Building Bridges and Marine Structures

With Structural Lightweight Aggregate Concrete

Why Use Structural Lightweight Concrete (SLC) In Bridge Construction?

1. Lower Weight

- ∆ Structural Lightweight Concrete 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.

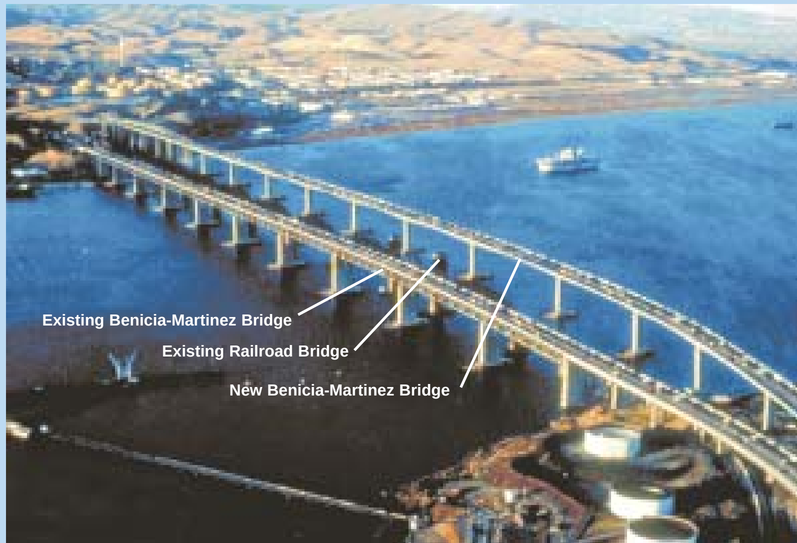
2. High Durability

- ∆ Low permeability.
- ∆ High resistance to freezing and thawing
- ∆ Good resistance to deicing salts and chemicals.
- ∆ The close elastic compatibility between the aggregate and the mortar fraction reduces internal stresses and also minimizes microcracking.
- ∆ Superior bond and transition zone between the aggregate and cement paste.
- ∆ Non-polishing and a higher skid resistant surface improves roadway safety.

Benicia-Martinez Bridge

Hwy. 680 between the cities of Benicia and Martinez, California
Beginning: 2001

Bridge Type: 5-lane balanced pre-stressed CIP segmental cantilever sand lightweight concrete box girder with room for light rail on west side. Built with SLC, steel hinges, and deep foundations to help withstand 1,000-2,000 year-return earthquake.



Maximum Span: 200 m. *Typical Span:* 161 m. *Total Length:* 2,716 m.
SLC: 6,500 psi at 28 days. *Owner:* State of California, Caltrans.
Design: T.Y. Lin International and CH2M HILL

Silver Creek Overpass

Over I-80, Summit County, Utah
Completed in 1968
Bridge Length: 191 feet, 9 inches
Maximum Span: 99 feet, 9 inches
Bridge Width: 44 feet
Engineer: Utah Department of Transportation Structures Division
Highway expansion in 2001 resulted in removal of this structure. Examination of the SLC after 33 years in use showed little or no deterioration.

On The Cover

Coronado Bridge
San Diego, California
Inset Cover Photos

- Boknasundet Bridge
  Under Construction
  Rogaland County, Norway (Left)
- Pontoon Supports for
  Nord Hordland Floating Bridge
  Bergen, Norway (Middle)
- Hibernia Offshore Platform
  Newfoundland, Canada (Right)

Cooper River Bridge

Charleston, South Carolina
Shown under construction in 1991
Bridge Length: 16,450 feet
Bridge Width: 93 feet, 3 inches
Engineer: Howard-Needles-Tammen & Bergendoff

The Test of Time

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 has confirmed that, in terms of durability, structural lightweight concrete performs equal to or better than normal weight concrete.

In the study “Criteria For Designing Lightweight Concrete Bridges” (August 1985) the Federal Highway Administration reports that evidence was produced during visits to 30 bridges, and in contacts with state and industry representatives, that good lightweight concrete has equal or better durability than some normal weight concrete.

