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ABSTRACT

This thesis is dedicated to the Ayashsky license block that is located near the northeastern part of the Sakhalin Island. A concept of the development of this offshore block of fields will be discussed in this work. Special attention will be given to a selection of installation method of oil and gas field structure since the installation of various facilities or equipment at an offshore field in Arctic conditions is a real problem due to the harsh weather conditions.

The thesis aims to find a solution for the development of this offshore field that will be compatible with weather conditions in this region. Besides, to determine the most appropriate way of placing a chosen structure in the field.

Both objectives are planned to be achieved with the help of detailed environmental analysis. Successful fulfilment of an installation process requires detailed information regarding the specific Arctic waters. The study is based on the data of the Okhotsk Sea located near Sakhalin Island (the Russian Far East). This region does not belong to the traditional Arctic region (the northernmost part of Earth). Nevertheless, the sea conditions are prescribed as the Arctic ones. Environmental analysis is a very sophisticated process that encloses evaluation dozens of factors that can influence an obtained result. In this thesis, the environmental analysis includes assessment of seasonal weather and ice conditions, water depth, seasonal temperature, current and waves assessment.

Besides, an analysis of existing technologies for the development of offshore projects is required. Such analysis will help to choose the most appropriate option for the Ayashsky license block based on the environmental assessment.

CONTENTS

List of abbreviations

AZRF – Arctic zone of the Russian Federation

HC – hydrocarbons

HMS – hydrometeorological station

ITS – integrated template structure

LA – license area

NGL – natural gas liquids

NSA – North Slope of Alaska

OGS – offshore oil and gas structures

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INTRODUCTION

Twelve seas wash Russia, however, most of them are characterized by such harsh natural and climatic conditions that these seas become technically inaccessible to any marine operations. Therefore, all emphasis is made on more accessible seas, including the Okhotsk Sea.

The shelf of the Okhotsk Sea along the eastern coast of Sakhalin is rich in hydrocarbons. At the moment, most of the offshore projects in Russia are concentrated there, of which three are in the active development phase.

Recently, two new oil and gas-bearing structures were discovered there – Ayashskaya and Bautinskaya, which were united by one name – the Ayashsky license area (LA). The geological reserves of this section are impressive, so now the experts have an important task – to be able to maximize the oil potential of these structures. One of the crucial factors for the successful completion of this task is a correctly selected field arrangement scheme, as well as an offshore oil and gas structure (OGS). Therefore, the topic of this work is hugely relevant.

The main goal of this master's thesis is the reasonable selection of an offshore oil and gas structure (OGS) for the arrangement of the Ayashsky structure. Goal achievement requires the completion of several tasks. Among them: analysis of the natural and climatic conditions of the Okhotsk Sea, identification of factors determining the choice of OGS, analysis of the current state of the country's technical and technological base.

The second goal is to determine the installation method of the selected OGS. The following tasks should be fulfilled to achieve the goal: analysis of existing installation methods, identification of vessels used and calculation of rental charge.

1. A HISTORY OF THE ARCTIC AND ITS DEVELOPMENT EXPERIENCE

1.1 A HISTORY OF THE ARCTIC DEVELOPMENT

The Arctic (Greek: ἀρκτικός — «under the constellation Ursa Major», «northern») is the northernmost polar part of the globe, occupying about a sixth of the Earth’s surface, which includes the outskirts of the continents of Eurasia and North America and almost the entire Arctic Ocean (Fig. 1.1).

Figure 1.1 Political map of the Arctic region

Scientists believe that even 10 thousand years ago, primitive people began to develop these lands. It was discovered that in those days the Proto-Eskimo tribe inhabited the Far Eastern North. It was they who became the first indigenous inhabitants of the Arctic region [1].

However, the real development of the North began with the Phoenician merchants, who were the first to go beyond the Mediterranean Sea and set off north. In the Middle Ages, the Normans (inhabitants of the Scandinavian Peninsula), in search of free land, sailed to the White Sea, reaching Greenland and the Baffin Land [2].

However, only from the 15th century, the true colonisation of the North began. The countries of the Scandinavian peninsula (Norway, Sweden, Finland), as well as Denmark, expand their expansion far to the North. As a result of European enlargement on the American continent in the 16th century, the Svalbard and Bear Islands were discovered by the Dutch navigator Barents (1594) [2].

After the Barents, for some time, the sea route along the northern shores of Asia was forgotten. Instead, the flowering of polar expeditions was observed, caused by attempts to seize the Northwest Passage.

So, at the beginning of the XVII century, the Hudson and Baffin Bays were discovered by their eponymous researchers. Baffin also discovered the Lancaster Strait, which led further west and could be considered the beginning of the Northwest Passage. However, Baffin failed to unleash the potential of the strait discovered by him, having decided that there was no northwestern passage [2]. Such expedition results weakened interest in polar research in the northwest, and there was a lull, as in the northeast.

The second half of the 16th and entire 17th centuries were marked by the active advance of Russians in the Arctic direction. Russian Pomors and explorers made voyages along the Arctic Ocean using river tributaries. Thus, they carefully examined the central coastal part of the Arctic and also opened the way to the Pacific Ocean [1]. A series of large Russian expeditions marked the first half of the 18th century. So, during the years 1725-1741, the Russian navigator Bering made several significant polar voyages, and the Aleutian and Commander Islands were discovered [2].

In the XIX century, in connection with the development of technology, the revival of polar expeditions began, new opportunities opened up with the advent of steamboats. The steamboat allowed freer to manoeuvre in the rapidly changing conditions of the Arctic, and this circumstance played a significant role.

Perhaps the grandest event in the development of the Arctic in the 19th century can be considered Franklin’s famous campaign and several other related activities. In 1845, Franklin led an expedition on two screw ships, intending to pass through the Northwest Passage to the Great Ocean. Having reached the Baffin Bay, Franklin’s expedition went missing. Subsequently, rescue expeditions were organised, which played an exceptional role in the study of the Arctic. Thanks to them, many important observations were made, studied and recorded on a map of the coast; the Smith Strait was opened, leading from the Bay of Baffin to the pole bypassing the coast of Greenland. Finally, the northwest passage was found [2].

The polar expeditions of the 19th century for the Russians were still concentrated in the eastern part of the Arctic Ocean, including the Bering Strait, and in the Novaya Zemlya region. Thanks to Kruzenshtern (1803–1806) and Kotzebue (1815–1817), the shores of Kamchatka and Alaska were studied. The expeditions of Wrangel and Anjou (1820–1822) made it possible to explore the northern coasts of Siberia from Olenek to the island of Kolyuchin. And in 1832, Pakhtusov’s expedition circled the southern island of Novaya Zemlya, passing through the Kara Gate to the Kara Sea [2].

In the second half of the 19th century, intensified attempts to get to the pole from the Smith Strait by Austro-Hungarian sailors led to the discovery and exploration of new islands and lands (Franz Josef Land) and the study of Greenland. Moreover, in 1882-1883, 15 polar research stations were organised for scientific observation. This event went down in history under the name of “the first international polar year” [2].

In 1878, the Swedish traveller Nordenscheld for the first time in history successfully travelled the northeast path and in the summer of 1879 entered the Pacific Ocean.

In 1893, the Norwegian polar explorer Nansen made a bold venture. On a specially designed ship that can withstand ice compression, the Nansen expedition crossed the Kara Sea from the west and reached the Novosibirsk Islands. Here his ship «Fram» was frozen into the ice and from here began its three-year drift. Noticing the movement of the vessel south of the pole, Nansen attempted to reach the pole on the ice with dog sledging and skiing. Without success, he had to return to the Land of Franz Joseph. Meanwhile, «Fram» arrived in Norway, completing a lengthy and challenging hike [2].

In 1903, the Norwegian Amundsen set sail on a small motor ship from the east, intending to pass the northwest route from east to west. The victory was again won. The northwest route was successfully covered with two wintering grounds [2].

The development of technology opened up new paths in the development of the Arctic. In England in 1899, based on the idea of the Russian navigator Admiral Stepan Makarov, the first icebreaker Ermak was built [1]. This event marked the beginning of a new era of Arctic exploration, as the high strength and size of icebreakers became a real means of fighting ice.

During the years 1910–1915, the Taimyr and Vaigach ice-breaking steamers made voyages from Vladivostok to the East Siberian Sea each summer. They carried out hydrographic surveys. On a flight in 1913, they discovered Severnaya Zemlya [2].

The World War of 1914–1918 was a turning point in the history of the development of the Arctic. Conflicts arose between Canada with Denmark and the United States over rights in territories in the adjacent polar waters. From 1924 until the very last time, a dispute lasted between Norway and Denmark over the rights to Greenland. In 1926, the USSR decided to protect its rights and interests in the Arctic, setting borders from the coast of the USSR to the pole. Within this sector, all open and potentially open lands and islands are considered to belong to the USSR. Subsequently, over ten years, 19 weather stations were built in areas adjacent to the Arctic Ocean [1]. A little later, polar drifting research stations were created thanks to the idea of polar explorer W. Wiese.

Expeditions of the 19th–20th centuries proved that human activity in the Arctic is possible, despite all the difficulties that can be overcome by the development of technology. Steamboats, icebreakers, high-quality scientific work of the polar stations – all these are conditions, which ensure victory over the harsh force of nature.

Today, the Arctic region is an essential strategic space for all adjacent countries, as it provides defence, environmental and recreational functions. Moreover, the Arctic is the custodian of large hydrocarbon deposits. Over the past 45 years alone, more than 20 billion TOE has been extracted from the bowels of the Arctic of Russia, Norway, the USA and Canada (Fig. 1.2) [3].

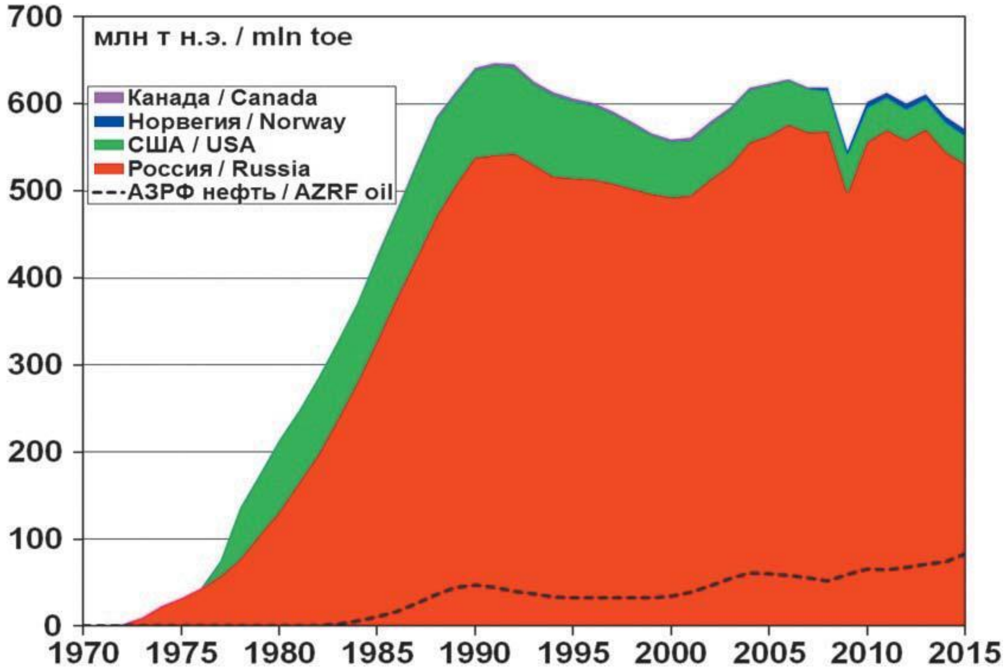


Figure 1.2 Hydrocarbon production in the Arctic [3]

*Where AZRF oil means the share of oil production in the Arctic zone of the Russian Federation (AZRF)

These values will grow in the future since many offshore fields are only waiting for their discovery. The next part of the dissertation will present the history of the discovery of Arctic shelf deposits and their role in the development of their country.

1.2 A HISTORY OF THE ARCTIC SHELF DISCOVERY

Each country with Arctic shelf territories has its unique history of the discovery and development of these regions. Consider the most significant events of each country on the way to their advance into the Arctic.

RUSSIA

The continental part of the Russian Arctic began its development with the search for oil and gas fields back in the distant 30s of the twentieth century. In this sense, Russia was a pioneer, since other countries did not make any attempts. The first evidence of oil emergence in the Arctic region was recorded in 1935 on the surface of the Laptev Sea [4].

However, it was only in the early 80s that it was decided to begin research directly on the Arctic shelf. Regarding the study and deep exploratory drilling, priority was given to the regions of the Barents, Pechora and Kara Seas [5]. The result was the discovery of the following fields:

Table 1.1

Fields of the Russian Arctic shelf discovered in the 80s

Sea name	Field name	Type	Discovery year	Reserves
The Barents Sea	Murmanskoye	G	1983	120,6 billion m^3
	Severo-Kildinskoye	G	1985	15 billion m^3
	Shtokman	GC	1988	3,9 trillion m^3 (G)
				56 million t (GC)
The Pechora Sea	Pomorskoye	GC	1985	22 million t
	Severo-Gulyaevskoye	OG	1986	52 billion m^3 (G)
				13 million t (O)
	Prirazlomnoye	G	1989	72 million t
The Kara Sea	Rusanovskoye	GC	1992	3 trillion m^3
	Leningradskoye	GC	1992	3 trillion m^3

G – gas; GC – gas-condensate; O – oil; OG – oil-gas.

Later, many more offshore fields were discovered in the Arctic region. Still, not one of them went to the development stage until 2013, when it was decided to start developing the Prirazlomnoye field in the Pechora Sea [5]. However, if we take into account the shelf of the subarctic region, then the first marine object on the Russian shelf can rightfully be considered the Odoptu-More field (North Dome). The first oil from this field was obtained in 1998 using an inclined well drilled from land [5].

In subsequent years, a lot of large-scale work was done to study the seas of the Russian Arctic shelf; many unique and large deposits were discovered. Some of these fields were embodied in large-scale and unique hydrocarbon production projects. Table 1.2 below represents and describes briefly Russian offshore projects.

Today, over 70% of all world gas reserves and over 40% of all world oil reserves are concentrated on the Russian Arctic shelves [6].

Russia is a leader in several areas in the development of Arctic resources. The Soviet Union - Russia was the first to discover hydrocarbon deposits in the Arctic, created exceptional technologies, explored and began their development, designed and built large transport systems that have no analogues in the world.

Table 1.2

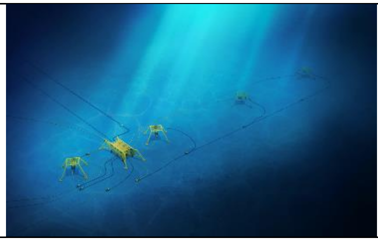
Existing projects on the Arctic and subarctic shelf of Russia

Sea	Company	Field name			Production/ discovery	Description
The Okhotsk Sea	PJSC Rosneft Oil Company	Odoptu-More field (North Dome)	OG		1998 year	Hydrocarbon (HC) production is carried out in a directional well drilled from the coast to the sea deposit.
	Sakhalin Energy Investment Company Ltd. (Sakhalin-2)	Piltun-Astokhskoye	OG	 	1999 (1986) year	Extraction is carried out from two platforms: Molikpak (PA-A) and Piltun-Astokhskaya-B (PA-B). Then, through the trans-Sakhalin pipeline, hydrocarbons are delivered to the Prigorodnoye production complex (includes the LNG plant and the oil loading terminal) through an intermediate integrated coastal technological complex.
		Lunskoye	OGC		2009 (1984) year	Extraction is conducted from the Lunskaya-A platform. Hydrocarbons are supplied to the integrated coastal technological complex, where oil, condensate and gas are separated, as well as gas processing. Further, everything is transported to the Prigorodnoye PC.

Table 1.2 (continuation)

	Exxon Neftegas Limited, PJSC Rosneft Oil Company, ONGC, SODECO (Sakhalin-1)	Chayvo	OGC	 	2005 (1979) year	Hydrocarbons are extracted simultaneously from the land through horizontal wells (Yastreb rig) and from the sea (Orlan platform). The extracted volumes go to the Chayvo onshore preparation complex for processing. Finished oil is sent to the De-Kastri terminal, and gas is sent to the Far East of Russia.
		Odoptu	OG		2010 (1977) year	Development and production are carried out from the coastal site through horizontal wells that were drilled first from the Yastreb rig and later from Krechet.
		Arkutun-Dagi	OG		2015 (1989) year	The hydrocarbons are extracted from the Berkut platform, after which they are transported to the Chayvo onshore preparation complex via an underwater infield pipeline.

Table 1.2 (continuation)

	PJSC Gazprom (Sakhalin-3)	Kirinskoye	GC		2014 (1992) year	The field is exploited through a subsea production system (SPS). All hydrocarbons are collected in the central manifold and then transported by pipeline to the onshore processing complex.
The Caspian Sea	The PJSC Lukoil Oil Company	The Yuri Korchagin	OGC		2010 (2000) year	Extraction is conducted from an offshore ice-resistant stationary platform. Further, hydrocarbons are transported through pipelines to a marine transhipment complex.
		The Filanovsky	OGC		2016 (2005) year	Extraction is conducted from an offshore ice-resistant stationary platform, after which the hydrocarbons are treated at the central technological platform. Further, oil is transported by the pipeline to the coast and gas is carried by the pipeline to Stavrolen.
The Pechora Sea	PJSC Gazprom	Prirazlomnoye	O		2013 (1989) year	Oil is extracted through the Prirazlomnaya offshore ice-resistant stationary platform and stored in tanks inside the platform until the tanker arrives. Oil is shipped to a tanker via a shipping line.

NORWAY

The history of the Norwegian oil and gas industry began about 50 years ago when the first field was discovered. However, twenty years earlier, few believed in the potential of the Norwegian shelf.

The first doubts began to appear in 1959 when a giant gas field Groningen was found in the Netherlands. In 1962, the American oil company Phillips Petroleum requested Norway exclusive rights to study part of the Norwegian continental shelf for the search for hydrocarbons, but the request was rejected [7].

