OFFSHORE STRUCTURES IN ICE-INFESTED WATERS

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Contents

Summary

There are various offshore structures employed in ice infested waters, including oil platforms, lighthouses, bridges and ships. Every offshore structure can be classified as either a fixed foundation or a floating unit. Different ice conditions may be encountered in the high latitude waters, such as level ice sheets, ice ridges and icebergs, each presents distinct risks to offshore structures. Ice loads acting on a structure depend on many factors including the mechanical properties of both the ice and the structure, failure modes of the ice, and the drifting ice velocity.

Engineers have to evaluate different risks caused by the ice to ensure the safety of structures. A structure must have adequate strengths to withstand the extreme static ice

load. The dynamic fatigue damages to the structure, impact on crews and facilities on the structure have to be evaluated when a structure undergoes vibrations induced by dynamic ice actions. After decades of research work, many different formulations for both static and dynamic ice actions have been developed. However, the subjects related to ice actions and ice-resistant structures are far from mature. Future research is needed to better understand the fundamentals behind ice-structure interaction. In this chapter the following subjects are introduced in more detail: 1) historical background of offshore structures in ice-infested waters; 2) classification of structures employed in ice covered waters; 3) ice types in high latitude seas; 4) ice loads acting on structures; 5) risks of structures under ice actions

1. Introduction

The offshore drilling and production activities in ice covered waters date back to 1960's, when the oil platforms were deployed in Cook Inlet, Alaska where the sea surface routinely froze for a couple of months every winter. Since then, different types of offshore structures like oil platforms, lighthouses, channel markers and vessels have been employed in high latitude seas.

If we classify the offshore structures in ice-covered seas by their functions, they are: 1) platforms or vessels for drilling oil and gas; 2) lighthouses and channel markers for providing ship navigation; 3) bridges for connecting lands; and 4) ice breakers or other ships for transporting goods. However, for offshore structure engineers, a classification according to their functions is not as useful as by their boundary conditions, i.e. fixed on the seabed or floating in water. In the family of fixed structures, there are jacket platforms which are fixed deeply into the seabed by a group of piles, and gravity based structures (GBS) which are positioned by their own weights. On the other hand, floating structures are traveling vessels and structures positioned by dynamic positioning systems or mooring lines. These offshore structures are introduced in detail in Section 2.

Loads from ice actions are important for the offshore structure design along with other environmental actions like wind, wave and current. In nature, different types of ice exist, e.g. level ice sheets, ice ridges, icebergs etc. Different types of ice can cause different problems to offshore structures. However, not all ice types are present in a given region, and the ice condition in one region can be totally different from another. These ice conditions are introduced in Section 3.

Ice loads depend on the mechanical properties of the ice. For instance, the strength of ice plays a very important role in determining the ice load. Unfortunately, the mechanical behavior of ice-structure interactions depends on the properties of ice in a very complicated way. The property variation from sample to sample is extremely scattered. There is not a simple definitive law that can precisely quantify the relevant ice mechanics during an interaction. In addition to ice strength, there are many other factors that influence the ice load during an ice-structure interaction, such as the ice thickness, ice type and the failure mode when an ice interacts with a structure, i.e. bending or crushing. In the past several decades, many engineers and scientists have spent significant efforts on this topic. Their work is briefly discussed in Section 4.

Although the subjects related to ice mechanics and ice-structure interactions are still far from well established, some codes and regulations have been developed to enable offshore structure designs in ice infested waters safely. These codes and regulations are based on current understanding of ice actions on fixed and floating structures, which are discussed in Section 5.

Ice loads may cause problems not only to the structure itself but also to the crew who work on the structure, and also to other facilities mounted on the structure. Time-varying ice loads might induce severe vibrations of the structure, which can reduce its fatigue life and cause damage to pipelines. These topics are summarized in Section 6.

Human activities in ice infested seas are still work-in-progress, which means that some risks and problems are beyond our understanding at present. Extensive studies are needed in order to discover and solve problems in ice covered seas. These considerations are concluded in Section 7.

2. Offshore Structures in Ice-Infested Waters

There are various offshore structures for different applications in ice infested waters. In this section these structures are introduced according to their functions first, and then classified in the structure engineers' point of view: fixed on the seabed or floating in water.

2.1. Functional Classification

Oil platforms – Jacket platforms are usually deployed in relatively shallower waters for oil and gas explorations and productions. A jacket platform consists of steel pipes of different sizes welded at joints. All the necessary facilities like the drilling derrick, the gas processing system and the helideck (deck for helicopters landing) are placed on the decks at different heights.

