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Norway's National GeoTest Site Research Infrastructure (NGTS)

L'infrastructure de recherche Norvégienne GeoTest Site (NGTS)

J.S. L'Heureux, T. Lunne, S. Lacasse, R. Carroll, S.O. Strandvik, Z. Ozkul
Norwegian Geotechnical Institute (NGI), Norway, jsl@ngi.no

A. Instanes
University Centre in Svalbard (UNIS), Norway
A. Sinitsyn
Sintef, Norway
S. Degago
Norwegian Public Road Administration(NPRA), Norway
Steinar Nordal
Norwegian University of Sciences and Technology (NTNU), Norway

ABSTRACT:

Benchmarking is a key to the reliability of the solutions in geotechnical engineering, both for testing and verifying innovative soil investigation methods and verifying and calibrating foundation solutions. NGI and its partners, NTNU, SINTEF, UNIS and the Norwegian Public Roads Administration (NPRA), received funding from The Research Council of Norway to develop a new Norwegian GeoTest site research infrastructure. From 2016 to 2019, five benchmark sites will be established. The research infrastructure is unique in its wingspan, and the benchmark test sites will be available for at least the next 20 years. The five test sites cover a wide range of soil conditions: soft clay, silt, sand, quick clay and frozen soil (permafrost). The benchmark sites will be made available to industry, public authorities, research organizations and academia worldwide for testing new soil investigation methods and test equipment, verifying new foundation solutions, doing long term observations and performing specialized testing to, for example, develop soil models. The Norwegian infrastructure will also establish a network of specialists working on test and benchmark sites abroad and a dynamic database to include the information gathered at each site.

RÉSUMÉ :

L'analyse comparative sur le chantier est d'une grande importance en géotechnique pour tester et vérifier, à titre d'exemple, nos méthodes de sondage et nos solutions de fondation. Entre 2016 et 2019, le NGI avec ses partenaires NTNU, SINTEF, UNIS et le Ministère du transport norvégien, recevront du financement du Conseil de Recherche Norvégien pour développer une nouvelle infrastructure de recherche "GeoTest Sites". Cette opportunité est unique en son genre et permettra le développement de cinq sites de recherche sur sols différents (i.e. argile molle, argile sensible, silt, sable et pergélisol) qui resteront disponibles pour plus de 20 ans. Nous encourageons l'industrie, les autorités publiques, les organisations de recherche et les universités dans le monde entier à utiliser ces sites de références pour tester leurs équipements, faire des essais à long terme, développer de nouveaux moyens de sondages en géotechnique et tester les modèles de comportement du sol. L'objectif primaire de cet article est de très brièvement présenter les cinq sites en discutant les premiers résultats de sondage et d'essai au laboratoire.

KEYWORDS: Norway, geotest sites, silt, sand, quick clay, soft clay, permafrost, site characterization.

1 INTRODUCTION

The Norwegian Geotechnical Institute (NGI) and its partners, the Norwegian University of Science and Technology (NTNU), SINTEF Building and Infrastructure, the University Centre in Svalbard (UNIS), and the Norwegian Public Roads Administration (NPRA) have established five National GeoTest Sites (NGTS) in Norway for testing and verifying innovative soil investigation methods and foundation solutions. This project, funded by The Research Council of Norway (RCN), is unique because of the size of the research infrastructure, the wide range of soils covered and the availability of the test sites to all users for at least the next 20 years. Characterization and documentation of the test sites are to be completed by 2019. The field laboratories will then be well documented geo-experimentation field sites, for soil conditions ranging from soft clay, quick clay, silt, medium dense sand to frozen soil (permafrost). Industry, public authorities, research organizations and universities worldwide are welcome to use these sites as benchmark to test new and existing investigation methods, study the behavior of soil, do model tests and long term tests, verify foundation solutions and perform specialized testing to develop new soil models. This paper presents briefly the NGTS infrastructure and of its five test sites.

2 THE FIVE NORWEGIAN GEO-TEST SITES

Figure 1 shows the geographical location of the five Norwegian sites. Two of the sites are located in southeastern Norway; the soft clay site in Onsøy and the silt site in Halden. The quick clay and medium dense sand sites are situated in mid-Norway, close to Trondheim. The permafrost site is located on Svalbard in the vicinity of the University Centre UNIS in Longyearbyen.