In 1963, the Norwegian government declared sovereignty over the Norwegian continental shelf, and later, in 1965, was reaching an agreement on the division of borders with Denmark and Great Britain, it opened its way to the development of the shelf [7].

The first Norwegian licenses were issued in April 1965. Four years later, in 1969, almost on Christmas Eve, the first Norwegian oil field Ekofisk was discovered, which then turned out to be one of the largest. From that moment, the great history of Norway in the oil and gas sector began.

In the next few years, a whole series of large-scale offshore fields were discovered (Fig. 1.3).

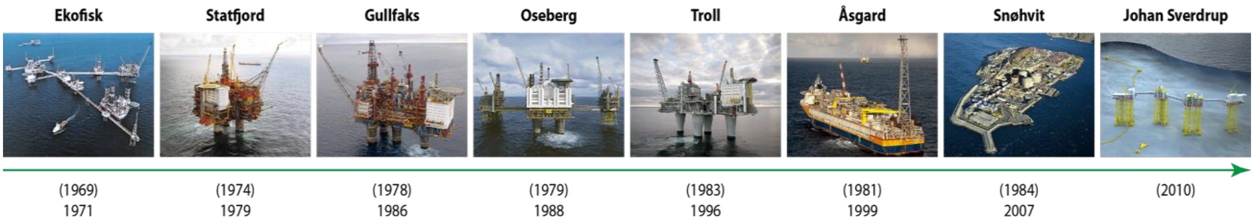
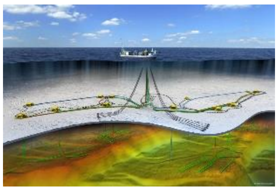


Figure 1.3 Discovery timeline of the important Norwegian fields [7]

To date, the Norwegian shelf has 88 fields in the status of “in production”. However, if we talk about the Arctic part of the Norwegian shelf, located in the Barents Sea, then there are only two active projects: Snøhvit and Goliat. Johan Castberg is in the status of “approved for production” [8]. Table 1.3 summarises the primary information about these fields.

Table 1.3

Existing projects on the Norwegian Arctic shelf

Company	Field name			Product ion/disc overy	Description
Equinor Energy AS (former Statoil and later Statoil Hydro)	Snøhvit	GC		2007 (1984) year	The field is developed through the series of SPS. Produced natural gas, NGL and condensate are transported via subsea pipeline to the LNG plant at the Melkøya island.
Vår Energi AS	Goliat	O		2016 (2000) year	The 8 SPS produces oil, afterwards, hydrocarbons are supplied to the FPSO Sevan 1000. After that, the oil is exported to tankers.
Equinor Energy AS (former Statoil Hydro)	Johan Castberg	OG		- (2011) year	The field is going to be developed from the FPSO along with the SPS. Afterwards, hydrocarbons will be exported to the tankers.

Norway is one of the leading countries with offshore hydrocarbon reserves. However, the government have yet to develop its Arctic part of the shelf based on their experience in the Norwegian, Northern and Barents Seas.

THE USA (Alaskan continental shelf)

Mostly, the US Arctic deposits are located on the Northern slope of Alaska (NSA), in total there are about 78 of them, 22 of them in the Beaufort Sea (including land-sea transition zones) [5]. The first oil searches in the US Arctic region began in the distant 1946 and already at the turn of the 1940s – 1950s the first small deposits on land were discovered [4]. However, the first significant fields were found in 1967 – Prudhoe Bay (unique gas-oil field) and in 1969 – Kuparuk-River (large oil field).

Later was discovered the first offshore field – Gwydyr Bay. Additionally, it was found the most significant deposits on the Northern slope of Alaska – Endicott and Point McIntyre. The first offshore oil began to be produced from the Endicott field in 1987 and is still ongoing. Also, production is conducted from another nine areas. Alaska shelf projects are summarised in Table 1.4.

Table 1.4

US Arctic projects on the Alaskan continental shelf

	Company	Field name		Production/ discovery	Description
L	BP, ConocoPhillip, ExxonMobil	Prudhoe Bay	OG	1977 (1968) year	Production is realised from the land by horizontal wells.
L	ConocoPhillips Alaska	Kuparuk-River	O	1981 (1969) year	
L	BP, Hilcorp	Milne Point	O	1985 (1969) year	
O	ExxonMobil, Hilcorp	Endicott	O	1987 (1978) year	Extraction of HC is provided from an artificial bulk island. Transportation is realised by surface pipeline to the mainland and then through the Trans-Alaska Pipeline System.
L	BP, ConocoPhillip, ExxonMobil, Chevron	Point McIntyre	OG	1993 (1988) year	Production is realised from the land by horizontal wells.
L	ConocoPhillips Alaska	Alpine	O	2000 (1994) year	
O	Hilcorp	NorthStar	O	2001 (1984) year	Extraction of HC is provided from an artificial bulk island.
O	Eni	Oooguruk	OG	2008 (-) year	
O	Eni	Nikaitchuq	O	2011 (-) year	
L	ExxonMobil, Hilcorp	Point Thomson	GC	2016 (1965) year	Production is realised from the land by horizontal wells.

L – land field; O – offshore field.

Based on the data in Table 1.4, it is clear that the US oil industry is not strong in the development of its Arctic shelf territories. All fields are developed either from land by horizontal wells (6 projects) or from artificial bulk islands at shallow depths (4 projects). The central part of the Beaufort Sea (especially its northern territories) remains unexplored. Cumulative oil production in the continental and offshore regions of the basin at the end of 2019 amounted to about 174.6 million barrels [9].

CANADA

Intensive exploration of the Arctic part of Canada began only in the 1970-1980s with the discovery of the Beaufort–Mackenzie basin. More than 80 exploration wells were drilled on this shelf, and 32 deposits were found [5]. The first, Adgo offshore oil and gas field, was discovered in 1973. In 1983, the largest Amauligak oil and gas field was found. In 2006, the same large Paktoa oil and gas field was found. Thus, the initial recoverable reserves at 32 fields amount to 153 million tons of oil and 156 billion m^3 of gas [5]. Even though there are a lot of explored deposits (Fig. 1.4), none of them is being developed [10].

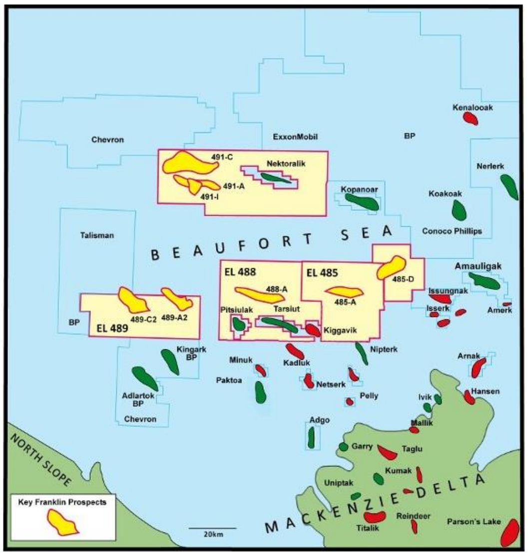


Figure 1.4 Offshore fields of Canada on the territory of the Arctic islands [11]

Searches were also conducted on the territory of the Arctic islands and the adjacent waters of Canada, where 19 fields were discovered, mainly gas. However, they are also not being developed (Fig. 1.5) [11], [5].

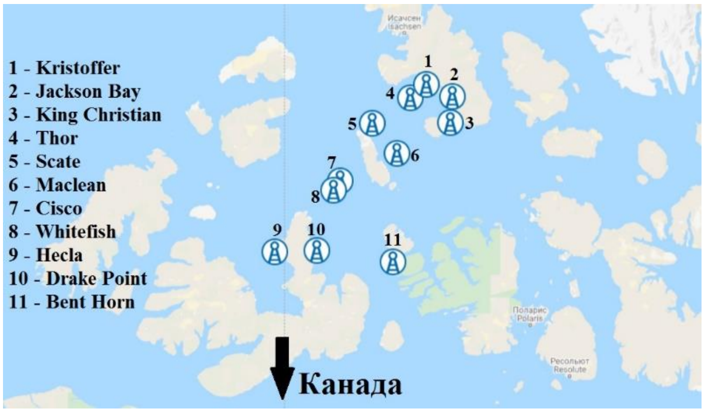


Figure 1.5 Fields of the Beaufort–Mackenzie basin [10]

DENMARK (GREENLAND)

Research on offshore territories of Denmark, namely in the water area of Greenland, began in 1970 [12]. In the 70s, several European and American companies drilled five exploratory wells on the Greenland shelf. However, none of them was commercially successful.

In 2006–2007, oil and gas companies again turned their eyes to the Greenland shelf, having received licenses from the state. So, in 2010–2011, the Scottish company Carpicorn drilled eight exploratory wells [12]. Some of them were successful and proved the presence of oil and gas source rocks. However, this was not enough to continue a commercial activity. Despite this, the government does not lose hope of discovering hydrocarbon deposits.

Conclusion

Currently, only three out of five Arctic countries are producing hydrocarbons on their shelves: Russia (the Pechora Sea, the Okhotsk Sea and the Caspian Sea), Norway (the Barents Sea) and the United States (the North Slope of Alaska). Each country has its own unique experience, applied technology and knowledge in field development. Russia managed to succeed in the fight against ice by installing large-scale ice-resistant platforms. Norway used the subsea production systems in the development of the Arctic shelf and showed how effective it could be in the Arctic. The USA managed to overcome ice and cold using horizontal wells and gravel islands.

Further progress towards the Arctic becomes apparent since the prospects for discovering new deposits are incredibly high. However, only by combining the acquired knowledge and skills, it will be possible to achieve sustainable and safe development of the oil industry in such an environmentally sensitive region.

2. ENVIRONMENTAL CONDITIONS OF THE OKHOTSK SEA

This chapter will describe all parameters of the Okhotsk Sea in the vicinity of the licensed area. Since the northern part of Sakhalin Island by its characteristics belongs to the Arctic region, it is also necessary to consider the natural and climatic obstacles that may be encountered here.

2.1 ENVIRONMENTAL CHARACTERISTICS OF THE ARCTIC

The Arctic region is determined by harsh environmental conditions that complicate field development. This section describes the main climatic obstacles that exist on the shelf of Sakhalin Island.

Low temperatures

Low temperatures are a common occurrence in winter throughout the Arctic Region. Low temperatures can lead to cancellation or delayed operations, as installations and equipment must be protected, and personnel will not be allowed to work outdoors for extended periods.

Icing of facilities

At low temperatures, sea spray immediately hardens upon contact with a ship or facility, which creates significant problems for marine operations and the safety of personnel. The combination of icing caused by wind or waves with air temperature can increase the risk of disturbing the stability of floating installations, reduce performance, freeze mechanisms, make decks and stairs slippery, and, in some cases, can block communication and evacuation systems.

Isolated location

Most of the Arctic region is located at a considerable distance from existing infrastructure, increasing the time of transportation by ships and helicopters. This fact, in combination with the unreliability of meteorological forecasts, gives a source of uncertainty that can, in many cases, delay operations. In some places along the coastal part of Sakhalin, there is the necessary infrastructure. However, it is close to existing large-scale projects. New projects that are remote from existing ones will need to be provided with a new resource base from scratch.

Seawater ice

Sea ice can vary in shape, thickness, age, and hardness. The ice situation in the Arctic seas is dynamic, which leads to substantial annual, seasonal and regional differences, creating not only diverse but also serious problems for ships and installations operating in different parts of these regions. The Sakhalin shelf is also prone to the formation of ice, hummocks, floating ice, etc.

Polar lows

Polar depressions occur when cold winds blow from the ice-covered northern regions over areas with a relatively warm sea. As a rule, polar lows last from several hours to several weeks, accompanied by strong winds and subsequent snow or rainfall, which pose a severe threat to security and a problem for operations in the Arctic including a shelf of the Sakhalin Island.

Visibility (presence of fog)

Operations in ice-covered waters should be carried out in conditions of excellent visibility to see ice, other vessels or installations. However, fog is a frequent occurrence in the marginal zone of ice. It is an obstacle for helicopter flights, which can lead to delays and restrictions in operations.

Since the scope of this work includes the study of the installation of objects in the Sea of Okhotsk, it is necessary to evaluate its specific properties.

2.2 ENVIRONMENTAL CONDITIONS OF THE OKHOTSK SEA NEAR THE NORTHEASTERN PART OF THE SAKHALIN ISLAND SHELF

Within the framework of this section, it is necessary to assume that all the parameters of the climatic conditions of the Ayashsky block coincide with the parameters of the Arkutun-Dagi and Piltun-Astokhskoye fields since they are close to each other. The above assumption is necessary due to the lack of data on the Ayashsky license block.

2.2.1 Geographical characteristics of the Okhotsk Sea

The Okhotsk Sea is located in the Far East of Russia and is an integral part of the Pacific Ocean. On the South, it is separated from the Pacific Ocean by the Kuril Islands. The other boundaries are with the Kamchatka Peninsula and Asia. The average depth of the sea is 821 m, and the most considerable depth is 3521 m (in the Kuril basin) [13]. Figure 2.1 presents a map of the Sea of Okhotsk [14].

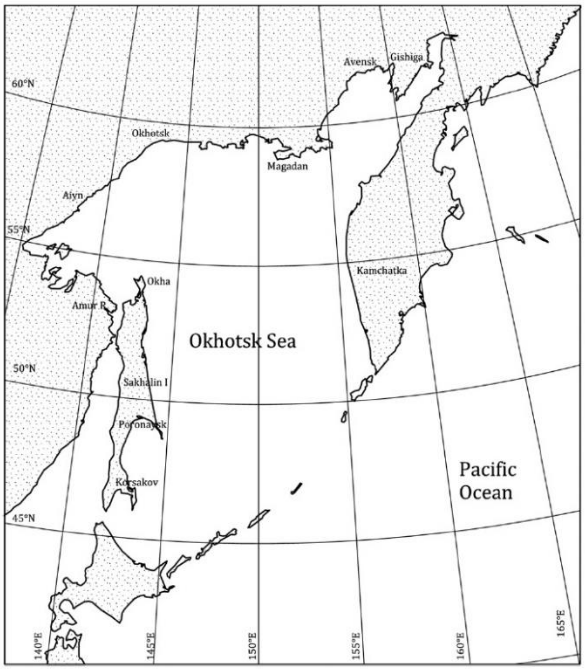


Figure 2.1 Map of the Okhotsk Sea [14]

The main structural zones of the seabed topography are the shelf, the mainland slope with separate underwater elevations, depressions and islands, as well as a deep-sea basin. The shelf zone (0–200 m) with a width of 180–250 km occupies about 20% of the sea area. The broad and slightly sloping, in the central part of the basin, continental slope (200–2000 m) occupies about 65%, and the deepest basin (more than 2500 m) located in the southern part of the sea makes up 8% of the sea area [13].

2.2.2 Climate conditions

The Okhotsk Sea belongs to the monsoon climatic zone of the temperate latitudes. In general, it is considered cold for many reasons. Firstly, in the western part, the sea extends actively to the coast and therefore lies quite close to the pole of cold Asian land. Secondly, the ridges of the Kamchatka Peninsula limit the approach of the warm air of the Pacific Ocean to the sea. In this regard, the Okhotsk Sea is characterised by cold and long winters. Therefore, the marine climate of this region is similar to the environment of the polar seas.

Wind

The main transport of air masses on Sakhalin is associated with monsoon circulation in the atmosphere. The period from October to April is characterised by the presence of an Asian (winter) monsoon, influenced by western, northern and northwestern winds, often reaching storm forces. Cyclones are mainly of continental origin; therefore, air temperature decreases, and wind intensifies [13]. Wind speed in winter can reach 10–11 m/s.

Between May and October, the Pacific (summer) monsoon prevails with southern and southeastern winds, which cause significant cloud cover, precipitation, and fog. Wind speed can reach 6–7 m/s. Typhoons sometimes lasting 5–8 days with increased winds can sometimes be observed. Despite this, sometimes more substantial North and northwest winds may appear in June-July [13].

Hydrometeorological conditions in this region vary significantly from month to month, including wind speed. Figure 2.2 shows a graph of the distribution of wind speeds by month in the area of the Piltun-Astokhskoye field [15].

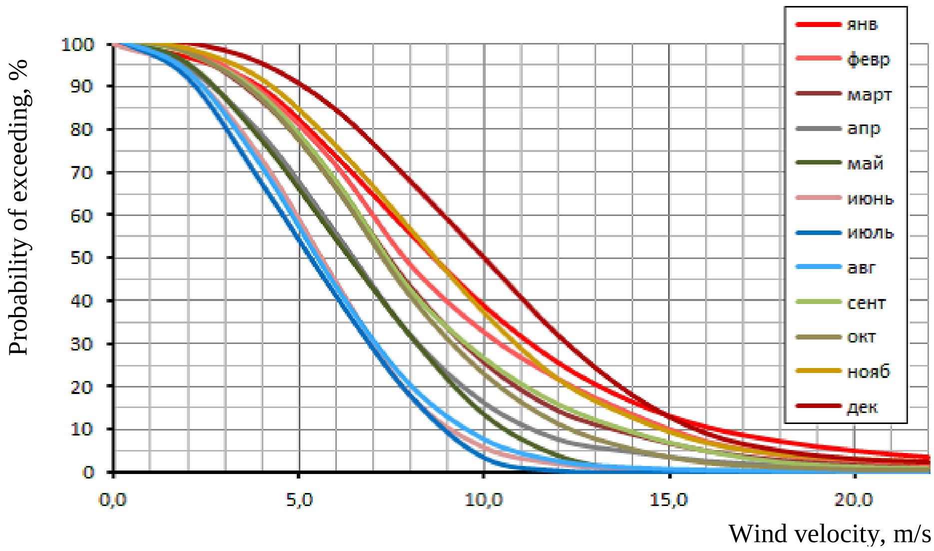


Figure 2.2 Seasonal distribution of wind speeds in the region of Piltun-Astokhskoye field [15]

So, with a probability of exceeding the wind speed of 10%, the most severe wind speeds are observed in winter (December, January, February) ≈16 m/s, and the calmest in summer (June, July, August) ≈9 m/s.

