Lightweight
High Performance Concrete
for Bridge Decks

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Lightweight HPC for Bridge Decks

Introduction ⬅

Benefits

Examples of Bridge Decks

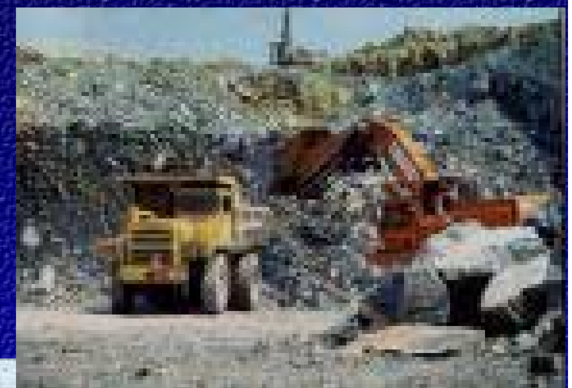
- **Cast-in-place decks**
- **Precast decks**

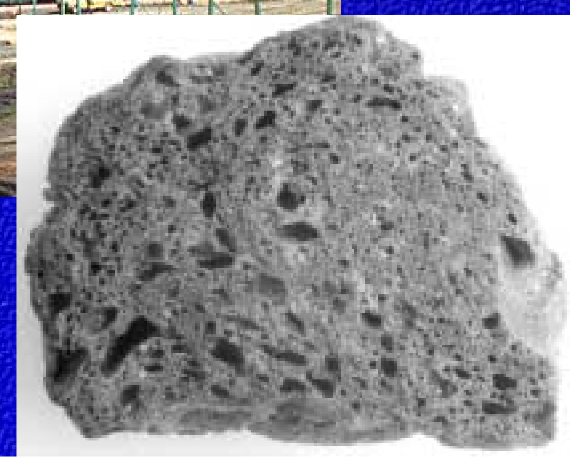
Cost Comparison

Structural Lightweight Aggregate

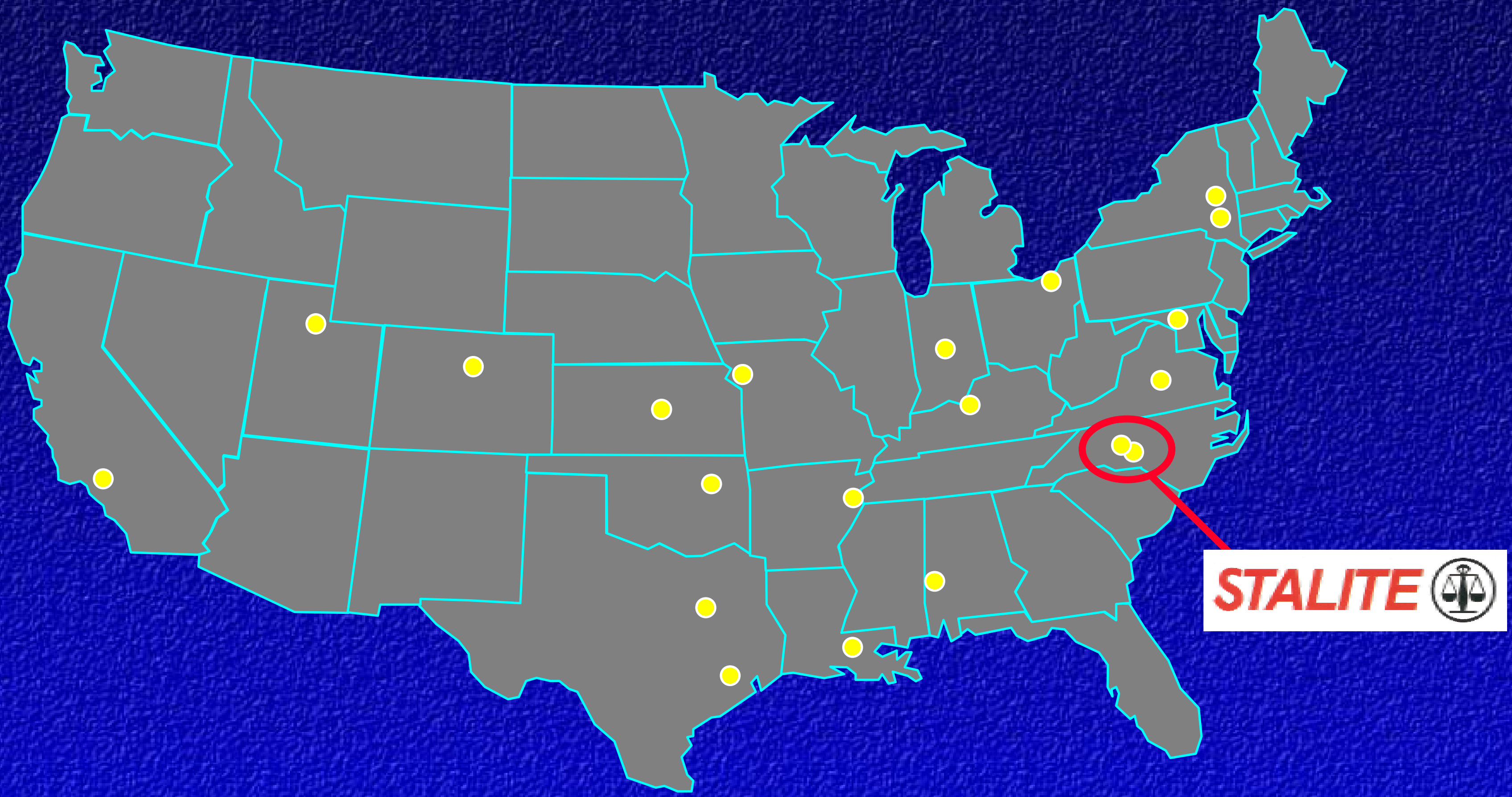
Manufactured aggregate

- ***Expanded shale, clay or slate***
- ***Manufactured in a rotary kiln***





ESCS Manufacturing Plants in US



20 plants in the US

See www.escsi.org for locations

Relative Density of Lightweight vs. Normal Weight Aggregate

Relative density for rotary kiln expanded lightweight aggregates

- ***Range from 1.3 to 1.6***

Relative density for normal weight aggregates

- ***Range from 2.6 to 3.0***

Often used as LW structural fill

- ***Behind retaining walls***
- ***On compressible soils***

1 lb. of each type of aggregate

Definitions of Lightweight & Normalweight Concrete

Lightweight concrete

- ***Typical density range of 103 to 125 pcf***
- ***AASHTO LRFD Specs: "… air-dry unit weight not exceeding 0.120 kcf …"***
- ***"All lightweight" – fine and coarse aggregates are lightweight***
- ***"Sand lightweight" – lightweight coarse aggregate and normal weight sand***
- ***Density is checked during casting***

Definitions of Lightweight & Normalweight Concrete

Lightweight concrete

- Typical density range of 103 to 125 pcf
- AASHTO LRFD Specs: "… air-dry unit weight not exceeding 0.120 kcf …"

Normalweight concrete

- Typical density range of 140 to 150 pcf
- AASHTO LRFD Specs: "Concrete having a weight between 0.135 and 0.155 kcf."
- Density is not a criteria for acceptance

Definitions of Lightweight & Normalweight Concrete

Lightweight concrete

- AASHTO LRFD Specs: "… air-dry unit weight not exceeding 0.120 kcf …."

Normalweight concrete

- AASHTO LRFD Specs: "Concrete having a weight between 0.135 and 0.155 kcf."

