PGSuper Tutorials

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Lightweight Concrete

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Title PGSuper Tutorial – Lightweight Concrete			**Publication No.** BS08022010-1
Abstract This document provides a discussion of the new lightweight concrete features in PGSuper.			
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Introduction

The enhancements made in PGSuper Version 2.4 include support for modeling lightweight concrete. Engineers can now define both the girder and deck concrete as normal weight, sand lightweight, or all lightweight concrete. The equations for estimating modulus of elasticity, creep, and shrinkage given in the AASHTO LRFD Bridge Design Specifications have been modified with aggreate correction factors to account for the mechanical properties of lightweight concrete. This tutorial will take you through the new lightweight concrete features in PGSuper.

Lightweight Concrete

Lightweight concrete has many applications in bridge construction. Lightweight concrete can be used to reduce the weight of prefabricated girders for handling and transportation as well as to reduce the overall superstructure weight to improve structural efficiency and seismic performance.

Lightweight aggreates are manufactored using shale, clay and slate. After crushing and grading of the raw material it is heated in a rotary kiln to 1,800 to 2,300 °F. The aggreate expands as gases are released. As the material cools many small, discontinuous pores form resulting in an aggreate that is significantly lighter than the raw material while retaining much of its strength. Lightweight aggregate is typically 15%-30% lighter than an equal volume of normal weight aggregate.

More information about lightweight aggregate can be found at the Expanded Shale, Clay, and Slate Institute (ESCSI) web site at http://www.escsi.org.

Definitions

Lightweight Concrete (LWC) – Concrete containing lightweight aggregate and having an air-dry unit weight not exceeding 0.120 kcf.

All-lightweight Concrete (ALW) – Lightweight concrete without natural sand.

Sand-lightweight Concrete (SLW) – Lightweight concrete in which all of the fine aggregate consists of normal weight sand.

Normal Weight Concrete (NWC) – Concrete having a unit weight between 0.135 and 0.155 kcf.

Specified Density Concrete (SDC) – Concrete having a combination of normal weight and lightweight course and fine aggregates proportioned to achieve a target density.

Material Properties

As of this writing, AASHTO does not provide comprehensive guidance on the material properties of lightweight concrete. This is due to the fact that properties vary widely based on the aggregate source and the concrete mix design. Extensive research of the structural and mechanical properties of lightweight concrete is still required. From a structural point of view, strength, modulus of elasticity, creep, and shrinkage are of primary concern. Durability, porosity, and reactivity are concerns for long term performance of the material.

The small pores in lightweight aggregate lead to a reduced strength of the raw aggregate compared to normal weight aggregate. However, with proper mix design compressive strengths up to 10 ksi can be achieved.

A flexible model for estimating concrete material properties is used in PGSuper. This model is based on NCHRP Report 496, *Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders*. NCHRP Report 496 is the basis for the modulus of elasticity, creep, shrinkage, and prestress loss requirements in the AASHTO LRFD Bridge Design Specifications since 2005.

The following relationships are used to estimate modulus of elasticity, creep, and shrinkage:

$$E_c = 33{,}000 K_1 K_2 w_c^{1.5}\sqrt{f_c'}$$

$$\psi(t,t_i) = 1.9 K_1 K_2 k_s k_{hc} k_f k_{td} t_i^{-0.118}$$

$$\varepsilon_s = K_1 K_2 k_s k_{hs} k_f k_{td} 0.48x10^{-3}$$

The modulus of elasticity, creep, and shrinkage equations are those found in AASHTO with the addition of two aggregate correction factors, K_1 and K_2. These equations have been developed for a national average based on actual aggregate and concrete mix samples from Nebraska, New Hampshire, Texas, and Washington. The aggregate correction factors account for the effects of local aggregates. The values of K_1 and K_2 are determined by research.

A correction factor $K_1 = 1.0$ corresponds to an equal average of all predicted values and all measured values. The correction factor K_2 is based on the 90th percentile upper-bound and the 10th percentile lower-bound of a set of measured data.

NCHRP Report 496 provides modulus of elasticity aggregate correction factors for Nebraska, New Hampshire, Texas, and Washington. Contact local producers and providers for more information about materials available in your area.

LWC Provisions in the AASHTO LRFD Bridge Design Specifications

The lightweight concrete provisions in the AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010 are summarized in this section.

