SUMMARY

In planning for large scale developments in built-up urban areas on sedimentary ground, the stability of the site is a crucial factor. This is consistent for both the excavation and construction phases. It is especially important that the ground water conditions are stable and no unpredictable movement will influence surrounding buildings and infrastructure.

Whilst there are many ways to stabilize the ground, one specific project in Kristiansand, Norway, utilised an innovative approach by stabilizing the surrounding ground using large volumes of concrete cast underwater.

The city centre in Kristiansand is situated near to the coast, with high ground water conditions. During the construction of a new building, the excavation was required to reach a depth of 5.0m below sea level. The site retention system comprised a combination of secant piles and sheet piles. During the spoil removal stage, it became evident the retention system, at the lowest points could not cope with the high ground water in the localised vicinity. Spoil removal continued to the required depth and soon after, the excavation was flooded with a several meters of water (a mix of sea-water and ground water). Before the foundation work could commence, the site had to be de-watered.

It was decided to support the site’s footprint with a thick plate of concrete at the base of the excavation before de-watering could take place. A total of 3,740 m$^3$ of specially designed underwater concrete was pumped and cast into the base of the water-filled site in five separate operations.

This paper discusses the issues, the materials, the solutions and the many tests that were conducted to enable the project’s stakeholders overcome some major construction and engineering hurdles.
DESCRIPTION OF PROJECT
In the city of Kristiansand, located on the south coast of Norway, a construction project was started in 2006. A new shopping centre, The Sandens Senter, was to be constructed in between existing buildings. The size of the shopping centre is 40,000 m². and the contract value was 317 million NOK (= 40 million €). The foundation of the new shopping centre was to be constructed at five metres below sea level.

Picture 1: Location of construction site

The main contractor for the project was Skanska and project owner was Steen & Strøm.

TASK

Description
Water was flowing into the excavated basement from the surrounding ground and from the sea. The construction site soon filled with five - six metres of water.

In order to support the excavation, sheet piles and secant piles were installed (see picture 2).

The Construction Contractor and their Consultants decided to use a thick layer of concrete in the base of the excavation; in order to support the walls prior to any attempt to dewater the site.

There was an agreement to use a specially designed under-water cast concrete in the flooded lower section of the site. The concrete pours would be divided into five separate sections. Each section would be cast in one continuous operation.

Picture 2: Flooded Construction site
Theory
When casting concrete under water, there is always a great risk of turbulence and mixing of surrounding water into the concrete. These effects often cause a significant loss of cement and binder as they are washed out from the concrete and also increased water-cement ratio.

Cohesion promoting, anti wash-out admixtures are produced in powder form and specially designed for making under-water cast concrete. The admixture is a mix of efficient stabilizers, combined with superplasticisers and defoamers. The admixture used in this project, Rescon T, was supplied in 15 kg paper bags, and a dosage of 1 x 15 kg bag per m³ of concrete.

The mix design of the concrete was based on a combination of knowledge and experience. It is always recommended to perform tests and pre-qualification in order to evaluate all the factors that can influence the final result.

The efficient stabilizers make the concrete cohesive and slow moving even though the concrete may have a high flow.

The defoamer is important due to the fact that the stabilizers entrain air into the concrete.

CONCRETE
Concrete formulation
Concrete for under water casting has to be designed in order to fulfil the specific requirements of the project. In this project, the total water-cement ratio (w/c) was set to 0.45, allowing use of factor 2.0 for silica fume. The amount of binder was approx 550 kg in order to design a concrete which is cohesive and has a good flow potential. Since there is a high binder content in the concrete mix, it is recommended to use more large aggregate in the total amount of aggregates. In this case 51 % of aggregates were greater than 16 mm. The binder and the stabilizing anti wash-out admixture prevent segregation of the concrete. The amount of superplasticiser must be adjusted and will normally be dosed at higher levels compared to an ordinary concrete.

Anti wash-out admixture
The anti wash-out admixture, Rescon T, was in powder form and was supplied and manufactured by Rescon Mapei. It consists of stabilizing admixtures, superplasticiser, defoamer and fillers. The stabilizing admixtures are also dosed at quite high levels. These act as a retarder therefore causing an extended open-time in the concrete. Setting of concrete can typically occur after 10 hours. The high amount of stabilizing admixtures can also cause air to be entrained into the concrete. It is recommended to control the amount of air in the concrete, and tested to verify that the defoamer in the admixture is working. This is carried out with a normal 8 litre air content device (see picture 3).