Specified density concrete

- Between the ranges for LWC and NWC
- Generally a blend of lightweight and normalweight coarse aggregates

Specifying Density of Lightweight Concrete

"Equilibrium density" of LWC is now specified

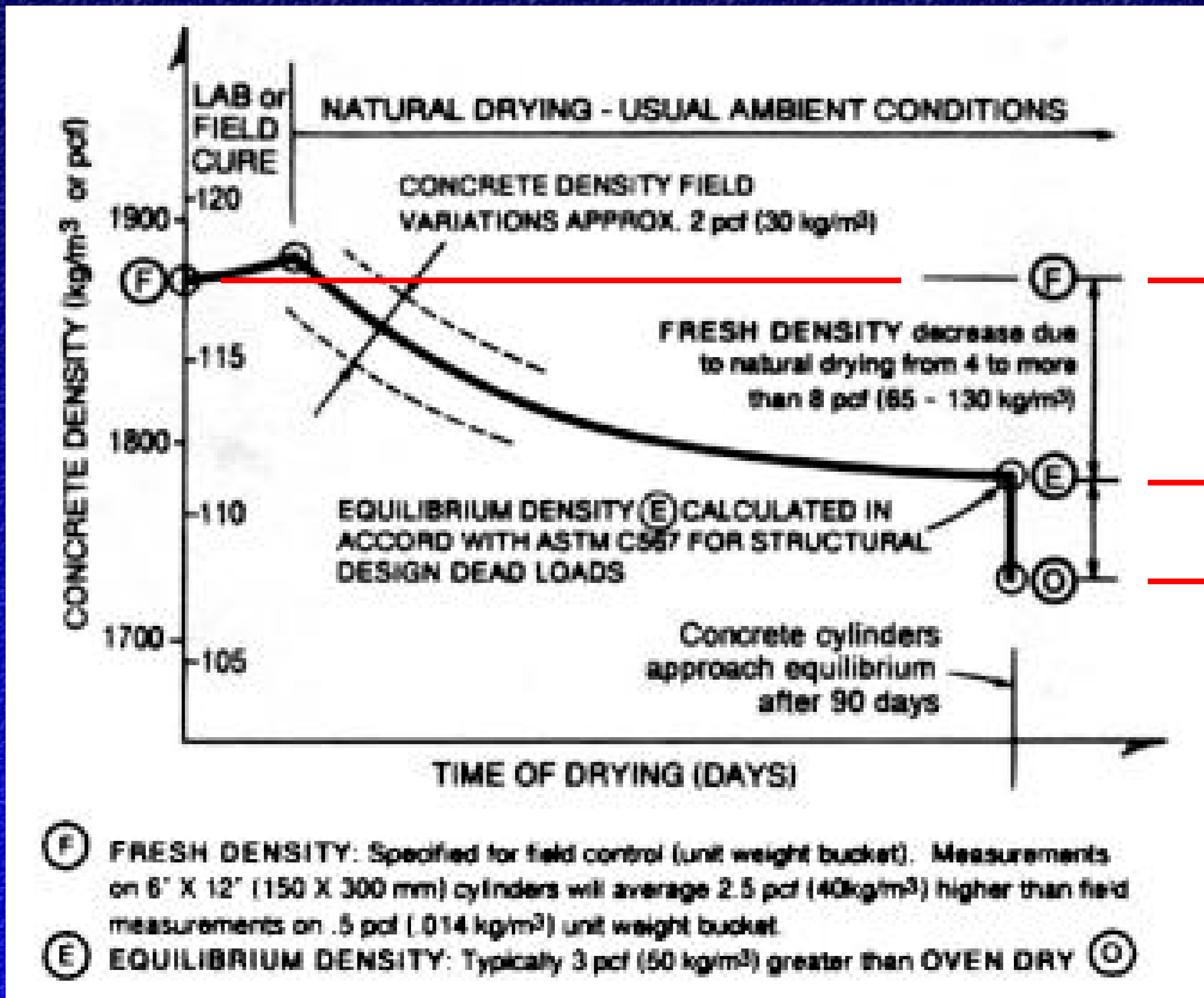
- Defined in ASTM 567
- Density after moisture loss has occurred

"Fresh density" needed for QC during casting

- Supplier may establish fresh density corresponding to specified eqm. density
- Designer may specify fresh density
- Use for handling loads at early age

Be sure to add reinforcement allowance when computing dead loads (typically 5 pcf)

Specifying Density of Lightweight Concrete



Fresh

4 to > 8 pcf

Equilibrium

Oven-Dry

3 pcf

Holm, ASTM Standard Technical Publication 169C (2001)

