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Methodology for oil rig critical infrastructure network safety and resilience to climate change analysis

Keywords

critical infrastructure, oil ring, network, oil and gas pipeline infrastructure, climate change, resilience

Abstract

The paper explores the terminology which refers to oil rigs critical infrastructure network. Moreover, there are presented definitions of oil rigs critical infrastructure network interconnections and interactions within the Baltic Sea region. The impact of changing climate/weather conditions on the critical infrastructure and its operation are also considered.

1. Introduction

To ensure compatibility in this paper and across the next papers concerned with this topic, the common "working terminology" should be fixed. Offshore oil and gas exploitation is a stable growing energy sector, especially for the South – Eastern Baltic Region. But this is also a challenge for developers, statutory regulators including economy, environment and maritime administration, because of the fact that offshore oil and gas exploration and exploitation rigs together with the auxiliary servicing create navigational and environmental hazards. Based on the actual investments in Polish and Kalingrad's Region, this article will collect the definitions concerned with oil rings critical infrastructure network interconnections and interactions with the other Baltic Sea region critical infrastructure networks. From the ecological point of view all mentioned infrastructure networks create the impact on the given area [8].

2. State of art

Before the considerations on critical infrastructure at Baltic Sea Region taxonomy, we refer to definitions of selected basic notions concerned with critical infrastructures and climate and weather impacts on their safety included in the report [6].

At first, we have to define the term concerned with critical infrastructures terminology. The *Baltic Sea infrastructure*, which is an industry and other system (e.g. drilling platforms, gas and oil pipelines, wind farms, telecommunication systems, waterways, maritime transport, ports with their intermodal connections), performing activities within the Baltic sea area. These activities may be: *gas and oil production, storage and transportation*. A critical infrastructure characterized by the production and holding facilities for natural gas, crude and refined petroleum, and petroleum-derived fuels, the refining and processing facilities for these fuels and the pipelines, ships, trucks, and rail systems that transport these commodities from their source to systems that are dependent upon gas and oil in one of their useful forms [14].

Primary energy (also referred to as *energy sources*) is the energy embodied in natural resources (e.g., coal, crude oil, natural gas, uranium) that has not undergone any anthropogenic conversion. It is transformed into secondary energy by cleaning (natural gas), refining (oil in oil products) or by conversion into electricity or heat. When the secondary energy is delivered at the end-use facilities it is called final energy (e.g., electricity at the wall outlet), where it becomes *usable energy* (e.g., light). Daily, the sun supplies large quantities of energy as rainfall, winds, radiation, etc. Some share is stored in biomass or rivers that can be harvested by men. Some share is directly usable such as daylight, ventilation or ambient heat.

2.1. Oil rigs critical infrastructure network terminology

Offshore platforms are huge steel or concrete structures used for the exploration and extraction of oil and gas from the earth's crust. The *offshore oil and gas platforms* are generally made of various grades of steel, from mild steel to high-strength steel, although some of the older structures were made of reinforced concrete. Offshore platforms have many uses including oil exploration and production, navigation, ship loading and unloading, and to support bridges and causeways. They are very heavy and are among the tallest manmade structures on the earth. The oil and gas are separated at the platform and transported through pipelines or by tankers to shore. *Offshore structures* are designed for installation in the open sea, lakes, gulfs, etc., many kilometres from shorelines. These structures may be made of steel, reinforced concrete or a combination of both. *Rigs* are the structures used for the drilling of the wells and platforms are installed in the field for extracting oil/gas operation [11].
The *oil rigs critical infrastructure network* is defined as more than one mining platform unconnected technologically, but organizationally linked by the operator, operators association or *jurisdiction* (the legal power to make decisions and judgments [2]). Within the category of steel platforms, there are various types of structures, depending on their use and primarily on the water depth in which they will work. Different types of offshore oil rigs and platforms are used depending on the offshore oil/gas field water-depth and situation. Main types of rigs and platforms are briefly explained as follows. *Drilling* for natural oil/gas *offshore*, in some instances hundreds of miles away from the nearest landmass, poses a number of different challenges from drilling onshore. With drilling at sea, the sea floor can sometimes be hundreds of meters below sea level. Therefore, while with *onshore drilling* the ground provides a platform from which to drill, at sea an artificial drilling platform must be constructed [11].

