HIGH PERFORMANCE LIGHTWEIGHT CONCRETE BRIDGES - NORWEGIAN BACKGROUND AND EXPERIENCE.

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ABSTRACT

Since more than 70 years lightweight concrete has been used in the marine environment. Prime examples of such use are the ship Selma, grounded off Galveston, TX; and several other ships of that age laid up, still able to float. Thus, history is well established.

Over the last couple of decades, growing interest in the actual performance of lightweight concrete in the marine environment has generated several studies covering durability, mechanical properties and design procedures.

As a consequence of this experience, lightweight concrete highway bridges are built on a regular basis in Norway. The material is chosen when it gives the best total economy while maintaining the durability necessary to obtain long service life. The paper gives an overview of LWC bridge construction and some of the development work leading up to the current status of the material - in particular the durability aspect

Keywords: Lightweight concrete, durability, bridges, silica fume, marine, chlorides

INTRODUCTION

For more than 70 years lightweight concrete has been used in the marine environment. Prime examples of such use are the ship Selma, (for many years grounded off Galveston, TX), and several other ships from that time that are laid up, but still able to float. Thus, there is a well established record of good performance, as described by Vaysbourd[1] and by Holm & al[2] – among others.

Figure 1. Heidrun platform. LWC tension leg platform commissioned 1995 by Conoco

The technology used in Norwegian lightweight concrete (LWC) bridges relies on the development work that was done for the purpose of offshore oil production. A general interest in development of floating structures and a need for control of the density of concrete of gravity structures during the construction phase led to a number of research projects on the dependable use of lightweight concrete in the marine environment. The main projects were:

- LWC for floaters
- Lightcon
- Lettkon
- EuroLightcon

The appendix lists the published reports from these projects as well as other reports concerning LWC from Norwegian projects on HPC. These research projects have considered most aspects of using LWC, with a focus on the marine environment, so the reports listed in the appendix give a very comprehensive basis for the use of high quality LWC.

RESEARCH BACKGROUND

GENERAL

Norwegian studies of and use of lightweight aggregate structural concrete is closely tied in with offshore concrete construction. Lightweight concrete was part of several of the important joint industry projects of the 1980's, such as the first Norwegian High Performance Concrete project (Materialutvikling høyfast betong), - and of the High Strength Concrete projects financed by oil companies*. However, it was only when the "Floaters" program: (Lightweight concrete for

* One of the requirements set up by the Norwegian Government when allocating exploration rights on the Norwegian Continental Shelf, was that the oil companies who wanted drilling rights should sponsor research in Norway. Concrete design, construction and materials technology were beneficiaries of this policy

floaters) was initiated, that the dedicated study of high performance lightweight concrete structures really took of.

The purpose of the Joint Industry Program (JIP) “Floaters” was to study all aspects of using high performance LWC in practice; from design and performance to logistics and construction procedures. Unfortunately, this program only received the allotted government funding for two out of three years originally promised, thus a number of individual projects had to be terminated prematurely, and some of the results have not even been properly reported. However, through this project and through the concurrent construction of Conoco’s production structure “Heidrun” (mobilized in 1995), sufficient confidence in the performance of lightweight concrete was generated to awaken the interest of the Norwegian Road Authorities. With their support, another JIP, “Lightcon”, was established, and this program had many of the same participants and thus brought much of the experience from “Floaters” forward. Subsequent to Lightcon, a European project, EuroLightcon, was established, funded to a large part by the European Commission. In parallel, Norwegian industry formed a project to coordinate efforts within the European project; this was called LettKon.

As these projects progressed, the Road Authorities actually started to use lightweight concrete in bridges. Therefore, when in the late 90’s a project was started on the durability performance of Norwegian bridges, even some lightweight bridges had sufficient history to be included in the study (e.g. Østmoen[3]).

PROJECT EXPERIENCES

The experiences can be divided into three categories:

- Design,
- Construction and
- Durability.

For details of the project results, please refer to the reports from the individual projects. (Some of these will be in Norwegian, but with summaries and captions in English also). However, the conclusions are quite clear:

Design

The provisions made in Norwegian Standard for Concrete Design (NS 3473)[4], which is based on the European Model Code, are adequate. This means that this standard is a means of safe, probably conservative, design of lightweight concrete structures of high strength. Even if plain LWC members can exhibit brittle behavior, the use of steel reinforcement gives the same structural ductility as for normal density concrete. The code provisions, based on the Model Code and further developed by the knowledge gained through the various projects, make modifications to code requirements based on the density of the concrete. Thus, the use of lightweight concrete is integrated into the ordinary structural standard. Key design parameters that are modified are allowable cube compressive strength (down from 105 MPa for ordinary land-based structures (115 MPa for offshore structures)), design modulus of elasticity and creep properties.

Construction

Production of and construction with lightweight concrete structures require some procedural changes. As an example, it has been found that re-tempering a mix before actually pouring is beneficial; thus concrete transported by rotary truck showed higher strength to density ratio than concrete pumped directly from the mixer to the form. Also, there is a need to be careful to distinguish between "free water" and water that will be absorbed into the aggregate in the fresh concrete. Thus, estimation of the w/cm-ration may become difficult, unless the water-uptake is known.

