Features of geotechnical surveys and leg penetration analysis for drilling platforms in the Arctic seas

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Abstract. In recent years, one of the most important direction in the development of offshore hydrocarbon exploration is the expansion of the oil, gas and gas condensate fields of the Russian Federation to the Arctic shelf areas. Extensive and complex engineering surveys are actively performed in the Barents Sea and the Kara Sea. In the last year, a wide range of engineering investigations has been implemented on prospecting and exploratory wells. The geotechnical surveys are mandatory before the drilling of exploratory and production wells to obtain the data for the upper part of the geological profile to provide necessary information for safe positioning of drilling rigs. This is extremely important as the upper part of the soil interacts with an engineering structure whether it is a drilling rig, pipeline, subsea production system or any other structure. The data of the stated surveys is used for optimal location selection for drilling rig positioning and the necessary stability calculations. The use of geophysical and geotechnical methods in engineering surveys provide an effective solution for the geological challenges and ensures the availability of sufficient information regarding soil composition, properties and strength conditions.

1. Introduction
The exploratory and prospecting wells are necessary components within the scope of work for hydrocarbon fields development in the Arctic seas. Drilling of these wells is performed with the use of jack-up and semi-submersible platforms. Prior to positioning of the platforms the complex investigation of geophysical, geotechnical, hydrometeorological conditions is to be performed, and necessary engineering calculations are to be completed.

An important part of the investigations is the identification and mapping of geological hazards on the site of the planned well. Some geohazards are typical for sea shelf generally. However a number of particular hazards have been discovered in the Russian Arctic shelf. A complex of methods has been developed for investigation of different geohazards which includes both traditional well-established marine survey methods and some special methods for Arctic seas.

Analyses and calculations for drilling platforms positioning are regulated by specific standards. In the current moment, many international standards have been implemented and used by most of the oilfield service companies. However, in the Arctic conditions, some additional factors, not described in the standards should be taken into consideration.
2. **Geohazards on oil and gas fields of the Arctic shelf and methods for their investigations**

Investigation of geological hazards, their presence and their possible propagation, is necessary for determination of the location for positioning of rigs for exploratory and production drilling. In areas of the Russian Arctic shelf, the following geohazards are distinguished:

- **Gravity processes:**
  - Slides/slumps;
  - Sediment creep;
  - Effects of turbidity currents;
  - Rockfalls.
- Sediments with increased gas content («gas pockets»), with channels («gas pipes») and with the presence of gas hydrates.
- Areas of focused fluid release (including mud volcanos);
- Areas with abnormal formation pressure;
- Presence of permafrost; sporadic and insular permafrost;
- Ice gouging (bottom exaration) by icebergs and stamukhas;
- Seismic – earthquakes;
- Areas with soft sediments like soft clay or silt

Because of the geological hazards, the typical challenges for engineering surveys in the Arctic seas are the following:

- Determination of the presence and expansion of dangerous natural processes and events (geohazards);
- Investigation of geotechnical profile features, including composition, texture, properties and conditions of the soils.

Several methods in complex engineering surveys are addressing these challenges. For example,

- **Engineering-geodetic surveys (hydrographic works):**
  - Multibeam bathymetric surveys;
  - Side screen sonar surveys (SSS) – definition of ground forms and objects on the sea bottom);
  - Hydromagnetic surveys – identification of metal-containing objects;
  - Navigation support of all types of works.
- **Engineering-geological surveys (including geophysical investigations):**
  - Continuous seismo acoustic profiling – high resolution and low resolution;
  - High resolution seismic;
  - Geotechnical works: soil sampling, drilling, laboratory testing (offshore and in an onshore laboratory).
- **Engineering-Hydrometeorological surveys, including:**
  - Hydrometeorological condition investigations: measurements of temperature, wind speed, pressure determination due to extreme values of the wind speed, identification of wind rose etc. (meteorological station);
  - Hydrological conditions investigations: measurements of high tides, current speed and salinity, determination of extreme values of currents, current rose, swell parameters, ice regime (autonomous bottom station).
- **Environmental surveys, including:**
  - Investigations of air and water pollution, radiation, ecosystem assessment, marine mammal observations, weather forecasts and recommendation issues.

Apart from standard geophysical (high resolution seismic, low/high frequency seismic-acoustic profiling, hydromagnetic surveys) and hydrographic (Multibeam, SSS) surveys, for the Arctic seas in
regions with potential for permafrost, the following tasks are performed: transcendent electromagnetic soundings in near field, geotechnical drilling with in-hole thermometric investigations, and soil sampling with laboratory testing in an offshore laboratory (Figure 1).

