U.S. Department of Transportation
**Federal Highway Administration**

# *LIGHTWEIGHT CONCRETE BRIDGE DESIGN PRIMER*

## A New Resource for Bridge Designers – ABC Applications

Source: Christopher Vanek/WSP

Monthly Webinar Series
FIU ABC-UTC

June 29, 2023
1:00-2:15 PM EDT

Reid W. Castrodale, PhD, PE

# Disclaimer

# 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)
  - Main benefit was its reduced density
  - Also found to be very durable

San Francisco Oakland Bay Bridge (1936)

Source: FHWA

# LWA is a manufactured product

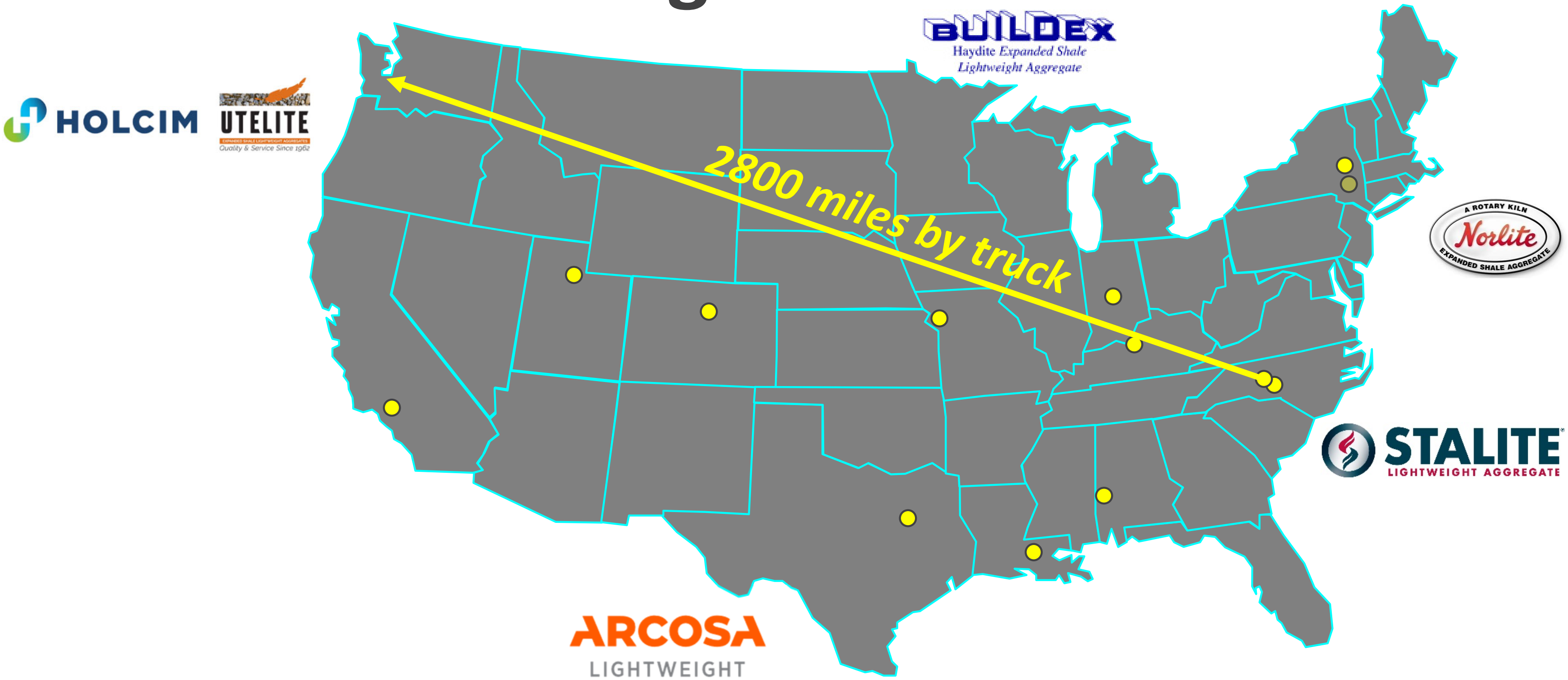
- Raw material is shale, clay, or slate
- Heated in kiln to over 2,000 degrees Fahrenheit

- Gas bubbles form in softened material
- Gas bubbles remain after cooling
- Clinker is crushed and screened

Source: FHWA

All photos © Stalite Structural Lightweight Aggregates except as noted

# ESCS Manufacturing Plants in US



**13 plants in the US**

**See *www.escsi.org* for member company locations**

# Structural Lightweight Concrete

- When the original patent expired in the 1950s, the use of LWC increased rapidly as other manufacturers entered the market
- Rapid growth continued until the mid 1970s
  - ☐ Oil crisis increased energy costs
  - ☐ Introduction of pollution controls increased production costs
- Result: Industry production was reduced, then became relatively constant at a lower level
  - ☐ Promotion was curtailed

# FHWA Efforts Related to LWC

- In the early 2000s, FHWA saw LWC as an underutilized technology that had potential for improving the economy and performance of bridges
    - ☐ Information was needed to equip owners and designers to properly evaluate the potential benefits of using LWC
    - ☐ Information should include laboratory data and field experience that demonstrate that LWC can be durable and cost effective for bridge designs
    - ☐ Additional research was needed to answer some questions, especially about “specified density” concrete in range between LWC and normal-weight concrete (NWC)

# FHWA Efforts Related to LWC

- In 2005, the Federal SAFETEA-LU legislation included funds for FHWA to use for research on high performance concrete (HPC)
  - ☐ The funds were eventually used to begin work on LWC at FHWA's Turner Fairbank Highway Research Center (TFHRC)
  - ☐ Efforts were coordinated with NCHRP Project 18-15 "High-Performance/ High-Strength Lightweight Concrete for Bridge Girders and Decks," which produced NCHRP Report 733 (2013)

# FHWA Efforts Related to LWC

- Using the results of the two research efforts and earlier work, the Load and Resistance Factor Design (LRFD) Specifications were revised by AASHTO
  - ❑ 2014 – Revised equation for modulus of elasticity, $E_c$ – better correlation for LWC and high strength concrete
  - ❑ 2015 – A package of revisions related to LWC was adopted including
    - New definition for LWC
    - Introduction of the concrete density modification factor, $\lambda$
    - Insertion of $\lambda$ into equations where appropriate
  - ❑ Changes appear in the binding *AASHTO LRFD Bridge Design Specifications,* 8th ed. (23 CFR 625.4(d)(1)(v))

