FHWA LWC Research Leads to LRFD Specification Changes

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Lightweight aggregate stockpiles at precast concrete plant. All Photos and Figures: FHWA.

Lightweight concrete (LWC) is a class of concrete materials that has been available for use in structural and nonstructural applications for many decades. Modern use dates back to the middle of the twentieth century when the production of expanded shales, clays, and slates began and thus the necessary coarse and fine aggregates became available from suppliers spread across the United States. Bridge design specifications in the United States have included provisions related to LWC for much of this timeframe, up to today with the American Association of State Highway and Transportation Officials' (AASHTO's) *AASHTO LRFD Bridge Design Specifications*.

The AASHTO Subcommittee on Bridges and Structures (SCOBS) recently considered and adopted a series of recommended changes to the AASHTO LRFD specifications that increase the consistency, uniformity, and usability of the provisions as they relate to LWC. Previously, the LWC provisions were constituent-based and they only addressed concrete unit weights below 120 lb/ft^3. The AASHTO LRFD specifications define normal-weight concrete as concrete having a unit weight between 135 and 155 lb/ft^3.

This created challenges for designers who were unlikely to know the type of fine or coarse aggregate that would be used in the concrete and who might want to use a concrete whose unit weight was between 120 and 135 lb/ft^3. The existing provisions also required the use of a lower shear resistance factor due to the perception that there was limited data available on the performance of LWC in shear.

The bridge design and construction community had recognized these challenges to the use of LWC by the early 2000s, leading to the growing interest in executing research efforts that would systematically address the needs. The largest efforts were completed through:

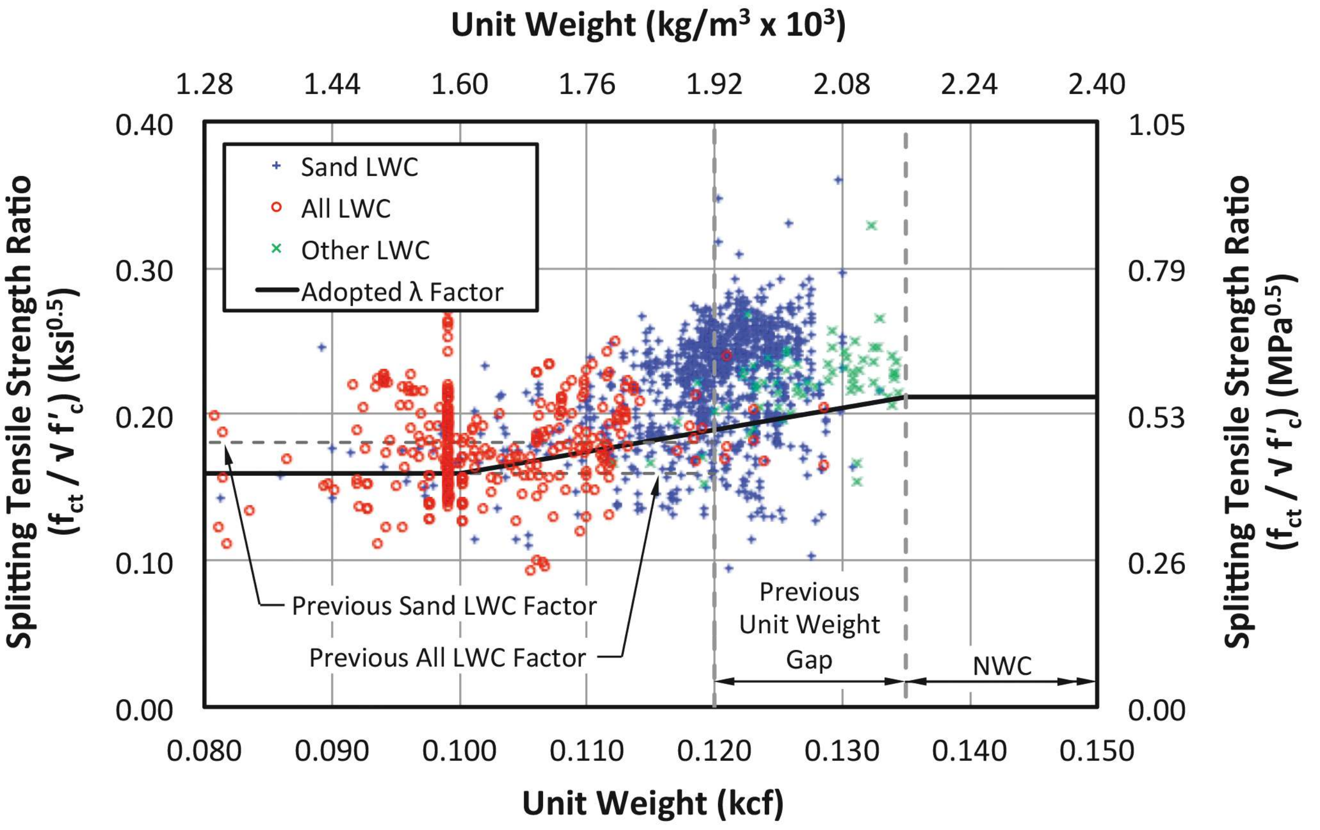
- the National Cooperative Highway Research Program's Project 18-15, which produced Report 733, and
- the Federal Highway Administration's (FHWA's) Turner-Fairbank Highway Research Center, which executed an ambitious experimental and analytical study that has culminated in working with AASHTO SCOBS Technical Committee for Concrete Design (T-10) to revise the LRFD specifications.

