TRANSNAV
http://www.transnav.eu
the International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 9
Number 4
December 2015

DOI: 10.12716/1001.09.04.16

# Specificity of Geotechnical Measurements and Practice of Polish Offshore Operations

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ABSTRACT: As offshore market in Europe grows faster and faster, new sea areas are being managed and new ideas on how to use the sea potential are being developed. In North Sea, where offshore industry conducts intensive expansion since late 1960s, numerous wind farms, oil and gas platforms and pipelines have been put into operation following extensive research, including geotechnical measurement. Recently, a great number of similar projects is under development in Baltic Sea, inter alia in Polish EEZ, natural conditions of which vary from the North Sea significantly. In this paper, those differences are described together with some solutions to problems thereby arising.

## 1 BALTIC SEA

Baltic Sea in a mediterranean sea of an Atlantic Ocean, situated in its north-eastern part. Enclosed by mainland Europe from south and east and by Scandinavian Peninsula from north and west, it is only connected to the ocean by narrow Danish Straits. It is also very shallow with medium depth of only 55 metres and maximum of less than 460 metres. It can be covered by ice in an extent of up to 45% of its surface area, especially in the northern part: Gulfs of Bothnia and Finland but southern part can also be affected by ice accumulation during severe winters. Geology of the surrounding area was formed mainly during glacial episodes (global cooling and warming) and was further enhanced by effluents from the numerous rivers flowing into it. That created a seabed covered by various kinds of sediments, ranging from loam (east of Bornholm and in Gulf of Gdańsk) through fine-grained sand (Bay of Pomerania) and coarse sands (along the shore) to gravel and stones (Słupsk Bank) - geological conditions are very complex and can vary significantly even in relatively small areas. Each of sea bottom kinds has some characteristic features describing its ability to support nearshore and offshore structures (Kaszubowski, L.J. & Coufal, R. 2008). The Baltic Sea is characterized by little variation in water level, with almost negligible tide range. Sea currents are weak with usual setting of ¼ knot which however can be increased even to 2 knots by gale force winds. Those conditions combined make Baltic Sea resemble a big, navigable lake rather than a sea. Main natural resources include: oil and gas, wind energy, sand and marine organisms.

The specific natural conditions of Baltic Sea have many practical implications. The most important of them is a low salinity of the water, caused by its limited exchange with an ocean, significant inflow of freshwater from the rivers and seabed topography in Danish Straits. Here the salty oceanic water, being heavier than the fresh one, encounters banks and shallow areas and only in certain conditions a great mass of ocean water finds its way to the Baltic Sea. Such phenomenon usually occurs in late Autumn and Winter, the most recent one in December 2014, when as much as 198 cubic kilometres of saline water reached Baltic Sea, making it the third largest inflow ever observed. Ice accretion also contributes to changes in salinity (Mohrholz, V. et alia. 2015). Furthermore, a strong stratification of Baltic Sea water can be observed, with upper layer containing significantly less salt than the lower one with halocline separating them. Shallowness and a relatively low volume of water makes it vulnerable to temperature changes – it resembles a lake in this matter. Sea water temperature varies from 0°C in Winter up to 18°C in Summer.

Years of progress in surrounding countries' agriculture without regard to environment protection, especially in former socialist countries led to enormous accumulation of fertilizers originally used to boost crops ashore. Those now led to rapid growth of marine organisms - especially algae - lack of oxygen in lower layers of the sea and eventually to vast portions of the seabed turning into 'deserts' instead of areas supporting marine life.

To complement an analysis of conditions influencing the geotechnical measurements in Baltic Sea, some attention must be paid to human activity, especially in the past. First of all, Baltic has been used for trade purposes for centuries with some authors dating such activity back to the times of Roman Empire and further to the past. Some underwater investigations led to discovery of settlements dating back to 7000 BC (Fischer, A. 1995), not to mention more recently sunken wrecks of 'Vasa' and 'Wilhelm Gustloff', all of those constituting significant historical and cultural value and can limit human activity in certain areas. Such can also be caused by old chemical weapon, only to mention sulphur mustard, sunk in the Baltic Sea after World War II by various nations. Its quantity is estimated to be around 32 thousand tonnes (Missaien, T. et alia. 2010) and it causes significant risk to marine and human life, especially when tampered with. Areas in which it can be encountered have been identified and shall be avoided by any vessels conducting seabed-related activities, such as anchoring, trawling or construction.

