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Cyclic Ice Loading on the Molikpaq

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ABSTRACT

The Beaufort Sea is located north of Northwest Territories, the Yukon and Alaska, and west of Banks Island. The centre and northern part of this sea is frozen solid all year round, and the sea is exposed to considerable ice scour. Petroleum exploration in the ice packed Beaufort Sea in the 1960's led companies to develop offshore structures that would withstand extreme ice loading. In 1984 Gulf Canada Resources Ltd. deployed a mobile arctic caisson into the Beaufort Sea called the Molikpaq. The Molikpaq was installed on an artificially constructed berm, where it completed exploratory drilling during four subsequent winters.

At the time that the Molikpaq was designed, ice loading on structures was a little known matter. To alleviate this knowledge gap, hundreds of sensors were installed on the Molikpaq to observe and attempt to predict behaviour due to loading.

In 1986 the Molikpaq platform was brought to within minutes of failure due to cyclic loading. In this particular event the ice loading occurred at such a frequency that vibration occurred, causing liquefaction of the inner sand core. The sensor readings and detailed observations of this event and the various other loading encounters on the Molikpaq have provided a considerable amount of information for future projects.

This paper compiles information on the design and installation of the Molikpaq in the Beaufort Sea. This drilling structure had various successes in regards to resisting ice loading, but eventually came near failure due to the unfamiliar characteristics of cyclic loading. This event will be explored, noting the lessons learned, and how this has affected and will continue to affect other offshore structures deployed in ice-filled waters.

1 INTRODUCTION

Petroleum exploration and production in the Beaufort Sea was of major interest in the 1980's. The sea conditions in this area are mostly ice covered, and the water is quite shallow near the coast, resulting in particularly active ice and wave loading on drilling structures. Drilling structures had to be designed to resist these loads while maintaining their structural integrity and drilling capabilities.

The Molikpaq was deployed in 1984 by Gulf Canada Resources Ltd. into the Canadian Beaufort Sea, on an artificially constructed berm in order to complete exploratory drilling [1]. Due to the gap in knowledge about extreme ice conditions at the time, the Molikpaq was equipped with hundreds of sensors in order to observe the behaviour of the structure due to loading events [2].

One type of loading that can occur is cyclic ice loading, where a face of the structure is continuously loaded and unloaded. An event occurring on April 12, 1986 is of particular interest as the Molikpaq was close to failure due to cyclic loading.

2 BACKGROUND

The Beaufort Sea is located north of Alaska, the Yukon and Northwest Territories. The waters are frozen solid much of the year. Historically petroleum exploration was done in the Beaufort Sea using drill ships during the short melt period in the summer, and from artificially constructed islands in the winter months. Evidently the icy conditions created challenges for deploying structures into the Beaufort Sea, and due to the little knowledge about extreme ice conditions available at this time, many structures were equipped with measuring sensors and devices [2].

Artificial islands were used for shallow water exploration, where the ice was generally solid, and subject to little movement. These islands were constructed of gravel in the 1970s and then sea spray became more common in the 1980s. Caisson structures were used to explore in deeper water with more extreme conditions, where artificial islands were less economical. These structures would allow for year around drilling, and five of them were deployed in the Arctic in the 1980s. One of these was the Molikpaq [2].

2.1 Project Description

The Molikpaq is a mobile arctic caisson that was deployed in September, 1984 by Gulf Canada Resources Inc. to drill exploratory wells in the Beaufort Sea. It was situated on an artificially constructed submerged berm which brought the foundation to 19.5 meters below sea level [3]. Figure 1 is an image displaying the Molikpaq in the Beaufort Sea.

Figure 1: Photo of the Molikpaq in the Beaufort Sea [2].

The Molikpaq was designed as a steel caisson that was filled with sand and was submerged to a depth of 21 meters. The benefit of the caisson is that it decreased the berm height requirement, reducing its radius at the deepest part.

2.2 Project Challenges

The Beaufort Sea presented various challenges for exploration units, particularly as drilling moved into deeper waters. When Gulf Canada Resources Inc. undertook the project to drill in water depths greater than twenty meters, ice conditions and the consequent loading effects on structures was considered to be a little known science. Along with drilling exploratory wells, Bruce [1] describes that the Molikpaq was to be designed to meet the following requirements:

- year round operation,
- ability to be located in deep water,
- easily transported,
- reduce dredging requirements in deep water.

The year round requirement eliminates the possibility of using a ship. The depth and conditions of water considered for this project created a challenge for using an artificial island. The amount of material that would be required to construct an artificial island of this height would have been unrealistic given the side slopes required for the available sand. Erosion from wave loading prior to protection from freezing would also create a problem for an island this size [1].