2.1.1. Offshore oil rig and platform types [11]

There are two types of offshore drilling rings/platforms. The first type is *moveable offshore drilling rigs* that can be moved from one place to another and the second type is the *fixed rigs/platforms*.

Drilling barges are used mostly for inland, shallow water drilling. This typically takes place in lakes, swamps, rivers, and canals. They are large, floating platforms, which must be towed by tugboat from location to location. Suitable for still, shallow waters, drilling barges are not able to withstand the water movement experienced in large open water situations.
Jack up rigs are similar to drilling barges, with one difference. Once a jack up rig is towed to the drilling site, three or four 'legs' are lowered until they rest on the sea bottom. This allows the working platform to rest above the surface of the water, as opposed to a floating barge. However, jack up rigs are suitable only for shallower waters, as extending these legs down too deeply would be impractical. This rig type can only operate to 150 m in the depth of water. These rigs are typically safer to operate than drilling barges, as their working platform is elevated above the water level.
Submersible rigs, also suitable for shallow water, are like jack up rigs in that they come in contact with the ocean or lake floor. These rigs consist of platforms with two hulls positioned on top of one another. The upper hull contains the living quarters for the crew, as well as the actual drilling platform. The lower hull works much like the outer hull in a submarine – when the platform is being moved from one place to another, the lower hull is filled with air – making the entire rig buoyant. When the rig is positioned over the drill site, the air is let out of the lower hull, and the rig submerges to the sea or lake floor. This type of rig has the advantage of mobility in the water; however, once again its use is limited to shallow water areas.
Semi-submersible platforms / rigs are the offshore oil rigs that have a floating drill unit includes columns and pontoons that, if flooded with water, will cause the pontoons to submerge to a depth that is predetermined. These rigs are the most common type of offshore drilling rigs, combining the advantages of submersible rigs with the ability to drill in deep water. Semi-submersible rigs work on the same principle as submersible rigs; through the 'inflating' and 'deflating' of its lower hull. The rig is partially submerged, but still floats above the drill site. When drilling, the lower hull, filled with water, provides stability to the rig. Semi-submersible rigs are generally held in place by huge anchors, each weighing upwards of ten tons. These anchors, combined with the submerged portion of the rig, ensure that the platform is stable and safe enough to be used in turbulent offshore waters. They can also be kept in place by the use of dynamic positioning. Semi-submersible rigs can be used to drill in much deeper water than the rigs mentioned above. Now

with a leap in technology, depths of up to 1800 m can be achieved safely and easily. This type of rig platform will drill a hole in the seabed and can be quickly moved to new locations.

Drill ships are the ships designed to carry out drilling operations. These boats are specially designed to carry drilling platforms out to deep-sea locations. A typical drill ship will have, in addition to all of the equipment normally found on a large ocean ship, a drilling platform and derrick located on the middle of its deck. In addition, drill ships contain a hole called a "*moonpool*", extending right through the ship down through the hull, which allows for the drill string to extend through the boat, down into the water. This offshore oil rig can drill in very deep waters. Drill ships use 'dynamic positioning' systems and are equipped with electric motors on the underside of the ship's hull, capable of propelling the ship in any direction. These motors are integrated into the ships computer system, which uses satellite positioning technology, in conjunction with sensors located on the drilling template, to ensure that the ship is directly above the drill site at all times.

In certain instances, in shallow water, it is possible to physically attach a *fix platform* to the sea floor. This is what is shown above as a fixed platform rig. The 'legs' are constructed of concrete or steel, extending down from the platform, and fixed to the seafloor with piles. With some concrete structures, the weight of the legs and seafloor platform is so great, that they do not have to be physically attached to the seafloor, but instead simply rest on their own mass. There are many possible designs for these fixed, permanent platforms. The main advantages of these types of platforms are their stability; as they are attached to the sea floor, there is limited exposure to movement due to wind and water forces. However, these platforms cannot be used in extremely deep water; it simply is not economical to build legs that long.

Template (jacket) platforms are the fixed platforms mainly consist of jacket, decks and piles (*Figure 2*).