Durability

In this context durability means resistance to chloride initiated corrosion and to salt scaling. The research done has thoroughly documented that lightweight aggregate concrete is at least as durable as normal density concrete of the same binder quality (Jørgensen[5]). It was even found that for calculation of chloride ingress the same models could be used that are used for normal density concrete – as long as the paste quality is the same (Maage & al[6]).

The experiences from structures that have been built support the assumptions made when lightweight concrete was chosen. As mentioned above, the design guidance from the standards are conservative and concrete members behave in a similar fashion to normal density concrete members, and the durability of LWC that was thoroughly documented through the four projects mentioned above appears to be realistic. Several of the structures in place have been equipped with instrumentation for structural monitoring and/or facilities for verification of durability – either by dummy samples exposed adjacent to the structure or by cores from the structure (guides are inset in the wall to allow controlled sampling).

TYPICAL MATERIALS

BRIDGE CONSTRUCTION IN GENERAL

On average, Norway builds one or two LWC bridges every year. LWC is usually used only in parts of the structure, i.e. where reduced weight is most important. All bridges, lightweight or normal density, are built according to Process-code 2 of the Norwegian Road Directorate([7]) and designed according to Norwegian Standard NS 3473.

In the interest of durability (chloride resistance), Norwegian authorities require the use of silica fume. This has additional benefit in lightweight concrete, since the cohesivity of silica fume concrete contributes to the uniformity, pumpability and placeability of lightweight concrete in addition to silica fume giving a high strength binder with low permeability.

The Process Code distinguishes between different chloride exposure zones with different requirements to concrete composition. As shown in table 1, the two parameters that vary between exposure zones are water/cementitious ratio and silica fume content. Since the design code includes provisions for the use of lightweight concrete, the design process is fairly straightforward.

Table 1. Process code requirements to concrete composition in Norwegian bridges

Environmental class	Concrete specification code	Max. effective w/cm-ratio= w/(c+k*s) Note *	Minimum cement content lb/cu.yd (Kg/m^3)	Silica fume content % of cement
NA**	SV-50	0.50	539 (320)	0-2
MA	SV-40	0.40	590 (350)	3-5
MA	SV-30	0.38	624 (370)	8-10

Notes to table:
* c= cement, s=silica fume, k=”efficiency factor”=2.
** NA (slightly aggressive) is very seldom used in practice

CORROSION RESISTANCE

A primary concern in the creation of the Process Code has been the risk of chloride initiated corrosion of the reinforcement. A number of studies have been concerned with this aspect. The studies done on lab and field samples, as well as investigations of structures, indicate that LWC is at least as resistant to chloride ingress as normal density concrete with the same binder quality. Typical initiation times for concrete covers of 40mm have been estimated to at least 80 years based on these observations (e.g Carlsen 2000[8]).

THE ROLE OF SILICA FUME

As seen from table 1, above, silica fume is a natural part of bridge building in Norway, the main reason being the large increase in resistance to chloride initiated corrosion. However, silica fume is also important to the production of a homogenous lightweight concrete.

Essentially, Norwegian LWC-technology is characterized by low w/cm-ratios, very fluid concrete and the use of silica fume. Low w/cm and silica fume contribute to high strength and high durability; the fluidity means a highly workable concrete, essentially self consolidating, that can be placed with confidence even if the geometry is complex or there is congested reinforcement. The high slump can be used without risk of segregation because even moderate amounts of silica fume makes the fresh concrete very stable and resistant to segregation. Thus silica fume has a dual purpose in high performance lightweight concrete: Stability in the fresh mix and strength and durability of the hardened concrete.

An additional potential benefit was described by Rønne and Hammer[9]. Since LWC typically has high cement content, low specific heat and less thermal conductivity the normal density concrete, high temperatures have been found during hydration. In the laboratory the high temperature has been found to be a potential cause of delayed ettringite formation (DEF). The authors found that the use of silica fume reduced or possibly eliminated the detrimental expansion.

LIGHTWEIGHT AGGREGATES

Three different aggregates have been used in Norway. Two are based on expanded clay, one on expanded shale. They were:

- LECA: (Light Expanded Clay Aggregate) from OPTIROC, a company in the Heidelberg group
- LIAPOR: This is pelletized and expanded clay from LIAPOR in Germany
- STALITE: Expanded shale aggregate from Carolina Stalite Company of North Carolina, USA

2.5 OTHER MATERIALS

For the early structures, the cement used was the so-called P30 (Portland 30) from Norcem. Later structures used Norcem's high strength cement, first called HP30-4A, subsequently called "Anlegg" - "Anlegg" is Norwegian for "heavy civil engineering project". These cements had originally been developed for the offshore concrete construction industry. Chemical admixtures varied between the projects, mostly they were supplied and blended from local suppliers. The natural sand used was typically a specially graded sand from the suppliers to the offshore concrete industry.

BRIDGE EXAMPLES

NORDHORDLAND BRIDGE

Figure 2. Nordhordland Bridge

Nordhordland bridge, north of Bergen, crosses a very deep fjord (more than 500 meters in places). The bridge carries the main road along the west coast from north to south in Norway, and is an essential part of the infrastructure network – carrying goods and people to the markets of Continental Europe. As with almost all Norwegian bridges, the structure is owned and operated by the local department of the Road Authority.

