BULB-T BEAMS IN THE MATTAPONI RIVER BRIDGE

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ABSTRACT

Lightweight HPC Bulb-T beams from Route 33 over the Mattaponi River in Virginia have been evaluated to determine the concrete properties, including the time dependent material property functions. These functions are used to verify the assumptions used to design the bridge.

Four bulb-T beams have been instrumented with vibrating wire gauges and thermocouples. These gauges have been continuously taking strain measurements starting before the casting of the beams. The camber profiles of the bulb-T's have also been measured over time. Large-scale shrinkage specimens were cast with the beams and have remained with the beams to provide matched environmental conditions. The Modulus of Elasticity and Coefficient of Thermal Expansion has also been determined.

This paper presents the concrete ingredients, the fresh and hardened properties, and the hardened time-dependent properties derived from tests. Early indications from the full-scale measurements are that the assumed design properties overestimated time-dependent creep and shrinkage of the lightweight concrete in the bulb-T's.

Keywords: Lightweight concrete, Bulb-T beams, time dependent properties, strength, shrinkage, creep

INTRODUCTION

Lightweight high performance concrete (LWHPC) has the benefits of the normal weight HPC, namely high strength, high durability, or both (1, 2, 3). However, it has the additional advantages of reducing dead weight, a more continuous contact zone between the aggregate and the paste, and the presence of moisture in the voids of aggregates contributing to internal moist curing (4, 5, 6, 7). These benefits in LWHPC beams are expected to result in increasing longevity, reducing the number of beam lines, and longer beams leading to cost savings.

Use of LWHPC in bridge beams is very limited. There are still concerns about the tensile strength, modulus of elasticity, durability, shrinkage and creep characteristics of LWHPC. In 2001 the Virginia Department of Transportation (VDOT) constructed a LWHPC bridge on Rte. 106 over the Chickahominy River near Richmond, Virginia (8). This bridge had LWHPC AASHTO Type IV beams with a specified minimum 28-day compressive strength of 8,000 psi, and a maximum permeability indication of 1,500 coulombs when tested in accordance with ASTM 1202. The length of the beams is 84 ft with a 10 ft beam spacing, and the bridge is three spans made continuous for live load. The structure was in very good condition after four winters with only minimal transverse deck cracking located over the interior piers. Successful use of LWHPC on Rte. 106 over the Chickahominy gave VDOT confidence to build longer span lightweight concrete bridges. Also, VDOT has begun using Bulb-T beams that are more efficient in spanning long distances compared to the standard AASHTO beams.

VDOT is building two long bridges on Rte. 33 at West Point, Virginia. Rte. 33 over the Mattaponi River is 3,454-ft long, with 2,195 ft constructed using LWHPC beams, girders, and deck. The other bridge is over the Pamunkey River, and is 5,354-ft long with 2,195 ft of LWHPC superstructure. Both bridges have very long spans extending to 240 ft. using spliced LWHPC girders, and to 145 ft. using simple spans made continuous for live load. The Mattaponi River Bridge was constructed first, and the early results from the instrumentation are presented in this paper.

PURPOSE AND SCOPE

Lightweight HPC Bulb-T beams from Unit B of the Mattaponi River Bridge have been evaluated in order to check the accuracy of the concrete properties assumed for the design of the HPLWC portion of the bridge. Bridge Unit B shown in Figure 1 was constructed as 145 ft. simple spans made continuous for live load. These beams undergo a large strain change at prestress transfer, and another large strain change at the time of deck placement. These two loading events will be instrumental in determining a time-dependent creep function for this LWHPC. As of the time of the preparation of this paper, the deck had not been placed and the beam concrete was only 180 days old. Therefore the aging influence on the creep behavior of the beam concrete was not included in this paper.

The beams have a specified minimum 28-day compressive strength of 8,000 psi and a maximum permeability of 1,500 coulombs. The unit weight for beam concrete was 120pcf. Initially, trial batches were cast and material properties evaluated. Then the concrete for the beams was prepared and tested. The coefficient of thermal expansion was also determined.

Four Bulb-T beams were instrumented with vibrating wire gauges to measure strains near the top and bottom of the cross-section. These gauges have been in continuous operation, starting just before the beams were cast. The camber profiles of these Bulb-T's have also been measured over time. Large-scale shrinkage specimens were cast with the beams, and have remained with the beams to provide matched environmental conditions. Analysis using the strain, deflection, and shrinkage specimen data will eventually be used to determine a time-dependent shrinkage function for the concrete in the bridge beams. Data will be collected for a sufficient number of years to develop accurate creep and shrinkage functions for this LWHPC.

