# PUMPING OF HIGH PERFORMANCE LIGHTWEIGHT CONCRETE FOR THE RAFTSUNDET BRIDGE


| **AUTHORS** | **COMPANY NAME**<br>**CITY AND STATE** |
| --- | --- |
| 1. JAN-EIRIK NILSSKOG | AS ANLEGG<br>TRONDHEIM<br>NORWAY |
| 2. ROLF VALUM | POLKONSULT AS<br>TROMSOE<br>NORWAY |
| 3. KENNETH S. HARMON | CAROLINA STALITE<br>COMPANY<br>SALISBURY, NC |

## SYNOPSIS

Pumping of lightweight concrete is traditionally not used as a means of placing lightweight concrete in Norway. For bridge construction, this procedure has not been permitted for placing high performance concrete due to the high absorption of expanded clay or shale lightweight aggregate normally used in Europe.

The recently completed Raftsundet Bridge is a 711-meter long free cantilever concrete bridge spanning the Raftsundet Straight in northern Norway. The main span, with a total length of 298 m and a sailing height of 47 m, is constructed with high performance light weight concrete with a hardened density of 19.75 kN and a 28-day compressive strength of 60 MPa (LC60).

In order to obtain permission to pump lightweight concrete for the Raftsundet Bridge, the contractor AS Anlegg developed an elaborate program of testing and documenting concrete properties. The program was implemented in order to demonstrate that by using a rotary kiln expanded slate lightweight aggregate (LWA), high performance lightweight concrete could be pumped without any measurable adverse affect on concrete properties.

This paper will discuss the concerns regarding pumping of high performance lightweight concrete, outline the testing program developed for the Raftsundet Bridge and report the results from parallel testing of both normal weight and lightweight concrete performed during the period of construction.

## INTRODUCTION

The recently completed Raftsundet Bridge is situated in one of Norway’s most scenic areas, more than 300 km north of the Arctic Circle. The 711 m long bridge spans the Raftsundet Sound, providing a "ferry free" road connection between the Lofoten Archipelago and the main highway system in northern Norway.

The geometry of the bridge is shown in Fig 1. The bridge is a continuous post-tensioned, cast-in-place, box section concrete bridge, supported on three rows of slender, rectangular twin columns providing a free "under bridge" clearance of 46 m. The four spans are respectively 86, 202, 298 and 125 m long. The depth of the box section is more than 14 m at the main span columns, and 3 m at mid-span. The central 224 m of the 298 m long main span is constructed from high performance lightweight concrete (HPLWC) with a hardened density of 19.75 kN, and a 28-day compressive strength (cube) of more than 60 MPa (grade LC 60). The rest of the superstructure and the columns are normal weight concrete (NWC) with a hardened density of 24.00 kN, and 28-day compressive strength (cube) of more than 65 MPa (grade C65).

The Norwegian Public Road Department, Nordland Road Office, awarded the contract for construction to AS Anlegg of Trondheim, Norway in early 1996. Structural design is by Dr. Ing. A. Aas-Jakobsen AS of Oslo Norway, and architectural design is by Boarch Arkitekter AS of Bodoe Norway. Construction started in May 1996, and was completed as planned in October 1998. At the time of completion, the bridge represented the longest span ever built using this type of bridge, and is the first use of Stalite expanded slate lightweight aggregate in Europe. The bridge also

**Fig 1. Raftsundet Bridge. Final segment of the construction of the 298-meter long main span. Construction proceeded simultaneously from both sides in order to minimize deflection prior to "mating"**

represents the first major use of pumping to place lightweight concrete in Norway.

**LIGHTWEIGHT CONCRETE**

Although lightweight concrete is routinely pumped in some parts of the world, i.e. North America, it is not considered feasible for high performance concrete (HPC) in Norway. Design specifications for highway bridges in Norway have, until recently (1999), specified that: "Lightweight Concrete shall not be pumped." The design specifications also called for stringent moisture control of the LWA material during storage, and specific procedures including re-mixing of the LWA concrete at the job site, prior to pouring.

For the Raftsundet Bridge the contractor's prefered method of concrete distribution on the superstructure was by hoisting concrete from mixer trucks onto the superstructure using tower cranes placed at each row of columns, and then using pumps to distribute the concrete to the point of placement.

The contractor felt that in this way he would have better control of final concrete quality, as well as provide better consolidation and finishing, than if the concrete had to be dropped the 14 m down the walls of the box section.

By using a pre-wetted, low absorption LWA material, it was thought that the lightweight concrete could be distributed and placed using the same equipment and procedures as was the case with normal weight concrete, and that re-mixing of the concrete would not be necessary. Also, by using this type of aggregate, the need for indoor storage and a tight moisture control could be greatly reduced.

