Back-Up Statistics to

Building Bridges and Marine Structures

With Structural Lightweight Aggregate Concrete

Coronado Bridge, San Diego, CA

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Back-Up Statistics to
BUILDING BRIDGES and other Marine Structures with Structural Lightweight Aggregate Concrete

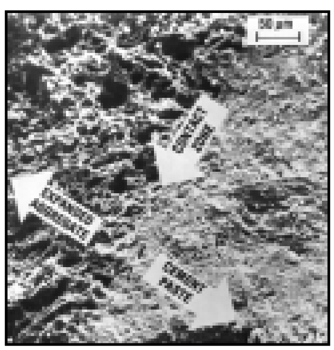
Structural Lightweight Concrete Weathers the Test of Time

Over 80 Years of Performance

For more than 80 years, Structural Lightweight Aggregate concrete (SLC) has solved the weight and durability problems associated with exposed structures. This concrete made with rotary kiln expanded shale, clay, or slate (ESCS) lightweight aggregate, has a proven performance history in bridges and other marine structures. Examination of the structures confirmed that, in terms of durability, structural lightweight concrete performs equally well, or better than, normalweight concrete.

In the study “Criteria for Designing Lightweight Concrete Bridges” (August 1985), the Federal Highway Administration reported that good lightweight concrete had better durability than some normalweight concrete. These findings were based on evidence gathered during visits to 30 bridges and in contacts with state and industry representatives.

In 1975 an independent study of the Lane Bridge across the Chesapeake Bay concluded that “concrete containing porous lightweight aggregate is less susceptible to deterioration from freezing and thawing” than normalweight concrete.



Contact Zone

A survey of Japanese bridges in service for up to 20 years revealed that cracking, carbonation, and salt penetration were reduced with Structural Lightweight concrete bridges, and SLC provided high degrees of durability that surpassed normalweight concrete.

Also, investigations of a number of marine environment SLC structures in service for more than 80 years verify laboratory results indicating good weathering resistance.

(See page 11, William Preston Lane Jr. Bridge, for specific information on the durability of SLC after 33 years.)

Why So Durable?

Resistance to freezing and thawing in any type of concrete (normalweight or lightweight) is achieved by using durable aggregates encased in a durable cement mortar. Although expanded shale, clay and slate (ESCS) aggregates are absorptive, they are also very durable, being composed of vitrified silicates. Laboratory tests showing high Durability Factors after 300 cycles of freezing and thawing are normal for structural lightweight aggregate concrete. It is no surprise properly proportioned air entrained SLC made with ESCS lightweight aggregate is quite durable.

ESCS aggregates have other unique properties that lead to increased durability. These properties include better elastic compatibility, internal curing and improved contact zone between the lightweight aggregate and the cement paste.

ESCS aggregates are less rigid than normalweight aggregates. Moreover, their stiffness closely matches that of the air entrained mortar fraction used in bridge deck concrete. Studies show that this elastic compatibility results in significantly lower stress concentrations at the aggregate-paste interface and greatly reduces the tendency for microcracking.

The contact zone is the transition layer connecting the coarse aggregate particle and the enveloping cement mortar. The quality of this interface is a decisive factor in the long-term durability of concrete. Several studies have shown that the contact zone in lightweight aggregate concrete is far superior to that of normalweight concrete. In deed, the adhesion of the lightweight aggregate to the mortar matrix exceeds tensile strengh of the lightweight particle.

The water absorbed in lightweight aggregate provides moisture available for term-enhanced cement hydration. The absorbed water does not affect the water-cement ratio. The enhanced cement hydration results in improved durability, less micro-cracking and lower permeability.

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

SLC: Ideal for All Types of Bridge Construction

Prestressed, Precast, and Cast-In-Place

Structural Lightweight concrete (SLC) is ideal for all types of bridge construction. The lower self-weight makes it economical to transport larger sized precast sections, reduce the need for extensive falsework, speed erection, and allow for the smaller, more economical equipment.

The overall weight reduction with SLC affords designers greater latitude to meet today's challenges of terrain, budget, seismic conditions, and construction schedules. In addition, reduced weight lowers seismic forces, and allows for reduction of reinforcing and structural steel, as well as smaller foundations and longer spans. The result is a substantial cost savings.

Structural Lightweight concrete also allows the deck thickness to be increased without increasing overall weight compared to normalweight concrete. This affords increased stiffness and additional cover for reinforcing, thereby improving durability.

Renovation and repair

In 1990 more than one-half million bridges in the United States alone were classified as "deficient" in terms of structural integrity or functional capacity. This staggering need for renovation, repair or replacement can be largely addressed with the use of Structural Lightweight Concrete (SLC).

One of the most extensive applications of SLC can be seen in bridge re-decking. **SLC decking achieves two significant goals: low deadload and high durability.** The combination of these two factors often means that bridge widths, traffic lanes, and the thickness of structural slabs can be increased while utilizing existing piers, footings and other structural members. Depending on the nature of the renovation, the use of SLC often increases the live load capacity for older bridge structures, thus meeting the current load specifications.

The use of SLC in bridge structures constitutes a powerful renovation tool. This lighter, more durable material helps designers by providing design solutions for bridge structures that adequately address both expansion and economic issues.

Structural Lightweight Concrete (SLC) Allows for Innovative Bridges

1. Lower Weight

- ∆ SLC is typically 25% to 30% lighter.
- ∆ Requires less reinforcing, prestressing and structural steel.
- ∆ Increases live load capacity
- ∆ Permits longer spans.
- ∆ Permits deeper sections without increasing dead load.
- ∆ Allows for bridge upgrades and expansion without replacing or adding support foundations.
- ∆ Reduces seismic forces

2. High Durability

- ∆ Low permeability.
- ∆ High freeze/thaw resistance.
- ∆ Good resistance to deicing salts and chemicals.
- ∆ The close elastic compatibility between the aggregate and the mortar fraction reduces internal stresses and minimizes microcracking.
- ∆ Superior bond and transition zone between the aggregate and cement paste.
- ∆ A non-polishing, higher skid-resistant surface improves roadway safety.

3. Low Cost

- ∆ Provides versatility for renovation and retrofitting. Decks can be widened or replaced without altering existing support system.
- ∆ Reduced cost of transportation and erection are realized with precast members. More precast members can be transported per truck and less crane capacity is required.
- ∆ Lower foundation costs result from reduced size and/or number of supports.
- ∆ Lower construction costs result from reduced need for extensive falsework/ formwork, less reinforcing steel, and smaller structural members.
- ∆ Longer pieces mean fewer joints.
- ∆ Greater design flexibility to meet today's challenges of design and construction.
- ∆ High compressive strengths capable of meeting modern engineering requirements.

4. Excellent Performance Record

- ∆ Structural Lightweight Concrete has a proven performance of successful use in severely exposed marine and bridge construction for more than 80 years.Over this period it has been subjected to extreme weather and loading conditions, and has proven sound and durable.

