

First Successful Subsea Pipeline In The Arctic: Northstar

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ABSTRACT

Due to the growing demand for oil and gas in the world, there is an increasing interest to explore new areas for petroleum production. According to a United States Geological Survey, the Arctic Circle has 90 billion barrels of undiscovered oil which represents 13% of the undiscovered oil in the world. Therefore, the development of offshore oil and gas resources in the Arctic has gained a renewed interest in the last decade. However, there are many challenges associated with design, construction and installation of arctic subsea pipeline. Some of the technical design challenges of the arctic pipelines encounter are ice gouging, permafrost thaw settlement, strudel scour, and upheaval buckling.

According to literature review, BP Exploration Alaska's Northstar pipeline has set a baseline by operating safely for the last 13 years and has demonstrated that offshore arctic pipelines can provide safe and reliable oil and gas transportation system. Northstar is the first Arctic offshore development connected to shore by subsea pipeline. This is located about 10 km (6 miles) northwest of Prudhoe Bay in about 12 meter of water. Northstar oil flows to the Trans-Alaska Pipeline System through a subsea pipeline. The primary load conditions controlling Northstar pipeline design and trenching requirement were ice gouging and permafrost thaw.

The industry can apply this experience on other pipelines in arctic that has potential ice load conditions. The paper reviews main challenges in the Arctic, design criteria and lesson learned relating to the Northstar offshore pipelines for protection from ice gouging that can be considered for future offshore Arctic pipelines.

1 INTRODUCTION

The demand for oil and gas in today's world is growing and thus there is a need to explore new areas for more petroleum production. According to the United States Geological Survey, Arctic Circle has 90 billion barrels of undiscovered, recoverable oil which represents 13% of the undiscovered oil and 30% of gas in the world [1]. However, there are many challenges associated with the design, construction and operation of offshore structures in the Arctic region, primarily due to a very harsh winter climate condition and the presence of ice ridges. The industry has somewhat limited experience, due to unique climatic condition of arctic. According to Lanani, [5] due to lack of single industry standard and also due to the increasing interest on the arctic oil and gas in the petroleum industry, the need for new design and operation regulations and standards have grown in the last decade.

An example of an operational subsea pipeline in Alaskan Beaufort Sea is the Northstar Project. Northstar is the first Arctic offshore field connected to shore only by pipeline. Northstar was developed by British Petroleum (BP) Exploration (Alaska) and started production in 2001. The Northstar oil flows to the Trans-Alaska Pipeline System (TAPS) through a subsea pipeline. A significant knowledge and experience has been gained from the design, installation and operation of this project, which surely laid foundation and provided valuable information for future offshore arctic pipelines. The paper gives a brief overview of Arctic environment and primary loadings any offshore pipeline may face in the arctic region as well as a brief account on the NorthStar pipeline case and important aspects of offshore pipeline design that have been learned from this pioneer pipeline.

2 THE ARCTIC ENVIRONMENT

2.1 The Arctic

The design of offshore pipelines in the Arctic remains considerable challenges due to the harsh climatic condition and ice coverage. The Beaufort Sea remains covered with ice for nine months of the year. The ice in Beaufort sea typically breaks up in June and summer open water condition starts from July to Mid October. Also, Ice floes can be often present during summer and their movement is influenced by wind and current [2]. The construction methods for summer and winter construction vary considerably. The winter construction is mainly governed by the ice environment which means that the ice is sufficiently thick and is able to support the weight of the equipment without which construction cannot begin. Also, ice ridges could also affect construction [2].

2.2 Pipeline loadings in the Arctic region

The primary loading conditions that the harsh Arctic environment usually poses are

1. Ice-gouging;
2. Permafrost Thaw settlement/ frost heave;
3. Uplift buckling and
4. Strudel Scour

The ice gouging phenomenon begins by wind and current forces piling up sea ice into ice ridges [3]. These ice ridges have a keel that extends below the water surface. The ridges can cut deep gouges into the seabed once they enter shallower water if water depths are less than the keel. Pipelines may not be able to withstand the ice contact forces, thus, pipelines need to be buried below certain predicted

extreme ice keel scour depths known as “burial depth” for protection. Ice gouging generally increases with decreasing water depths [3].

