

Artificial ice island

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Abstract. The development of the regions of the Far North is currently the most important task for the extraction of the mineral resources. However, when conducting offshore drilling in the Arctic seas, the selection of appropriate hydraulic structures is crucial. Factors such as severe natural and climatic conditions, remoteness from developed areas, and the presence of permafrost soils necessitate specific considerations. This paper examines the limitations and advantages of different offshore hydraulic structures for exploration and development drilling in the Arctic. It is concluded that artificial island structures, particularly ice islands, offer the most effective solution for year-round prospecting and exploratory drilling in shallow Arctic shelf zones. Ice islands provide increased resistance to ice loads, lower costs, and minimal environmental impact. However, their usage is restricted to the winter period, as they melt or collapse during the summer. Additionally, ice islands cannot be converted into production platforms if a commercial deposit is discovered. Understanding these limitations and advantages is crucial for successful offshore drilling operations in the challenging Arctic environment.

1 Introduction

The development of oil and gas resources of the continental shelf is the most important task for the economic development of countries [1-4]. Offshore drilling in extreme environments, such as the Arctic seas, requires careful consideration of various factors to ensure the effectiveness and safety of the hydraulic structures involved. The challenges associated with severe natural and climatic conditions, remoteness from developed areas, and the unique characteristics of the Arctic environment necessitate specific approaches and technologies. This introduction provides an overview of the considerations involved in selecting offshore hydraulic structures for exploration and development drilling in such harsh conditions.

The Arctic region presents a range of challenges that must be accounted for when choosing the appropriate hydraulic structures. These challenges include prolonged and harsh winters, polar nights, ice impacts, permafrost soils, and the geological structure of bottom sediments. These conditions demand robust structures capable of withstanding extreme forces exerted by the environment. Additionally, the remoteness of Arctic locations

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from industrial hubs and main transport routes poses logistical challenges that must be addressed.

Water level fluctuations, especially during river floods, can be significant in the Arctic, adding another layer of complexity to offshore operations. The ability to adapt to these fluctuations and ensure the stability of hydraulic structures is crucial for their successful deployment and operation. Moreover, the utilization of ice as a building material and the cold climate itself can provide unique opportunities for construction productivity and efficiency.

A considerable portion of the anticipated oil and gas resources in the Arctic seas is found in shallow water areas. However, conventional floating drilling platforms are not suitable for exploration drilling in such regions. Existing floating drilling platforms are designed for water depths exceeding 15-20 meters and have limited operating windows during the inter-ice period. The depth of exploration wells on promising structures often exceeds 3000-3500 meters, necessitating alternative approaches.

To address the challenges posed by shallow Arctic shelf zones, one option is the use of ice-resistant shallow draft drilling rigs. These rigs can withstand the impacts of 2-meter thick ice fields and the resulting loads up to 1300-1500 tons per square meter of contact surface. However, achieving the necessary shear stability for these structures presents significant technical and economic obstacles.

For year-round prospecting and exploratory drilling in severe ice conditions typical of the shallow Arctic seas, artificial island structures become the most viable option. These island structures offer increased resistance to ice loads and greater reliability compared to other hydraulic structures. However, it is important to note that these artificial islands are not designed for long-term use.

The construction of artificial island structures involves various considerations. Earthworks play a crucial role, with costs influenced by factors such as the length, slopes, and quarry locations. The initial period of prospecting and exploration work often yields low success rates, and the dismantling of soil structures can also be costly. To mitigate expenses, the construction of ice-ground and ice islands is often recommended. Ice-ground islands consist of an ice platform surrounded by a ground berm frozen until it contacts the seabed.

As water depth increases and the distance from the earth pit becomes greater, specialized devices and systems must be employed to protect slopes from erosion and ice impact. In some cases, the costs associated with constructing earth and ice-ground islands may render these structures economically unfeasible. Therefore, artificial ice structures offer a more effective solution for exploratory drilling in severe ice conditions.

Ice islands, either artificially frozen platforms or islands created on the ice cover, present a viable option for exploration drilling in the Arctic shelf zone. By increasing the thickness of natural ice to 5-8 meters, an ice platform with a diameter of 200-250 meters can accommodate necessary equipment. Panarctic Oil has successfully built over 20 floating ice platforms at depths exceeding 200 meters. The construction process for such platforms typically spans around 60 days.

Various methods exist for constructing ice islands. The layer-by-layer freezing method reduces the strength of the ice through the salinity of seawater, while increasing construction time and cost. Another approach involves spraying the ice island with solid particles of significant weight, cooled below freezing, to expedite construction. Additionally, the use of ice blocks sawn from natural ice fields can provide structural strength superior to artificially frozen ice. The blocks are transported to the construction site, submerged, and layered with soil to form the island. To ensure ease of equipment movement, additional ice freezing is performed to level the surface.