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Martinez-Benicia Bridge • California, USA

Martinez-Benicia Bridge

Date of Construction: 1962
Location: State Highway I-680 over the Carquinez Straits
Owner: State of California
Engineer: CalTrans
PO Box 942874
Sacramento, CA 94274
Contractor: Yuba consolidated Industries
LWC Used In: Deck and super-structure
Wearing Surface: Polyester LWC Concrete Applied in 1991
Traffic: Very Heavy
Trucks: 25%

Mix and Design Information:
Density: 115 pcf
Cement Content:
611 #cy-658 #/cy
Air Content: 4-6%
Lightweight Supplier:
Port Costa Materials, Inc.
Coarse Aggregate Type: Baypor F-43
Fine Aggregate Type: Natural Sand
Compressive Strength: 4,000 psi

Martinez-Benicia Bridge

Other Pertinent Data:
No. 10 span is a steel deck truss on reinforced concrete hollow-shaft piers supported by box footing on 72-inch reinforced concrete caissons imbedded in bedrock. Plate girder approach spans are on reinforced concrete piers of various types on spread footings and reinforced concrete abutments on steel piles. The deck is lightweight reinforced concrete. Superstructure spans No. 3-12 are lightweight reinforced concrete slabs on continuous Warren deck trusses. Spans No. 4, 6, 10, and 12 are lightweight suspended spans. Approach spans No. 1,2, and 13-18 are lightweight reinforced concrete slabs on welded steel plate girders.

Pertinent Construction Information:
Bridge length is 6,215 feet. The longest span is 528 feet. The lightweight deck average width is 72 feet. Maximum vertical clearance is 138 feet. Lanes expanded from 4 to 6 in 1991.

Bridge Condition on Most Recent Inspection:
April 16, 1991 rating was 6. Original rating was 7.

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Silver Creek Overpass Bridge • Utah, USA

Silver Creek Overpass Bridge

Date of Construction: Spring1968
Location: State Highway No. 40 over I-80 in Park City, UT
Owner: Utah Department of Transportation
Engineer: Alex Blumfield, Charles Clay and A.R. Mansour
Contractor: Yuba consolidated Industries
LWC Used In: Deck
Wearing Surface: Originally Structural Lightweight Concrete. Later the bridge was paved with an asphalt overlay
Traffic: Heavy
Trucks: 30%

Mix and Design Information:
Designed Density: 100-110 pcf
Cement Content: 611 #/cy
Air Content: 5 ±1%
Lightweight Aggregate Producer: Utelite Corporation
Coarse Aggregate Type: 1/2-inch expanded shale (725 lbs)
Fine Aggregate Type: Expanded shale (267 lbs) and natural sand (873 lbs)
Designed Compressive Strength: 3,000 psi
Split Tensile Strength: Not specified

Silver Creek Overpass Bridge

Pertinent Construction Information:
Placed with slump range 6-8 inches without super-plasticizer.

Bridge Condition on Most Recent Inspection:
On December 3, 1991 the lightweight concrete was in excellent condition. Shown below are the chloride content test results from cores which were taken and tested by the Utah Department of Transportation Materials and Research Section.

Chloride Content Test Results

Depth	LWC Deck		NWC Adj. Approach	
0–1/2 in.	.947%	36.7 #/cy	.528%	20.5 #/cy
1/2 in. –1 in	.466%	18.0 #/cy.	.464%	18.0 #/cy.
1–1 1/2 in.	.199%	7.7 #/cy	.404%	15.7 #/cy
1 1/2 – 2 in.	.012%	.5#/cy		

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Cooper River Bridge • South Carolina, USA

Cooper River Bridge

Date of Construction: June, 1992
Location: State Highway I-526 (Mark Clark Expressway) serving Charleston,SC
Owner: State of South Carolina – Columbia
Engineer: Howard, Needles, Tammen & Bergendorf, Atlanta, GA
Contractor: Cooper River, A Division of Guy F. Atkinson Company.
LWC Used In: Cast-in-place deck over precast lightweight panels and barriers
Wearing Surface: Lightweight concrete deck
Traffic: Heavy **Trucks:** 15%
Mix and Design Information:
Density: 112 pcf ± 2 pcf
Cement Content: 681 #/cy
Air Content: 4.5 ±1.5%
Lightweight Aggregate Producers:
Carolina STALITE Company (cast-in-place)
Carolina SOLITE Corp. (pre-stressed/precast)
Coarse Aggregate Type: Stalite 3/4 inch to # 8; Carolina SOLITE 1/2 inch to # 4 (AASHTO M-195)
Fine Aggregate Type: Sand
Designed Compressive Strength: 4,000 psi for cast-in-place; 6,000 psi for precast deck used as forms
Split Tensile Strength: 485 psi

Cooper River Bridge

Pertinent Construction Information: The bridge has a total bridge length of 16,450 ft. and a typical width of 93 ft. 3 in. The main span employs a modified Warren Truss 800-ft long, and lightweight concrete decking. In other areas, lightweight concrete decks are cast over precast lightweight panels These are carried by Type V prestressed concrete girders with spans of 125 feet. The use of lightweight concrete helped reduce foundation and seismic loading and increase span length and shorter truss spans.

Because the concrete batch plant had limited overhead aggregate storage space, only one grading of lightweight could be used (ASTM C 330 - 3/4 in. to # 8). The relatively low specified air content coupled with the low slumps associated with bridge deck construction made pumping this concrete mixture particularly challenging. Not counting the SLC used in the precast members, more than 15,000 cu. yds. of Lightweight Aggregate concrete were cast in the pile caps and decks. The majority of this material was placed by pumping. Maximum distance pumped was 100 feet vertically and 850 feet horizontally.

This bridge was designed to endure hurricane-force winds in excess of 155 mph, earthquakes causing ground accelerations of 0.051g, and the impact of ship collisions.

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Boknasundet Bridge • Rogaland County, Norway

Boknasundet Bridge

Date of Construction: March 1989 - Dec. 1990
Bridge Type: Balanced cantilever, box girder
Location: State Highway No. RV 9, Norway, over Boknasundet
Owner: Department of Public Roads
Engineer: Department of Public Roads
Contractor: Aker Entrepreneur
LWC Used In: Beams and deck
Wearing Surface: Normal density concrete C-65 with steel fiber
Traffic: Heavy **Trucks:** 20%
Mix and Design Information
Density: 1,950 kg/m^3 (121.7 pcf)
Cement Content: 430 kg/m^3 (724 #/cy)
Air Content: 3 - 4%
Lightweight Aggregate Producer: Liapor
Coarse Aggregate Type: Liapor 8
Fine Aggregate Type: Natural sand 0-5 mm
Compressive Strength: LWC 60 MPa cube strength (8,700) psi (multiply by .9 for approx cylinder equivalent)
Bridge Condition: 1991, Excellent

Antioch Bridge
California, USA

Antioch Bridge

Date of Construction: 1978
Location: State Highway No. 12, over the Carquinez Strait
Owner: State of California
Engineer: Caltrans, PO Box 942874 Sacramento, CA
Contractor: Peter Kiewit & Sons
LWC Used In: Deck
Wearing Surface: Polyester SLC
Traffic: Moderate **Trucks:** 15%
Mix and Design Information
Density: 1,840 kg/m^3 (115 pcf)
Cement Content: 658 #/cy
Air Content: 4 - 6%
Lightweight Aggregate Producer: Port Costa Materials
Coarse Aggregate Type: Baypor F-43
Fine Aggregate Type: Natural sand
Compressive Strength: 4,000 psi

Antioch Bridge

Pertinent Construction Information:
2-lane bridge with a total length of 9,437 ft.; longest span, 460 ft.; Maximum vertical clearance 135 ft. Average width, 43.5 ft.