Picture 3: Control of air content in fresh concrete.
PRE-QUALIFICATION
In total, three rounds of testing and pre-qualification were carried out by Unicon, the supplier of concrete for this project. It was necessary to carry out tests to verify that the concrete formulation had efficient flow, cast-ability and anti wash-out effect. In order to verify the flow and anti wash-out effect, an “L-box” was used (see figure 1 and picture 4).

![Figure 1: L-box for testing of flow and anti wash-out effect in under-water cast concrete.](image)

The L-box has a vertical and a horizontal column. Between the vertical and horizontal column is a door which is closed initially. The vertical column is filled with concrete and the horizontal is filled with water. When the door is opened the concrete flows into the horizontal column. Various parameters can be evaluated when the concrete is released into the horizontal column. Anti wash-out effect and the time it takes to flow from the opening between the two columns and to the opposite side of the horizontal column are the major considerations (see pictures 5 and 6).

![Picture 4: L-box is used to evaluate flow and anti wash-out effect](image)
The L-box test is quite easy to carry out, however it demands greater volumes of concrete, demands more space and is not easy to clean (as it is made of wood). The L-box could be used as a quality check at the project site, however in this project, parallel tests with slump cone were carried out to verify the concrete’s slump and slump retention (see picture 7). The slump cone test was later used at the project site to evaluate flow of each load of concrete arriving at site.
In this project an even greater test was carried out in addition to tests in L-box and with slump cone. A 20ft shipping container was filled with water and approximately 12m³ of concrete was poured and tested in order to evaluate the flow, cast-ability and anti-wash-out effect on a larger scale (see pictures 8 and 9).

![Picture 8: Container filled with approx. 1 metre of water](image)

![Picture 9: Concrete pumped into water-filled container](image)

When test-casting the concrete in the container, the concrete settled on the base, causing the water level to rise. At one end of the container is an outlet, where water can be collected and disposed of.

Mix design, additional testing and pre-qualification are important steps to carry out prior to the project casting. The project-designed container test carried out in this case is not always necessary; however the test with L-box and correlation to slump cone is always recommended.

FULL SCALE CAST
In May and June 2007, the total area of the flooded basement was covered with a volume of 3,740m³ of underwater cast concrete. The casting was divided into five separate pours with an intentional delay of up to 10 days between the plate sections. The concrete floor plate was lightly reinforced, with heavy reinforcement at the construction joints.

Each pour could take up to 20 hours, and the largest sections were in the range of 1,000m³ of concrete. The concrete was supplied to the site in standard 6m³ concrete trucks. The anti wash-out admixture was added manually to the concrete at the batching plant. The distance from mixing plant to the project site was relatively short and the casting process was continuous. Specifically for this project, Unicon in Kristiansand had arranged extra personnel and additional concrete trucks. Each batch of concrete that arrived on site was tested for slump (see pictures 10 and 11).
Continuous delivery of concrete to the project site. One truck is supplying concrete, one is in position ready to start supplying and another truck is arriving at the site.

One concrete truck supplying concrete, another one has just entered and a sample for slump test is taken out

The concrete was pumped with a piston pump. The hose was submerged into the flooded basement to discharge below the water to the correct locations on the basement floor (see picture 12).

Concrete pump hose submerged to correct location of pour. Concrete is pumped continuously.

Once the five separate castings were completed, the water was still not pumped out due to fears the plate would “float” from the hydrostatic pressure. Columns and precast retaining walls were installed with the use of divers in the flooded site.
Dewatering could take place after a pre-determined mass was established, weighing the site down. The massive concrete plate at the base of the excavation now enabled the site activities to continue by preventing groundwater from entering at the lowest level. This meant the surrounding buildings and the project site itself had been stabilized and the risk of any damage by dewatering the area had been averted (see picture 13).

![Picture 13: Silt removal after de-watering](image)

The construction phase could carry on and the shopping centre was opened Nov 6th 2008 (see picture 14).

![Picture 14: The shopping centre on opening day](image)

**CONCLUSION/SUMMARY**
Underground construction in high ground water conditions can be challenging. When removing water from an excavated site, there is a risk that the removed water will negatively influence the water table in the local vicinity which can have consequences for the foundations of surrounding buildings.

This project shows it is possible to use under-water cast concrete as a means of providing ground support and a platform from which the development can rise.

When using specially designed under-water cast concrete it is essential to put time and effort into pre-testing and pre-qualification in order to avoid un-necessary complications related to mixing, flow, pumping and casting during the construction period.

**REFERENCES**
1. [Norwegian Concrete Association, Publication no. 5, (2003) page B15.](#)