Compressive Strength of Lightweight Concrete

Minimum compressive strength for structural lightweight concrete

- ***2,500 psi***

Most structural lightweight aggregates can be used for design compressive strengths up to

- ***5,000 psi***

A limited number of lightweight aggregates may achieve design compressive strengths from

- ***7,000 to 10,000 psi***

Design using Lightweight Concrete

- Tensile strength of concrete, f_r or f_{ct}
- Flexure
- Shear
- Horizontal shear
- Modulus of elasticity, E_c
- Prestress losses
- Development length for mild reinforcement
- Transfer and development lengths for prestressing strand

Lightweight HPC for Bridge Decks

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- Precast decks

Cost Comparison

Main Benefits of Using Lightweight Concrete

- Reduced weight (dead load) of structure
- Reduced handling and transportation costs for precast components
- Enhanced durability

Reduced Dead Load

Using lightweight concrete typically reduces structure weight up to 25% compared to normal-weight concrete

- ***Improved structural efficiency***
  - ***Increased spans or wider girder spacings***
  - ***Reduced structure mass for seismic designs***
  - ***Reduced no. and/or size of foundation elements***
  - ***Reduced reinforcement and prestressing***
  - ***Increased deck width on same superstructure***
- ***Reduced transportation costs for precast elements***

Enhanced Durability

- Bond between aggregate and paste
- Elastic compatibility
- Internal curing
- Reduced modulus of elasticity
- Resistance to chloride intrusion
- Freeze-thaw performance
- Wear and skid resistance

Bond between Aggregate and Paste

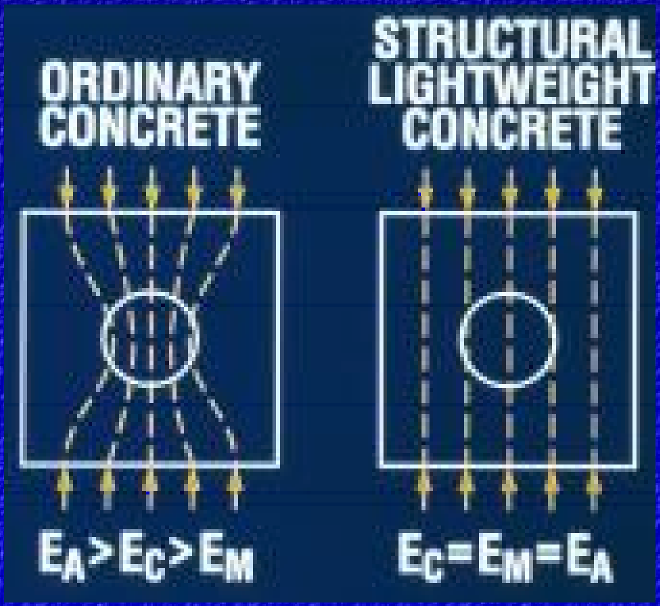
Bond between cement paste and lightweight aggregate is improved compared to normalweight aggregates

- ***Cellular structure and irregular surface of aggregate (mechanical bond)***
- ***Chemistry of the aggregates and cement (pozzolanic bond)***
- ***Transition zone***
- ***Improves durability by reducing micro-cracking***

Elastic Compatibility

Modulus of elasticity of lightweight aggregates are closer to the modulus of the cement paste than normalweight aggregates

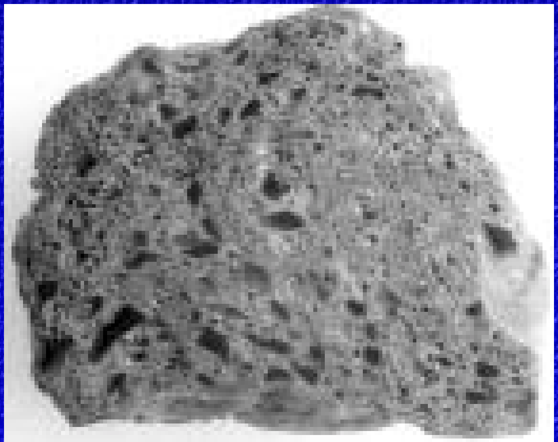
- **Reduces stress concentrations that form around stiffer normalweight aggregate**
- **Reduces microcracking, autogenous shrinkage, and shrinkage cracking**
- **Improves durability by reducing micro-cracking**



