Practical Guidance for Designing Lightweight Concrete Bridges – The FHWA *LWC Design Primer*

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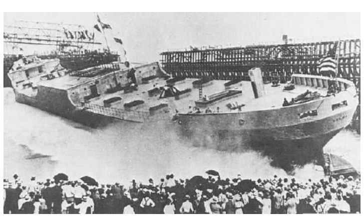
NBC3: New Girder and Pretensioning Technology

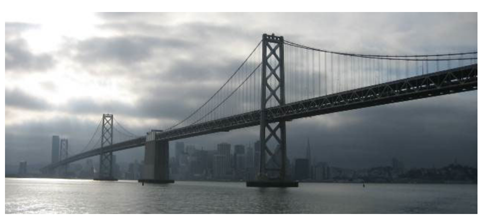
Structural Lightweight Concrete

Structural lightweight aggregate (LWA) has been commercially manufactured in USA since 1920 – not a new material!

It was immediately used to produce structural lightweight concrete (LWC)



USS Selma 1918



San Francisco Oakland Bay Bridge 1936

- Obvious benefit was reduced density
- Also found that the material was very durable

LWA is a manufactured product

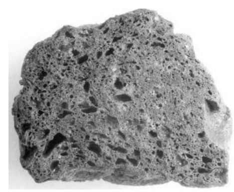
Raw material is shale, clay or slate

Heated in kiln to about 2200 deg. F

Gas bubbles form in softened material

Gas bubbles remain after cooling

Clinker is crushed and screened



Structural Lightweight Concrete

When the original patent expired in the 1950s, the use of LWC increased rapidly

- ESCSI was formed and strong development and promotion activities were begun

Rapid growth continued until the mid 1970s when the cost to produce LWA increased

- Oil crisis
- Beginnings of pollution control and the EPA
- Size of industry contracted and promotion was curtailed

Since that time, its use has not increased as would be expected

FHWA Efforts Related to LWC

FHWA saw LWC as an under-utilized technology that had potential for improving the economy and performance of bridges

- Additional information needed in marketplace to encourage its use
- Additional research was needed to answer some questions, especially about "specified density" concrete in range between LWC and NWC

In 2005, the Federal SAFETEA-LU legislation included funds for FHWA to use for research on high performance concrete (HPC)

- These funds were eventually used to begin work on LWC at FHWA's Turner Fairbank Highway Research Center (TFHRC)
- These efforts were coordinated with NCHRP Project 18-15 titled "High-Performance/High-Strength Lightweight Concrete for Bridge Girders and Decks" which resulted in Report 733 (2013)

FHWA Efforts Related to LWC

Using the results of the two research efforts and earlier work, FHWA spearheaded development of revisions to the LRFD Specifications that were adopted by AASHTO

- 2014 – New E_c equation – better for LWC & high strength concrete
- 2015 – New definition for LWC, introduction of λ, and insertion of λ into equations

FHWA Efforts Related to LWC

It still appeared that the marketplace needed more information about design of LWC bridges to improve the use of the material

- Designers and owners did not seem comfortable with using LWC
- Some misconceptions about LWC existed

A LWC Primer was identified as a product that would be useful to advance the use of LWC

- A concise summary of the full range of information needed to design a LWC bridge

LWC Design Primer

FHWA sent out the following work statement that was included in an RFP for a larger project:

Develop a concise design guide primer on designing highway structures with lightweight concrete (LWC). This guidance shall highlight the benefits of LWC in various applications and cover the primary design and construction subject areas needed to design LWC highway structures. This guidance shall identify and describe purpose for recent changes in the AASHTO LRFD Bridge Design Specification pertaining to LWC as well as include guidance on designing LWC for internal curing.