Figure 1. Unit B 3-span approach from West Point to splice girder channel span units.

METHODOLOGY

This section describes the measurement program for the trial batches, the small-scale specimens made at the time the beams were cast, and the instrumentation of the beams.

Trial Batches

The precast prestressed concrete plant fabricating the lightweight beams had developed the mixture proportions given in Table 1. Type II cement was used. Fly ash was Class F with a specific gravity of 2.2. NW coarse aggregate was granite and the LW aggregate expanded slate meeting the #67 size. The maximum aggregate size is ¾ in. Fine aggregate was natural sand. Corrosion inhibiting, air entraining, and regular and high-range water reducing admixtures were used. A batch of concrete was prepared and properties determined at the fresh and hardened states for approval by VDOT. At the fresh state slump, air content using the volumetric method, and unit weight were measured. Compressive strength, elastic modulus, creep, shrinkage, and permeability were measured for the hardened concrete. The hardened concrete test procedures and sample sizes are given in Table 2.

Table 1: Mixture Proportions

Material	Amount
Cement	750
Flyash	185
Water	287
w/cm	0.31
FA	949
CA NW	250
CA LW	800
Air (%)	5.5 ± 1.5
Calcium Nitrite (gal)	3.5
WRA (fl oz)	36
HRWRA (fl oz)	46

Table 2: Test and Specimen sizes

Tests	Specifications	Size (in)
Compressive strength	AASHTO T 22	4x8
Elastic Modulus	ASTM C 469	4x8
Modulus of rupture	ASTM C 78	4x4x14
Splitting tensile	ASTM C 496	4x8
Permeability	AASHTO T 277, T 259	2x4
Drying Shrinkage	ASTM C 157	6x6x14
Creep	ASTM C 512	6x12
Freeze-thaw durability	ASTM C 666	3x4x16

Casting of Beams

Four 95.5 inch deep PCEF Bulb-T beams were instrumented from Span I of Unit B. One of the beams is shown during fabrication in Figure 2. There were seven beams in the superstructure cross-section with a 10 ft 6 in beam spacing. Beam 4 was cast on January 4, 2005, Beams 5 and 7 were cast the next day, and Beam 1 was cast on January 10, 2005. On January 4 and 5 a batch of concrete was tested for the following: slump; air content, using the volumetric method; unit weight, at the fresh state; and for compressive strength, elastic modulus, shrinkage, permeability, resistance to freezing, thawing, and coefficient of thermal expansion (CTE) in the hardened state. The hardened concrete test procedures and sample sizes are given in Table 2. The beams were not steam cured, thus Beams 5 and 7 were two days old at transfer, and Beam 4 was three days old at transfer. Concrete strength at prestress transfer was 6,000 psi. The beams and specimens were air dried.

Figure 2. Construction of 145 ft. long by 95.5 in. deep Bulb-T for Unit B

Instrumentation

To determine the hardened time-dependent properties, vibrating wire gauges (VWG) were placed in the top and bottom flanges of the three beams. At each location two

VWG were placed for redundancy as shown in Figure 3 for the top flange. The strain measurements were collected, beginning at the time of fabrication of the beams. Collection of data will continue for years, allowing the accurate determination of the creep and shrinkage functions. Data presented in this paper is from the first 180 day and before deck placement.