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 normal weight concrete.

A survey of Japanese bridges in service for up to 20 years reveals that cracking, carbonation and salt penetration was reduced with structural lightweight concrete bridges, and SLC provided high degrees of durability that surpassed normal weight concrete. Also, investigations of a number of older marine environment SLC structures in service for over 80 years verify laboratory results indicating good weathering resistance.

Why Use Structural Lightweight Concrete (SLC) In Bridge Construction?

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.
- ∆ Greater design flexibility to meet today's challenges of design and construction.
- ∆ High compressive strengths capable of meeting modern engineering requirements.

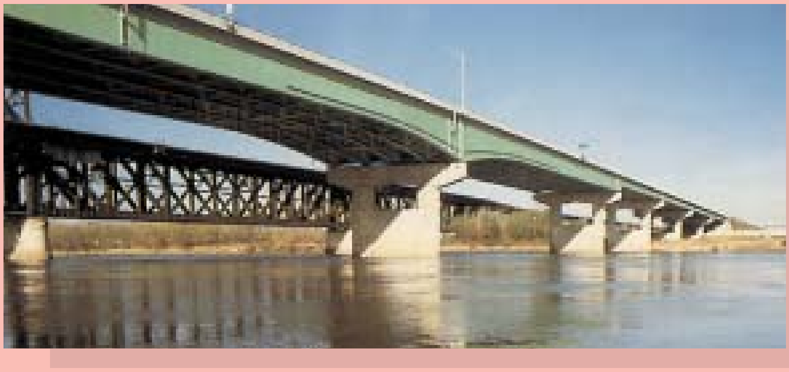
Boknasundet Bridge
Rogaland County, Norway
Bridge Type:
Balanced cantilever
Length:
1270 feet (385 meters)
Maximum span
627 feet (190 meters)
Bridge Width:
36 feet, 4 inches (11 meters)
Engineer:
Bridge Department
Director of Public Works

William Preston Lane Bridge

Chesapeake Bay at Annapolis, Maryland
Deck replacement.
Engineer: Greiner Engineering
Note: SLC bridge decks constructed in 1952 demonstrated superior performance when compared to companion heavyweight concrete decks; therefore, SLC bridge decks were chosen by the owners and engineers for the parallel span opened in 1975.

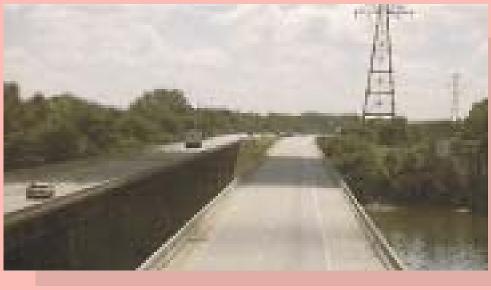
Heart of America Bridge

Kansas City, Missouri
Completed in 1985
Composite deck, SLC cast-in-place topping over precast SLC panels.
Maximum Span: 440 feet
Engineer: Howard-Needles-Tammen & Bergendoff



Ohio Turnpike Twin Bridges

Maumee River, Toledo, Ohio
Deck replacement and widening.
Bridge Length: 1384 feet
Maximum Span: 176 feet, 6 inches (longest)
11 spans (composite with post-tension SLC)
Engineer: J.E. Greiner Company



Neuse River Bridge

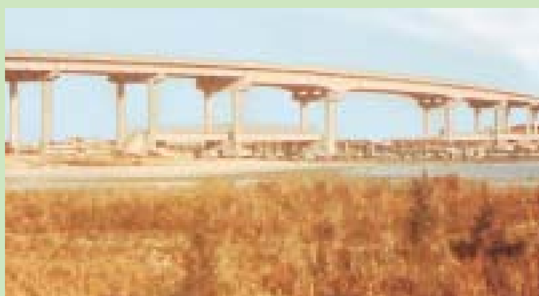
U.S. 17 at New Bern, North Carolina
Conventional design using SLC decks on normal weight AASHTO beams.
Elevated interchanges were required because of sensitive wetlands (north) and historic district (south)
Engineer: Ralph Whitehead Engineers
Owner: NCDOT

Why Use Structural Lightweight Concrete (SLC) In Bridge Construction?

