Chapter 10
Difficulties of Geological Engineering in Arctic Seas

Yuliia Tcibulnikova

Abstract The Arctic continental shelf is a promising area for oil and gas exploration and mining. Extremely harsh environmental conditions affect the work of engineering geologists, whose work is essential for building and construction of pipelines and rigs for the petroleum industry. With the massive interest and growth of fossil fuels offshore production, more and more geotechnical issues are to be solved. The necessity of studying marine sediments becomes clear when the specific physical and mechanical properties of bottom soils in the Arctic sea shelf are taken into consideration. Certain geological aspects determine what marine soils comprise and how they behave under loads exerted by a construction. Traditional methods of measuring deformation and strength parameters are reviewed, compared and contrasted by their feasibility of using to study marine sediments from offshore the Arctic. A substantial range of published studies has been analyzed and the findings summarized to provide potential solutions. The article stresses the importance of proper geotechnical survey and collaboration between industries and environmental scientists to achieve best results in studying the Arctic and building long-term human capacity alongside with protection of its vulnerable environment.

10.1 Introduction

Industries all over the world require an external energy supply. Up to the present days, the fossil carbohydrate fuels, such as oil and natural gas, have been the main energy resource, and despite of developments in alternative energy forms, the fossil fuels are still undoubtedly in huge demand. The petroleum exploration, development and mining has been ongoing for past century and a half. The sovereign states are pressing territorial claims in different areas of the Arctic Ocean, which Russian Federation tends to do as well, considering the Arctic continental shelf as a promising area for oil and gas industry.

Y. Tcibulnikova (✉)
St. Petersburg State University, Sankt-Peterburg, Russia
e-mail: juxik@yandex.com

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Harsh environmental conditions in the arctic sea areas make it rather difficult location to conduct economic activities that have recently been part of massive industrialization of the region in general. Both mounting vessels and petroleum industry constructions themselves must take the region's specific circumstances into consideration when planning long-lasting projects. The very fact that the sea bottom has to be reached introduces additional struggles to geological engineering. The object of studies (bottom sediments) lies several hundred meters deep under water, what makes it significantly hard to access. What is more, due to water entrainment the essential physical and mechanical properties of a soil may vary out of range of traditional testing methods. Even though ocean water masses downgrade the temperature variations, staying for long periods in the near-zero-degree water can be difficult to bear for divers who operate sea bottom sampling and drilling. Harsh environmental conditions also affect the vessel crews' performance of tasks. All the fore mentioned examples stress out the particular features and challenges of geological engineering offshore the Arctic.

10.2 Glimpse to the History of Petroleum Development Offshore the Arctic

Scientists first realized the necessity of studying sea bottom sediments in the 1930s. Until that time, the question had never been properly raised due to the absence of technologies allowing deep sea sampling. First ever continuous sequence of marine sediments was delivered by the German Meteor Expedition in the early 1930s. Scientists managed to determine the quaternary ice ages and global climate changes based on the data obtained. The expedition used so called the Kullenberg's piston corers that allowed taking unsplit samples of marine soils up to 20 meters depth (Kennett 1982).

When the GloMar Challenger research vessel was launched in 1968 in the United States, it had already been equipped with the echo-location positioning system. The high-accuracy scanning sonar captures the location of the initial borehole to continue drilling exactly in the same location in the next drilling session (Kennett 1982; DSDP 1969). After evidence of the Groningen gas province was discovered in Dutch part of the North Sea, in 1950s-1960s Norwegian petroleum scientists and entrepreneurs encouraged oil and gas exploration within the continental shelf of Norway (NP 2016). On the other side of the Arctic, Canadian government assumed the necessity to explore potential gas and oil deposits offshore the Northern Territories. In the late 1980s Canada granted licenses for petroleum activities in the Beaufort Sea and the McKenzie delta.

Offshore the Russian Arctic, only the Prirazlomnoye oil field is currently under the development. It was discovered in 1989 in the Pechora sea. Gazprom owns the production license for it. The extracted oil is in export demand on a massive scale. Theoretically it is possible to develop the Stockman gas condensate field in the

Barents Sea, which is currently suspended due to the shortage in financial support and the lack of required technological supplements.

10.3 Geological Engineering Conditions of the Region

Even though geological history, stratigraphic sequences and lithological features of marine sediments have been being studied for several decades (Rokos and Lyusternik 1992), the offshore soils required further in-depth research. Continental shelf is a submerged prolongation of the continent, featuring flattened underwater relief and geology complimentary to the adjacent firm land. Relatively shallow seas form above. For example, the average depth of Russian Arctic shelf seas is rarely more than 150 meters (Rokos and Lyusternik 1992; Kozlov 2012). The shelf areas only form by passive continental margins, where excessive tectonic deformations do not occur, where thick sedimentary cover can build up evenly during millions of years burying the oil and gas deposits. As studies from the Eastern Arctic area prove, the sedimentary cover has formed undisturbedly since the last stage of Caledonian orogeny circa 450 Ma, this being the average age of folded basement (Vinogradov et al. 2004). The sedimentary cover itself consists mainly of terrigenic sediments, altogether reaching the thickness of 17 km (Kozlov 2006). The desired fossil fuels are mainly found within the pore layers of those down to depths of 3 km.