Different types of fixed offshore platforms are shown in *Figures 1-3*.

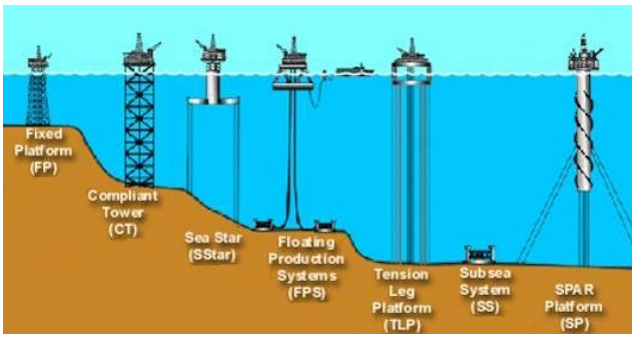


Figure 1. Comparison of height of different types of offshore fixed platforms [1]

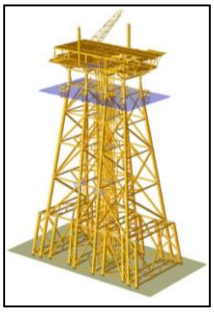
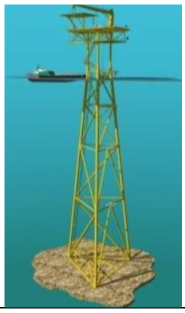
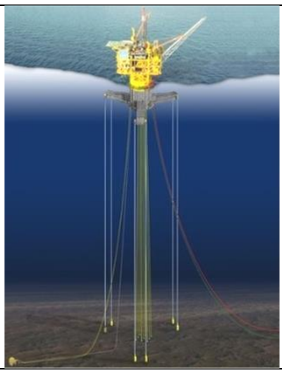


Figure 2. Offshore template (jacket) platform [10]

Compliant towers are much like fixed platforms. They consist of a narrow tower, attached to a foundation on the seafloor and extending up to the platform. This tower is flexible, as opposed to the relatively rigid legs of a fixed platform. The flexibility allows it to operate in much deeper water, as it can absorb much of the pressure exerted on it by the wind and sea. Despite its flexibility, the compliant tower system is strong enough to withstand hurricane conditions.

Sea star platforms are like miniature tension leg platforms. The platform consists of a floating rig, much like the semi-submersible type discussed above. A lower hull is filled with water when drilling, which increases the stability of the platform against wind and water movement. In addition to this semi-submersible rig, however, Sea star platforms also incorporate the tension leg system employed in larger platforms. Tension legs are long, hollow tendons that extend from the seafloor to the floating platform. These legs are kept under constant tension, and do not allow for any up or down movement of the platform. However, their flexibility does allow for side-to-side motion, which allows the platform to withstand the force of the ocean and wind, without breaking the legs off. Sea star platforms are typically used for smaller deep-water reservoirs, when it is not economical to build a larger platform. They can operate in water depths of up to 1000 m.

Floating production systems are essentially semi-submersible drilling rigs, as discussed above, except that they contain petroleum production equipment, as well as drilling equipment. Ships can also be used as floating production systems. The platforms can be kept in place through large, heavy anchors, or through the dynamic positioning system used by drill ships. With a floating production system, once the drilling has been completed, the wellhead is actually attached to the seafloor, instead of up on the platform. The extracted petroleum is transported via risers from this wellhead to the production facilities on the semi-submersible platform. These production systems can operate in water depths of up to 1800 m.

			
Fixed platform	Sea star platform	Subsea system	Floating production system

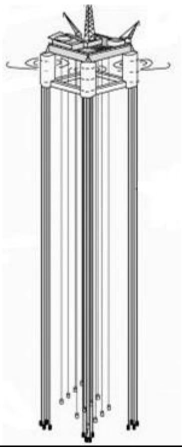
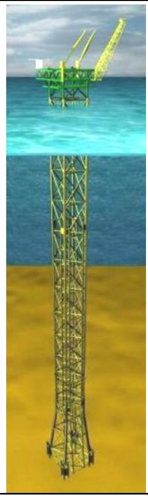
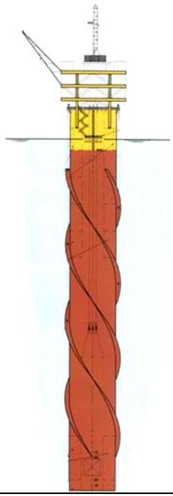
		
Tension leg platform	Compliant tower	Lateral catenary system (SPAR)

Figure 3. Offshore production platforms of oil extraction from sea flow [1]

Tension leg platforms are larger versions of the Seastar platform. The long, flexible legs are attached to the seafloor, and run up to the platform itself. As with the Seastar platform, these legs allow for significant side to side movement (up to 6 m), with little vertical movement. Tension leg platforms can operate as deep as 2100 m.