The advantages of ice islands include lower costs compared to other hydraulic structures. For example, the Hekla-52 platform constructed by Panarctic company costs approximately \$2 million with a three-layer ice thickness. An ice island measuring 18 meters in height and 120 meters in diameter, with a depth of 9 meters, costs less than \$5 million. Furthermore, an artificial island with filler in water depths ranging from 3 to 6 meters can range from \$3 to \$11 million. These structures do not require sophisticated equipment, as the primary material used is seawater.

From an ecological standpoint, regulatory agencies possess the authority to demand the removal of an ice island with filler from the Beaufort Sea once drilling operations are completed if no commercial reserves are found. While the removal process is more expensive than construction, it minimizes environmental impact. Alternatively, ice islands can be melted or destroyed in their location with minimal environmental consequences.

Compared to other types of hydraulic structures, ice islands offer a shorter preparatory period, ranging from 2 to 6 months. In contrast, preparation for an island with filler construction may take 3 to 24 months, while designing and delivering conical structures can require 3 to 5 years. Therefore, ice islands provide a more time-efficient solution for drilling operations.

However, the use of ice islands is limited to shallow water areas and requires drilling to occur exclusively during the winter period. Ice obtained through rapid freezing methods may have lower strength due to insufficient time for thermal energy to escape into the atmosphere, resulting in absorption by the ice island. Consequently, drilling from ice islands is not feasible during the summer months, as the islands will either melt or collapse due to rising temperatures and the natural dynamics of the ice cover.

Furthermore, if a commercial deposit is discovered during drilling operations on an ice island, it cannot be transformed into a production platform. The seasonal limitations and inherent instability of ice islands prevent their long-term utilization for production operations.

When considering offshore hydraulic structures for exploration and development drilling in severe Arctic conditions, various factors must be taken into account. The unique natural and climatic challenges, remote locations, and specific characteristics of the Arctic environment require specialized solutions. While floating drilling platforms are commonly used in deeper waters, artificial island structures, such as ice islands, prove to be the most effective option for year-round prospecting and exploratory drilling in shallow Arctic shelf zones. These structures offer increased resistance to ice loads, lower costs, and minimal environmental impact. However, their usage is limited to the winter period, and they cannot be converted into production platforms if commercial deposits are discovered.

2 Analysis

When choosing the type of offshore hydraulic structures intended for both exploration and development drilling, the following should be taken into account:

- severe natural and climatic conditions, long and severe winter, polar night, ice impacts, geological structure of bottom sediments, the presence in many cases of permafrost soils;
- remoteness from industrially developed areas and main transport routes;
- significant (in some cases) fluctuations in the water level, especially during floods in river mouths;
- the possibility of using ice as a building material and cold as a factor contributing to building production.

A significant part of the predicted oil and gas resources in the conditions of the Arctic seas is confined to shallow water areas, where floating drilling platforms (FDRs) are most common; and hydraulic structures cannot be used for exploration drilling. Existing FDRs are designed to operate at water depths of more than 15–20 m and only during a relatively short inter-ice period, during which shallow exploration wells can be drilled, while the depth of exploration wells on promising structures exceeds 3000–3500 m [5].

To drill exploratory wells under these conditions, it is possible to use an ice-resistant shallow draft drilling rig capable of withstanding the effects of ice fields 2 m thick and the loads arising from these effects up to 1300–1500 t/m of the contact surface. However, if the provision of the required local and overall strength of such structures does not cause any special technical difficulties, then it is practically impossible and economically impractical to achieve the required shear stability.

Massive ice-resistant gravity platforms with a large cargo draft are also unsuitable for shallow Arctic shelf zones.

Thus, it is possible to conduct year-round prospecting and exploratory drilling only from artificial island structures (ground, ice and ice-ground islands). They are characterized by increased resistance to ice loads and reliability, and unpaved islands impossibility of long-term use. The stability and strength of soil islands depends on the stability and protection of slopes.

The cost of earthworks depends on the length, slopes, location of quarries. The success of prospecting and exploration work is low in the initial period, the dismantling of soil structures is also worth it. In order to reduce costs, it is advisable to build ice-ground and ice islands. Ice-ground islands are an ice platform surrounded by a ground berm and frozen until it touches the seabed.

As the depth of water at the construction site increases, the remoteness of the earth pit, the use of special devices and systems to protect slopes from erosion and ice impact, the cost of earth and ice-ground islands may increase so much that these structures turn out to be economically unprofitable. Therefore, for exploratory drilling in severe ice conditions typical for the shallow part of the Arctic seas, artificial ice structures are a more effective type of hydraulic structures.

Ice islands: For exploration drilling in the shelf zone of the Arctic seas, artificially frozen platforms or islands created on the ice cover can be used. To do this, the thickness of natural ice is increased to 5–8 m. The diameter of the ice platform can be 200–250 m, which allows you to place all the necessary equipment on it. Panarctic Oil has created more than 20 floating ice platforms at depths of more than 200 m. It takes about 60 days to build such a platform [6].

