Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)

Challenges with sampling coarse-grained permafrost: an experience in Svalbard

T. M. H. Le
Sustainable Arctic Marine and Coastal Technology (SAMCoT), Centre for Research-based Innovation (CRI), Norwegian University of Science and Technology, Trondheim, NORWAY

M. Wold & M. G. Bærverfjord
Sweco, Trondheim, Norway

ABSTRACT: The need for better understanding about permafrost (i.e. frozen soils) has grown recently due to increasing interest from oil companies in the potential oil and gas reserve in the Arctic regions. Building sustainable infrastructures along the Arctic coasts for the exploration and exploitation of oil and gas requires reliable data on permafrost properties. However, retrieving samples of permafrost is a challenging task particularly for coarse-grained soils, due to their low water content. In this study, tests of four sampling methods (permafrost corer, commercial core barrel, percussion sampler and conventional auger) have been conducted with coarse-grained coastal permafrost on Svalbard. The tests show that none of the four methods were able to cut and retrieved undisturbed cores in the low water content, coarse-grained permafrosts found at several locations on Svalbard. Even though the permafrost corer and the conventional core barrel have been shown to be efficient in fine-grained permafrost, they failed to cut through the large grains in the soils on Svalbard. The percussion sampler and the conventional auger can only retrieved heavily remoulded samples which can be used for some index tests but are unsuitable for strength testing. Although no satisfactory methods were found, the tests reveal some specific issues with sampling in coarse-grained permafrosts including low water content and heat generated by friction. These issues are discussed which will provide a useful reference for future work on developing sampling method for coarse-grained permafrost.

1 INTRODUCTION

The potential reserve of oil and gas resources in the high Arctic regions has led to an increased interest from oil companies and contractors in investigation of permafrost (i.e. frozen soil that remains frozen for more than two consecutive years). Particularly, the demand for development of sustainable and adapted infrastructure in Arctic regions sets new challenges for geotechnical engineering with regard to retrieving reliable permafrost samples for measuring properties and strength parameters. Reliable samples require first and foremost that the samples are undisturbed during the sampling process. Undisturbed samples would reduce uncertainties regarding soil strength parameters and improve the accuracy of geotechnical assessment for the site.

Up to the 70s a large amount of work on permafrost sampling was conducted in Alaska and Canada. Early attempts of core drilling in coarse-grained permafrost reported in Lange (1963) and Hvorslev & Goode (1963) were successful. A number of studies in the 80s conducted at the Cold Regions Research and Engineering Laboratory, United States (CRREL) have led to development of a drill system which can be used for fine-grained frozen soils (Brockett & Lawson 1985; Sellmann & Brockett 1986a; Sellmann & Brockett 1986b, Sellmann & Brockett, 1987). More recently, a small portable earth drill system for permafrost studies has been developed at the Laval University, Canada (Calmels et al. 2005). The system is however limited to shallow samples (within 7 m depth), and also requires an ice volumetric content of minimum 5 – 10 % and fine soil materials for the drilling to be successful. Very few studies have reported development in drilling equipment that can handle coarse-grained frozen soils. Saito & Yoshikava (2008) tested a small portable drilling system for coarse-grained permafrost. The system can work but require the pore spaces among the coarse grains to be filled with clayey and silty materials to be able to operate effectively (Saito & Yoshikava 2008)

Cooling the drilling system to protect the equipment and maintain the sample quality is also an important issue to be considered. Past work normally used a cooled flushing liquid which had a temperature below the actual ground temperature (Lange 1963; Hvorslev & Goode 1963). The low temperature of the fluid preserved the freezing bonds in the soil and made it possible to keep the cores intact during sampling. In the past, diesel was commonly used as drilling fluid. However, there have been concerns about the interference of these liquid media with the water/ice content of the sample, and thereby altering the strength properties of the soil. Since both ice and pore water chemistry are important features of permafrost, core drilling equipment using a liquid as coolant and borehole fluid should be used with caution, as brine or antifreeze liquids may contaminate the retrieved cores and influence the results (Agergaard et al. 2012). In addition, environmental regulations in many Arctic regions now strictly forbid the use to liquid that could contaminate the environment. The use of oil/diesel flushing liquids is therefore not possible in many Arctic regions nowadays.