A lot of ship traffic meant that the structural solution had to allow for fairly large vessels to pass. The final structure consists of a high cable stayed bridge and a floating bridge, the total length is 1 766 yd (1 615 m). The high bridge allows ship traffic to pass, while the floating bridge allows a crossing to be established despite the large water depth.

The unique structure was designed by the architects: Lund & Slaatto and Lund & Løvseth, Hindhammar Sundt Thomassen, in cooperation with structural designers Dr. ing Aas-Jakobsen A/S, Instanes A/S / Søvik & Kloster A/S for the high bridge and Consulting Eng. A.R. Reinertsen for the floating bridge

The high bridge was built by Selmer AS of Norway, while the floating structure was built by a joint venture consisting of Veidekke and Norwegian Contractors for the concrete work and Kværner Eureka for the steel superstructure.

Characteristics of the structure:

- High bridge:
  Single tower reaching 328 ft (98 m) above sea level. The 163 m main span is in LWC, Normal density C45 (6520 psi (45 MPa) characteristic 4 in cube (100 mm) strength) was used in the rest of the structure.
- Floating bridge:
  A continuous 1363 yd (1 246 m) high grade steel box girder supported by 10 pontoons (138x67x23/29 ft (42 x 20.5 x 7.2-8.9 m)) made with LWC. The pontoons were built in a dry-dock near Fredrikstad and floated to site.

Lightweight concrete volumes:

- High bridge:
  LC55: 1 504 cu.yd. (1 150 m^3), density< 118 lb/cu.ft (1 900 kg/m^3).
- Floating bridge:
  LC55: 11 117 cu.yd. (8 500 m^3), density: 121.7 +0/-3.1 lb/cu.ft (1 950 +0/-50 kg/m^3).

The mixture compositions for the two structures that compose the bridge are given in table 2.

Table 2. Concrete mixtures for the Nordhordland Bridge

High Bridge LC55:	lb/cu.yd (kg/m^3)
Cement (CEM1)	725 (430)
Microsilica	59 (35)
Natural sand, 0-0.2in (0-5mm)	1062 (630)
LWA Leca, 0.15-0..3 in (4-8 mm)	497 (295)
LWA Leca, 0.3-0.5 in (8-12 mm)	464(275)
WRA	50 fl.oz (1.5 l)
HRWRA	186 fl.oz. (5.5 l)
AEA	0.34 fl.oz (0.01 l)
Total water	329 (195)

Floating Bridge LC55	lb/cu.yd (kg/m^3)
Cement (CEM1)	691 (410)
Microsilica	56 (33)
Natural sand, 0-0.2 in, (0-5 mm)	1138 (675)
LWA Liapor 8, 0.15-0.3 in, (4-8 mm)	455 (270)
LWA Liapor 8, 0.15-0.6 in, (4-16 mm)	548 (325)
WRA	67-118 fl oz (2-3.5 l)
HRWRA	1.6-2 gal (6-7.5 l)
AEA	1.7-5 fl.oz (0.05-0.15 l)
Retarder	(0-0.3 l)
Total water	337 (200)

At the time of construction of the high bridge, specimens were cast and exposed adjacent to the structure in order to investigate long term behavior in the field. When economy permits, these will be investigated.

The bridge is in excellent shape.

STOLMA BRIDGE

With a main span of 987.5 ft (301 m) and total length of 1532 ft (467 m), Stolma bridge, completed in 1998, holds the current world record for concrete bridges built by the balanced cantilever method.

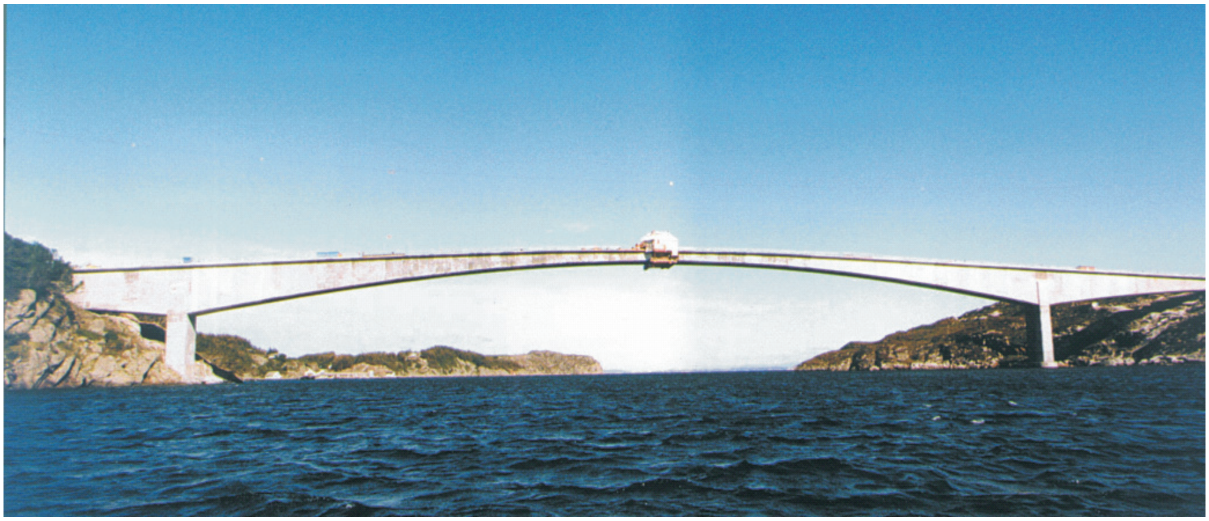

Figure 3. Stolma bridge on closure

The bridge is situated in the outermost islands of the archipelago between Bergen and Stavanger. The bridge means that the fishing industries in these islands have a much more reliable conduit for getting their products to market. This archipelago is a center for fish farming – destined for the international market, therefore the bridge is important for efficient transport.