Permafrost thaw settlement is another major concern for pipeline design in the arctic areas. It occurs in shallow waters and at the shore crossing where soil ice bonded permafrost lie beneath the pipeline [3]. When the pipeline becomes operational, the temperature of surrounding soil increases. Due to the temperature increase of the buried warm oil pipeline, a permafrost thaw bulb can be created which decreases the load carrying capacity of the soil. Permafrost causes settlement in areas that are comprised of sand, clay and gravel as the spacing between the particles initially covered with frozen water becomes porous and thus increases settlement. The settlement results in overstress and strain in pipes, which then can result in pipe to burst [3].

An axial compressive force can develop if pipeline is not let to expand freely. This is because when temperature and pressure changes, from that experienced during installation, as due to the restrain provided by the surrounding soil [3]. If there is an imperfection in the trench bottom during installation, this axial force can move the pipeline upward at points of residual vertical curvature. At this point upheaval buckling can occur if the upward force exceeds downward forces, due to the combination of pipeline stiffness, soil cover, and pipeline’s self weight [3].

Near shore zones, when fresh water in rivers and streams flows over the surface of frozen shore-fast, ice strudel scours can occur [3]. If this water seeps through ice sheet cracks very fast and water depth is shallow, this can scour seabed and generate long free spans. This exposes the pipeline to high strains due to high current load on pipeline [3].

3 THE FIRST ARCTIC SUBSEA PIPELINE : NOTHSTAR

3.1 Brief overview of Northstar Pipeline

Northstar offshore pipeline is BP’s first offshore arctic field development to use a subsea pipeline. This is the most challenging offshore island project completed to date in Alaska and located at an exposed site 10 km north of the mainland shore, Prudhoe Bay, at a water depth of 12 m [4]. It was constructed on top of a shoal formed by remains of an abandoned exploratory island called Seal Island in 2000 [4]. Figure 1 below shows the location map of Northstar pipeline [4].

