Lightweight Concrete: Improving Concrete Member Efficiency, Performance, and Durability

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Lightweight concrete is not a new material, although many engineers may not be familiar with it. It has been used successfully for the construction of bridges since soon after commercial production of lightweight aggregate began in the United States over 100 years ago.[1] The American Association of State Highway and Transportation Officials' (AASHTO) bridge design specifications have included some mention of lightweight concrete since at least 1969, and provisions similar to those in the eighth edition *AASHTO LRFD Bridge Design Specifications*[2] have been present since 1983. A comprehensive report on the use of lightweight concrete for prestressed concrete members was developed in 1966 by the International Federation for Prestressing Commission on Prestressed Lightweight Concrete.[3] In 1985, the Federal Highway Administration (FHWA) published *Criteria for Designing Lightweight Concrete Bridges*.[4] That report stated that lightweight concrete has a "sufficient record of successful applications to make it a suitable construction material … for bridges" and "sufficient information is available on all aspects of its performance for design and construction purposes."

Benefits of Lightweight Concrete

An obvious reason for using lightweight concrete in bridges is the reduced unit weight of the concrete, which leads to a reduction in member self weights that are supported by a structure. That can improve design efficiency in several ways,[5] including the following:

- Allowing for extended span ranges, wider girder spacings, or shallower girder sections
- Decreasing design loads on bearings, substructure elements, and foundations
- Reducing the weight of precast concrete components for handling, transportation, and erection

A second benefit is less obvious and perhaps counterintuitive: enhanced durability. While it might seem likely that using a porous aggregate would reduce the durability of concrete, and therefore the expected service life of a bridge, field and laboratory experience have shown that lightweight concrete has equal or improved durability compared with normalweight concrete with the same compressive strength.[6–9] Reasons for the enhanced durability of lightweight concrete include the following:

- Internal curing from prewetted lightweight aggregate, which reduces shrinkage, cracking, and permeability
- Elastic compatibility due to the similar stiffness of aggregate and paste, which reduces internal microcracking and also reduces permeability
- Lower modulus of elasticity, which tends to reduce cracking
- Lower coefficient of thermal expansion, which also tends to reduce cracking

In recent years, the concept of internal curing, in which prewetted lightweight aggregate is substituted for a portion of the conventional sand in an otherwise conventional concrete mixture, has increasingly become recognized as an effective approach to improve durability of concrete.[10–12] In this way, internal curing uses prewetted lightweight aggregate to deliver curing water to the interior of concrete rather than using the aggregate to reduce density.

Reasons to Use Lightweight Concrete

Lightweight concrete has been used in bridges for many reasons; most are related to the reduction in the weight of the structure and the associated improvements in efficiency. As noted previously, durability and extended service life are also recognized as significant benefits of lightweight concrete.[6,13] While this discussion divides reduced weight and enhanced durability into separate topics, the topics are often interrelated.

Reduced Weight or Load

Typically, the main benefit of using lightweight concrete is the reduction of the weight of the structure or an element that results in improved design efficiencies and reduced costs for girders, substructures, and foundations. This reduced weight or load allows for improved design efficiency, increased span lengths, improved seismic performance, lower member handling and hauling loads, and reduced substructure/foundation loads with possible reuse of substructures for bridge replacements.

Enhanced Durability

Using lightweight aggregate in concrete for a bridge can lead to improved durability. The durability of lightweight concrete may be comparable or even improved over normalweight concrete with the same compressive strength and similar mixture proportions.

The properties of lightweight aggregate and lightweight concrete related to durability include reduced permeability, reduced cracking, and good resistance to freezing and thawing. It is also anticipated that using lightweight concrete for mass concrete applications will reduce the cracking potential in members.[14,15]

The reduced coefficient of thermal expansion of lightweight concrete is expected to reduce thermal movements in bridges, which can extend the life of bridge joints and bearings, which are often maintenance problems. In some cases where there is a risk that deck restraint from girders could lead to early-age cracking, the reduced stiffness of lightweight concrete can be beneficial. For the same reason, if the columns were constructed using lightweight concrete, the restraint from short columns on the superstructure would be lessened.