Situated in a very exposed environment, a highly durable structure is a necessity.

The owner/client is the Norwegian Road Authorities, Hordaland. The bridge was designed by Instanes A/S, Bergen and built by NCC Eeg-Henriksen a/s.

603 ft (184 m) in the middle of the main span is high-strength lightweight aggregate concrete LC60. C65 concrete was used for the rest of the structure. The concrete volumes were:

- Lightweight concrete LC60: 2 093 cu.yd. (1 600 m^3)
- Normal density concrete C65: 12 883 cu.yd. (9 850 m^3)

For the lightweight concrete, the mean compressive cube strength at 28 days was 10 210 psi (70.4 MPa) with a mean density of water-cured LC60 cubes after 28days of 121 lb/cu.ft (1940 kg/m).

Table 3. Mixture design Stolma Bridge

Mix design LC60	lb/cu.yd	kg/m
Cement (CEM1)	708	420
Microsilica	59	35
Natural sand, 0-8 mm	1180	700
LWA HF Leca 800, 4-12 mm	1011	600
Water (absorbed in LWA)	81	48
Water (added) *	270	160
AEA	2.7 fl.oz.	0.08 l
Stabilizer	338 fl.oz.	10 l
Retarder	33.8 fl.oz.	1.0 l

* The water cementitious ratio is calculated using the "effective" water content, discounting the water absorbed in the aggregate.

BOKNASUNDET BRIDGE

Figure 4. Boknasundet bridge

Boknasundet bridge is also on the main West-Norway road. It serves, with several other bridges, to use a chain of islands north of Stavanger to shorten the ferry route. (A route completely without ferries would require a subsea tunnel of much more than 18 miles (30 km), presently not considered a viable proposition – though planning is going on).

- Owner/client: Norwegian Road Authorities, Rogaland
- Consultant: Directorate of Public Roads, Bridge Dept.
- Contractor: Aker Entreprenør A/S

- Main span: 633 ft (190 m)
- Side spans: 2, each 320 ft (97.5 m)
- Built: 1989-90
- Concrete volumes: Lightweight LC60: 3 270 cu.yd (2500 m^3)
  Normal density C55 : 589 cu.yd. (450 m^3)
  Normal density C45 : 2 747 cu.yd (2100 m^3)

In the main span and in 62 meters of each side span, LWC grade LC60 was used. In the other parts of the bridge, concrete grades C45 and C55 were used.

- Density of fresh LWC: <122 lb/cu.ft. (1950 kg/m^3)
- Achieved characteristic compressive strength: 9 195 psi (63.4 MPa.)

In 1993 in-situ cores from the bridge were investigated. The tests show a dense concrete with good durability in terms of chloride diffusion.

Table 4. Mixture composition Boknasundet Bridge

Mix design LC60	lb/cu.yd.	kg/m^3
Cement (CEM1)	725	430
Microsilica	42	25
Natural sand, 0-8 mm	1146	680
LWA Liapor 8, 4-8 mm	563	334
LWA Liapor 8, 8-16 mm	447	265
Water	320	190
WRA	145 fl.oz.	4.3 l
HRWRA	135 fl.oz.	4.0 l
AEA	5 fl.oz.	0.15 l

RAFTSUNDET BRIDGE

Raftsundet bridge is the first part of a ferry free connection between the mainland and the islands of the Lofoten archipelago in Northern Norway. Located just north of the Trollfjord, it is an impressive portal for ships passing into the archipelago from the North.

When the cantilevers were joined on June 24 1998, Raftsundet bridge, with a main span of 977.7 ft (298 m) and a total length of 2333 ft (711 m), was the longest concrete cantilevered span in the world for a few weeks.

The structure is exposed to very severe wind conditions, with design gust wind speeds of nearly 60 m/s (134 mph). The surrounding alpine topography, with mountains rising up to 3300 ft (1000 m) above sea level, creates large magnitude fluctuating wind forces on the bridge.

The main span is built in 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 150x590 ft (45 x 180 m).

Figure 5. Raftsundet bridge

- Owner/client: Norwegian Road Authorities, Nordland
- Consultant: Dr. Ing Aas-Jakobsen
- Contractor: AS Anlegg
- Architect: Boarch Arkitekter A/S
- Main spans: 663 + 977.7 ft (202 + 298 m)
- Side spans: 282 + 410 ft (86 + 125 m)
- Concrete volumes: LC60: 3 139 cu.yd ($2\ 400\ m^3$)
  C45: 2 093 cu.yd. ($1\ 600\ m^3$)
  C65: 13 995 cu.yd ($10\ 700\ m^3$)

Table 5. Concrete composition Raftsundet Bridge

Mix design LC60	lb/cu.yd.	kg/m^3
Cement (CEM1)	725	430
Microsilica	42	25
Total water	295	175
Natural sand	1256	745
LWA Stalite 2-16 mm	927	550
HRWRA	135fl.oz.	4.0 l
WRA	85 fl.oz.	2.5 l
AEA	17 fl.oz.	0.5 l

SANDHORNØY BRIDGE

Sandhornøy bridge connects a large island south of Bodø with the local infrastructure. Using LWC in the side-spans made the economics of the structure more viable, since the foundations for the supports could be placed where they were most cost effective.

