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Abstract for

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Water Waves and Floating Bodies in the perspective of Arctic Offshore Engineering.

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Introduction and objective of paper

The Arctic area is expected to hold 25% of the world's undiscovered hydrocarbon resources and is therefore at present being extensively explored. Large-scale *oil and gas developments* are taking place at several locations of the Arctic, such as:

- Offshore Sakhalin, where AkerKværner of Oslo are building two concrete support structures for the Piltun- Astokhskoye and the Lunskoye platforms for the Sakhalin II development project (Operator: Shell, Russia)
- In the Pechora Sea where the Sevmash yard in Severodvinsk is fabricating a steel caisson for the Prirazlom field (Operator: Severomore neftegaz)
- On the North Slope of Alaska where the North Star field has been developed (by British Petroleum) from a man-made island called Seal Island.
- Offshore the Grand Banks of Newfoundland where the Hibernia and Terra Nova fields (requiring reliable iceberg management) have been developed by Petro Canada
- In the Bohai Bay of China where several platforms are exposed to ice loads in most winters
- In the Cook Inlet where the platforms installed are designed to withstand waves and ice loading

Further hydrocarbon developments in the Arctic region are planned, like developments of:

- The giant gas and condensate field Shtokman in the Eastern Barents Sea (Rossneft, Gazprom and partners)
- The Sakhalin I area, where the developments are expected to be initiated by ExxonMobil in the near future

In the sub arctic region (where ice is not encountered) Statoil is presently developing the Snøhvit field with sub sea templates at the offshore location and full well stream to LNG (Liquefied Natural Gas) producing facilities onshore Melkøya close to Hammerfest.

It should also be recognized that ice does represent a challenge for *shipping* in the Russian and Canadian waters as well as in other locations of the world, like on the Great Lakes and in the Bothnian and the Baltic. The safe transport of hydrocarbons in the Arctic is of main concern due to the Arctic's potential vulnerability to environmental pollution and studies have been carried out (e.g. the European Union financed initiative Arcdev (1)) to investigate the Northern Ship route from Europe to Japan. The interaction between ice and water waves is therefore of considerable interest for shipping.

As platforms in Arctic region are exposed to ice loads and also in some instances potentially to iceberg loadings, the ice is in general attracting the highest attention by the designers and operators. There are, however, a number of issues related to the water waves that are of considerable interest for these projects. This paper will highlight on some of these issues. Basic research on some of the issues may represent cost savings and increase the safety of operations.

Contrary to what is the case for most bodies placed in the open sea, the water waves may not represent the design loading on Arctic structures, but may put severe restrictions on operations so that the developments may not become economically viable without the proper attention to the action from water waves. This may in particular relate to the water wave action on floating bodies in the Arctic. The objective of the paper is thus to give an introduction to potential interesting and challenging issues related to water waves and floating bodies in the perspective of Arctic Offshore Engineering. In view of the venue of the workshop, the paper is considered relevant, although no attempts have been made to fully explore state of art. The recognition of the research of others through a thorough state of art review is, however, considered the first stage of proper research projects.

Challenges related to water waves and floating bodies in the Arctic region

In the Sub Arctic Region

Our knowledge about weather statistics in the Sub Arctic Region is limited. One aspect that causes concern is the fact that Polar Low pressures occasionally emerge from the ice edge into the seas and that these often are missed by the lack of a sufficiently dense grid of weather stations. The Polar Lows are limited size low pressures and could locally cause very strong winds and waves. A Polar Low could therefore suddenly emerge and the associated winds and waves could become dangerous for floating bodies. In case of waves from two directions, the seas could become very steep and it will be difficult to keep a ship up against the waves whereby heavy roll may be expected. At the Norne field offshore central Norway there has been situations where the oil producing ship (an FPSO) has been rolling heavily in crossing seas. Water wave statistics under Polar Low pressures should be collected.