Geotechnical fieldwork and fieldwork in general in Arctic regions sets high demands to both equipment and personnel. Operating in cold climate, with limited access to workshops and spare parts, combined with the environmental challenges related to fieldwork in the fragile Arctic nature impose additional challenges for conducting soil investigations. Collecting cores with sufficient quality has proven challenging in fine-grained permafrost, and even more so in coarse-grained permafrost. This paper presents some test attempts to retrieve permafrost samples with four different methods (permafrost corer, conventional core barrels, percussion sampler and conventional auger). The tests were performed in coarse-grained coastal permafrost on Svalbard.

2 SITE DESCRIPTION

The tests were conducted on Svalbard which is an island north of the mainland Europe, midway between continental Norway and the North Pole (Figure 1 - right). Many scientific activities are being conducted on the island which provides a well-supported base for this research operation. The temperature regime in the area is well-documented. The main test site is located at Hotellneset, close to the airport in Longyearbyen on Svalbard. Most of the tests were performed at Vestpynten which is a point west on Hotellneset (Figure 1 – right).

Observation of the bluff front at Vestpynten clearly shows stratification of the permafrost profile with many layers dominated by gravels/pebbles (Figure 2). Earlier attempts to collect samples in Vestpynten relied on conventional auger which was the only available methods to the research group in spring 2012. This resulted in heavily remoulded bag samples which were used for observation of basic properties such as grain size distribution. The storing and protection of the bag samples taken in 2012 were not good enough for accurate measurement of water/ice content.

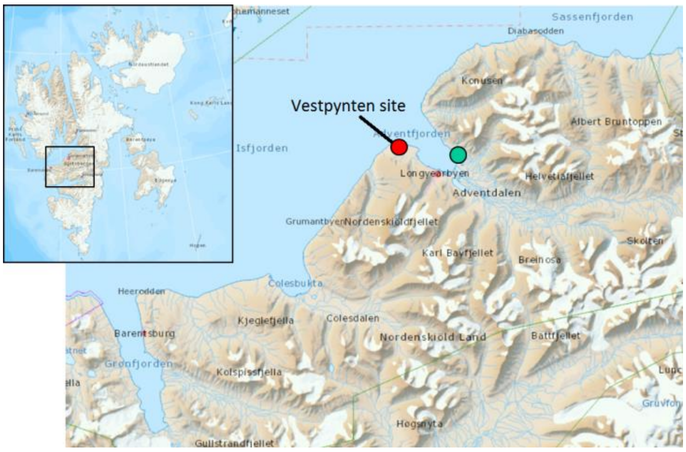

Figure 1. Location of Vestpynten study site on Svalbard.

The samples show that soils at the Vestpynten site consist of a well-graded material with particles varying between gravel and silt. The gravels/pebbles fraction varies considerably in sizes, but is dominated by particle range from 1-3 cm. The soil is covered with an organic top layer at most locations. The soil materials appear very dry and loose indicating very low ice/water content (Guegan & Christiansen, 2016).

Figure 2. Stratification observed in the bluff at Vestpynten

3 DRILLING EQUIPMENT AND METHODS

3.1 *Drilling rig*

The investigations described in this paper were conducted by using a geotechnical 504 drilling rig which has been specially equipped to cope with the harsh climatic condition on Svalbard. The drill rig is owned by SINTEF and stationed on Svalbard (Figure 3). The rig can be divided into four sections, each weighing less than 1300 kg, which enable them to be transported by helicopter to sampling locations. The rig has a rotation speed up to 180 rpm which can reduce the drilling time in hard soils and bedrocks. This is especially important when cutting cores in very hard permafrosts and bedrocks.

Figure 3. Geotech 504 drilling rig for Arctic condition

During cutting, the system is ventilated with a cooled air flow which is delivered at 27 m^3/min by an air compressor (Atlas Copco XRVS 476). The air cooling is important in permafrost drilling since it reduces the problem with thawing. Compared with a liquid flushing system, it has an advantage because it does not introduce a foreign liquid into the soil, which can alter the water content and hence the strength of permafrost.