Subsea production systems are wells located on the sea floor, as opposed to at the surface. As in a floating production system, the petroleum is extracted at the seafloor, and then can be 'tied-back' to an already existing production platform. The well can be drilled by a moveable rig and instead of building a production platform for that well, the extracted oil and natural gas can be transported by a riser or even undersea pipeline to a nearby production platform. This allows one strategically placed production platform to service many wells over a reasonably large area. Subsea systems are typically in use at depths of 2100 m or more, and do not have the ability to drill, only to extract and transport.

Spar platforms are among the largest offshore platforms in use. These huge platforms consist of a large cylinder supporting a typical fixed rig platform. The cylinder however does not extend all the way to the seafloor, but instead is tethered to the bottom by a series of cables and lines. The large cylinder serves to stabilize the platform in the water, and allows for movement to absorb the force of potential hurricanes.

2.1.2. Offshore construction project stages [11]

Similar to the other fields of activities, the offshore platform construction services can be provided on a *turn-key basis*, i.e. covering investment feasibility studies, basic and detailed design and procurement, installation of steel structures and equipment, and commissioning. All or any of the above listed work stages can be performed under the supervision of an independent certifying authority followed by the issue of a class certificate. Basically an *offshore platform construction project* includes the following phases:

- Investment feasibility studies;
- Construction site survey including diving inspections of installation locations;
- Conceptual, basic and detailed design;
- Platform element strength calculations;

- Design approval by the regulating authorities;
- Procurement;
- Fabrication of steel structures;
- Preparation of platform elements transportation and offshore installation procedures;
- Load out, transportation and installation operations;
- Commissioning.

Usually, fabrication of steel structures for such facilities as offshore platforms is carried out at locations significantly remote from the installation site. Transportation of such large-sized elements is a complicated operation requiring a special design, with structural strength calculations for the transportation conditions. Since offshore construction operations require prompt response and coordination of design, engineering, material or equipment supply and steel structure fabrication activities, some of them are often performed simultaneously due to the tight scheduling requirements.

2.2. Climate change terminology

Any offshore structure can be subject to various loads like [12]:

- Permanent loads;
- Operating loads;
- Environmental loads;
- Construction, loads;
- Accidental loads.

Permanent loads involve the construction loads like the weight of the entire structure, ballast systems, weight of machinery, accommodation and other equipment. For members below the waterline it involves the hydrodynamic forces and also the hydrostatic pressure forces like the buoyancy and pressure loads. On the other hand, *operating loads* involve the loads subservient under the ongoing operations like loading and unloading, drilling, mooring operations, additional loads generated by cranes and derricks. They take into account impact, momentum, vibration, slosh dynamics, material fatigue etc. Also involves weight of manpower, equipment, storage like the crude oil which has been extracted, life-support systems and so on.

Environmental loads may be subdivided into the various categories:

- *Wind loads.* These loads act on the above portion of the platform by virtue of the blowing winds of varying extremities. For instance during regular sea breeze, this aspect is not to be taken care of but where the situation is graver like in case of gale storms ruffling the seas hither and tither, the consequent aftermath on the structure is a pressing concern. Especially when height to width ratio is more than 5, the cyclic wave loads due to the induced vortex flow has to be taken seriously into account. Structural members have to be designed such that they can withstand longitudinal loads with greater endurance than transverse for higher slenderness ratios. Snowfall or frost heaving which is a phenomenon of abnormal swelling of soil during cold temperature may pose a potential threat to the structure.
- *Temperature and atmospheric pressure loads* cause thermal expansion, contraction and sometimes deformation. Suppose a platform amidst the cold during winters, have to endure high amount of low pressure and temperature vagaries while somewhere else during summer, it may be subjugated to high temperatures, pressures, humidity or warm underwater currents sometimes leading to expansion.
- *Seismic activities* often take place in the underwater oceanic plates where they drift, vibrate, intimate or recede away from each other.
- *Lateral loads* from soil, groundwater or seabed may endanger their piling or foundations hence often aggravated by seafloor scour.
- *Wave loads* are the most prominent terror that poses threat to all offshore structures. The waves are basically gravity contact forces energy transfer phenomenon that occurs due to wind pressure on the water surface with a given force or speed, duration and *fetch* (distance over which the wind blows). Waves may be one of the following types:
  - internal;
  - external;
  - normal sea waves;
  - swells;
  - breaking waves.

  The preliminary design of any offshore structure takes care of its resilience to the waves it faces.
- *Marine growth* accumulates on the submerged surfaces, increasing the wave forces through higher drag forces and surface roughness.

Construction / installation loads. These are temporary loads that arise during the fabrication or erection of the platform or its components. During fabrication erection lifts of various structural components generate lifting forces, while in installation phase, forces are generated during platform load out, transportation to the site, launching and upending, as well as lifts related to installation.

According to [4], *accidental loads* are those which may occur as a result of pure accident or exceptional circumstances. The worst instances may be collision, breakage, flooding of buoyant parts, fire or explosion. Since the majority of offshore platforms deal with oil, gas, petroleum which are inflammable storage and productions needs to be with umpteen care. Evacuation measures need to be implemented in case of the unwarranted [12]. *Accidental Limit States* (ALS) ensure that the structure resists accidental loads and maintain integrity and performance of the structure due to local damage or flooding, whereas *fatigue* means degradation of the material caused by cyclic loading [5].

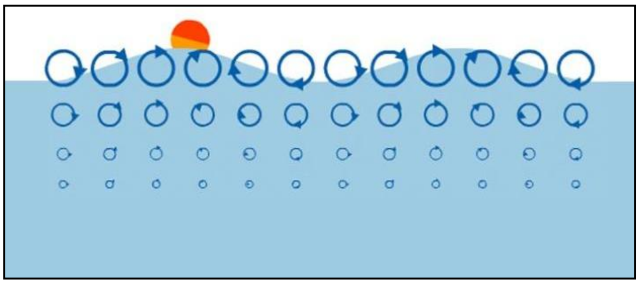


Figure 4. Wave disturbances in water surface [12]

2.3. Resilience terminology

According to [5], the *DNV offshore standards* are documents which present the principles and technical requirements for design of offshore structures. The standards are offered as DNV's interpretation of engineering practice for general use by the offshore industry for achieving safe structures. A *limit state* is a state beyond which the structure no longer satisfies the requirements. The following categories of limit states are of relevance for structures [5]:

- ULS - *ultimate limit states* - corresponding to the ultimate resistance for carrying loads;
- FLS - *fatigue limit states* - related to the possibility of failure due to the effect of cyclic loading;
- ALS - *accidental limit states* - corresponding to damage to components due to an accidental event or operational failure;
- SLS - *serviceability limit states* - corresponding to the criteria applicable to normal use or durability.

The design and analysis of offshore platforms must be done taking into consideration many factors, including the following important parameters [11]:

- Environmental (initial transportation, and in-place 100-year storm conditions);
- Soil characteristics;
- Code requirements;
- Intensity level of consequences of failure.

As it has been dramatically demonstrated in a variety of accidents, offshore oil rigs activities entail the hazard of an *accident* (an intended event or injury resulting in victims, loss or destruction of property or environmental damage [2]) with potentially severe consequences to the life and health of workers, pollution of the environment, direct and indirect economic losses, and deterioration of the security of energy supply. The main hazards include:

- fire, after ignition of released hydrocarbons;
- explosion, after gas release, formation and ignition of an explosive cloud;
- oil release on sea surface or subsea.