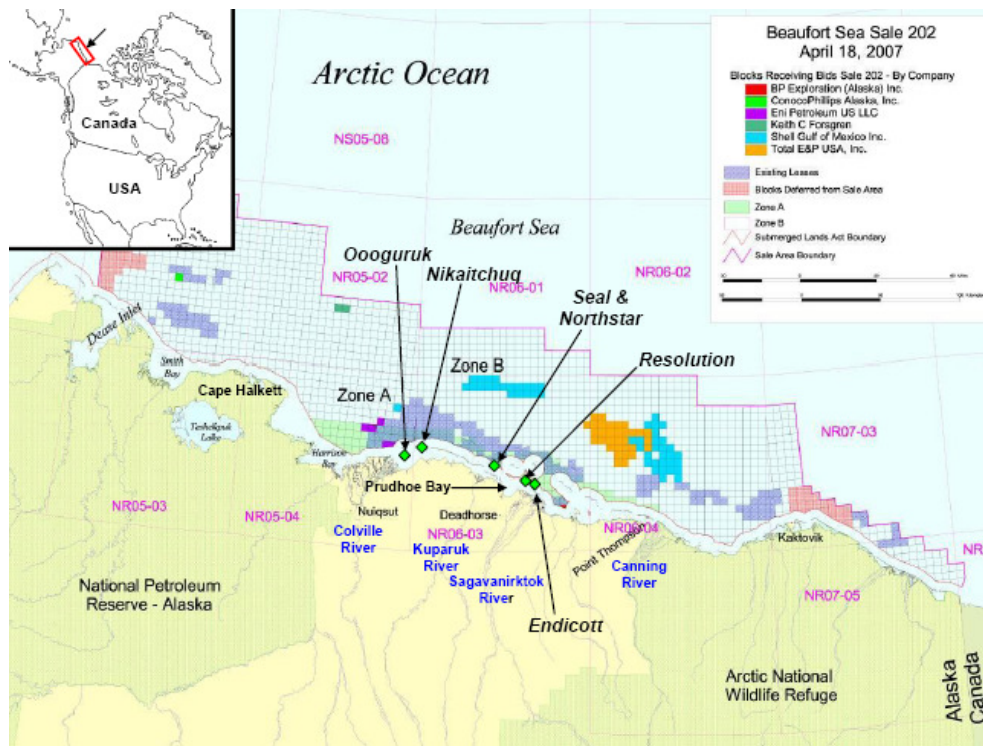


Figure 1: Location map of Northstar in Beaufort sea

The field contains approximately 176 million barrels of recoverable reserves. The construction of the Island commenced in January 2000. Following the construction of 3 m thick ice road, approximately 600,000 m³ of gravel were hauled by truck from onshore quarry. The sheet pile walls that surround the work surface and the dock structure were driven in winter [4]. The Northstar Production was designed for a 15-year design life but its service life may be extended. The design of the island included modular concrete mat system. During the same winter a twin-pipeline bundle was installed through the winter ice sheet and buried 2.7 m beneath the seabed. The bundle and included a 10 inch oil export pipeline and 10 inch line supplying gas to the field for reservoir pressure maintenance[6]. Figure 2 below [2] shows the northstar twin subsea line that was installed as a bundle.

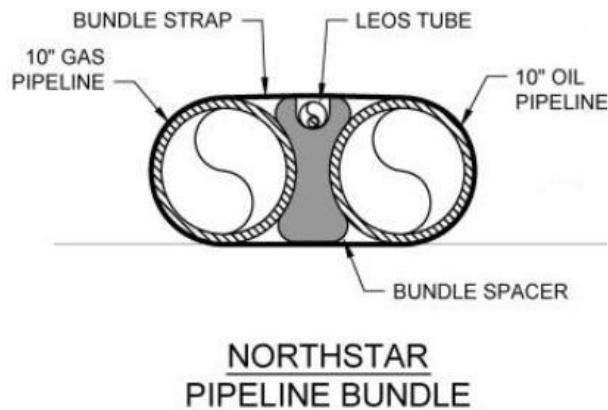


Figure 2: Northstar pipeline bundle Cross-section

3.2 Environmental loading on Northstar

The primary loading conditions that controlled Northstar design and trenching was the seabed ice gouging and permafrost thaw [5]. Strudel Scour and upheaval bucking were not considered during the design process of Northstar as they were found not to be the controlling factor for trench depth.

Ice gouging in Beaufort Sea occurs mainly due to sea ice ridges [1]. The statistical ice gouge analysis method was used for the Northstar subsea pipeline, to select design pipeline burial depths for protection against ice gouging [6]. Seabed ice gouging and 10 years pipeline route bathymetry surveys carried out prior to construction of the pipeline. The statistical method was applied to data collected prior to the pipeline installation in 2000 to predict the design extreme ice gouge depths expected along the pipeline route [6]. It was observed that the deepest seabed ice gouge was less than a meter and maximum predicted ice gouge in the pipeline vicinity during 100 year return period was estimated to be approximately 1 m (3.5 feet). For safe pipeline design, it is normally preferred that the pipeline is buried to deeper than the maximum gouge depth expected during its design life due to the he soil displacement induced at the pipeline depth, and the resulting pipe strains must be assessed against design limits. The minimum pipeline depth of cover of approximately 2.1 m (7 feet) with maximum bending strength of 1.4% was calculated [5]. The minimum pipeline depth was calculated based on limit states design for pipe bending.

Also according to literature review, as ice-bonded permafrost was found along the pipeline route in water depth below 1.5 m and thus a thaw bulb can form. This is due to the fact that Northstar operates above soil pore water freezing point, thaw settlement can occur. The maximum predicted thaw settlement of 0.6 m (2 feet) was calculated that could cause pipe bending strains of 1.1%. [5]

Strudel scour survey data has been collected recently in the vicinity of Northstar site at Beaufort Sea indicated that the maximum horizontal dimension of any strudel scour was 30 meters at the seabed, and that the maximum depth measured was 1.7 meters. Usually strudel scour is more severe in areas located near rivers, or at river delta [3]. This verified the fact that strudel scour was not controlling design loading.

