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CERTAIN ENGINEERING AND GEOLOGICAL PECULIARITIES OF BORING IN THE BALTIC SEA

The peculiarities (engineering and geological) of geological-engineering In the Baltic Sea have been studied. The results have demonstrated that two methods among those used for hole boring can be applied under engineering and geological conditions of the Baltic Sea. Certain recommendations on the selection or boring equipment and boring parameters defined are given together with the boring methods used "In situ", which increase the boring efficiency.

1. General concepts

The off-shore boring has certain peculiarities which significantly differ from those on-shore. The most important of these are:

— influence of hydrometeorologilcal factors on the boring process and their mutability in time,

— necessity to use special floating;

— necessity to fasten the buoyant drilling rig above the borehole;

— restricted dimensions of the working space;

— necessity to apply a special drilling riser;

— necessity to provide a continuous boring process: from the beginning until the completion of the boring;

— a variety of methods and technical means used for boring of holes;

— continuous soil sampling from different types of soils;

— different tests in boreholes by the methods "in situ" applying various geotechnical equipment;

— increased physical and emotional stresses of the personnel.

The geological structure of floor sediments of modern seas including the Baltic Sea goes on changing. For the boring geological-engineering boreholes in the Baltic Sea, where seabed sediments characterized by silts, sands, sandy-gravel soils, cobble and clay soils, moraine containing rock fragments sandstone etc., the most rational and expedient are drilling rigs, which allow to drill both soft and hard soils. The choice of borehole design and method used for boring depends on the geological section.

2. Design of boreholes

The design of marine borehole is determined by its designation, design depth, properties of soils in the lithological section. All these fetors stipulate the number of casing columnes and the depth of these penetration as well as the finite diameter of the borehole, when the possibility to apply borebole geotechnical equipment used to carry out different investigations by the "in situ" methods should be predetermined.

One of the most important design unit of the borehole is the drilling riser, connecting the drilling rig to the well mouth. The drilling riser has two main functions: to contribute to the drill running into the borehole at repeated runs of boring and to reliably separate the inside of the bore hole from the outside that is very important for a qualitative cleaning of the borehole. One should note that at the boring by easy floating means, the riser can serve as the anchor pile. Referring to the design peculiarities of drilling riser, the latter can be classified into two, widely spread, types:

— with a guide pipe or conductor, and

— with a telescopic compensator.

Two main units of drilling riser — the conductor and compensator — are designated for abolishing the impact of vertical vibrations of buoyant drilling rig on the drilling riser . The first version: the casing string is run in through the conductor, which is installed at the a floating mean and prevents the deviation of the casing due to the sea heaving. The length of submersed part of the conductor is assumed to be by 1.0–2.0 m higher than the maximum vertical amplitude of sea heaving. The second version: a telecompensator is installed into the drilling risers rigidly pinched from the above. The stroke of the telecompensator by 1.0–2.0 m should exceed the maximum vertical amplitude of the floating mean due to sea heaving.

Eventually, for example, at boring in closed water areas of ports where vertical heaving is insignificant, the casing column not fastened from the above and without compensating units can be used.

It should be noted that the both design versions of drilling risers have certain disadvantages, however, the versions with the compensator seems to be much more promising minding the fact that the design of telecompensator is being perfected, and in the nearest future can provide as well:

— the compensation of small angular deviations of drilling riser from the borehole axis,

— the penetration of drilling riser into the soil by percussion method,

— the rotation of drilling riser for its predrilling.

Thick-walled coupling pipes with a diameter 127–219 mm are usually used as marine casing column.

The boreholes are cased with drilling risers until they meet hard soils. Hard soils are usually explored without casing the borehole walls. Occasionally, for example, to avoid difficulties, the casing column can be inserted through the riser. Standard 108-mm and 127-mm diameter casing columns (nipple connection) can be used as intermediate casing columnes for geological investigations.

3. Methods for boring engineering-geological boreholes

As mentioned above, the design of borehole and the methods used for these boring depend on presumed geological conditions. The drilling method stipulates the choice of drilling equipment. The sort and set of the chosen drilling equipment define the parameters of boring regime and procedure: length of run, kind and properties of flushing, conditions determining the transition from one drilling method to another, etc. The complicated geological section of bottom sediments in the Baltic Sea has predetermined a wide application of two main drilling methods used in engineering-geological investigations in its water area: cable-tool percussion and rotary core boring. Table presents the types and methods of boring most widely used in the water area of the Baltic Sea, their application and characteristic technological features.

3.1. Cable Boring

This boring method is mostly used for boring sandy, cobble and clay soils. The following types of cable-tool percussion boring are used dependent on the composition and properties of soils: percussion drilling, picking, bailing.

