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Geotechnical and environmental aspects of a land reclamation made by blasted rock from tunnel construction

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ABSTRACT

Kadettangen in Sandvika, just outside of Oslo, has in recent years become the most popular beach and recreational area for people in and around the city. On warm Summer days, hundreds or thousands of people use the area located by the Oslo fjord. The app. 20.000 m^2 area is a result of land reclamation and a collaboration between the municipality and the national road authorities. The Norwegian Geotechnical Institute (NGI) has been responsible for the geotechnical and environmental design of the land reclamation, making use of blasted rock from a nearby tunnelling project. The paper presents the geotechnical and environmental aspects of the land reclamation project, and shows how excess masses from a tunnel can turn into a highly used recreational area. This paper is a combination of a case history and a presentation of the key learning points from the project

Keywords: Land reclamation, marine sediments, geotechnics, environmental, case history, learning points

1 INTRODUCTION

Kadettangen in Sandvika, just outside of Oslo, Norway, has in recent years become the most popular beach and recreational area for people in and around the city. On warm summer days, hundreds or thousands of people use the area located by the Oslo fjord.

The area has been used as an outdoor recreational and bathing area by the population of Bærum, a municipality with approx. 120.000 inhabitants, for a long time – mostly due to its central location.

The area has been subject to several land reclamation projects over the years, the development from 1956 to 2011 is shown in the two photos below.

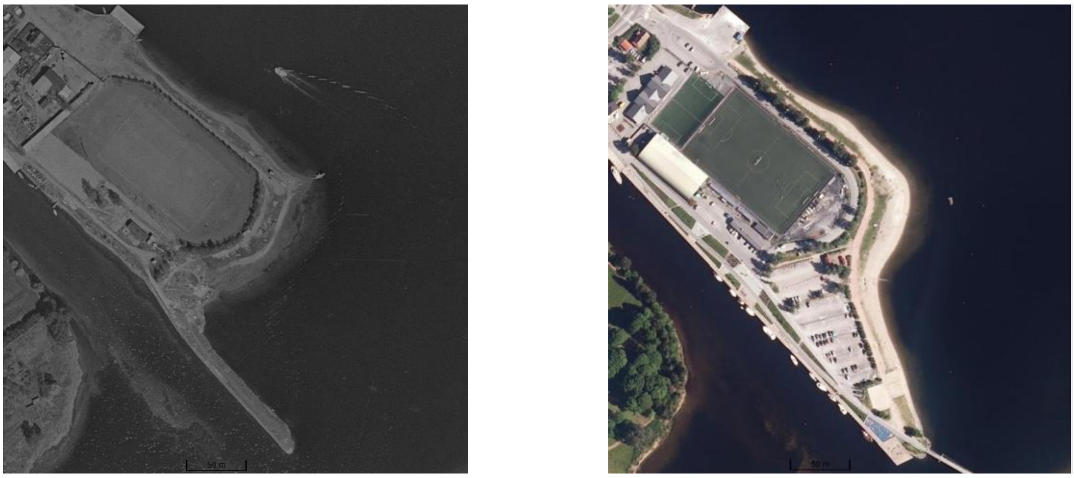

Figure 1. *Aerial photo from 1956 (left) and 2011 (right)*

Even though the area was already being used as a recreational area, the municipality has in the last decades planned for an extension of the area, with the aim of making it both larger and more attractive.

This was carried out in the mid-2010s, and this paper presents the geotechnical and environmental aspects of the land reclamation project at Kadettangen, with focus on the key learning points with clear recommendations to future reclamation projects.

2 EXCESS MASSES FROM TUNNELING IN THE OSLO AREA

2.1 Quantity of excess rock

There are several large construction projects in the Oslo area that include the establishment of tunnels in bedrock, both projects in the planning phase and under construction. The tunnels are made for new roads, railways, subways, water supply etc. All these projects generate millions of cubic meters of blasted rock.

Depositing these masses near the projects is often challenging, as the project locations are in urban, built-up areas and any virgin land near the city center is often protected. In addition, the ground conditions in the Oslo area are challenging, with primarily soft marine sediments, which are unsuitable or impossible to establish large fills on.

The solution has therefore often been to transport the masses by road to areas outside of the city, often 10s of kilometers, with the consequence of increased traffic load, road dust and related emissions.