![Figure 1](image)

**Figure 1.** Soil testing in the offshore laboratory.

Geotechnical borehole drilling is performed in order to clarify the geotechnical data and geological conditions on-site for drilling rig positioning. The data needed include the determination of engineering geological profile; obtaining data regarding soil properties, texture and conditions as well as confirmation of electrical data for identification of frozen soils. To confirm the frozen soil presence and conditions, thermometric investigations are performed after the completion of the borehole.

During geotechnical drilling, the main goal is to obtain the maximum undisturbed core samples, appropriate for laboratory testing. The method for geotechnical borehole drilling in regions with permafrost expansion is characterized by many technological features special for the Arctic seas.

Engineering survey performance has several additional features in the Arctic, comparatively with similar works in the Southern regions. During the planning of fieldwork, including these methods it is necessary to take into account the specifics of the Arctic region and pay attention to the following aspects:

- **Short navigation period.** The navigation period is rather limited and depends on the particular conditions. In the Kara Sea - from the second half of July/ beginning of August – to the end of October. The suitable weather window is wider in the Barents Sea. However, the working period can shrink due to frequent storms. Thus, the preparation of the research vessel and equipment should start early, and considerable waiting time due to weather may be expected.

- **Remoteness from the closest supply port.** Murmansk and Arkhangelsk are the most developed ports in the Russian Arctic. The distance to the port from the oil and gas field could reach 600-700 km in the Barents Sea and more than 1500 km in the Kara Sea. The engineers have to identify the necessary reserve of equipment, spare parts, packing materials and other necessary details. Rather often in case of any difficulties and equipment malfunction or necessity to change the method of works, the engineers have to be ready to solve the problem only using the materials on the board of the vessel.

Soil samples treatment and testing also have some features. In the Arctic seas, the chilled soils are common. Soil testing has to be started immediately after the core has been pulled on board of the vessel to obtain the accurate properties. Measurements of temperature and investigations of thermal-physical soil properties also should be done fast.
3. Calculations for drilling rigs

Based on the data obtained after soil analysis in the offshore and stationary laboratory, the necessary calculations should be performed. The specific calculations depend on the type of platform.

The stability calculations and predictions of footing penetrations should be implemented in the course of the planning of drilling work with jack-up platforms. Prior to projects with semi-submersible rigs, the calculations for the anchors penetration and dragging distance as well as anchor holding force should be completed.

The drilling rig positioning process involves several companies, clients, contractors and operators, large human and financial resources are involved in the procedure. Due to these and many other tasks, a working day of the whole team costs a colossal sum of money. For this reason the calculations, including all possible factors influencing rig positioning, take an extremely important role.

For the current theme, a number of standards have been developed. In international practice, the most popular detailed standards are the following:

− SNAME Technical & Research Bulletin 5-5A. Guidelines for Site-Specific Assessment of Mobile Jack-Up Units, 2008 [1].
− ISO 19905-1 – Site-specific assessment of mobile offshore units – Part 1 – Jack-up platforms [2].

Some engineering standards, like SP 22.13330.2016 [3], SP 58.13330.2012 [4] and some others are used for calculations in Russian projects, although the named standards are not designed especially for jack-ups.

Generally, jack-up platform footing penetration analysis both in international and Russian standards can be summarized by following main stages:

− Design of the spudcan model;
− Computing of the vertical bearing capacity of the footing at various depths;
− Plotting of the vertical bearing capacity versus depth curve and comparison with the specified maximum preload and determination of the predicted footing penetration.

When comparing the calculation methods in Russian and international standards certain differences can be noticed. Generally the formulas for vertical bearing capacity calculations are nearly identical. However, in Russian SP 22.13330.2016 (1) a single formula is used for all types of dispersive soils, while the international standards, for example, SNAME 5-5A use two different formulas for clays (2) and sands (3):

\[ N_u = b' \cdot l' \left( N_p \psi_y b' \psi_f + N_q \psi_q d + N_c \psi_c c_u \right) \]  \( \text{(1)} \)

\[ F_v = A \left( c_u N_c s_c d_c + p_0 \right) \]  \( \text{(2)} \)

\[ F_v = A \left( 0.5 \gamma' N_p s_p d_p + p_0 N_q s_q d_q \right) \]  \( \text{(3)} \)

where \( b' \) and \( l' \) – the breadth and the length of the foundation (spudcan); \( N_p, N_q, N_c \) – bearing capacity non-dimensional coefficients, dependent on soil friction angle, \( \psi_y, \psi_q, \psi_c \) – foundation (spudcan) form coefficients, \( \gamma_f \) and \( \gamma'_f \) - submerged unit weight of soil values, \( kN/m^3 \), \( c_u \) – specific cohesion of soil, \( kPa \), \( d \) – foundation (spudcan) depth, \( m \).