Air temperature

The coldest month of the year is January with an average monthly air temperature of −19.7°C to −21.3°C, depending on the site of the hydrometeorological station (HMS). The average daily temperature transitions to positive values in late April – early May, so frost-free days last 50–154 days [16].

The warmest month is August; the average daily air temperature can vary between 11.5°C – 15.2°C. In summer, the average monthly air temperature in August drops from southwest to northeast (from 18°C to 10.5°C). The average daily temperature changes to negative values in October, although the first frosts are already observed at the end of September.

Table 2.1 presents the monthly air temperatures according to the coastal HMS Odoptu and Val. The HMS Val measurements are of the most considerable importance for this work since it is closest to the studied licensed area.

Table 2.1

c

HMS	**Months**											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Average temperature												
Odoptu	-9,1	-6,8	-11,9	-3,8	1,0	5,8	10,2	12,9	9,8	3,0	-7,1	-4,0
Val	-19,1	-16,2	-10,4	-2,3	2,8	8,0	12,1	13,8	10,3	2,8	-7,6	-15,7
Average maximum temperature												
Odoptu	-5,6	-2,5	-7,1	-0,4	4,5	10,1	14,3	16,7	13,0	6,2	-3,6	-06
Val	-15,1	-11,6	-5,6	1,6	7,0	13,4	16,9	18,6	14,7	7,0	-3,5	-11,9
Absolute maximum												
Odoptu	-0,2	-0,8	8,0	11,8	25,6	31,3	32,0	30,6	25,0	17,8	9,0	1,0
Val	0,8	0,7	11,1	15,8	25,8	33,0	32,4	30,6	27,0	19,0	11,0	1,6
Average minimum temperature												
Odoptu	-2,3	0,7	-16,6	-7,1	-1,2	3,2	7,4	10,1	7,3	0,4	-0,7	-7,5
Val	-22,8	-20,5	-15,2	-5,8	-0,3	4,1	8,6	10,3	6,6	-0,9	-11,4	-19,3

Table 2.1 (continuation)

Absolute minimum												
Odoptu	-8,6	-5,0	-33,2	-6,1	-11,0	-2,8	0,6	3,5	-0,4	-5,4	-5,2	-3,3
Val	-42,8	-38,0	-35,1	-24,1	-8,4	-3,7	0,0	1,6	-4,1	-19,8	-27,9	-39,9

Precipitations

The average annual precipitations in the area of Piltun-Astokhskoye field is 600 mm/year. From November to April, the primary type of precipitation is snow, from May to October – rain. The maximum rainfall occurs in August-October, the minimum – in January-February.

In the warm season (April to September) fogs form in this region, which is quite dangerous for offshore structures. The highest number of days with fog occurs in June-July. Fog can last from several hours to several days in a row. In winter, fog is infrequent and short-lived. The average number of days with fog at this time of the year (December to March) is 1.1 days per month [15].

Among other things, humid air and other phenomena (fog, cold rain, water splashes) can cause icing of marine structures, ice accumulation and stick of wet snow to the surface of marine structures and their elements [17].

2.2.3 Hydrological conditions

The main parameters affecting the hydrology of the Sea of Okhotsk are geographical location, significant meridional extent, monsoon change of winds and good sea connection with the Pacific Ocean and the Sea of Japan through the straits. In turn, the influx of Pacific waters significantly affects the distribution of temperature, salinity, the formation of the structure and general circulation of the Okhotsk Sea waters [13].

Water temperature

In winter, the surface temperature of seawater ranges from –1.8°C to –1.5°C. An increase in temperature in the spring months affects only the melting of ice, and only then on the heating of water. So, in summer, the temperature reaches values in the range from 10°C to 18°C [14].

The vertical distribution of water temperature varies from season to season and from place to place. In the cold season, changes in temperature with depth are less complex and varied than in warm seasons. Summer temperatures warm the sea to a depth of 30 to 75 m. However, the deeper layers (≈ 150 m) have negative temperatures, approximately –1.6°C although the deeper layers (from 750 m to 1500 m) are heated by the warm waters of the Pacific Ocean to temperatures from 2.0°C to 2.5°C [14].

Table 2.2 shows the monthly average water temperature in the area of the Piltun-Astokhskoye field.

Table 2.2

The average monthly water temperature (°C) on the surface of the sea [15]

Months											
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
-	-	-	-	0,4	4,0	8,7	11,9	10,8	5,8	4,1	-0,9

Wave conditions

The wave climate is dynamic with seasonal variability. It becomes unusually stormy in the autumn and early winter periods. From January to April, the wave occurrence is prevented by ice cover. About 55–70% of storm waves occur during the autumn-winter periods, during which the wave height can reach 10–11 m [13]. The southeastern and southern regions of the sea are considered the harshest.

In the summer (July-August), southeast and south waves dominate with heights (H_s) of up to 2 m, with a frequency of 88.4%. The repeatability of wave heights in the range of 2.1–4.0 m is of 11%, and more than 4.0 m is of 0.6% [18]. Summer storms can cause the formation of waves with a height of 4.1 to 4.5 m.

In September, the frequency of wave disturbance in the northeastern and northern directions sharply increases, although the southeastern and southern ones prevail with heights (H_s) of up to 2 m, with a frequency of 72.1%. The repeatability of wave heights in the range of 2.1–4.0 m increases compared to July-August to 22.7%, and more than 4.0 m to 5.1%. In October-November, the wave disturbance of the northern rumbas prevails. The frequency of waves with heights (H_s) up to 2 m is 52.5%. The repeatability of wave heights in the range of 2.1–4.0 m increases to 33.6%, and more than 4.0 m to 13.9%. Waves with heights of more than 6 m are characteristic of the northern and northeastern directions [18].

Currents and tides

The Okhotsk Sea is characterised by an extremely variable current caused by winds and tides of the Pacific Ocean. Also, stable anticyclonic cycles are observed in the sea [13].

Along the northeastern coast of Sakhalin, there is a constant cold East Sakhalin current (Fig. 2.3). In the winter-spring period, the velocity of the bottom current varies within 10–20 cm/s; in the summer-autumn period, values range from 5–7 cm/s [15]. In summer, the emergence of wind-drift currents of northern directions in the presence of southern and southeastern winds is noted.

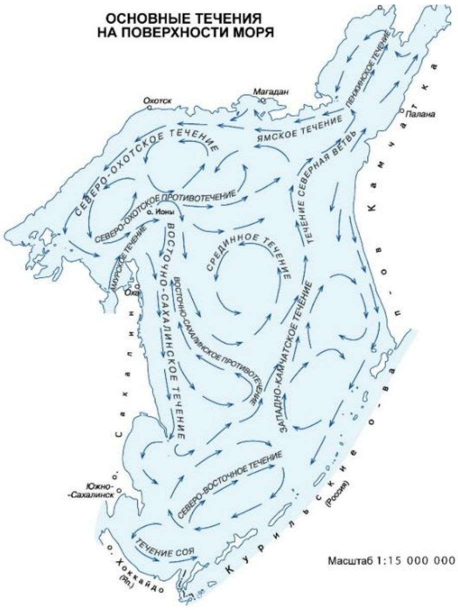


Figure 2.3 Currents and their directions on the surface of the sea [13]

The tidal currents have the most significant impact. They are observed at sea in the range from 5–10 to 20–25 km. In the area of the Piltun-Astokhskoye field, a speed of 60–80 cm/sec was noted. In the Chayvo area, the rate of tidal currents was observed at 35 cm/sec [16].

Tides are caused by tidal waves from the Pacific Ocean and have a daily nature. The most common tidal amplitudes of the Okhotsk Sea range from 1 to 7 m [14]. They significantly affect the hydrological regime of coastal zones. Velocities of tidal currents are small: up to 4 m/s, however, near bays and coasts velocities increase.

2.2.4 Ice conditions

Since the winter period is particularly severe, most of the Okhotsk Sea (from 60% to 97%) is covered with ice [14]. Ice begins to form at the end of the third week of November along the coastal waters of the northeast shelf (ice needles, sludge, snow slush) [15]. By the end of December, all drifting grey-white and thin first-year ice fill the Sakhalin bay, and in January it is carried to the shelf of the north-east coast. Favourable conditions for the formation of fast ice are created. In January, ice formation continues, first in the form of nilas and grey ice, and then in the form of grey-white and thin first-year ice [15]. In February, the entire shelf is already covered with ice and hummocks begin to form, as well as stamukhas, which bring with them a danger to the bottom structures (depths less than 30 m) [16]. Emerging storms with strong winds increase the drift to the South, and the headwind drives the ice back, which only enhances the formation of ice ridges and hummocks [16]. In March and early April, the ice state reaches its most considerable difficulty. In years with typical winter weather conditions, the sea is cleared of ice by mid-May, in more severe years – by the end of June [16].

On average, ice is present in this region most of the year, from about six to seven months. Icebergs in this sea are not found at all. Only first-year ice is the only type that exists in the Okhotsk Sea. The ice level can vary from 1.6 to 1.7 m by the end of winter. The average ice velocity is 0.3–0.4 m/s (in winter) [17].

In mid-winter, the average number of ice ridges with heights of the surface part of hummocks exceeding a height of 1 m is 5–7 per km [17]. The average height of the hummock sail used to develop design criteria for ice loads ranges from 5.5 to 6.0 m. The keel depths are distributed in the range from 22 to 24 m. The consolidated part of the hummock has an average thickness from 2.4 m to 2.8 m [17].

The concentration of sea ice in the Arctic regions is shown in Figure 2.4 [19].

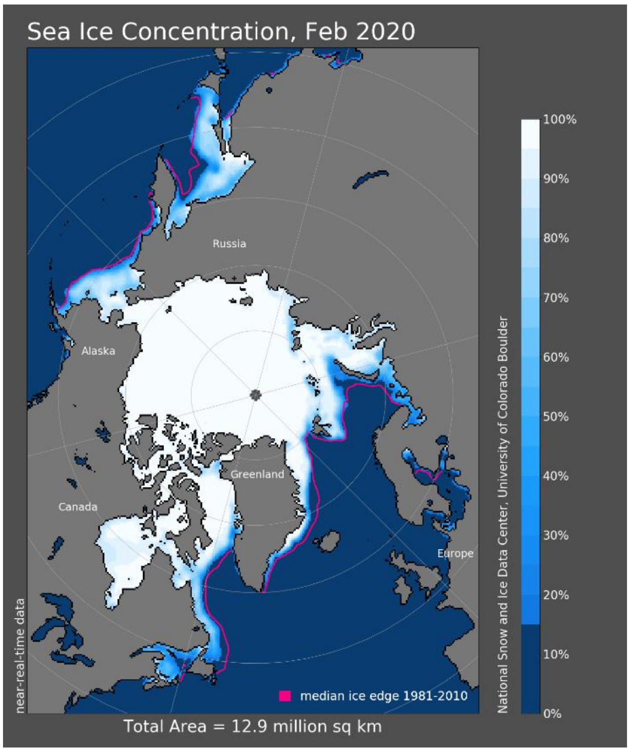


Figure 2.4 Sea ice concentration in the Arctic regions, February 2020 [19]

As can be seen from this figure, the ice concentration in the region of Sakhalin Island reaches values from 60 to 100%. Compared to other Arctic regions, the ice conditions are quite moderate. However, ice conditions are still severe enough to develop offshore deposits. More detailed ice conditions of the Okhotsk Sea off the coast of Sakhalin Island are presented in Figure 2.5 [20].

Figure 2.5 shows the ice conditions of the Okhotsk Sea in the region of Sakhalin Island; the data are valid to February 10, 2020. As can be seen, thin first-year ice with a thickness of 30 to 70 cm extends along the entire eastern coast of the island. Large ice fields (100–500 m) and fragments of ice fields (100–500 m) are also found in places. If we move east, to the central part of the sea, a change in the ice cover will be observed. First, grey-white ice (thickness 15–30 cm) with interspersed coarse ice will be encountered, and then nilas (thickness up to 10 cm). In the southern part of the island, in Aniva Bay, nilas is mainly concentrated up to

10 cm thick, as well as coarse ice. To the south of the bay, closer to Cape Aniva, there is a debris of ice fields (100-500 m), as well as coarse ice (20-100 m).

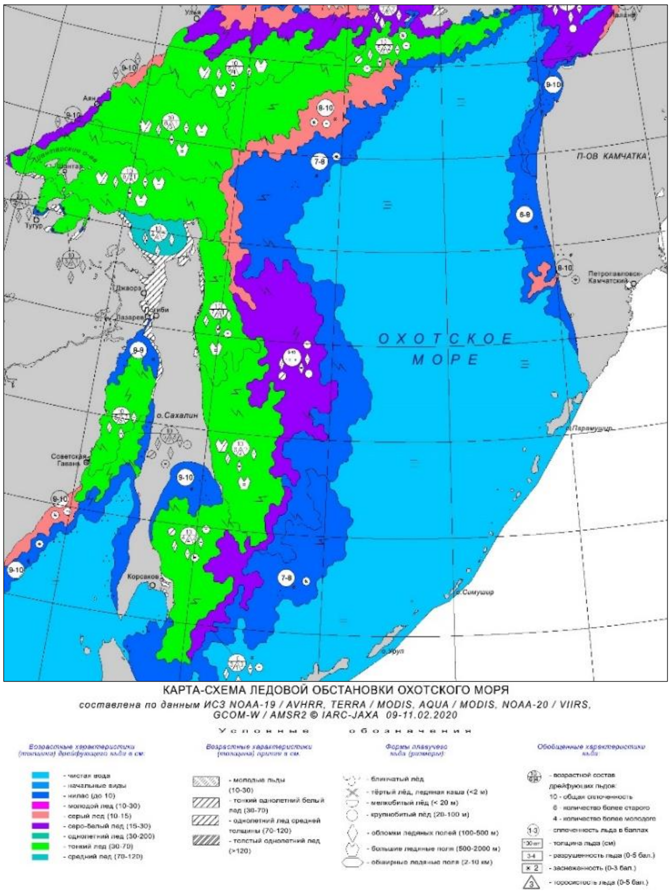


Figure 2.5 Ice conditions of the Okhotsk Sea near Sakhalin Island, 10/02/2020 [20]

The most significant ice concentrations (90–100%) occur in the southeast from Cape Terpeniya to Cape Aniva. The northeastern part of the sea is covered by ice from 80% to 90%. Since most deposits are located along the northeast coast of the island, the field development project should take into account the current ice situation.

2.2.5 Seabed characteristics

The island shelf is an area with active sedimentation and erosion. The relief of the seabed is continuously changing the influence of wave disturbance, currents and ice gouging.

The Sakhalin shelf is characterised by a rather sharp increase of depth from the coastline, approximately 6 m. At depths of 6–12 m, the bottom slope will already be 0.2%. In the coastal zone (with a water depth of 0 to 12 m), discontinuous sandbars stretching from 0.5 to 1 m high extend parallel to the coastline [16].

Bottom sediments in the area of the license block are mainly formed: fine undifferentiated sands along the coastline, very fine Aleurites and fine silt sludges further from the coast, clayey silts in the depths of the sea [13].

Table 2.3 represents the characteristics of the seabed.

Table 2.3

Characteristics of the seabed [21]

Parameter	Description
Seabed topography	Plain terrain with a slight slope (in places with small ridges and hills)
Depth of the sea, m	63–93
Seabed soil	Tight sandstones and gravel with small boulders (4–6 m).

2.2.6 Seismic activity

The Far East, including the Okhotsk Sea, is considered a seismically active zone, which leads to the likelihood of earthquakes. Therefore, the design process should include an assessment of the effects of earthquakes and tsunamis.

Seismicity

According to the general seismic zoning maps (OSR-97), the northeastern coastal part of Sakhalin and the adjoining part of the continental shelf is characterised by an 8–9 point seismicity. Average recurrence period of such earthquakes of 500 years, in some areas an 8–9 point seismicity with a recurrence period in 1000 years [18].

In general, the seismicity indices of the Piltun-Astokhskoye field are lower compared to those in the regions that experienced the most significant earthquakes (Nogliskoe 1964 and Neftegorsk 1995). Based on seismic zoning, the studied shelf area can be attributed to the zone of moderate seismic activity [18].

Tsunami

The primary source of tsunamis in the Okhotsk Sea is earthquakes in the Pacific Ocean. However, the sea does not feel the tsunami spread to a great extent since the main part of its energy is perceived by the Kuril ridge. Also, mathematical modelling was carried out to predict tsunamis with a frequency of once every 50 years. The results showed the following wave heights: for Nabil - 3.1 m, for Katangli - 3.9 m, for Chayvo - 5 m [16].

Conclusion

This chapter discussed various climatic characteristics and environmental features of the Arctic region as a whole. This study showed that the Arctic region is an extremely harsh climatic zone of the Earth with challenging weather conditions for the development of offshore deposits.

The climatic conditions of the Okhotsk Sea are examined with an emphasis on ice conditions in the region of the northeastern part of Sakhalin Island. The results of the study showed that, although the Okhotsk Sea does not belong to the Arctic region in a geographical sense, its natural conditions are entirely comparable with the Arctic.

3. AYASHSKY LICENCE BLOCK DESCRIPTION

The Ayashsky license block is a block of fields that is part of a large-scale oil and gas project - Sakhalin-3, which also includes three more blocks – Kirinsky, Vostochno-Odoptinsky and Veninsky (Fig. 3.1).