FHWA's research included the full-scale testing of nearly 100 beams and girders to assess behaviors including shear resistance, reinforcement detailing, and strand bond, as well as the compilation of databases of material scale and structural scale test results that allowed for the development and assessment of potential design provisions.

The framework for the specification revisions comprises four interrelated topic areas: LWC definition, material properties, resistance related to tensile strength, and resistance factors.

The revised definition speaks to concrete containing aggregate conforming to AASHTO M 195, *Standard Specification for Lightweight Aggregates for Structural Concrete*, and having an equilibrium density not exceeding 135 lb/ft^3 as defined by ASTM C567, *Standard Test Method for Determining Density of Structural Lightweight Concrete*. This definition will allow a designer to engage LWC on terms that are known at the design stage, leaving it to the contractor to develop the concrete mixture proportions with the appropriate set of properties.

LWC can be produced at compressive strength levels up to 10 ksi; however, it is recognized to commonly exhibit slightly less tensile strength and a slightly lower modulus of elasticity as compared to a similar compressive strength normal-weight concrete. Both high-strength LWC and concrete whose unit weight was between 120 and 135 lb/ft^3 have seen increased usage. The material properties of LWC have been refined within the material properties section of Section 5 of the AASHTO LRFD specifications through the revised modulus of elasticity equation that was approved in 2014 and the tensile response revisions that were just recently approved in 2015 and will be included in the 2016 Interim Revisions to the AASHTO LRFD specifications.



Splitting tensile strength of lightweight concrete as a function of unit weight and type. Note: f_{ct} = concrete splitting tensile strength; f'_c = concrete compressive strength.

Shear testing of lightweight concrete prestressed girder.

Many service and strength limit state provisions throughout Section 5 rely on the tensile strength of the concrete as a key parameter in the predictive expressions. Most commonly, these expressions inferred the tensile resistance of the concrete through the use of a $\sqrt{f'_c}$ term. The approved specification revisions implement a framework that allows the reduced tensile strength of LWC to be addressed by defining a modification factor that can be referenced from any relevant Section 5 provision. In short, this factor, λ, can be determined either from ASTM C496 splitting tensile strength test results on the particular mixture proportions or from a calculation based on the unit weight of the concrete. The value of λ varies linearly from 0.75 for a 100 lb/ft^3 concrete to 1.0 for a 135 lb/ft^3 concrete. For concretes heavier than 135 lb/ft^3, λ =1.0.

The resistance factor for LWC in shear had previously been set to a lower value than that used for normal-weight concrete. These resistance factor values were based on a smaller number of full-scale shear tests than normal-weight concrete and the fact that LWC can have a lower shear resistance than normal-weight concrete. This led to uncertainty in the level of conservatism provided by the shear design expressions for LWC and thus a lower resistance factor. A set of recent studies[1] on LWC shear performance has expanded the database of results and demonstrated that the use of the same shear resistance factor for LWC and normal weight concrete is appropriate. The phi-factor for both is now set at 0.90.

The two LWC-related ballot items that passed AASHTO SCOBS in April 2015 comprised a total of 39 sub-items spread across the AASHTO LRFD specifications and one item in the *AASHTO LRFD Bridge Construction Specifications*. In total, the revised specifications allow for a more consistent, uniform treatment of LWC and thus will facilitate broader use of this important construction material.

Reference

1. Greene, G., and B. Graybeal. 2015. *Lightweight Concrete: Shear Performance*. FHWA-HRT-15-021, FHWA, Washington, DC.