The Baltic Sea is administratively divided into sectors over which each coastal state has a jurisdiction as per UNCLOS – territorial water and exclusive economic zone whichever the case might be. Many of coastal states introduced some elements of spatial planning, covering their areas of responsibility and describing what activities might be performed in those. Some had been excluded from the authorization to perform drilling or any similar activities due to environmental, historical or military reasons.

## 2 GEOTECHNICS

Geotechnical engineering, also referred to as engineering geology, is a scientific discipline of applying geological knowledge to engineering or construction problems. Practically, it can be described as an art of calculating mutual interactions between soil and man-made structures.

Future offshore construction site investigation process can be divided into three parts: desk study, geophysical surveys and geotechnical surveys. In first stage, information about planned development area is gathered from available sources, i.e. environmental reports of scientific literature and analysed. It is then decided what range of geophysical research shall be performed *in situ*. This includes: seismic survey, precise bathymetry, sub-bottom acoustic profiling and use of underwater vehicles to investigate areas of particular consideration. Results of those are complemented by geotechnical surveys consisting of seabed sampling, drilling and laboratory soil testing.

In offshore geotechnical engineering, more factors apply and it is generally more difficult to perform surveys than ashore. Reasons for this are:

– possible existence of ocean currents and waves, generally stronger wind over sea area than on the land – which combined create significant loads on the structures;
– other natural conditions not present in onshore environment, e.g. presence of hydrates;
– planned structures reach hundreds of meters in height which requires their foundations to be particularly well-designed and installed;
– hydroacoustics being virtually the only method of remote sensing in sometimes hundreds-of-meters deep water;
– necessity of employing dedicated research ships with highly sophisticated equipment and well-paid crews (including divers) which increases costs of such operation.

## 3 GEOTECHNICAL MEASUREMENTS IN BALTIC SEA - CONDITIONS

As a consequence of above described conditions specific for Baltic Sea, there are significant differences between the way the geotechnical measurements are being performed in the open seas and in the Baltic.

Firstly, as a Baltic Sea bathymetry was surveyed extensively by coastal states, major hazards for surface navigation and other activities have been identified and are quite well-known. However, a risk of encountering of II World War sea mines or wrecks still exists and must be taken into account. A wrecked aircraft carrier 'Graf Zeppelin' was found, for instance, accidentally during routine survey of B3 oil field in Polish EEZ.

When carrying on a hydroacoustic survey, it is characteristic for a Baltic Sea that the most important factor in such activities, which is sound speed, varies significantly depending on changes in sea water's salinity and temperature. Those in turn, highly depend on air temperature (varying seasonally), ice coverage, volume of water inflows from rivers and North Sea. Furthermore, stratification of water into two layers: upper (less saline) and lower (more saline) creates additional difficulties. To cope with such, sound velocity profile (SVP) in water must be monitored and proper corrections applied. Moreover, as most of hydroacoustic devices, i.e. echosounder or sonars are designed to be used in seas of approximately 35 PSU salinity, lower salinity causes their range to decrease (Grelowska, G. & Kozaczka, E. 2005).

As multibeam echosounders (MBES) and side-scan sonars (SSS) are widely considered as very useful in imaging of the seabed itself (Gerwick, B.C.Jr. 2000), there are two main methods of its structure remote investigation: seismoacoustics and non-linear acoustics. First one is based on creating strong pulse of acoustic wave which penetrates the seabed and – reflected by interphase boundary between different layers of sediments (or other characteristic objects, i.e. buried shipwrecks) is then received by hydrophones, placed on state-of-the-art devices towed abaft of seismic vessels called 'streamers' as can be seen in Figure 1. This method enables large areas to be surveyed in a time, cost of such operation being enormous due to a high charter rates for specialized vessels. It is therefore only practicable in large offshore projects.