During the first three years of the NGTS project (i.e. from 2016-2019), the activities will center on completing a full geotechnical characterization of the five sites, and on establishing the necessary infrastructure at the five sites to make them amenable for specimen testing and model testing up to prototype scale. The installations includes, for example, permanent *in situ* piezometers, thermistor strings and pressure cells, electricity and water supply to the sites, climate stations and shelters. Each of the five sites are briefly described below, with focus on the properties of the soft clay and silt sites.

Figure 1. Location of the five test sites in the new Norwegian infrastructure.

2 .1 *Soft Clay Site – Onsøy, south-eastern Norway*

Because of the thickness of the clay deposit and its very uniform nature, the Onsøy site has been used for research purposes for many years. The site is located in southeastern Norway, about 100 km south of Oslo (Fig. 1). The new area of investigation at Onsøy is about of 3,500 m^2 (i.e. 50 x 70 m). In addition, there are other locations in the area to increase the testing area in Onsøy clay.

The engineering properties of the Onsøy clay have previously been documented extensively in for example Lunne *et al.* (2003). The natural water content varies between 40 and 70% for the new site (compared with 45 and 65% at the historic site). The average plasticity index varies from about 45 in the upper 8 m to about 25-30 below 8 m. These values are very similar to those of the historic site. The sensitivity (S_t), as measured by fall cone tests, is constant at around 6 down to about 13 m. Beyond this depth it increases to a value of 45 at approximately 19 m becoming a quick clay at just above bedrock.

The salt content of the pore water is an important characteristic of the Onsøy clay. The percolation of freshwater from the surface has caused an almost linear salinity increase from zero at the surface to 30 g/l at about 7.5 m depth. Beyond this depth, the salinity remains constant.

Organic content values, determined by chemical oxidation with nitric acid, show values around 0.8% in the top 9 m and around 0.6% below this depth.

The overconsolidation ratio (OCR) was determined from oedometer tests on high quality Sherbrooke block samples (c.f. Lunne *et al*., 2003). The OCR at Onsøy decreases from about 4 near the surface to 1.2 at 30 m depth.

The soils at the Onsøy site are marine clays. Such clays were deposited during deglaciation and the early postglacial period (Holocene) at times of higher relative sea level. Marine clays are found extensively in Norway, Sweden and Finland. The Onsøy clay has many similarities to marine clays in, e.g. Canada, Japan and southeast Asia. The Onsøy clay is also remarkably similar to clays found offshore at the Troll, Gjøa, Luva and Aasta Hansteen oil and gas fields. The apparent preconsolidation at all these sites is caused by ageing.

Figure 2 presents a comparison of CPTU results from Onsøy and the Luva gas field. The similarities in characteristic and behaviour with many clays around the world illustrate the significance of the Onsøy deposit as a benchmark site.

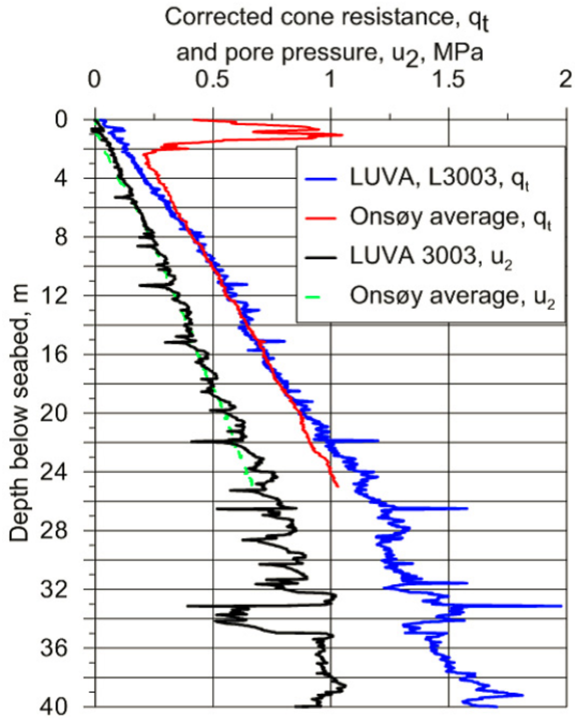

Figure 2. Comparison of corrected tip resistance and pore pressure at Onsøy and at the Luva gas field offshore Norway (from Lunne et al. 2012).

2 .2 *Silt Site – Halden, south-eastern Norway*

Intermediate soils such as silts are challenging materials in geotechnical design. Therefore, finding a deposit with silt over a reasonable depth was one of objectives of the NGTS infrastructure. After a search over the country, the Halden site was selected. Halden is located in southeastern Norway, approximately 120 km south of Oslo (Fig. 1). The deposit consists of marine and fjord marine sediments that emerged from the sea following a fall in relative sea level in the Oslofjord region during the last c. 11 000 years. There is up to 10 m of uniform silty soil at the site. The area available for site investigation and model testing in Halden is about of 3,500 m^2.