Figure 6. Sandhornøy bridge

The owner/client was Norwegian Road Authorities in Nordland county. It was designed by Dr. Ing Aas-Jakobsen a/s and the contractor was Eeg Henriksen a/s (today NCC)

Critical numbers:

- Main span: 505 ft (154 m) normal density concrete C45
- Side spans: 2 x 361 ft (2 x 110 m) in LC55
- Concrete volumes: C45: 3 140 cu.yd. (2400 m^3)
  LC55: 1 755 cu.yd. (1300 m^3)

Sandhornøy Bridge was one of the early Norwegian projects utilizing LWC for free-cantilever bridges. Unusually, in this bridge LWC was used to enable the very long side-spans. The bridge was completed in 1989.

STØVSET BRIDGE

Figure 7. Støvset bridge

The owner/client for this North Norway bridge was Norwegian Road Authorities, Nordland. the consultant was Johs. Holt A.S and the contractor was Selmer A.S (now Selmer Skanska).

- Main span: 772 ft (220 m) (middle 476 ft (145 m) in LWC)
- Side spans: 2 x 328 ft (2 x 100 m)
- Concrete volume: LC55 1 243 cu.yd. (950 m^3)
  C55 9 220 cu.yd. (7 050 m^3)

Table 6. Concrete composition Støvset Bridge

Mix design, LC55	lb/cu.yd.	kg/m^3
Cement (CEM1)	716	425
Microsilica	51	30
Natural sand, 0-8 mm	1155	685
LWA Liapor 8, 4-16 mm	876	520
Total water	327	194
WRA	34 fl.oz	1.0 l
HRWRA	152 fl.oz	4.5 l
AEA	5 fl.oz	0.15 l
Eff. Water/Binder-ratio	<0.40	

Obtained results

- Characteristic 28 days cube strength, LC55: 8 600 psi (59.3 MPa)
- Fresh density at mixing plant: 123.6 lb/cu.ft. (1 980 kg/m^3)
- In-situ density: 120 lb/cu.ft. (1 920 kg/m^3)

BERGSØYSUNDET FLOATING BRIDGE

Bergsøysund bridge is a floating bridge consisting of a continuous 2756 ft (840 m) steel truss frame on 7 pontoons in high strength LWC. The average distance between the pontoons is 346 ft (105,5 m).

Uniquely, the bridge is only anchored at the endpoints, taking transverse forces as compression or tension in the arch. The absence of tethers to the seabed made this type of structure feasible.

The pontoons were built in environmental class MA with w/(c+s) ratio < 0.35 (slipform 0.38). The bottom slab and slipformed pontoon walls were built on a barge. The top slab was constructed on the floating pontoon. A density of 118 +0/-3 lb/cu.ft (1900 +0/-50 kg/m^3) was produced.

Figure 8. Bergsøysundet bridge

During slipforming, cooling pipes with circulation of water were used to reduce the maximum curing temperature below the required limit of 65o C. Achieved characteristic compressive strength was 7774 psi (53.6 MPa) with an average compressive strength of 9094 psi (62.7 MPa) and hardened density of 119 lb/cu.ft. (1907 kg/m^3).

6150 lb/cu.ft. (4700 m^3) LWC were used for the 7 pontoons, each 65 x 79 ft (20m x 24 m). Five pontoons had a height of 20 ft. (6.1m), the two at the ends were 23 ft (7 m) high. The owner was Norwegian Road Authorities, Møre & Romsdal, concrete design was by Johs. Holt A/S and the LWC pontoons were made in Stavanger by Norwegian Contractors. The bridge was built 1991-1992.

The mix design for the pontoons are shown table 7.

Specimens produced during construction are exposed in seawater, both adjacent to the structures and in a laboratory. Additionally, drilling guides have been cast into the concrete to allow drilling of concrete cores without damaging the reinforcement.

The bridge is heavily instrumented. The instrumentation shall monitor corrosion, structural performance and leakage, and the data are recorded on a continuos basis.

Table 7. Concrete composition Bergsøysundet Bridge

Mix design, LC55	lb/cu.yd.	kg/m^3
Cement (CEM1)	725	430
Microsilica	38	22.5
Natural sand, 0-5 mm	1129	670
LWA Liapor 8, 4-8 mm	447	265
LWA Liapor 8, 8-16 mm	548	325
Water for wetting LWA	59	35
Water (excl. Absorption)	266	158
HRWRA	237 fl.oz.	7.0 l
AEA	34 fl.oz.	1.0 l

SUNDØY BRIDGE

Currently under construction

Figure 9. Sundøy bridge immediately after closure, April 4, 2003. The ferries are busy.