Bridge Description
Lightweight reinforced concrete deck is on two continuous composite welded corten steel girders. Spans No. 1-4 are on reinforced concrete two-column piers on precast, prestressed concrete piles. Continuous reinforced concrete slabs (No. 41-70 are on reinforced concrete 4-column bents on precast, prestressed concrete piles. The condition upon the most recent inspection (7-12-92), rating was 7. The original rating was 9.

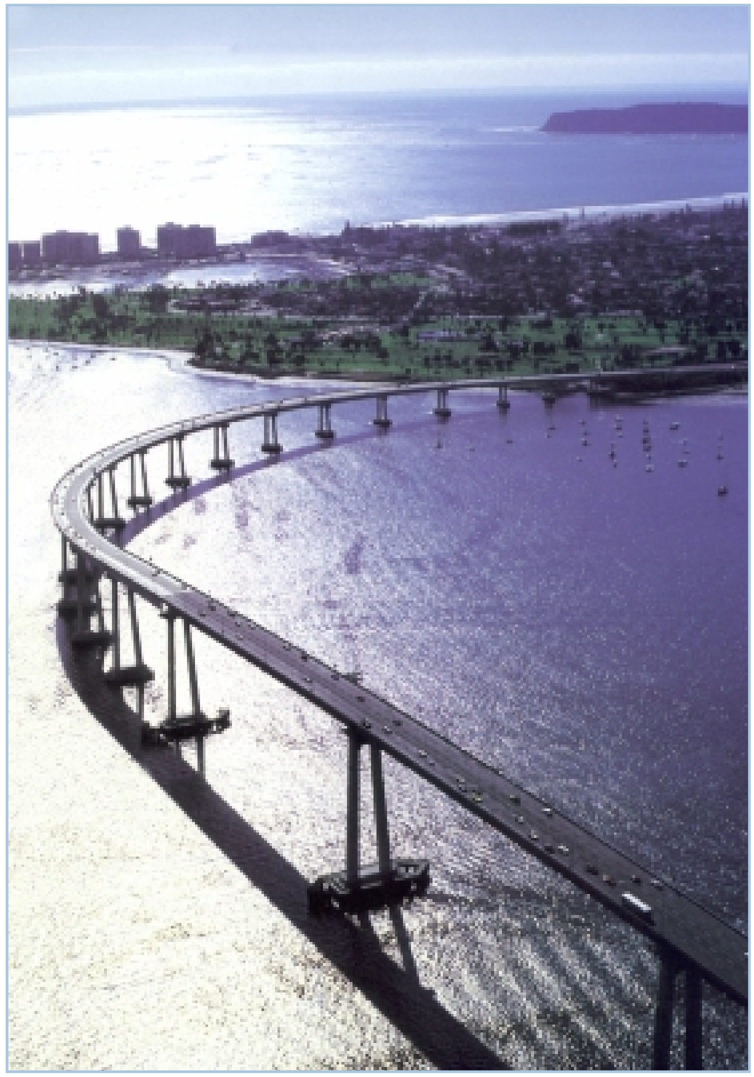
BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Coronado Bridge • California, USA

Coronado Bridge

Date of Construction: 1969
Location: State Highway No. 75 over San Diego Bay, San Diego, CA
Owner: State of California
Engineer: E.R. Foley
Contractor: Murphy-Pacific Company; W.F. Maxwell, Inc; Jay Atkinson Company
LWC Used In: Lightweight precast, prestressed concrete girders
Wearing Surface: Normal weight concrete
Traffic: Moderate **Trucks:** 15%

Mix and Design Information
Density: 115 pcf air-dry
Cement Content: 705 #/cy
Air Content: 3%
Lightweight Aggregate Producer: Pacific Lightweight Products Co.
Coarse Aggregate Type: Expanded shale
Fine Aggregate Type: Natural weight sand
Compressive Strength: 5,500 – 6,000 psi at 28 days
Other Pertinent Data: 11,179 ft. long, 200 ft. high



Coronado Bridge

Pertinent Construction Information:

A total of 307 precast/prestress structural LWA girders were produced more than 100 miles from the bridge site, and then transported overland for installation on the bridge spans. Of these girders, 206 are 5 feet 6 inches deep, and 41 are 7 feet 6 inches deep. The average length of the smaller girders is 95 feet with a maximum length of 117 feet, while the deeper girders are 151 feet long with two-foot-wide top flanges and 8-inch webs.

The structural LWC used for the pretensioned beams made possible the benefits of plant fabrication and overland transportation to the bridge site. Precast in Santa Fe Springs, CA, the beams were produced under close quality control. The elements were steam cured under conditions permitting tight controls on shrinkage and modulus of elasticity.

Weight reduction of the smaller 5-foot 5-inch deep girders transported to the bridge site by highway was a major factor in making this type of transportation feasible. The giant 151-foot girders were transported by the Santa Fe Railroad to the bridge site. Each girder was loaded aboard three 60-foot flat cars with the first and third cars supporting their weight. The center car served as a spacer. The girders were laterally braced for transportation by means of the specially designed framing and cradling system.

Two 115-ton capacity truck cranes were used for their erection at the site. In all, the 11,179-foot-long bridge contains 6,000 cubic yards of prestressed lightweight concrete.

Bridge Condition at Last Inspection: Good

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Heart of America Bridge • Missouri, USA

Heart of America Bridge

Date of Construction: 1985
Location: Missouri State Highway No. 9 over the Missouri River, Kansas City
Owner: State of Missouri
Engineer: Howard, Needle, Tammen, and Bergendorf, Kansas City, MO
Contractor: Wilkerson-Maxwell, Kansas City, MO
LWC Used In: Lightweight precast, concrete
Wearing Surface: Lightweight concrete deck panels with SLC placed on top
Traffic: Heavy urban commuter and commercial

Mix and Design Information
Density: 110 pcf
Cement Content: 696 #/cy
Air Content: 6%
Lightweight Aggregate Producer: Buildex, Inc.
Coarse Aggregate Type: Buildex
Fine Aggregate Type: Kaw river sand
Compressive Strength: 4,000 – 5,000 psi

Heart of America Bridge

Pertinent Construction Information:
The heart of America Bridge is a vital link between downtown Kansas City, MO and the industrial and residential areas of KC which lie north of the river. It was built to increase traffic capacity and replace the aging ASB bridge. Using structural lightweight concrete in the bridge deck allowed increased spans and reduced dead loads. This improved the overall economy of the structure. The deck is composed of cast-in-place Structural Lightweight Concrete (3,000 cy), which was placed on top of the precast Structural Lightweight Concrete deck panels.

The concrete used in both the precast and cast-in-place portions of the deck met standard Missouri Highway and transportation Department specifications for Structural Lightweight Concrete: a 7.4 sack, air-entrained mix with a density of 105 -120 pfc. Aggregates used included 3/8 x No. 8 and No. 4 x 0 Buildex lightweight aggregate and normalweight siliceous river sand.