Internal Curing

Absorbed moisture within lightweight aggregate is released over time into the concrete providing enhanced curing

- ***More complete hydration can occur***
- ***Especially helpful for high performance concrete that is nearly impermeable to externally applied curing moisture***
- ***Improves tolerance of concrete to improper curing***



Reduced Modulus of Elasticity

NCHRP Report 380 "Transverse Cracking in Newly Constructed Bridge Decks" (1996)

- "Using low-elasticity aggregates should therefore reduce thermal and shrinkage stresses, and the risk or severity of transverse cracking."
- Recommends using concretes with a low cracking tendency
  - Low early modulus of elasticity
  - Low early strength concrete

Lightweight concrete provides low modulus but retains strength

Resistance to Chloride Intrusion

LWC has improved resistance to Cl^- intrusion

Silver Creek Overpass, UT constructed in 1968

Chloride content after 23½ years in service

Depth	LWC Deck	NWC Appr. Slab
0" to ½"	36.7 lbs / CY	20.5 lbs / CY
½" to 1"	18.0 lbs / CY	18.0 lbs / CY
1" to 1½"	7.7 lbs / CY	15.7 lbs / CY
1½" to 2"	0.5 lbs / CY	

Resistance to Chloride Intrusion

San Francisco-Oakland Bay Bridge

- Upper deck constructed with lightweight concrete in 1936 – still in service today

Cores of LW upper deck taken in 1979

- Surface was highly contaminated with Cl^-
- Concentration < 1.0 lb/cy with depth
- No spalling

Cores of NW deck on approaches taken in 1984

- Cl^- content up to 10 lb/cy found to 4" depth
- Some spalling on NW decks

Freeze-Thaw Performance

LWC has excellent freeze-thaw performance, even with aggregate exposed by wear

William Preston Lane, Jr. Memorial Bridge over Chesapeake Bay built in 1952

Deck examined during rehab in 1975

- Concrete containing porous LW aggregate is less susceptible to deterioration from freezing and thawing than NW concrete

Deteriorated NWC decks replaced with LW concrete

Wear and Safety

LWC bridge decks have demonstrated

- Uniform wear
- High skid resistance

Lightweight aggregates can satisfy abrasion tests

Lightweight aggregates are non-polishing

Lightweight HPC for Bridge Decks

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- Precast decks

Cost Comparison

Boulevard Bridge, Richmond, VA

- Two lane bridge
- Deck replaced after 34 years in service

- Wear was minimal
- Wear was uniform
- No deterioration
- No corrosion

Sebastian Inlet Bridge, FL

Constructed in 1964

- Drop-in span has LWC deck, girders and parapet

- Remainder of superstructure is NWC

Examination of deck after more than 30 years

- Wear of the lightweight concrete deck was "essentially the same if not slightly less" than the adjacent normal weight decks

Suwanee River Bridge, Fanning Springs, FL

Constructed in 1964

- *LWC used to achieve long spans*
- *Lightweight concrete deck*
  - *f'_c = 4,000 psi with fresh density of 120 pcf*
- *Lightweight concrete AASHTO Type IV girders*
  - *121 ft continuous spans*
  - *f'_c = 5,000 psi with fresh density of 120 pcf*

Extensive research and field measurement program for several years

Suwanee River Bridge, Fanning Springs, FL

Bridge testing was repeated in 1992 after 28 years of service

- "Deflection and strain data … indicates no increase in flexibility over time."
- "The structural lightweight aggregate concrete used in the decks and girder of this experimental bridge have met expectations and performed satisfactorily in this unique design."

Still in service after 41 years

Photo taken in 2005

Rte. 106 over Chickahominy River, VA

Three span bridge demonstration project

- Lightweight concrete continuous deck
  - f'_c = 4,000 psi with fresh density of 120 pcf
- Lightweight prestressed concrete beams
  - f'_c = 8,000 psi with fresh density of 120 pcf

Only a few deck cracks since opened in 2001

Route 33 Bridges at West Point, VA

Two demonstration projects now under constr.

