HPC Bridge Views

Sponsored by
U.S. Department of Transportation
Federal Highway Administration
Co-Sponsored by NCBC

Issue 61
May/June 2010

Contents

HPC Bridge Views is published jointly by the Federal Highway Administration and the National Concrete Bridge Council.

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This material is based upon work supported by the Federal Highway Administration under Cooperative Agreement No. "DTFH61-07-H-00041".

The use of high strength lightweight concrete reduced shipping weights.

High Strength Lightweight Concrete for Use in Precast, Prestressed Concrete Bridge Girders in Georgia

Paul Liles, Georgia Department of Transportation and R. Brett Holland, Georgia Institute of Technology

The development of high strength concretes has allowed for the use of longer precast, prestressed concrete bridge girders throughout the United States. In Georgia, the increased lengths result in girders that often are too heavy to transport across some existing bridges and require a super-load permit if they are to be transported at all. The use of high strength, high performance lightweight concrete (HSLWC) can result in longer span lengths and lighter weight girders.(1) Previous research at the Georgia Institute of Technology (Georgia Tech) showed that HSLWC bridge girders can be constructed with 10,000 psi (69 MPa) compressive strength concrete with a very low permeability, while achieving up to a 20% decrease in shipping weight.(1)

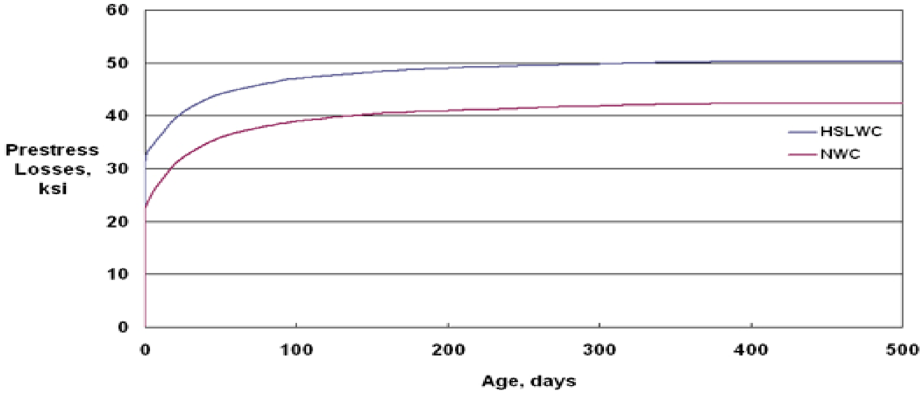
To determine the practicality and in-place performance of HSLWC bridge girders, the Georgia Department of Transportation (GDOT) designed and constructed a bridge with two spans having HSLWC in the girders. The center two spans of the four-span I-85 Ramp crossing State Route 34 in Newnan each consist of AASHTO BT-54 girders made with HSLWC using expanded slate coarse aggregate and manufactured granite sand and a composite deck with normal weight concrete (NWC). The girders have a span length of 110 ft (33.5 m) and a concrete design strength of 10,000 psi (69 MPa). The girders were the first use of HSLWC by the GDOT and were part of a research project to monitor the performance and material properties of girders constructed with HSLWC, as discussed in the next article.

The results of the previous research were compared to the results from the field production of the girders. The 56-day compressive strengths exceeded the required 10,000 psi (69 MPa) design strength and the chloride ion permeability tests (2) showed very low values (284 to 360 coulombs at 56 days).(3) Therefore, the research knowledge was successfully transferred to field production. The girder construction emphasized the importance of adequately soaking the lightweight aggregate prior to batching, otherwise early and later-age strengths were reduced.

Design and Construction Considerations with HSLWC

The GDOT was concerned about the camber of the girders and the deflection due to the dead load of the deck slab so that the roadway profile was accurately constructed with a minimum of grinding. An accurate estimate of the modulus of elasticity and girder stiffness was essential in order to predict deflections as well as prestress losses. For HSLWC with expanded slate aggregate, the modulus of elasticity is less sensitive to the unit weight than the AASHTO LRFD(4) equation predicts. The modulus of elasticity of the HSLWC with expanded slate aggregate was estimated by Meyer's equation,(1) $E_c = 44{,}000\ [f'_c\ (w_c/145)]^{0.5}$ where f'_c is compressive strength in psi and w_c is unit weight in lb/ft^3. Georgia Tech load tested five of the lightweight concrete bridge girders to verify their stiffness; results of these tests verified the E_c value.