3.2 *Sampling methods*

3.2.1 *Permafrost corer*

The permafrost corer is a sampling equipment, developed internally by the SINTEF/NTNU workshop in Trondheim during autumn 2012 (Figure 4). Over many years, SINTEF has worked on several projects in Svalbard, gathered experience and modified the equipment in order to adapt it to different applications in permafrost investigation. The corer consists of a cutting bit attached to a thick-walled hollow core collecting auger (Figure 4a), similar to the modified CRREL core barrel for ice-drilling (Veillette, 1974). The permafrost corer uses a highly durable poly-crystalline diamond composite (PCD) inserts to increase it cutting capacity into specially hard materials such as cobbles and rocks (Figure 4d). The corer has proven to be efficient in collecting cores in fine-grained frozen soils and can produce intact samples of high quality.

The tested version of the corer in this investigation is a modification of a previous version which was built in 2007. This first version has the ability of cutting cores with a diameter of 70 mm. This gives the possibility of trimming cores down to 54 mm for standard strength testing in Norwegian geotechnical laboratories. For this new modified version, the rotation direction, the diameter and the wall thickness are modified to increase its capacity to penetrate into hard materials. The new corer has reduced diameter to reduce resistance during drilling and produces cores with a diameter of 45 mm. This also reduces the required effort for pre-drilling,

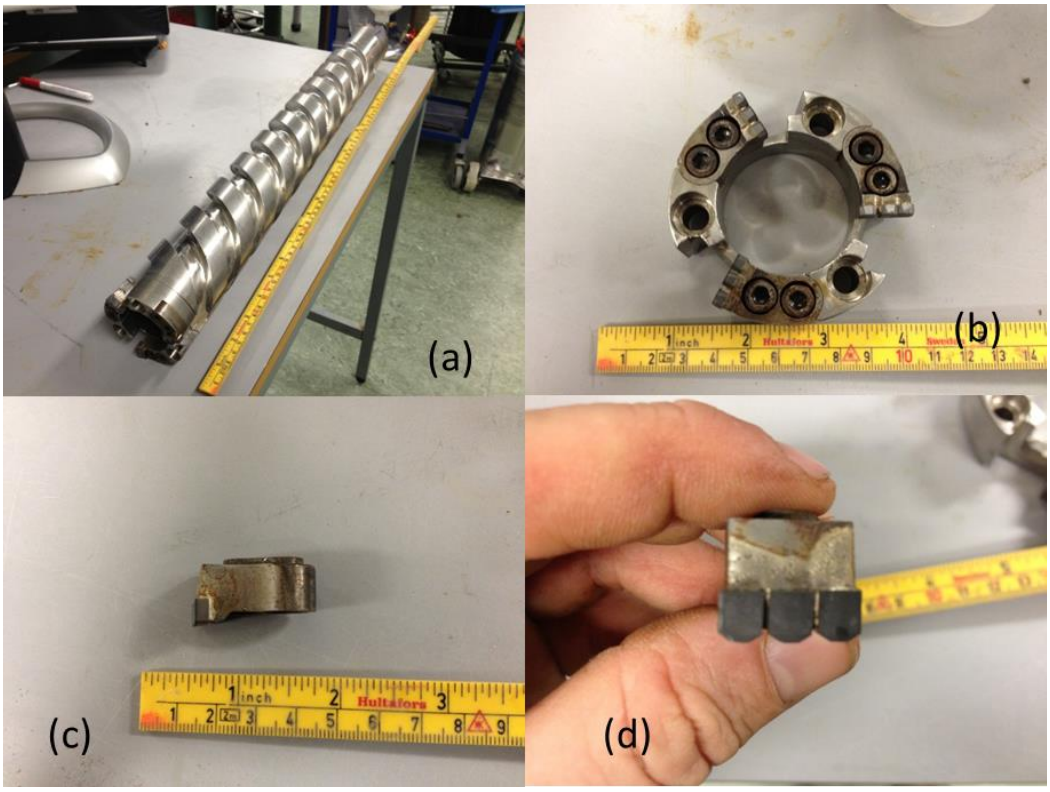

Figure 4. Permafrost corer (a) assembled (b) drill bit (c) cutting tool (d) poly-crystalline diamond composite inserts

which can decrease the total drilling time considerably. The wall thickness of the corer is also reduced to approximately 15 mm to reduce resistance and the heat generated. The modified corer rotates left which makes it compatible to use in the rock drilling rod system normally employed in Norwegian geotechnical drilling rigs.