- ***Mattaponi River Bridge***
- ***Pamunkey River Bridge***

LWC decks are used on LWC girders

- ***Longer approach spans***
- ***Two 200'-240'-240'-200' spliced units with haunched pier segments***

Photos taken in 2005

Route 33 Bridges at West Point, VA

Lightweight concrete was used to reduce foundation loads

- Estimated 10% reduction in piles for main piers
- Also reduced foundation size

Lightweight concrete deck

- f'_c = 5,000 psi with max. density of 120 pcf

Lightweight concrete bulb tee girders

- f'_c = 8,000 psi with max. density of 125 pcf

Material testing and construction monitoring by VTRC

Virginia Dare Bridge at Manteo, NC

The longest bridge in NC at 5.2 miles

LW concrete deck on bulb-tee girders

Highly corrosive coastal environment

- HPC was used for all elements of bridge
- 100 years target service life before any member needs repair as a result of corrosion

Specified properties for the LW deck concrete

- 31 MPa (4,500 psi) compressive strength
- 120 pcf maximum plastic density
- 115 pcf maximum equilibrium density

Whitehurst Freeway, Washington, DC

Rehabilitation of major artery on Potomac River

- Upgrade from H20 to HS20
- Increase bridge width
- Normal weight deck with topping was replaced with lightweight concrete deck
- Only minor modifications to steel framing