In case of critical operations that cannot safely be carried out under sudden waves or in crossing waves it will be necessary to increase the density of the weather statistics or rely on satellite pictures to ensure that shelter harbor is sought in due time prior to the appearance of the low pressure.

It should, furthermore, be realized that temperatures in the Arctic often are sub zero and that water spray can freeze to ice. In such instances the additional weight of the ice can cause capsizing and sinking. The effect of waves on icing is not well demonstrated and icing is considered particularly dangerous should the waves appear suddenly and unexpectedly as caused by a Polar Low pressure.

In the Marginal Ice Zone

Open ocean waves enter an ice floe through the marginal ice zone, the MIZ (2). The MIZ is an area in transition. In the MIZ, ice is forming and ice is melting due to a variety of processes including wave-ice interaction. After passing through the MIZ, waves encounter thicker and older ice in the form of pack ice or fast ice. Fast ice is ice that is bound fast to a continent. Pack ice is an ice floe that is packed together by the motion of waves and winds and as the word floe suggests, pack ice is mobile.

Sea ice acts as a low pass filter for surface ocean waves that is the shortest waves are damped or stopped by the effect of the ice floating on the water. Short waves are also attenuated or stretched out by the influence of the sea ice floating on the water. The end result of the damping and attenuation is that only the longer waves penetrate to the interior areas of ice floes. A complete analytical study of the reflection and transmission of surface gravity waves incident on ice-covered ocean is given in (3). The ice cover is idealized as a plate of elastic material for which flexural motions are described by the Timoshenko-Mindlin equation.

A dramatic account of long waves propagating into the interior of an ice field is contained in *Endurance*, which is the story of a maritime vessel's crew stranded in the Antarctic pack ice. When the crew of the Endurance was nearing the edge of the Antarctic ice floe, they became ever more aware of the long ocean swell that became stronger and more persistent as they neared the edge of the pack ice, see ref (4). These aspects will become important for transport in ice when the vessels reach the ice edge and get out in open waters. Care will have to be taken to navigate properly under such conditions. See also references (5) and (6).

In Ice-Covered Seas

In ice covered seas the ice is consisting of a combination of level ice and pack ice. Even in such ice conditions waves have been encountered (7). It is at present, however, uncertain as to what are the consequences of such waves in the winter season. Further basic research into the phenomenon is called for should problems of any kind materialize.

The main problems related to water waves in the ice-covered seas appear in the ice breakup season when floating ice rubble and ice ridges represent a hazard to floating bodies, in particular when substantial waves cause ice ridges to move with high velocity. For some seas the ridges may not melt in one season and multiyear ridges resemble bergy-bits (small icebergs) in terms of ice strength. These multiyear features are of particular concern for ships in the region.

In seas with icebergs

In seas with icebergs there is a considerable concern that the icebergs can interact with platforms or floating bodies and cause large damaging loads. The icebergs float with the current while the wind could have an effect, although only 10% of an iceberg is above water. The larger icebergs on the Grand banks of Newfoundland are, however, moved away by towing them with a wire or a net taken around the iceberg (8). The ice management at the hydrocarbon producing area of the Grand Banks has so far proven efficiently although the vulnerable Terra Nova hydrocarbon producing ship is designed for quick release in case of emergency.

Some smaller icebergs, however, will most likely slip an iceberg management operation and will, like the multi-year ridges discussed above, exert large loads on structures installed in the sea. Platforms and ships must be strengthened locally to cope with such loads that will be exaggerated in case of large movements of the ice in waves. The actual magnitude of the ice design loads is not well known and should be investigated further.

The design philosophy is to design for local high loads due to interaction with the smaller ice features in waves, while damage will be allowed should the ice management fail in case of encounters with the larger ice features.

While most of the discussion above has been related to production units, any drilling operations as well as service vessels and commercial shipping must take the same aspects into account. The ship (or floating body) that is "unsinkable" has still to be designed.