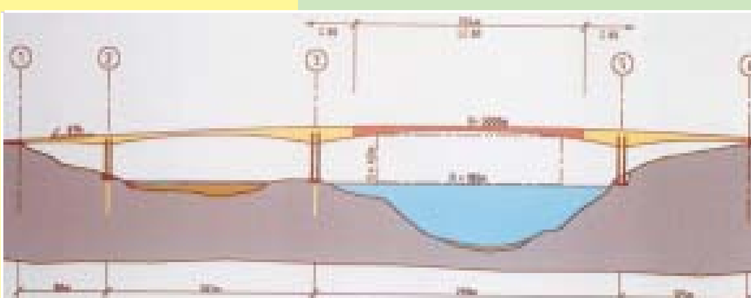
4. Excellent Performance Record

∆ 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.

Sabestian Inlet Bridge
Vero Beach, Florida
Completed in 1964. 1991 review showed SLC deck to be in good condition. Precast and prestressed girder system with cast-in-place deck.
Maximum Span: 180 feet



Sandhornøya Bridge
Giddenskill, Nordland County, Norway
Completed in1989
Bridge Type: Balanced cantilever box girder
Total Length: 1234 feet, 2.4 inches (374 meters)
Maximum Span: 508 feet, 2.4 inches (154 meters)
Bridge Width: 25 feet, 9 inches (7.8 meters)
Engineer: Aas Jakobsen, Oslo



Raftsundet Bridge
Raftsundet Sound, Norway
Located over 300 kilometers north of the Arctic Circle.
Bridge Type: 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.
Engineer: Dr. Ing Aas-Jakobsen

Lightweight Aggregate Concrete In Norwegian Bridges

by Steinar Helland, Selmer Skanska AS, Oslo, Norway.

"To help bridge designers in their efforts to create optimum structures, the Norwegian concrete industry, in the 1980's, started to

(*Continued on page 11)*

Lewiston Pump-Generating Plant Bridge

Lewiston, New York

204 prestressed SLC girders of 68 feet each.
6000 precast SLC roadway slabs (4000 psi)
3 inches thick (7 feet x 2 feet each)
24 special walkway girders ("U" shaped,
6 feet wide and 4 feet deep).
Engineer: Uhl, Hall & Rich

Antioch Bridge

Antioch, California

Completed in 1972.
2-lane SLC deck
placed by pumping.
Bridge Type:
Prestressed concrete
multiple box.

Why so Durable?

Resistance to freezing and thawing in any type of concrete (normal weight 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.

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

ESCS aggregates are less rigid than normal weight 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 normal weight concrete. Consequently the lightweight aggregate bond to the mortar matrix exceeds the bond of normal weight aggregate.