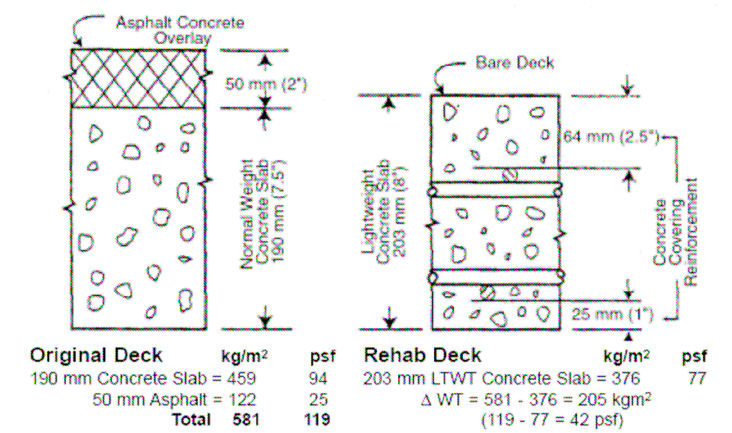

Figure 6. Original and Rehabilitated Decks for Whitehurst Freeway

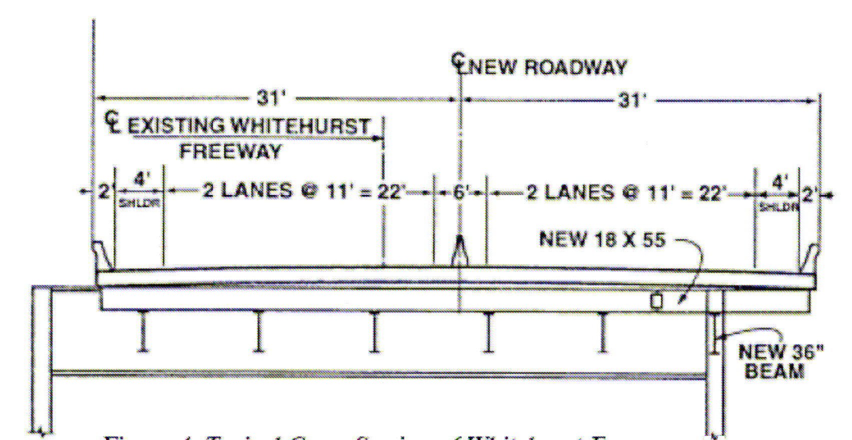

Figure 4. Typical Cross Section of Whitehurst Freeway

Lightweight HPC for Bridge Decks

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Examples of Bridge Decks

- Cast-in-place decks
- Precast decks

Cost Comparison

Woodrow Wilson Bridge, Washington, DC

Bridge built in 1962

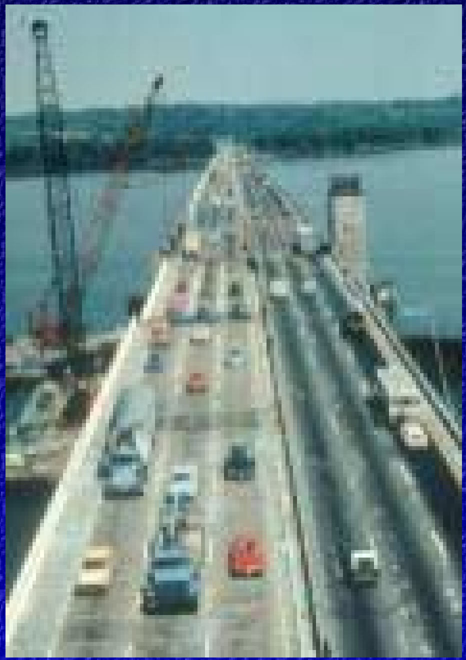
- 2 – 38 ft roadways
- In 15 years, the NWC deck had deteriorated

Deck replacement completed in 1983

- Roadways widened to 44 ft
- Full-depth precast deck panels selected
  - Speed construction to reduce impact on public
  - Improved quality of plant-cast concrete
  - Used 1026 panels each weighing 22 tons

Woodrow Wilson Bridge, Washington, DC

Lightweight concrete deck panels



- f'_c = 5,000 psi with air-dry density of 115 pcf
- Allowed thicker deck slabs
  - Improved stiffness and durability
- Allowed wider deck
  - 38 ft to 44 ft roadway width
- Improvements made without strengthening the existing superstructure
- No deterioration after 13 years in service

James River Bridge, Richmond, VA

I-95 through downtown Richmond

- *Replace deck while maintaining traffic*
- *Prefabricated full-span units with lightweight concrete deck*
  - *Max. dry density of 115 pcf for deck concrete*

Coleman Bridge, Yorktown, VA

Original structure completed in 1952

- 26 ft wide with 2 lanes

Bridge replaced in 1996

- 74 ft wide with 4 lanes and shoulders

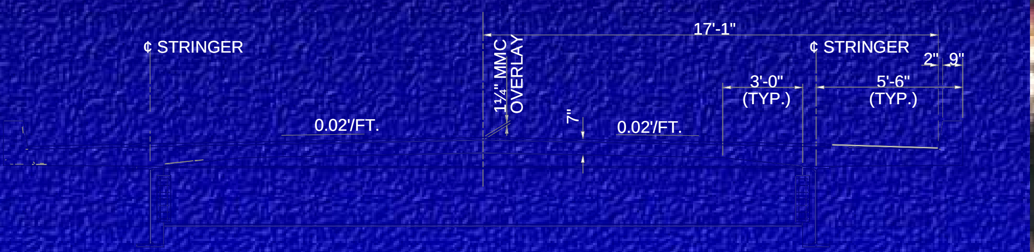
LW concrete deck option was selected based on cost savings and good experience in VA

With reduced deck weight

- The pier caps only had to be widened
- Reduced the steel required in new trusses

Lewis & Clark Bridge, OR & WA

Deck replacement on existing truss spans

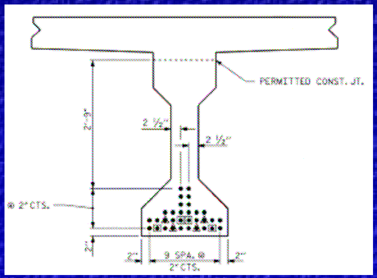


- Precast deck units with floorbeams
- Used LW concrete for deck at 119 pcf
- Deck unit with LWC weighed 184 kips
- Assuming 26 pcf difference, LWC saved about 28 kips for largest deck panel unit