Waves caused by iceberg calving and iceberg movements

During calving of icebergs from glaciers, large waves can be set up (9). Normally, floating bodies will keep away form the ice frontier, however, when ships approach a glacier, the danger of ice calving should be kept in mind.

Challenges from water waves for the design and operation of the different structures and floating bodies considered in the Arctic region

This chapter will summarize issues for particular structures placed in the Arctic Seas to produce hydrocarbons or to transport goods and services. Of concern in this paper are the challenges the water waves represent and the interaction with the ice features of the Arctic region.

Sub sea production equipment

As sub sea equipment is placed on the seafloor, the equipment will not interact with waves, however, any floating body (semi submersible or ship shaped vessel) servicing them will be prone to interaction with waves, currents, wind and ice. Working in the Arctic means that the interaction will have to take into account the movements of the ice with waves, an issue that will cause service vessels to be particular strengthened. Furthermore, the issue of icing due to water spray is of high attention when working in the wave climate of the Arctic waters during the freezing season. Polar Low pressures coming up unexpectedly pose a severe threat to operations.

Offshore production structures (fixed platforms and floating bodies)

Water waves will exert loads on the structures to be placed in the offshore region and there is a concern that the wave and ice action on platforms must be balanced such that the wave load does not become higher than the ice loading. The structures must furthermore be designed for local impact loads due to floating ice features and be capable of operating in all year wave conditions. Particular concern is expressed for operations of floating bodies when operating in crossing wave conditions where storm waves from one direction are combined with swells or waves from Polar Lows coming from another direction.

Tankers for transport of stable hydrocarbon products (oil and stable condensate)

Tanker transport of stable hydrocarbon products in the Arctic must take into account the ice and be strengthened for the ice load. The interaction of waves with the ice in the marginal ice zone where the tankers are going out of the ice or into the ice is of particular concern. Ice features like ridges drifting in this zone might also be of concern for the strength of the ship. In these conditions it is obvious that only double walled tankers can be allowed so any damage to the hull of the ship will not cause an environmental disastrous oil spill.

Ships for operation in the Arctic

Not only for the transport of hydrocarbons but also for shipping in the Arctic a design to resist ice loads is required. A ship designed to break ice will need to have a special type of bow that efficiently will break the ice. This type of ship will, however not be efficient for ocean going traffic. There is thus a need for transshipment onto ocean going vessels. In the Russian arctic a large tanker terminal is installed in the Murmansk fjord where the smaller tankers are bringing in hydrocarbons from Arctic fields. Efficient and larger ocean going tankers offload the oil from the storage tanker for delivery to European or US refineries.

Further research into design of efficient ocean going vessels that can operate in ice during the ice season is suggested. These ships can then operate efficiently in the Arctic bringing hydrocarbons to ice free tanker terminals from where the oil and condensate can efficiently be transported to the market.

Ships for breaking ice that will be able to act as supply ships in the ice-free season or service vessels in the field all year around are also needed. Such ships could be equipped with azipod thrusters to handle the ice and be maneuverable. Aker Finnyards in Helsinki are at present building stand by vessel for the Sakhalin I project, having the required features, see Figure 1.

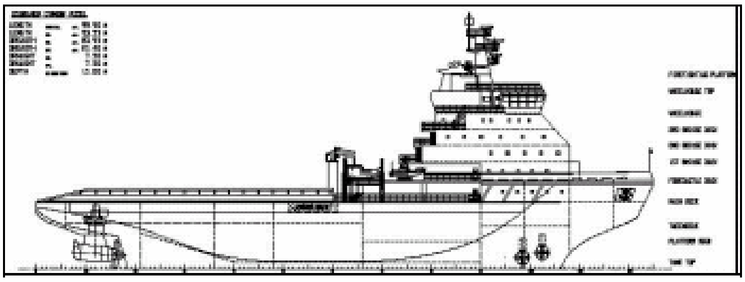

Figure 1. Example of stand by vessel for Arctic operations.

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