# FHWA Efforts Related to LWC

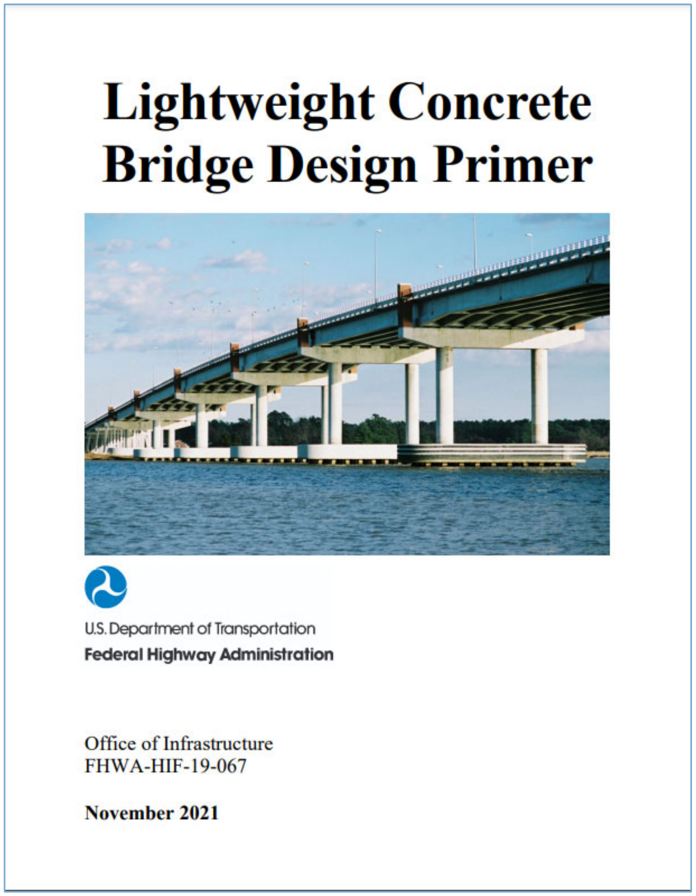
- Even after these changes were made to the LRFD Specifications, LWC was still not being commonly used for bridge design
  - Designers and owners did not see LWC as a reasonable option
  - Perceived higher cost of the material
  - Designers were unsure of how to select properties of LWC for design
- A LWC Primer was identified as a product that would be useful to advance the use of LWC by addressing these concerns
  - Provide basic information for design of LWC bridges
  - Provide information to allow evaluation of potential benefits of using LWC for bridges

# *Lightweight Concrete Bridge Design Primer*

- The LWC Primer was developed to advance the use of LWC by providing
  - Basic information for design of LWC bridges
  - Information to allow evaluation of potential benefits of using LWC for bridges
- The document (FHWA-HIF-19-067) is available for download at:

[https://www.fhwa.dot.gov/bridge/concrete/hif19067_Nov2021.pdf](https://www.fhwa.dot.gov/bridge/concrete/hif19067_Nov2021.pdf)
or at the Concrete Bridges webpage on the FHWA website

Link is also on the FIU ABC *Monthly Webinar Archives* Webpage and in email announcement for this webinar



**Lightweight Concrete Bridge Design Primer**

U.S. Department of Transportation
**Federal Highway Administration**

Office of Infrastructure
FHWA-HIF-19-067

**November 2021**

Source: FHWA

# 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*. (Note: AASHTO M 195 and ASTM C567 are not Federal requirements.)
- Not a new material
  - LWC has been in the 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*."

# Introduction

- Benefits of LWC for Bridges
  - Structural
    - Extended span ranges
    - Wider girder spacings
    - Shallower girders
    - Reduced design loads on bearings, substructure elements, foundations, especially for locations with potential for seismic activity
    - Reduced weight of precast elements for handling, hauling, erection
    - Reuse of substructure elements

# Introduction

- Benefits of LWC for Bridges **for ABC**
  - Structural
    - Extended span ranges
    - Wider girder spacings
    - Shallower girders
    - Reduced design loads on bearings, substructure elements, foundations
    - Prefabricated Bridge Elements and Systems (PBES)
      - Reduced weight of precast elements for handling, hauling, erection
      - Predecked modular girder units
      - Precast substructure units
    - Reuse of substructure elements

# Introduction

- Benefits of LWC for Bridges
  - Durability
    - Internal curing with prewetted LWA reduces shrinkage, cracking, and permeability
    - Similar stiffness of aggregate and paste reduces microcracking and permeability
    - Lower modulus of elasticity reduces cracking
    - Lower coefficient of thermal expansion reduces cracking

# 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
- The increased cost of LWA and LWC is not insurmountable, as evidenced by the many successful projects completed using LWC
- Other concerns may be based on misconceptions or can be addressed in design

# Introduction

- Examples of the Effective Use of LWC for Bridges
  - ☐ San Francisco Oakland Bay Bridge, CA – 1936
  - ☐ I-5 over Skagit River, WA – 2013
  - ☐ Rugsund Bridge, Norway – 2000

# San Francisco-Oakland Bay Bridge, CA

- Upper deck of suspension spans was built in 1936 using all-LWC (95 pcf)
  - ☐ Saved $3M of original $40M total cost
- Lower deck was reconfigured for highway traffic using LWC in 1958
- Both decks are still in service
  - ☐ Have had wearing surfaces

Source: FHWA

# I-5 over Skagit River, Mt Vernon, WA

- Emergency replacement of collapsed truss span on I-5
  - Total weight of replacement span held to < 915 tons to avoid reanalysis and retrofit of piers
- Sand-LWC used for precast deck girders
  - First LWC girders for Washington State DOT
    - Sand-LWC also used for diaphragms & barriers
  - Design compressive strength of girders: 9 ksi at 123 pcf
    - Actual design compressive strength = 10,600 psi
  - 162 ft LWC girders weighed 84 tons each
    - Girders were 65” deep with a 6.5-ft-wide top flange