- A webinar and seminar based on the completed Primer would also be developed and presented

LWC Design Primer

Current status

- **WSP was awarded the contract with CEC as subconsultant for Primer**
- **50% draft submitted and reviewed**
- **Final draft submitted for review; still in progress**
- **Had hoped to be farther along by now**

This presentation is based on unreviewed DRAFT – still preliminary

- **Author's opinion – not FHWA**

Note that the intent was for a "concise" document

- **It will not be comprehensive, but will cover necessary topics**

Table of Contents

1. Introduction

Definition of LWC

***Concrete containing lightweight aggregate conforming to AASHTO M 195 and having an equilibrium density not exceeding 0.135 kcf, as determined by ASTM C567*.**

Not a new material

- **LWC has been in AASHTO design specifications since at least 1969**
- **FHWA's *Criteria for Designing LWC Bridges* (1985)**

  LWC has a "*sufficient record of successful applications to make it a suitable construction material … for bridges*" and that "*sufficient information is available on all aspects of its performance for design and construction purposes*."

1. Introduction

Benefits of LWC for Bridges

- **Structural**
  - **Extended span ranges; wider girder spacings; shallower girders**
  - **Reduced design loads on bearings, substructure elements, foundations**
  - **Reduced weight of precast elements for handling, hauling, erection**
- **Durability**
  - **Internal curing from prewetted LWA; reduces shrinkage, cracking, permeability**
  - **Similar stiffness of aggregate & paste reduces microcracking & permeability**
  - **Lower modulus of elasticity reduces cracking**
  - **Lower coefficient of thermal expansion reduces cracking**

1. Introduction

Perceived Disadvantages of LWC for Bridges

- Increased cost of LWA and LWC
- Reduced durability
- Reduced structural capacity
- Availability of lightweight aggregate
- Lack of familiarity of contractors with lightweight concrete

But several of these perceived disadvantages are not true

Even increased cost of LWA and LWC is not insurmountable, as evidenced by the many successful projects completed using LWC

1. Introduction

Examples of the Effective Use of LWC for Bridges

- San Francisco Oakland Bay Bridge, CA – 1936
- I-5 over Skagit River, WA – 2013
- Rugsundet Bridge, Norway – 2000

San Francisco-Oakland Bay Bridge, CA

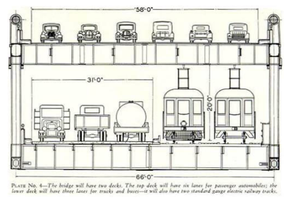
Upper deck of suspension spans across the Bay was built in 1936 using 95 pcf LWC

- LWC saved 25 psf ⇒ 31,600 kips ⇒ $3 million of $40 million when built in 1936

Lower deck reconfiguration in 1958 also used LWC

Both LWC decks are still in service today

- Have been protected with wearing surfaces



I-5 over Skagit River - Mt Vernon, WA

Span replaced using LWC deck girders

- 65” deep deck girders with 6.5 ft wide top flange
- Girder length = 162 ft
- Girder weight = 84 tons

LWC properties for girders

- Design density of LWC = 122 pcf
- Design compressive strength = 9,000 psi
  - Actual design compressive strength = 10,600 psi

LWC used for girders cost 2x usual NWC

- But avoided costs and delays for seismic reanalysis and design of piers

Rugsundet Bridge, Norway

LWC used for center of span for alternate design

- Increased main span from 564 ft to 623 ft (+10%)
- Used same quantity of post-tensioning even with longer span
- Moved foundations into shallower water or to the edge of the water
- Reduced length of ballast-filled side spans
- Shortened overall length of structure 33 ft

