Concrete, particularly for the oil and gas industry

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From a structural point of view the importance of a reliable material is evident.

Major parts of this paper are based on a presentation of Atle Berge of Ølen Betong, a large Norwegian concrete company, and on Ref. 4.

In the early 1970’s concrete was introduced as a proper construction material for offshore structures for the oil and gas industry. Due to the high loading and the particular construction method, the importance of high strength and low weight is evident. Considerable research and development has been conducted in Norway for these reasons. Recently attention has been paid to arctic use of concrete.

The large LNG production facility at Melkøya, far north in Norway, has called for some 200,000m³ of concrete. Not particularly high strength, as in the deepwater platforms, but lots of challenges up north was experienced.

The MPU Heavy Lifter is a concrete vessel intended to lift entire topsides or jackets in one piece by Archimedes’ principle. For optimum lightship weight versus displacement, the hull is made of high performance LWA concrete with an in situ density less than 1,600 kg/m³ based on lightweight aggregates in all fractions.

Unfortunately, the owner of the vessel went broke, so the vessel is not completed. However, a lot of experience is gained on the all LWA concrete.

Keywords: Concrete, LWA Concrete, Offshore concrete structures, harsh environment, Arctic.

1. INTRODUCTION

Offshore concrete structures have been installed in the North Sea for more than 35 years. These platforms which must be designed during temporary and towing operations as floating bodies subjected to a considerable hydrostatic pressure difference were all towed to location and subsequently ballasted on to the seabed.

Figure 1 The environment of the sea.

Looking at the environment at sea, Fig. 1 indicates the importance of material quality.

Plans for further oil and gas exploitation in ever increasing harsh environments have accelerated the focus and interest for the efficiency of offshore concrete structures.

2. THE ARCTIC

Some of the challenges associated with the arctic are ice loads and ice abrasion, limited installation windows, limited access for mitigation of unforeseen events, extreme focus on HSE (health, safety and environment), and the consequences of pollution.

Concrete is a very well suited material to build rough structures for the arctic.

Several structures are built. Fig. 2 shows one of the Sakhalin II platforms, built in Nahodka south of Vladivostok, after installation, but prior to deck installation.
The Sakhalin II platforms are subjected to sheet ice. Ice is a science of its own, and must be understood to determine the actions the platforms are subjected to. Fig. 3 shows another type of ice, the ice berg. The coast of Newfoundland is subjected to these, and the Hibernia platform, a concrete GBS, is designed to resist them. The platform has been in operation for a decade.

Icebergs also exist on the southern hemisphere, as will be known in New Zealand.

### 3. MELKØYA – LNG PRODUCTION

Gas is arriving from sub sea wells to the island Melkøya for LNG production and export.

The Norwegian company Ølen Betong (betong means concrete in Norwegian) got the challenging task of producing some 200,000 m³ of concrete for the various structures, including the LNG tanks.

Ølen Betong has been delivering concrete for the oil and gas industry for many years, both for platforms and for industrial plants. Ølen Betong has supplied more than 50% of all concrete used in construction of onshore facilities.

During the last 35 years concrete has been a very important material, and concrete has been used in large quantities. The Norwegian oil and gas industry has significantly improved the Norwegian concrete technology. These improvements are available to new projects.

At Melkøya quality, capacity, logistics and price have been key factors.

Some requirements were:

- Medium strength requirements. Strict requirements regarding durability and the properties of fresh concrete
- Performed all concrete transportation from the concrete plant to various building sites
- Approx. 95% of all concrete has been pumped. All pumping was performed by mobile pumps
- For LNG tanks, the walls and roof are pumped by stationary pumps

Some key information:

- 200,000 m³ concrete requires 500,000 tonnes of supplied materials.
- Cement: Total consumption approximately 75,000 tonnes in total. Supply varied, up to 1,000 tonnes per day. The cement had to be imported from relative far away locations.
- Large storage capacity was required on the plants.
- Aggregates: Approximately 400,000 tonnes were used in total, mainly from local suppliers in the northern region of Norway; some had to be transported from the
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southern part of Norway. It is important to use local aggregate materials, if possible.

**Figure 5** One of the production plants at Melkøya

Two concrete production plants, one with 60-70 m³/h and one with 100 m³/h production capacity, were set up. Two plants were necessary for capacity and backup. The plants were equipped with modern IT control systems providing required documentation.

The largest single job was for the LNG tank foundations of 4 000 m³ - approx. 100 m³/hour.

Continuous slip form job for the tank walls, approximately 5-600 m³/day, for two weeks duration for each tank.

At peak the monthly production was 20,000 m³. In general the monthly production was 8-10 000 m³.

Delivered quantity was high also during the winter months, approximately 6 – 8,000 m³/month. In the cold weather it is crucial with appropriate insulation and large capacity heating on the plant, 1 MW capacity on each. The concrete was heated to 20 – 30°C throughout the winter season. To manage this it is essential to control the supply of heat.

**Figure 6** Winter production

**4. A PARTICULAR LWA CONCRETE**

The **MPU Heavy Lifter** is a semi-submersible concrete vessel developed for removal or installation of fixed offshore platforms.