Next Steps

While lightweight concrete has been successfully used for bridge projects for over 80 years, and design provisions for lightweight concrete have been provided in AASHTO specifications for many years, the material is not commonly used for bridge construction. In some cases, owners, designers, contractors, and others may assume that lightweight concrete is not a reasonable option for bridges. Another potential obstacle to the use of lightweight concrete is the perceived higher cost of the material. However, when evaluating the cost of using lightweight concrete for a project, long-term costs related to durability and service life should be considered, as well as initial costs. **Tables 1** and **2** list several bridge projects where lightweight concrete has been used. Finally, designers may be unsure about how to select properties of lightweight concrete for design, and how to perform design calculations.

To address these knowledge gaps, the Federal Highway Administration developed the *Light-*

Table 1. Projects where lightweight concrete was used to allow reuse of existing structural members

Project name (state)	Lightweight concrete application*	Specified unit weight, kcf	Design compressive strength, ksi	Year built
Interstate 895 Bridge over the Patapsco River Flats (MD)	Deck panels	0.100	4.5	2019
Shasta Arch Bridge on Southbound Interstate 5 (CA)	PS girders and bent caps	0.120	5.5	2018
Route 198 (Dutton Road) Bridge over Harper Creek (VA)	PS girders, deck, and railings	0.105 to 0.115	4.0 to 5.0	2016
Interstate 5 Bridge over the Skagit River (WA)	PS girders, diaphragms, and railings	0.122	4.0 to 9.0	2013
Beach Bridge – North Haven (ME)	PS girders	0.120	6.0	2013
Ben Sawyer Bridge – Sullivan's Island (SC)	Deck	0.115	5.0	2010
Massaponax Church Road Bridge over Interstate 95 (VA)	Deck and railing	0.120	4.0	2009
Brooklyn Bridge over the East River (NY)	Deck panels	0.118	3.6	1999
Coleman Bridge over the York River (VA)	Deck	0.115	5.0	1983
Woodrow Wilson Bridge over the Potomac River (DC)	PS deck panels	0.115	5.0	1983

Source: Data are from reference 16.

* Elements listed in this column are reinforced concrete, except for those noted as being prestressed concrete (PS).

Table 2. Projects where lightweight concrete was used to improve the structural efficiency of the bridge

Project name (state)	Lightweight concrete application*	Specified unit weight, kcf	Design compressive strength, ksi	Year built
Marc Basnight Bridge over the Oregon Inlet (NC)	Deck on approach spans	0.120	4.5	2019
Pulaski Skyway Bridge Rehabilitation (NJ)	Deck panels	0.120	6.0	2018
Benicia-Martinez Bridge (CA)	Cast-in-place segmental PS box girder	0.125	6.5	2007
Route 33 Bridges over the Mattaponi and Pamunkey Rivers (VA)	PS girders and PS spliced girders	0.125	8.0	2007
	Deck	0.120	5.0	
Francis Scott Key Bridge (MD)	Deck	0.112	4.0	1977
San Francisco–Oakland Bay Bridge (CA)	Deck	0.095	Unspecified	1961

Source: Data are from reference 16.

* Elements listed in this column are reinforced concrete, except for those noted as being prestressed concrete (PS).

weight Concrete Bridge Design Primer,[16] which was published in 2021 and can be downloaded from https://www.fhwa.dot.gov/bridge/concrete/hif19067_Nov2021.pdf. This document offers basic information relating to lightweight concrete so owners, designers, specifiers, and contractors can be equipped to properly evaluate the potential benefits of using lightweight concrete. Featuring laboratory data, information from field experience, and references, it demonstrates that lightweight concrete can be durable and cost effective for bridge designs and can reduce member weight for shipping and handling.

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