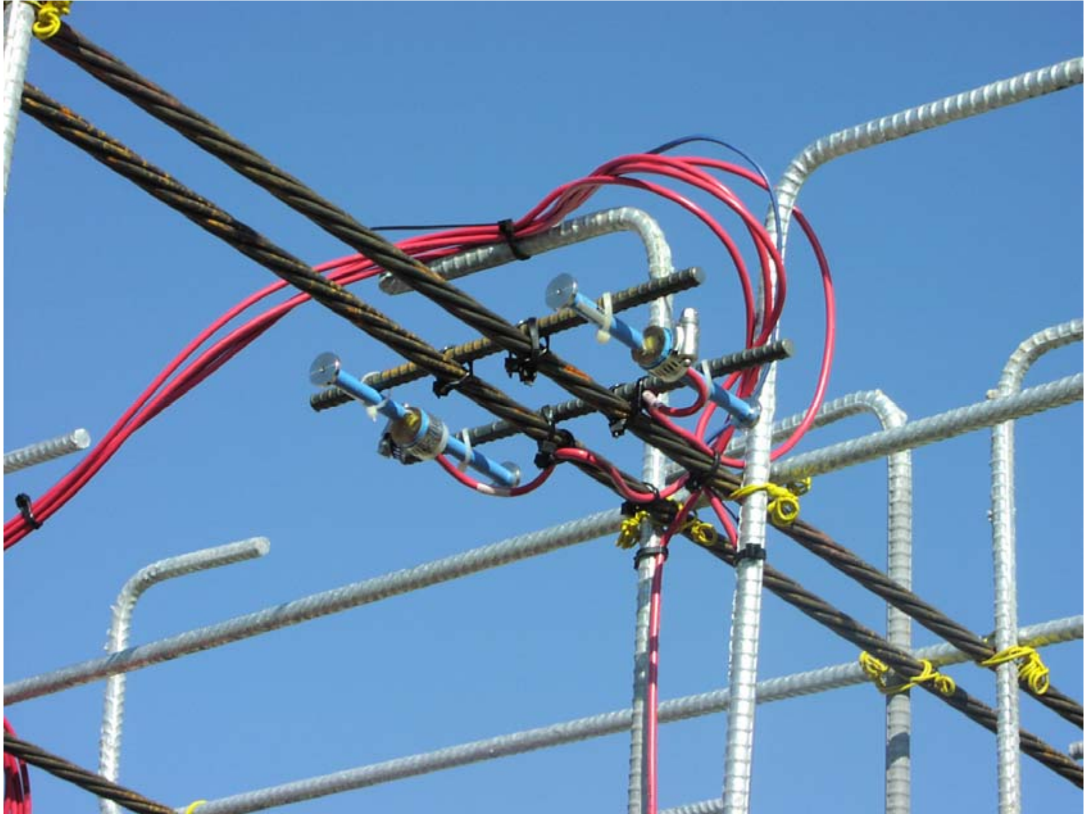

Figure 3. Vibrating wire gauges located at top of beam.

RESULTS AND DISCUSSION

Trial Batches

The fresh and hardened concrete properties of the trial batch are given in Table 3. Personnel from Standard Concrete Products and Stalite produced a workable concrete with an acceptable air content and unit weight. The release strength could be achieved in three days and the 28-day compressive strength was much higher than the 8,000 psi required. The elastic modulus was satisfactory, exceeding the 3.2×10^6 psi specified, while permeability less than 1500 coulombs was obtained. The creep and shrinkage values was also satisfactory as determined from small-scale specimens.

Bridge Beams

The fresh and hardened concrete properties of the concretes for the beams are given in Table 4. Slump, air content, and unit weight values were within specifications.

Satisfactory compressive strength and elastic modulus were obtained. The splitting-tensile stress was lower than for normal weight concrete. The concrete with 6% air had a satisfactory durability factor (DF), but the concrete with 5% air had a low DF (much below the satisfactory value of 60). The specimens of the failed batch of concrete did not exhibit weight loss but absorbed water and failed.

Table 3. Fresh and hardened properties of the trial batch

Property	Age (days)	Value
Fresh concrete:		
Slump (in)		8
Air content (%)		5.5
Unit weight (lb/ft^3)		120.4
Hardened concrete:		
Compressive Str. (psi)	3	5950
Compressive Str. (psi)	28	10680
Elastic modulus (10^6)	28	3.85
Permeability (coulombs)	36	644
Creep[a] (microstrain)	90	421
Creep[a] (microstrain)	180	512
Shrinkage	28	306

[a]Creep load level: 30% of f'_c

Table 4. Fresh and hardened properties of the concrete in beams

Property	Age (days)	Batch 1	Batch 2
Fresh concrete:			
Slump (in)		7.0	6.5
Air content (%)		6.0	5.0
Unit weight (lb/ft^3)		118.7	122.7
Hardened concrete:			
Comp. Str. (psi)	28	8300	9180
Elastic modulus (10^6)	28	3.23	3.51
Splitting tensile (psi)	28	640	565
Permeability (coulombs)	6 mo.	356	334
Freeze/thaw:			
Durability factor		67	19
Weight Loss (%)		0.7	*

*Absorbed water until failure at 200 cycles.

The measured strains in the bridge beams are plotted in Figure 4. Note that there is about a 50 microstrain difference between the measured and calculated strains beginning at the time of transfer. It is believed by the researchers that temperature effects and perhaps other factors resulted in permanent shape change of the beam while in the form. This presents a problem when interpreting the strain and camber measurements, but does not have significant influence on the actual stresses from prestressing and self weight forces as long as the strands were stressed at a temperature that was close to that of the fresh concrete.