When operating in cold climate, environmentally unfriendly additives often have to be used in order to prevent the cooling liquids from freezing. These additives are prohibited by the strict environmental regulations in Svalbard. Therefore, the coring barrels are used without drilling fluids in the tests presented in this paper. In principle, the corer can be fitted with a bit holder which is compatible with the rock drilling rod system with possibility for flushing with air. This would be an advantage in coarse and dry gravels in order to remove the cutting and cool down the drilling bit, but was not available at the time of this study.

3.2.2 *Atlas Copco 76 T2 Core barrel*

The Atlas Copco 76 T2 corer is a standard double-walled core barrel with the ability of cutting 1.5 m long cores having a diameter of 61.7 mm. Figure 5a shows the different parts of the core barrel. This corer has previously been used to collect cores in bedrock and coal deposits in Svalbard but has not been thoroughly tested in coarse-grained permafrost prior to this study. This type of core barrel is very versatile and can be fitted with a variety of drill bits depending on the materials. This system can also use both air and water as drilling coolants. In this system the flushing is released through the bit throat. The use of face discharge drill bits is recommended for coring in permafrost (Hvorslev & Goode 1963), but it is not possible to attach face discharge bits to this system.

Two different drill bits were tested. The surface set diamond coring bit which has previously been used for cutting cores in bedrock and coal deposits in Svalbard (Figure 5b). This bit is oversized to allow airflow up in the hole. To ensure the performance of this drill bit, the material has to be hard and abrasive enough to wear down the bit so that the surface set diamonds remains sharp. The tungsten carbide drill bit has a more aggressive cutting surface with large tungsten carbide inserts (Figure 5c). This bit is built to give high penetration in soft rock formations. This bit is not oversized, but could be combined with a reaming shell to ensure good airflow. Reaming shell was not used in this study.

3.2.3 *Moraine percussion sampler*

The moraine percussion sampler consists of a conventional destructive drilling bit (Figure 6) which is attached to an open thick-walled cylinder. This bit ensures penetration in almost any soil or rock and has previously been used to collect samples in moraine areas both on land and offshore in the Norwegian mainland. The method is efficient when collecting samples in soils where a conventional piston corer cannot be used. The moraine percussion sampler is rotated and hammered down with flushing to the actual depth where the sample is to be collected. The flushing is then shut off and the sampler is hammered down to fill the cylinder. The hammering energy fills and packs the cylinder tightly which allows sample retrieval. However, this method can only produces disturbed samples.

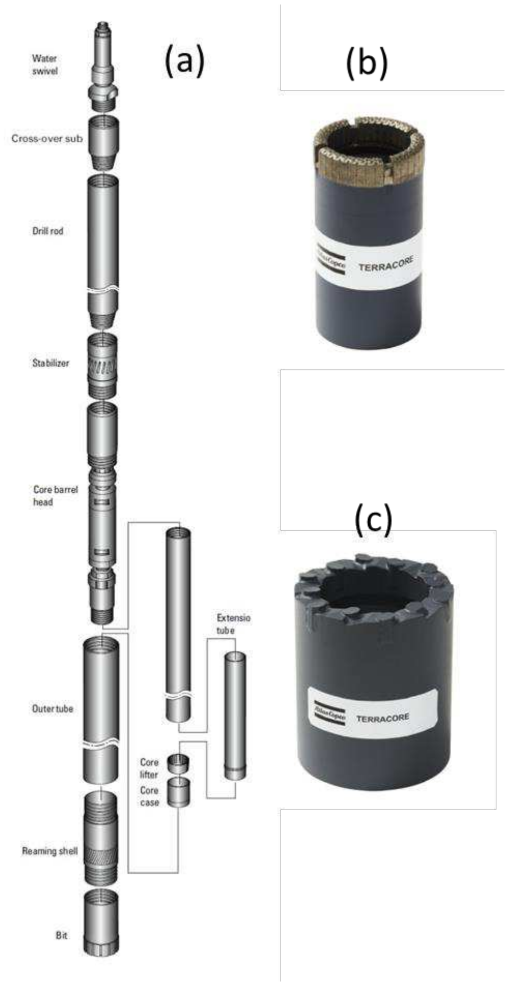

Figure 5. Atlas Copco 76 T2 core barrel (a) split drawing (b) surface set diamond drill bit (c) tungsten carbide drill bit (Source: Atlas Copco).