3.1.1. Percussion Boring Method. It is used for boring of dense clay, sandy and cobble soils. If this boring method applied, the drill (e.g., sample taker, percussion barrel) is percussed into the soil by the drilling jars, the percussion tool touches the bottom. The weight of drilling jars is usually about 100–150 kg. The fault throw of drilling jars rod connected to the barrel is determined by the design of the latter and equals 0.5–1.0 m.

3.1.2. "Picking" Boring Method. The drill tool is thrown onto the face from a certain, empirically found, height. The barrel due to kinetic energy is hammers penetrated into the soil, then it is removed from the well for cleaning. This boring method is most efficient in clay soils: silts, flowing clays, soft loam. One should note that the borehole sinking in silty, flowing and soft plastic soils has some peculiarities. The impact can destroy completely the natural composition of such soils, they turn into a structureless mass. This phenomenon is characteristic for sand-loam silts as well as for silts with layers composed of water-saturated sands. As a rule, for exploring weak soils the percussion barrel with a catcher (usually 0.8 m long) is used as a drill. The fault throw of drill is found out experimentally and should satisfy the condition, under which the barrel does not penetrate into the soil for more than full length and the soils does not dilute. In case the natural structure of weak soils is damaged, the fault throw of the drill is reduced during the boring.

The percussion boring as well as the "picking" one supply the qualitative geological data. The samples of soil in the form of a column obtained by the cable boring method allow to allowable accuracy register the soil layers.

3.1.3. Bailing. The procedure: multiple lifting and throwing down of a bailer from a certain height onto the borehole bottom. This method is applied for exploring sandy and cobble soils and for cleaning of cutting from the borehole. As a matter of fact, the number of bailer strokes (hits) per min is 20–30, the fault throw is 0.15–0.2 m at exploring sandy soils. It seems expedient to load the bailer with a 80 kg drill collar.

Table. Main Methods and Type of Engineering-Geological Boring in the Water Area of the Baltic Sea

Boring Method	Boring Type	Drilling Tool	Features of Boring Procedure	Type of Soil
1	2	3	4	5
Cable-tool Percussion Boring	Percussion	Sample-taker	The sampler enters the soil by the drilling jars not breaking off the borehole bottom. The run length is 1.0m	Clay, sand and soils with cobbles
	"Picking"	Sample-taker with ball check valve	The sampler penetrates the soil when falls onto the borehole bottom	Silt, flowing clay, soft loam
	Bailing	Bailer	Repeated falls of the bailer onto the bottom from 0.15-0.2m. The run length — till 1.5m	Sand and soils with cobbles
Rotary Core Boring	Slow-rotary	Spoon, auger or spiral drill bits	The length of run – till 1.0m. Rotary speed of drill — 0–40 rpm	Clay, non rock, stable soils
	Pump-free with near-face back circulation of flushing	Special core barrel with ball check	The boring is performed from the winch by kelly. The length of run — till 1.0m	Soft, sandy clayey soils
	With flushing by water	Single tube core barrel, double tube core barrel	The rotary speed of drill — 0–300 rpm. The length of run – till 3.0m. Unclosed circulation of flushing	Stable clay and, rock.
	With flushing by mud	Single tube core barrel, double tube core barrel	The rotary speed of drill – 0-300 rpm. The density of mud 1.2g/cm³. The length of run – till 3.0m. Closed circulation of flushing mud	Unstable sandy clay, rock.

A significant problem arises at boring loose and water-saturated silty sand, which are often met in marine sediments. A sandy plug often occurs at boring of these soils. That is why the most important problem here is to separate all sandy layers by casing column. The bailer is often sticked or jammed. In order to escape these problems, the 3 m long bailers should be used. The bailer should be thrown from a minimum height, the diameter of bailer should be much less than the inner diameter of casing column to prevent the piston phenomenon at the bailer's lifting that contributes to the sucking of sand and formation of a sandy plug in casing column. Besides, the upping to the borehole bottom can be decreased by the pressure of water continuously supplied into the casing column during boring.

The soil bailing method, if compared to percussion and picking boring methods, does not supply qualitative engineering-geological data because this method is applied to the soils, where not possible to take undisturbed samples.

3.1.4. Some Problems of the Cable Boring Method. As a rule, the strengthening of the borehole walls by casing column at cable boring is done together with the drilling.

In loose sandy soils the casing column usually penetrate the soil driven by their own weight at boring.

The boring in dense cobble soils is forestalled (advanced) by the penetration of casing column: first, the casing column: first, the casing column go through by percussion or vibration, then the soils is removed from the inside of casing column. The experience requires to satisfy the condition when the casing shoe lead should lie in a 1.0–1.5 m range with regard to the borehole bottom. The increase of this value, in fact, results in the soil consolidation inside the casing, and this complicates the operation of the drill. Besides, at too deep submersion, thin layers of silts or stiff to hard clays often met in the marine sandy sediments can be explored.