In order to prepare a request for simplifying the LWC procedures, and to be allowed to pump the LWA concrete, AS Anlegg together with Polkonsult AS of Tromsoe, Norway, developed a mix design for a pumpable HPLWC (Table 1) based on Stalite lightweight aggregate (LWA).

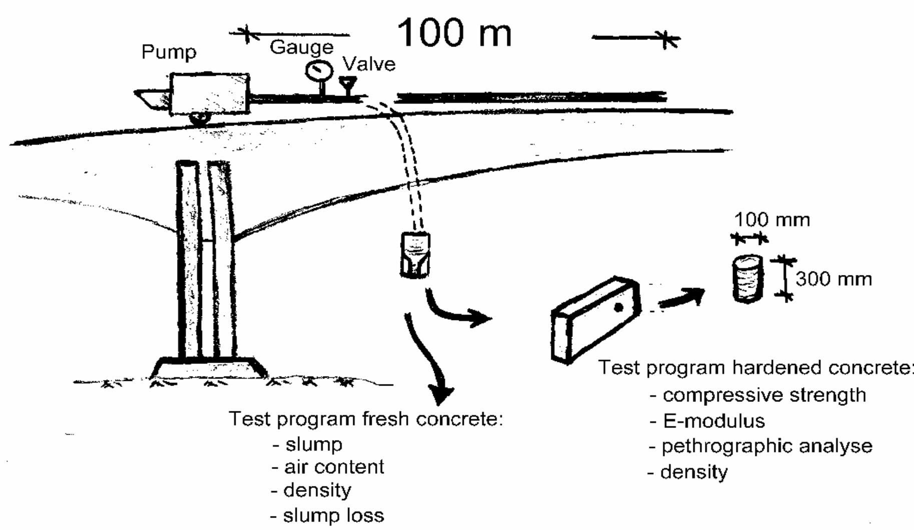
| | Quantities kg/m$^3$ |
|---|---|
| Cement Norcem HS65 | 430 |
| Silica fume | 23 |
| Fine NWA 0-8mm | 745 |
| Stalite LWA ½"-#8 | 550 |
| Water total | 175 |
| Water reducer Scancem P | 3.2 |
| Plasticizer Scancem SP40 | 4 |
| Air entrainm. Scancem (L) M | 0.5 |

**Table 1 HPLWC Mixture Proportions**

**TEST PROGRAM**

It was thought that any in-homogeneity due to pumping would show up as variations in compressive strength between pumped and non-pumped lightweight concrete, and that this in-homogeneity could be verified by petrographic examination of the mortar/aggregate interface using a thin section

**Fig 2. General layout of rig for pumping trials.**



method. In order to verify that pumping would not have any adverse effect on the LWA concrete, a semi-realistic, full-scale, pumping trial was performed. Acceptance to pump lightweight concrete for the project would be based on the outcome of this pumping trial.

The general layout of the test rig is shown in Fig 2 representing procedures and equipment as close to that of a normal pumping arrangement as possible. The pump was a Reed Multi M40 concrete pump fitted with various lengths of 5" steel pipe and a 10 m long, 5" rubber hose placed along a completed section of the bridge deck. In this way the normal inclination of 5% over the length of the pump line could be achieved. The outlet end of the pump was fitted with a guillotine valve that could be closed during pumping in order to simulate a situation of blockage in the line. A situation like this would bring the full pressure capacity of the pump to bear on the entrapped concrete.

Lightweight concrete was batched, sampled and trucked to the bridgehead following normal procedures. On arrival at the pump station, the nearly 30 minutes old concrete was tested for slump, air and fresh density. The truck then continued to a heated storage where a reinforced “wall section” shaped reference block (L x H x W = 1.5 x 1.0 x 0.4 m) was poured in order to verify flowability and finishing characteristics of the lightweight concrete. Specimens cored from this concrete block were later used to document in-situ strength and hardened density of non-pumped concrete.

After returning to the test area, pumping was resumed at normal pumping speed and pressure.
The guillotine valve was then closed and a concrete pressure of 100 bar was maintained for 5 minutes to simulate a blockage of the pump line. The concrete was at this time more than 1 hour old. After relieving pressure, the concrete was sampled at the end of the pump line, for air, slump and fresh density: Additional concrete was pumped at normal pressure through the 10 m long 5" rubber hose, over the side of the bridge deck into a concrete hopper suspended below the bridge. This concrete was then brought to the shed, and another wall section was poured, representing concrete that had been significantly pressurised by pumping.

