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Beaufort sea rubble fields: Characteristics and implications for nearshore petroleum operations

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ABSTRACT

Experience with past offshore platforms in the Beaufort Sea has shown that in some regions, a stable rubble field of ice may surround the platform during the winter months. These rubble fields can influence marine operations, emergency evacuation systems and can reduce ice loads on the platform. This paper analyzes the historical rubble information that has been collected pertaining to the nearshore Beaufort Sea and it examines potential empirical relationships between rubble field characteristics and a variety of ice and environmental parameters. Historically, offshore structures in this region were in open water for approximately 100 days. During the remaining time, quasi-stable, grounded rubble could be present around a structure for extended periods — for example, on average 65% of the time that there was moving pack ice in the autumn. Rubble fields formed between 76%–87% of the time when a drilling structure was in water depths from 5 to 32 m. This review shows that grounded rubble fields in the Beaufort Sea can be extensive with areas up to 1 km^2 with maximum sail heights up to 14 m. The extent and shape of each field is interdependent upon a number of factors, such as water depth, number of days the site is in moving ice, and the size and shape of an island, caisson or a submarine berm. But no one factor could guarantee the formation of grounded rubble. Upper bounds to the size of a rubble field are proposed based upon three separate data sets. The potential presence of rubble to such a great degree indicates that operators should clearly identify the strategies to be used to either manage grounded ice rubble or account for its presence with respect to marine operations and emergency evacuation methods. However, the data also show that rubble fields often don't form, even if conditions seem to be favorable for their formation.

1. Introduction

Broken ice is common in Arctic waters. Moving pack ice often fractures when it interacts with a stationary structure or ice floes with a differential speed. Ice pile-ups have been observed around offshore drilling platforms, along shorelines, and in the form of ice ridges. All of these broken-ice features can cause problems for offshore operations. This paper focuses on the ice pile-ups surrounding offshore petroleum platforms, and at sites where these platforms used to be located, in the shallow waters of the Canadian and American Beaufort Sea. These pile-ups can be floating or grounded. In most cases, floating rubble piles do not persist for any length of time since changing environmental forces and directions can move these broken ice piles away from the platform. However ice that is grounded persists (see Fig. 1) and can remain around the platform well into the spring breakup. These pile-ups can impact operations in several ways. For example, they restrict access to the platform for marine vessels. This can affect marine operations for both re-supply and petroleum offloading to tankers. Further, these grounded rubble fields can hinder emergency evacuation in the event that helicopters cannot be used for personnel movement during an emergency. But they do offer the advantage that they tend to “shield” the platform from oncoming ice movement and this shielding results in significantly lower ice loads (Croasdale et al., 1994, 1995; Timco and Wright, 1999). All of these issues must be considered and addressed by careful planning. To do this reliably, quantitative information about the formation, size, characteristics and duration of these rubble fields is essential for proper engineering design and operations in nearshore waters. This paper investigates these aspects of grounded rubble fields in the Beaufort Sea based upon a large amount of historical data and new field observations, in an effort to present reasonable relationships and some upper-bound envelopes. As the mechanics of rubble field formation has been examined elsewhere (see, for example, Canatec (1994)), this is not re-examined here. The present paper summarizes the lessons learned about past grounded rubble fields in the Beaufort Sea, as these features relate to offshore exploration and production considerations.

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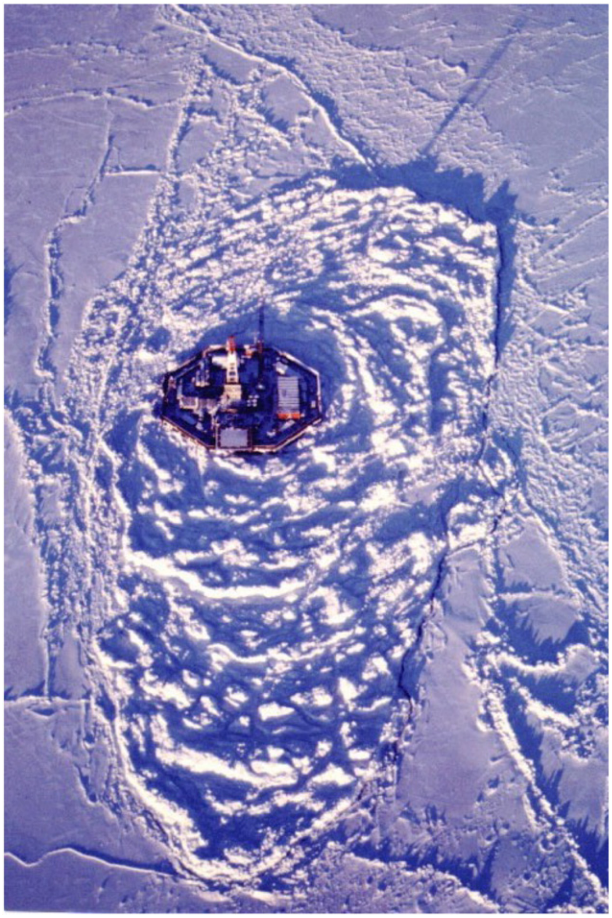

Fig. 1. Photograph of the Caisson-Retained Island (CRI) at the Kaubvik I-43 site, showing its extensive surrounding ice rubble field (photograph courtesy of Imperial Oil Ltd.).