Series of geophysical, geological and geotechnical investigations were carried out *in situ* and in the laboratory to characterize the deposit. Characterization and engineering properties of the Halden silt site have been presented in Blaker *et al.* (2016) and Paniagua *et al*. (2016). The homogenous silt deposit at Halden has no structure. The silt layer of interest is below a 4.5m thick layer of sand and above a 6m thick deposit of clay. Soil classification charts (e.g. Schneider *et al*. 2008) suggest the Halden silt to be at the interface between "transitional soil" and "silt and 'low rigidity index' clays. Classification tests in the laboratory indicate a low plasticity silt with essentially the same mineralogy with depth (40% quartz, 13% K-F – Potassium Feldspar, 29% plagioclase, 8% mica (muscovite and possibly illite), 4% chlorite and 6% amphibole. The clay content in the silt varies slightly from 9 to 15%.

Basic parameters for the Halden silt are presented in the log on Figure 3. The natural water content (*w*) in the silt decreases only slightly between depths of 4.5 to 11 m, with values at about 30%. From 11 to 15 m, the water content decreases more rapidly to about 21%. The changes in water content are

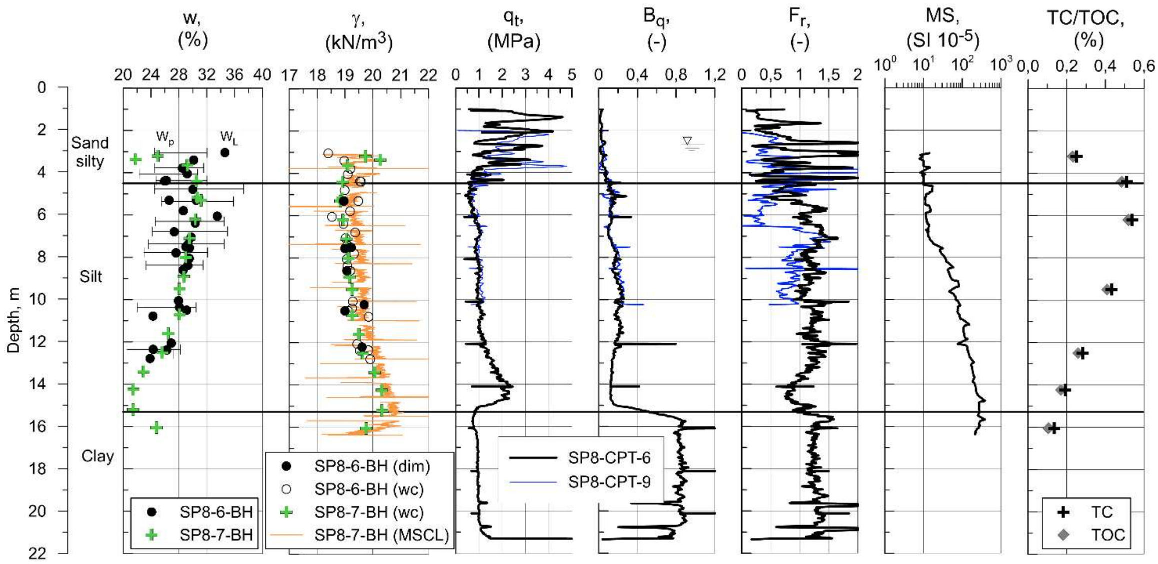

Figure 3. Basic parameters for Halden site: corrected cone resistance, q_t, pore pressure ratio, B_q, friction ratio, F_r, versus depth from CPTU, magnetic susceptibility (MS) from MSCL, and total carbon (TC) and total organic carbon (TOC). Whole core Gamma density (i.e. wet bulk density) is shown in yellow on the total unit weight log (after Blaker et al. 2016).

reflected in the unit weight profile, with an increasing unit weight in depth.

Total Carbon (TC) content and total organic carbon (TOC) content were measured as 0.5% in the upper 2 m of the silt deposit. Below 2m, both TC and TOC drop linearly to 0.1% at 15 m depth. Whole core Gamma density (i.e. wet bulk density) and magnetic susceptibility (MS) were measured using the GEOTEK Standard Multi-Sensor Core Logger (MSCL-S) at 0.5 cm resolution with 5 s exposure/measurement time, see Figure 3.