Approximately 2.5 hours after the concrete left the batch plant, the full 100 m pipeline was connected to the pump, and the remaining 5 cubic meters of lightweight concrete was successfully pumped through the line at normal pressure. No sampling was performed at this stage. A number of test cubes and cylinders were prepared from each station for documentation of hardened density, compressive strength, E-modulus and petrographic testing (thin section). A tabulation of the test results is shown in Table 2.

## CONCRETE SAMPLING AND TESTING

All concrete for the project was produced by an independent batch plant operator located in a small hamlet approximately 20 km west of the bridge location, and transported in mixer trucks to the site.

The test program for the pump trial, as well as all consecutive sampling and testing of production concrete, was executed at the contractor’s site laboratories. This included testing of fresh concrete properties as well as compressive strength and density testing on standard 100x100 mm cubes. All testing of cylinder specimens was performed by an

**Table 2. Tabulation of test results.**

| | Density kN/m$^3$ | | | Compressive strength cube | | | | E-modulus Gpa $E_0$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** | **4** | **1** | **2** | **3** |
| Fresh concrete | 20.06 | 20.11 | 19.92 | | | | | | | |
| 2 days | 19.83 | 19.93 | 19.94 | 35.6 | 37.4 | 35.6 | | | | |
| 3 days | 19.88 | 20.00 | 19.82 | 46.4 | 48.8 | 47.1 | | | | |
| 7 days | 19.83 | 20.06 | 19.90 | 57.5 | 57.0 | 61.0 | | | | |
| 14 days | 19.90 | 19.96 | 19.87 | 66.9 | 67.8 | 65.5 | | | | |
| 28 days | 19.82 | 20.06 | 19.92 | 73.5 | 75.8 | 71.0 | 66.0 | 24.2 | 24.5 | 23.0 |

Ratio Cylinder/cube = 0.93.
1 Pumped concrete
2 Blocked
3 Unpumped concrete

independent testing laboratory at the Narvik Technical High School in the nearby town of Narvik. This included establishing the ratio of compressive strength between cylinders and cubes, E-modulus and in-situ strength of pumped/non-pumped concrete cored from the test blocks, as well as compressive strength and E-modulus on standard cylinder test specimens. Petrographic analyses of the interface area between LWA particles and mortar in hardened concrete were carried out by the research foundation Sintef in Trondheim, Norway. This analysis was performed on thin section specimens from the pump trial to see if there was any structural evidence of degrading of the LWA concrete due to the pumping action. Fig 3 shows a segment from a typical thin section specimen showing an interface section of LWA/mortar. The arrows indicate micro cracking within the mortar matrices and in the interface LWA/mortar zone.

The full-scale pumping trial demonstrated without doubt that the proposed LWC mix was fully pumpable. The concrete was stable and robust and as can be seen from Fig 4, the LWA concrete did not require re-mixing prior to pouring, but maintained an acceptable slump level for a long (2.5 hour) time. As seen in Table 2 and Fig 5, variations in density and compressive strength between the concrete that had been pumped and concrete that had not been pumped was very small and not significant. If any thing, the results indicate that LWA concrete that had been pumped and had experienced a blockage, exhibited properties equal to, or higher than concrete that had not been pumped.