Prestress losses affect the camber in the girder, as well as the service load stresses. The figure below shows a comparison of the calculated total prestress losses of a 10,000 psi (69 MPa) HSLWC girder versus a 10,000 psi (69 MPa) NWC girder using the Tadros method.(5) The Tadros method is the basis for the current AASHTO LRFD method for refined estimates of time-dependent losses. HSLWC undergoes increased elastic shortening losses compared to NWC due to the lower modulus of elasticity. In addition, GDOT research at Georgia Tech has indicated that HSLWC has similar long-term losses due to creep and shrinkage as a high performance NWC.(6) The long-term evaluation of the I-85 Ramp Bridge is designed to determine if this research prediction is correct. To date, results have shown that the current AASHTO LRFD bridge design specifications may be safely used for HSLWC girders as long as the appropriate value for the modulus of elasticity is used and appropriate care is taken in girder construction.



Comparison of total calculated losses for high strength lightweight and normal weight concrete.

Summary

The construction and monitoring of Georgia's I-85 Ramp crossing State Route 34 using HSLWC girders demonstrated that the HSLWC research can be applied to construction practice and that lightweight concrete provides an effective material for reducing the weight of a bridge; thus permitting longer spans to be efficiently constructed. The construction has verified that special attention needs to be given to soaking the aggregate prior to batching and that attention needs to be paid in evaluating the modulus of elasticity so that deflections can be accurately predicted. Otherwise, it appears that HSLWC girders can be used in routine design applications for highway bridges.

Further Information

For further information on HSLWC use for precast, prestressed concrete bridge girders in Georgia, please contact Paul Liles at pliles@dot.ga.gov or Brett Holland at rbholland@gatech.edu.

References

1. Meyer, K. F., "Transfer Length and Development of 0.6-inch Diameter Prestressing Strand in High Strength Lightweight Concrete," Doctoral Thesis, Georgia Institute of Technology, 2002, 616 pp.

2. Standard Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, AASHTO T 277, American Association of State Highway and Transportation Officials, Washington, DC.

3. Dunbeck, J., "Evaluation of High Strength Lightweight Concrete Precast, Prestressed Bridge Girders," Master's Thesis, Georgia Institute of Technology, 2009, 186 pp.

4. AASHTO LRFD Bridge Design Specifications, 4th Edition, American Association of State Highway and Transportation Officials, Washington, DC, 2007.

5. Tadros, M. K., Al-Omishi, N., Seguirant, S. J., and Gallt, J. G., "Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders," NCHRP Report 496, Transportation Research Board, Washington DC, 2003, 73 pp.

6. Lopez, M., "Creep and Shrinkage of High Performance Lightweight Concrete: A Multi-scale Investigation," Doctoral Thesis, Georgia Institute of Technology, 2005, 530 pp.

High Strength Lightweight Concrete Properties of the I-85 Ramp over State Route 34

R. Brett Holland and Lawrence F. Kahn, Georgia Institute of Technology

Load test of a high strength lightweight concrete girder

The high strength lightweight concrete (HSLWC) girders for the center two spans of the I-85 Ramp over Georgia State Route 34 were fabricated by Standard Concrete Products in Atlanta, GA, in August 2008. Concrete material properties were measured using cylinders cast during girder construction and cured in a moist room in accordance with ASTM C31.(1) Cylinders from all concrete batches were tested at 56 days for compressive strength and modulus of elasticity. At other ages, cylinders from the concrete batch used for the center portion of each beam were tested. Additionally, vibrating wire strain gages (VWSG) were embedded in the girders to monitor strains and thermal profiles within the girders.

Concrete Mix Proportions

Materials	Quantities (per yd^3)	Quantities (per m^3)
Cement, Type III	740 lb	439 kg
Fly Ash, Class F	150 lb	89 kg
Silica Fume	100 lb	59 kg
Normal Weight Fine Aggregate	932 lb	553 kg
Lightweight Coarse Aggregate	980 lb	581 kg
Water	267 lb	158 kg
Water Reducing Admixture	30 fl oz	1.16 L
High-Range Water-Reducing Admixture	59 fl oz	2.28 L
Air Entrainment	2 fl oz	77 mL

Set Accelerator	148.5 fl oz	5.74 L
Wet Unit Weight	121 lb/ft^3	1938 kg/m^3

Compressive Strength

The compressive strength of the cylinders was measured in accordance with AASHTO T 22.(2) Figure 1 shows the average strength gain curve for the girders along with bars showing ± one standard deviation. A statistical analysis showed that all batches used for each girder, as well as for all the girders, were statistically equivalent within a 95% confidence interval. All girders met the specified strength of 10,000 psi (69 MPa) by 56 days.