Bid for LWC design was 15% less than NWC bid

Pumping of LWC was major issue

- LWA from USA was used so owner would allow the LWC to be pumped

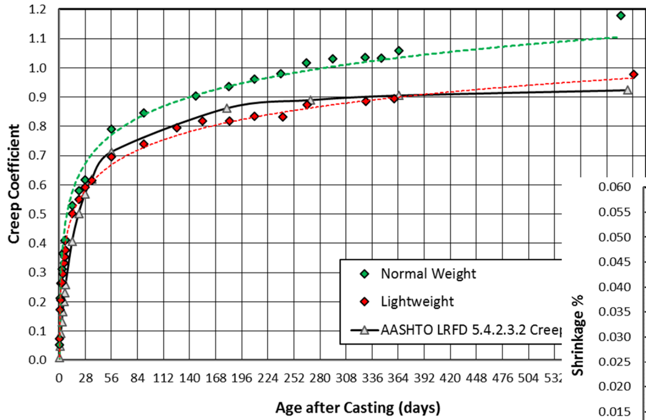
2. Properties of LWA and LWC

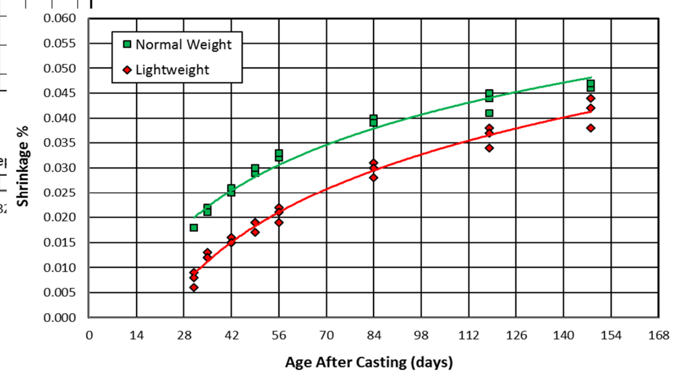
Provide basic test data on material properties

- LWA
  - Mechanical and durability properties
- LWC
  - Types and definitions
  - Fresh and hardened properties
  - Design parameters
  - Seismic and durability properties
  - Service life and safety properties
- Internal curing
  - Modifying NWC by replacing some fraction of fine aggregate in mixture with prewetted LWA to provide curing water from within

2. Properties of LWA and LWC

For example – creep & shrinkage





2. Properties of LWA and LWC

Internal curing (IC): replacing fraction of NW sand with prewetted LWA fines

- **Absorbed water is released within concrete to cure from the inside out**
- **More effective than externally applied water, especially with less permeable high-performance concretes**
- **NYSDOT reduces wet cure for IC decks**

Example near Denver:

- **Concrete placed at 92°F air temp. and 20% RH**
- **No conventional curing**
- **Appearance next morning**

Any type of LWC using prewetted LWA provides internal curing

3. Initial Design Considerations

Reasons to consider using LWC in bridges

- Reduced weight or load
- Enhanced durability and other benefits
- Types of elements where LWC could be used

Concerns about LWC

Selection of material properties for design

Estimating the cost of using LWC

Design considerations for elements and structure types

- *These 3 items have not been easily found in the past*

4. Design of LWC using LRFD Specifications

Review of recent changes in LRFD Specifications related to LWC

Itemized discussion of different articles in LRFD Specifications that address LWC, or where a lack of mention is significant

- Example: Art. 5.4.2.3 – Creep & Shrinkage: No mention of LWC indicates that current provisions apply without modification to LWC
- Comments are given on provisions when appropriate

During development of the Primer, some items were identified that may need to be considered for future revisions

5. Construction Considerations

Quality control

Proportioning LWC mixtures

Prewetting LWA

Batching

Placing

Finishing

Curing

Grinding & grooving

Heat of hydration

6. Specifying LWC

Density

Material properties

Test methods

Construction specifications

Internal curing

7. Project Examples where LWC was used

A limited list of bridges for which LWC has been successfully used is presented

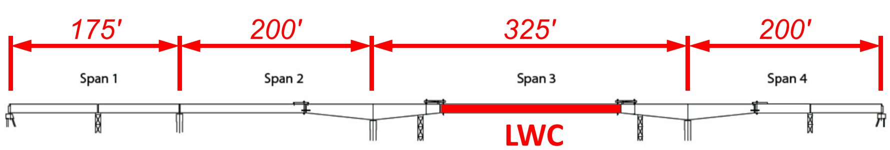
A wide range of bridge projects is included