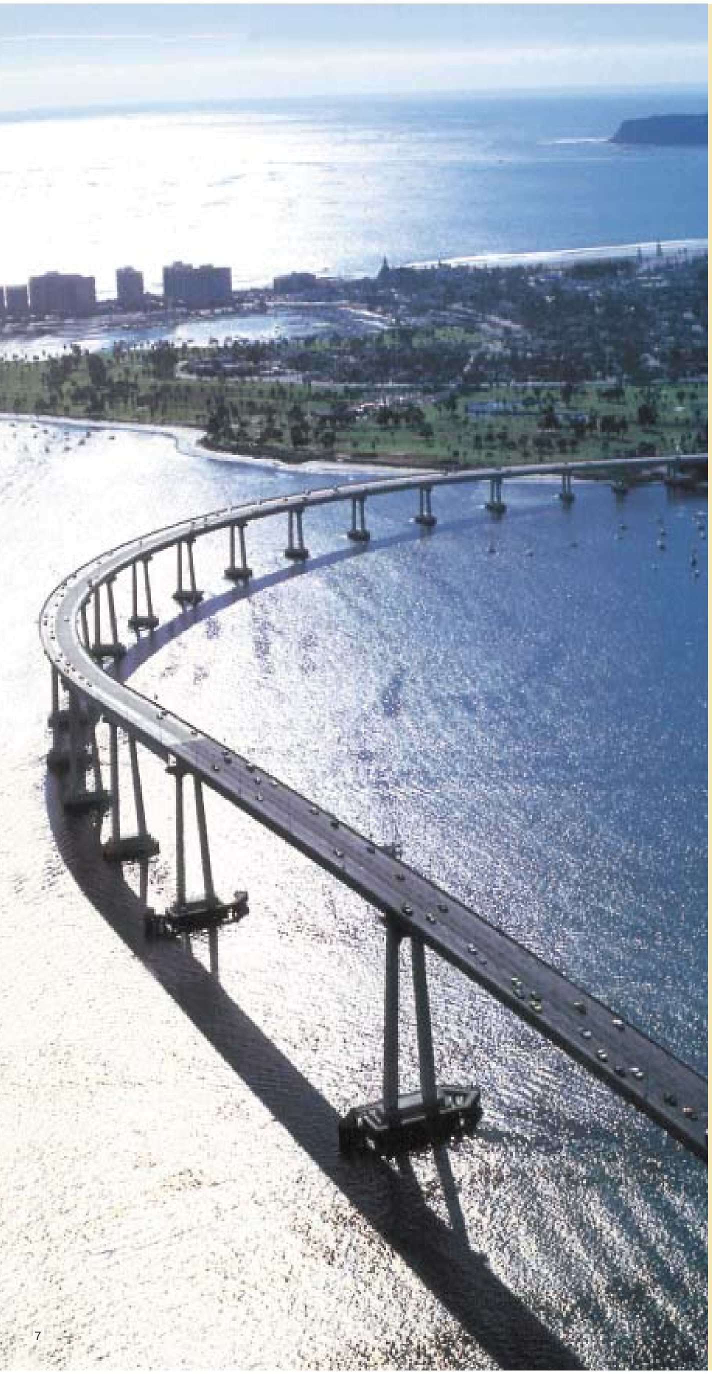
The water absorbed in lightweight aggregate provides available moisture for enhanced cement hydration. The water does not affect the water-cement ratio. The enhanced cement hydration results in improved durability, less microcracking and lower permeability.

Prestressed, Precast and Cast-In-Place

Structural Lightweight Concrete is ideal for all types of bridge or other marine construction. The lower weight makes it economical to transport sizeable precast sections, reduces the need for extensive falsework, speeds erection and allows for the use of smaller more economical equipment.

The overall weight reduction with SLC affords designers greater design latitudes to meet today's challenges of terrain, budget, seismic conditions and construction schedules. In addition, reduced weight produces less seismic force, and allows for reduction of reinforcing and structural steel, 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, as compared to normal weight concrete. This affords increased stiffness and additional cover for reinforcing, thereby improving durability.



American River Bridge

City of Folsom, California • Completion: 1999

Bridge Type: 4-lane prestressed concrete box girder road with a 6.1 m median for future light rail. *Span:* Maximum of 100 m • *Total Length:* 690 m

SLC Concrete: 5,000 psi at 28 days

Owner: City of Folsom, California • *Design:* HDR Engineering

Construction: C.C. Myers, Inc. • *Ready Mix:* RMC Lonestar

8th Street Bridge

Sheboygan, Wisconsin

First bascule bridge in the world with reinforced concrete deck. This single-leaf, unbalanced bascule bridge consists of a 6-inch SLC deck carried by a pair of longitudinal steel girders interconnected at the pivot end by circular cross girders. There is no counterweight. Hydraulic power lifts and lowers the bridge.

Bascule Span: 81 feet. *Bridge Width:* 75 feet.

Owner: State of Wisconsin/City of Sheboygan

Engineer: Teng and Associates, Inc., Chicago, Ill.

Concrete Supplier: Sheboygan Concrete

Coronado Bridge

San Diego, California

307 precast-prestressed SLC girders were used.