The consequences of accidents should be clearly distinguished from emissions and pollution during normal operation activities, even if these activities are extended through the whole life-cycle of an installation. While the latter (*pollution from normal operation*) results in relatively small quantities of pollutants ending in the sea during long periods, the accidental events result in release of huge quantities of hydrocarbons and pollutants discharged uncontrolled in the sea during relatively short periods. Normal operation discharges are regulated by international conventions, while accidental risks are regulated by national legislation or the proposed *European legislation* on offshore safety. While consequences of potential accidents to life and health of the workers, pollution of the environment and especially of the neighbouring coastal areas, and direct economic damage are direct effects and can easily be assessed, indirect economic damage and effects of the accident to security of energy supply are more difficult to be assessed. The *indirect economic damage* may include losses from the fall in the price of the shares of the company after the accident. The impact on security of energy supply can be understood by considering the ban of certain exploration activities in some countries [3].

3. Oil rigs critical infrastructure network at Baltic Sea region taxonomy

3.1. Oil rigs critical infrastructure network taxonomy

Energy production and transportation in, on or across the Baltic Sea has fossil and renewable dimensions. Oil is extracted from four oil platforms, all of them being located in the south-eastern part of the Baltic Sea. Three of the platforms are in Polish waters, and one is in Russian waters. *The Baltic Oil Rig Critical Infrastructure Network* (BORCIN) is composed of 4 oil rigs, 3 of them operating in Polish EEZ and 1 operating in Russia EEZ. The Polish part and the Russian part of the BORCIN work separately and independently. The Polish part of the BORCIN is cooperating with several tankers that are the components of the *Baltic Shipping Critical Infrastructure Network* (BSCIN) and with 1 gas pipeline that is the component of the *Baltic Gas Pipeline Critical Infrastructure Network* (BGPCIN). The Russian part of the BORCIN is cooperating with one oil pipeline that is the component of the *Baltic Oil Pipeline Critical Infrastructure Network*

(BORCIN) [8].

The *unmanned platform* is small platform designed to be operated remotely under normal conditions, only to be visited occasionally for routine maintenance or well work [13]) PG-1 and Baltic Beta do not form an oil rigs critical infrastructure network, but the Baltic Beta and Petrobaltic do form a network. Polish platforms do not form a network with the Russian platform; Norwegian platforms form a network within the area because of the jurisdiction and NOFO (*Norwegian Clan Seas Association for Operating Companies*). On the Baltic Sea there can be also distinguished the following oil rigs critical infrastructure networks: BP network, Chevron network, Conoco-Philips network, Exon Mobil network, Shell network, Statoil network, Total network. Various oil rigs locations in the Baltic Sea area are presented in *Figure 5*.

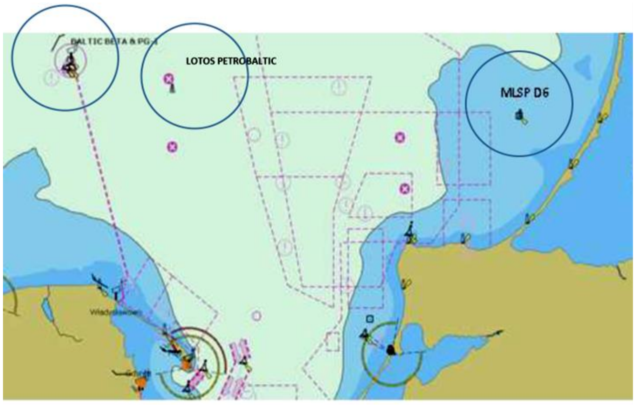


Figure 5. Oil rigs locations in the Baltic Sea area

Lotos Petrobaltic S.A. is the Polish company that explores and produces oil, gas and hydrocarbons on the Baltic Sea. Fields are located in the eastern part of the Polish Exclusive Economic Zone. The company owns three production rigs "Baltic Beta", unmanned facility "PG-1" located on the field B3 and "Lotos Petrobaltic" on the field B8 [8].

The company is responsible for implementing its strategic objectives related to exploration for and production of crude oil and natural gas. The company operates in the Polish offshore area covering approximately 29 thousand km2. LOTOS Petrobaltic holds licenses for exploration and appraisal of hydrocarbon reserves, which cover seven areas totalling over 7,100 km2, situated in the eastern part of the Polish offshore area. The total quantities of natural gas reserves amount to as much as 4 billion cubic metres. The company has also been awarded oil production licenses relating to the B3, B4, B6 and B8 fields. The B3 field is currently in production, while the B8 field has already started exploration [9].