2.2 Excess rock used for Kadettangen

In connection with the construction of a new two-lane rock tunnel for the E16 highway through Sandvika, it became clear that the early-stage planning of the project had not accounted for a landfill site or plan for reuse of the tunnel masses.

The first option considered was transporting the masses to Drammen, which is located about 30 km west of Kadettangen. This would have resulted in tens of thousands of trips with trucks along an already busy road network, which would give large effect on both traffic and emissions.

As a second option, a collaboration was established between the developer of the E16, the Norwegian Public Roads Administration (NPRA), and the owner of Kadettangen, Bærum municipality (BM), to see if the masses could be used for extending an already existing recreational area on Kadettangen. Enabling use of the excess masses at Kadettangen would result in a transport distance of only 1 km.

It was decided that approximately 500.000 m^3 of the tunnel masses should be driven to Kadettangen, so that the existing bathing and recreational area could be expanded. The geometry of an early version of the filling is shown in figure 2. Here the dotted lines are the geometry of the fill. The grid pattern has 100 m between each line

NGI was responsible for the geotechnical and environmental design and follow-up of the construction work for the land reclamation.

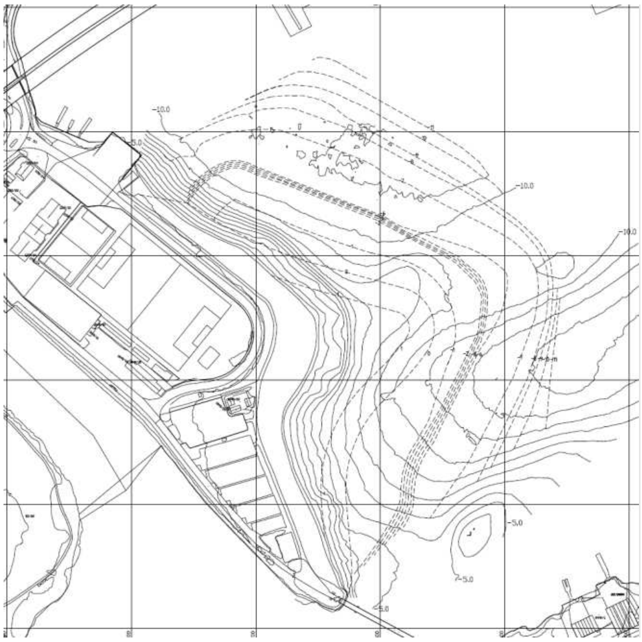

Figure 2. *Early version of the fill geometry. The lines are terrain model and terrain contour, the dotted lines are the fill geometry*

3 GROUND CONDITIONS

3.1 Geotechnical conditions

Geotechnical site investigations were carried out with a geotechnical drilling rig on a barge. The samples were tested in NGI's lab. The ground conditions in the area of the fill consist of from 10 to over 45 m of soft marine sediments. In the top 1-2 m there is a very soft dune layer with a high water content. Under this there is a 2 to 4 m thick layer of silty and sandy clay. Below this, there is normally consolidated clay to bedrock. The clay in the area is not sensitive or quick. The water depth varies between 0 and about 15 m.

On land, much of the area consists of previous landfills, over similar ground conditions as described above. The thickness of the landfills varies over the area.

3.2 Environmental conditions

Environmental site investigations were carried out from a small boat, and samples were taken in 6 locations, sampling the topmost 20 cm. The samples were tested in a laboratory, and the results showed that the sediments were contaminated with tributyltin (TBT), polycyclic aromatic hydrocarbons (PAHs), lead (Pb), copper (Cu), zinc (Zn) and oil compounds (aliphates). Based on the sediment classification system of the Norwegian Environment Agency, the masses were classified as moderately to very contaminated, which was as expected for sediments in the Oslo Fjord.

4 DESIGN AND REQUIREMENTS FOR LAND RECLAMATION

All land reclamation in Norway requires an application for a permit from the County Governor of Oslo and Akershus to carry out the filling. In this application, the principles of the filling had to be given, and one had to describe how to prevent the spread of the contaminated masses. A summary of the principles is given below.

4.1 Geotechnical design

The geotechnical stability of the fill was calculated in several sections with the software GeoSuite Stability, to achieve sufficient factor of safety for both the temporary and permanent situations. An example of one of the calculations is shown in figure 3.