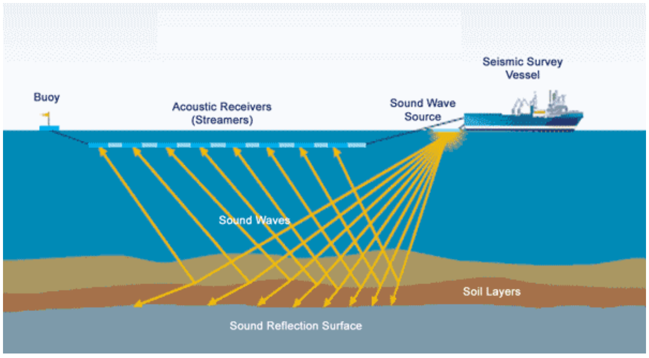


Figure 1. Principle of seismoacoustic survey. http://captainsvoyage-forum.com/. Retrieved 15-06-2015.

A parametric acoustics method enables small boats to survey a seabed in relatively small areas using a single but modified echosounder. Here, an effect of interaction between two high frequency acoustic waves of a small differential frequency between them allows for creation of a secondary hydroacoustic wave that enables good seabed penetration and vertical resolution simultaneously. Detailed description of this method and results of survey utilising it can be found in (Grelowska, G. & Kozaczka, E. 2008). A major disadvantages of this method is that a sound velocity in a kinds of sediments being likely to encounter during a survey must be known *a priori*, and as one can never know what kind of seabed lies below an upper-most layer – parametric sounding can only be used in conjunction with old-fashioned core sampling. Knowledge possessed from core sampling is then used for sediments' layers acoustic impedance estimation. Poor efficiency of secondary wave is also an issue (Lurton, X. 2010). All those factors combined make parametric sounding useful in surveying relatively small areas with shallow water, geological structure of which is roughly known, like Baltic Sea for instance.

After a geophysical survey is completed, designers of a future oil field or offshore wind farm possess some knowledge regarding its ability to support structures. However, coastal states require more detailed investigation to be performed in the exact locations of i.e. wind turbines. For example, Polish Ministry of the Environment's regulations rule that for each and every wind turbine, a core penetration test (CPT) must be carried out (or under each of jacket structure legs). Furthermore, core sample drilling must be performed in each of future wind farm's corners and in its central part and samples acquired are then tested in the laboratory against its moisture content, dry density, particle specific gravity, particle size distribution, Atteberg limits and carbonate content etc., sometimes also particle mineralogy and geological classification (X-ray testing) (Randolph, M. et alia. 2005). Those requirements can be more stringent whenever deemed necessary. Apart from obvious differences in the way a wind farm construction project is developed in onshore and offshore environments, a requirements concerning site investigation are more strict in the latter case due to an unstable nature of seabed sediments being a highly unpredictable environment. Hydration of seafloor creates major concern and sometimes can even cause difficulties in determining where exactly lies the boundary between water and seabed.

## 4 DAY-TODAY OPERATIONS IN POLISH EEZ

Lotos Petrobaltic, member of partly state-owned Lotos Group, is the only entrepreneurship in Polish EEZ having licenses for oil and gas exploration (Fig. 2) and one of the most active ones in terms of geological and geotechnical surveys. It operates two drilling platforms, same number of exploration rigs, two AHTSs and guard vessels, oil tanker and a research vessel 'St. Barbara' (Fig. 3). It is also an owner of a thermal power plant near Władysławowo in a northernmost part of Poland. The company itself was created as a joint venture by Soviet Union, German Democratic Republic and Polish People's Republic in late 1960s. Most of field development projects have been ever since conducted by its employees without significant support from oil majors which led to the formation of highly qualified team of specialists. Geotechnical measurements, the preliminary stages of field development were conducted from the deck of 'St. Barbara' (2324 GT, app. 80 meters long, in operation since 1977). She is or may be equipped (according to actual operational needs) with:

- Drilling rig;
- Down-hole penetrometer;
- Vibrocorer;
- Moonpool;
- Cesium magnetometer;
- Multibeam echosounder;
- Side-scan sonar;
- Seismoacoustics equipment;
- USBL underwater navigation system;
- Remotely Operated Vehicles (ROVs).

