Ocean Engineering 38 (2011) 1220–1224

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Major challenges of offshore platforms design for shallow water oil and gas field in moderate ice conditions

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ARTICLE INFO

Article history:
Received 4 May 2010
Accepted 15 May 2011
Available online 16 June 2011

Keywords:
Ice-resistant structure
Ice-induced vibration
Structural failure modes
Conceptual design

ABSTRACT

Offshore engineers and scientists face fascinating economical and technical challenges in designing offshore platforms for shallow water oil and gas fields in moderate ice conditions. Petroleum production systems in these ice-infested areas such as the Bohai Bay of China, Cook Inlet, Barent Sea, and Caspian Sea must be designed to accommodate the harsh environmental conditions, among which the first-year sea ice is one of the major design consideration. Extreme ice loads and ice-induced vibrations still remain an area of uncertainty in offshore platforms. This paper demonstrates the main technical aspects on the use of jackets in the Bohai Bay, with particular focus on ice loads and the failure modes of slender ice-resistant structures, which are the two key issues in design considerations. A design proposal and some considerations for economical ice-resistant structures for safe development in the cold region are also conceptually discussed.

1. Introduction

Different types of steel structures are increasingly being used in offshore hydrocarbon fields in areas with moderate ice conditions. Fig. 1 depicts previous and planned hydrocarbon development and exploration areas within ice-infested regions. Exploitation of petroleum reserves in ice-infested seas presents significant challenges. Production systems must be designed to accommodate the harsh environmental conditions.

It has been known that offshore platforms designed for ice covered areas need to withstand not only extreme static ice forces, but also the dynamic ice forces, which may result in structure vibrations. Two types of steel offshore structures are commonly used in ice environments: caisson structures (such as JZ9-3 in the Bohai Sea, Molikpaq in the Beaufort Sea, and Prirazlomnoye in the Barent Sea) because of their good performance in withstanding both extreme ice actions and dynamic ice forces, and jacket structures because they are more economical as they use less steel for a given water depth. However, jacket structures are more flexible and more susceptible to ice-induced vibrations. At present, jacket platforms have been widely used in Cook Inlet and in the Bohai Sea. Ice-induced vibration problems are common in both of these areas.

Ice-induced vibration is a key concern for safe deployment of ice-resistant structures. The phenomenon of ice-induced structure vibrations has been discovered and studied since the early 1960s (Peyton, 1968). In the 1970s, lighthouses in the Gulf of Bothnia encountered ice-induced vibrations and one of them collapsed (Engelbrekston, 1977). In the 1980s, the sand filled core of the Molikpaq caisson structure experienced liquefaction problems because of ice-induced vibrations (Wright and Timco, 1994). In the late 1980s, ice-induced vibrations were noticed after the deployment of the first platform in Bohai Sea (Yue and Bi, 2001).

The current design codes (ISO 19906, 2007) for offshore structures in moderate ice conditions mainly deal with static ice loads. This is because the interaction between ice and the structure is very complex. Dynamic ice actions are difficult to simulate and practical dynamic ice force models have not been well developed.

The Bohai Bay of China represents such conditions, as does some arctic areas of the Cook Inlet, the Beaufort Sea, the Barent Sea, the Caspian Sea, etc., though the design ice conditions in the other arctic areas are generally more serious than in the Bohai Bay. So this paper provides an overview of how to meet challenges when operating oil platforms during winters in the Bohai Bay. Sea-ice related design issues are discussed, such as ice forces on structures, and structural failure modes caused by ice-induced vibrations. Finally, the ice-resistant structural design conception and considerations for safe development of arctic areas are proposed.