Settlement calculations for the fill showed that up to 1 to 2 m of settlements could be expected for the seabed. During the design, it was therefore decided to install prefabricated vertical drains (PVDs) throughout the fill area, to both speed up settlement development but also to reduce the pore pressure build-up during the construction phase. The use of the PVDs also meant that a layer of sand had to be laid out first to secure the drainage path.

The use of PVDs will result in a faster consolidation and thus a faster increase in undrained shear strength for the normally consolidated clay. In the stability calculations, it was decided to be somewhat cautious about exploiting this effect to a large extent. The reason for this was uncertainties when it came to the progress of the filling and to allow for a robustness in the time management in the construction phase. The main fill therefore ended up with extensive counter fills below sea level to ensure that the calculated safety was maintained, see figure 3 below.

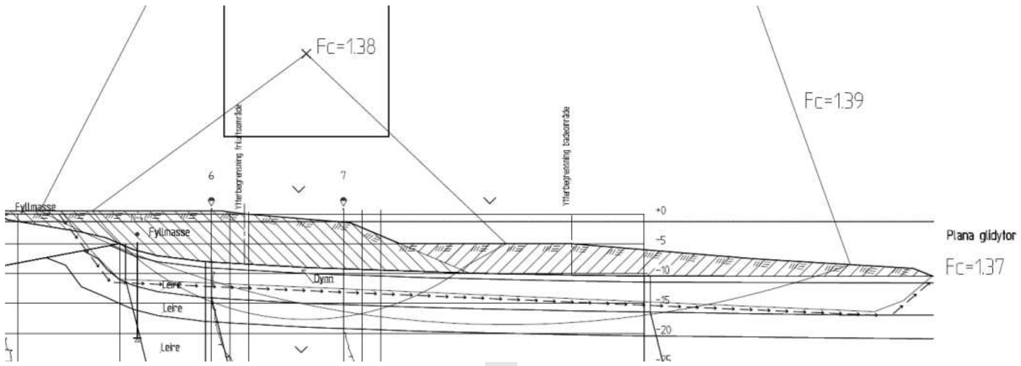

Figure 3. *Calculations for geotechnical stability. The geometry of the new fill is shown with a hatch, below is the original sea bottom. The different factors of safety are for different potential failure mechanisms*

4.2 Environmental design

To ensure that the contaminated sediments in the sea were not swirled up, suspended in the water and potentially spread to new areas, a range of environmental measures were included in the design.

Firstly, it was decided early on that the entire area should be covered with a layer of sand that enclosed the contaminated sediments. This was the same layer of sand that was geotechnically exploited to secure the drainage paths from the vertical drains.

In addition, a silt curtain was established from sea level down to the seabed. This was established to prevent spreading of upwelling sediments, or fines from the filling outside of the boundaries of the remediation. Figure 4 shows the clear distinction between the outside (left) and the inside (right) of the project area, with the silt curtain in the middle.

Figure 4. *Effect of silt curtain*

5 MONITORING

5.1 Geotechnical monitoring

Piezometers were installed in four different locations on the seabed, at three different depths for each location. The piezometers were attempted to be placed midway between the vertical drains.

Deformation plates were also placed in 10 different locations. The plates were placed on top of the sand layer so that it would be possible to monitor the settlements on seabed.

Cables were laid from all the measuring points to logging cabinets on land, which allowed for real-time monitoring and access to the updated values from the measurements presented in the contractors monitoring platform software.

5.2 Environmental monitoring

Before the construction work, a flow survey was carried out to determine the expected direction of movement of fine particles that were swirled or deposited as part of the filling.

Turbidity was measured outside of the silt curtain throughout the project, with two locations: one monitoring buoy just outside of the silt curtain and one reference buoy that was placed some distance away in an area that was not expected to be influenced.

Water samples were also taken and tested throughout the construction period, initially every 14 days with somewhat less frequent over the project period.

Sampling for analysis of dissolved nitrogen were also carried out in the water, both outside and inside the silt curtain, during the construction period.

6 PHASES OF CONSTRUCTION WORK

The length of the construction period was app. 2 years.

First the silt curtain was established around the area affected by the fill, at the same time the turbidity buoys were started up for logging potential changes.

A layer of sand was then laid out over the entire area, both to cover the contaminated sediments and to ensure the drainage of the vertical drains. The thickness of the sand layer was 0.5 m.