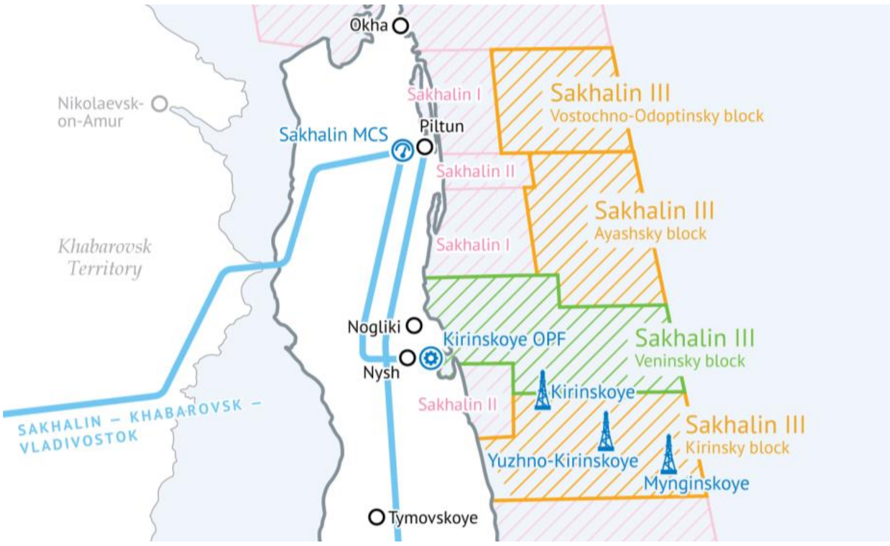


Figure 3.1 Map of the Sakhalin III project

According to experts, Sakhalin-3 is an up-and-coming project, since the predicted recoverable resources (C1 + C2 categories) exceed 700 million tons of oil and 1.3 trillion m^3 of gas [22].

The Ayashsky license area (LA), whose territory is 4294 km^2, is located on the northeast shelf of Sakhalin. Gazprom has owned the license for its development since January 2017, and Gazpromneft-Sakhalin is responsible for the development activities. Previously, 3D-seismic exploration was carried out on 2150 km^2 of license block. Based on the results of the analysis of geological and geophysical data, the two most promising structures, Ayashskaya and Bautinskaya, were selected for subsequent work.

In mid-2017, drilling was carried out on the Ayashskaya structure. In October of that year, an influx of oil from prospecting and an appraisal well was received. The field was called Neptune, whose geological reserves are estimated at 255 million tons of oil equivalent (in 2018, geological reserves were estimated at 415.8 million tons of oil in categories C1 + C2). The field is located 55 km from the coast, the depth of the sea in the drilling area is 62 m, and the depth of productive formations is 2–2.7 km [23], [24].

In November 2018, as a result of drilling a second exploratory and appraisal well, the second field on the Bautinskaya structure was discovered. This field was named Triton. The geological reserves of this field are estimated at 137 million tons of oil equivalent. The sea depth in the area of well's drilling is 80 m, and the depth of productive formation is up to 3 km [25]. The distance between the two fields is estimated at 30 km.

Figure 3.2 represents the map of the Ayashsky license block with the discovered fields.

Figure 3.2 Map of the Ayashsky license block

At the moment, the deposits are still at the stage of geological exploration, followed by the evaluation stage up to 2022–2023. Field exploitation is expected to begin in 2025–2030 with estimated production volumes of up to 8 million tons of oil per year [26].

Table 3.1 represents summarised data about both of the fields.

Table 3.1

Data of the Ayashsky licence block fields

	Sea depth	Depth of productive layers	Geological reserves	Recoverable reserves	Initial flow rate
Neptune	62 м	2–2,7 km	415,8 million tons of oil (C_1+C_2)	70 million tons	N/A
Triton	80 м	3 km	137 Mtoe	45 million tons	230 m^3/day

4. SELECTION OF A FIELD FACILITIES FOR DEVELOPMENT OF AYASHSKY LICENSE BLOCK

The choice of a development method of any field is a crucial component of project success. Offshore fields are prone to this to the highest degree since, in the process of choosing the development concept of an offshore field, it is necessary to take into account the influence of three spheres of the planet: atmosphere, hydrosphere and lithosphere [27]. Where, in turn, the hydrosphere makes the most significant contribution to the creation of adverse working conditions. Since the influence of such aggravating natural phenomena as currents, waves (tidal and wind), ice, icebergs and others are continuous.

The consequences of the wrong choice can be fatal for the entire project, from low production rates and unprofitability of production to an environmental disaster in case of violation of the offshore oil and gas facilities integrity. Based on this, it becomes obvious the importance of making the right decision at the very beginning of the field concept development. We are talking about the initial stages because only then it is possible to make the least costly changes to the development project. Figure 4.1 shows a graph demonstrating the relationship between the changes made to the project and the costs involved [28].

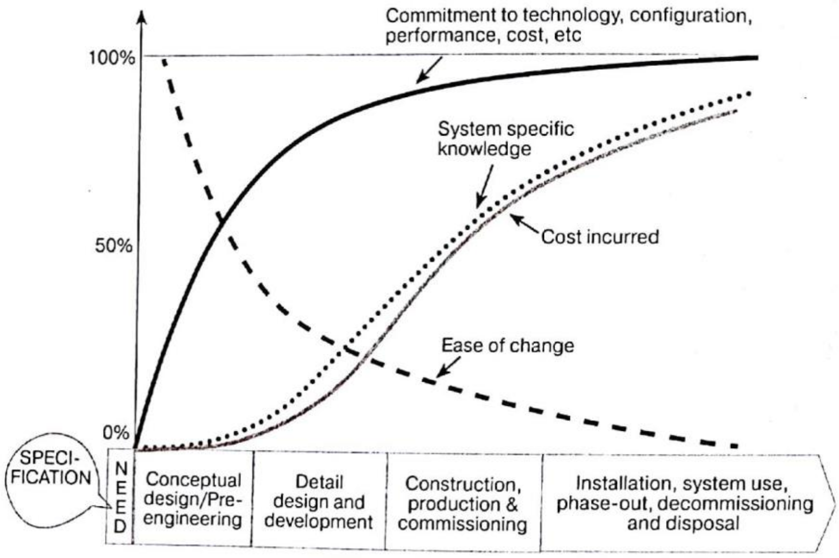


Figure 4.1 Project phases and commitment to costs and technical issues [28]

As can be seen from the graph in Fig. 4.1, permissible changes that do not cause a sharp increase in the actual cost of the project are possible at the conceptual design stage. The next phase of detail design and development will already mean an increase in actual price in case of changes. That is why it is necessary to choose the right concept, which has gone through several approval stages.

Then a logical question arises – what is the basis of decision-making? In the next chapter, we will consider the main factors affecting the choice of an offshore structure for the development of an offshore field.

4.1 FACTORS AFFECTING SELECTION OF OIL AND GAS OFFSHORE STRUCTURE

The validity of the choice of a specific offshore oil and gas structure is determined by the degree of its compliance with several factors. Since the list of these factors is quite extensive, they are combined into five main groups [27]:

1. Hydrometeorological and geographical;
2. Engineering and geological;
3. Technological;
4. Manufacturing;
5. Ecological.

In order to make a reasonable selection of an offshore oil and gas structure (OGS) in the future, it is necessary to study and analyse each group in detail separately.

Hydrometeorological and geographical group

This group is fundamental in choosing an offshore structure. The following list includes factors [27] from this group, as well as their significance for the selection of offshore facility.

The sea depth at the installation site	→	Determines the type of structure (seismicity must be taken into account).

Ice conditions	→	Defines the class of structures and anti-icing measures
Duration of the ice-free period	→	Determines the timing of drilling and construction work
Hydrological conditions (currents, wind, waves, water properties)	→	Determines the magnitude of the loads on the structure from the appropriate forces and material for the construction
Air temperature	→	Determines the choice of surface equipment
The geographical position of the field	→	Determines the remoteness of the structure from the coast, and therefore the type of serving transport

The above list reflects the almost fundamental importance of this group since all factors are of crucial importance in choosing the type of structure, as well as the entire field development concept. The parameters of all factors of this group were considered in section 2.2.

Engineering and geological group

The current group of factors is necessary to determine the foundation of the structure. It helps to determine what the underwater part of the structure will be (for example, gravity or pile) depending on many geological parameters. The following is a list of factors [27] and their significance for the process of offshore facility selection.

Geology of the bottom at the installation site	→	Determines the characteristics of soils, and hence the foundation type
Parameters of the topsoil	→	Determines the necessary degree of protection of the base in the fundamental part of the structure from erosion as a

		result of the total impact of currents and storm waves
Current data on tectonic processes in the region	→	Determines the variability of the bottom, which requires additional attention when choosing the base of the structure
Physico-mechanical properties of soils	→	Determines the type of fundamental part of the structure (gravity or pile)

The above list reflects the importance of knowledge of the engineering-geological factors' characteristics. Since their incorrect assessment or underestimation can cause an emergency condition of the engineering structure during installation or, in the worst case, during operation. The latter outcome can cause widespread damage to the ecological state of the region.

Technological group

The current group has the most considerable influence on the design choice of the marine structure topside. The list of factors is given below [27].

Well type	→	It determines the dimensions of the topside since the composition of the necessary equipment depends on the kind of well (prospecting, exploration, production).
Number of wells	→	
Drilling depth	→	Determines the type of drilling equipment whose dimensions affect the mass and dimensions of the structure's topside
Hydrocarbons type	→	Defines the method of operation and the composition of equipment for operation
Technological scheme of product preparation	→	Determines the necessary equipment, its location, and therefore the dimensions of the topside

Hydrocarbons transportation method	→	Determines the need for storages for extracted hydrocarbons

Hydrocarbon process analysis shows that the main criterion for choosing the topside of the offshore structure is equipment. Since its composition and quantity significantly affect the mass and dimensions of the topside of the structure. Additionally, it is necessary to take into account the presence of residential units, as well as a helipad for crew change or supplying the structure with everything essential to ensure smooth operation. Based on this, it is necessary to conduct thorough and detailed modelling of the scheme of the future topside of the platform to take into account all the required elements of the platform.

Manufacturing group

This group of factors has an indirect effect on the selection of the offshore structure type. It determines the availability of a technical and raw material base to support construction and operation. Below are several significant factors [27], as well as their significance for the choice of offshore facility type.

The presence of enterprises for the manufacture of structures	→	Determines the need to create technologies for transporting the assembly in place (if the enterprise is far away)
Availability of equipment for creating foundations	→	Determines the choice of foundation design of the structure
Infrastructure	→	Determines the need to build temporary or permanent coastal bases to support the construction of the facility and field exploitation
Parameters of available auxiliary transport vessels	→	Determines the permissible mass and dimensions of the facility parts for

		transportation and method of mounting the topside
Availability of equipment for the construction of artificial objects	→	Determines the possibility of building soil islands and protective berms around the fundamental part of the structure

A series of the above factors indicate that the construction of such large-scale structures requires significant production and technical support capacities. The list of influencing factors can be expanded depending on the specific project based on a thorough technical and economic analysis.

Ecological group

This group of factors does not have a direct impact on the choice of an offshore facility. However, it must be taken into account in the development of a modern project. Currently, more and more attention are paid to the integrity and preservation of nature, subject to the influence of multiple technological processes. Therefore, all modern projects take into account measures to reduce environmental impacts. Environmental factors are used to adjust this effect. Below are some key factors [27] and their importance for environmental monitoring.

The ecological vulnerability of the area	→	Determines the scope of work to create environmental safety against potential technological threats
Minimisation of industrial waste dumps	→	Determines the need to create technologies and related equipment to perform these processes
Providing a monitoring system	→	Determines the need for technology to ensure environmental control

One of the essential criteria of modern oil production is the maximum preservation of the primaeval environment in the area of oilfield activity. A group of environmental factors is a primary means of regulating ecological safety.

Once the main factors that influence the selection of an offshore structure for oil and gas production have been identified, it is possible to start the structure selection for the conditions described in section 2.2.

4.2 SELECTION OF AN OFFSHORE OIL AND GAS STRUCTURE

The design of an offshore facility for the project field is carried out at the stage of concept development for an offshore oil and gas field [27]. Before this, the following steps must be performed:

- Exploration stage;
- Stage of the investment construction project (including feasibility study);
- The step of creating design and technological documentation for the development of oil and gas fields.

Only after passing through these stages, it is possible to start the field infrastructure development. The main objective of this stage is the technical and technological feasibility of the approved schemes [27].

There are several ways to classify offshore facilities. If you approach from functional characteristics, then you need to use the first level of classification. It distinguishes two types of structures depending on the well kind [29]:

1. For exploratory drilling;
2. For drilling and production.

Within the framework of this work, it is planned to select an offshore facility for hydrocarbon production from an already explored field with proven reserves (see Table 3.1). Therefore, based on the above classification, the selection of structure should be carried out from the list of facilities for wells drilling and production.

There is also a second level of classification, which involves the division of structures based on ice resistance. Accordingly, ice-resistant and non-ice-resistant structures are distinguished [29]. Since the Okhotsk Sea belongs to the category of seas with seasonal ice formation (see 2.2.4 Ice conditions), the choice must be made from the list of ice-resistant structures.

Based on the two above classifications, in the framework of this work, it is necessary to consider offshore facility included in the group of ice-resistant structures for wells drilling and operation. The following list of structures falls under these criteria [29]:

- Ice resistant artificial gravel islands;
- Tunnels and mines;
- Ice-resistant piled stationary platforms;
- Ice resistant gravity platforms;
- Subsea production systems.

This list can be expanded by adding an FPSO in ice-resistant design. Two of these vessels (Terra Nova and SeaRose) have had successful field experience near Newfoundland Island in Canada.

Section 4.1 outlined in detail the factors that influence the choice of offshore facility type. Each of them has its meaningful significance. However, they are quite detailed and made for a thorough study of the selected type of marine structure design. If it is necessary to make only a fundamental choice of technical facility, then they are limited to a narrower range of factors. Usually, these factors are selected from the analysis of the hydrometeorological and geographical group, supplemented by a group of manufacturing factors.

The most obvious way to select the appropriate type of structure(s) is through comparative analysis based on a matrix diagram. In Table 4.1, a comparative analysis is carried out between the above types of facilities based on the factors established in section 4.1. Depending on the extent the type of structure meets the requirement of the presented factor, it is assigned an appropriate rating. After the table is completed, the results are summarised.

Before filling out the table, it is necessary to clarify the requirements of the factors:

- Sea depth: 60–80 m (Table 3.1);
- Ice conditions: first-year drifting ice (section 2.2.4);
- Remoteness from the shore: 55 km (Figure 3.2);
- Infrastructure: is there a suitable infrastructure to provide this type of facility;
- Availability of enterprises.

Table 4.1

Comparative analysis of offshore oil and gas structures

Group	Factors	Type of facility					
		Ice resistant artificial bulk islands	Tunnels and mines	Ice-resistant piled stationary platforms	Ice resistant gravity platforms	Subsea production systems	FPSO*
Hydrometeorological and geographical	Sea depth	🔴	🟡	🔴	🟢	🟢	🟢
	Ice conditions	🟢	🟢	🟢	🟢	🟢	🟢
	Remoteness from the shore	🟢	🟡	🟢	🟢	🟢	🟢
Manufacturing	Infrastructure	🔴	🔴	🟡	🟡	🟡	🟡
	Availability of enterprises	🟡	🔴	🟡	🟡	🔴	🔴

🟢 – applicable;
🟡 – research is required;
🔴 – not applicable.
*Ice management required

The analysis of Table 4.1 shows that if we proceed from the most crucial factor determining the fundamental type of structure, the depth of the sea, then only three types of structures can fit the current conditions:

- Ice resistant gravity platforms;
- Subsea production systems;
- FPSO (with ice management implemented).

Ice-resistant artificial bulk islands are limited to depths of up to 15 m, and ice-resistant stationary pile platforms up to 50–60 m [29]. If we talk about tunnels and mines, it is necessary to conduct a thorough preliminary analysis of soils to find out whether it is possible to create such a type of structures under the seabed in this region.

The criterion of remoteness from the coast can be a problem for such types of structures as tunnels and mines. Based on the available data, this technology is applicable in areas at a distance from the coastline from 25 to 50 km, which does not meet the given conditions [30]. For all other types of structures, the specified distance from the coast is not critical. However, this criterion needs to be analysed in more detail regarding the choice of transporting method of hydrocarbons to land.

Factors from the manufacturing group turned out to be the most controversial in terms of assessment. If we talk about infrastructure, then only two types of structures do not satisfy this factor: ice-resistant artificial bulk islands and tunnels and mines. The reason is that there are no raw material bases for the continuous provision of such structures on the northeastern coast of Sakhalin. An island structure requires a coastal base connected with the island, for example, an artificial bulk road (which is impossible due to the depth of the sea). If we talk about the tunnel-mine type of structures, then there should be a full-fledged base on the shore. It should provide all the needs for the construction and operation of deposits, facilities for processing and preparing of HC, residential blocks for personnel etc. The remaining types of structures also require the creation of their infrastructure. However, if the production capacities of the neighbouring projects Sakhalin-1 (onshore processing facility – Chaivo OPF) and Sakhalin-2 (onshore processing facility in Nogliki) allow for the adoption of additional volumes, then through the contract it was possible to agree on the joint use of coastal complexes. However, this requires further analysis.

The last factor – the availability of factories – turned out to be inapplicable to three types of structures: to subsea production systems and FPSO. The reason is that there are no enterprises for the construction of such structures and no experience in our country. Only in 2019 began the test production of some elements of the subsea production system at the Izhorskiye Zavody enterprise [31]. However, they are still waiting for testing and far from mass production. Accordingly, the use of these types of structures will require imports, which will entail additional questions on how to transport equipment to the site.

Enterprises where it would be possible to build such types of offshore facilities as ice-resistant artificial bulk islands, ice-resistant pile stationary platforms and ice-resistant gravity platforms exist on the territory of the Russian Federation. However, the experience in creating such structures is small; therefore, additional research is required. Potential sites for the construction of such structures in the Far East can serve:

- OJSC Amur Shipbuilding Plant (the support of the Molikpak platform was built, and the Orlan platform was modernised);
- The Zvezda shipyard;
- Vostochny Port (here were built the following structures: the reinforced concrete support base of the Berkut platform, the concrete base with four supports of the Lunskaya platform and the concrete base of the Piltun-Astokhskaya B platform).

Based on the analysis, we can conclude that the most suitable structures for the exploitation of an offshore field in the Okhotsk Sea under the given conditions can be:

– Ice resistant gravity platforms;

– Subsea production systems;
– FPSO.

It is also necessary to evaluate the approximate economic component to understand the appropriateness of applying the three above options.