Most notable projects conducted by 'St. Barbara' are: survey of future gas pipeline track from B3 oil field to Władysławowo, bathymetrical and magnetometer surveys in the oil fields, CPTs of planned wind farms, core sampling in future drilling sites etc. She also took a part in extraction operation of a Douglas A-20 aircraft wreck from the seabed.

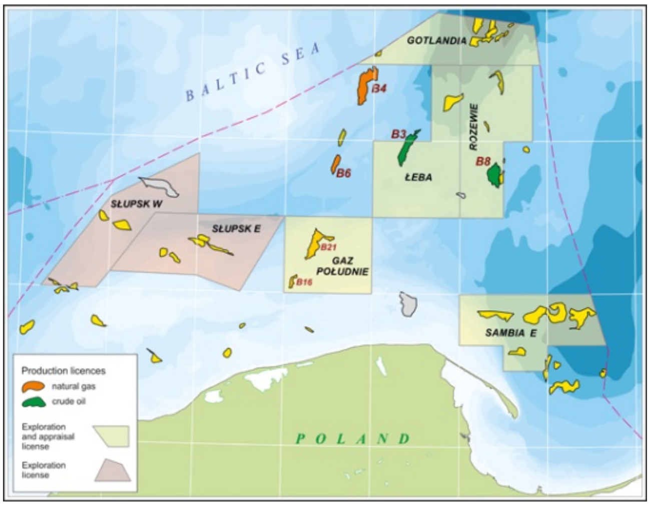


Figure 2. Hydrocarbon production licenses of Lotos Petrobaltic. http://www.lotos.pl/ Retrieved 05-06-2015.

Figure 3. Research vessel 'St. Barbara'. http://www.lotos.pl/ Retrieved 05-06-2015.

It is a common practice for this vessel to conduct a complex geotechnical survey of a particular areas, ranging from initial bathymetric soundings using multibeam echosounder, then more detailed scanning by a towed side-scan sonar. Those two surveys can only provide information regarding seabed's surface which makes additional tests necessary. Seismoacoustic methods can be applied but their great disadvantage is that even if a big anomaly is found – it is difficult to determine whether it is a natural feature or of a human origin (the latter being generally more dangerous as it could be explosive, chemical weapon etc.). That is why magnetometer scanning is performed and in case of any magnetic anomalies being found – ROV investigation follows, which enables for some detailed view. ROVs are equipped with digital cameras and short-range sonars. When at this stage the site is considered clear and deemed safe for construction of offshore structures, a final analysis is carried out which includes CPT tests and core sample drilling. Samples obtained this way or by a grab can be analysed in an on-board laboratory. In an oil rig's case, CPT is conducted under each of future structure's legs and drilling to approximately 30 m into the seafloor takes place in the exact position where future borehole is planned. For a pipeline, CPTs are done along its route in a distance of 200-300 meters one from another and a drilling for one in three CPTs' positions. All those surveys combined give a good information regarding bathymetry, unexpected objects lying on the seafloor and its geological structure. Proper design, quality control during manufacture process and thorough site investigation creates condition for a safe operation of a structure in each stage of its life, taking into account factors such as: settling, dynamic loads, soil liquefaction and erosion and reducing geotechnical hazard.