Jack-ups used to drill oil or gas beneath the seabed, are often employed in shallow water and somewhat flat seafloor. This type of structure consists of a polygonal deck and several legs. The legs are built with trusses or simple cylindrical-shaped columns. The most interesting feature of a jack-up is that the deck can be lifted up and down along the legs by a gear-rack teeth system. Normally, the jack-up is transported to the desired location first. Then legs are put down until they are mounted on the seafloor. Finally the deck is lifted up to a certain level to start the drilling operation.

Caisson or man-made islands are wide and heavy structures. Man-made islands use earth materials. Caisson is made of concretes or steels. Caissons are usually employed under severe ice conditions, e.g. ice thickness up to more than one meter and ice season longer than 4 months.

Floating platforms can also be used for oil and gas production in ice covered regions. These floating platforms are often positioned by a group of mooring lines. In deep waters where ice is absent, several types of floating platforms have been employed successfully, including Tension Leg Platform (TLP) and semi-submersibles. Floating platforms have to be employed in ice covered waters where the water depth is not suitable for jacket or caisson platforms.

Lighthouse and channel marker – Lighthouses and channel markers are used to guide ships to navigate through the waterway safely. In ice covered waters these structures are particularly important. Even though satellites and land or ship based RADAR systems have replaced the function of these structures now, some of the lighthouses and channel markers are still useful as perfect platforms to study ice loads and performance of structures under ice actions.

Bridges –There are many river crossing bridges around the world subject to ice conditions in the winter. The most famous one is the Confederation Bridge across the Northumberland Strait in Canada.

Ice breaker and other vessels – Several different kinds of vessels may navigate in ice covered seas. For example, ice breakers which are used to break a path for other ships, cargo tankers which are used to transport crude oil or other goods around the world, and ships that are unable to break heavy ice covers but still capable of navigating in light ice conditions.

2.2. Structural Classification

Regardless of the functional purpose, structure engineers are in general concerned with the following aspects when designing an offshore structure:

- Materials used to build the structure, i.e. steel, concrete, rock or others;
- Boundary conditions of the structure, i.e. fixed or floating;
- Distribution of structural components, i.e. both the structure elements and the facilities attached.

Within these aspects, the most important one is the boundary condition of an offshore structure, since fixed and floating structures have totally different dynamic characteristics and different interaction processes with ice floes.

Fixed structures – Fixed structures are installed by different ways: some of them are fixed rigidly by a group of steel piles built deep into the soil (such as jacket platforms); whereas some fixed structures are positioned by their enormous weight (such as caissons). Some new-conceptual fixed foundations have recently been adopted in offshore engineering, e.g. bucket foundation structures which are fixed into the seafloor by the difference between hydraulic pressure and vacuum inside the bucket. Figure 1 shows five typical fixed foundation structures (Bjerkås, 2006).

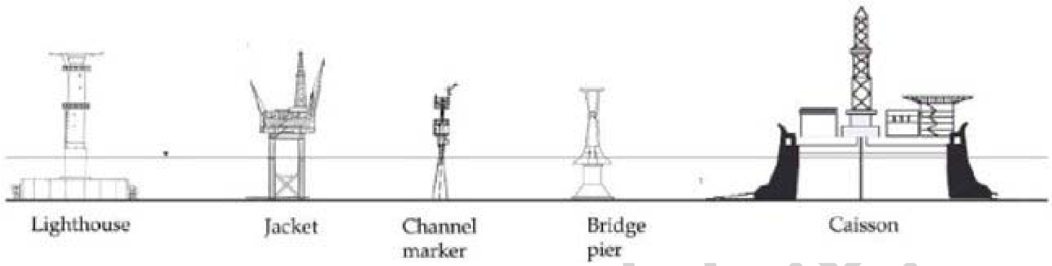

Figure 1. Offshore structures of fixed foundations (from Bjerkås, 2006)

Floating structures – Floating structures include vessels which move under their own power, and passive objects positioned by mooring lines or other dynamic positioning system. A floating structure can be considered as a rigid body approximately when it interacts with an ice floe, in spite of the possible local deformation of the structure.

An ice floe impacting a floating structure may not fail, but crushed fragments are often created when an ice floe hits fixed vertical structures. Results of the ice floes interacting with a structure depend on the type of the structure. The methodologies of calculating ice actions on fixed or floating structures are different, which will be discussed in Section 5.

3. Ice in Nature

In the polar and sub-polar regions, many different kinds of sea ice may be encountered. Different types of ice pose different challenges for offshore structures.