2. Typical shallow-water Beaufort Sea structures

Various types of systems were used as shallow-water (<100 m) drilling platforms in the Beaufort Sea during the 1970s to 1990s, including floating drill-ships in marginally deeper waters, bottom-based caisson structures in more moderate water depths (from 15 to 30 m), and artificial sand/gravel islands and grounded ice pads in shallower waters (see e.g. Timco and Frederking, 2008, 2009 for a detailed review). This paper examines only the sites that had bottom-founded structures or artificial sand/gravel islands. There are three structural configurations that were investigated in this study. The first two represent situations where the rubble was generated at a location while exploration drilling operations were taking place. The third situation is post-drilling and there was no drill rig present. All three configurations are outlined below and shown in Fig. 2 through Fig. 4.

A large number of natural shoals and artificial islands were used in the Beaufort Sea for exploration activities. The islands were made of either dredged material or granular fill that was trucked from shore and dumped on site. These islands generally had a low freeboard. Additionally, they could have a sandbag-retained or sacrificial beach design

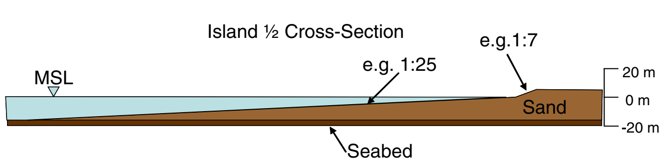

Fig. 2. Example of a half-island cross-section along one direction of a sand island. A drilling rig would have been located on the top surface.

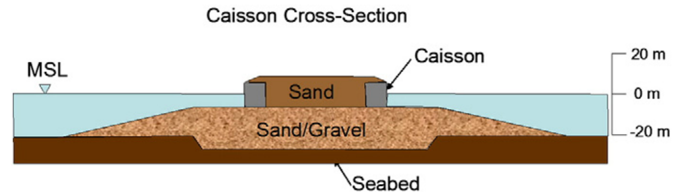

Fig. 3. Example caisson cross-section. A drilling rig would have been located on the sand fill or steel deck of the caisson.

(see Exxon, 1979). Fig. 2 shows an example profile of an island configuration. The surface area of these artificial islands could be quite large, with diameters in the order of 100 m with much larger submarine berms. In the 1970s and 1980s, this type of drilling platform was thought to be the most cost effective in shallower water depths (<20 m). Note that in the 1990s, spray ice pads proved to be a much more effective exploration alternative in shallow water (see Weaver and Poplin, 1997).

The second configuration was one that used a caisson platform. Fig. 3 shows a schematic of a typical caisson cross-section arrangement. An exploration platform with this type of configuration would generally consist of an outer concrete caisson (Tarsiut caissons, Concrete Island Drilling Structure (CIDS)) ring which was back-filled with sand for stability, or a steel structure (Molikpaq, Caisson Retained Island (CRI), Single Steel Drilling Caisson (SSDC), which could have sand or water fill for added stability. Caisson structures were typically set down upon a sand or gravel berm (or for one structure (SSDC), a fabricated, removable berm was employed). Typically, the caissons had a surface length around 100 m, with freeboards that varied from 5 m to about 20 m. The sides of these structures were generally vertical, but some had slight inclinations depending upon their set-down depth. These types of platform would typically be used today in water depths of approximately 15 m to 30 m, with an upper limit depth dictated largely by cost and ease of construction/use. When the drill rigs were removed after the drilling was complete, the islands and submarine berms for caissons were left to erode from wave action. However they did not completely erode to the seabed and this presents a current-day situation of submerged, remnant berms (see Fig. 4). Thus, unlike the previous two types of configurations, which had surfaces or structures that were above the water-line, the remnant berm sites are not surface-piercing. Note that the remnant berms from island sites are generally substantially larger in aerial extent than those from caisson sites. These berms erode down over time, and also slightly migrate horizontally due to local water currents and tidal effects. Several of these sites were examined in four separate field programs by the authors (in conjunction with Brian Wright) from 2006 to 2010 (see e.g. Barker et al., 2006a, 2007, 2008a, 2008b, 2009a, 2009b; Spencer et al., 2007; Timco and Barker, 2015). These sites are referred to as the Barker field sites in this paper.

Thirty-seven locations were examined in this study. Eighteen of these locations were examined in detail, with source information from historical documents contained in the NRC Centre of Ice-Structure Interaction (Timco, 1996) for each site [see Barker and Timco (2006) for a detailed overview of the rubble sites]. The comprehensive reports on

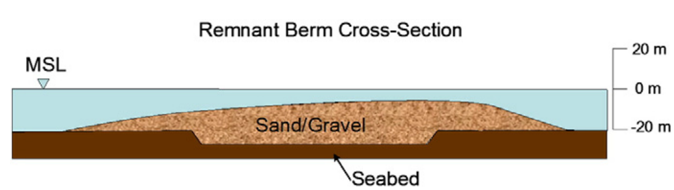

Fig. 4. Example remnant berm cross-section. Note that the berm is not surface-piercing, as there is no drilling structure anymore. A remnant berm can be affiliated with either an island or a caisson site; the latter remnant berms are smaller than the former.