As mentioned above, at the moment in the Russian Federation, there are neither production facilities nor technologies for offshore structures manufacturing. This fact leads to the need to purchase OGS from foreign manufacturers.

Until recently, ice-resistant gravity platforms were the only way to develop offshore fields. All projects of Sakhalin, except for the Kirinsky deposit (Sakhalin–3), are equipped with gravity platforms. This conceptual solution is justified for the natural and climatic conditions of the Sea of Okhotsk. The reinforced concrete platform can withstand the enormous loads of wind, waves, ice, currents, as well as the seismic activity of the region. Moreover, in our country, there is a technological experience in the manufacture of reinforced concrete foundations for gravity platforms (see above). However, the price for such a structure is quite high. For example, the cost of the Berkut platform from the Arkutun-Dagi field is estimated at $ 1 billion. Other platforms on the Sakhalin shelf are also of the high price.

However, two factors must be considered here. Firstly, the topsides of all platforms were manufactured and fitted up with a foundation in Korea, since Russia lacks experience and technologies for designing the topside of the platform. This fact imposes an increase in the cost of the entire structure since double transportation will be required: first, the foundation to Korea, and then the assembled platform to the site. Secondly, all Sakhalin platforms are installed in the shelf zone at shallow depths. The minimum depth is 15 meters (the Orlan platform at the Chayvo field), and the maximum depth is 48 meters (the Lunskaya-A platform at the Lunskoye field). Given that the Ayashsky licence block deposits are at depths of 62 and 80 m (Table 3.1), the foundation for the platform will need to be significantly increased in height. And this means additional capital costs, which leads to an increase in the final price of the structure. So, for example, the cost of the reinforced concrete foundation of the Norwegian platform Statfjord B is estimated at $ 1.8 billion. The sea depth at the platform installation site is 145 meters. Based on this, we can conclude that the cost of the platform for the Ayashsky licence block will exceed the price of the common platform of the Sakhalin shelf in $ 1 billion.

The subsea production system is a fairly common way to develop offshore fields. For example, Norway has long applied this technology on its shelves on a large scale. This technology is characterised by high environmental safety, since the equipment does not experience stress from the natural effects of ice, wind, low temperatures, and it is also not subject to icing. The likelihood of equipment integrity damage or destruction due to environmental influences is less than that of the platform or the FPSO. But most importantly, the SPS does not require the presence of maintenance personnel at the field during the development process. All management is entirely autonomous, which means that this type of OGS does not constitute an object of increased danger for working personnel. This technology has not been used on the Russian shelf for a long time since the lack of technology and production bases did not allow this. However, in 2010, Gazprom dobycha shelf signed a $ 190 million contract with the American company FMC Technologies (now TechnipFMC) for the manufacture and supply of subsea equipment for the development of the Sakhalin–3 project Kirinsky field [32]. This event was a new stage in the development of the domestic offshore oil and gas industry. The use of this type of OGS allowed abandoning the installation of an expensive platform. However, it should be noted that despite the relatively low cost of the SPS compared to the platform, just the equipment by itself does not form the price of the entire project. The rental charge of equipment for transportation and installation of the SPS makes a significant contribution to total costs. This is because the process of installing all the SPS elements on the seabed takes a very long time and often does not occur in one weather window. This fact entails equipment downtime and the need to pay additional rent. Cost analysis of this stage is fundamental in the process of assessing the value of the project.

The FPSO has never been used on the Russian shelf. However, this method is quite cost-effective, since all the necessary equipment for the development of the field is onboard, and this vessel does not require a long and expensive installation (compared to other stationary OGS). Additionally, the laying of subsea pipelines is not needed, since all products are offloaded to tankers from the vessel. However, based on publicly available data, the cost of such a construction varies within $ 800 million, which is extremely expensive. Also, based on the climatic conditions of the Okhotsk Sea, this vessel should be ice-resistant, since most of the year the sea is covered with annual ice with the formation of ice structures. The FPSO should also be adapted to the harsh sea and ice conditions of the Okhotsk Sea. Such modernisation of the vessel imposes additional costs, which ultimately leads to an increase in the final price of the structure.

The above approximate estimate of the economic component of the three selected OGS allows assessing the applicability of each of the structures to the conditions of a given license block. The results showed that at this stage, the applicability of the FPSO is not advisable for the conditions of the Okhotsk Sea. Otherwise, it will require costly modernisation of the entire ship, as well as the winterisation of the equipment. The accumulated world experience is still small for the implementation of such a solution in Arctic shelf projects.

The ice-resistant gravity platform and the subsea production systems are the most realistic concepts for the development of Ayashsky license block of deposits, as there is already experience in using such offshore structures on the Sakhalin shelf. The use of both facilities implies the involvement of foreign partners as suppliers, as well as for contract job. The SPS has the advantage of environmental and human safety and gravity platforms in the form of vast accumulated experience. However, it is worth paying attention that the costs of developing offshore fields via platforms exceed more than two and a half times the costs of developing using subsea production systems (Fig. 4.2) [27].

Based on the graph in Figure 4.2, we can say that the use of SPS is a more profitable technology. Therefore, in my opinion, the arrangement of the Ayashsky license block must be carried out using these systems.

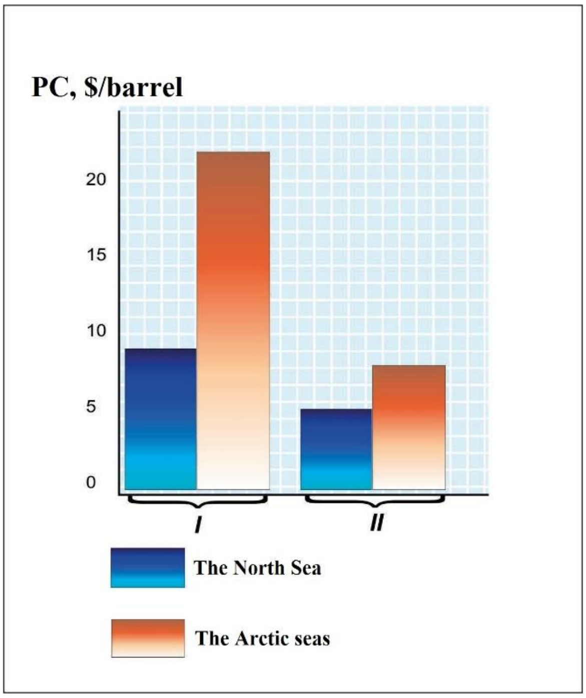


Figure 4.2 Comparison of production costs (PC) from the platform (I) and the SPS (II) [27]

Conclusion

In this chapter, an analysis of the existing factors that influence the choice of an offshore oil and gas structure was carried out. A review of offshore structures was carried out, the use of which is possible on the shelf of the Okhotsk Sea in the conditions of the Ayashsky license block. Then, based on the results obtained, a comparative analysis of the identified structures was carried out, guided by the previously described factors. The study helped to identify the three most suitable types of structures: ice-resistant gravity platforms, subsea production systems and FPSO. The analysis finished in a fair economic assessment, which helped to identify the most suitable structure for use – the subsea production systems.

5. THE SELECTION OF THE INSTALLATION METHOD OF THE FIELD FACILITY

There are a considerable number of auxiliary technical means that are usually involved in the development of an offshore field. The list is vast, starting with a simple small-sized transport vessel and ending with huge heavy-lift cranes. This diversity is since each marine structure requires an individual approach to the installation, taking into account the existing limitations for it. This chapter will discuss the basic installation methods for the three types of OGS selected in Section 4.2, as well as the vessels applied for this.

5.1 INSTALLATION METHODS

5.1.1 Installation of floating structures

There are exist several floating structures that are used for offshore development. Among them can be named FPSO (floating production storage and offloading vessel), semi-submersible vessel, conventional TLP (tension leg platform) and spars, which are also known as deep draft caisson vessel.

The main thing that unites all these floating structures is mooring lines. Mooring lines keep the vessel on its prescribed place. Mooring lines can be installed before the ship will arrive on its location (in case of FPSO, TLP (tendons are used) and spar vessels) or after arriving (in case of a semi-submersible vessel) [33]. The ship is usually transported to the site by towing with the tugs (FPSO), so-called wet towing, or on the deck of the cargo barge (hull and deck of the structure are transported separately and assembled on the site) – dry towing.

To install the vessel successfully, it should be stable during the whole process of connection with mooring lines or during the assembly of the hull and deck (spar and TLP). It could be achieved only in conditions of the calm sea (no harsh waves) and light wind. Moreover, the connection can be made only in iceless terms.

5.1.2 Installation of platforms

A few methods are used for platforms installation.

Heavy lift

This method is considered as a conventional one for the installation of the offshore platforms. Two types of vessels are involved in this method: a transportation vessel and a crane vessel. The platform is connected with the hook of the crane vessel via the lifting lugs and slings. The crane lifts the platform from the transportation vessel and then lower it into its position.

When an increased capacity is required, heavy lift vessels are used.

Launch

This method is usually applied for the installation of jackets platforms, in a case when its weight is too significant for the lifting capacity of available cranes [33]. In this method, the jacket platform arrives at the site on the deck of the launch barge. Then the barge starts trimming to initiate the sliding of the jacket over its stern. When the centre of gravity of the platform passes over the rocker arm hinges, the barge starts to move in the opposite direction. Due to these motions, the platform completely slides over the barge into the water. Then the final installation is realised.

Mating

This method is also known as “deck mating” or “floatover”. It is usually utilised when the weight of the deck exceeds the lifting capacity of a crane vessel. The mating operations involve the application of the transporting vessel, which can be represented by a flat top cargo barge or a heavy lift ship [33]. The most common deck mating method is the internal float over where the transportation vessel is manoeuvred between the legs of a fixed platform jacket.

All the methods mentioned above require excellent stability of the vessel to install or connect parts of the structure. Adverse conditions can cause installation errors and inaccuracies, which ultimately can lead to fatal consequences. Wind, waves and current conditions should be favourable enough to carry out the installation operation. Additionally, air temperature should be above zero to avoid the icing of the elements of equipment. Ice coverage should absent since none of the above methods is possible to realise with its presence.

5.1.3 Installation of subsea facilities

There are several installation methods for this type of structure, which can be grouped by the mode of transportation of the elements:

1. Wet transportation;
2. Dry transportation.

Wet transportation

This method of transportation implies that the necessary subsea elements are delivered to the field underwater. The following methods can be assigned to this group.

- Moonpool installation

This method was developed by Subsea 7 to install four templates in the Tyrihans field [34]. Three types of vessels are involved in the installation process: a cargo barge, crane vessel and an installation vessel (usually a monohull vessel) with moonpool. A feature of this installation process is the presence of an intermediate stage. This stage implies that the necessary elements of the SPS are transported by the cargo barge to the coastal zone, after which the crane vessel transfers the structures from the barge deck to the seabed for wet storage. When the installation process of the construction begins, the monohull vessel is positioned above the element. Afterwards, the ROV connects the ship with the structure using the rigging through the moonpool. After that, the suspended structure is transported underwater to the installation site and lowered to the bottom by a winch. ROV makes the final installation; it opens the protective hatches of the structure and cuts the hang off wires. Figure 5.1 shows the main elements of the winch lifting system [34].

- Pencil buoy method

Aker Marine Contractors patent this method. The main idea is to remove the load from the barge crane due to the weight of the structure (template or manifold). Three types of vessel are involved in the operation: a crane vessel, a cargo barge, and an installation vessel. In this method, the structure is lowered underwater in the coastal zone and then transported to the site suspended on a pencil buoy [35].

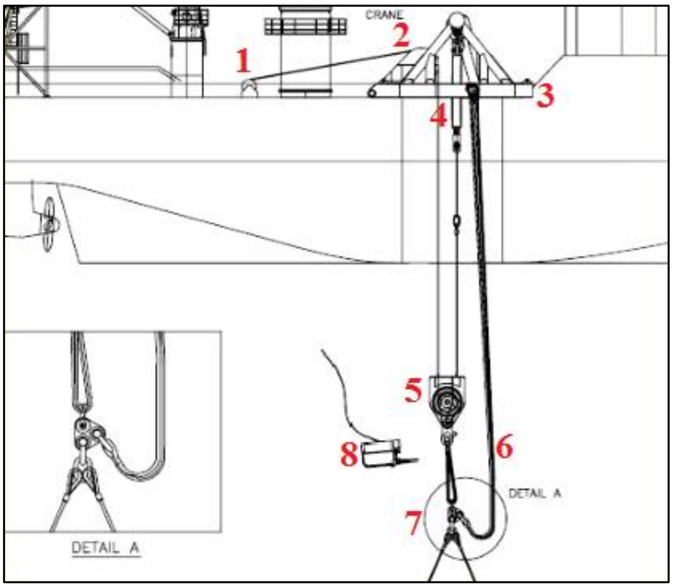


Figure 5.2 Hoisting system [34]

1 – winch; 2 – fairlead; 3 – hang off tower; 4 – cranemaster shock absorber; 5 – sheave; 6 – tow/hang off wire; 7 – structure rigging; 8 – ROV

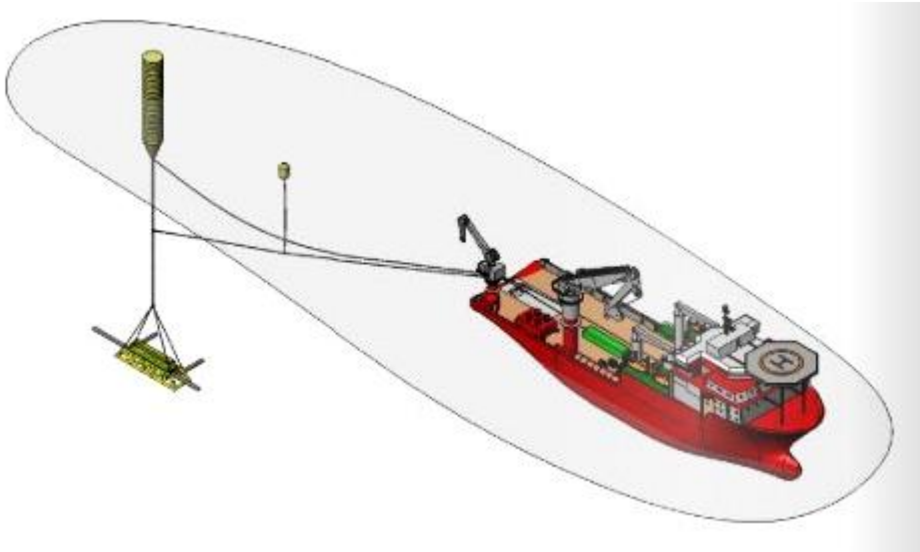


Figure 5.1 Pencil buoy method [35]

This method includes three main stages [36]. The first stage is carried out close to the coast. The crane vessel lifts off the structure from the cargo barge and positions it next to the installation vessel. Then the crane lowers the structure underwater whereby the load is transferred from the crane to the pencil buoy. The second stage is towing the structure connected with the buoy to the field. An auxiliary buoy and towing cables are used. The third stage is the installation of the structure in the site. The pencil buoy is disconnected, and the weight is transferred to the tow wire. The process is carried out by a tow wire supported by a heave compensator.

- Pendulous installation method

This unconventional method was developed by the Brazilian company Petrobras for great depths [37]. Two vessels are usually involved in the installation process: a crane vessel and an installation vessel. The main requirement is that the installation vessel should be located at a distance of approximately 90% of the installation depth of the subsea structure. When the desired position is reached, the crane lowers the element under the water and releases it. The structure is submerged via the pendulum trajectory until it reaches the target depth. After that, the final installation is made by the installation vessel (Fig. 5.3). Thus, three main phases of this method can be distinguished: the underwater lowering phase, the phase of free fall and the phase of the final installation.

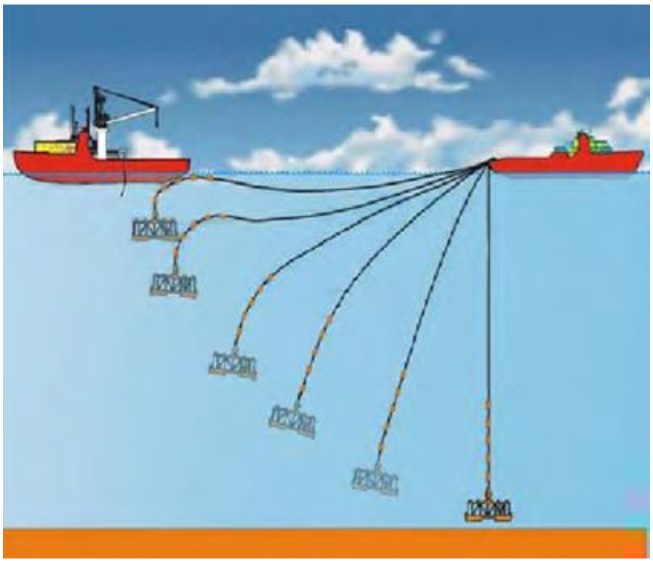


Figure 5.3 Pendulous installation method [37]

Dry transportation

This method implies that the structure will be transported to the installation site on the deck of a specialised vessel. The following methods can be assigned to this group.

- MODU installation

This installation method requires pre-installing piles through a temporary pile guide frame. The installation process is realised by keelhauling the template (other subsea structure) below the rig and lowering the template to the seafloor using the drill pipe [33].

- Heavy lift crane

The process of installation is straightforward. The crane of a crane vessel lifts the subsea facility from the transporting barge and then lowers it into water. Then the structure is further lowered to the sea bottom on the crane hook using the crane's underwater block.

5.2 TRANSPORTATION EQUIPMENT

In the previous section, possible ways of offshore structures installation at the sea bottom were described. Each method involves the use of specific transportation equipment. Therefore, this section presents vessels that can be used for the installation of OGS. In particular, for the subsea structures since this type of offshore structure was chosen for the arrangement of Ayashsky LA.

Barges

This type of vessel is used to transport structures from the coast to the field. Since they have a relatively simple design, their cost is quite low. Most often, the barge is towed to the place by specific tug boats. Barges come in various lifting capacities, and heavy ones are used for transporting offshore structures. There is a type of barge – a crane barge. Such a vessel is equipped with one or two cranes for moving structures, for example, the Ersai 1 barge.