Bridge Condition on Most Recent Inspection:
3/93 –Good

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

ESCSI Information Sheet # 4700.4

Lewiston Pump-Generating Plant Bridge • New York, USA

Lewiston Pump-Generating Plant Bridge

Date of Construction: 1960
Location: State Highway I-190
Owner: New York State Dept. of Transportation
Engineer: UHL, Hall & Rich, Boston, MA
Designer: Schupack & Zollman, Newton Square, PA
Contractor: Tuscarora Contractors Niagara Fall, NY
LWC Used In: Prestressed Lightweight Girders, Lightweight slabs
Wearing Surface: 2.5 inch asphaltic
Traffic: Heavy

Mix and Design Information
Cement Content: 658 #/cy
Air Content: 6%
Lightweight Aggregate Producer: Hydraulic Press Brick Company
Compressive Strength: 5,000 psi

Lewiston Pump-Generating Plant Bridge

Pertinent Construction Information:

Precast units were manufactured by George Rackle & Sons, Cleveland OH. After more than 40 years of continuous service carrying heavy traffic under well-known severe winter conditions, the Lewiston Bridge in New York near Niagara Falls will continue to carry traffic for many more years.

The bridge is constructed of 204 prestressed lightweight concrete girders and nearly 6,000 precast lightweight concrete roadway slabs. The units were plant produced near Cleveland, OH, and shipped approximately 220 miles to the site. Using high-strength Lightweight Structural Concrete in the elements was an important factor in reducing shipping costs and gaining the advantages of an efficient plant-casting operation. The design approach, which made full use of precast units, greatly reduced bridge construction costs, especially since the deck of the bridge was about 100 feet above the reservoir floor.

The 68-foot “I-shaped girders are 54 inches deep and were post-tensioned at a plant using 1.5 inch diameter cables made up of 12-wire assemblies. A 5,000-psi lightweight concrete using 7 sacks of Type I cement provided sufficient strength in 16 hours so that the units could be removed from the forms and placed in storage for additional curing. Stressing operations followed in three or four days. In addition to these I-shaped girders, 24 special walkway girders were required; u-shaped sections are 6 feet wide and 3 feet 8 inches deep.

The roadway slabs are 3 inches thick and generally measure 6 feet 10 inches by 2 feet. A 4,000 psi lightweight concrete mix was used for these units. At the bridge site, the slabs were set into span between girders and act as forms to receive the 5-inch, cast-in-place concrete deck. The girders have shear connectors extending from the top flange into the deck concrete, and the slabs have roughened top surfaces so that a composite 8-inch deck is achieved for full live-load capacity.

Bridge Condition on Most Recent Inspection:

The 1991 inspection by NY DOT Region 5 reports that the lightweight concrete structural members and the concrete deck are in almost new condition.

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Ohio Turnpike Twin Bridges • Ohio, USA

Ohio Turnpike Twin Bridge

Date of Construction: Original normalweight ,1953; LWC deck replacement in 1983-4
Location: Ohio Turnpike I-80
over the Maumee River near Toledo, OH
Owner: Ohio Turnpike Commission, Berea, OH
Engineer: J.E. Greiner Co, OH
Contractor: National Engineering and
Contracting Company, Strongville, OH
LWC Used In: Deck and Parapet Walls
Traffic: Heavy
Trucks: 20%

Mix and Design Information
Density: 114-117 pcf
@ 28 days, avg. 116 pcf
Cement Content: 715 #/cy Type II
Air Content: 6%
Lightweight Aggregate Producer:
Hydraulic Press Brick Company
Coarse Aggregate Type:
Haydite 3/4 x No.4
Fine Aggregate Type: Natural Concrete Sand
Compressive Strength: 4,500 psi
Other Pertinent Data:
Twin Bridges' deck widened with lightweight concrete from 35 ft. 10 in. to 40 ft. 8 in., 8.5 in.. thick.
Deck length: 1,394 feet
Pertinent Construction Information:
11 spans – composite with post-tensioned lightweight concrete
Bridge Condition on Most Recent Inspection:
1992. very good

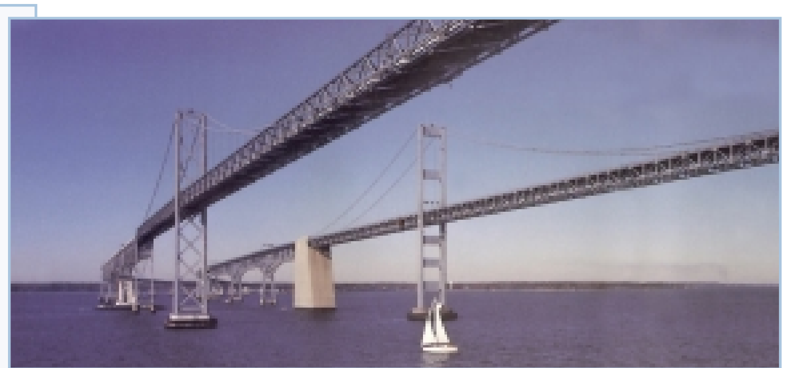
BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

William Preston Lane Jr. Bridge • Maryland, USA

William Preston Lane Jr. Bridge

Date of Construction:
East bound (original) 1952
West bound 1975
Redecked East bound 1988

Location: State Highway No. 50 over Chesapeake Bay
Owner: Maryland Toll Facilities Administration
Engineer: Greiner Engineering Sciences
Contractor: Whiting Turner
LWC Used In: All concrete decks, barriers and parapet walls
Wearing Surface: Various materials
Traffic: Very heavy (80,000 vehicles/day in summer)
Mix and Design Information
1952 East Bound
Density: 103 pcf
Cement Content: 705 #/cy
Lightweight Aggregate Producer: Carolina SOLITE Corp.
Aggregate Type: Carolina SOLITE 3/4 in.- No.4, #4-0 and Natural Sand
Compressive Strength: 3,500 psi
1975 West Bound
Lightweight Producer: Norlite Corporation
1988 Redecking (East Bound)
Lightweight Producer: Carolina SOLITE Corp.
Parapet Walls: Constructed with extruded, zero slump, 3-way mix consisting of Carolina SOLITE coarse aggregate, AF Old SOLITE fine aggregate, and a minimum amount of natural sand; design weight: 105 pcf



William Preston Lane Jr. Bridge

Other Pertinent Data: From a durability perspective, the lightweight concrete outperformed the normalweight concrete used in the approach-spans.

Pertinent Construction Information: *The Chesapeake Bay Bridge: Lightweight Concrete Remains durable After 33 Years*, by T.A. Holm, P.E., F.A.C.I.

Built in 1952 over the Chesapeake Bay, the William Preston Lane Jr. Memorial Bridge was made of structural lightweight concrete with the following batch quantities for a cubic yard of concrete: 7.5 sacks of cement, 1370# of fine lightweight aggregate and 750# of coarse lightweight aggregate. Water-cement ratio was 0.40, 28-day compressive strength, 4,830 psi; and air-dry unit weight, 103# per cubic foot. In 1975, after the second parallel bridge crossing had been built, the first bridge was temporarily closed for inspection and maintenance. Petrographic analysis on core samples taken after the asphalt wearing surface was removed showed secure adhesion between the aggregate and cement paste and little evidence of cracking. Additional examinations in 1983 supported the findings of the 1975 studies and disclosed negligible further deterioration.