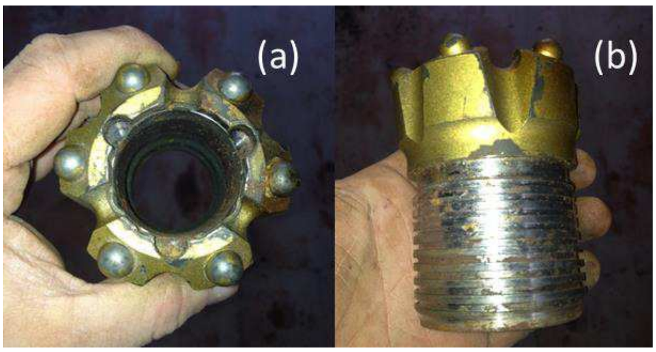

Figure 6. Moraine percussion sample drill bit (a) top view (b) side view

3.2.4 *Conventional auger sampler*

Tests of permafrost sampling are also conducted with conventional auger which is rotated and hammered down. The materials rotated up or stuck to the auger flightings are collected in bags. The main drawback with this method is that it remoulds the soil before it can be collected and also crushes rocks during penetrating. It is also important to note that this method of sampling generates heat, especially in coarse-grained soils. This heat melts the ice in the permafrost and this may influence the measured water content in the samples. The moraine percussion sampler, described in the previous section, seems to retrieve less remoulded material and more depth specific than the auger sampling.

4 RESULTS AND DISCUSSION

4.1 *Permafrost corer*

One test was attempted by starting the coring process from the surface (Figure 7). The permafrost corer penetrated easily through the frozen organic peat at the top of the soil profile. However the drilling must be stopped when the drill bit hit a rock. When restarting after the stop, the problem became evident. Due to the low water-content of the permafrost at the test site, the coarse materials had no freezing bonds to hold the soil materials together. Therefore, the forces exerting by the drilling system mixed and remoulded the permafrost instead of cutting through it. The large rocks which were not cut through were pushed and became wedged between the core barrel and the sidewalls of the borehole. In order to prevent damage to the equipment, the test was aborted when the problem was discovered.

Another test with the permafrost corer was conducted in a borehole where a new thermistor was going to be placed. At this location the active layer contains large rocks and exists in unfrozen condition which can cause significant challenge for drilling. The hole was therefore predrilled down to 1.8 m. The permafrost is expected to start close to this depth. The core barrel was attached to the rod system and lowered down to the bottom of the hole. The corer immediately hit large rocks and encountered the same problem as described in the previous attempt. It became evident that this attempt failed and must be aborted.

The causes for the failure become apparent after these two attempts. The main problem with drilling in coarse-grained permafrost was the low water content of the soils. There are therefore few freezing bonds to hold the grains together to exist as large strong mass, similar to rock mass or permafrost with high water content. Therefore, the grains move easily under forces exerted by the drilling system, which lead to remoulding of the materials instead of cutting. In addition, even though the barrel of the permafrost corer has reduced wall thickness compared with its earlier version, the core barrel still needs to remove quite a significant amount of soil materials during cutting cores. It was observed in the tests that the permafrost corer generated a lot of heat due to lack of an adequate cooling system. Therefore, even if the drilling bit was able to cut the material, the heat would have destroyed the samples in these tests.