Monohull vessel

A monohull vessel with a crane is used for the transportation of heavy cargos. Such a vehicle has a higher carrying capacity than barges. Monohull vessels are often equipped with a dynamic positioning system for improved navigational properties. Such floating cranes have a relatively high transit speed (8–14 knots) and are also well adapted to harsh environmental conditions. Floating crane vessels are often used as the main or auxiliary means of transport for the installation of offshore structures. An example of such a ship is the Saipem 3000.

Semi-submersible crane vessel (SSCV)

This vessel is another type of heavy cargo ship. The fundamental difference from the previous example is the design of the vessel itself. It consists of two or four pontoons and several columns, depending on the model. These types of ships are equipped with more powerful cranes with a higher carrying capacity than previous ones. However, due to the huge cranes and the large dimensions of the vessel, the transit speeds are reduced (8–10 knots). An example of such a structure is the Saipem 7000, Sleipnir and Thialf.

Support vessels

Auxiliary vessels are obligatory for any offshore operation. Below there is a list of such vessels [37]:

- ROV vessel – transports auxiliary equipment for the ROV and also serves as a place for its storage and maintenance;
- Diving vessel – contains all necessary outfit for diving operations;
- Supply vessel – a multipurpose vessel for transportation and supply purposes.

Installation of subsea facilities is highly dependent on the weather conditions. When the facility crosses the water level, it experiences a slamming load. Slamming loads in combination with other hydrodynamic loads profoundly influence on the stability of the object. They can cause undesired motions of the object – roll, pitch, and yaw – which lead to additional loads on the hanging wire that connect the hook and the crane tip. If these loads are of large magnitudes, the cable will eventually rupture. That is why the wave conditions should be strictly observed. It is also necessary to know whether the coincidence of the vessel Eigen period and the wave period is possible. It is essential to know to avoid resonance since such an event can also provoke negative consequences.

5.3 SELECTION OF THE INSTALLATION VESSEL

Since the conditions of the Okhotsk Sea are rather severe, with frequent wind waves, swell and storms, it is necessary to understand the applicability of the above transport vessels for these conditions. Based on the fact that the resonance of a ship and waves can cause severe difficulties in the installation process, it is necessary to understand whether the above-designated vessels can continue to operate in deteriorating conditions. It is required to determine the natural period of the ships.

Initial data are the characteristics of each vessel.

Barge "Ersai 1"

Length	(L)	= 139,84 m;
Breadth	(b)	= 42 m;
Height	(H)	= 8,4 m;
Typical draft	(d)	= 4 m;
Crane capacity	(C)	=1800 t + 300 t.

Monohull "Saipem 3000"

Length	(L)	= 162 m;
Breadth	(b)	= 38 m;
Height	(H)	= 9 m;
Draft	(d)	= 6,3 m;
Crane capacity	(C)	=2177 t + 544 t.

SSCV "Saipem 7000"

Pontoon length	(L)	= 165 m;
Breadth	(b)	= 87 m;
Pontoon sizes	(H_p)	= 165 m x 33 m x 11,25 m;
Height to the deck	(H)	= 43,5 m;
Column sizes	(a_c)	= 27x27 m;
Operational draft	(d)	= 27,5 m;
Crane capacity	(C)	= 7000 t + 7000 t.

Initial equation of motion in heave is [38]:

$$m\ddot{u}(t) + c\dot{u}(t) + ku(t) = Q(t) \tag{5.1}$$

where
m – mass, kg;
c – viscous damping;
k – stiffness, N/m;
$\ddot{u}(t)$ – acceleration, m/s^2;
$\dot{u}(t)$ – velocity, m/s;
$u(t)$ – displacement, m;
$Q(t)$ – external forces.

In the case of forced oscillations, the solution will take the form:

$$u(t) = u_h(t) + u_p(t) \tag{5.2}$$

where
$u_h(t)$ – homogeneous solution;
$u_p(t)$ – particular solution.

To solve the homogeneous part, it is necessary to assume c = 0 and also to establish the following initial conditions: $u(t=0)=0$ and $\dot{u}(t=0) = \frac{H}{2}\cdot\omega_0$. Then the solution will be:

$$u_h(t) = \frac{H}{2}\sin(\omega_0 t) \tag{5.3}$$

where
H – amplitude, m;
ω_0 – eigenfrequency, Hz.

The following equation can found eigenfrequency:

$$\omega_0 = \sqrt{\frac{k}{m}} \tag{5.4}$$

Then the Eigen period can be found as:

$$T_0 = \frac{2\pi}{\omega_0} \tag{5.5}$$

So that, stiffness and overall mass are required to find the value of the Eigen period.

The stiffness is determined as the resistance against the vertical motion [39]:

$$k = A_w \rho g \tag{5.6}$$

where A_w – an area in waterline, m^2;

ρ – water density, kg/m^3;

g – gravitational accelaration, m/s^2.

An overall mass in the Eq. 5.4 consists of the mass displacement of the vessel m_v and added mass m_A. Mass displacement of the vessel can be found:

$$m_v = \rho A_w d \tag{5.7}$$

where d – draft, m.

So, the final equation for the natural period of the vessel in heave looks like:

$$T_0 = 2\pi \sqrt{\frac{m_v + m_A}{A_w \rho g}} \tag{5.8}$$

Each vessel has its value of the added mass since it depends on the vessel shape. That is why the added mass should be calculated for the barge, the monohull and the SSCV separately.

Barge added mass can be found by the formula for the long cylinder in the infinite fluid [40]:

$$m_A^{bar} = \frac{1}{2} \rho C_A^{bar} A_R L \tag{5.9}$$

where C_A^{bar} – the added mass coefficient for the barge, in the present case $C_A^{bar} = 1,21$ [40];

A_R – reference area (for the barge $\pi \left(\frac{b}{2} \right)^2$), m^2;

L – length, m.

Added mass for the monohull vessel can be found assuming that it has the rectangular plate shape [40]:

$$m_A^{mh} = \rho C_A^{mh} V_R \tag{5.10}$$

where C_A^{mh} – the added mass coefficient for the monohull vessel, in the present case $C_A^{mh} = 0,88$ [40];

V_R – reference volume (for the monohull $\frac{\pi}{4} b^2 L$), m^3.

Added mass for the SSCV can be calculated, assuming that it has the shape of square prism [40]:

$$m_A^{ss} = \rho C_A^{ss} V_R \tag{5.11}$$

where C_A^{ss} – the added mass coefficient for the SSCV;

V_R – reference volume (for the SSCV $b^2 L$), m^3.

Now we can calculate natural periods for the three vessels.

The natural period in heave for the barge:

$$T_0^{bar} = 2\pi \sqrt{\frac{\rho A_w d + \frac{1}{2}\rho C_A^{bar} \pi \left(\frac{b}{2}\right)^2 L}{A_w \rho g}} = \tag{5.12}$$

$$= 2\pi \sqrt{\frac{1025,9 \cdot 139,84 \cdot 42 \cdot 4 + \frac{1}{2} \cdot 1025,9 \cdot 1,21 \cdot \pi \cdot \left(\frac{42}{2}\right)^2 \cdot 139,84}{139,84 \cdot 42 \cdot 1025,9 \cdot 9,81}} \approx 9,81 \text{ s.}$$

The natural period in heave for the monohull vessel:

$$T_0^{mh} = 2\pi \sqrt{\frac{\rho A_w d + \rho C_A^{mh} \frac{\pi}{4} b^2 L}{A_w \rho g}} = \tag{5.13}$$

$$= 2\pi \sqrt{\frac{1025,9 \cdot 162 \cdot 38 \cdot 6,3 + 1025,9 \cdot 0,88 \cdot \frac{\pi}{4} \cdot 38^2 \cdot 162}{162 \cdot 38 \cdot 1025,9 \cdot 9,81}} \approx 11,44 \text{ s.}$$

The natural period in heave for the SSCV (floating on the pontoons at the operational draft):

$$T_0^{SSCV} = 2\pi\sqrt{\frac{\rho A_w d + \rho C_A^{ss} b^2 L}{A_w \rho g}} = \tag{5.14}$$

$$= 2\pi\sqrt{\frac{\rho(6V_к + 2V_{понт}) + \rho C_A^{ss} b^2 L}{6a_к^2 \rho g}} =$$

$$= 2\pi\sqrt{\frac{1025,9\cdot(6\cdot 27\cdot 27\cdot 16,25 + 2\cdot 165\cdot 33\cdot 11,25) + 1025,9\cdot(0,25\cdot 165\cdot 33\cdot 11,25\cdot 2 + 0,47\cdot 27^2\cdot 16,25\cdot 6)}{6\cdot 27^2\cdot 1025,9\cdot 9,81}} \approx 15,39 \text{ s.}$$

Table 5.1 combines the obtained results.

Table 5.1

Figures of the natural periods in heave for the three vessels

Name of the vessel	Period, s
Barge “Ersai 1”	9,81
Monohull vessel “Saipem 3000”	11,44
SSCV “Saipem 7000”	15,39

Based on the fact that the peak period of the waves in the Okhotsk Sea varies between 4–12 seconds, it can be argued that the most suitable option is the SSCV Saipem 7000. Only its natural period of oscillations does not coincide with the waves period. However, the Saipem 3000 crane vessel is located in the border zone, so it is also acceptable for utilisation, provided that the weather and wave conditions are permanently monitored. It is also possible to increase the weight of the structure using ballast. This method will increase the added mass, and, therefore, the value of the natural period.

The value of the natural period oscillations in heave for the barge was the smallest one. The probability of resonance is extremely high, so the use of this vessel is not recommended in the conditions of the Okhotsk Sea. However, there are special devices – bilge keels. Their application helps to increase the added mass of the barge and subsequently the period of natural oscillations.

So, the most appropriate means of transport for the conditions of the Okhotsk Sea are the monohull vessel and the SSCV.

Conclusion

In this chapter, various installation methods for offshore structures were presented. Also, were discussed possible options for transport equipment to perform installation operations. The calculation and selection of the most suitable vessels for use in the Okhotsk Sea conditions were also carried out. According to the analysis, the best performance is possessed by the monohull vessel and the semi-submersible crane vessel.

6. INSTALLATION OF THE SUBSEA PRODUCTION SYSTEMS ON THE SHELF OF THE OKHOTSK SEA

The installation of any field facility in the seawaters requires a thorough preliminary analysis. Firstly, it is necessary to identify the most favourable time for operations taking into account the natural and climatic conditions of the sea. Secondly, each installation process should be accompanied by careful planning of the operation schedule to rationalize the rental charge of transport equipment. Thirdly, the previous point must be supported by an accurate weather forecast to avoid dangerous situations. All these points are the minimum set of requirements for the implementation of offshore operations in the safest, least costly and fastest way.

6.1 ANALYSIS OF THE WEATHER RESTRICTIONS

Low temperatures, wind, waves, tsunamis, severe ice conditions, seismic activity, as well as many other natural phenomena complicate the normal development of deposits in the field. Additionally, they can provoke emergencies, aggravate the development of emergency processes, and also make it challenging to deal with the consequences of possible accidents, evacuation and rescue of personnel.

The following parameters should be assessed to provide a safe installation operation in the Arctic region:

- Wind conditions;
- Temperature (including temperature limits and icing of facilities);
- Waves and currents;
- Ice conditions (including ice drift and ice management).

Wind conditions

Monsoons of temperate latitudes influence the wind regime of this region, which has a well-defined seasonal periodicity. An average value of wind velocity on the northeastern coast of Sakhalin Island comprises 6,8–7,0 m/s. The maximum wind speeds are observed mainly in the cold season (November-January) and with the passage of deep cyclones and typhoons (wind speed of 20 m/s or more and gusts of up to 25 – 30 m/s). Since storms are a very unpredictable phenomenon, it poses a significant danger to marine and offshore installation operations because of the substantial impact on stability.

In addition to that, a strong wind can trigger a wind-induced surge. For instance, the wind-induced surge in southern Okhotsk Sea off the northeastern Sakhalin Island induces a range in water depth from 0,6 m to 1,1 m. Such variation can harm the installation operation (for example, a subsea facility can experience high slamming loads during its lowering through the water surface).

Based on the data above and graph from the Figure 2.2 it can be concluded that the best time for carrying out offshore operations are the periods free from the typhoons and strong gusts – from May up to August.

Temperature conditions

The air temperature in the summer months on the northeastern coast of Sakhalin Island is lower than the corresponding latitudes of the western coast, which is associated with the presence of a cold East Sakhalin current, as well as the influence of drifting ice (in some years until July). The average annual air temperature in the areas of deposits is negative and differs little. The data from Table 2.1 show that the most favourable months with positive average monthly temperatures are from May to October. The months from June to August are the only ones with only positive temperatures.

Low temperatures do not compatible with any offshore operations for various reasons. First of all, they can be dangerous for health and the life of personnel. Low temperatures in combination with cold winds can cause frostbite. Then, low temperatures can be the reason for the icing of facilities. In addition to that, negative temperatures induce an expansion of frozen water. Such an effect can be fatal for that equipment which is filled with water before lowering operations (spools, pipes, spool-jumpers).

That is why all installation operations should be fulfilled when the values of air temperature are quite moderate (from May to October).

Wave and current conditions

As was mentioned before, the wave climate is a dynamic parameter. It can significantly vary from time to time. On average, the height of the waves does not exceed two meters (H_s = 2 m); however, in winter periods, it can reach four meters. Also in summer, storms occur, forming waves with a height of 4.1 to 4.5 meters. The values of the peak period of swell waves (T_P) fluctuate within 4–12 s.

According to DNV-OS-H101, marine operations with reference period (T_R) less than 96 hours and planned operation period (T_{POP}) less than 72 hours are considered to be weather restricted. Weather restricted operations are the operations with defined restrictions to the particular environmental conditions, planned performed within the period for reliable weather forecasts [41].

Depending on the installation operation that is fulfilled (platform, floating structure or subsea structure), the process will be considered as restricted or unrestricted. Establishment of an operation’s type involves the determination of maximum wave height that is allowed for it. If an activity is regarded as unrestricted one, the normal wave conditions should be defined following long-term statistical data. If an operation is considered as restricted one, the maximum wave height can be found using the following relation [41]:

$$H_{\max} = STF \cdot H_S \tag{6.1}$$

where STF – storm factor equals to 2,0 (for all reference periods);

H_S – significant wave height, m.

Thus, the maximum permissible wave height for operations in the Okhotsk Sea is 4 meters.

Current conditions along the eastern coast of Sakhalin Island vary from the season. During the spring the average current velocity fluctuates in the range from 0,07 m/s to 0,10 m/s, while in summer these values become larger: 0,10 m/s–0,15 m/s. The largest magnitudes are observed during the autumn season. They can be in 2–2,5 times larger than the summer one. It is also important to monitor tidal currents since they have more significant values. All restrictions can be combined in one term that is called "weather window". Any marine operation should be fulfilled during the weather window.

Ice conditions

Ice is the most significant issue in the development of offshore fields. All the on-site operations are entirely dependent on the ice conditions.

First of all, any offshore operations can be performed only during the ice-free period. For the Okhotsk Sea, this season lasts for six months (from the begging of July until the middle of November). Moreover, an allowable period for construction works comprises 55+/-10 days (due to waves, wind, fog and ice). Thus, installation operations should be fulfilled in 2 months [17]. Limitations in the installation are provided to avoid adverse consequences. The motion of ice, ice adfreeze to structures and ice accumulation can lead to several hazards [42]:

- Loss of structural stability;
- Reduction of structure's strength;
- Increasing of fatigue loads;
- Progress collapse.

Other damaging actions of ice are abrasion, seabed gouging, water level fluctuations and thermal effect of ice (thermal expansion) [42].

In addition to that, the icing of equipment can occur. In the Arctic seas, there are often rains, snowfalls and fogs, which extremely complicate the conditions of extraction of mineral resources on the shelf and increase the risk of shipping. Ice cover occurs due to humid air, cold rain, accumulation of dense fog on the structure (atmospheric ice), or water splashing in the event of waves hitting the structure. Icing affects the performance of offshore production facilities in various ways, including the duration of repairs and the rate of equipment failure. Such influence can result in loss of power, economic damage, and safety hazards. The icing of some parts of equipment during its installation can lead to auxiliary equipment failure that can play a crucial role in the installation process. It is extremely risky for people and equipment.

Thus, combining the permissible time intervals in all respects, we can conclude that the best time for carrying out offshore operations is from May to August (September).

Besides, it is essential to remember about ice management in any offshore project in the Arctic conditions. Ice management assumes the reduction of the ice action on the marine structures. Three main functions of ice managements can be distinguished [42]:

- Detection, tracking and prediction of ice;
- Threat assessment;
- Physical ice control (under certain circumstances).

According to ice conditions in the Okhotsk Sea (section 2.2.4), ice drift could occur due to significant current velocities. So, ice management needs to be applied to drift ice. In this case, three stages of hazard identification are observed [42]. The first stage assumes problem recognition and assessment of its danger degree. Usually, the time frame of this step is 300 km away from the site. The second stage is the detection of the hazardous ice condition presence and taking measures for its eliminating. The time frame for this step is the time needed for getting ready specialised ice management vessels. The third stage is the confirmation of a collision inevitability. Thus, urgent shut down of all operations. The time frame for this stage is the time needed for winding up all the activities and leaving the site [42].

6.2 ANALYSIS OF THE INSTALLATION EQUIPMENT

Since in the framework of this work, the subsea production systems were chosen as the development method of the Ayashsky LA, it is necessary to analyze the installation process of required elements on the seabed. The installation of the template will be considered as an example.

As mentioned earlier, any marine operation requires careful planning of its schedule. Below is an approximate list of works needed to install the template:

1. Template transportation from the Sakhalin harbour to the site;

2. Pre-installation works at the site (vessel positioning near the installation point, cutting off sea fastenings, fixing the tugger lines, preparation for lift-off);
3. Lift-off of the template from the vessel’s deck and lowering through the splash zone;
4. Further lowering to the seabed (approximate velocity is 0,2 m/s) and positioning above the installation place;
5. Final installation of the object, setting the position and disconnect.