Source: Christopher Vanek/WSP

# I-5 over Skagit River, Mt Vernon, WA

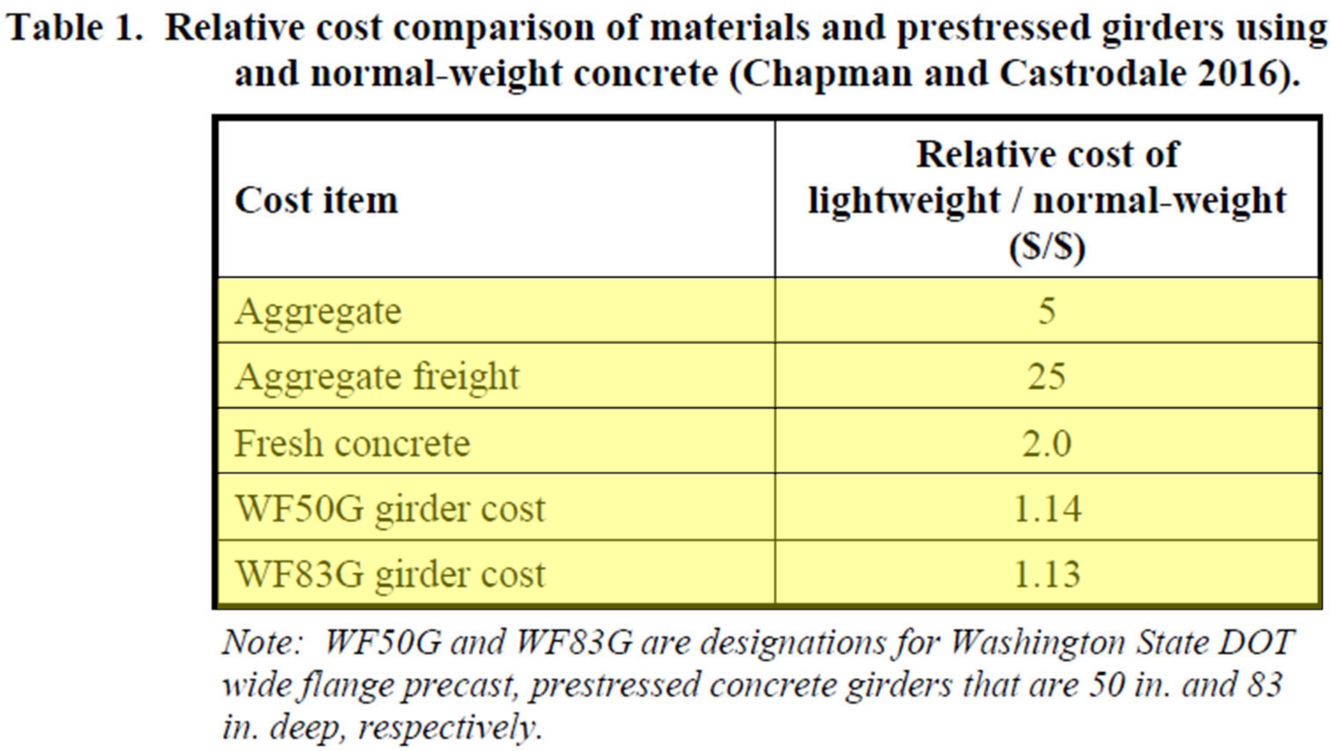


**Table 1. Relative cost comparison of materials and prestressed girders using lightweight and normal-weight concrete (Chapman and Castrodale 2016).**

| Cost item | Relative cost of lightweight / normal-weight (\$/\$) |
|---|---|
| Aggregate | 5 |
| Aggregate freight | 25 |
| Fresh concrete | 2.0 |
| WF50G girder cost | 1.14 |
| WF83G girder cost | 1.13 |

*Note: WF50G and WF83G are designations for Washington State DOT wide flange precast, prestressed concrete girders that are 50 in. and 83 in. deep, respectively.*

Source: FHWA

**LWA**

**Freight from NC to WA**

**LWC**

**Cost of completed girders < 15% more**

# Rugsund Bridge, Norway

- Alternate box girder design used LWC for 604 ft of main span
    - ❑ Increased length of 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 edge of water
    - ❑ Reduced length of ballast-filled side spans and overall bridge length
    - ❑ Construction was completed in 2001
- Bid for LWC design was 15 percent less than for the NWC design
- Contractor wanted to pump LWC; couldn’t pump using local LWA
    - ❑ LWA was shipped from USA to allow pumping of LWC

# 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
    - Modify NWC by replacing a fraction of the fine aggregate in mixture with prewetted LWA to provide curing water from within

# Properties of LWA

- Types of LWA
  - ☐ Properties vary depending on source and processing

© 2013 NAS

  - ☐ LWA can be uncrushed or crushed

© 2016 PCA

# Properties of LWA

- Gradations for coarse LWA from AASHTO M 195 (2011)

| Nominal Size Designation | 25.0 mm (1 in.) | 19.0 mm (¾ in.) | 12.5 mm (½ in.) | 9.5 mm (3/8 in.) | 4.75 mm (No. 4) | 2.36 mm (No. 8) | 1.18 mm (No. 16) | 0.075 mm (No. 200) |
|---|---|---|---|---|---|---|---|---|
| 25.0 to 4.75 mm | 95-100 | -- | 25-60 | -- | 0-10 | -- | -- | 0-10 |
| 19.0 to 4.75 mm | 100 | 90-100 | -- | 10-50 | 0-15 | -- | -- | 0-10 |
| 12.5 to 4.75 mm | -- | 100 | 90-100 | 40-80 | 0-20 | 0-10 | -- | 0-10 |
| 9.5 to 2.36 mm | -- | -- | 100 | 80-100 | 5-40 | 0-20 | 0-10 | 0-10 |

- ☐ Sizes are identified by nominal sizes, typically ¾”, ½”, and 3/8”

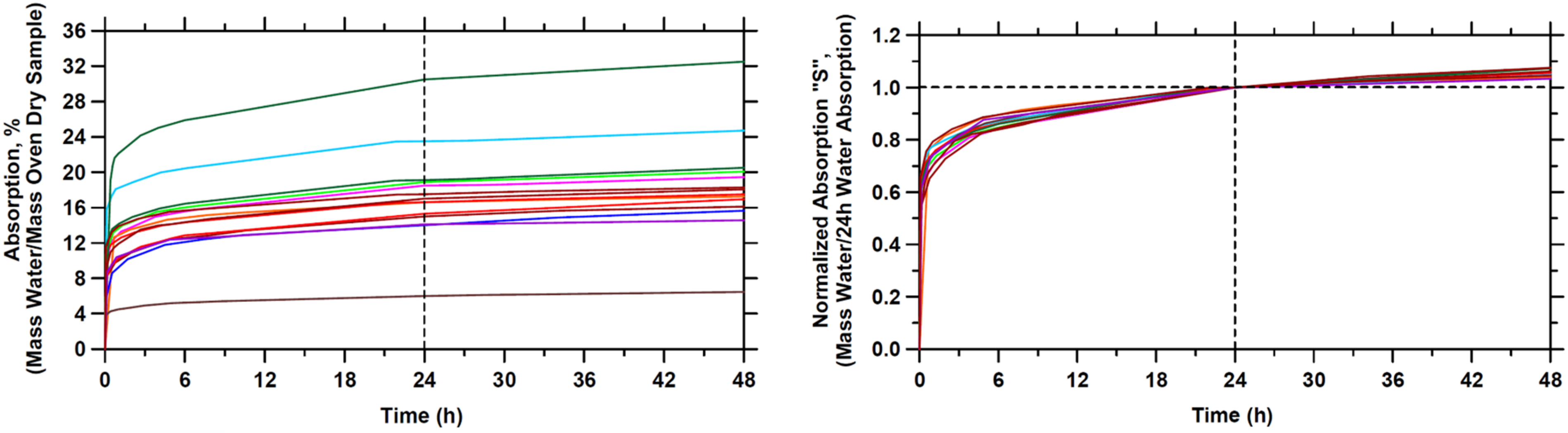
Note: Use of AASHTO M 195 is not a Federal requirement.