After the sand layer, vertical drains with a center distance of 1.8 m were installed from a large barge. The drains were installed to either 30 m below seabed or to bedrock if this was shallower than 30 m. This gave about 240.000 m of drains in approximately 10.000 locations.

Once the sand layer and vertical drains were in place, the geotechnical instrumentation was placed on top of the sand layer. This work was carried out with a combination of small barge and divers.

Then one could start the filling by using a split barge and towing boat. A grid system was established over the entire fill area, with each rectangle in the grid having a size of 5 m x 10 m. The split barge would then distribute the uploaded volume, which was 100 m^3, over 4 of these rectangles, resulting in a theoretical layer of 0,5 m.

Once the fill had been placed with split barges where the water depth was in excess of 6 m, the filling was carried out by pushing the rock masses with dozer from the existing land area.

Finally, a surcharge fill was added, in order to pre-load the underlying soft soil and reduce the future settlements. The surcharge fill remained for a given period before it was removed.

7 KEY LEARNING POINTS AND DISCUSSION

In the following, the learning points from the project are discussed.

7.1 Use of silt curtain

The conditions for using a silt curtain varied throughout the project. Even though there were limited currents in the area, there was still some movement in the silt curtain due to wind and waves. There were also several boats that crashed into the silt curtain, and so better visibility and marking of the silt curtain would be advantageous.

In addition, the silt curtain at Kadettangen was in place through two winter seasons where the fjord was fully or partially frozen. The curtain was therefore locked in the ice for several months.

The key to the success of the silt curtain working was that the contractor had fixed and regular routines for maintenance. If any small damages or problems were observed, this was handled and fixed immediately.

Overall, the use of the silt curtain worked very well throughout the construction period.

7.2 Plastics in the blasted rock

In an early phase of the project, it was agreed between NPRA and BK that the shotcrete used in the "drill and blast" tunnelling should be reinforced with steel fibre instead of plastic fibre. Using steel fibres is more expensive, but it meant that potential shotcrete that came out of the tunnel and thus became part of the filling, would contain steel fibres that sank instead of plastic fibres that would float. Floating plastic from shotcrete is something that has previously resulted in extensive plastic contamination in other projects in Norway.

What caused challenges on Kadettangen however, were all the plastic fuses that came with the blasted rock. When these masses were filled in the sea, the rock masses sank, and the plastic fuses floated. This was especially the case when it came to filling from the barge.

This gave a significant amount of plastic in the reclamation area, inside of the silt curtain. On days with increased waves and/or wind, the plastic fuses also emerged beyond the silt curtain.

To prevent the spreading of the plastic fuses, an additional floating containment boom was placed on the inside of the silt curtain. The height of this boom was 30-40 cm above the water and so it acted as an efficient barrier. The contractor gathered all the floating fuses along the containment boom a few times a week, making sure no plastics were released into the environment.

7.3 Installation of prefabricated vertical drains

Prior to installing the prefabricated vertical drains (PVDs), geotechnical site investigations had been carried out to map the depths to bedrock. This was important information for the contractor responsible for the PVDs, since they were to be installed down to bedrock or to a maximum depth of 30 m.

Unfortunately, the level of accuracy of the bedrock surface from the site investigation was not high enough, resulting in several occasions where the PVDs reached bedrock at a shallower depth than expected. This could potentially damage the PVD installation rig. To produce a better 3D-model of the bedrock surface and avoid damage to the rigs, acoustic ground investigations should have been carried out.

Figure 5 shows both the variations in the lengths of the vertical drain (left) and the approximately 50 m high rig on the barge during installation of the drains.