These conditions were fulfilled when the Molikpaq was designed as a deep structure to be submerged 21 meters, where it would sit on a constructed berm. The decreased height requirement for the berm was realistic with respect to fill material, and the unit would be relatively easy to transport [1]. A significant challenge that the Molikpaq would encounter in the Beaufort Sea was ice loading.

2.3 Molikpaq Ice Loading Design

The Molikpaq was designed such that loads exerted on the steel caisson would transfer to the hydraulically placed sand inside the caisson. The sand resisted approximately 80 percent of the horizontal loads exerted on the structure [4]. Figure 2 is an image displaying the Molikpaq sitting on the constructed berm. In this figure the inner sand core can be identified, and the structure depth in relation to the water level is displayed. The steel face surrounding the sand core would encounter loads.

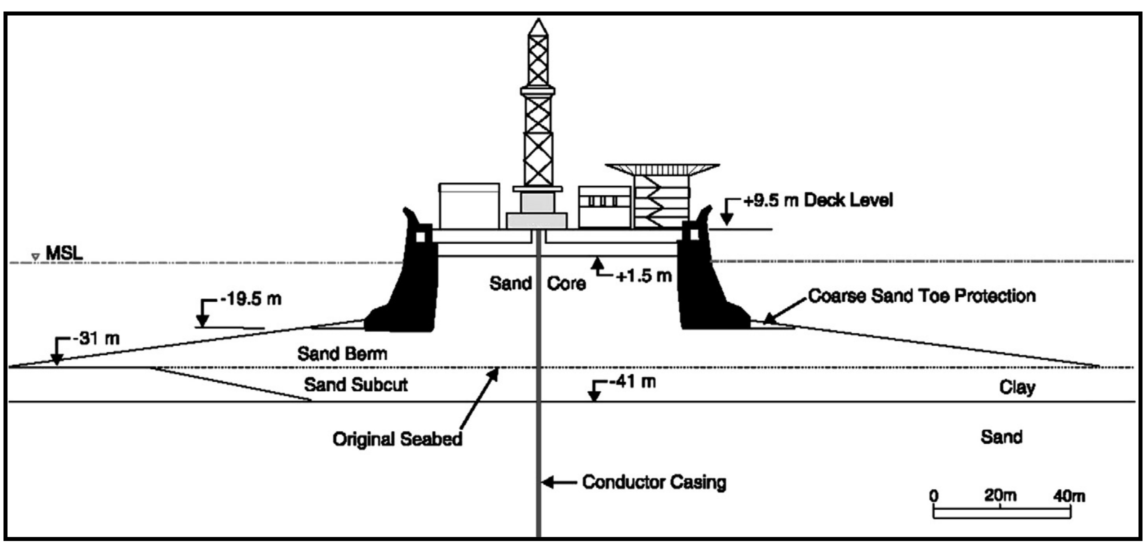

Figure 2: Cross-sectional view of the Molikpaq [5]

The response of the structure when ice impacted the steel face was the formation of a positive pore pressure from the increased stress in the sand core. This increase would be recovered after unloading, and the pore pressure would fall back down [6].

The Molikpaq was also equipped with various sensors to measure and study the conditions encountered during its time in the Beaufort Sea. This equipment included MEDOF panels, strain gauges, and extrensometers for analyzing the ice loads [4]. According to Timco and Johnston [4], the MEDOF panels compress when ice impacts the structure face causing fluid levels in a stand pipe to change. This change is measured to get "hydrostatic head changes" and was then converted into caisson loads [4]. Cameras as well as reports were used to document characteristics of the loading events.

The Molikpaq was deployed in four locations during its years in the Beaufort Sea and it experienced various ice conditions. The loading events included first-year and multi-year ice impact on the vertical and sloped walls, and cyclic ice loaded [4].

2.4 Cyclic Loading on the Molikpaq

One type of ice loading that the Molikpaq encountered was cyclic loading. This type of impact is the repeated loading and unloading of ice against the caisson face. This can occur as wind and waves move ice up against the structure. Even though there was very little experience with cyclic ice loading, the Molikpaq was designed with quasi-static scenarios. However, according to Jefferies [7], no vibration was expected to occur in the structure.

When cyclic loading occurred on the Molikpaq, the pore pressure in the sand core would rise and then begin to fall during unloading, but before it could be completely relieved another load sequence would occur [6]. Cyclic loading occurred on the Molikpaq multiple times, but on April 12, 1986 the structure was brought very close to "platform-loss" when this type of loading occurred [7]. Figure 3 displays the building of pore water pressure during the ice cyclic loading against the face of the Molikpaq. The significance of this figure is that the pore water pressure is not completely relieved between loading sequences.