# Properties of LWA

- Absorption of LWA
  - May range from 5% to more than 25% by mass of dry aggregate after soaking for 24 hours
    - Significantly higher than typical NWA
    - Depends on LWA source and size
  - Cautions
    - Absorption alone should not be considered as the single determinant of acceptable performance of LWA
    - In past, some agencies have prohibited use of LWA crushed after firing to minimize absorption. May apply to a few types of LWA but is not necessary for others.

# Properties of LWA

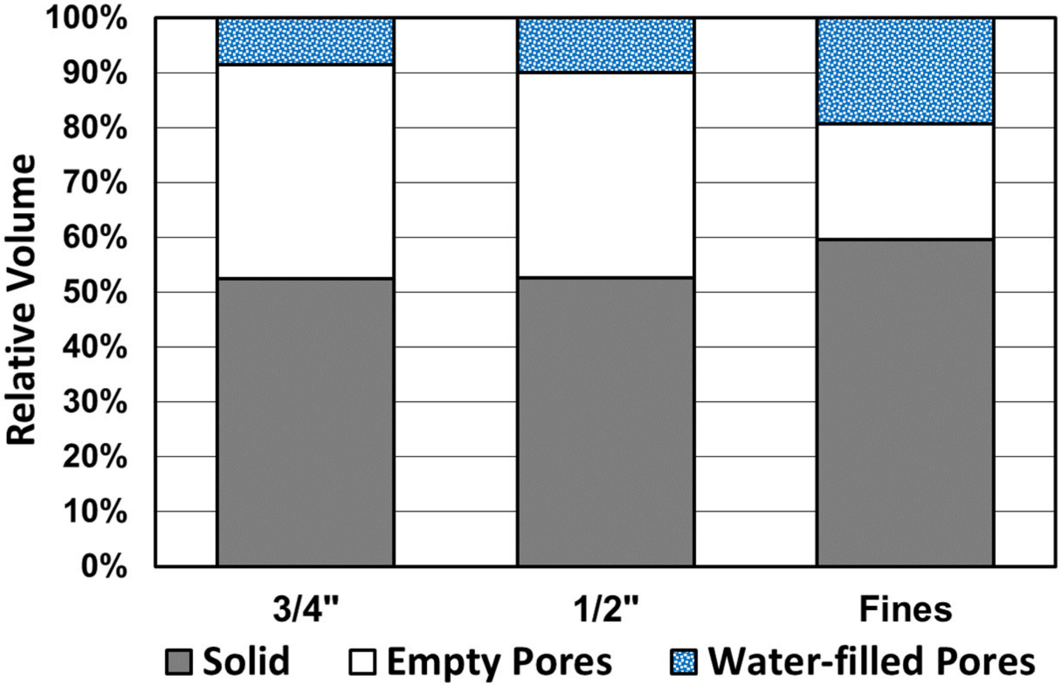
- Absorption of fine LWA from oven dry condition
  - ☐ Wide range (5 to 30%) for sources in U.S. (left)
  - ☐ Absorption normalized to 24 hr value is very consistent (right)



All figures © 2011 Javier Castro

# Properties of LWA

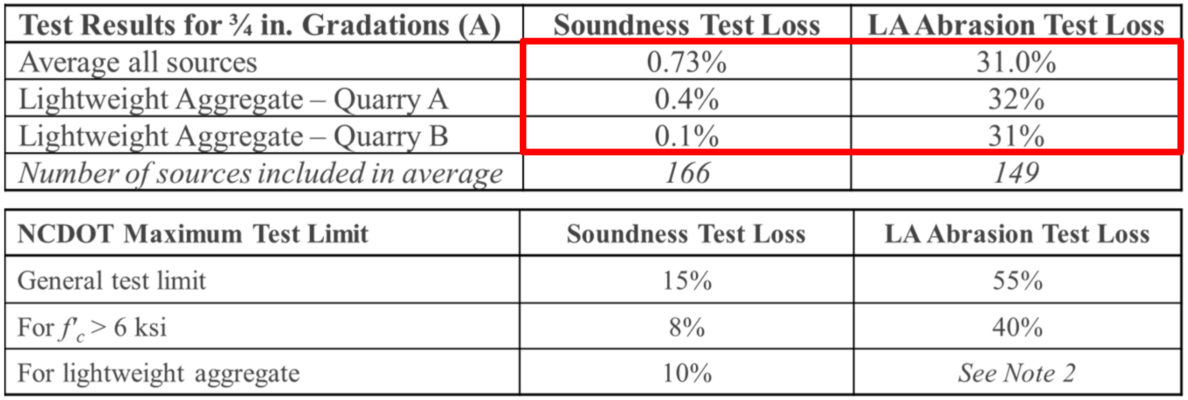
- Condition of LWA with absorbed water
  - Figure represents LWA from one source
  - Varies with size of LWA
  - Less than half of gross volume of LWA is pores
  - Only a fraction of pore volume fills with water
    - Only 20 to 50% of pore volume fills with water



Source: FHWA

# Properties of LWA

- Durability of LWA
  - Soundness and Los Angeles abrasion loss data from North Carolina DOT approved coarse aggregate list with NCDOT maximum test limits



| Test Results for ¾ in. Gradations (A) | Soundness Test Loss | LA Abrasion Test Loss |
|---|---|---|
| Average all sources | 0.73% | 31.0% |
| Lightweight Aggregate – Quarry A | 0.4% | 32% |
| Lightweight Aggregate – Quarry B | 0.1% | 31% |
| *Number of sources included in average* | *166* | *149* |

| NCDOT Maximum Test Limit | Soundness Test Loss | LA Abrasion Test Loss |
|---|---|---|
| General test limit | 15% | 55% |
| For $f'_c > 6$ ksi | 8% | 40% |
| For lightweight aggregate | 10% | *See Note 2* |