These studies confirm that lightweight concrete is durable when exposed to freezing and thawing cycles. Because the modulus of elasticity of lightweight aggregate is close to the modulus of elasticity of the concrete mortar, stresses in the contact zone between aggregate and mortar are significantly reduced. The aggregate and mortar, in this case, tend to behave as one homogeneous material. On the other hand when the modulus of elasticity of aggregate differs significantly from that of the mortar, the mortar and aggregate as dissimilar materials: Example: When the concrete consists of stiff aggregate in soft mortar (normalweight concrete), bond strength between aggregate and mortar may be exceeded and contact zone microcracking may occur. When concrete consists of soft aggregate instill mortar (very low density, nonstructural lightweight concrete), the soft aggregate is crushed. However, when aggregate and mortar have similar strength and elastic properties (Structural Lightweight Concrete), aggregate and mortar are securely bonded and microcracking is reduced. Fewer microcracks mean fewer places for water and de-icers to enter the concrete and cause damage.

A 1973 Russian study has shown that for lightweight concrete, the micro-hardness of mortar in contact with aggregate is much greater than the micro-hardness of mortar outside this zone. This is due in part to a chemical reaction between the products of cement hydration and the aluminosilicates formed at the surface of the lightweight aggregate during high temperature production of the aggregate.

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Sebastian Inlet Bridge • Florida, USA

Sebastian Inlet Bridge

Date of Construction: 1964
Location: Florida State Highway No. A1A over the Indian River outlet in to the Atlantic Ocean
Owner: Florida Road Department
Engineer: Florida Department of Transportation with Howard, Needles, Tammen, and Bergendorf, Orlando, FL
Contractor: Cleary Brothers Construction Co., W. Palm Beach, FL
LWC Used In: Decks, long span, precast beams, railings, etc.
Wearing Surface: Solite Lightweight Concrete
Traffic: Moderate 1982: 3,227 vehicles per day; 1.18 million vehicles per year

Mix and Design Information
Density: 115 pcf
Air Content: 6%
Lightweight Aggregate Producer: Solite Corporation
Coarse Aggregate Type: Solite 3/4 to No. 4
Fine Aggregate Type: Natural sand
Compressive Strength: 4,000 psi - deck; 5,000 psi - beams

Sebastian Inlet Bridge

Other Pertinent Date: Innovative “drop-in spans.” This bridge was built in 1964 using a precast and pre-tensioned concrete girder system with spans of 100 ft., 180 ft., and 100 ft. cast-in-place concrete deck.
Pertinent Construction Information:
Fishermen Get Lucky Break at New Prestressed Bridge, by William E. Dean, Principal Engineer at Howard, Needles, Tammen & Bergendorf.

Motorists and fishermen welcome the bridge across east coast Florida’s Sebastian Inlet because of the fishing walkways aside the 1,548 foot-long bridge. Three conditions were imposed on the designers by the Florida Road Department: 1. With the ocean only 200 yards away, a structure unaffected by the corrosive action of salt air, and thus not requiring constant maintenance painting, was indicated. 2. The channel, in constant use by vessels, had to be kept open all during construction. 3. The swift currents of Sebastian Inlet (6 to 8 fps during tide cycles), with consequent navigational hazards, precluded any construction of the channel opening by falsework.

Precast, prestressed concrete beams, requiring no painting and capable of erection without support within the channel opening, seemed to be the answer, except for one more problem. The US Army Corps of Engineers required that any bridge crossing the channel had to have a main span 180 feet long. This was completely unprecedented for prestressed bridge construction in Florida. Before this, the longest beam length ever used was 100 ft.

The engineers evolved a design which could utilize standard AASHTO-PCI prestressed I-sections, cast in any of the several nearby prestressing yards, and which combined with and unusual design expedient, made use of lightweight concrete.

At both ends, approaches are eight simple spans of 73 ft., using five Type III girders in each span, supported on pedestal piers that are footed on concrete piles. At the center are three main spans: 100, 180 and 100-feet long. The two 100-ft spans are made up of 65-ft long anchor girders that extend from the pier to a splice point, then 65-ft. long anchor-cantilever girders that reach from the splice point across the channel piers and cantilever 30 ft. beyond. The cantilevered arms from each side support 120-ft-long drop in girders that complete the required 180 ft. span over the main channel.

The cantilever concept directed the designers to lightweight concrete because it was obviously highly desirable to keep the weight of the drop-in section to a minimum. The pre-cast-prestressed girders and the cast-in-place deck slabs, curbs, and parapets for the drop-in portion are Structural Lightweight Concrete. The 6-ft.-deep 120-ft. girders weighed only 51 tons each, while the 65-ft.-long anchor-cantilever girders of conventional concrete weighed 42 tons each. 28-day strengths of 5,000 psi and 4,000 psi were specified for the girders and deck, respectively. These mixes provided strength that averaged 1000 psi more than specified.

Compared to steel girder construction, the “first cost” of the new bridge was substantially less, and additional savings will accrue from reduced maintenance.

The Sebastian Inlet Bridge won the Prestressed Concrete Institute Special Award in 1964.

Bridge Condition on Most Recent Inspection:
Feb. 1993 – Excellent condition after 30 years of service.

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Sandhornøya Bridge •Nordland County, Norway

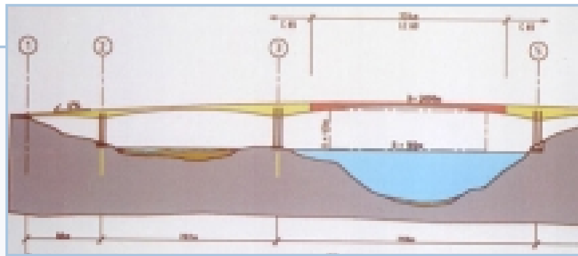
Sandhornøya Bridge

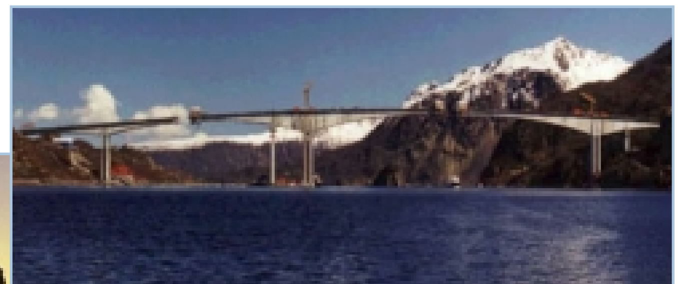
Bridge Type:
Balanced cantilever, box girder
Date of Construction
3/88 – 9/89
Location:
State Highway No. RV 17, Norway
Owner: Department of Public Roads
Engineer: A. Aas Jacobsen, A.S.
Contractor: Eeg Henriksen, A.S.
LWC Used In: Deck and beams
Traffic: Heavy **Trucks:** 15%

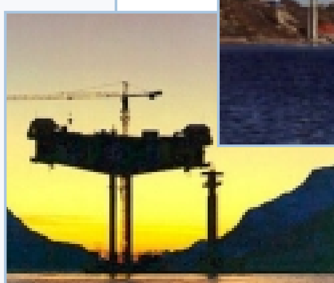
Mix and Design Information
Density: 1950 kg/m^3 (fresh)
Cement Content: 400 kg/m^3
Air Content: 3 -4%
Lightweight Aggregate Producer:
Liapor
Coarse Aggregate Type: Liapor 8
Fine Aggregate Type: Sand 0-4
Minimum Compressive Strength:
Lightweight Concrete
55 MPa Cube Strength
Bridge Condition on Most Recent Inspection:
1992 - Excellent