Figure 3 presents the results of piezocone tests (CPTU) with the cone resistance, pore pressure ratio and friction ratio versus depth. In the first 8 m of silt, the corrected cone resistance (q_t) is very uniform and about 1 MPa. From 12 to 14.5m, q_t increases to 2 MPa. Pore pressure, u_2, is not presented but increases steadily with depth to about 380 kPa at 14 m depth. By combining the results of *in situ* tests, classification tests and magnetic susceptibility (MS) tests, one can appreciate behavioral changes in the silt. The upper and lower part of the silt deposit differ slightly in terms of water content, total unit weight and magnetic susceptibility. This correlates also with an increase in corrected cone resistance below 12 m. Reasons for this gradual change are not fully understood yet, but one possibility is that they are linked to variations in organic matter (cf. Keller 1982, Booth & Dahl 1986).

2.3 *Sand Site – Øysand, mid-Norway*

The Øysand sand site is located near Trondheim and consists of a glaciofluvial deposit approximately 20 m thick. The sand layer is relatively homogenous and consists mostly of fine to medium uniform sand with predominantly quartz minerals, some plagioclase and micas. The area available for geotechnical investigations at the sand site is about 35,000 m^2 and has been used until now for agricultural purposes (Fig. 4).

Preliminary geophysical, geological and geotechnical investigations have been conducted at Øysand in 2016. The field investigations included total soundings, piezocone tests (CPTU), seismic dilatometer tests (SDMT), soil sampling (with 54 mm piston sampler), MASW profiling and seismic refraction studies. The laboratory work conducted included multi-sensor core logging (MSCL) of the 54 mm core samples, X-ray imaging of the cores and some grain size analyses.

Results from *in situ* soundings show that the sand deposit is fairly uniform over the entire area (Fig. 4). The results from CPTU tests are consistent over a radius of more than 500 m. There is a coarser layer of gravelly sand in the top 5 to 6 m which varies in thickness depending on location. Field testing and grain size distribution test results show the presence of a fairly consistent silty medium sand with 6 to 12% fines content. Classification charts (e.g. Robertson 1990) for piezocone soundings show that the soil behaviour type (SBT) at depth intervals of 6-20 m varies between 4, 5 and 6 (i.e. silt mixture, sand mixtures and sands).

The interpretation of SDMT results show that the sand has a friction angle between 32 and 36 degrees and a fairly consistent shear wave velocity profile (V_s) at about 180 m/s (Fig. 4).

Figure 4. Overview of the sand test site at Øysand near Trondheim.

2.4 *Quick Clay Site – Tiller, mid-Norway*

Deposits of sensitive marine clay are found over large areas of Norway, Sweden, Finland and Canada. Such deposits are extremely challenging to deal with. In particular, quick clay deposits are frequently associated with landslides triggered by natural or man-made events. Examples of such landslides in the Trondheim region are numerous, with recent events at Rissa (1978), Kattmarka (2009) and Esp (2012).

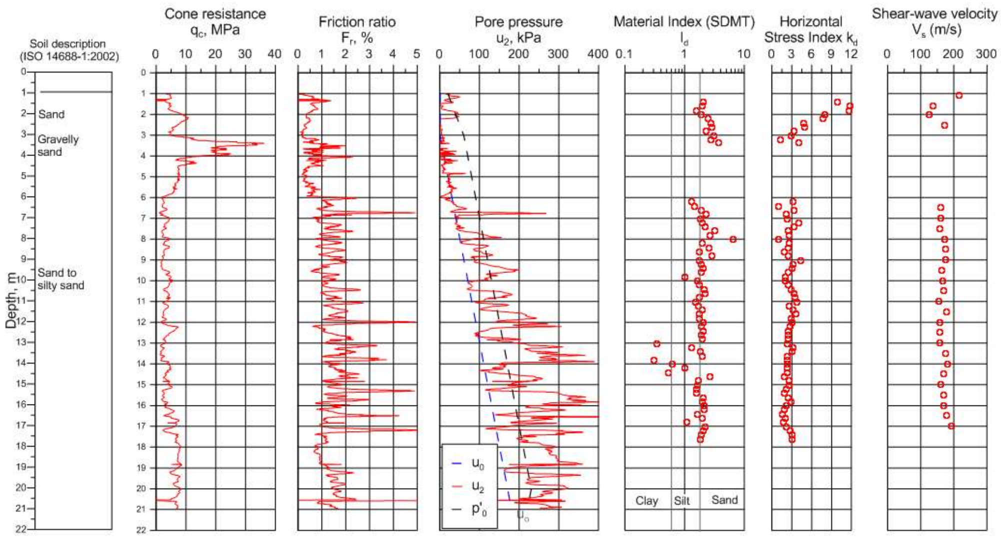

Figure 5. Results from piezocone tests at locations 9, 10 and 12 and seismic dilatometer test at location 9 at the Øysand site.