In the Russian Standards, the specific cohesion of soil is used. The current parameter is determined in consolidated drained triaxial tests. In SNAME and ISO the values of undrained shear strength are applied. However the undrained shear strength value can be obtained by different methods including the following: undrained unconsolidated triaxial, laboratory vane, CPT and other. The method which is to
be used for undrained shear strength determination is not specified in the standards and the values obtained by the named methods can be rather different. Thus, this is a point for discussion.

In both calculation methods the identical bearing capacity factors \((N_r, N_q, N_c)\) are used. However, in each standard the calculation methods and the obtained values for the current factors are quite different. The difference can be mostly distinguished in values for silica sands with friction angle 30-40 degrees and in sandy silts with similar properties [5].

It worth noting that in particular oil and gas service companies, for instance, in Fugro, some intradepartmental standards are developed. This kind of documents may be appropriate for specific regions where the company proceed with projects. However, these documents are used only inside the companies and are available for common use.

Proceeding the leg penetration depth determination, an engineer should pay attention to some factors specific for marine conditions and Jack-up rig type structures, including the following:

- Differences of forms and sizes of Jack-up leg spudcans. A precise model of the spudcan should be built prior to calculations.
- Specifics of Jack-up rig positioning procedure.
- Possibility of the appearance of alternative soil failure mechanism:
  - Squeezing - when a stronger soil layer is underlayered by soft soils.
  - Punch-through – a failure processes when a strong layer overlies a weak layer and hence a rapid additional penetration of the spudcan can occur, associated with a significant reduction in bearing capacity.
- Possibility of soil back-flow into a cavity over a spudcan.

The back-flow of the soils during spudcan preloading can occur by the following mechanisms: soil flows over the top of the foundation, cavity wall failure and sediment transport from the sea bottom into the cavity hole [6]. These three mechanisms are illustrated in Figure 2.

![Figure 2](image-url) Illustration of possible back-flow mechanisms during spudcan penetration in centrifuge testing [6].

The above-named alternative soil failure mechanisms (squeezing and punch-through) are presented in Figure 3, where the designations in the figure stand for

- \(Q_v\) – applied factored vertical load;
- \(p_0\) – effective overburden pressure at depth D.
- \(A, V, B\) – Spudcan bearing area, volume and diameter
- \(T\) – thickness of a weak clay lay.
4. Conclusions
Geophysical and geotechnical methods are performed in order to obtain the fullest data for soil composition, texture, properties and conditions. The use of geological data obtained in a high quality manner and application of different calculation methods and standards makes possible performance of necessary assessment of foundation soils and comparison of the results taking into account different factors. All these applied methods make possible the completion of the main goal – determination of appropriate, safety and economically effective location for positioning of a drilling platform.

Jack-up rigs leg penetration analysis – is one of the challenges, which has to be performed prior to drilling works. A number of technological modifications of spudcans, legs and other mechanisms of a platform may be dependent on the calculation results. In certain cases it may be necessary to select an alternative platform instead of one preplanned earlier.

The appearance of the factors as back-flow, squeezing and punch-thorough is possible jack-up rig positioning procedure in any regions – all these factors should be taken into account. However, when planning any procedures and calculations for Arctic seas, several additional features should be taken into account. Engineers performing the calculations should pay attention that the bottom soils in the Arctic seas have the following features: possibility of permafrost presence and presence of chilled soils. In certain regions strong lateral variety of soil properties has been detected.

Due to the named above factors it can be concluded that a leg penetration calculation method should be updated for each specific region either by specific coefficient inputs or by application of a single method considering features of the region. In should be also noted that in order to avoid the uncertainty of geotechnical properties, especially in areas with strong lateral variety of soils, geotechnical investigations should be performed in the quality and precise manner. Scope of work for site survey should include geotechnical boreholes designated for location of each jack-up platform leg apart.

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