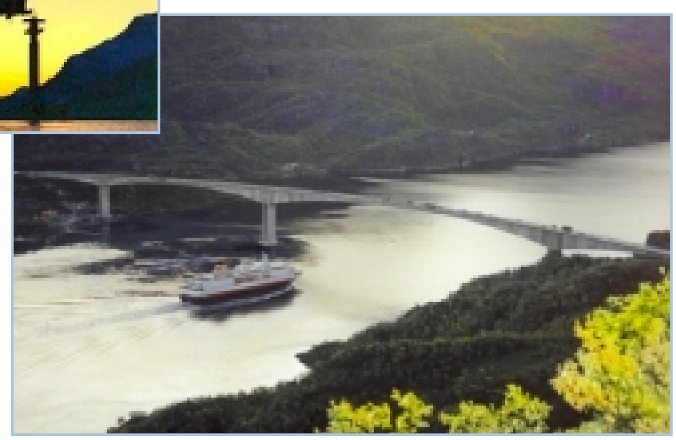
BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Raftsundet Bridge • Raftsundet Sound, Norway









Raftsundet Bridge

Date of Construction: 1998
Location: Raftsundet Sound, Norway, 300 Kilometers north of the Arctic Circle
Owner: Norwegian Road Authorities, Nordland
Engineer: Dr. Ing Aas-Jakobsen
Contractor: AS Anlegg
Architect: Boarch Arkitekter A/S
Main Span: 200 + 298 m
Side Spans: 86 = 125 m
Concrete Volume: LC60: 2,400 m^3
C45: 1,600 m^3; C65: 10,700 m^3
Mix and Design Information
Density: 19.5 kN/m^3
Cement Content: 430 kg/m^3
Air Content: 3-6%
Lightweight Aggregate Producer:
Carolina Stalite Company
Coarse Aggregate Type: Stalite 4-16 mm
Fine Aggregate Type: Natural Sand
Compressive Strength: 60 Mpa Cube Strength

Raftsundet Bridge

Pertinent Construction Information:
Continuous post-tensioned, cast-in-place, box section. Central 224 meters of the 298 meter main span is constructed of high performance structural lightweight concrete.

Other Pertinent Data:
Raftsundet bridge, with a main span of 228 m and a total length of 711 m, was the longest concrete cantilevered span in the world when the cantilevers were joined on June 24, 1998. The structure is exposed to severe wind conditions, with a design gust wind speed of nearly 50 m/s. The surrounding alpine topography, with high mountains rising up to 1000 m above sea level, creates fluctuation wind forces of large magnitude against the bridge. The main span is built of high-strength lightweight aggregate (LWA) concrete LC60, the side spans and piers in normal density (ND) concrete C65. The bridge is high and provides a ship channel of 45 x 180 m.

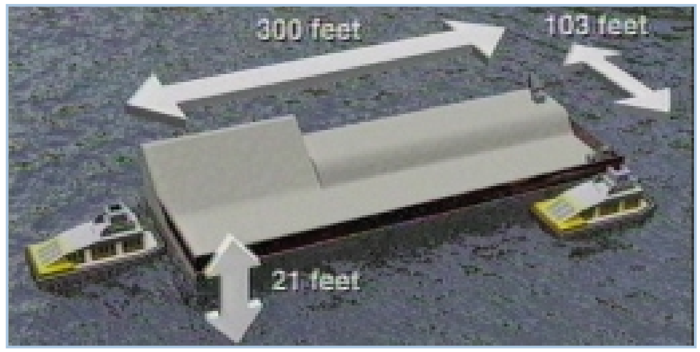
BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Braddock Gated Dam • Pennsylvania, USA

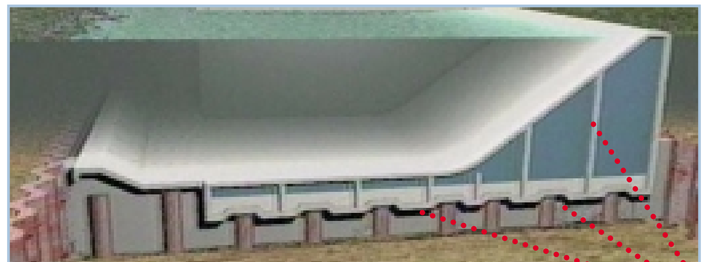
Braddock Gated Dam

Date of Construction:
Scheduled for Completion:
November 2003

Location: Monongahela River, Braddock, PA
Owner: U.S. Army Corps of Engineers
Engineer: Ben C. Gerwick
Contractor: J.A. Jones, Traylor Bros. (Joint venture)
Architect: Bergman Associates
LWC Used In: Pre-cast interior dam supports and floor sections
Mix and Design Information
Specified Compressive Strength @ 28 days: 5,000 psi
Specified Maximum Saturated Density @ 28 days: 125 lb/ft^3
Air Content: 6%
Super plasticizer (Bottom Slab Only): 48 oz/yd^3
Specifications:
Weir Bay Sections: 110 ft. x 103 ft.
Dam Section One: 333 ft. x 103 ft.
Dam Section Two: 265 ft. x 103 ft.
Lightweight Aggregate Producer: Hydraulic Press Brick Company
Coarse Aggregate Type: Haydite 3/4”- No. 4
Fine Aggregate Type: Tri-State Dredge 16
Compressive Strength: 5,886 psi



(above) Floatable section to be placed on pier foundation



Cast-in-place SLC interior supports and floor sections

Floatable section under construction (Feb. 2001)

Floatable section (bottom left) passing Pittsburg, PA

Braddock Gated Dam

Other Pertinent Data:
Structural lightweight construction was begun in March 2000. Precast and cast-in-place elements were used to construct dam sections in dry-dock 30 miles down river from the dam site. 1,500 yd^3 of structural lightweight Concrete (SLC) was in the pre-cast interior dam support walls, and 2,600 yd^3 in the floor sections. Sections were floated up river and set in place on a pier foundation system. Because lightweight concrete was used, the actual draft was only 11 feet. Additional precast and cast-in-pace construction was done to accommodate lock gates, control facilities and a pedestrian bridge.

The project is the first ever “in-the-wet” dam construction and is scheduled for completion in November of 2003.

Neuse River Bridge • North Carolina, USA

Neuse River Bridge

Location: New Bern, North Carolina over the Neuse River
Owner: NC DOT
Engineer: Ralph Whitehead Engineers
Contractor: Traylor Brothers
LWC use in: Interchanges and navigable portion, deck width variable; widest - 85 feet
Wearing Surface: Grooved lightweight concrete
Traffic: Heavy **Trucks:** 15%

Mix and Design Information
Density: 115 lbs/ft^3
Cement Content: Approx. 570 cement and 170 fly ash
Air Content: 6%
Lightweight Aggregate Producer: Carolina STALITE Company
Coarse Aggregate Type: STALITE 3/4 - #4
Fine Aggregate Type: Natural sand
Compressive Strength: 4,500 psi

Neuse River Bridge

Other Pertinent Data:

Conventional design using SLC decks on normal weight AASHTO beams. Elevated interchanges were required because of sensitive wetlands (north) and historic district (south).