Deck Girder Bridge, Stanley County, NC

Bridge replacement project by NCDOT

- Deck cast on AASHTO III before release
  - Girder length = 107' - 4"
  - Girder spacing = deck width = 6' - 6"
  - Deck thickness varies from 8 to 9"
  - Constant 2" buildup
  - Girder erection took 3½ hours
  - Girder weight = approx. 70 tons
  - If LWC, girder wt. = approx. 58 tons



SCDOT is considering a similar bridge

Lightweight HPC for Bridge Decks

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- Precast decks

Cost Comparison

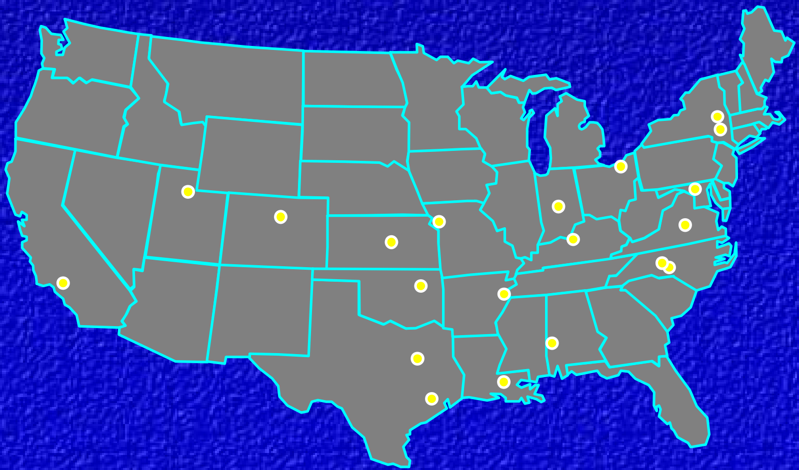
Cost of Lightweight Concrete

Increased cost of aggregate

- Additional processing



- Shipping from the manufacturing plant



Cost Comparison for LW Concrete Deck

From Holm & Bremner, 2000

		LWA & LWC	NWA & NWC	Relative Cost
		A	B	A/B (%)
Cost of coarse aggregate	\$/ton	45	10	450%
Coarse aggregate for 1 yd^3 of concrete	lb	900	1710	--
Cost of coarse aggregate for 1 yd^3 of concrete	\$/yd^3	20.25	8.50	238%
Cost increase with lightweight aggregate	\$/yd^3	11.75	--	--
Typical cost of concrete delivered to project, including small increase for additional cement in lightweight concrete	\$/yd^3	85	70	121%
Cost of concrete in-place, including formwork, reinforcement, conveying, finishing and curing	\$/yd^3	365	350	104%

LWA – Lightweight aggregate; LWC – Lightweight concrete

NWA – Normal weight aggregate; NWC – Normal weight concrete

Cost Premium for Lightweight Deck Concrete

Typical range of cost premium per CY of deck concrete

- *Assuming 8 in. thick deck*

Cost / CY	Cost / SF
$20 / CY	$0.49 / SF
$25 / CY	$0.62 / SF
$30 / CY	$0.74 / SF

Cost Comparisons for Lightweight Concrete

Simple comparisons neglect important factors

- ***Reduced handling and transportation costs***
- ***Reduced erection costs***
- ***Reduced strand and reinforcement***
  - ***For one bridge, a 20-25% reduction in post-tensioning has been estimated***
- ***Reduced cost of substructure & foundations***
  - ***For some bridges, a 10-20% reduction in pilings or foundation costs has been estimated***

Cost Comparisons for Lightweight Concrete

To take full advantage of potential cost reductions from using LWC

- *Typically requires a complete preliminary design including foundations*
- *Increased effort in early design phases*

Can pay large dividends in reduced construction costs

The real test …

- *Many bridges have been successfully constructed using lightweight concrete*

Cost Comparisons for Lightweight Concrete

Rugsundet Bridge, Norway

Using LWC in center span allowed revised design

- *Increased main span from 564 ft to 623 ft using same quantity of post-tensioning*
- *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*

LWC alternate bid was 15% less than NWC bid

Questions?

For more information, please call, or visit

www.stalite.com or www.escsi.org

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