Source: NCDOT

  - These LWA sources meet the NCDOT test requirements and are similar to average test results shown which are for all approved aggregates

# Properties of LWC

- Types of LWC
  - ☐ All-LWC: All aggregate in concrete mixture is LWA
  - ☐ Sand-LWC: This mixture uses coarse LWA and NWA fines (sand)
  - ☐ Specified-density concrete: any blend of NWA and LWA to obtain a specified density, which can range from all-LWC to NWC
- These definitions were dropped in the LRFD Specifications, 8th edition
  - ☐ The density of LWC is specified
  - ☐ The supplier determines the blend of aggregates to achieve it

# Properties of LWC

- Types of density used to specify LWC
  - Fresh: The density of fresh concrete in its plastic state
    - Used for acceptance at delivery
  - Equilibrium: The density of concrete exposed to a drying environment for sufficient time to reach a constant mass
    - Not typically measured directly with long-term drying
    - Generally based on a density calculated from mix proportions
- The terms “density” and “unit weight” are usually used interchangeably in specifications

# Properties of LWC

- Typical range of densities
  - Concrete density varies with $f'_c$
  - LWC density for typical bridge applications: 0.110 to 0.125 kcf
    - NWC density is typically 0.140 to 0.155 kcf; so LWC is about 20% less
  - Densities as low as 0.090 kcf may be achieved for lower strength applications such as decks; so LWC is about 35% less
  - Specified densities are for plain concrete
    - Add allowance for increase in density with reinforcement
    - Typically, 0.005 kcf is used, but this can be inadequate in some cases such as heavily reinforced girders

# Properties of LWC

- Hardened mechanical properties
  - ☐ Some tests show that LWC has reduced mechanical properties compared to NWC with the same compressive strength
  - ☐ However, in some cases, LWC can have properties that are similar to or greater than for a comparable NWC mixture
  - ☐ Even when LWC properties may be reduced, designs have been successfully completed and structures have performed well, as illustrated by the limited sample of LWC bridges presented in Chapter 7

# Properties of LWC

- Compressive strength
  - For deck concrete, the same compressive strength used for NWC decks can be used for LWC decks
    - If a reduced tensile strength is expected for LWC, some designers have compensated by increasing the specified compressive strength for the LWC deck
    - However, this may not be necessary if tensile properties of LWC are similar to or possibly better than for NWC
  - For girder concrete, a 28-day compressive strength of 8.5 to 10 ksi has been successfully used
    - Some researchers have not achieved high strengths with some LWA. Consult LWA suppliers when considering high compressive strengths

# Properties of LWC

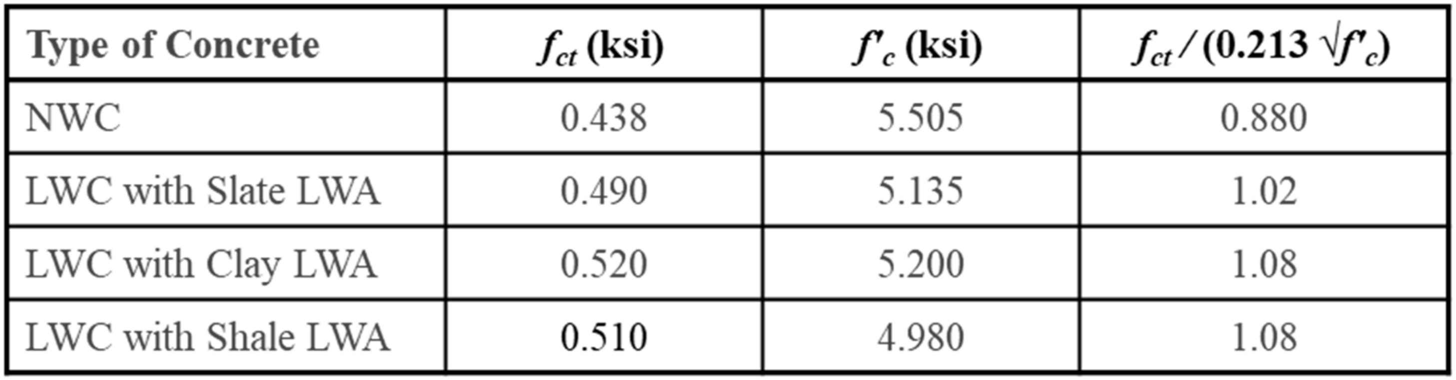
- Compressive strength
  - Compressive strength gain with time is similar for LWC
  - Stress-strain curve in compression is typically linear to a higher level of stress compared to NWC
    - This behavior reflects a delay in the development of microcracking to higher levels of stress within LWC compared to NWC

# Properties of LWC

- Tensile strength
  - The modulus of rupture, $f_r$, has often been used as the tensile strength
    - This quantity has limitations but may be used for decks or pavements
    - LRFD Specifications (8th ed.) Equation 5.4.2.6 includes the following expression to define $f_r$ : $0.24\ \lambda\sqrt{f'_c}$
  - The splitting tensile strength of concrete, $f_{ct}$, is typically used to assess the tensile strength of LWC
    - It is generally accepted that $f_{ct}$ provides a better estimate of the tensile strength in larger bending elements like girders
    - LRFD Specifications (8th ed.) Equation 5.4.2.8-2 can be solved for the splitting tensile strength: $f_{ct} = 0.213\ \lambda\sqrt{f'_c}$

# Properties of LWC

- Tensile strength
  - Test data for deck concrete mixtures made using NWA (river gravel) and three sources of coarse LWA



| Type of Concrete | $f_{ct}$ (ksi) | $f'_c$ (ksi) | $f_{ct} / (0.213 \sqrt{f'_c})$ |
|---|---|---|---|
| NWC | 0.438 | 5.505 | 0.880 |
| LWC with Slate LWA | 0.490 | 5.135 | 1.02 |
| LWC with Clay LWA | 0.520 | 5.200 | 1.08 |
| LWC with Shale LWA | 0.510 | 4.980 | 1.08 |

Source: Byard and Schindler (2010)

  - In this case, all LWC mixtures exceeded the expected $f_{ct}$ for NWC, while the NWC concrete was below the expected value