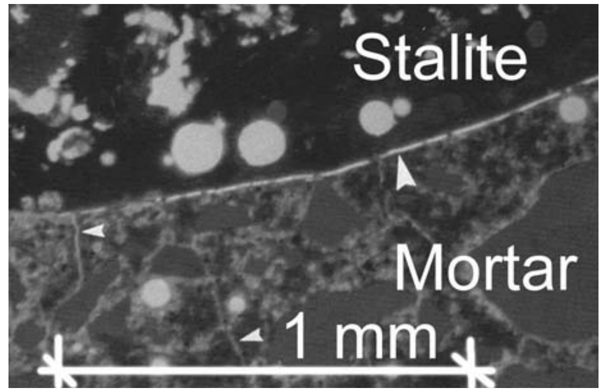


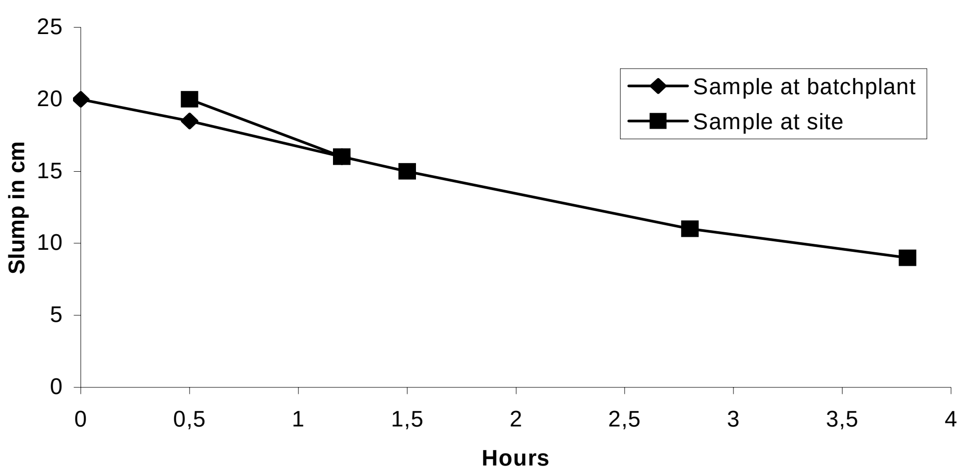

**Fig 3. Segment of thin section photography from petrographic analysis showing interface of Stalite particle (upper half) and sand/cement matrix. Arrows indicate micro cracks. Spherical objects in matrix are entrained air bubbles; light areas in Stalite particle are microcells**

The report issued by Sintef of the petrographic examination of concrete from the pumping trials concluded that no noticeable negative effect from pumping was apparent in any of the concrete samples. The concrete in the samples was homogeneous, and there was no sign of bleeding pockets or enrichment of air in the LWA/mortar interface. The number, and nature, of micro cracks observed in the samples, showed no significant difference between pumped, and non-pumped concrete, and was of no consequence.

**PRODUCTION TEST RESULTS**

During the construction of the Raftsundet Bridge the

**Fig 4. Slump loss in non-pumped concrete used in pumping trials. The slow and gradually declining curve is a consequence of the retarding effect of lignosulphonate based admixtures. During cold weather concreteing, part of the lignosulphonates was replaced by melamine or naphtalene based admixtures.**



contractor sampled more than 600 batches of concrete as part of his receiving control and as final concrete documentation. A number of these samples, both NW and LW, were collected at the pump discharge allowing direct comparison of NW and LW concrete produced and placed under the same physical conditions.

The test results for the construction period November 1997 to February 1998, can be summarized as follows:

| Comp.Str. | 28 d | NWC C65 | LWC LC60 |
|---|---|---|---|
| No. of Tests | (n) | 68 | 68 |
| Aver. St. | (x) | 71.9 MPa | 65.9 MPa |
| St. Dev. | (s) | 5.8 MPa | 3.7 MPa |

| E-Modulus | 28 d | NWC C65 | LWC C60 |
|---|---|---|---|
| No. of Tests | (n) | 4 | 4 |
| Aver. St. | (x) | 27.5 GPa | 23.5 GPa |
| St. Dev. | (s) | 4.1 GPa | 1.1 GPa |

| Density | 28 d | NWC C65 | LWC LC60 |
|---|---|---|---|
| No. of Tests | (n) | 36 | 36 |
| Aver. Dens. | (x) | 24.63 kN/m3 | 19.32 kN/m3 |
| St. Dev. | (s) | 0.28 kN/m | 0.30 kN/m3 |

| Air Content | | NWC C65 | LWC LC60 |
|---|---|---|---|
| No. of Tests | (n) | 70 | 65 |
| Aver. St. | (x) | 4.0 | 4.4 |
| St. Dev. | (s) | 0.6 | 0.7 |

The results show that a high performance lightweight concrete based on a pre-wetted Stalite LWA material can be produced and placed under the same general conditions, using the same equipment and procedures as for a NW concrete. The general testing of production concrete demonstrated that the LWA concrete at Raftsundet Bridge could be pumped over distances of 100 m without showing significant reduction in strength. The concrete also experienced pressure surges from pipe blockages without showing any significant reduction in density, compressive strength or E-modulus. The LWA concrete proved to be very stable, and exhibited less variation in most parameters compared to the NW concrete used on the project. This included parameters such as fresh and hardened density, air content, and slump as well as compressive strength and E-modulus. In our opinion the test results should help to "de-mystify" HPLWC as a construction material.

## REFERENCES


1. Hoff, G. C., Valum, R., Weng, J.K., Nunez, R. E. (1995) "The use of Structural Light Weight Aggregate in Offshore Concrete Platforms." Proceedings International Symposium on High Strength/High Performance Concrete. Sandefjord, Norway

2. Hoff, G. C., (1992) High Strength Lightweight Aggregate Concrete for Arctic Applications, Sp-136, Structural Lightweight Aggregate Concrete performance, ACI, Detroit USA.


**Fig 5 Strength development of LWA concrete used at the pumping trial and NW concrete pumped at normal pressure.**