The *technological exploitation process* consists of two stages [8]:

- Stage one – transportation of oil from wells, through the pipelines to the main processing oil rig – Baltic Beta. The unmanned oil rig PG-1 is used as an auxiliary exploitation facility, with the exploitation well placed on the platform.
- Stage two – transportation of oil from Baltic Beta oil rig, through the flexible pipeline, placed on the sea bottom to the anchored mooring buoy and through this handling facility to the oil tanker Icarus III, which plays the role of a temporary storage, with capacity of 40.000 tonnes. The technological scheme is showed on the picture below.

Lukoil's Kravtsovskoye (D-6) *oil field* is located in the Russian sector of the Baltic Sea. It was discovered in 1983 at a distance of 22.5 km from the coast of Kaliningrad region. The depth of the water is 25m to 35m. The initial exploration drilling followed a *geological survey by Lukoil-Kaliningradmorneft*. This confirmed that oil reserves of the C1+C2 categories at Kravtsovskoye were estimated to be 21.5 million tonnes. Recoverable reserves were put at 9.1 million tonnes. The development is being carried out from an offshore ice-resistant stationary complex manufactured at Kaliningradmorneft steelworks. This is the first production platform in the Russian offshore sector to be designed and manufactured domestically. It has been designed to resist 0.3m-thick ice and survive 9m storm waves [7]. The exploitation of the rig differs slightly from Lotos Petrobaltic one because both the oil and oiled water are transported through over 50 km long pipeline.

3.2. Climate change terminology

A set of *hydrological parameters* to be measured includes [8]:

- seawater temperature;
- salinity;
- dissolved gases;
- current speed and direction;
- the wave parameters;
- the ice thickness.

In shallow waters the sensors are mounted in a frame on the bottom.

The *soil investigation* is vital to the design of offshore structures, because it is the soil that ultimately resists the enormous forces and movements present in the piling, at the bottom of the ocean, created by the presence of the platform in the storm conditions. The under seabed soil normally can be clay, sand, silt, or a mixture of these. Each project must acquire a site-specific soil report showing the soil stratification and its characteristics for load bearing in tension and compression, shear resistance, and load-deflection characteristics of axially and laterally loaded piles [11].

Design temperature for a unit is the reference temperature for assessing areas where the unit can be transported, installed and operated. The design temperature is to be lower or equal to the lowest mean daily temperature in air for the relevant areas. For seasonal restricted operations the lowest mean daily temperature in air for the season may be applied. In all cases where the temperature is reduced by localised cryogenic storage or other cooling conditions, such factors shall be taken into account in establishing the service temperatures for considered structural parts [5].

3.3. Resilience taxonomy

A brief hazard identification and description is presented below, where the holistic oil and gas production process is included, without considering the classification of corresponding technological or technical operations [8]:

- Blow-out;
- Destruction
  - destruction due to contact with vessel;
  - destruction due to the weather conditions;
- Fire, explosion;
- Technical failure
  - failure of well capping system;
  - failure due to the damage of underwater piping system;
  - failure of the processing plant;
  - failure of the flexible underwater pipeline;
  - failure of the mooring buoy system;
  - failure during STS transfer;
  - other failure on the rig;
- Damage of moored tanker;
- Collision
  - contact between tankers;
  - collision of the tanker during the voyage to the Northern Port;
  - contact of the tanker in the Northern Port.

The more detailed risk analysis with event frequency, rate consequences and comments to the possible climate impact is considered in [8].

Corrosion allowance means extra wall thickness added during design to compensate for any anticipated reduction in thickness during the operation. *Corrosion control* of structural steel for offshore structures comprises [5]:

- coatings and/or cathodic protection;
- use of a corrosion allowance;
- inspection/monitoring of corrosion;
- control of humidity for internal zones (compartments).

Coating is a metallic, inorganic or organic material applied to steel surfaces for prevention of corrosion.

4. Conclusions

In the paper the terminology and methodology on for oil rigs critical infrastructure network are presented. More detailed description is given in the report [7].

Acknowledgments

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