Typical Detection Range For Common Objects

| | | |
|---|---|---|
| 1. | Ship 1000 tons | 0.5 to 1 nT at 800 ft (244 m) |
| 2. | Anchor 20 tons | 0.8 to 1.25 nT at 400 ft (120 m) |
| 3. | Automobile | 1 to 2 nT at 100 ft (30 m) |
| 4. | Light Aircraft | 0.5 to 2 nT at 40 ft (12 m) |
| 5. | Pipeline (12 inch) | 1 to 2 nT at 200 ft (60 m) |
| 6. | Pipeline (6 inch) | 1 to 2 nT at 100 ft (30 m ) |
| 7. | 100 KG of iron | 1 to 2 nT at 50 ft (15 m) |
| 8. | 100 lbs of iron | 0.5 to 1 nT at 30 ft (9 m) |
| 9. | 10 lbs of iron | 0.5 to 1 nT at 20 ft (6 m) |
| 10. | 1 lb of iron | 0.5 to 1 nT at 10 ft (3 m) |
| 11. | Screwdriver 5 inch | 0.5 to 2 nT at 12 ft (4 m) |
| 12. | 1000 lb bomb | 1 to 5 nT at 100 ft (30 m) |
| 13. | 500 lb bomb | 0.5 to 5 nT at 50 ft (16 m) |
| 14. | Grenade | 0.5 to 2 nT at 10 ft (3 m ) |
| 15. | 20 mm shell | 0.5 to 2 nT at 5 ft (1.8 m) |

Figure 4. Typical detection range of cesium magnetometer. M-882 Magnetometer specification. Geometrics, Inc.

One of the biggest challenges in conducting the above tests is a precise navigation since 'St. Barbara' is not equipped with a dynamic positioning system. It is a particularly difficult task during magnetometer surveys as an instrument itself is towed behind the vessel's stern and must be located within 2.5 m range from a pre-planned profile it should follow in order to detect the anomalies. Furthermore, the sensor must be positioned approximately 3 to 7 meters above the seabed (4 meters as an optimum) by operating towing winch. If one considers a 200 or even 300 meters long umbilical connecting the device to the ship, influence of wind, waves and current and a navigator's ability to control the vessel only by using rudder and propellers, it is truly a masterpiece of navigation. Vessel's position and course are provided by GPS with differential corrections received from DGPS reference station in Rozewie, Poland. Furthermore, position of a magnetometer or side-scan sonar in relation to the ship is measured by Ultra Short Base Line (USBL) hydroacoustic navigation system and can be imposed on a map showing profiles. Entire operation is controlled by a Qinsy software developed by QPS BV. Even if all data gathered by echosounder, DGPS, USBL, towline length sensor etc. are mutually consistent (which not always must be the case), it is still an issue to determine whether an anomaly found indicates existence of a small object lying on the seafloor or a bigger one buried in it. Typical detection range of cesium magnetometer is presented in a Figure 4.

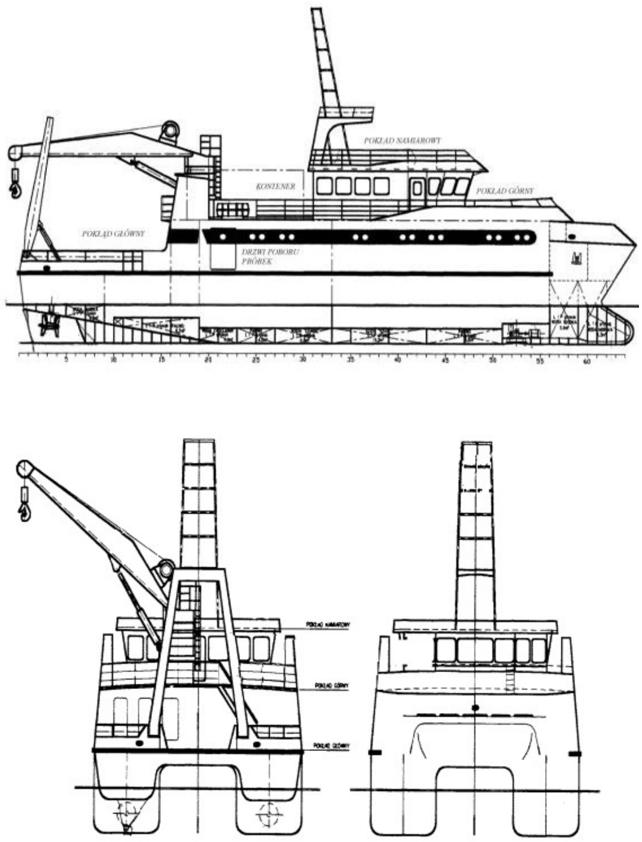


Figure 5. Layout of r/v "Imor'. http://www.im.gda.pl/. Retrieved 10-06-2015.