The Norwegian State Road authority is the owner of the bridge project. The bridge will create a permanent connection to the mainland for the large Sund island. When completed, the main span will be the second longest in the world. Construction of this 1765 ft (538 m) long bridge started in January 2001 and is scheduled for completion in September 2003.

High performance concrete is central to the design of the bridge – both normal weight HPC and lightweight HPC. Normal weight concrete, at approximately 156 lb/cu.ft. ($2500kg/m^3$), is used for the 394 ft (120m) side spans, while lightweight concrete, which weighs in at about 123 lb/cu.ft. ($1970kg/m^3$), is used for construction of the 978 ft. (298m) main span. This enables construction to proceed using the balanced cantilever method.

In order minimize problems with water absorption during pumping, the contractor has selected a low absorption aggregate, similar to what was done at Raftsundet Bridge – importing Stalite aggregate from South Carolina in the USA. Stalite has low absorption of approximately 6%.

The mid part of the main span is based on use of light concrete, LC60, other parts of the construction is based on use of C65. Environment class for the concrete is very aggressive (MA)

Concrete volumes:

Concrete C45:	5820 cu.yd.	4 450 m^3
Concrete C65:	10 660 cu.yd.	8 150 m^3
Lightweight concrete LC60:	3 270 cu.yd.	2 500 m^3

- Consulting Engineer: Dr. Ing Aas-Jakobsen
- Architect: Boarch Arkitekter A/S

RUGSUND BRIDGE

Figure 10. Rugsund bru. Photo:Torbjørn T. Moe,Norconsult AS

This bridge in West Norway, finished in 2000, connects the district of Bremanger to the mainland. It is located in a harsh environment, wind speeds of more than 112 mph (50 m/s) were recorded during construction. The total length of the bridge is 991 ft (302 m). The long main span combined with the short side-spans, 164 ft (50 m), made necessary the use of LWC in the main span

The main span is 623 ft (190 m) and is currently the third longest bridge span in the world constructed using high performance lightweight concrete LC60. The side spans are designed using C55 concrete and are equipped with ballast rooms filled with gravel (olivine) to counter balance the main span.

Figure 11. Rugsund bridge. Photo Olav Handeland

By using lightweight concrete in the main span, this design was around 10% cheaper than the client's initial alternative, which specified C55 concrete in the main span. The lightweight concrete made it possible to increase the length of the main span from 564 ft (172 m) to 623 ft (190 m), and reduce the length of the side spans (the ballast rooms). In addition, the total length of the bridge was reduced by approximately 33 ft (10 m), enabling one of the pier foundations to be moved closer to the shore and significantly reducing the cost of the foundations.

SUMMARY

High performance lightweight concrete has become a regular material for concrete bridge building in Norway. The ability to adjust span widths to fit the location can mean large savings in total cost of the structure, despite increased materials cost. Research and practical experience from offshore concrete construction have given the owner and designers confidence in the long-term performance of high performance lightweight concrete with silica fume.

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Appendix.
Reports on lightweight concrete from Norwegian and European Joint Industry Projects.

GENERAL

This appendix lists a majority of the reports that have formed the basis for development of Norwegian concrete technology. For completeness all reports are included, even if a number of them are available in Norwegian only. Some of the Norwegian language reports will have summaries in English, and some figure and table captions may be in both English and Norwegian.

Reports with a STF-number are available from SINTEF, web address: www.sintef.no

PROJECT: HIGH STRENGTH CONCRETE:

(National JIP associated with oil exploration leases):

HIGH STRENGTH CONCRETE PHASE 3. SP4 - Materials Properties
Report 4.1. Properties of Concrete with Solite and Lytag LWA. STF70 A95020

LWA-CONCRETE FOR FLOATERS - LIST OF REPORTS (SINTEF REPORTS)

Utilization of Concrete Capacity in Floaters	STF70 A93035
SP1 Report 1.1 Mix Design of LC30 and LC40 Concretes	STF70 A93036
SP1 Report 1.2 Slipforming Tests	STF70 A93037
SP1 Report 1.3 Round Robin Test	STF70 A93038
SP2 Report 2.1 Impregnation of LWA	STF70 A93039
SP3 Report 3.1 Mechanical Properties of Concretes with Strength Grade LC30 and LC40	STF70 A93040
SP4 Report 4.1 A Theoretical Evaluation Based on Material Technology	STF70 A93041
SP5 Report 5.1 Rebar Corrosion and Frost Resistance	STF70 A93042
SP7 Report 7.1 Evaluation of Structural Behavior and Design Specifications	STF70 A93043
SP8 Report 8.1 Influence of Set and Initial Curing Temperature on Composition of Paste	STF70 A93044

MATERIALUTVIKLING HØYFAST BETONG (DEVELOPMENT OF HIGH STRENGTH CONCRETE MATERIALS)

Delprosjekt 2: LETTBETONG

2.1 Statusrapport: Lettbetong	STF65 A91020
2.2 Characteristics of lightweight aggregates for high strength LWA Concrete	STF70 A92022
2.3 The Interfacial zone between High Strength Lightweight aggregate and cement paste	STF70 A92023
2.4 Effekt av fuktforhold på mekaniske egenskaper	STF70 A92024
2.5 Effekt av høy herdetemperatur	STF70 A92025
2.6 Bestemmelse av virkelig Materialsammensetning	STF70 A92026
2.7 Brukerveiledning for produksjon av lett konstruksjonsbetong	STF70 A92027
2.8 Effekt av høy herdetemperatur på høyfast betongs permeabilitet	STF70 A92028
2.9 Kryp i høyfast lettbetong	STF70 A92029
2.10 Optimalisering av forholdet mellom trykkfasthet og densitet for lettbetong	STF70 A92030