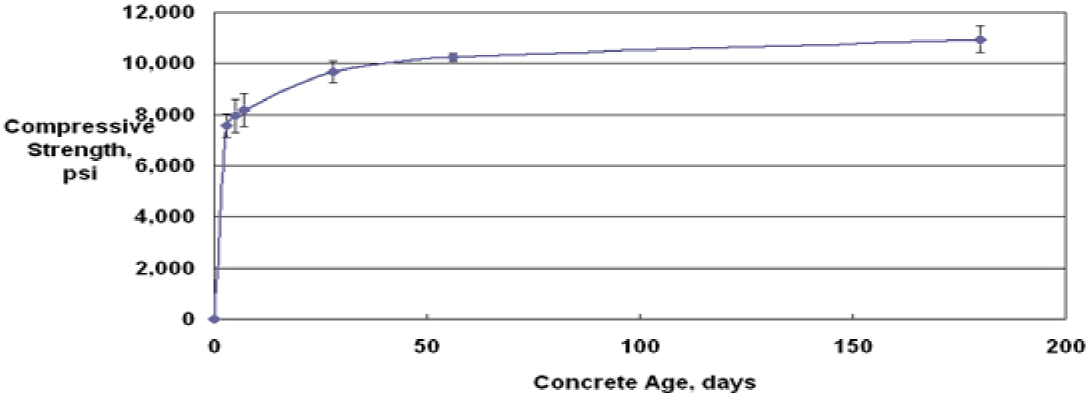


Fig. 1. Measured compressive strengths.

Modulus of Elasticity

The modulus of elasticity (E_c) of HSLWC was measured at an age of 56 days in accordance with ASTM C469.(3) In addition, five girders were loaded at an age of 56 days to measure their deflection, and thus determine E_c. Deflections of the girders were also measured during casting of the deck at an age of 14 months. The E_c values from cylinder tests and from the girder load tests were not in agreement, but the girder test modulus of elasticity matched previous work done with the same concrete mix design.(4) The results of the different methods for determining the modulus, as well as the values using the AASHTO LRFD(5) and Meyer(4) equations are shown in Figure 2. The values were calculated using the 56 day measured concrete compressive strength and an air-dry unit weight of 118 lb/ft^3 (1890 kg/m^3). Meyer's equation, $E_c = 44{,}000\ [f'_c\ (w_c/145)]^{0.5}$ where f'_c is compressive strength in psi and w_c is unit weight in lb/ft^3, gave the best estimate. It was developed specifically for HSLWC made using expanded slate aggregate.

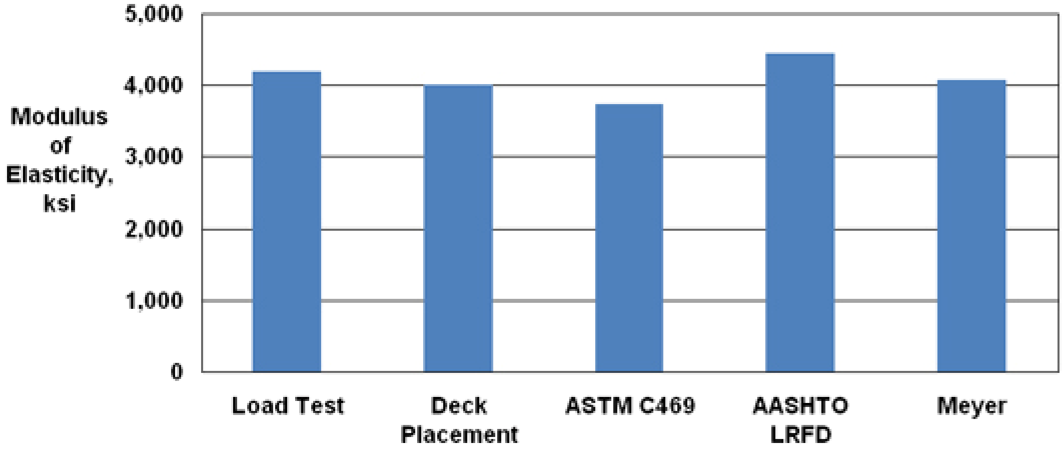


Fig. 2. Comparison of measured and predicted values of modulus of elasticity.