Another important branch of geotechnical measurements in Polish EEZ refers to the nearshore areas: ports, river estuaries, shallow water for instance. Here, most of works is connected to ports development projects like construction of a new oil and container terminals in Gdańsk, gas terminal in Świnoujście, nuclear power plant in Choczewo and others. Surveys are conducted by numerous motor boats operated by private companies and by r/v 'Imor' (Fig. 5), a catamaran owned by Maritime Institute in Gdańsk, which is equipped with: MBES, SSS, USBL, ROV, vibrocorer, magnetometer, boomer and DP class I. Due to relatively small draught of 2.3 meters, she is capable of conducting complex research even in quite shallow areas and may be supported by other vessels operated by the Institute of even greater operational abilities in a nearshore sector.

## 5 CURRENT OFFSHORE ACTIVITY IN POLISH EEZ

As of June 2015, major activities taking place in Polish Exclusive Economic Zone are: hydrocarbon production and distribution (by shuttle tanker and gas pipeline), seabed resources exploitation (aggregates, i.e. sand), construction of objects aiming in coast protection, construction of new container and oil product terminals and investigations on the sites of projects at different stages of development, of which the most notable are: wind farms, Mierzeja Wiślana crosscut, CNG terminal in Bay of Puck, new gas pipeline to connect B8 oilfield with power plant in Władysławowo.

The company being the most active in this sector is Lotos Petrobaltic, member of Grupa Lotos. With annual production of approximately 1.2 million boe only from its license in Polish EEZ (B3 field, Fig. 6), it is one of the biggest hydrocarbon production companies in the country, supplying oil and gas to various customers, including a refinery in Gdańsk. In a few months to come, it is planning to commence a production in B8 field with preparations for starting up a tight gas production in further areas.

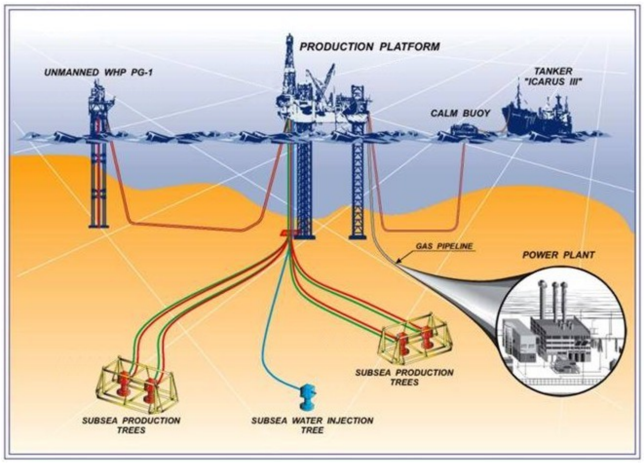


Figure 6. Layout of B3 oilfield infrastructure. http://www.lotos.pl/ Retrieved 05-06-2015.

A branch of offshore economy that many hope to develop in a near future is wind farming, particularly when taking European Union environmental policy into consideration. Special planning process allowed maritime administration to identify few areas in which such projects might be developed by private companies and a number of licenses has been issued, however there are still administrative, technical and fundraising problems to be solved. First electricity is expected to be produced in south-eastern Baltic in next decade.

## 6 CONCLUSIONS

However underdeveloped Polish offshore sector can be regarded, especially comparing it to highly innovative and profitable activities in not so distant North Sea, it is clear that capabilities of companies engaged in offshore investigation business exceed operational needs of the clients. The obstacles to the development of Polish offshore sector are not the lack of proper equipment or personnel being not enough qualified, but the administrative, legislative and sometimes lack of assets among the enterprises interested in nearshore and offshore activities, including oil and tight gas exploration, wind energy etc. Research, investigation and measurements of virtually any kind can be carried out by numerous local companies, even in conditions specific for Baltic Sea, provided the weather permits.

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