NATIONAL PROJECT “LETTKON”

STF22 A00714	HOVEDRAPPORT M.Maage, T.O.Olsen, T.Isaksen, S.Helland, S.Boström, B.Sjetnan, Ø.Kvaal
DP 1 -	NYE BRUKSOMRÅDER
Rapportnr	
STF22 A98737	1.1 Sammendrag. Konstruksjonseksempler LL.Mathisen, E.Strand, S.E.Jakobsen
ctlparSTF22 A98755	1.2 Lettvektsbetong i etasjeskillere. Parameterstudium (Regnark med et eksempel for: Prisoptimal, fritt opplagt plate dimensjonert av krav til nedbøyning) E.Thorenfeldt
STF22 A98743	1.3 Markedsplan - Lettkon Løftefartøy H.Düring
STF22 A98744	1.4 Oppfølging av pågående prosjekter - Colosseum Park. Oppsummering av resultater og praktiske anbefalinger H.Düring
STF22 A98756	1.5 Balkonger i lettbetong E.Heimdal, A.Monsen, B.Stensrud, H.Andreassen
DP 2 -	KONSTRUKTIVE ASPEKT
Rapportnr	
STF22 A98742	2.1 Superlette betongkvaliteter H.Stemland, E.Thorenfeldt
STF22 A98752	2.2 Prosjekteringsveiledning T.Isaksen, H.Stemland, I.Holand, S.Fergestad, S.A.Haugerud, D.E.Brekke, E.Strand
STF22 A99735	2.3 Skjærkapasitet av lettbetongbjelker uten skjærarmering H.Stemland, E.Thorenfeldt
STF22 A99746	2.4 Langtidskryp A.Tomaszewicz
STF22 A00711	2.6 Sammenligning av beregningsmetoder TT Moe
DP 3 -	BESTANDIGHET OG FUNKSJON

Rapportnr	Rapport-tittel Forfattere
STF22 A98729	3.1 Kloridinntrengning på lettbetongdel av Nordhordlandsbrua og Boknasundet bru J.E.Carlsen
STF22 A98735	3.2 Potensialmålinger på armerte betongkonstruksjoner Ø.Vennesland
STF22 A98736	3.3 Tetthet mot vanninntrenging i lettbetong M.Rønne, E.Aa.Hansen
STF22 A98757	3.4 Østmarkneset testblokker. Tilstandsundersøkelse etter 63 måneders eksponerng M.Rønne, Ø.Vennesland, J.Havdahl,
STF22 A98754	3.5 Korrosjonsovervåking av pongtonger i lettbetong. Bergsøysundet bru - Nordhordlandsbrua F.Fluge
STF22 A98747	3.6 Chloride penetration into concrete with light weight aggregates M.Maage, S.Helland, J.E.Carlsen
STF22 A98753	3.7 Kloridinntrengning på Bergsøysundet flytebru J.E.Carlsen
STF22 A98745	3,8 Østmarkneset testblokker. Skadeundersøkelse M.Rønne, T.A.Hammer, I.Meland, T.Kanstad
STF22 A00712	3.9 Korrosjonshastighet og katodeeffektivitet for armering eksponert i lettbetong R.Antonsen
STF22 A00708	3.10 Effekt av høy herdetemperatur på motstand mot kloridinntrengning J.E.Carlsen, O.Skjølsvold, F.Fluge
STF22 A00715	3.11 Effekt av fuktighet og kloridinnhold på armeringskorrosjon i lettbetong J.Havdal, Ø.Vennesland
DP 4 -	PRODUKSJON
Rapportnr	Rapport-tittel Forfattere
STF22 A98738	4.1 Lettbetong med Leca 600. Forfukting og pumpeforsøk S.Boström, G.Norden, T.Cielicki, J.Teigland,G.Mathisen
STF22 A98751	4.2 Pumpbarhet av lettbetong med impregnerte, forfuktede og ubehandlede lettilslag S.Smeplass, F.Thomassen
STF22 A98731	4.3 Spesifikasjoner og produksjonsveiledning for lettilslag og lettbetong S.Smeplass, T.A.Hammer, M.Rønne, S.Helland
STF22 A98782	4.4 Uttørkning av lettbetong S.Smeplass
STF22 A99751	4.5 Resultater fra laboratorieforsøk på lettilslag og lettbetong S.Smeplass
STF22 A00709	4.6 Fullskalaprøving ved Colloseum Park T.Cielicki
STF22 A99766	4.7 Resultat og erfaringer med lettbetong på Stolmabrua S.Rosseland
STF22 A00710	4.8 Stolmabrua - Entreprenørens erfaring med bruk av lettbetong S.U.Hiim
STF22 A00716	4.9 Fullskala pumpeforsøk med Stalite som lettilslag S.Bostrøm