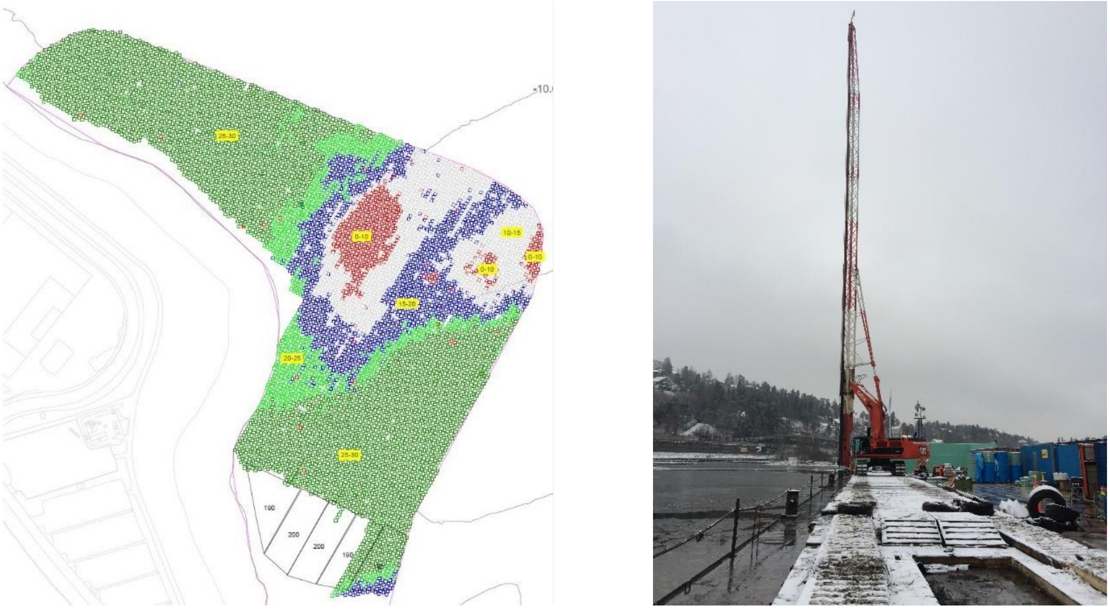

Figure 5. *Overview over executed drains (left) and picture of barge and rig for vertical drains (right). On the figure to the left the length of the drains is shown in red (0-10 m), white (10-15 m), blue (15-20 m), light green (20-25 m) and dark green (25-30 m)*

7.4 Filling with barge

As explained earlier, a grid pattern was used to plan and execute the filling with the split barge. All the rectangles in the grid had a unique name and coordinate, and for each layer of the filling the contractor was given a drawing and an excel-sheet which instructed which rectangles should be filled.

After the entire grid was covered according to the drawing, a sonar sounding was executed measuring the height of the fill. This was then the basis for the extension of the next layer, aiming to always have an even layering of the fill without any large, local height differences. The monitoring and level of control of fill placement was required in order to avoid local bearing capacity and slope stability failure in the soft soils beneath the fill, especially at the beginning of the operations.

An example of how the grid changed from layer 1 to 9 is shown in figure 6.

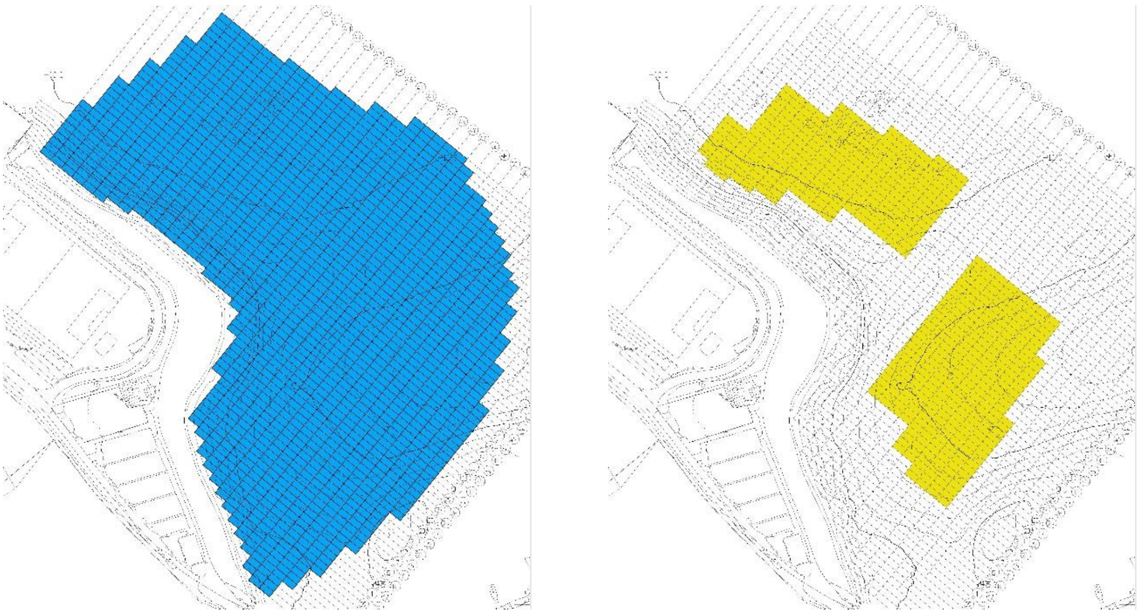

Figure 6. *Example of the grid for filling for layer 1 (left) and 9 (right)*

Nevertheless, placing fill using barges is a not a very precise work operation and distributing 100 m^3 evenly over 200 m^2 to get 0.5 m thickness is not practically possible. The grid methodology did however prove to be an adequate framework and visual tool for the consultants and contractors involved.