Napa River Bridge • California, USA

Napa River Bridge

Date of Construction: 1977
Location: Highway 29, Napa, California over the Napa River
Owner: State of California
Engineer: Caltrans
LWC use in: Decks

Napa River Bridge

Other Pertinent Data:

The Napa River Bridge was part of a project to shift traffic from a conventional highway, which went through the heart of downtown Napa, to a new freeway outside the densely developed downtown and associated residential areas. Napa, located northeast of San Francisco, has a mild climate. The Napa River drains into the San Francisco Bay and is subject to tidal influences at the bridge site.

The Napa River Bridge is a segmental prestressed bridge and was constructed using lightweight concrete. The bridge extends from a high approach fill to the east, across the Napa River, and down to a lesser approach fill to the west. The bridge is 2,230 feet long with spans varying from 250 feet in length over the main channel, to 120 feet to the west. The bridge, which has a constant superstructure width of 68 feet, is haunched with a minimum structure depth of 7 feet 9 inches at the center of the span, to a maximum structure depth of 12 feet at the piers. The bridge piers, supported on piles, are voided 8' x 25' columns with beveled edges and soft flares at the top.

BUILDING BRIDGES
and other Marine Structures
with Structural Lightweight Aggregate Concrete

Wabash River Bridge • Indiana, USA

Wabash River Bridge

Date of Construction: 1994
Location: 231 Bypass at
Lafayette, Indiana
over the Wabash River
Owner: State of Indiana
Engineer: Janssen and Spaans
Engineering
Contractor: Rieth-Riley
Construction Company
LWC use in: Medium weight bulb tees
Mix and Design Information
Density: 125 pcf
Cement Content: 752 lbs. Type III
Air Content: 6%
Lightweight Aggregate Producer:
Hydraulic Press Brick Company
Coarse Aggregate Type: 3/8 x # 8
Fine Aggregate Type: None
Compressive Strength: 4,500 - 5,500 psi

American River Bridge • California, USA

American River Bridge

Date of Construction:
1999
Location:
City of Folsom, California,
over Lake Natoma
Owner: City of Folsom
Engineer: HDR Engineering
Contractor: C.C. Meyers, Inc.
LWC use in: Two concrete box frames

Mix and Design Information
Density: 125 pcf
Cement Content: 752 lbs. Type III
Air Content: 6%
Lightweight Aggregate Producer:
TXI - Pacific Custom

American River Bridge

Pertinent Construction Information:
This bridge crosses lake Natoma and Negro Bar State Park, and connects Folsom Blvd. to the south with Folsom-Auburn Road to the north. The 690-meter-long structure consists of two structural lightweight concrete box frames supported by seismic isolation bearings. The substructure consists of deep, large diameter drilled shafts. The lake crossing consists of three 100-meter spans with 55-meter back spans of dual single cell, prestressed concrete, haunched box girders with a continuous 33.6-meter wide deck. Drilled shafts are 2.5 meters in diameter, with maximum trip about 27 meters below the lake surface. Precast, post-tensioned lightweight concrete decorative arches are below each cell of the main spans. Arch thrusts are supported by four inclined shafts, installed coincident with with the arch thrust line at each end of the two series of three arches. The park crossing consists of five 58-meter maximum spans of multi-cell, prestressed concrete, constant depth box girders, with a deck varying in width from 33.6 meters to 41.2 meters. Drilled shafts are 2.0 meters in diameter, and have a maximum tip about 10 meters below ground. The structure will carry four lanes of traffic, shoulders, sidewalks, and a median with sufficient width for future LRT/HOV lanes.

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Brooklyn Bridge • New York USA

Brooklyn Bridge

Opened to Traffic: 1883
Location: New York, NY
over the East River
Owner: City of New York
Engineer: Weidlinger Associates
Contractor: Yonkers Contracting Company
LWC use in: Emergency Deck Replacement/metal grid with LWA concrete fill (1999)
Wearing surface: Asphalt

Mix and Design Information
Density: 118 pcf
Cement Content: 6,000 cubic yards
Air Content: 5%
Lightweight Aggregate Producer:
Northeast Solite Corporation
Coarse Aggregate Type: 3/8”- # 8
Fine Aggregate Type: Natural sand
Compressive Strength: 3,500 psi

Brooklyn Bridge

Pertinent Construction Information:

Structural lightweight concrete allowed for re-decking and restoration of the Brooklyn Bridge, thus complementing and preserving its Historic Landmark designation. The expanded Esopus shale lightweight aggregate used on the project was processed in kilns owned and operated by Northeast Solite Corporation in Saugerties, Ulster County, New York. Coincidentally, the Brooklyn Bridge Brand natural cement used in the building of the uprights of the original bridge in 1886 came from Rosendale, NY, just twenty miles south of the Northeast Solite quarry.

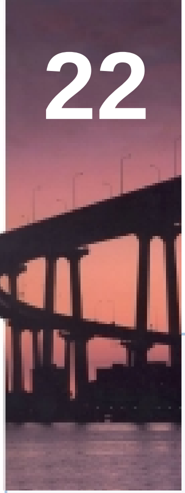
8th Street Bridge • Wisconsin, USA

8th Street Bridge

Date of Completion: September1995
Location: Sheboygan, Wisconsin
Owner: State of Wisconsin/ City of Sheboygan, WI
Engineer: Teng & Associates,Inc. Chicago, Ill.
Contractor: Lunda Construction Company, Black River Falls, Wisconsin
LWC use on: Deck
Bascule Span: 81 feet
Bridge Width: 75 feet
Lightweight Aggregate Producer:
Wisconsin Electric Power Company – Minergy LWA
Mix & Design Information:
- **Density:** Fresh density less than 120 lbs/cf
  Equilibrium density less than 115 lbs/cf
- **Cement Content:** 650 lbs/cf plus 55 lbs/cf silica fume
- **Air Content:** 8%
- **Coarse Aggregate:** Minergy LWA 1/2” x #4
- **Fine Aggregate:** Natural sand
- **Admixture:** High Range Water Reducer (superplasticizer)
- **Physical Properties:** Minimum 3000 psi at 7 days; 4000 psi at 28 days
  Rapid Chloride Ion Permeability Test: less than 1000 coulombs
  w/cm < 0.40

8th Street Bridge

Description:
First bascule bridge in the world constructed with a reinforced concrete deck. This single-leaf, unbalanced bascule bridge consists of a 6” lightweight concrete deck carried by a pair of longitudinal steel girders interconnected at the pivot end by circular cross girders. The bridge is built without a counterweight and relies on hydraulic power to lift and lower it.



BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Tarsuit Caisson Retained Island • Canada

Tarsuit Caisson Retained Island

Date of Construction: 1981
Location: Tarsuit area of the Beaufort Sea, Canada
Owner: Dome Petroleum Limited of Calgary
Engineer: Swan Wooster Engineering Company, Ltd.
Contractor: Dillingham Corp., North Vancouver Marine Division
LWC use in: 4 prestressed concrete caissons
Lightweight Aggregate Producer: Herculite, Calgary, Canada
Compressive Strength: 5,797 psi

Tarsuit Caisson Retained Island

Pertinent Construction Information:

The first consideration was the enormity of the finished concrete caissons. Each caisson measures 11.5 m (37.7 ft) high, 15 m (49.2 ft) wide and 69 m (227.4 ft.) long. Each weighs 5,300 tonnes (5,843 tons), and each has 17 cells to hold the fill material. Their size makes them some of the largest floating concrete structures ever constructed on the west coast.