Transportation starts from the harbour. There are eight harbours on Sakhalin Island. Only two of them are located in the maximum proximity to the Ayshsky LA – Moskalvo port (navigation period from June to November) and Poronaysk port (navigation period from April to November). Figure 6.1 represents an approximate route from harbours to the Ayashsky LA [43].

Figure 6.1 shows that the Moskalvo port is closer, about 400 km from the site (minus the distance to the coast – 55 km), compared with Poronaysk port – 570 km from the site. Therefore, the starting point is Moskalvo harbour.

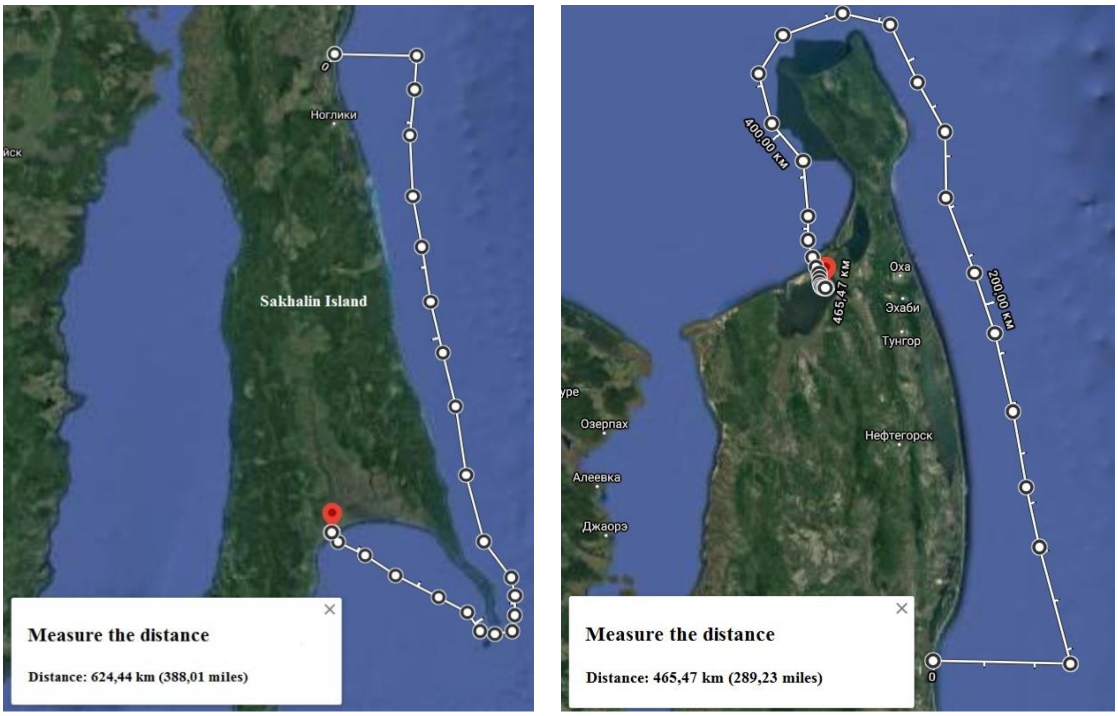


Figure 6.1 Distance from the harbours to the Ayshsky LA (from the left to Poronaysk port, from the right to Moskalvo port) [43]

Each of the installation steps takes a certain amount of time. Table 6.1 presents a phased work schedule with an approximate indication of the planned operation period time [39] and operational limits.

Table 6.1

Operation schedule for template installation

Operation phase	Operation name	Time (T_{POP}), hour	Operational limit (H_S), м
1	Transportation (400 km)	25	2,0
2	Pre-installation works	6	2,5
3	Lift-off and lowering through the splash zone	2	2,0
4	Lowering to the seabed and positioning (80 m)	3	3,0
5	Installation, position setting and disconnection	2	2,5
Total time (T_{POP})		38 hours	

The transportation time to the site was calculated based on the fact that the transit speeds of a monohull vessel and a SSCV vary between 8–9,5 knots (14.8–17.6 km/h). The rest of the time was estimated based on knowledge gained during lectures on marine operations course (Stavanger).

Assume that the Ayashsky structure (Neptune field) is going to be developed through the eight wells. Then we can suppose three possible options for the field development:

- Development through the eight satellite wells;
- Development through the two four-slotted integrated template structure (ITS);
- Development through the one eight-slotted ITS.

Based on this, each option will have its installation schedule for one structure, taking into account the time to change the location. An approximate estimation of the installation planned time for all elements of the SPS is presented in Table 6.2.

Table 6.2

Operation schedule for template installation for three options

		Option 1	**Option 2**	**Option 3**
1	Transportation, h	25	25	25
2	Pre-installation works, h	6	6,5	6,5
3	Lift-off and lowering through the splash zone, h	2	4	6
4	Lowering to the seabed and positioning (80м), h	3	4,5	5
5	Installation, position setting and disconnection, h	2	3	3,5
6	Location changing, h	7x1,5	1x1,5	–
7	Repeat phases 2–5, h	x8	x2	–
	Total time	**139,5 h 6 days**	**62,5 h 3 days**	**46 h 2 days**

The results of calculating the total operation time of each of the options show that the most extended installation is expected in the first option, for six days. The shortest installation is assumed in the third option, for two days. The difference in time of the work stages execution is explained by the different weight and dimensions of the structures used in each option.

So, the first option of the arrangement implies the installation of a protective structure for the x-mas tree (Fig. 6.2) [44]. This design is necessary to protect the wellhead equipment of the satellite well from ice, possible falling objects and trawling. The weight of the protective structure is estimated at 76 tons [32].

In the second and third options, an integrated template structure is installed with four slots and eight slots, respectively (Fig. 6.2) [45]. This design performs several functions for the well at once: support function and protection function. Also, the ITS features the internal installation of the manifold. The weight of the structure with four slots is estimated at 400–600 t [46]. The weight of the eight-slot template is estimated at 1300–1600 t [46].

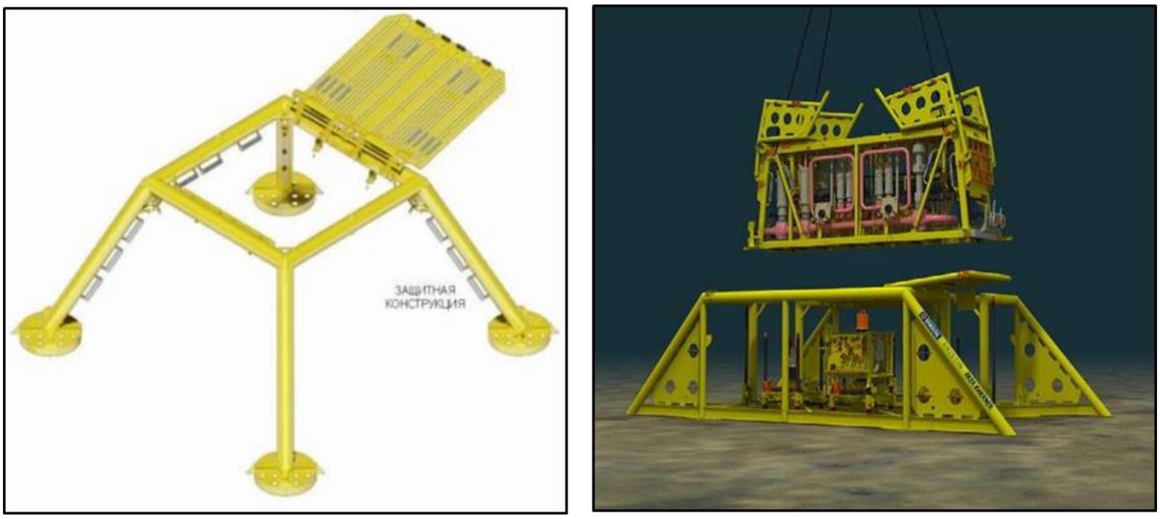


Figure 6.2 Objects for installation (on the left protective structure for the first option, on the right the ITS for the second and third options) [44], [45]

The next step is the evaluation of the economics of these options.

6.3 ECONOMICS ANALYSIS OF THE INSTALLATION OPERATION

Based on the fact that the total weight of the structures in each option does not exceed 1600 tons, it is assumed all the elements to be delivered by the barge to the field once. Additional return to the port is not implied. Besides, two other vessels will be involved in the installation process: ROV vessel and a support vessel. Thus, four types of ships will be needed. Table 6.3 shows the list of vessels with their approximate rental charge.

Table 6.3

Rental charges for vessels involved in the installation operation [47]

	SSCV	Monohull vessel	Barge	Supply vessel	ROV vessel
Rental charge, $/day	500.000	300.000	20.000	9.000	30.000

The table shows the two types of crane vessels for a reason. It is necessary to compare the final cost of the installation operation, depending on which one was used.

Since the lease of the vessel starts from the day it leaves the home port, the cost of transportation must also be taken into account. For this, it is required to know how many days it will take a vessel to get to the port of Moskalvo. Using the Marine traffic resource, the current location of Saipem 3000 (in Spain) and Saipem 7000 (in the Netherlands) was tracked. Based on these data and the vessels transit speed, the number of days was calculated for the ship to move to the Sakhalin harbour. Besides, based on the assumption that all the structures will be produced in Norway and delivered from the Stavanger port, the number of necessary transportation days was calculated. The results are shown in Table 6.4.

Table 6.4

The number of rental days for the vessels

		SSCV	Monohull vessel	Barge	Supply vessel	ROV vessel
Transportation to the port, days		54	56	36	5	5
Total days	Option 1	61	63	43	12	12
	Option 2	58	60	40	9	9
	Option 3	57	59	39	8	8

Table 6.4 presents the total number of lease days for each type of vessel for each option. Most rental days are required for the first arrangement. Least of all is necessary for the third option.

Now, based on the data in Tables 6.3 and 6.4, we can calculate the cost of the complete installation process of subsea structures for each option. It should be noted that when calculating the total cost, the total time required to rent the ships included the time needed to transport all the ships back to the port of Sakhalin from the field. The results are shown in Table 6.5.

Table 6.5

The total cost of operating costs for the installation of offshore structures for the three options, $ million

	Option 1	Option 2	Option 3
SSCV*	30,5	29,0	28,5

Monohull vessel**		18,9	18,0	17,7
Barge		0,86	0,80	0,78
Supply vessel		0,108	0,081	0,072
ROV vessel		0,360	0,270	0,240
Total cost, M$	*	**31,828**	**30,151**	**29,592**
	**	**20,228**	**19,151**	**18,792**

* – Total cost when using a SSCV;
** – Total cost when using a monohull vessel.

The results of Table 6.5 show that the use of a SSCV significantly increases the total cost of the installation operation for each option. Its application will be irrational for the budget since absolutely the same functions can be performed by a monohull vessel at a lower cost. Moreover, the power of its cranes will be enough to carry out the operation. Thus, in subsequent calculations and analyzes, the option with a SSCV will not be considered.

The diagram from Figure 6.3 demonstrates the cost of the operation for each option.

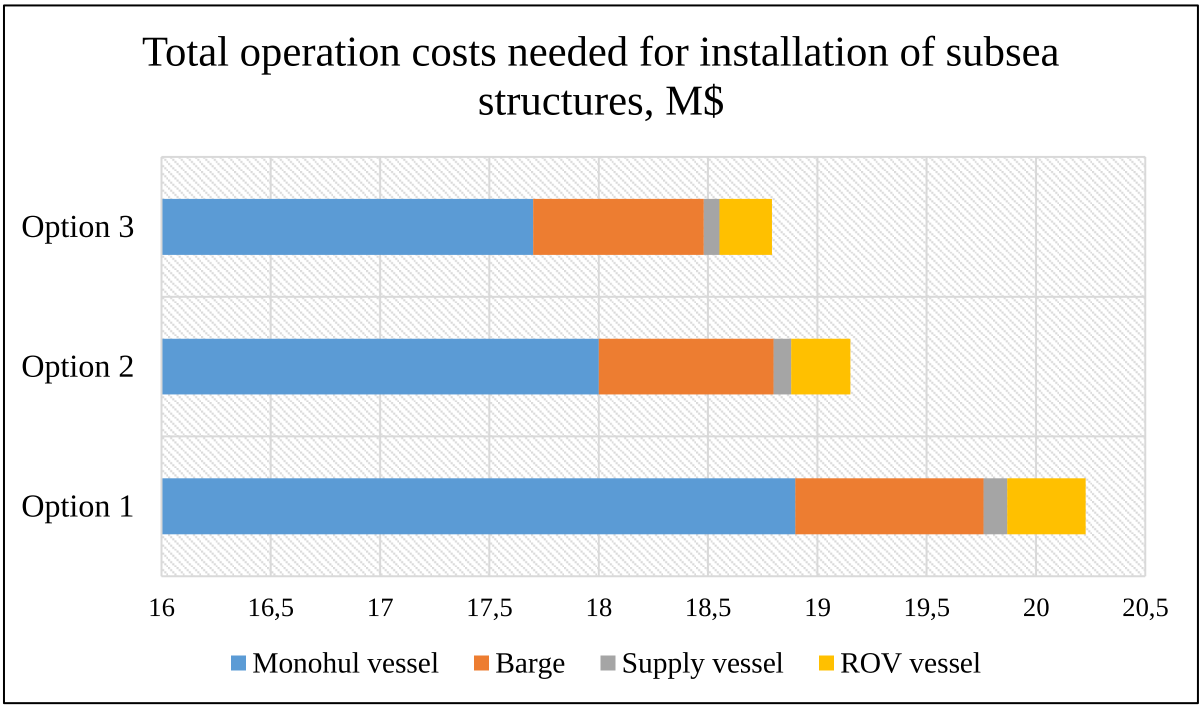


Figure 6.3 Cost chart of three installation operation options

The first option is the most expensive since several sub-operations need to be repeated eight times due to maintenance of each individual satellite well. The second and third options do not differ much from each other in terms of total cost since repeated operations need to be carried out only twice or not at all.

However, it must be remembered that the final cost estimate and the selection of the most cost-effective option require information about the location of the well grid. It is essential because, in the ITS, all the wellheads are located in one place, which means that the well's length to the well bottom increases. This moment imposes an increase in investment in the project, since drilling horizontal wells is a costly process. The longer the well, the more expensive it is. Therefore, at this stage, it is impossible to state that the second or third option is the best arrangement. Additional research required. However, it is possible to estimate the cost of subsea facilities used in each of the cases.

6.4 ASSESSMENT OF THE TOTAL COST OF SUBSEA FACILITIES AND THEIR INSTALLATION

Subsea production systems are of high cost, the complexity of execution and manufacture. For example, the cost of the SPS of the Kirinskoye field, manufactured by FMC Technologies, amounted to $ 200 million.

It is rather difficult to assess the cost of an element of the SPS outside the conditions of a particular field. Many parameters affect the design features of a specific structure, for example, bottom topography, soil properties, the corrosive activity of seawater, current conditions, seismic conditions in the region, the presence of trawling and many others. However, it is possible to estimate the approximate cost of an ITS depending on the number of wells planned for drilling.

Figure 6.4 shows a graph of the ITS manufacture cost versus the number of wells for a different number of slots [46].

The second and third options cover the installation of integrated template structures on four and eight slots, respectively. Taking into account that development considers eight wells, the cost of capital expenditures for the construction of ITS, based on the graph in Figure 6.4, will be $ 260 million for a four-slot structure and $ 200 million for an eight-slot structure.

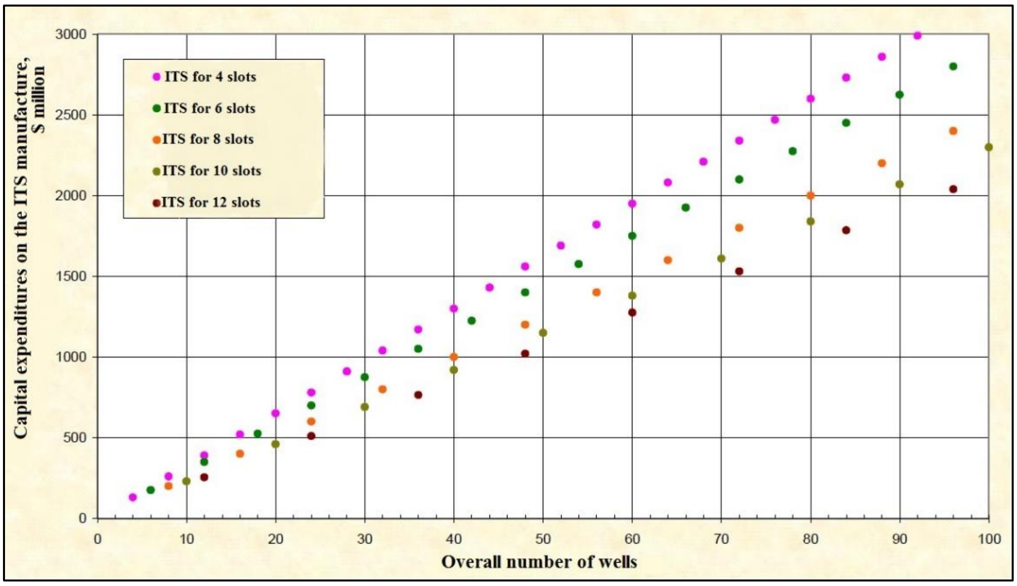


Figure 6.4 Cost of the ITS as a function of the number of wells [46]

The cost of one protective structure for the first option can be estimated at 24.7 million $. The price of all elements is combined in Table 6.6.

Table 6.6

The cost of structures for the arrangement of 8 wells

	Option 1	Option 2	Option 3
Cost, million $	198	260	200

Combining the data from Table 6.5 (**) and Table 6.6, the total cost of installation operation is obtained together with the manufacturing of structures (Fig. 6.5).

The second option is the most expensive since it has the highest cost of ITS manufacturing (ITS for four slots). The prices of the first option with the use of satellite wells and the third option with the use of an ITS are almost equivalent. Their initial difference in the rental charge of transport equipment was equalized due to a small difference in the cost of the structures themselves.