For the hull, reinforced concrete was deemed to offer distinct advantages over steel in terms of construction costs, robustness and durability. The drawback of the deadweight was outweighed by the use of LWA concrete, for which the lowest possible density without sacrificing structural efficiency was sought. For optimum lightship weight versus displacement, an all lightweight aggregate concrete (ALWAC) with a density of less than 1,600 kg/m³ and sufficient strength for use with prestress was targeted.

**Figure 7** Pumping concrete to one of the LNG tanks

**Figure 8** MPU Heavy Lifter

The use of structural lightweight concrete in a
permanently floating sea structure is not a novel concept. Manufactured LWA has been used in a large number of concrete ships and barges during the World War periods. More recently LWA concrete found application in two major floating platforms built for the North Sea; the Heidrun TLP and the Troll West, both installed in 1995. The Heidrun TLP is made of high performance LWA concrete with an in situ density of 1,950 kg/m³ whereas a modified normal density concrete (MND) with a density of 2,250 kg/m³ was utilized for Troll West. The use of LWA concrete in these platforms resulted from a Norwegian research campaign aimed to develop LWA concretes for floaters with typical densities in the range of 1,850 – 1,950 kg/m³. Significant research was also performed on lighter, high performance ALWA concretes with densities in the range of 1,450 – 1,550 kg/m³. These studies paid valuable contribution to the implementation of production and design provisions for LWAC into Norwegian concrete standards, meanwhile applicable for high-performance concretes with LWA in both coarse and fine fractions.

Yet, due to limited previous real-life experience, a comprehensive laboratory test program to investigate and document the concrete properties and structural performance was deemed necessary, Ref. 4.

The concrete mix was developed through a series of trial mixes, both in laboratory and in full scale, in order to meet the workability and performance criteria relevant for marine structures.

The concrete specification was based on EN-206-1:2001, Ref. 3, including Norwegian National Annex supplemented with project specific amendments. The required mean demoulding density was 1,580. The specified strength class was LC35/38. The prescribed durability class for the hull was MF40 implying an effective water/binder ratio less than 0.4, use of pozzolans or slag and a minimum air content of 4% according to the Norwegian National Annex to EN-206-1.

The trial batch tests resulted in the qualification of two concrete mixtures which were used for subsequent mock-up tests.

The aggregates, of type Liapor F 6.5 (2-10 mm) and Liapor-Sand K (0-2 mm), had a mean bulk density of 650 kg/m³.

In densely reinforced offshore structures (400 - 500 kg/m³) the predominant workability properties are high fluidity and negligible segregation.

In line with experience from earlier pump trials with similar LWAC compositions, pumping of the concrete proved not feasible. Placing was therefore to be performed by the use of cranes and skips (buckets).

The results of the mechanical properties are summarized in Table 1 (mean and standard deviations).

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<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>St. dev.</th>
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<tbody>
<tr>
<td>Demoulding density kg/m³</td>
<td>1565</td>
<td>8</td>
</tr>
<tr>
<td>Cylinder strength $f_{cc}$ MPa</td>
<td>42.2</td>
<td>2.8</td>
</tr>
<tr>
<td>E-modulus $E_c$ GPa</td>
<td>14.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Tensile strength (centric) $f_t$ MPa</td>
<td>2.9</td>
<td>0.3</td>
</tr>
<tr>
<td>E-modulus (tension) $E_t$ GPa</td>
<td>19.5</td>
<td>1.5</td>
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<td>Poisson’s ratio $v$</td>
<td>0.22</td>
<td>0.001</td>
</tr>
<tr>
<td>Thermal dilation CTE $10^{-6}$/°C</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>Creep factor $\phi_{\infty,ND}$</td>
<td>0.55</td>
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Constructability tests were conducted on full scale mock-ups with the objective to demonstrate proper placement and compaction of the concrete under field conditions.

The subsequent mock-up test (Fig. 9) also addressed other aspects pertaining to performance of the concrete, such as temperature development, demoulding density, hardened concrete properties and response to post-tensioning. The test replicated a 5 m high wall joint including ordinary reinforcement, post-tensioning cables and cast-in items as in the real structure. The main observations from this test were:
- The placeability of the concrete was sufficiently good.
- The LWAC mix proved stable and not susceptible to segregation when placed or compacted.
- No heat-induced cracking was observed. The temperature rise due to heat of hydration did not exceed the threshold value of 65°C. Hot weather concreting may require preventive measures (cooling conduits).
- The air content as measured by the pressure method was below the required minimum of 4 % (later overcome through optimization of the mixing procedure).

The compaction of the concrete and embedment of reinforcement was assessed by means of cores drilled through the entire wall section. The samples showed homogeneous distribution of aggregates and good embedment of the stirrups.
The relative low tensile strength (Table 1) has implications on shear resistance and anchorage lengths. The increase in shear reinforcement compared to NDC is moderate because structural members subjected to water pressure normally require shear reinforcement anyway. For anchorage and lap lengths the effect is more significant leading to nearly a doubling of the required lap lengths. This is mitigated by the extensive use of mechanical couplers and headed anchorage.

The relative brittleness of the ALWAC is compensated by careful reinforcement detailing. In addition to the precautions with respect to detailing included in NS 3473 (e.g. maximum bar diameter, limitation of equivalent diameter of bundles, minimum mandrel diameter), a minimum amount of transverse reinforcement has been introduced in all members to improve ductility and robustness.

REFERENCES