A total of 8,800 m^3 (11,509 cu.yds.) of semi-lightweight concrete was used in 80 placements – the first made on February 4 and the last on June 17. The large size of the caissons required a special lightweight aggregate. Herculite (weighing 60% of normal aggregate) was imported by truckload from Calgary, Canada.

Other Pertinent Data:

Four huge concrete caissons, each 2/3 the length of a football field, were towed from Vancouver Harbor approximately 5,500 km (3,418) miles by 8,000 horsepower tugboats to a desolate location in the Beaufort Sea. In September, these four caissons became the perimeter of a very ingenious man-made arctic island.

The reason for the island? Fuel. Dome Petroleum Limited of Calgary will use this island for year-round oil and gas exploration. (the type of man-made “islands” currently used for drilling operations are formed from dredge material. They are not only very susceptible to erosion, but also serve a one-time use. This concrete island is designed to be “de-dredged” of its cell-fill material and floated away to another location for reuse.

Hibernia Offshore Platform • Newfoundland , Canada

Hibernia Offshore Platform

Date of Construction: 1996
Location: Hibernia Oil Field, approximately 200 miles (315 Km) east-southeast of St. John's, Newfoundland, Canada
Owner: Hibernia Management & Development Company, Ltd.
Engineer: Doris Engineering, Paris, France
Construction Managers: Joint venture: Kiewet and Norweigian Contractors
LWC use in: Gravity base structure

Mix and Design Information
Average Density @ 28 days: 134 lb/cu.ft. (2,150 kg/cu m)
Cement Content: 450 kg/m^3
Air Content: 2.1%
Lightweight Aggregate Producer: Carolina STALITE Company
Coarse Aggregate Type: STALITE 1/2" - #4 + normalweight aggregate
Fine Aggregate Type: Natural sand
Compressive Strength: 11,588 psi (79.9 MPa)

Hibernia Offshore Platform

Other Pertinent Data: The Hibernia Project represents the largest single use of high strength lightweight concrete in North America. An 11,600 psi (80 MPa) cylinder strength concrete was produced by replacing approximately 50% by volume of normal weight aggregate with high quality Stalite LWA. As a result, a high performance, lighter weight concrete was achieved, with a density reduction of about 10%, and with mechanical properties comparable to its original normal density counterpart. Tests on compressive and tensile strength, modulus of elasticity, Poisson's ration, stress/strain behavior, permeability, and freeze/thaw resistance proved that the unique toughness of the Stalite LWA was a significant factor in achieving the high strength and durability specified in the design.

CIDS Island Drilling System • Beaufort Sea, Canada

CIDS Island Drilling System

Date of Construction: 1984

Location: Beaufort Sea, Canada

LWA Used In: Slabs and Connecting Walls

Compressive Strength: 6,500 psi (45 MPa)

Mix and Design Information

Density: 1750 pcf

Cement Content:

Slabs: 557 kg/m^3 + 61 kg/m^3 fly ash

Icewalls: 460 kg/m^3 + 46 kg/m^3 silica fume

Air Content: 6-8%

Lightweight Aggregate Producer: Mesalite

Coarse Aggregate Type: Mesalite

Fine Aggregate Type: Natural Sand

Compressive Strength: 6,500 psi (45 MPa)

CIDS Island Drilling System

Other Pertinent Data:

In 1984 with the use of High Strength Low Density Concrete the concrete drilling system was built in Japan and also towed to the Beaufort Sea. In addition to reducing draft during construction and towing, use of HSLDC in offshore gravity-based structures can be justified by the improved floating stability as well as the opportunity to carry more topside loads, A large part of the intermediate level of this structure was constructed with HSLDC.

BUILDING BRIDGES
and other Marine Structures with Structural Lightweight Aggregate Concrete

Heidrun Floating Concrete Offshore Platform
North Sea, Norway

Heidurn Floating Concrete Offshore Platform

Date of Construction: March 1993 to June 1995
Location: Heidrun Oil Fields, North Sea, Norway
Owner: Conoco Norway, Inc.
Engineer: Norwegian Contractors
Contractor: Norwegian Contractors

Mix and Design Information
Fresh Density: 1885 kg/m^3 (118 pcf)
Cement Content: 420 kg/m^3 + 20 kg/m^3 silica fume
Air Content: 3-5%
Lightweight Aggregate Producer: Liapor GmnH & Co., KG
Coarse Aggregate Type: Liapor 8, 8-16 mm
Fine Aggregate Type: Liapor 8,4-8 mm
Compressive Strength: >60 MPa (8700 psi) cube strength

Heidrun Floating Concrete Offshore Platform

Other Pertinent Data:
Heidrun TLP (Tension Leg Platform) is a floating platform installed at the Heidrun field at 345 m water depth. It is not only the largest floating concrete structure, but also the structure carrying the largest deck load ever. The concrete work took more than a year and a half, March 1993 to the end of 1994. A total of 65,700 m^3 of lightweight aggregate concrete was poured during the construction period. Norwegian Contractors a.s. designed and built both the TLP and the MSB (Module Support Beams), for the client, Conoco Norway, Inc.

Powell River Ships • British Columbia, Canada

Powell River Ships

Date of Construction:
Five reinforced lightweight concrete ships built between 1920 and 1945

Location: Georgia Straits at Pacific Paper's Powell River pulp and paper plant, British Columbia

Core samples reveal lightweight aggregate concrete has held up very well in extremely harsh marine conditions.

Powell River Ships

Pertinent Data:

Ten concrete ships are currently being used as a floating breakwater around the log pond at the Pacific Paper Powell River Plant in British Columbia, Canada. After approximately 55 to 80 years of marine exposure, these ships are showing varying degrees of deterioration. The ships were constructed with a double mat of reinforcing steel and expanded lightweight shale aggregate concrete. Two separate inspections were conducted over the last seven years to evaluate the conditions of the hulls, decks, and other components of five of the ships. Cores taken from various portions of the ships with different exposure conditions were subjected to laboratory analysis and testing, including testing for compressive strength and petrographic examination. Results of these tests indicate that the lightweight aggregate concrete that the ships are constructed of has performed well, considering the harsh marine environment to which they are exposed.

All the ships exhibited evidence of spalling induced by the corrosion of embedded steel reinforcement. However, the extent and severity of spalling varies between ships and was influenced by the depth of concrete covered over the reinforcement, the development of structurally-related cracking in the ships' hulls and decks, and the penetration of air, moisture, and salts to the level of the reinforcing steel. Lightweight aggregate concrete in parts of the ships not exhibiting delaminations are in generally good condition and the cement matrix exhibits a tight microstructure and apparent low permeability to seawater. The manufactured lightweight aggregate used in the concrete is essentially unchanged proving that it is durable in a harsh marine environment. Compressive strength of the concrete meets or exceeds the designed minimum compressive strength of 35 MPa (5,000 psi). Overall, the lightweight aggregate concrete is of excellent quality and has performed well for over 50 years.

Text taken from the ACI publication, SP 189-7, "Evaluation of Lightweight Concrete Performance in 55 to 80 Year Old Ship," *by R.D. Sturm, N. McAshkill, R.G. Burg, and D.R. Morgan.*