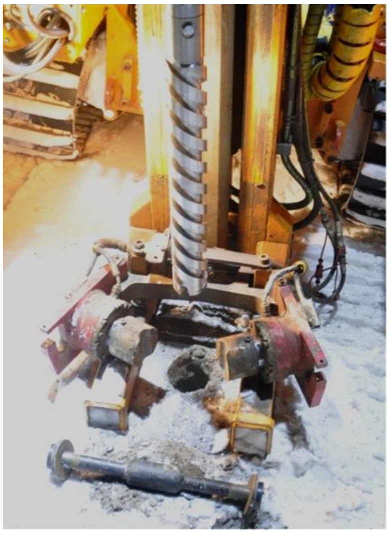

Figure 7. The drilling system with the permafrost corer set-up for sampling

4.2 *Atlas Copco 76 T2 core barrel*

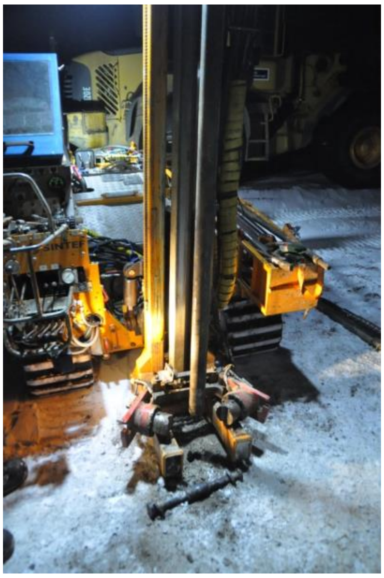

Figure 8. The drilling system with the Atlas Copco core barrel set-up for sampling

Two attempts were conducted with the Atlas Copco 76 T2 core barrel (Figure 8). The tests were started from the ground surface and showed that this system could also cut through the frozen organic peat at the top. At the beginning of the tests, it was observed that the air flushing exited up the hole and blew away the cuttings. As the drilling progressed, the flow of air up the drilling hole stopped. It seemed that the large cavities (or pores) among the dry and loose gravel allowed the air to disperse in all directions easily which reduced the air pressure in front of the drill bit. After penetrating approximately 1 meter in depth, the corer was retrieved, but the core barrel was found to be empty. This happened in both attempts. The temperature of the barrel was checked and it seemed that the cooled air used for flushing managed to reduce the influence of the friction heat generated during drilling.

The failure of these tests can also be attributed to the low water content of this coarse-grained permafrost, similar to the failure of the permafrost corer. With little presence ice, there was almost no bond to hold the soil materials together. The materials ended up being remoulded and blown away during drilling.

4.3 *The moraine percussion sampler*

The moraine percussion sampler was tested in coarse permafrost at an old coal quay in Hotellneset. The soil conditions in this area are similar to those found in Vestpynten with the exception of the water content. This area is below the sea level, hence the material is assumed to be fully saturated.

The sampler was drilled down to the desired depth with constant flushing to prevent material from entering the cylinder. The flushing was shut off and the sampler rammed down without rotation. The sample was taken at 28 m depth. To ensure that the sampler would be sufficiently filled, the sampler was rammed further than the cylinder length. This process compacted the materials which made it remain inside the cylinder instead of falling out. The sampler was then retrieved. The content was emptied into bags. The material retrieved with the moraine percussion sampler is remoulded. However, its ability to collect coarse materials at relatively large depths still makes it a useful tool in permafrost sampling.

4.4 *Conventional auger*

Figure 9. Sampling with auger

This method has been used in many different soil conditions earlier and is considered so far the most efficient method for material retrieval in Vestpynten (Figure 9). The soil materials, even with low ice/water content, can be quite effectively trapped between auger flightings and hence brought up to the ground surface. This methods and retrieve permafrost from quite large depths. However it remoulds the material, crushes and larger rocks and ice. Also the heat generated melts ice which can alter the water/ice content. The method does not give samples suitable for strength testing but can be used for some other tests (e.g. simple index tests).

5 CONCLUSIONS

None of the methods tested were able to cut or retrieved undisturbed cores in the low water/ice content and coarse-grained permafrost found in Svalbard. The following two main challenges are identified for sampling in coarse-grained permafrost (i) The low water content of coarse-grained soils means that there are few freezing bonds to hold the soil materials together. The soils therefore end up being remoulded rather than being cut under the forces exerted by the drilling system, and (ii) A large amount of heat is generated during cutting coarse-grained samples, therefore an efficient cooling system is essential and must be in place for sampling.

The permafrost corer and the Atlas Copco core barrels could not cut through coarse-grained loose permafrost in Svalbard. The moraine percussion sampler and the conventional auger can be used for sampling bag samples at a specific large depth, but the samples are highly remoulded.

6 ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support from the SAMCoT through the Research Council of Norway and all the SAMCoT partners.

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