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doi:10.1016/j.oceaneng.2011.05.012

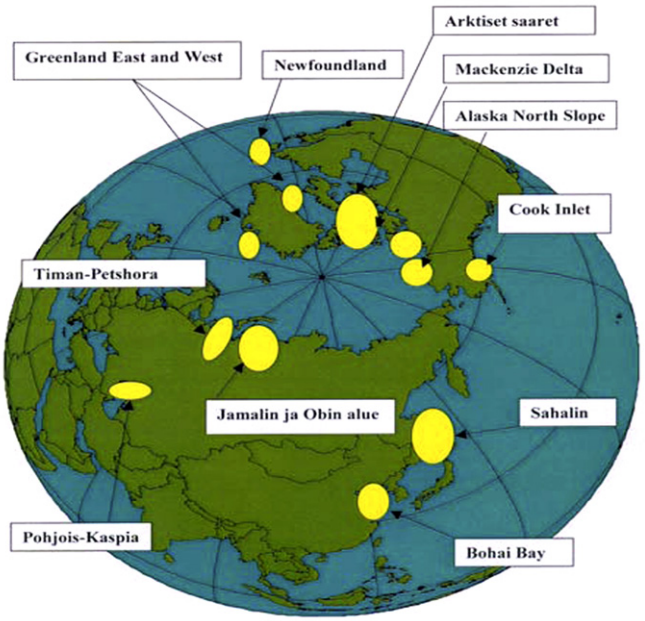

Fig. 1. Ice-infested sea areas with hydrocarbon resources.

Fig. 2. Multi-leg jacket platform of JZ20-2 oil field.

Fig. 3. Caisson platform in JZ9-3 oil field.

2. Sea ice conditions and oil exploitation in the Bohai Bay

The Bohai Bay is located in the northeast of China and spans between 37° N and 41° N. After the ice disaster of 1969s winter, the investigations on ice conditions of the Bohai Sea were widely conducted, especially, in Liaodong Bay, where is the north of the Bohai Bay. Zhang (1986) described the early surveys on the Bohai Sea ice. Wu et al. (2000) and Liu et al. (2000) reviewed the studies on ice condition simulation and satellite monitoring of the Bohai Sea. In the area of interest, the water depth varies from 5 to 20 m. The low temperatures are in January with average temperature between -4 and -8 °C and an extreme low of -25 °C. The ice season is generally from December to March. Ice forms under the influence of cold air flowing south from Siberia. Due to the southerly position of the Bohai Bay, the first-year ice is the only ice type, and mainly is floating pack ice. Ice conditions can vary significantly from north (more severe) to south (less severe). First-year year ice ridges are generally found in the shallow waters of the northern portion of the Bohai Bay in both normal and severe ice years. Surface ice temperatures are warm and are generally above -10 °C. The maximum floe ice thickness is 0.6 m. The maximum ice speed is no more than 1.2 m/s. Yang (2000) described the design ice conditions of the Bohai Sea.

The first drilling platform in the Bohai Sea was erected in 1965. Three kinds of structures, multi-leg jacket platform, caisson, and FPSO (Floating Processing Storage and Offloading Unit) have been constructed. Various types of structures were adopted considering the environmental conditions and oil reserve. Caissons have only been adopted in very shallow areas. Fig. 3 shows the caisson structure in the JZ9-3 oil field. But in the marginal oil field, the jacket platforms have been widely used. A multi-leg jacket is shown in Fig. 2.

The uncertainty of ice loading was always the key problem for the design and performance of ice-resistant structures in the Bohai Sea. Since the beginning of oil exploitation, the understanding of ice loading was accumulated and different ice problems were met. Firstly, the threaten of ice motion was neglected at all, so the offshore structures were not strong enough to withstand the ice loads. Two platforms were recorded to collapse due to ice-floe loading in 1969 and 1979. Since then, much attention has been paid to ice loading during platform design stage in the Bohai Sea. In the early 1980s, external advanced ice-resistant structural design techniques were applied in the Bohai Sea, which, unfortunately, led to overly conservative designs. Then, the relatively economical ice-resistant platforms were designed by determining the extreme ice force and ice parameters properly. However, these platforms were designed based on the extreme static ice force and did not account for the dynamic ice force and ice-induced vibrations.

3. Ice loads and ice-induced vibrations

3.1. Vertical structures

Full-scale tests of dynamic ice forces on compliant vertical structures have been conducted on jacket structures in Cook Inlet