The sea cable boring has certain important advantages if compared to another bore hole drilling methods: the procedure and drilling equipment are simple enough, the time of tripping is not long. Besides, this boring methods is less influenced by the environmental factors, e.g., sea heaving. All these reasons explain the wide use of the cable boring method mainly for sandy soils in marine engineering-geological investigations.

3.2. Rotary Core Boring

The most universal method used for the boring of marine engineering-geological boreholes is the rotary core boring method. Its main advantage is that together with good quality of engineering-geological data supplied by this boring method, it is used for the boring of different soils. Moreover, this method is the only one used for the boring of stiff, hard soils and rocks. The following types of rotary boring are most often used in marine boring:

— core boring with water flushing;
— core boring with clay flushing;
— pump-free core boring with local reverse circulation.

There is also a slow-rotary boring method by auger, shell drills and spoon drills. But the current article will not discuss since these are extremely seldom applied in marine boring.

3.2.1. Types of Core Boring and Field of Application. Core boring together with direct water flushing and unclosed circulation is used for the boring in stiff to hard clay soils, when the bore hole walls are stable. Single tube core barrels serve here as drills.

The tube core barrels with clay flushing and closed circulation are used for exploring loose, soft to firm washing-out soils, with unstable watts of boreholes. The exploring of unstable soft soils always faces difficulties associated with sampling and preservation of the core during boring. This problem is solved by different means, one of which is the apwhich is the application of double tube core barrels. At present, the following kinds of double tube core barrels are the most widely used in marine boring:

— double tube core barrel with outside and inside barrels rotating simultaneously, which prevents the core washing-out by running fluid;

— double tube core barrel with outside rotating barrel and resting inside barrel preventing the core washing-out, vibrations and mechanical impacts.

It should be stressed that in order to prevent the cutting setting during boring the drill tool (composed of a double tube core barrel), should include a sludge barrel.

The core recovery of soft soils can be increased by a special core tool used for pump-free boring with local reverse circulation of flushing. Such a core tool must include a closed (or open) sludge barrel. Low efficiency of the method is its most significant drawback: it is two times lower than the efficiency of the usual core boring with direct flushing. Besides, the maximum run should not exceed 1.0 m.

Different type of drill bits made of hard alloys and related to different soil types are used as drills for core boring of engineering-geological boreholes in the water area of the Baltic Sea.

3.2.2. Features of Core Boring. One of the main peculiarities of core rotary boring is the influence of sea heaving on the borehole drilling. The amplitude of the drilling rig vertical vibrations depends on the wave height, but in case of resonance can significantly exceed the mean wave height. The following situations can occur as the after-effect of sea heaving:

— when the vertical vibrations of buoyant drilling rig reaches the highest point, the drill linked to the drilling rig breaks off the borehole bottom;

— when the vertical vibrations of buoyant drilling rig reaches the lowest point, the drill is subject to overload practically equal to the displacement of buoyant drilling rig, and such short-term overload can damage the drill.

In order to escape (prevent) the above difficulties at boring, two different methods exist and can be successfully applied.

One method suggests the application of rotor-type swivel head with hinge bushings, which interact with the kelly (its cross-section is square or hexahedral). In this case, the boring is performed from the "winch", and the necessary loading (charging) on the drill is created by the drill collars.

Another method suggests the use of moving rotary drive (the hydraulic system of this has a special compensator). In this event, the boring is performed as by hydraulic loading of the drill as by drill collars.

The experience of marine core rotary boring confirms the expedient use of the drill collars to produce the necessary load on the drill bit. Such a construction of the boring string works in an extended state, and the drill pipes do not suffer bending stresses. The large diameter of the drill collars gave the rigidity to the drill string and prevents the bending of boreholes.

3.2.3. Core Boring Technology (Procedure). The choice of boring technology (procedure) is very important at the borehole boring, namely: the optimal combination of parameters of boring regime, the type of core tools and the duration of drill runs. All the enumerated reasons should provide the maximum penetration rate together with a high enough core recovery and necessary quality of engineering-geological data.

3.2.3.1. Rotary speed of the drill tool. Special technical publications describe numerous methods and formulae used for calculating the rotary speed of a drill tool dependent on the diameter of a drill and its peripheral velocity. There one can also find recommendations on the choice of the drill bit peripheral velocity, however, the longterm practical experience allows to draw the following conclusion: with regard to the marine engineering-geological boring, the maximum value of penetration rate corresponds to the peripheral velocity of drill bit in the 0.9–1.3 m/s range. Hence, the optimal rotary speed of drill tool lies in the following ranges:

— for 93-mm-diameter drill bits — till 200 rpm;

— for 112-mm-diameter drill bits — till 180 rpm.