# Properties of LWC

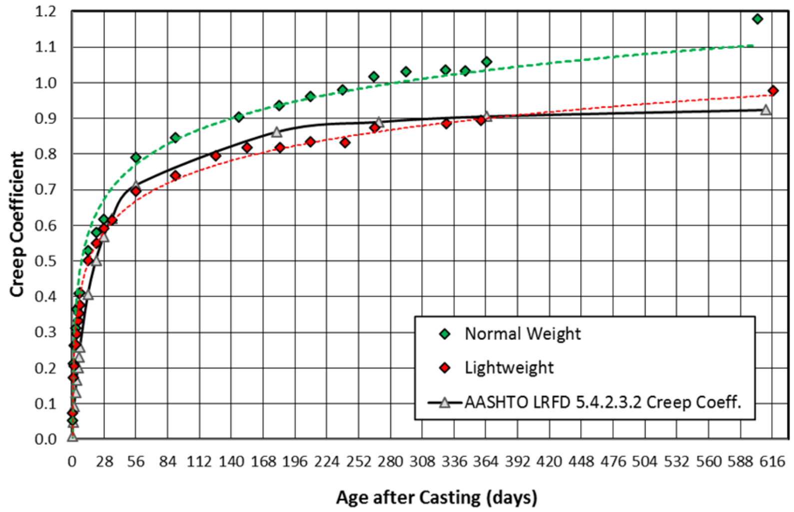
- Modulus of elasticity
  - The modulus of elasticity of LWC is less than most NWC
  - LRFD Equation 5.4.2.4-1 was adopted by AASHTO in 2015 (also in 8th ed.) to better reflect the expected modulus for LWC

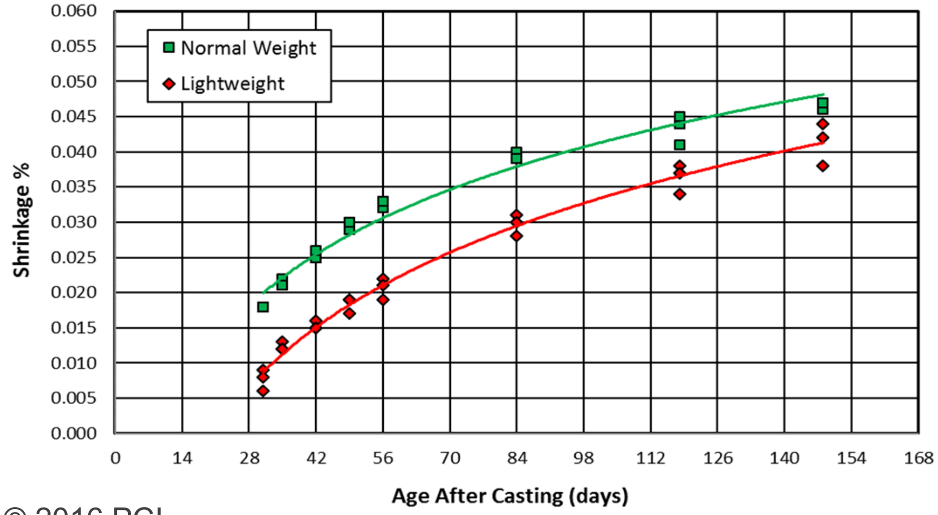
$$E_c = 120{,}000\, K_1\, w_c^{2.0}\, f'_c{}^{0.33}$$

  - The effect of LWC is accounted for by including $w_c$, the unit weight of concrete
  - Need to remember that there is wide scatter in this data for both LWC and NWC

# Properties of LWC

- Creep & shrinkage of LWC for PS girder (10 ksi)



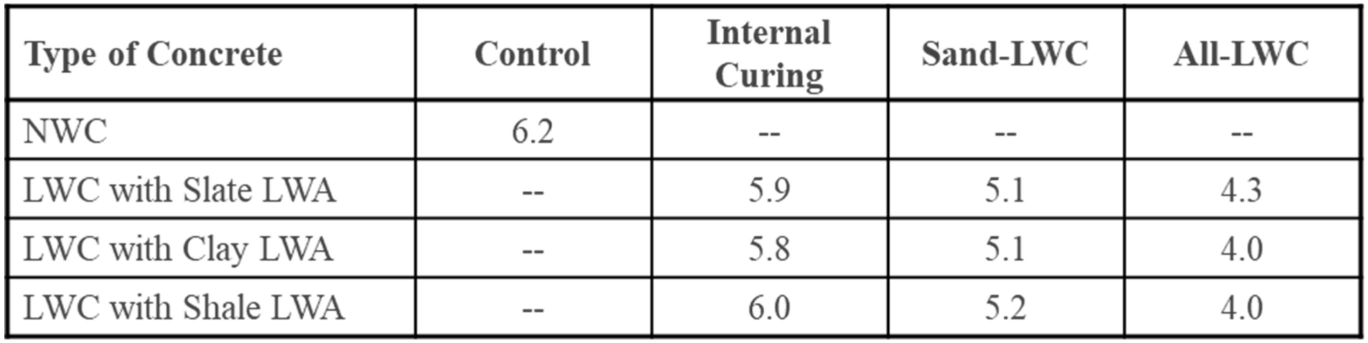


Original Graphs: © 2016 PCI

- Values for LWC were less than the NWC mixture
  - Even though the LWC had a higher cement content

# Properties of LWC

- Coefficient of thermal expansion
  - ☐ Values for LWC are generally less than for NWC
  - ☐ Test data for deck concrete mixtures made using NWA (river gravel) and three sources of LWA for the coarse aggregate



| Type of Concrete | Control | Internal Curing | Sand-LWC | All-LWC |
|---|---|---|---|---|
| NWC | 6.2 | -- | -- | -- |
| LWC with Slate LWA | -- | 5.9 | 5.1 | 4.3 |
| LWC with Clay LWA | -- | 5.8 | 5.1 | 4.0 |
| LWC with Shale LWA | -- | 6.0 | 5.2 | 4.0 |

Source: Byard and Schindler (2010)

  - ☐ For these mixes, sand-LWC was about 80% and all-LWC was less than 70% of the values for NWC

# Properties of LWC – Design Parameters

- The following design parameters are briefly discussed
  - ☐ Equivalent rectangular stress block
  - ☐ Prestress losses
  - ☐ Camber
  - ☐ Transfer and development of pretensioned strands
  - ☐ Vertical and horizontal shear
  - ☐ Resistance factors
- Provisions in LRFD Specifications (8th ed.) can generally be used for these design parameters

# Properties of LWC – Durability

- The following aspects of durability are briefly discussed
    - ☐ Permeability
    - ☐ Cracking tendency
    - ☐ Corrosion resistance
    - ☐ Freeze and thaw resistance
    - ☐ Alkali-aggregate reactivity
    - ☐ Abrasion
    - ☐ Thermal effects
- Performance of LWC has been shown to be comparable to NWC for these aspects of durability