5.4.2.1 – Compressive Strength

For lightweight structural concrete, air dry unit weight, strength and any other properties required for application shall be specified in the contract documents.

5.4.2.2 – Coefficient of Thermal Expansion

In the absence of more precise data, the coefficient of expansion may be taken as $5.0x10^{-6}$/°F

5.4.2.6 – Modulus of Rupture

Sand-lightweight concrete $0.20\sqrt{f_c'}$

All-lightweight concrete $0.17\sqrt{f_c'}$

5.5.4.2 – Resistance Factors

Shear and Torsion, lightweight concrete $\phi = 0.70$

5.8.2.2 – Modifications for Lightweight Concrete

Where lightweight aggregate concretes are used, the following modification shall apply in determining resistance to torsion and shear:

- *Where the average splitting tension strength of lightweight concrete, f_{ct} is specified, the term* $\sqrt{f_c'}$ *in the expressions given in Articles 5.8.2 and 5.8.3 shall be replaced by* $4.7f_{ct} \leq \sqrt{f_c'}$
- *Where f_{ct} is not specified, the term* $0.75\sqrt{f_c'}$ *for all lightweight concrete, and* $0.85\sqrt{f_c'}$*0.85 for sand-lightweight concrete shall be substituted for* $\sqrt{f_c'}$ *in the expressions given in Articles 5.8.2 and 5.8.3.*

The effected equations are 5.8.2.5-1, 5.8.3.3-3, 5.8.3.3-5, 5.8.3.4.3-1, 5.8.3.4.3-3, and 5.8.3.4.3-4

5.8.4.3 – Cohesion and Friction Factors

For a cast-in-place concrete slab on clean concrete girder surfaces, free of laitance with surface roughened to an amplitude of 0.25 in, K_2 = 1.3 ksi for lightweight concrete.

C5.9.5.1 – Prestress Losses

For segmental construction, lightweight concrete construction, multi-stage prestressing, and bridges where more exact evaluation of prestress losses is desired, calculations for loss of prestress should be made in accordance with a time-step method supported by proven research data.

5.11.2.1.2 – Modification Factors which Increase l_d

The basic development length, l_{db}, shall be multiplied by the following factor or factors as applicable:

- *For lightweight aggregate concrete where f_{ct} (ksi) is specified* $\frac{0.22\sqrt{f'_c}}{f_{ct}} \geq 1.0$
- *For all-lightweight concrete where f_{ct} is not specified* 1.3
- *For sand-lightweight concrete where f_{ct} is not specified* 1.2

5.11.2.4.2 – Modification Factors

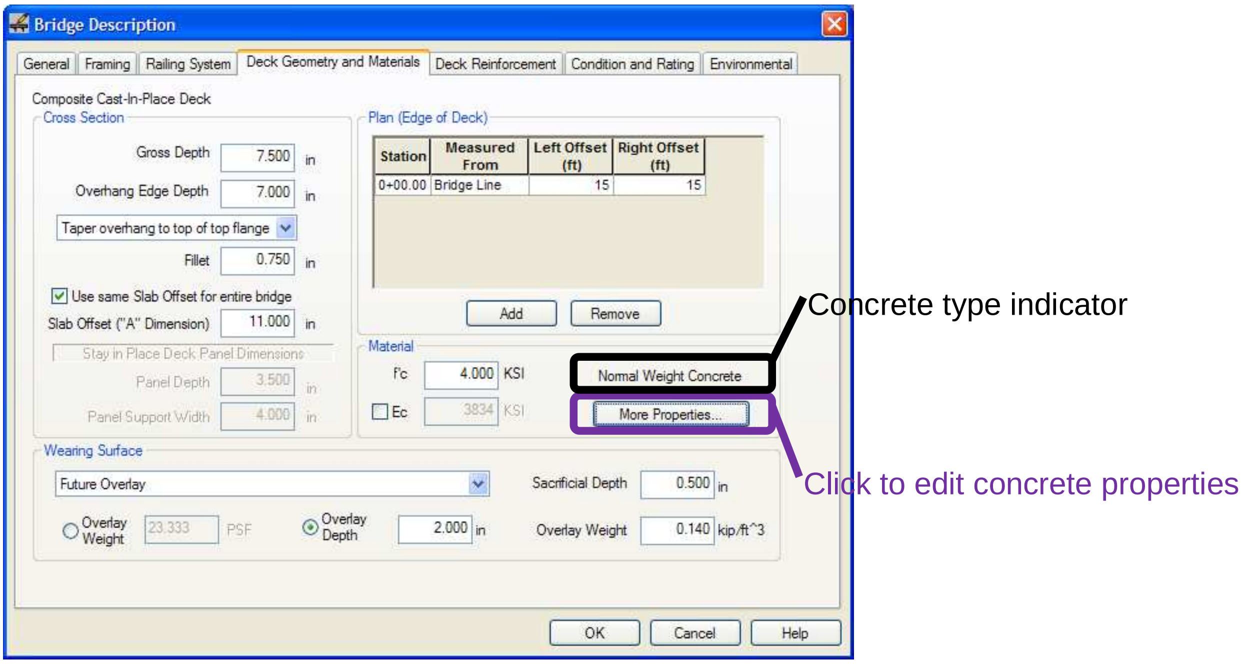
Basic hook development length, l_{hb}, shall be multiplied by the following factor or factors, as applicable, where:

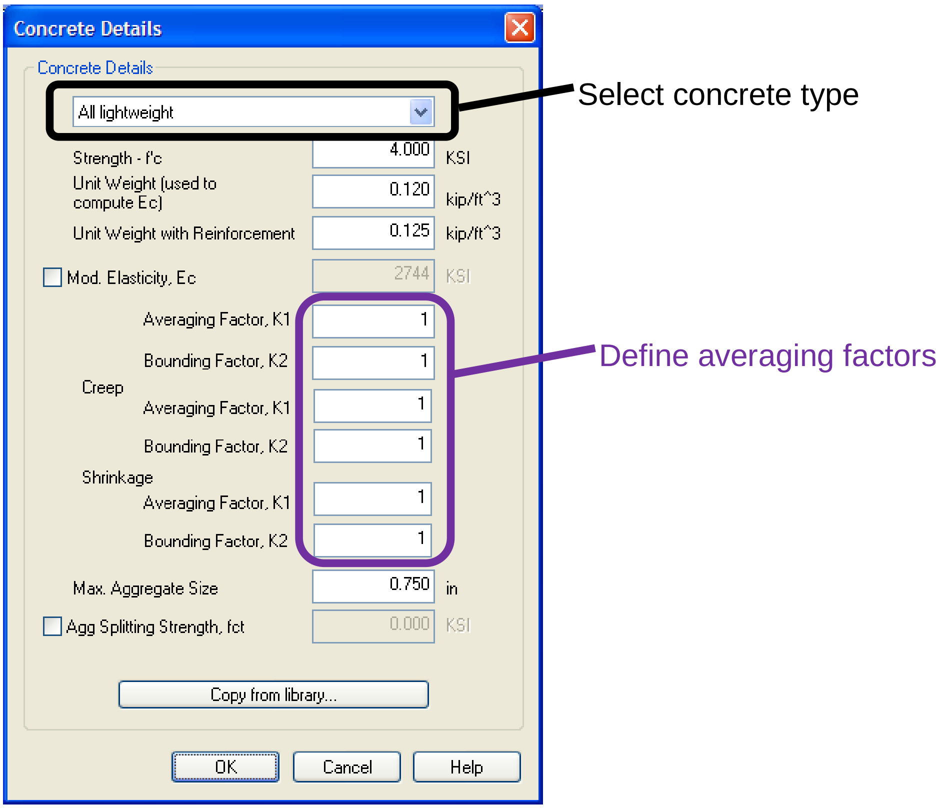
- *Lightweight concrete is used* 1.3

Lightweight Concrete using PGSuper

Using lightweight concrete in PGSuper is a fairly straight forward task. Concrete material properties can be defined for each girder and the deck. To define a lightweight concrete for the deck:

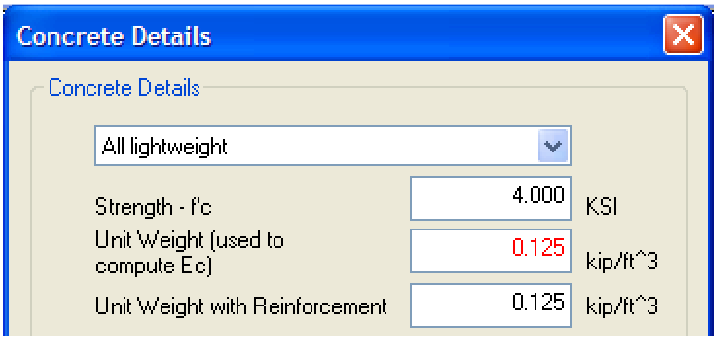
1) Select Edit | Bridge (or double click in the Bridge Model View). This brings up the Bridge Description Dialog.
2) Select the Deck Geometry and Materials tab of the Bridge Description Dialog.
3) Press the More Properties button in the Material group. This brings up the Concrete Details dialog.
4) Describe your concrete material in the Concrete Details dialog.
5) Notice that the concrete type is displayed in the Material group.