It should be noted that these values differ from those referred in special publications and, besides, they should be reduced for:

— soft soils;

— cracked soils;

— soils striped with layers of different hardness.

3.2.3.2. Axial charge on the drill bit (W.O.B.) The mechanical velocity of the hard taking core bit boring changes parabolically dependent on the axial loading on the drill bit. Every soil type has its maximum penetration rate velocity at different values of axial loading. In practice, the marine boring is not an exception as well, the rational value of axial loading on the drill bit is defined basing on the charges (the most effective for soil fracture) applied to one cutting edge or a cutting insert (for self- sharpening core bits). If the load on the drill bit is increased, the penetration rate increases too. However, the load increase on the drill bit is restricted by many factors. In soft soils, at large load the penetration rate of boring is high, and at normal flushing the borehole bottom is clogged with cutting and the drill pump is out of order. As a rule, the increase of drill pump delivery and that of flushing rate result of loss core recovery due washing-out. Hence, in this case the axial load should be chosen considering the optimal combination of penetration rate and borehole flushing rate.

3.2.3.3. Quality and delivery of the flushing. The minimum delivery of flushing to the borehole bottom should provide a good cooling of the drill bit, the complete removal of cuttings during boring and, at the same time, not to wash out the core and the borehole walls.

In the theory of the core boring the quantity of flushing fluid delivered to the borehole bottom is defined considering the recommended annular velocity of fluid upstream flow between the borehole walls and drill pipes, or the flow rate of drilling fluid per I mm of the drill bit diameter. The practical experience of engineering- geological boring in the water areas of the Baltic Sea and other seas shows that the quantity of flushing should be defined considering the following optimal values:

— for the velocity of upstream flow — 0.4–0.7 m/sec,

— for the flow rate per I mm of the drill bit diameter — 1.0–1.5 l/min.

It should be noted that despite of the recommendations, the flushing delivery should be controlled during boring dependent on the geological conditions.

Water is used as a drilling fluid at the boring of stiff and hard clayey soils. Clay mud are used when boring soft and loose soils. The preference should be given to flushing mud on the base of bentonite clays, since the properties of these are less influenced by admixtures of sate sea water.

The practical experience of engineering-geological boring describes situations, when the geological problem had been solved and the borehole drilled until the design level only under a permanent control of the delivery and quality of drilling fluid during boring.

4. Some peculiarities of "in situ" methods applied in boreholes

In those intervals of boreholes, where the boring is performed by taking of disturbed samples the sounding of soils is preferably to carry out under conditions of these natural bedding by different traditional "in situ" methods. Considering the lack of time, which is characteristic to the marine boring, the preference should be given to speedy methods of soils borehole testing in their natural state: dynamic sounding by the SPT methods and rotary section by the vane method.

In order to carry out the layer-after-layer borehole sounding of soils by the "in situ" methods, the drilling rig beside the necessary boring equipment should be equipped with one or two kinds of geotechnical devices, and the drilling crew should be skilful enough to apply these.

5. Another methods of marine boring

Besides the traditional methods of engineering-geological marine boring discussed in the current article (i.e., cable boring and rotary core boring), there also are another methods, e.g., the drilling with the transportation of core to the surface by retrievable core barrels without the run out of driving pipes out of the borehole, the boring by submersed drilling rigs etc. These methods can be applied for the borehole boring at sea depths more than 100 m. These methods require complicated drilling equipment and technology and, consequently, the cost of boring is very expensive. So, in the present economical situation, the boring by the removed samplers or submersed drilling rigs seems in expedient for engineering-geological investigations in the water areas of the Baltic Sea.

6. Conclusion

Concluding the current article, it should be emphasized that the engineering-geological boring can be considered not only as a mean to supply (as a core) the data on the composition and properties of soils, but also as a source of information obtained through interpretation the boring process characteristics. The main of these are:

— boring method;
— type of drilling tool;
— penetration rate;
— regime parameters of boring process;
— method and force applied for the casing strings run in/out;
— different borehole troubles, e.g., the cave of borehole walls, the sticking of the drill, the loss of flushing circulation, etc.

In order to truthfully interpret different parameters of the boring process, the borehole should be equipped with corresponding controlling and measuring devices, which allow to read not only the regime parameters (i.e., rotary speed of the drill, axial load, mud pump delivery, etc.), but the following parameters too as well: the penetration rate, the torque, etc. In spite of the variety and permanent perfecting of engineering- geological methods of marine investigations, the drilling of boreholes remains the main method. Its efficiency depends on the correct choice of boring method, drilling equipment, technological parameters of boring regime as well as on the rational combination with borehole sounding of soils by different "in situ" methods.