The bottom offshore the Eastern Arctic is a spatial diversity of upheavals and thoroughs; the latter provide the deepest sea marking the greatest thickness of sedimentary layers. This in many cases is a key factor for forming fossil fuels deposits. One of the striking examples is the Eastern Barents sea depression, which contains the large oil and gas bearing Barentsevomorskaya province covering area of 60,000 km^2, and the Ludlovskoye gas condensate deposit (Kozlov 2010). However, gas has a tendency to escape from deeper major deposits (due to lower density or to the unconformities in covering sediments) and accumulate in upper layers of soil under clay lenses. When covering clay is disturbed during a rig construction, gas bursts out with considerable force comparable to an explosion, what can cause destruction of construction parts and mounting vessels (Kozlov 2010).

Most of the soils on the Arctic shelf are composed of mixed sand and clay particles. The upper layer of sea bottom sediments cannot be considered as a significant construction base due to its high transfer liability, low pressure resistance or unsolid bedding. The underlying layer of ground that is older in age (up to 2 Ma), is often used as an appropriate base for drilling rigs. However, another challenge is often caused by the presence of ice. The permafrost constitutes the major part of the area both on land and offshore as the result of paleoclimatic events such as the sequence of quaternary Ice ages (Rokos and Lyusternik 1992). This extremely stiff solid formation of water frozen in the pores of a soil gets exposed in large areas at the sea bottom. In addition, the upper layer of marine soil may contain local lenses of recently formed clear ice (Kozlov 2012). Both ice types pose significant challenges to construction. Permafrost is extremely hard to drill through, what makes building of the drilling rigs significantly difficult.

All the before mentioned conditions have direct implications on projecting oil rigs or pipelines within the Arctic shelf seas. To ensure the durability, safety of usage and stability of future structures as well as to prevent accidents, decent strength and deformation properties of the bottom soil have to fit the previously calculated ones of that structure. At this stage of geotechnical research, the environmental conditions of the region play a vital role. For example, even though standard methods can be used for moisture, consistency and porosity characterization, and for defining the grain size composition, the ocean water saltiness has to be taken into consideration. The salt component makes soil grains stick together into larger particles, highly prone to unpredictable crumbling under a structure pressure.

10.4 Issues on Testing

Since the upper layer of marine soils are very loose and highly watered, studying them involves the use of nonstandard methods. The basic soil studies include laboratory testing carried out on soil samples taken from the sea bottom. Contemporary practice uses various sampling devices, such as piston and vibration corers, box samplers, dredgers, snapper samplers. Operating all of the listed equipment is rather difficult and pricey, because their use requires qualified staff (Kennett 1982).

When the sediment sample is obtained from the sea bottom and brought undamaged to the laboratory, the actual geotechnical testing begins. For every type of soil it is needed to find the main mechanical parameters, which determine how the soil behaves under pressure exerted by a structure above. The parameters are divided into two major groups – the deformation properties (such as the porosity ratio) and the strength properties (the inner friction angle and the inner cohesion between grains). An oedometer shows the dependence of porosity ratio on exerted pressure. However, marine sediments are so loose that the critical pressure cannot be tracked. Either water is squeezed out, not meeting the natural condition of the soil (Rokos and Lyusternik 1992).

To test the strength properties of a soil, the friction angle and the inner cohesion of a sample are measured by exerting both vertical and horizontal sheering pressure to it. A box sheer apparatus and stabilometer are commonly used in testing an average firm land soil, whereas for marine soils those are hardly useful. Marine soil is so loose that the mentioned instruments are not precise enough to mark critical pressure (Ziangirov et al. 1982).

In marine soil studies, penetration probations are widely spread (Kennett 1982). The downside of this method is that it allows only the determination of the general sheer resistance. The precise values of friction angle and inner cohesion, directly used in projecting and construction, are hard to calculate with this methodology.

10.5 Potential Solutions for Arctic Geological Engineering

For marine sediments, especially those at the Arctic sea bottom, testing should be done *in situ* in the soil's natural conditions. Until recently, hiring qualified professional divers was essential to operate the measurement tools at the sea bottom. Nowadays, engineering geologists have opportunities to use multifunctional probes of various configurations to operate from the research vessel, which basically negates human error.

Concerning the challenges caused by permafrost, thermodrilling may prove its effectiveness, as long as the resulting excessive heat is reduced, and the surrounding ice is preserved from unwanted melting. This can be achieved by attaching a heat-and-water-resistant cover to the drill bit, preventing the heat from spreading into the ocean. As for the gas lenses inside a soil layer, when a lens is discovered, tapping (puncturing) it to let the gas pop out can be considered a solution. In this case, development and construction can continue as soon as the bottom soil appears relatively stable.

Taking into consideration all the listed particularities of marine soils offshore the Arctic, a detailed investigation and study of the area is required once it is licensed for petroleum development or construction. In the Arctic oceans and its coastal areas, the main branches of industry that are in the need of geological engineering data, are petroleum industry and related construction. Bottom soils offshore the Arctic have to be studied in cooperation with geophysicists to request complementary remote sensing data. The information provided by geological engineers is needed to build constructions for gas and petroleum industries. This requires collaboration with all the involved professionals in those fields. The environmental authorities' approval has to be received for any project in the Arctic region. The Arctic ocean and its coastal area are a unique ecosystems that are extremely fragile and vulnerable. An accident at pipelines or oil wells causes risks of irreparable damage not only to that specific ecosystem, but to the whole planet Earth.

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