7.5 Filling from land

The first part of the fill was placed using barges, and this method was used until the fill reached 6 m below sea level. The remaining area, closest to the shoreline, was filled from land and directly on to the original seabed.

Starting this work with pushing the rock masses into the water with a dozer, resulted in at least one minor failure in the ground beneath the fill and the dozer carrying out the work. Luckily this failure was not a large movement and was of limited consequence. The only damage was a breach in the cables for half of the instrumentation equipment, which resulted in loss of the signal in half of the piezometers and deformation plates.

An alternative to the dozer would be a long-arm excavator laying out the stretch between land and the filling carried out by the split barge. This would have provided a more controlled filling operation and reduced the chances of a failure.

It is otherwise extremely important to focus on HSE when working with dosing out to sea and on soft sediments and underlying soils. The front of the fill can be almost vertical during this work, and there is therefore a risk of failures underneath the machine. The following safety measures were put in place to ensure the safety of the drivers: a) always wearing life jackets b) they had a hammer to break windows c) they had to drive with the door open (even during the cold Norwegian winter) and d) there should always be an extra person on land who followed the dozer work.

7.6 Geotechnical and environmental measurements

7.6.1 Turbidity measurements

It is extremely important to have continuous maintenance of the turbidity buoy to avoid false high values. At Kadettangen, there was a requirement that if 3 consecutive measurements with a 20 min interval exceeded the maximum value of 10 NTU, all the works had to be stopped and mitigating measures performed. The consequence of false alerts was thus rather large.

Especially during summer with algal blooms, alerts were triggered and thus the construction work had to stop. When this happened the contractor had to manually check the buoy, and there was also a comparison between the values from the buoy and the reference buoy. In some cases, additional manual measurements were carried out. It was also experienced that boat traffic affected the measurements on the buoys.

During the construction period there was no need to stop the work because of NTU-values in the water exceeding the allowable limits. The few times the alarm from the buoy was triggered, this was because of either algae, traffic or leaves etc that affected the measurement.

7.6.2 Dissolved nitrogen in the water

Both before and during the project, questions were asked by the supervisory authority, the County Governor of Oslo and Viken, whether the filling affected the content of nitrogen in the water. The background for the question is that the explosives used during blasting results in the blasted stone receiving nitrogen, which is then potentially washed into the sea when the fill is placed.

To map this, manual water samples were taken. These showed that there was an impact within the immediate project area, but that just beyond the silt curtain the measured values corresponded to the background values, see figure 7.

Parameter		NH_4^+	NH_3	N-total	Salinitet	pH	NO_3^-	NO_2^-
Enhet		mg/l	mg/l	mg/l	o/oo		mg/l	mg/l
Innenfor siltgardina	VK1	0,31	0,006	0,56	23	7,9	<0,030	0,064
	VK2	0,33	0,008	0,509	23	8	<0,030	0,066
	VK3	0,29	0,007	0,605	23	8	<0,030	0,062
Utenfor siltgardina	VK4	0,21	0,004	0,472	23	7,9	<0,030	0,05
	VK5	0,13	<0,004	0,303	22	7,8	<0,030	0,03
	VK6	0,118	<0,004	0,325	23	7,9	<0,030	0,031
Utenfor Kalvøya	VK7	0,104	<0,004	0,251	23	7,9	<0,030	0,02
	VK8	0,101	<0,004	0,269	23	7,9	<0,030	0,019
	VK9	0,082	<0,004	0,239	22	7,9	<0,030	0,018
Utløp Sandvikselva	VK10	0,153	<0,004	0,462	22	7,9	<0,030	0,035