EUROLIGHTCON

BE96-3942/R1	Definitions and International Consensus Report (0.24 Mb)	Version of 1999-04-22
BE96-3942/R2	LWAC Material Properties State-of-the-Art (1.03 Mb)	Version of 1999-04-22
BE96-3942/R3	Chloride penetration into concrete with lightweight aggregates (1.23 Mb)	Version of March 1999
BE96-3942/R4	Methods for Testing Fresh LightWeight Aggregate Concrete (0.58 Mb)	Version of December 1999
BE96-3942/R5	A rational mix design method for lightweight aggregate concrete using typical UK materials (0.21 Mb)	Version of January 2000
BE96-3942/R6	Properties of Lytag-based concrete mixtures strength class B15-B55 (0.68 Mb)	Version of January 2000
BE96-3942/R7	Grading and composition of the aggregate (0.40 Mb)	Version of March 2000
BE96-3942/R8	Properties of lightweight concretes containing Lytag and Liapor (0.14 Mb)	Version of March 2000
BE96-3942/R9	Technical and economic mixture optimisation of high strength lightweight aggregate concrete (11.8 Mb)	Version of March 2000
BE96-3942/R10	Paste optimisation based on flow properties and compressive strength (0.31 Mb)	Version of March 2000
BE96-3942/R11	Pumping of lightweight aggregate concrete based on expanded clay in Europe (1.84 Mb)	Version of March 2000
BE96-3942/R12	Applicability of the particle-matrix model to LWAC (0.90 Mb)	Version of March 2000
BE96-3942/R13	Large-scale chloride penetration test on LWAC-beams exposed to thermal and hygral cycles (0.77 Mb)	Version of March 2000
BE96-3942/R14	STRUCTURAL LWAC Specification and guideline for materials and production (1.57 Mb)	Version of August 2001
BE96-3942/R15	Light Weight Aggregates (0.10 Mb)	Version of August 2001
BE96-3942/R16	In-situ tests on existing LWAC (2.56 Mb)	Version of March 2000
BE96-3942/R17	Properties of LWAC made with natural lightweight aggregates (0.15 Mb)	Version of June 2000
BE96-3942/R18	Durability of LWAC made with natural lightweight aggregates (0.12 Mb)	Version of August 2001
BE96-3942/R19	Evaluation of the early age cracking of the lightweight aggregate concrete (0.35 Mb)	Version of August 2001
BE96-3942/R20	The effect of the moisture history on the water absorption of lightweight aggregate (0.14 Mb)	Version of August 2001
BE96-3942/R21	Stability and pumpability of lightweight aggregate concrete Test methods (0.24 Mb)	Version of August 2001
BE96-3942/R22	The economic potential of lightweight aggregate concrete in c.i.p. concrete bridges (0.54 Mb)	Version of August 2001

BE96-3942/R23	Mechanical properties of lightweight aggregate concrete (0.22 Mb)	Version of June 2000
BE96-3942/R24	Prefabricated bridges (0.27 Mb)	Version of August 2001
BE96-3942/R25	Chemical stability, wear resistance and freeze-thaw resistance of lightweight aggregate concrete (0.12 Mb)	Version of August 2001
BE96-3942/R26	Recycling lightweight aggregate concrete (0.09 Mb)	Version of June 2000
BE96-3942/R27	Mehanical properties of LWAC compared with both NWC and HSC (4.35 Mb)	Version of August 2001
BE96-3942/R29	A prestressed steel - LWA concrete bridge system under fatigue loading (3.14 Mb)	Version of May 2000
BE96-3942/R30	Creep properties of TWAC (0.44 Mb)	Version of May 2000
BE96-3942/R31	Long-term effects in LWAC: Strength under sustained loading Shrinkage of High Strength LWAC (0.15 Mb)	Version of August 2001
BE96-3942/R32	Tensile strength as design parameter (0.11 Mb)	Version of August 2001
BE96-3942/R33	Structural and economic comparison of bridges made of inverted T-beams with topping (0.56 Mb)	Version of June 2000
BE96-3942/R34	Fatigue of normal weight concrete and lightweight concrete (0.53 Mb)	Version of June 2000
BE96-3942/R35	Composite models for short- and long-term strength and deformation properties of LWAC (0.67 Mb)	Version of June 2000
BE96-3942/R36	High strength LWAC in construction elements (0.17 Mb)	Version of June 2000
BE96-3942/R37	Comparison of bridges made of NWC and LWAC. Part 1: Steel concrete composite bridges (6.73 Mb)	Version of June 2000
BE96-3942/R38	Comparing high strength LWAC and HSC with the aid of a computer model (0.40 Mb)	Version of June 2000
BE96-3942/R39	Proposal for a Recommendation on design rules for high strength LWAC (0.09 Mb)	Version of June 2000
BE39-3942/R40	Comparison of bridges made of NWC and LWAC. Part 2: Bridges made of box beams post-tensioned in transversal direction (0.22 Mb)	Version of June 2000
BE39-3942/R41	LWA concrete under fatigue loading. A literature survey and a number of conducted fatigue tests (1.33 Mb)	Version of June 2000
BE96-3942/R42	The shear capacity of prestressed beams (1.49 Mb)	Version of June 2000
BE96-3942/R42	Appendix (6.97 Mb)	Version of June 2000
BE96-3942/R43	A prestressed steel - LWA concrete bridge system under fatigue loading (3.14 Mb)	Version of August 2001

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