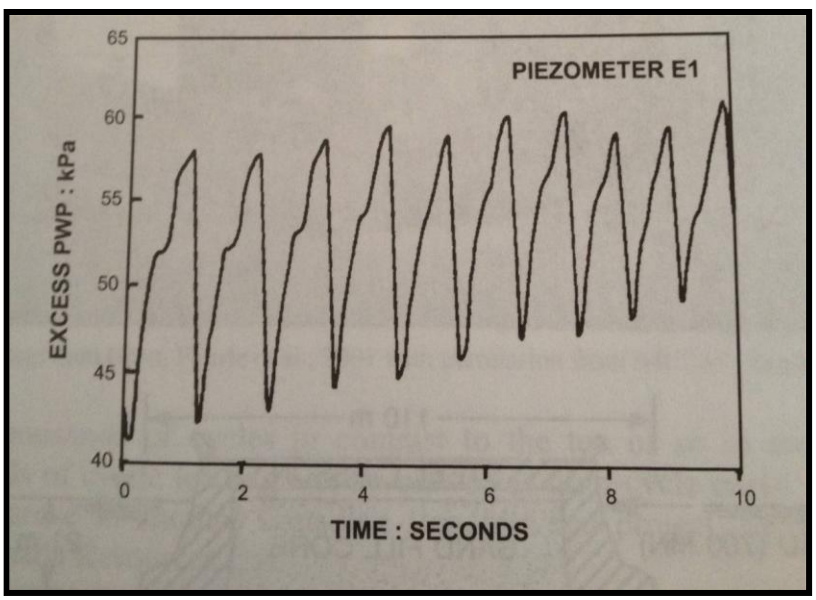

Figure 3: Excess pore water pressure against time during April 12, 1986 event [6]

This particular loading event progressed when an ice ridge of approximately 75 meters long and 12 meters thick moved against the east face of the caisson. The cyclic loading caused vibrations on the caisson structure. According to Jefferies and Been [6], the frequency of the cyclic loading was between 0.5-2 Hertz and it lasted for fourteen minutes, equaling approximately 900 loading cycles. When the sensor equipment was checked it was found that liquefaction had occurred in the sand core [6].

Sand liquefaction occurs when saturated soil loses its strength and stiffness, thereby losing its ability to transfer shear stress. This is caused by pore pressure rising high enough that it holds the sand particles apart, making it act as a liquid [8]. As described, when the Molikpaq was exposed to this cyclic loading event, the pore pressure was never relieved, causing it to build until this phenomenon occurred [6]. When the ice that was exerting the cyclic loading on the face of the Molikpaq became grounded, the loading stopped, allowing the structure to stabilize. It has been observed that the platform of the Molikpaq was within minutes of loss [7].

When the Molikpaq was designed, cyclic mobility computations did not exist, therefore centrifuge tests were used to simulate cyclic loading [6]. These tests showed that the system would become fully drained, and liquefaction would not occur. This testing was considered to be reliable, and therefore the hydraulic fill was thought to have the ability to resist cyclic loading. According to Jefferies and Been [6], the sand in the core of the Molikpaq did not behave as simulations displayed.

After its time in the Beaufort Sea, the Molikpaq underwent redesign, and in 1998 it was installed approximately 16 km offshore in the Piltun-Astokhskoye field. It was retrofitted with a 15 m steel piece to increase its depth capability. In 2008 the Molikpaq began to be used year around at this location [9].

3 LESSONS LEARNED

Although there was confidence in the simulations that were done in the design of the Molikpaq, it was also known that there were gaps in the knowledge about ice loading at this time. It was for this reason that the Molikpaq was equipped with hundreds of sensors in order to observe the response of the structure due to loading events. The observations and data that were collected during the deployment of the Molikpaq aided immensely in the understanding of ice loading on offshore structures, and it continues to be studied. However, a lesson that was learned from the April 12, 1986 event was that data collected during the observational method can give false confidence. In the case of the Molikpaq, many ice loading events were reported, and showed the structure was responding very well, and according to Jefferies [6], this caused misplaced confidence in the structure. He states that “where behaviour can snap-through to an undrained liquefaction, the observational method is simply inapplicable” [6].

Nevertheless, much was learned from the data obtained, even though the observational method did not aid in stopping this event from occurring. It was learned that liquefaction can occur in such a situation and conclusions could be made as to what could be done to stop this from occurring in the future.

4 CONCLUSION

The extreme conditions in the Beaufort Sea created a unique set of design requirements for the Molikpaq. Due to a basic lack of knowledge regarding ice loading at the time, the sensors were installed on the Molikpaq providing an immense amount of data and reports on reactions of a steel caisson structure due to loading events. This data is still studied and has had various applications for future projects since the Molikpaq deployment.

The dissimilar behaviour of the soil in the Molikpaq when compared to the behaviour during centrifuge testing demonstrates that even when using “best engineering estimates” [6] to make conservative assumptions with respect to design simulations, things can be missed or overlooked. Another application that arose from this event, which continues to be studied is if better soil drainage would have prevented liquefaction, and if this can be used in future designs [7].

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