# Internal Curing

- Internal curing (IC) is provided by replacing a portion of NW sand with prewetted LWA fines
  - ☐ Absorbed water is released within concrete to cure from inside
  - ☐ More effective than externally applied water, especially with less permeable high-performance concretes
  - ☐ NYSDOT specification allows the reduction in required duration of wet cure for IC concrete decks

- Any LWC using prewetted LWA provides internal curing

# Internal Curing

- Trial placement compares conventional and IC concrete
  - Conditions when concrete was placed near Denver, CO
    - 92°F air temp.
    - 20% RH
  - No conventional curing of any type was applied to either concrete
  - Appearance the next morning – concrete with IC has not dried out

© 2012 Arcosa Lightweight

# 3. Initial Design Considerations

- Reasons to use LWC in bridges
  - ☐ Reduced weight or load
  - ☐ Enhanced durability and extended service life
  - ☐ Other benefits
- Concerns about using LWC in bridges
- Selection of material properties for design
- Estimating the cost of LWC
- Design considerations for elements and structure types

# 4. LWC Design Using *LRFD Specifications*

- Reviews changes for LWC adopted in 2014 and 2015
- Discusses articles that address or could possibly address LWC
  - ☐ Example: Article 5.4.2.3[1] – Creep and Shrinkage: LWC is not mentioned; provisions can be used for LWC without modification
  - ☐ Comments on applying provisions are given when appropriate
- Note: Some changes identified during development of the *Primer* have now been adopted by AASHTO (not Federal requirements)

[1] *AASHTO LRFD-8 Design Specs, AASHTO 2017, incorporated by reference at 23 CFR 625.4(d)(1)(v).*

# 4. LWC Design Using *LRFD Specifications*

- Selected highlights of revisions to specifications
  - ☐ Designer specifies unit weight, $w_c$, of LWC
  - ☐ Concrete density modification factor, λ, is computed using $w_c$
    - λ factor has been inserted into all equations where appropriate
  - ☐ When LRFD was introduced, $\phi$ for shear for LWC was 0.70; $\phi$ for shear for LWC is now 0.90, the same as for NWC
  - ☐ Equation for modulus of elasticity, $E_c$, has been revised
    - More accurate for LWC and high strength NWC
  - ☐ CR, SH, and PS losses can be computed for LWC using standard equations – no modifications required for LWC

# 5. Construction Considerations

- Topics discussed related to construction using LWC
  - ☐ Quality control
  - ☐ Proportioning LWC mixtures
  - ☐ Prewetting LWA
  - ☐ Batching
  - ☐ Placing and Finishing
  - ☐ Curing
  - ☐ Grinding and grooving
  - ☐ Heat of hydration

# 6. Specifying LWC

- Information is provided for selected topics to help designers prepare construction specifications for LWC
  - ❑ Density
  - ❑ Material properties
  - ❑ Test methods
  - ❑ Construction specifications
  - ❑ Internal curing

# 7. Project Examples Where LWC Was Used

- A list of bridges for which LWC has been successfully used for the following reasons:
    - ☐ Improved structural efficiency
    - ☐ Reduced element weight for shipping & handling
    - ☐ Allowed reuse of existing structural elements

# 7. Project Examples Where LWC Was Used

- A wide range of bridge projects is included
  - Large and small; short and long spans; new and old
  - Elements and bridge types include:
    - Decks
    - Pretensioned girders
    - Segmental box girders
    - Suspension bridges
  - Internal curing is mentioned
    - Examples are not provided, but references are given

# Project Examples Where LWC Was Used

- **Projects that reused existing structural elements**
  - I-895 Bridge over the Patapsco River Flats – Baltimore, MD
  - Shasta Arch Bridge on Southbound I-5 – Shasta County, CA
  - Route 198 Bridge over Harper Creek – Gloucester County, VA
  - I-5 Bridge over the Skagit River – Skagit County, WA
  - Beach Bridge – North Haven, ME

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# I-5 over Skagit River, Mt Vernon, WA

- Emergency replacement of collapsed truss span
  - ☐ Total weight of replacement span held to < 915 tons to avoid reanalysis and retrofit of piers
- Sand-LWC used for precast deck girders
  - ☐ First LWC girders for Washington State DOT
    - Sand-LWC also used for diaphragms & barriers
  - ☐ 162 ft LWC girders weighed 84 tons each
    - Girders were 65” deep with a 6.5-ft-wide top flange
  - ☐ Design compressive strength of LWC girders: 9 ksi at 123 pcf
    - Actual design compressive strength = 10,600 psi

Source: Christopher Vanek/WSP

# Beach Bridge, North Haven, ME

- NEXT D beams used to replace 2 span bridge on island off coast of Maine
  - First use of sand-LWC for a NEXT beam bridge
    - LWC allowed reuse of pier
    - Avoided design and construction of new foundations at difficult site
    - Reduced beam weight for shipping and handling
- Properties of self-consolidating LWC
  - Minimum design compressive strength of 6 ksi
  - Maximum plastic density of 120 $lb/ft^3$

# Project Examples Where LWC Was Used

- **Projects that reused existing structural elements** (*cont'd*)
  - Ben Sawyer Bridge – Sullivan's Island, SC
  - Massaponax Church Road over I-95 – Spotsylvania Cty, VA
  - Brooklyn Bridge over the East River – New York City, NY
  - Coleman Bridge over the York River – Yorktown, VA
  - Woodrow Wilson Br over Potomac River – Washington, DC

# Ben Sawyer Bridge, Mt Pleasant, SC

- Replace swing span and approaches
  - ☐ Swing span constructed off-site and floated in
  - ☐ Approach spans constructed off-line and slid in
- LWC used for decks on swing span and approach spans
  - ☐ LWC addressed concerns regarding seismic performance and poor soils
  - ☐ Existing foundations reused

Source: FHWA

# Coleman Bridge, Yorktown, VA

- Bridge with twin 500 ft swing spans completed in 1952
  - ☐ 26 ft wide with 2 lanes
- Superstructure replaced in 1996
  - ☐ 74 ft wide with 4 lanes and shoulders
- LWC deck was selected based on cost savings and good experience in VA
- With reduced weight from using LWC deck
  - ☐ Pier caps only had to be widened
  - ☐ Steel quantity for new trusses was reduced

All photos source: FHWA

# Woodrow Wilson Bridge, VA/DC/MD

- Deck replacement in 1983 used full-depth precast post-tensioned deck panels
- Use of LWC for deck panels allowed:
  - ❑ Thicker deck for improved durability
    - ■ But lower shipping cost and erection loads
  - ❑ Wider roadway with no super- or substructure strengthening
    - ■ Project cost and duration were reduced by avoiding strengthening
- LWC deck performed well until bridge was replaced to improve traffic capacity