The strain calculations were calibrated to match the shapes of the measured strains and cambers over time. As a result the free shrinkage value for the beam concrete was estimated to be about 260 microstrain at 180 days as compared to the small-scale specimen result of 306 microstrain at 28 days. The beam concrete Modulus of Elasticity (based on instantaneous application of load) assumed in the analysis was 3200 ksi at day 1 and transitioned to 3370 ksi by day 7 and beyond. The creep coefficient determined for the beam concrete through calculation was 0.54 for the period from day two to day 180. The small-scale specimen results gave a creep coefficient of 0.80 over this same period. It is very interesting to note that the creep behavior of Beams 1, 4 and 7 were not appreciably different even though Beam 4 was one day older at the time of transfer. Also, Beam 5 is showing less total strain change at the bottom of the beam, as well as the least camber.

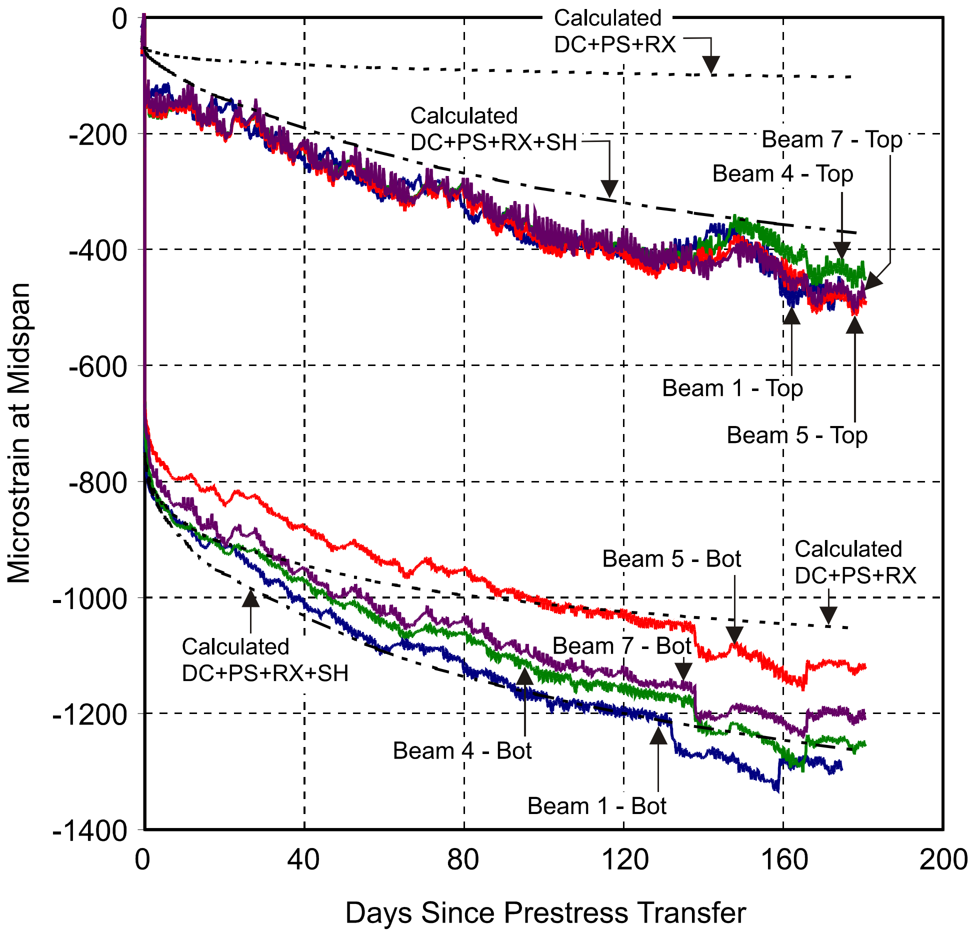

Figure 4. VWG strain data for 95.5 in PCEF bridge beams.

The measured-beam cambers for the instrumented beams, shown in Figure 5, were consistently 0.6 in less than calculations predicted. Once again the conditions in the form during curing and at the time of transfer were thought to be the primary influence on this difference. The camber curve's shape and change in magnitude compare very well with the calculated camber over time with the exception of Beams 2 and 3. These beams exhibited considerably higher creep than the four instrumented beams based on these camber measurements. These two beams were not instrumented with strain gages. The continuation of this measurement program during and after the placement of the HPLWC deck will provide valuable data for determining the influence of the beam concrete's age on the creep coefficient. Both the creep and shrinkage functions for this concrete will be determined at this time. The creep and shrinkage functions used in the analysis predict the change in shape of the plotted strains well for the first 180 days as shown in Figure 4. They cannot be used to calculate strains beyond the 180 day data set as of this time.

