Paper #6-5

DEVELOPMENT DRILLING AND PRODUCTION PLATFORMS

Prepared for the

Technology & Operations Subgroup

On March 27, 2015, the National Petroleum Council (NPC) in approving its report, *Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Technology & Operations Subgroup. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 46 such working documents used in the study analyses. Appendix D of the final NPC report provides a complete list of the 46 Topic Papers. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

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Topic Paper

(Prepared for the National Petroleum Council Study on Research to Facilitate Prudent Arctic Development)

6-5	**Development Drilling and Production Platforms**
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SUMMARY

Fixed Platforms can be safely and reliably designed for year round drilling and production activities in the Chukchi and Beaufort Seas based on established technology. This includes (by increasing water depth progression) slope protected manmade islands, retained manmade islands, and Gravity Based Structures (GBS). The water depth limit for a GBS is dependent upon ice loads and geotechnical conditions, but is estimated to be in the 70-120 m range based on economic considerations.

Floating platforms are required beyond the feasible limit of GBS. Floating platforms based on established technology are limited to the open water and ice shoulder seasons. Feasibility is limited by ice loads and mooring capacity or resistance. Future technology development, including ice management, may extend operating limits, but is unlikely to enable year round operation. Floating platforms for development drilling in the open water and ice shoulder seasons are covered in TP7 – Exploration drilling – fixed and floating.

GBS are a proven concept for Arctic and sub-Arctic environments. Examples include the Sakhalin I and II platforms in the Sea of Okhotsk designed for first year ice conditions and Hibernia, east coast Canada, platform designed for icebergs. GBS required for the Chukchi and Beaufort Seas, while step outs from established practice in terms of larger ice loads, are building on this proven technology.

Established design practice for fixed and floating structures has been codified in ISO 19906. This standard, consistent with the ISO 19900 series uses a limit states design method for safe and reliable design. Limit states that need to be evaluated include Ultimate, Serviceability, Fatigue, and Abnormal (Accidental). Load and resistance factors for the Ultimate and Abnormal limit states have been calibrated to achieve an annual failure probability of 1.0x10-5 for a manned platform with high consequence exposure level. Code calibration included representative loads for Chukchi and Beaufort Seas GBS.

Methods for determining ice loads are covered in ISO 19906 and are also the subject of industry design tools and guidance. Methods for determining first year ice actions (loads, and for

manmade islands ice pile up and ride up) are well established and supported by field measurement data. Methods for determining ice action from interaction with multiyear ice are developed, but lack the same field measurement support as first year ice loads. Nevertheless, uncertainties are sufficiently known to allow for safe and reliable design in the hands of competent engineers. Furthermore, design methods are based on limit stress approaches, while limit force – a known limiting effect – is largely ignored in design approaches due to insufficient supporting measurements.

For perspective, the understanding of first year ice loads has come a long way since the 1960s when the first platforms were designed and installed in Cook Inlet Alaska. The collective understanding of multiyear ice loads is further along than the understanding of FYI loads in the 1960s when the first Cook Inlet platform was designed and installed. It should be noted that these platforms have successfully withstood ice interactions from installation to the present.

Ice characterization is covered under Characterizing & Measuring the Ice Environment Subgroup's topic paper on Historical R&D efforts pertaining to Alaskan Beaufort and Chukchi Seas.

This topic paper addresses interface considerations and experience. Interface issues for Development Drilling and Production Platforms are topsides payload and deck space, wellbay and moonpool design and provision for consumable storage and tubular laydown. These issues are well understood and covered by established practice.

Production facility winterization and working environment issues are well understood and also covered by established practice.

Introduction

The purpose of this paper is to summarize the state of offshore development drilling and production platforms as related to future Alaska oil and gas development. Specific objectives are to

- Summarize established practice and state of knowledge as applicable to Alaska
- Summarize ongoing research aimed at reducing uncertainty and enabling step outs
- Highlight opportunities to reinforce ongoing research and initiate new research

The scope of this paper is stationary platforms that include drilling and production facilities with a geographic focus on the Chukchi and Beaufort Seas. This includes fixed structures like manmade islands and Gravity Based Structures (GBS) and floating structures that are intended for year round operation. Floating structures intended for drilling only are covered under TP7 – Exploration drilling – fixed and floating. Other key paper interdependencies include

- TP2 – Historical background on Arctic E&P technology Development. TP2 provides the authoritative summary of industry experience. Some of this experience is repeated here for illustrative purposes.