# Project Examples Where LWC Was Used

- **Projects that improved structural efficiency**
  - Marc Basnight Bridge over Oregon Inlet – Outer Banks, NC
  - Pulaski Skyway Bridge Rehabilitation – Between Newark, NJ
  - Benicia-Martinez Bridge – Benicia, CA
  - Route 33 Bridges – West Point, VA
  - Stolma Bridge – Hordaland, Norway
  - Nordhordland Bridge – Hordaland, Norway
  - Francis Scott Key Bridge – Baltimore, MD
  - San Francisco-Oakland Bay Bridge, CA

# Benicia-Martinez Bridge, CA

- I-680 over the Carquinez Strait north of San Francisco
  - ☐ Cast-in-place box girder completed in 2008
  - ☐ 82 ft (25m) wide deck with 658 ft (201m) max. spans
- Entire segmental box girder cross-section was LWC
  - ☐ LWC used for entire 6500 ft bridge except for pier segments
  - ☐ Use of LWC reduced seismic forces, foundations, and cost
- Similar span (640 ft) to Parrotts Ferry Bridge completed in 1979 that was retrofitted for excessive midspan sag
  - ☐ But no problems with sag for the Benicia-Martinez Bridge

# VA Route 33 Bridges, West Point, VA

- Bridges across Mattaponi and Pumunkey Rivers were completed in 2006 and 2007
- Approach spans are continuous for LL
- Each bridge has two 200'-240'-240'-200’ spliced units with haunched pier segments
- LWC girders and decks reduced foundation loads on poor soils

Source: Standard Concrete Products, Inc.

Source: FHWA

# Stolma Bridge, Hordaland, Norway

- World record span when completed in 1998
- Cast-in-place single-cell segmental box
  - ☐ Center span is 988 ft (301m)
  - ☐ Side spans are 308 ft (94m) and 236 ft (72m)
  - ☐ LWC (LC60 ≈ 8.7 ksi) in middle 604 ft (184m) of main span
- LWC was used to achieve better balance between main and side spans

# 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 stay cables and size of hold-down structure
- LWC also used for pontoons on floating bridge
    - ☐ Saved 3 to 7% of cost of smaller pontoons
    - ☐ Reduced wave forces ⇒ reduced load on structure
- A few other cable-stayed bridges have also used LWC

# San Francisco-Oakland Bay Bridge, CA

- Upper deck of suspension spans was built in 1936 using all LWC (95 pcf)
  - ☐ Saved $3M of original $40M total cost
- Lower deck was reconfigured for highway traffic using LWC in 1958
- Both decks are still in service
  - ☐ Have had wearing surfaces

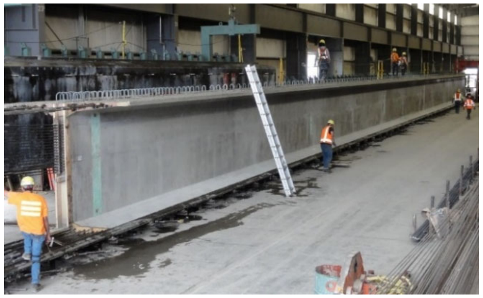
Source: FHWA

# Project Examples Where LWC Was Used

- **Projects that reduced weight for shipping & handling**
  - ☐ I-5 Portland Avenue to Port of Tacoma Southbound Ramp – Tacoma, WA
  - ☐ I-95 Bridge over James River and North – Richmond, VA
  - ☐ Route 22 Bridge over the Kentucky River – Gratz, KY
  - ☐ I-85 Ramp over State Route 34 – Newnan, GA
  - ☐ Automated People Mover (APM) Project – Atlanta, GA

# Portland Ave/Puyallup River, Tacoma, WA

- New US record for longest single piece girder
  - ☐ 223 ft long – plus severe skews (add 7 ft)
  - ☐ WF100G Mod – 8’-4” tall; 5’-1” wide top flange
  - ☐ Same LWC mix as I-5 over the Skagit River
  - ☐ Using LWC enabled transporting girder to site



All photos source: Concrete Technology Corp.

# I-95 over James River and Other Overpasses

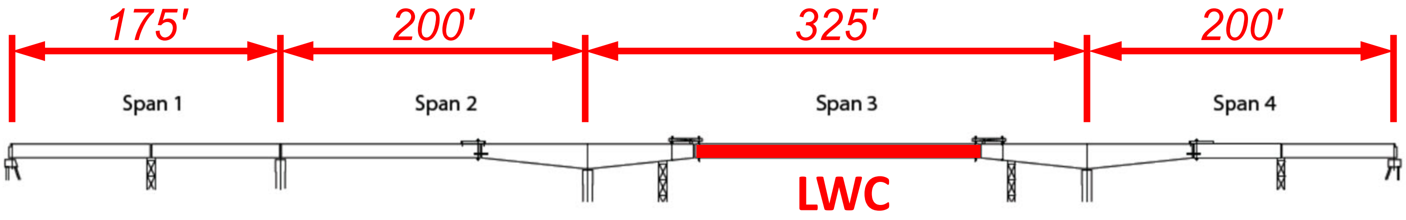

Source: VDOT

- Prefabricated full-span units
  - ☐ Steel girders and sand-LWC deck to reduce weight of predecked girder units
  - ☐ James River Bridge replacement (2002)
  - ☐ 11 overpass replacements (2014)
- Maximum precast unit weight for 2014 project

| | |
|---|---|
| ☐ As designed with sand-LWC (120 pcf): | 116 tons |
| ☐ If NWC had been used (145 pcf): | 132 tons (+12%) |
| ☐ If all-LWC had been used (105 pcf): | 106 tons (-8%) |

# Route 22 over the KY River, Gratz, KY

- PS concrete spliced girder proposed by contractor to owner as alternate to original steel girder design
  - ☐ 4 spans with 325 ft main span - record for US (2010)
  - ☐ LWC used for 185 ft long drop in girders – erected in pairs



Source: Janssen & Spaans Engineering, Inc

All photos source: Haydon Bridge Co.

# LIGHTWEIGHT CONCRETE BRIDGE DESIGN PRIMER

## A New Resource for Bridge Designers – ABC Applications

https://www.fhwa.dot.gov/bridge/concrete/hif19067_Nov2021.pdf

Source: FHWA

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Source: Christopher Vanek/WSP

U.S. Department of Transportation
**Federal Highway Administration**