Transfer Length

Five HSLWC girders were instrumented with mechanical strain gage points to determine the transfer length using the concrete surface strain method. The average transfer length was 27.9 in. (710 mm) at strand release and 27.6 in. (700 mm) at 28 days. This value is less than the 36 in. (915 mm) calculated using the AASHTO LRFD Specifications.(5)

Prestress Losses

VWSGs were used to determine the prestress losses in the girders by monitoring the changes in strain throughout the depth of the girders. Creep tests were performed in accordance with ASTM C512(6) to compare the creep coefficient with the estimates provided in the prestress loss calculations. The creep tests were performed with a stress equal to 40% of the cylinder strength and were loaded at the time of strand release. The AASHTO LRFD(5) and Tadros(7) methods both predicted a creep coefficient of 0.89, which was slightly larger than the measured value of 0.82.

Prestress Loss Component	**Measured**	**AASHTO LRFD Lump Sum (5)**	**AASHTO LRFD Refined(5)**	**Tadros Method (7)**	**Shams Method (8)**
Elastic Shortening	27.55	26.95	26.95	27.59	26.95
Shrinkage of Concrete	N/A	N/A	5.83	5.73	4.50
Creep of Concrete	N/A	N/A	17.69	18.17	22.51
Steel Relaxation	0.22	N/A	0.22	0.17	1.15
Total Time-Dependent	28.87	20.83	23.74	24.07	28.16
Total Losses	56.42	47.78	50.69	51.66	55.11

All losses are ksi units.

The above table shows a comparison between the measured values and losses predicted by four different methods. The measured time-dependent loss from creep and shrinkage was extrapolated to 100 years for comparison with the predicted values by fitting a logarithmic curve to the data. A calculated steel relaxation loss of 0.22 ksi (1.5 MPa) was included with the measured loss so that the total measured and calculated losses could be compared on the same basis. All methods underestimated the losses. The Tadros(7) and Shams(8) methods provided the closest estimates of the prestress losses. The current AASHTO LRFD refined prestress loss calculations are based on the Tadros method, but have a few minor differences that lead to a slightly smaller value for the predicted losses. The AASHTO LRFD lump sum method underestimated losses the most.(5)

Summary

The results of the ongoing research project suggest that the modulus of elasticity for design of HSLWC with expanded slate coarse aggregate should be calculated using the Meyer equation, the transfer length can be estimated using the AASHTO provisions, and prestress losses may be estimated using the Tadros or Shams method.

Further Information

The research was sponsored by the Georgia Department of Transportation (GDOT), Research Project 2041. The opinions expressed herein are those of the authors and do not represent the opinions, conclusions, policies, standards, or specifications of the GDOT. For further information about the I-85 Ramp over State Route 34, please contact Brett Holland at rbholland@gatech.edu.

Reference

1. Standard Practice for Making and Curing Concrete Test Specimens in the Field, ASTM C31, ASTM International, West Conshohocken, PA.

2. Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens, AASHTO T 22, American Association of State Highway and Transportation Officials, Washington DC.

3. Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, ASTM C469, ASTM International, West Conshohocken, PA.

4. Meyer, K. F., "Transfer Length and Development of 0.6-inch Diameter Prestressing Strand in High Strength Lightweight Concrete," Doctoral Thesis, Georgia Institute of Technology, 2002, 616 pp.

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6. Standard Test Method for Creep in Concrete in Compression, ASTM C512, ASTM International, West Conshohocken, PA.

7. Tadros, M. K., Al-Omishi, N., Seguirant, S. J., and Gallt, J. G., “Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders,” NCHRP Report 496, Transportation Research Board, Washington DC, 2003, 73 pp.

8. Shams, M. K., “Time-Dependent Behavior of High-Performance Concrete,” Doctoral Thesis, Georgia Institute of Technology, 2000, 611 pp.

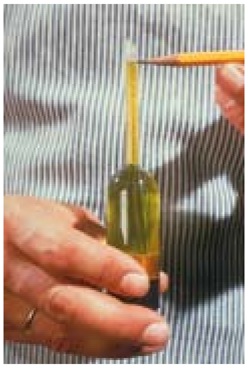
Measurement of Air Content in Concrete

Michelle L. Wilson, Portland Cement Association

AASHTO T 152 (ASTM C231)

AASHTO T 196 (ASTM C173)

AASHTO T 121 (ASTM C138)



AASHTO T 199

Several techniques are available for measuring the air content of fresh concrete. This article describes five techniques for use with fresh concrete and one technique for use with hardened concrete. The reader is referred to the appropriate AASHTO or ASTM standard for full details of each procedure. Failure to maintain and calibrate equipment and to properly follow test procedures are primary causes of problems in the measurement of air content. Samples should always be obtained in accordance with AASHTO T 141 (ASTM C172) Standard Method of Test for Sampling Freshly Mixed Concrete.