Completion: 1969

Bridge Length: 11,179 feet

Bridge Height: 50 to 200 feet

Maximum Girder Length: 151 feet

Engineer:

State of California

Department of Public Works,

Division of Bay Toll Crossings

E.R. Foley, Chief Engineer

Brooklyn Bridge

New York, New York

Emergency re-decking

Completion: October 1999.

Steel grid filled with 6000 cubic yards of SLC (4000 psi)

Owner:

New York City DOT

Contractor:

Yonkers Construction

Concrete Supplier:

Rahns Concrete

Braddock Gated Dam

Braddock, Pennsylvania
SLC Construction Begun: March 2000
Precast and cast-in-place elements are being used to construct dam sections up river. SLC is used in the interior dam support walls and floor sections to reduce weight and draft of the floatable sections. Maximum draft will be 10-14 feet. Sections will be floated down river and set in place on a pier foundation system. Additional precast and cast-in-place construction will accommodate lock gates, control facilities and a pedestrian bridge.
Wier bay sections: 110 feet
Dam Section 1: 333 ft. • *Dam Section 2:* 265 ft.
Contractor: J.A. Jones/Traylor Brothers
Owner: Army Corps of Engineers

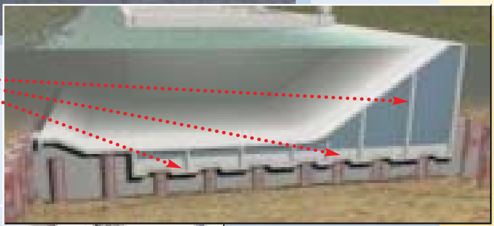
Napa Bridge

Hwy. 29 at Napa River, Napa, California
Completed: 1977
Type: 4-lane prestressed concrete box
Typical Span: 250 feet
Total Length: 2,230 feet
SLC Strength: 4,500 psi at 28 days
Owner: State of California
Design: Caltrans

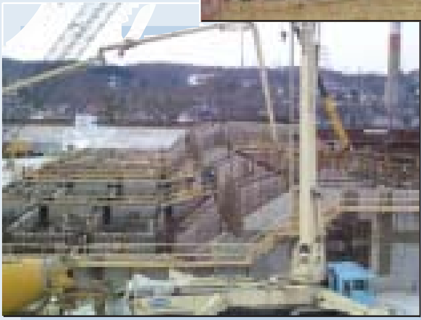
Longest Prestressed Post-tensioned Girder

Lafayette, Indiana
Production Date: 1994
Producer: Hydro Conduit/Lafayette
Girder Type: Prestressed post-tensioned bulb tee
Quantity: 96 Girders
Length: 175 feet • *Height:* 7.5 feet
Weight: 96 tons • 5-Day Strength: 7,000 psi
Design: High strength specified density concrete in combination with pre-stressed/post-tensioned strand. Weight was reduced by 17%.
Cost: The contractor chose the prestress concrete design over the steel design and saved $1.7 million on the $9.4 million Wabash River Bridge project. *(Bridge pictured on bottom right page)*

Braddock Gated Dam
Floatable section to be set in place on pier foundation



Cast-in-place SLC interior supports and floor sections



Braddock Gated Dam
Floatable section under construction (February 2001)

Wabash River Bridge, 231 Bypass
Lafayette, Indiana
Owner: State of Indiana • *Design:* Jansen & Spaans Engineering
Contractor. Rieth-Riley Construction Company
(Girder photo and information shown on left page)

Renovation & Repair

In 1990 more than one-half million bridges in the United States alone were classified as “deficient” in terms of structural integrity or traffic 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.

For more information on the advantages of lightweight concrete made with expanded shale, clay or slate, contact your local supplier of rotary kiln expanded shale, clay or slate lightweight aggregate.

www.escsi.org

(*Continued from page 5,*
LWAC In Norwegian Bridges)
combine the technology of HSC/HPC with that of lightweight aggregate concrete (LWAC). Ten major bridges were built with lightweight concrete in Norway. These comprised free cantilever, cable stayed, and pontoon bridges. The spans of the two latest free cantilever bridges – Raftsundet at 978 ft (298 m) and Stolma at 988 ft. (301 m) – represent world records."
(S. Rosseland et al)

The motivation for using LWAC for free cantilevers is the effect of reduced dead load. Additionally, the construction method requires a balanced load on both sides of the pylon during construction. This limits the choice of span lengths and the possibility of placing pylons according to the topography. By being able to adjust the material density of the cantilevers, the designer achieves greater freedom.