Initially, loads weighing 500 tons were placed on the ice platform, and gradually the bearing capacity of the platforms increased to 1500 tons. The platform was built and designed from the condition that the maximum elastic stress was limited to 345 kPa. And the limit in the deflection was chosen from the condition of excluding flooding of the ice cover. Figure 1 shows example of grounded ice island. Figure 2 shows photo example of the ice island (Nipterk spray ice island).

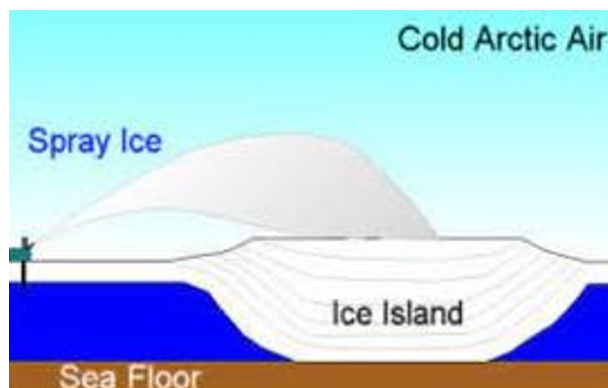


Fig. 1. Construction of grounded ice island (example)
(<https://www.uh.edu/engines/epi2716.htm>)



Fig. 2. Photo of the ice island (https://www.researchgate.net/figure/Photograph-showing-the-Nipiterk-spray-ice-island-Note-the-high-freeboard-of-the-island_fig1_44051168)

Types of structures and methods of construction

The main method of building ice islands is the method of layer-by-layer freezing. This method of building the island at the expense of the salinity of sea water reduces its strength, and the removal of the brine increases both the time and cost of construction [7-9].

To increase the construction time, the following methods of building the island were proposed [10]: freezing the island by spraying with the simultaneous inclusion of solid particles with a large weight and cooled to a temperature lower than freezing water.

The method of creating an ice island using ice blocks was also considered. In a natural ice field, ice blocks are sawn out and transported by water to the construction site. They immerse and drown due to the soil poured from above, and so on in layers. After the mark of the slab together with the poured soil exceeds the maximum design water level on the territory of the island, additional ice freezing is performed in order to level the surface for ease of movement of the equipment. The strength of the island is ensured by slabs of naturally frozen ice, which have a greater bearing capacity than artificially frozen ice.

If there is fresh water and a production base for construction, it is possible to build an island in the following way: an ice island is frozen in the form of a block, a cavity is created in its body to ensure its buoyancy. The island is delivered to the installation site, the cavity is filled with material with sufficient specific gravity to place it on the bottom of the foundation. This method of construction, despite its complexity of implementation, allows you to build a structure in the shortest possible time.

Bulk freezing method. The ice monolith is frozen with an annular cuff and pipes are installed inside it, which are connected to a cold source. These pipe elements serve as the reinforcement of the island, thereby increasing its strength and maintaining the required temperature of the island.

Advantages and disadvantages of ice islands

Requires less cost (Hekla-52 platform of Panarctic company \$2 million with the 3rd layer of ice. An ice island 18 m high and 120 m in diameter with a depth of 9 m costs less than \$5 million. An artificial island with filler in the area of water with a depth from 3 to 6 m costs from \$ 3 to 11 million. It does not require sophisticated equipment, and the material is sea water.

Ecological. Currently, the relevant regulatory agencies have the right to require the removal of the island with filler from the Beaufort Sea after drilling is completed if commercial reserves are not found. The operation to remove such an island is more expensive than its construction. The ice island, if necessary, may be melted or destroyed directly in the area of its location, while the impact on the environment will be minimal.

The preparatory period of the ice island is 2-6 months shorter, it takes 3-24 months to prepare for the construction of the island with filler, and 3 to 5 years are required for the design and delivery of conical structures. Plots in the sea

The use of ice islands is limited to shallow water areas. Allow drilling only in winter. Ice obtained using high-speed methods has less strength, since thermal energy does not have time to escape into the atmosphere and is absorbed by the ice island.

Drilling from ice islands is limited to the winter period. That is, in the summer the island will melt or collapse. If a commercial deposit is discovered, it cannot be turned into a production platform.

3 Conclusion and discussion

The construction of ice islands is less expensive and does not require sophisticated equipment, and the material is sea water.

The ice island, if necessary, can be melted or destroyed directly in the area of its location, while the impact on the environment will be minimal.

However, the use of ice islands is limited to shallow water areas, and they allow drilling operations only in winter. Ice obtained using high-speed methods has less strength, since thermal energy does not have time to escape into the atmosphere and is absorbed by the ice island [11].

It is necessary to ensure the safety of ice islands in the summer. As a result, it would be possible to build islands in deep sea areas. The issue of converting the ice island into a production platform should be studied.

Consideration should be given to climatic characteristics, island shear stability and artificial ice strength.

During the construction of the island, there are restrictions on the depth of the water area, since during one winter it is possible to freeze an artificial layer of ice of limited thickness.

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