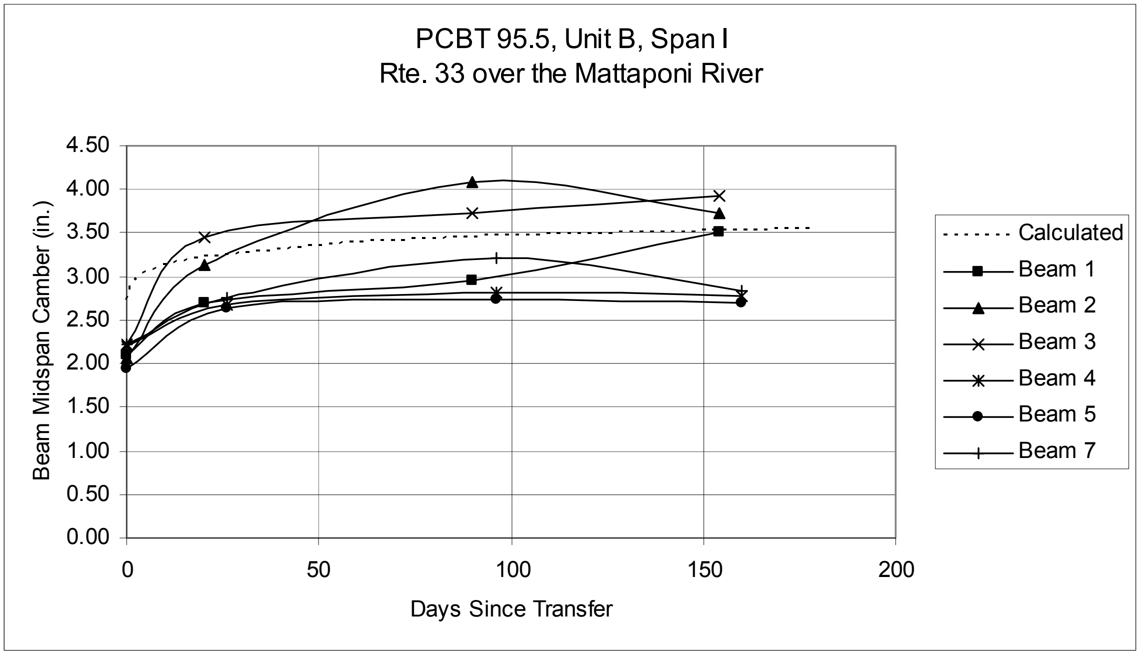

Figure 5. Bridge beam camber measurements.

DISCUSSION AND CONCLUSIONS

LWHPC with satisfactory strength, elastic modulus, and permeability values was obtained by the precaster. The problems seen in the freeze-thaw test need to be resolved. The splitting-tensile stress was lower than for normal weight concrete, and the beams exhibited considerable cracking at the ends. This topic will be presented in a separate paper. Early indications from the full-scale measurements are that the assumed design properties will overestimate the time-dependent creep and shrinkage of the lightweight concrete in the Bulb-T's. Also, the small-scale creep and shrinkage specimens gave higher strain changes than seen in the large-scale specimens and bridge beams because of the difference in specific surface area and relative humidity.

The material property that will be of the most interest to the bridge designer is the modulus of elasticity of the LWHPC. While the creep coefficient over the early age time interval appears similar to normal weight concrete, the secant modulus for the concrete is reduced from that of normal weight concrete because of the low stiffness of the lightweight aggregate. The stress in the bottom-most row of prestressing strands at midspan started at 75% of ultimate strength upon jacking, then fell to about 66% after transfer and to about 60% of ultimate strength at 180 days. If a concrete with Modulus of Elasticity of 5500ksi were substituted for the LWHPC while holding creep and shrinkage the same, these percentages would change to 75%, 69% and 63% respectively. The LWHPC bottom fiber stresses at midspan fell from about 2520 psi after transfer to 2180 psi at 180 days. The aging influence on the creep of the LWHPC is affected by the creep of the lightweight aggregate and the maturity of the paste. Therefore, the function for the creep coefficient will be determined from future measurements after placement of the deck concrete.

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