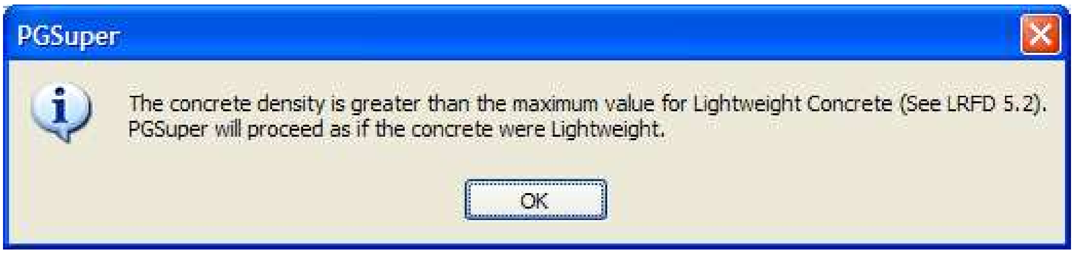


The procedure is similar for defining girder concrete.

While the definitions of lightweight and normal weight concrete are fairly strict with regards to the unit weight of the material, PGSuper allows you to use any unit weight for lightweight and normal weight concrete. The unit weight input will be displayed in red if it does not conform to the target unit weight of the specified concrete type.



After defining the concrete with the unit weight outside of the target range, you'll be given a warning that PGSuper will proceed based on the actual concrete type specified.



In this case, PGSuper will use all of the modifications for ALW concrete even though the unit weight exceeds 0.120 kcf.

Design Comparison

A preliminary design comparison was developed to demonstrate the structural benefits of lightweight concrete. Designs were performed using:

- Normal weight girder and normal weight deck
- Normal weight girder and lightweight deck
- Lightweight girder and lightweight deck

Designs were made for the TxDOT Tx54 girder.

The normal weight and lightweight concrete had unit weights of 0.145 kcf and 0.120 kcf respectively. 5 pcf was added to the dead load calculation to account for reinforcement.

The bridge configuration studied had 6 - Tx54 girders at 8 ft spacing. The deck overhangs were 3 ft. A typical interior girder was studied.

The first study held the span length at 123 ft. The total number of strands, release and final concrete strength, and total girder weight were determined. The results are summarized in the table below.

Girder	Normal weight	Normal weight	Lightweight
Deck	Normal weight	Lightweight	Lightweight
Number of 0.5" Strand	82	74	66
f'_{ci} (psi)	6,800	6,400	6,100
f'_c (psi)	8,000	6,600	6,200
Girder Weight (kip)	106	106	88

The second study evaluated the girder at its maximum span length. The results are summarized in the table below.

Girder	Normal weight	Normal weight	Lightweight
Deck	Normal weight	Lightweight	Lightweight
Max Span Length (ft)	123	127	131
Number of 0.5" Strand	82	86	86
f'_{ci} (psi)	6,800	7,000	6,800
f'_c (psi)	8,000	11,700	12,600
Girder Weight (kip)	106	109	94

Cost Comparison

Lightweight concrete costs more than normal weight concrete because of the additional processing and shipping requirements. Direct cost comparisons with normal weight concrete vary widely depending on many factors. With only 20 plants in the United States producing lightweight aggregate, transportation of the material can be a significant factor in the cost premium.

The cost benefit from using lightweight concrete comes from reduction in costs elsewhere in a project. A lighter superstructure will decrease the size of substructure components for dead load and seismic demands. A lighter superstructure can span further possibly eliminating piers from a bridge structure.

Customizing Analysis Capabilities

PGSuper has an advanced software architecture that allows third parties to extend and enhance its capabilities. At BridgeSight Software, we can add new analysis capabilities to meet your needs. For details, contact us at

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