Nevertheless, despite a similar result in the costs, it is worth remembering the need for drilling wells. The closer the wells are assembled, as in the third option, the farther the wellheads are located from the well bottom, the longer the well will have to be drilled. Moreover, the rate of the drill bit penetration may decrease due to an increase in the deviation angle during the construction of horizontal wells. All this ultimately can make a significant contribution to the rise in capital expenditures. Hence, the third option may, in the end, become the most expensive.

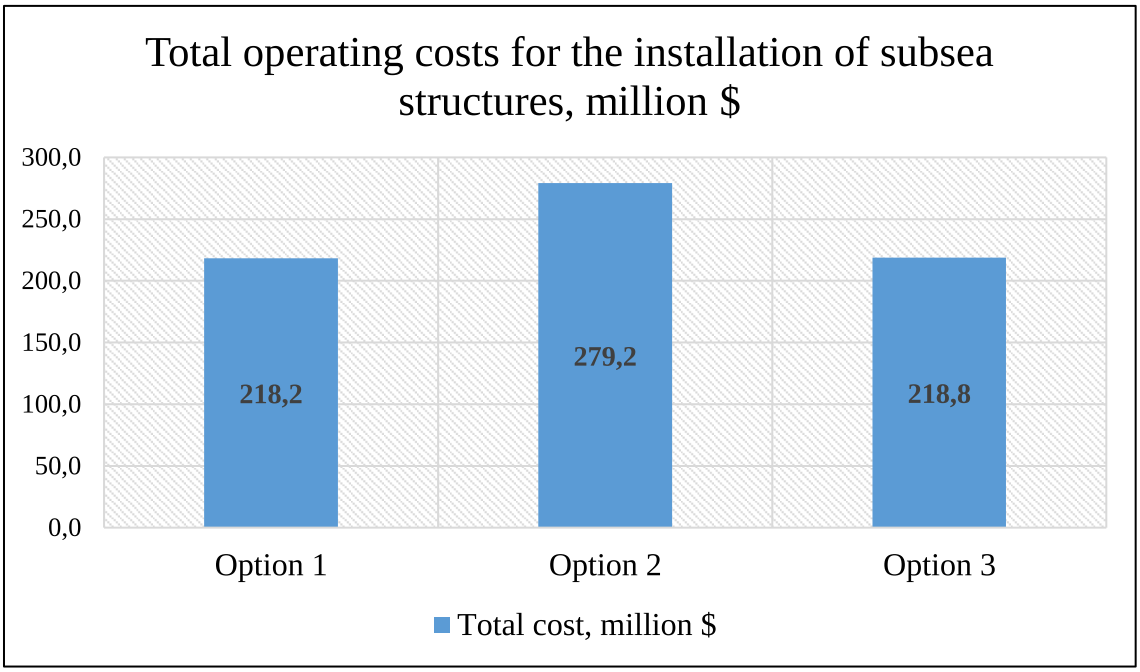


Figure 6.5 The total cost of field development options

Conclusion

In this chapter, a comprehensive analysis of the installation process of subsea structures in the Okhotsk Sea on the Ayashsky structure was carried out. Extreme weather conditions allowing maritime operations without consequences were identified. The time appropriate for the marine operations was set within May-August (September). An analysis of the installation process was carried out. As a result, a list of works required for the installation of subsea structures was determined. It was also proposed three options for arranging the Ayashsky structure using the SPS. For each option, a work schedule was compiled, and the time required to complete the operation was calculated. Based on this, a calculation was made of the lease of transport and a generalized cost calculation of arrangement, taking into account the manufacturing price of subsea structures. The result showed that the most preferred methods are satellite wells or an ITS with eight slots. However, further analysis is recommended taking into account the cost of drilling wells and laying the subsea pipeline.

7. RISK ANALYSIS OF THE SUBSEA STRUCTURES INSTALLATION

Arctic nature is rich in a wide variety of animals, plants and marine life, that is why it is susceptible to any external intervention. Oil and gas production is always connected with large equipment that produces loud noise and vibration. Such actions can make a significant impact on the animals because they are susceptible to low-frequency sounds. Such influence can lead to changes in animals migration and population. Another harmful result from petroleum production could be oil leakage. Leakage of hydrocarbons is hazardous in a low-temperature environment because negative temperatures lead to changes in the oil crystal lattice. It results in the impossibility of oil dissolution. So, to preserve such a fragile ecosystem, any operation in this area must be done with high caution. It is even more relevant for marine operations.

In order to avoid irreversible effects, risk analysis of marine operations was created. This analysis assumes four steps [39]:

1. Accept criteria;
2. HAZID (hazard identification), which includes:
    a. The known hazards;
    b. The known unknown;
    c. The unknown unknown (black swan effect).
3. Risk evaluation;
4. Risk mitigation measures.

Each step should be carefully assessed for each offshore procedure.

According to DNV-RP-H101, exposure from marine operations should be controlled over four spheres [48]:

- Personnel (health and safety);
- Environment;
- Assets;
- Reputation.

All these four spheres compile the first step of risk analyses – criteria acceptance. In other words, these spheres comprise the criteria.

The next step is hazard identification (HAZID). HAZID aims to detect undesirable consequences that can occur in each of the spheres from the previous step and to identify a list of potential hazards that can lead to these consequences.

Risk evaluation is usually fulfilled via the risk analysis matrix, which is considered as a qualitative assessment. This approach is subjective since a person assesses the risk according to the following relation:

$$Risk = probability \times consequence$$

A risk matrix usually consists of rows and columns. Rows denote the severity of impact from negligible to very high. Columns indicate the probability rating from very unlikely to very likely. Multiplication of rows and columns values results in a score of risk that varies from low to very high [49]. A typical risk matrix is represented in Figure 7.1.

		Probability rating (likelihood)				
		Very unlikely	Unlikely	Possible	Likely	Very likely
		1	2	3	4	5
Negligible	1	1 (Low)	2 (Low)	3 (Low)	4 (Low)	5 (Medium)
Slight	2	2 (Low)	4 (Low)	6 (Medium)	8 (Medium)	10 (High)
Moderate	3	3 (Low)	6 (Medium)	9 (Medium)	12 (High)	15 (High)
High	4	4 (Low)	8 (Medium)	12 (High)	16 (High)	20 (Very High)
Very high	5	5 (Medium)	10 (High)	15 (High)	20 (Very High)	25 (Very High)

Figure 7.1 Typical risk matrix [49]

Qualitative acceptance criteria of the matrix have the following ranking:

- 1-4 = Low risk (acceptable risk);
- 5-9 = Medium risk (as low as reasonably practicable – ALARP);
- 10-19 = High risk (not acceptable risk);
- 20-25 = Very high risk (not acceptable risk).

The final step of risk assessment aims to identify threats that can lead to hazard event and barriers, which can prevent this event. In this step, a bow tie analysis is usually applied. Typical bow-tie diagram is represented in Figure 7.2.

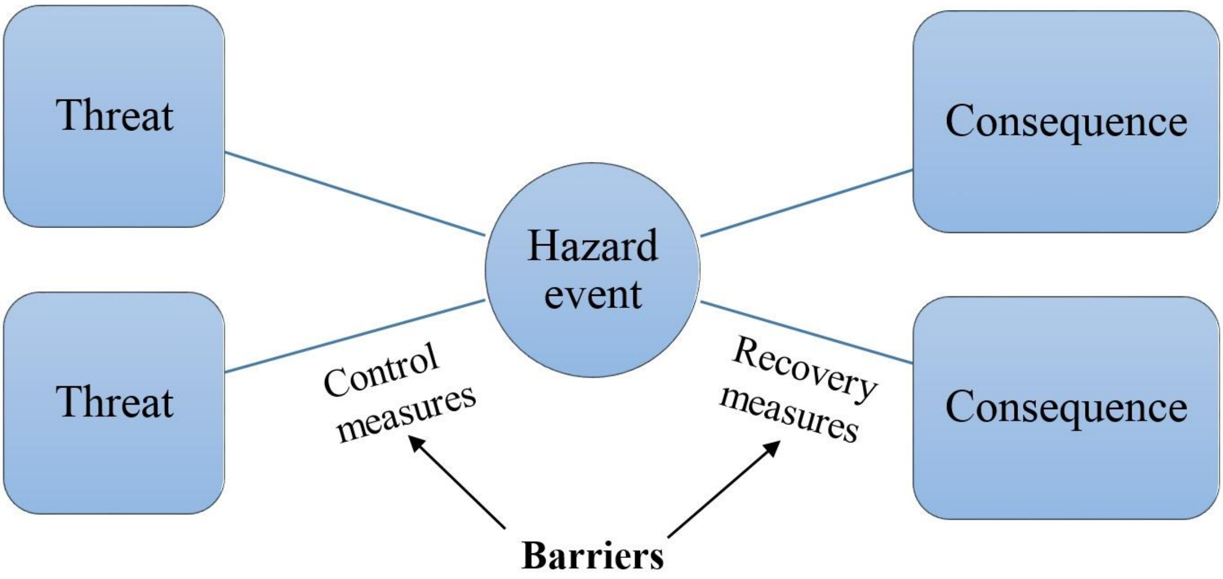


Figure 7.2 Elements of bow-tie diagram

Bow tie diagram is an object lesson of the hazard formation and consequences of its action.

Frameworks of this master's thesis cover risk analysis of the subsea structure installation process. Let us take make up the list of potential hazards that can occur during this operation. List of hazards:

1. Pendulum motions in the air;
2. High lowering velocity;
3. Slack wire while crossing the splash zone;
4. Bad weather conditions;
5. Weak sea fastening;
6. Vessel instability;
7. Snap loads in the lifting wire;
8. Unacceptable tension in lifting wire during lift-off;
9. Re-hit of the object by the barge after lift-off;
10. Loss of structure.

Now we can assess the risk value for each of the four criteria. Four risk matrices need to be compiled. Figures 7.3 – 7.6 represent risk matrices for personnel, environment, assets and reputation.

	1	2	3	4	5
A		2	3	7,10	
B				4	
C		8	6		
D		5	1,9		
E					

Figure 7.3 Risk matrix for personnel

	1	2	3	4	5
A		2,8	1,3,9	4	
B		5	6	7	
C				10	
D					
E					

Figure 7.4 Risk matrix for environment

	1	2	3	4	5
A					
B					
C			1,6		
D		2,8		4,7	
E		5	3,9	10	

Figure 7.5 Risk matrix for assets

	1	2	3	4	5
A		2,8	1,3	4	
B			6,9	7	
C		5			
D				10	
E					

Figure 7.6 Risk matrix for reputation

The figures from 1 to 5 denote the probability rating of the hazards as follows:

1 – very unlikely;

2 – unlikely;

3 – possible;

4 – likely;

5 – very likely.

In the same way, the letters A – E denote the severity of impact on each of the criterion as follows:

A – negligible;

B – slight;

C – moderate;

D – high;

E – very high.

Matrices analysis shows that assets are the most susceptible to hazards, which could occur during the installation process. Zones with not acceptable risk got 92 scores and ALARP zones scored 34 points. The personnel also could experience the impact of the hazards but in a less obvious way. Unacceptable risk zones scored 24 points. The most dangerous hazard is the loss of structure; it has the highest risk. If we want to avoid this event, it is required to move its the probability of occurrence from likely (4) to very unlikely (1). Such alteration involves the knowledge of barriers, that is why the bow-tie analysis of this hazard is essential. Figure 7.7 represents a bow-tie analysis of this hazard.

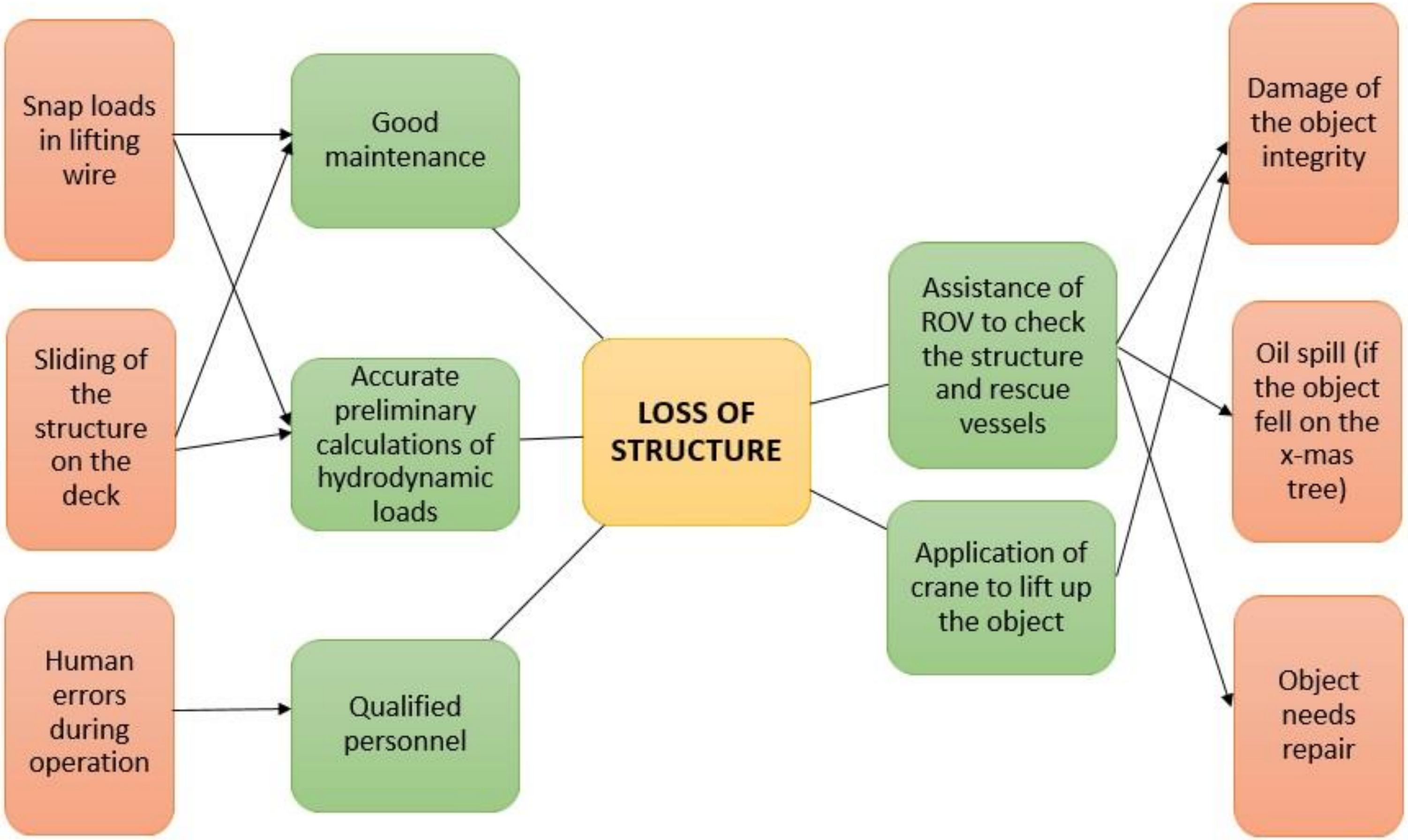


Figure 7.7 Bow-tie analysis of the hazard

Bow-tie analysis shows that the risk can be diminished, applying prevention and recovery barriers. Prevention barriers regarded as control measures. In this case, control measures are:

- Good maintenance;
- Accurate preliminary calculations of hydrodynamic loads;
- Qualified personnel.

Recovery barriers can be seen as recovery measures. In the diagram, they are:

- The assistance of ROV to check the structure and support of rescue vessels to remove oil spills;
- Application of crane to lift-up the object.

Conclusion

Risk analysis is an essential part of the offshore operation. Study in this chapter showed how it could help to carry out a marine activity. The analysis helps to foresee potential hazards and to take measures before it happens. What, in result, preserves nature, rescues personnel and saves money.

CONCLUSIONS

The main objective of this work was to carry out a reasonable selection of an offshore oil and gas development scheme for the development of the Ayashsky structure. To make a choice, a detailed analysis of existing facilities was made, as well as factors affecting the decision. Based on the data obtained, a matrix diagram in the form of a table was compiled (Table 4.1). The results revealed three potential structures that could be installed on the shelf at the Ayashsky structure. Further technical and technological analysis of the country's raw material base revealed the most suitable installation among the three selected structures. The most acceptable option was subsea production systems.

The second goal was to identify a reasonable selection of installation method for the previously approved OGS. First of all, an analysis of existing technologies for the installation of subsea structures was carried out. Next, the types of vessels required for a successful and safe installation were identified. Then, based on the wave characteristics of the Okhotsk Sea, two types of ships capable of completing the installation were detailed – a semi-submersible crane vessel and a monohull lift vessel. For the final determination of the most suitable option, the calculation of the rental charge of the transport was made, based on the planned operation period time for the installation operation. The most expensive option was the one with application of a SSCV. It was rejected because the same procedures could be carried out using a monohull vessel.

Three options for developing the Ayashsky structure with the installation of various subsea elements was thereafter considered. The first option is the arrangement of the structure with eight independent satellite wells. The second option is the arrangement with two ITS with four slots each. The third option is the arrangement with one ITS with eight slots. To determine the most suitable option, the cost of the structure installation onto the sea bottom for each of the options was calculated.

Additionally, the estimated cost of manufacturing such structures was evaluated. Establishment of the total cost (Figure 6.5) showed that the most expensive option is the second – two ITS with four slots. The first and second options were almost equivalent. However, for the final choice of arrangement, it is necessary to conduct an additional analysis taking into account the cost of drilling wells and laying the subsea pipeline. Accounting for the cost of drilling is extremely important since this factor can significantly increase the total cost of installation. This is since the closer the wells are located to each other, the farther the wellheads are from the well bottoms, which means the longer the well will have to be drilled. Given that offshore drilling of horizontal wells is a costly operation, the third option may eventually become the most expensive.

Thus, the selected type of OGS for the arrangement of the Ayashsky structure is the subsea production systems, either with the installation of satellite wells or an ITS for eight slots. The installation should be carried by lowering the structure to the bottom with a crane using a monohull vessel.

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