Over the last 15 years, extensive research in Norway has verified LWAC's performance in marine environments. Test results show that LWAC will withstand a structural design life of more than 100 years with comfortable margins.

Conclusion

"*To maintain the use of concrete in bridge construction, the range of material combinations had to be broadened in the 1970's and 80's. The introduction of higher strengths and better performance in marine and de-icing salt environments was the first step. The second step was to give designers the possibility of combining these characteristics with* ***the freedom to specify density.*** *Without these quantum leaps in technology, concrete's leading position in this market would have been questionable.*" (Steinar Helland)

The above is excerpted from an article in ***HPC Bridge Views,*** Issue No. 11, published by the Federal Highway Administration and the National Concrete Bridge Council. Sept./Oct. 2000

Marine Structures

CIDS Island Drilling System

Canadian Beaufort Sea

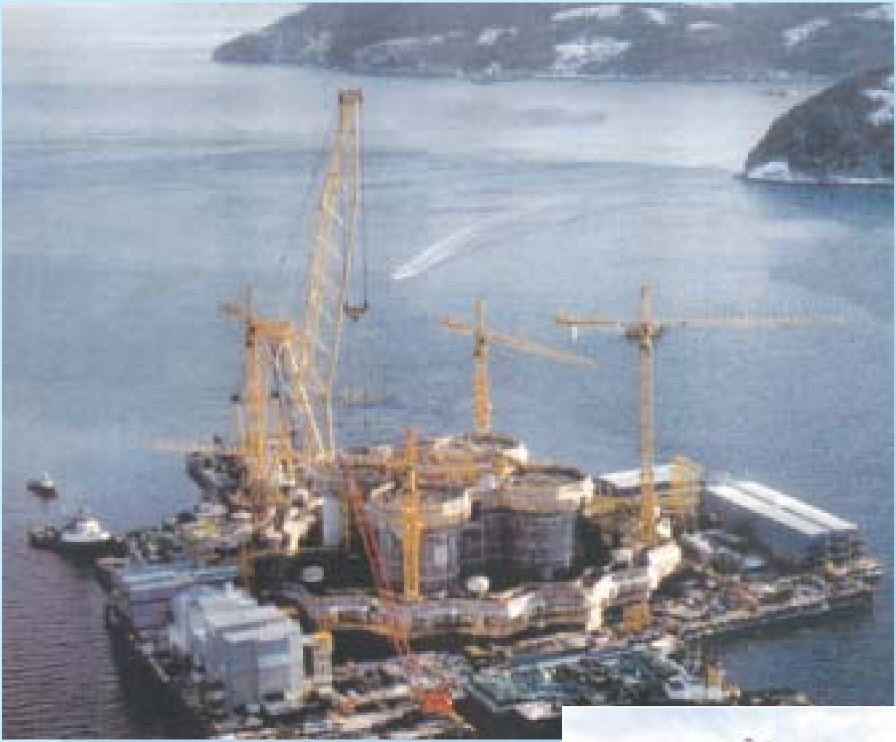
Built in Japan in 1984, the use of HSLDC reduced draft during construction and towing, improved floating stability, and improved topside loads. Much of the intermediate level of the structure was constructed with HSLDC. Compressive strength was 45 MPa (6,500 psi), and the density was 1,840 kg/m^3 (115 lb/ft^3).

Tarsuit Caisson Retained Island

Canadian Beaufort Sea

Built in 1981, this is the first Arctic structure using SLC. Four prestressed concrete caissons, 69x15x11 meters high (226x50x35 ft.), were built in Vancouver, towed around Alaska, and founded on a dredged sand berm 40 km (25 miles) offshore in the shear zone between winter landfast ice and moving Arctic ice. Space between the caissons was filled with dredged sand to form the working platform for the drill rig.