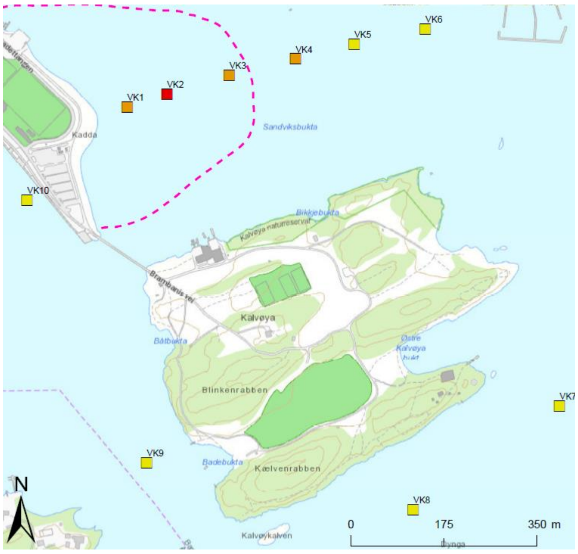

Figure 7. *Results from water samples testing nitrogen content. To the left are test results, to the right testing locations. The pink dotted line shows the silt curtain*

7.6.3 Measured deformations

The deformations measured by the deformation plates showed considerably greater deformations than those calculated in advance. After looking into this it is assumed that this is due to the upper 2 – 4 m of the soil, which consisted of very soft soil with a high water content (measured values between 50 and 80%). These soils resulted in a considerably larger deformations than calculated.

In retrospect, a monitoring system that returns 2D deformations, instead of only vertical displacement, would have been preferable. Using 10 different plates which only generates point information gives a very limited understanding of the over settlements and the behaviour of the fill.

7.6.4 Pore pressure

During the project the piezometers demonstrated and gave a certainty that the prefabricated vertical drains worked as intended. Most of the piezometers showed results that were most likely related to the filling process itself, although it challenging to correlate this accurately due to the simple principles of the filling methodology.

On several occasions there where unexplained peaks in the piezometer results. However, these were local variations that often declined, but were not always easy to explain.

7.7 Volume of the filling

As described earlier, filling with a split barge cannot be carried out with a high level of precision. In addition, the measured settlements were larger than what had been calculated. This meant that the calculated volume of the entire fill was smaller than the volume of rock actually used.

This was solved during the project, both through adjustment of the fill and by gaining access to more masses. However, for future projects involving filling onto the seabed, it is recommended to plan for access to at least 20-30% additional volume compared to the theoretical volume of the fill.

7.8 Surcharge load

For the surcharge load applied, it was decided that this should equate to an additional load of 20%. This means that if a fill had been added under and above water of about 150 kPa, the preload at the top would be at least 30 kPa. In addition, the preload should be left in place for a minimum of 9 months before it was removed.

Luckily, the road project where the blasted rock came from also needed a temporary area for storage of excess masses at the same time as the surcharge load at Kadettangen was required. This meant that the load exceeded the given 20%, and also that it was located there for a longer period than planned. Keeping track of the final surcharge was challenging and hence there is no accurate back-calculation for the effect of this.

But result of using the surcharge load was minimal settlements after the project was finished.

8 THE AREA TODAY

After the filling was completed, the area has been developed with an approximately 20 000 m^2 area with grass areas, beach volley courts, kiosk, playground equipment, diving tower, beach and more. The area is among the most popular outdoor areas on hot summer days, where there may be several hundred or thousands who uses the area.

Kadettangen has thus not only done a lot for the local community during the construction period, it has also become a great success for the inhabitants of the municipality afterwards.

Figure 8 is a picture taken from the diving tower an early summer morning.

Figure 8. *Kadettangen an early summer morning*

9 CONCLUSIONS

The Kadettangen project shows how good collaboration between different parties can optimize the use of excess rock from tunnels. This gave both a better construction period with less traffic/emissions, and an end-result the is highly appreciated by the inhabitants of Bærum municipality.

The projects also showed the importance of good geotechnical and environmental planning, design, and follow-up of the construction work. The project had several learning points, which later has been used in the planning/design of new land reclamation projects.

For the municipality the project has been such a success that they are aiming for more recreational areas based on the use of excess masses from tunnels.

10 ACKNOWLEDGEMENTS

A big thank you to Bærum municipality for hiring NGI for the job and also for a very good collaboration over many years.

During the projects it has also been a very good collaboration with the main contractor, Topaas og Haug AS, and their sub-contractors BAT-Cofra AB, Agder Marine AS and Cautus Geo AS.