3.1. Ice Types

The classification of ice types is complicated, herein only several typical ice types which are of the most interest for offshore structure design are introduced. For a thorough classification see http://www.aspect.aq/cdrom.html.

Level ice – When sea ice freezes under relatively calm conditions, it forms a sheet of nearly constant thickness. This type of ice is called “level ice”. Level ice can be seen in almost all the ice infested sea areas. When interacting with offshore structures, these ice sheets can cause both static and time-varying forces on the structure.

Ice ridge – At times, level ice sheet is likely to be fractured by thermal forces, wind, wave or other actions. In the process of fracturing, small fragments form and are pushed upward and downward on the existing ice sheet. The fractured ice piece above the former level ice sheet becomes the “sail”, whereas those under becomes the “keel”. Ice ridges are harmful to offshore structures because of two reasons: 1) the strength of consolidated layer is usually higher than that of level ice sheet; 2) the keel of ice ridge may touch the seabed, which may damage pipelines buried under the soil.

Icebergs – Icebergs are large ice blocks separated from glaciers near the coastline. Instead of an ice sheet which comes from sea water with a high salinity, icebergs are from fresh-water glaciers whose mechanical strength is much higher than that of sea ice. In addition, icebergs are enormous that it is almost impossible for any offshore structure to withstand them. The best solution is to predict their formation and the possible drift path to avoid them. If an iceberg cannot be avoided, it has to be towed away by ships, or be destroyed.

3.2. Ice Conditions in High Latitude Waters Worldwide

Figure 2 is a map of the high latitude seas around Arctic region, in which not all the sea areas are denoted. It should be noted that ice conditions in these seas can be very different from each other. For example, the ice in Baltic Sea is much thicker than that of the Bohai Sea. From the structure designer’s point of view, the following parameters are important: 1) level ice thickness; 2) ice ridges and the dimensions; 3) icebergs and the dimensions. Table 1 provides some data from three different seas in the cold regions .

Figure 2. Map of the high latitude sea areas (from Bjerkås, 2006). The location of sites and the duration of field observations of ice conditions are denoted.

Sea ice	**Parameters**	**Average annual value**	**Range in annual values**
Bohai Sea			
Level ice (first-year)	Ice thickness (m)	0.2	0.1~0.6
Ridges and ice bergs	None		
Baltic Sea			
Level ice (first-year)	Ice thickness (m)	0.5	0.3~0.9
Ridges	Sail height (m)	2	1~3
	Keel depth (m)	10	3~15
Ice bergs	None		
Barents Sea			
Level ice (first-year)	Ice thickness (m)	1.3	0.7~1.5
Level ice (second and multi-year)	Ice thickness (m)	2.5	2.2~3
Ridges	Sail height (m)	4.2	3~5
	Keel depth (m)	15	14~20
Ice bergs	Mass (tonnes)	Up to 6 000 000	——

Table 1. Basic parameters of ice conditions in several Seas.

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Biographical Sketch

Qianjin Yue is a full professor in Faculty of Vehicle Engineering and Mechanics, Dalian University of Technology (DUT), China. His main research interests are offshore engineering including environmental loads, offshore structure design and analysis. Especially, he is an expert in offshore engineering in cold regions. His research subjects include ice parameters' forecasting and statistics, ice mechanics, ice loads, ice induced structure vibration and mitigation technique, failure modes of structures under ice actions, etc. The author has been studying ice related subjects for more than 20 years. He has been conducting field tests in the Bohai Sea every winter to improve the methodology of evaluating ice actions and structural performance since the early 1990's. In 2006, the author accomplished the project "New ice-resistant platform technique", funded by China National High Technology Research and Development Program. During this project, the author was able to solve many practical offshore structure problems in the Bohai Sea. Some of the achievements have been adopted by the new ISO standard (ISO 19906, Petroleum and natural gas industries — Arctic offshore structures).Many of his research are innovative and helpful to the offshore technology in ice infested waters. The author's research group has close cooperation with experts from Finland, Norway, Germany, Canada, Japan, Singapore and U.S.A. The author is the committee member of the following academic organizations:

- POAC (Port and Ocean Engineering under Arctic Condition)
- IAHR (International Association of Hydraulic Research) Ice Symposium
- Ice technical committee member of ITTC (International Tank Technical Committee)
- Technical panel member of ISO-19906 WG8 TP1b and TP2b (International Standard Organization, Arctic offshore structure standard Technical Panel)
- Adviser of STRICE (Field test of Structure and Ice interaction) project of Europe committee
- CPOES (China Petroleum Offshore Engineering Standard)