- Large and small
- New and old
- Decks to pretensioned girders
- Segmental box girders to suspension bridges

Route 22 over the KY River - Gratz, KY

PS concrete spliced girder proposed as alternate to steel girder design

- 4 spans with 325 ft main span - record for US (2010)
- LWC used for 185 ft long drop in girders – erected 2 at once



From *ASPIRE* Magazine – Winter 2011 Issue

Benicia-Martinez Bridge, CA

I-680 over the Carquinez Strait north of San Francisco (2008)

Cast-in-place box girder

- 82 ft (25m) wide deck
- 658 ft (201m) max. spans

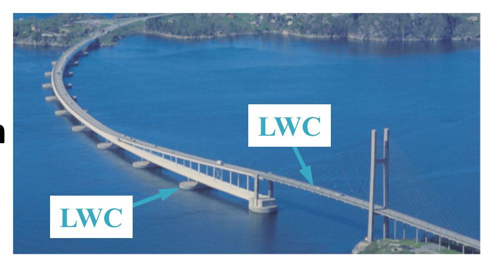
LWC was used for the entire segmental box girder cross-section

- LWC used for full length of 6500 ft bridge except for pier segments
- Reduced seismic forces, foundations & cost

If research on LWC ductility had been completed at the time of design, the bridge would probably have been LWC from the top of the footing

NordHordland Bridge, Hordaland, Norway

LWC was used for superstructure on the 535 ft cable-stayed main span completed in 1994



- LWC saved nearly 1% of total contract cost
- Reduced cost of stays and size of hold-down structure

LWC also used for pontoons for floating bridge

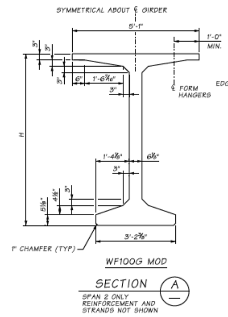
- LWC saved 3 to 7% of cost of smaller pontoons
- Reduced wave forces ⇒ reduced load on structure

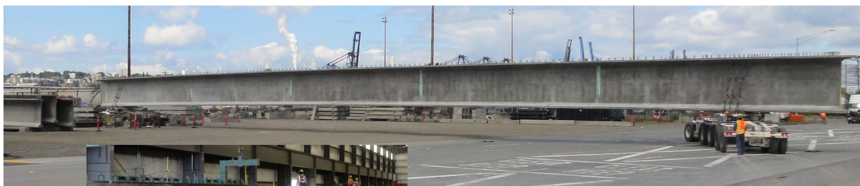
A few other cable-stayed bridges have used LWC

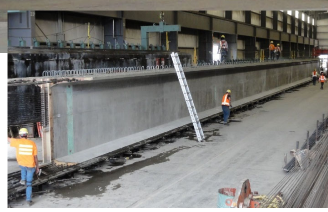
Portland Ave/Puyallup River - Tacoma, WA

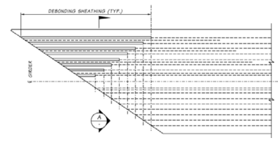
New US record for the longest single piece PS girder

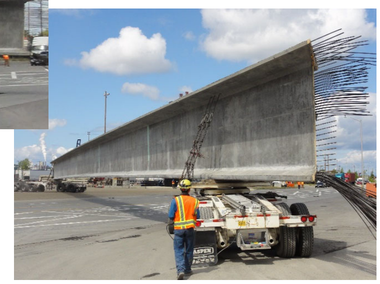
- 223 ft long – plus severe skews (add 7 ft)
- WF100G Mod – 8’-4” H, 5’-1” top flange
- Same LWC mix as I-5 over the Skagit River
- LWC required to be able to truck girder to site











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Questions?

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