North America's largest floating structure



Hibernia Offshore Platform

Newfoundland, Canada

To improve the buoyancy of the largest floating structure ever built in North America, structural lightweight aggregate replaced approximately 50% of the coarse aggregate fraction of the High Strength Specified Density Concrete used in the Hibernia Gravity Base Structure. This structure, with a mass of more than one million tons, was successfully floated out of the drydock, and towed to a deep water harbor area where construction continued. It was then towed to the Hibernia Oil Field site, 200 miles (315 Km) east-southeast of St. John's, Newfoundland, and set in place on the ocean floor. (see cut-away view at right)

The first floating platform with HSLDC

Heidron Floating Concrete Offshore Platform

North Sea, Norway

The Heidron oil fields lie 345 m (1,130 ft.) below the cold stormy surface of the North Sea. Because of the need to achieve the required buoyancy, the concept of using high-strength low density concrete (HSLDC) was introduced early in the planning stages.

The hull of the floating structure is constructed entirely of HSLDC (60 MPa / 8,700 psi cube strength). Almost 70,000 m^3 (91,000 yd^3) of HSLDC with a maximum density of 2,000 kg/m^3 (125 lb/ft^3) and a required elastic modulus of 22 GPa (3.19 x 10^6 psi) were used.

Floating SLC Vessels

Powell River Ships

Powell River, British Columbia, Canada

Ten concrete ships are being used as a floating breakwater at the Pacific Paper Powell River Plant. Evaluation of the ships for long-term service durability of the lightweight concrete were recently conducted. The ships range in age from 55 to 80 years, with one ship constructed in the 1920's, and the other nine in the 1940's. These ships demonstrate the excellent performance of structural lightweight concrete after more than a half-century of marine exposure.

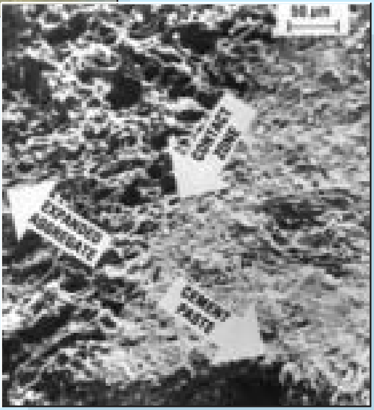
Petrographic studies conducted at CTL (Construction Technology Laboratory) revealed limited microcracking, excellent aggregate/matrix contact zone, complete hydration of the cement, and insignificant damage due to freezing and thawing. This microscopic examination clearly showed evidence of continued hydration and development of the cement matrix. This continued maturation of the concrete has contributed to the development of compressive strengths in the ships' hulls well beyond (up to 8700 psi) the minimum design strength (5000 psi) of the concrete. Concrete densities range from 106 lb/ft^3 to 130 lb/ft^3 .

According to the inspectors' report, the "paste-aggregate bond is consistently excellent in all the examined concrete specimens, in part attributed to mostly beneficial reactions along the paste-aggregate interface. Overall, the manufactured lightweight concrete used in the construction of the ships has performed exceptionally well in a harsh marine environment."

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

Powell River Ships *Core Sample*

Drilled core samples revealed that the SLC of the ship's hull had continued to mature and strengthen well beyond its design strength.



Paste-Aggregate Interface

Scanning electron microscope photograph of aggregate/matrix contact zone; from the cover of "*State-of -the-Art Report on High-Strength, High-Durability Structural Low-Density Concrete for Applications in Severe Marine Environments"* by Thomas A. Holm and Theodore W. Bremmer

Innovations For Navigation Projects Research Program
US Army Corps of Engineers Research and Development Center

Note: Additional information on the properties and performance of lightweight concrete can be obtained by viewing the referenced publication by Holm and Bremmer on the Army Corps of Engineers web site "Reports Page" – **(http://www.wes.army.mil/SL/INP/reports.htm)**