Pressure Method—AASHTO T 152 (ASTM C231)

AASHTO T 152, Standard Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method is based on Boyle’s law, which states that the volume occupied by air is proportional to the applied pressure. Two types of meters designated A and B are covered by the standard. The Type A meter is rarely used. With the Type B meter shown in the photograph, a separate air chamber is connected through a valve to the test bowl that is filled with concrete. With the valve closed, the separate chamber is pressurized to a predetermined operating pressure. When the valve is opened, the air expands into the test chamber, and the pressure drops in proportion to the air contained within the concrete sample. The pressure gauge is read in units of air content.

Sources of error in the pressure method include incomplete sample consolidation; over vibration; error in the pressure gauge which may result in incorrect application of pressure or in gauge malfunction; calibration tests; sampling methods; aggregate correction factor; and leaks in the needle valve, petcocks, or a poor fit when the mating surfaces are not clean.

The pressure meter should not be used for concrete made with lightweight aggregates. In these instances, the volumetric method should be used.

Volumetric Method—AASHTO T 196 (ASTM C173)

AASHTO T 196, Standard Method of Test for Air Content of Freshly Mixed Concrete by the Volumetric Method relies on displacement of air with water in a vessel of pre-calibrated volume. To perform the test, the concrete is consolidated into the bowl, the apparatus filled with water, and a measured quantity of 70% isopropyl alcohol is added to dispel the foam generated during agitation. Next, the meter is inverted and agitated to free the concrete from the base and to displace air from the concrete into the water. The meter is then "rolled and rocked" until all the air has been dispelled from the concrete and the water level is stable. The air content of the concrete is read directly from the sight tube.

Major sources of error in the volumetric air test are failure to dispel all the air from the concrete during the agitation process, and difficulty in reading the liquid level in the sight tube. Other sources of error include possible variations in percentage of alcohol, use of alcohols other than isopropyl, and failure to allow sufficient time for stability of the reading.

Gravimetric Method—AASHTO T 121 (ASTM C138)

AASHTO T 121, Standard Method of Test for Density (Unit Weight), Yield, and Air Content [Gravimetric] of Concrete determines air content of fresh concrete by comparing measured density or batch volume to calculated density or volume. The density (unit weight) is determined by weighing a known volume of fresh concrete. The air content is computed using two independent equations given in AASHTO T 121. A significant discrepancy in the results from the two equations is an alert to check test equipment, procedures, sampling, mix ingredients, and proportions.

The test is sensitive to consolidation and strike-off of the concrete in the container; accurate weighing; and the need for precise batch weights, moisture contents, and densities of all constituent materials.

Chace Air Indicator—AASHTO T 199

AASHTO T 199, Standard Method of Test for Air Content of Freshly Mixed Concrete by the Chace Indicator is identical in concept to the volumetric air meter, but the air collected in this hand-held device has been liberated from a small fraction of mortar. The sample size is so small that this is a semi-quantitative test at best, and should not be a substitute for the more accurate pressure, volumetric, and gravimetric methods. It should not be used for determining the compliance of air content with the specifications.

Air Void Analyzer

The air void analyzer (AVA) determines the volume and size distributions of air voids; thus an estimation of the spacing factor, specific surface, and total amount of entrained air can be made. Air bubbles from a sample of fresh concrete rise through a viscous liquid, enter a column of water above it, then rise through the water and collect under a submerged buoyancy recorder. The viscous liquid retains the original bubble sizes. Large bubbles rise faster than small ones. The change in buoyancy is recorded as a function of time and can be related to the number of bubbles of different sizes. For more details on this test, see HPC Bridge View Issue No. 34, July/August 2004.

Air-Void System—ASTM C457

ASTM C457, Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete describes procedures for microscopical determination of the air content of hardened concrete and of the specific surface, void frequency, spacing factor, and paste-air ratio of the air-void system in the hardened concrete. Differences between the air content measured on fresh and hardened concrete from the same batch are generally not more than ± 2 percentage points.

Further Information

Further information about air content is available in the following publications:

Whiting, D. A. and Nagi, M. A., Manual on Control of Air Content in Concrete, EB116, National Ready Mixed Concrete Association and Portland Cement Association, 1998, 42 pp.

Kosmatka, S. H., Kerkhoff, B., and Panarese, W. C., Design and Control of Concrete Mixtures, EB001, 14th edition, Portland Cement Association, Skokie, Illinois, 2002, 358 pp.