3.3 Design criteria of the pipeline

The Northstar offshore pipeline was designed to withstand the bending strains posed by the severe Arctic environmental load due to ice gouging and permafrost based on limit state design procedure. This approach avoids the need for robust pipe cross-sections [5]. It was noted due to extreme load conditions, plastic strain would be induced in the pipeline as it will go through large displacement but will not exceed the ultimate limit conditions [5]. Also, according to Lanan [5], “the Northstar pipeline limit state design for bending used a combination of existing US and international design codes and standards to perform Engineering Critical Assessment (ECA) for bending limit condition. However, due to lack of a single industry standard, the design procedure for Northstar was challenging and as a result great importance was placed on validation of the limit strain criteria” [5]. In addition, the Northstar pipeline design also satisfy the conventional pipe requirements such as throughput capacity, internal pressure, stability and other standard pipe failure mechanisms like bursting, excessive corrosion and vibration induced fatigue [5]. Also, the line pipe used in Northstar was manufactured to a project-specific specification and a project-specific welding specification was used incorporating features relevant to the bending limit state design. To be more conservative, a double inspection was done on 100% of the welds to remove any flawed welds [5].

The Northstar pipeline bundle design included LEOS leak detection system, a new technology at that time. These leak detection system designed to sense the presence of oil outside the pipes and can detect very small potential leaks which are difficult to address in conventional pipeline leak detection technology [5]. Also, a routine pipeline inspection pigging to identify potentially excessive pipe corrosion and permafrost thaw settlement induced bending strains ensured that pipeline repair work before a pipe failure [5].

3.4 The Northstar Experience and Monitoring

The BP Northstar gas pipeline initially started supplying fuel gas in late 2000 and then switched to supplying natural gas for reservoir pressure maintenance purposes [2]. Since 2001, the facility had successfully produced over 120 million barrels of sales-quality crude oil [2]. There have been 12 yearly pipeline route bathymetry surveys along offshore route and surveillance of shore crossing since pipeline installation which provided comprehensive information about the pipeline's performance in response to offshore loading conditions [4]. The pipeline surveillance results are reported annually to the Alaska State pipeline coordinator's office by BP Transportation (Alaska) [2]. Newly formed ice gouges are assigned unique number and these gouges are tracked in the evaluation of later survey. The deepest gouges were observed in a survey during 2007 due to an intense storm during October 2006 which produced high winds and waves as well multiyear ice floes located 180 ft east of the pipeline. The deepest observed 2007 gouge was ~1.6 m (5.1 ft), which exceeded the 100-year design ice gouge depth (3.5 ft) by a factor of 46%. However, the pipeline was not affected due to the safety factor and as it was designed for approximately 2.1 m.

3.5 Valuable lesson learned at Northstar

The operational experience from the Northstar pipelines can be used to other offshore structures or pipelines. The survey data collected over several year prior to the design of Northstar to define reliable loading condition, the limit state design procedures for high pipe bending strains and periodic monitoring, bathymetry surveys and leak detection systems, have allowed Northstar to be safe and successful. The seabed, near the Northstar field has been surveyed repetitively and thus understanding the data obtained will help develop at other fields around the world. The statistical ice gouge analysis method can be used to assess these surveyed data to get a better understanding of ice gouge depth and thus burial depth cost can be minimized by being less conservative in other Arctic Pipelines. Leaks in subsea pipelines need to be detected quickly to minimize the environmental issues or spills. Therefore, the operational experience of successful use of LEOS leak detection system for the first time in the Arctic can be beneficial for other offshore fields in the arctic environment.

4 CONCLUSION

The development of offshore oil and gas resources in the Arctic has gained a renewed interest due to the grown energy demand in the world. However, due to harsh environment and limited weather windows, the industry experience in the Arctic structure construction and installation is minimal. It is extremely important to identify the risks and impacts of Arctic offshore development and mitigate them for safe operation. The first subsea pipeline in the arctic, Northstar offshore pipelines has proved to be a successful subsea pipeline which has been providing safe and reliable oil and gas transportation system in harsh climate since 2001. The operational experience from the Northstar pipelines can be used to other offshore structures or pipelines.

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