The Norwegian quick clay site, called Tiller, for geotechnical testing is located near Trondheim within proximity of the project partners geotechnical laboratories. The site is about 70 m x 100 m in size. Initial investigations show that the soil deposit at Tiller is rather homogeneous and normally to slightly overconsolidated (OCR ~ 1.6 to 2.2) down to 20 m. Quick clay has been identified between depths of about 3 to 20 m over the entire investigation area. The sensitivity of the clay was measured as high as 224 and the remoulded undrained shear strength can be as low as 0.1 kPa.

2 .4 *Permafrost Site – Longyearbyen, Svalbard, Norway*

The behavior of the ground in the cold regions of the world is characterized by freezing and thawing cycles and the presence of discontinuous and continuous permafrost (frozen soil). Such temperature-dependent behavior has important geotechnical implications for the design of foundations and transportation and industrial facilities, such as highways, railways, airports, harbours, buildings and pipelines.

Four sites are planned as permafrost research facilities on Svalbard (Fig. 1). Each of the locations have different characteristics and hence are established with different research objectives. At the first location, foundation methodology in silty permafrost will be investigated. At the second and third locations, where slopes in frozen soil can be found, solifluction, creep behavior and soil/structure interaction will be investigated. The fourth location, with marine saline clay, will be devoted to the study of embankment behavior, foundations and artificial cooling systems.

3 OUTLOOK

The Norwegian National GeoTest Sites infrastructure has the objective to become a geotechnically well-documented arena for the entire geotechnical community for basic and applied research and education on soil testing, soil behavior and calibration of design methods. The availability of the sites, the high quality data and the established facilities so far has already lead to the use of the facility.

The new benchmark sites and research infrastructure will be able to contribute to increased outreach and greater cohesion of geotechnical data in Norway and abroad. Information about the sites will be shared with research organizations and the public through the project website (http://geotestsite.no/) designed for easy search and archiving capability. The NGTS project also aims to initiate an "International GeoTest Sites Network" where scientists and researchers can exchange information for a wide range of soil conditions. International workshops are planned in 2017 and 2018, and an international conference on GeoTest Sites will be organized in 2019. It is hoped that the next years will see an increased use of the benchmark sites as a research tool, and for training and teaching purposes.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

Blaker, Ø., Caroll, R., L'Heureux, J.S., Klug, M., 2016. Characterisation of the Halden silt. 5th Intern. Conf. on Geotechnical and Geophysical Site Characterisation, ISC'5 Queensland, Australia.

Booth, JS, and Dahl A.G. 1986. A note on the relationships between organic matter and some geotechnical properties of a marine sediment. *Marine Geotechnology* 6(3):281–297.

Keller, G. H. 1982. Organic matter and the geotechnical properties of submarine sediments. *Geo-Marine Letters 2*, 191–198.

Lunne, T., Andersen, K.H., Yang, S.L., Tjelta, T.I. and Strøm, P. 2012.. Undrained shear strength for foundation design at the Luva deep water field in the Norwegian Sea. In *Proc. International Conference on Geotechnical and Geophysical Site Characterization 4 (ISC-4), Recife, 18–21 September 2012*.

Lunne, T., Long, M., and Forsberg, C.F. 2003. Characterisation and engineering properties of Onsøy clay. Characterisation and engineering properties of natural soils. Singapore. 1, 395-428.

Paniagua-López, P., Carroll, R., Blaker, Ø., L'Heureux, J.-S., Nordal, S. 2016. Monotonic and dilatory excess pore water dissipations in silt following CPTU at variable penetration rate, 5th Intern. Conf. on Geotechn. and Geophys. Site Characterisation, ISC'5 Queensland, Australia.

Robertson, P. K. 1990. Soil classification using the cone penetration test. *Can. Geotech. J.* 27(1):151–158.

Schneider, J. A., Randolph, M. F., Mayne, P. W. Ramsey, N. R. 2008. Analysis of factors influencing soil classification using normalized piezocone tip resistance and pore pressure parameters. *Journal of Geotech and Geoenv. Eng.* 134(11):1569–1586.