- TP6 – Arctic well integrity and spill prevention methods and technology. TP6 covers subsea and surface wells and both drilling and completion. TP6 also covers source control for both subsea and surface wells. The current paper is limited to interface considerations.
- TP9 – Arctic subsea pipelines and subsea production facilities. The current paper is limited to interface considerations.
- TP10 – Offtake and tankering. The current paper is limited to interface considerations, specifically storage.
- TP11 – Ice management. Ice management is important for resupply, tanker export if applicable, and emergency response.
- TP13 – Others (materials, winterization, robotics and automation)

Key interdependencies outside EP Technology include:

- Characterizing and monitoring the ice environment → design basis
- Logistics and Infrastructure → resupply
- Safety and Emergency response → Escape, Evacuation, and Rescue (personal safety) and Oil Spill Response
- Ecology → non-technical design considerations
- Human Environment → non-technical design considerations

Concept Selection Drivers

<u>Water depth</u>

Water depth is one of the basic parameters in the choice of platform type. Manmade islands are best for shallow water depth, while Gravity Based Structures (GBS) become viable when water depth (10-15m) provides sufficient float in draft. The practical limit for GBS is highly dependent upon ice load and geotechnical conditions and could be in the range up to 70-120m (though the Troll A GBS is installed in more than 300m water depth in a non-ice environment). Floating systems and/or subsea are required beyond the feasible range of GBS. The minimum water depth for a floater could be in the range from 80-100m water depth but they have been used in shallower water. As will be discussed, year round floating systems are not seen as feasible at this point in time given the ice environment found in the Chukchi and Beaufort Seas.

<u>Platform Float in Draft</u>

The float-in draft for a fixed platform (GBS) can limit the towing route such as passing Point Barrow and where it can be used, especially with the topside installed. However, mitigations can be taken to optimize the design to adhere to the available draft. For GBS drilling and production platforms a draft of 20m (and possibly somewhat less) will be feasible.

A float in draft limitation will have a direct influence to the platform design as additional buoyancy has to be built in to the lower section of the platform structure. This buoyancy requirement is expected to be less for a steel structure than for a concrete and a steel structure will have a shallower draft.

<u>Topsides Weight</u>

Maximum topside weight related to the GBS buoyancy capabilities and stability is only applicable when installing the topside on the substructure prior to tow into the final platform location. It is not possible to set an absolute maximum topside weight the substructure can carry, as other factors such as storage volume and available tow-in draft also will influence the dimensions and thus the inherent substructure "payload".

Storage Volume

The storage volume both with respect to consumables as well as produced oil will have a large influence on the platform design, both topside and substructure. The philosophy for whether the platform shall be completely self-supported during the winter season or rely on frequent resupplies is crucial as will the export solution (pipeline versus offloading by tanker).

A "wet" storage system is used for most of the existing GBSs with storage. By this the storage tanks are always full as the oil is floating on top of sea water. When producing oil into the storage tanks the seawater will be displaced into sea. This water can contain traces of oil (typically 3-5 ppm) which could pose environmental issues. This system will always give a positive effect on the on bottom weight that is an important factor when determining the platform foundation sliding resistance against ice loads.

The alternative is a "dry" storage tank system , as used in crude carriers, with only oil and a blanket gas on top of the oil in the tanks. This system will require a large portion of the tanks to be above the water line to avoid empty tanks creating buoyancy and thus reducing the on bottom weight.

Export System Choice

Export through a pipeline versus offloading and export via tankers could be one of the important elements when designing a fixed (GBS) platform. If tanker offloading is chosen there will be a requirement for a substantial storage volume to allow for some contingency and poor tanker schedule regularity in some seasons. A storage volume of 250,000m^3 might be reasonable.

Number of Wells

To some extent the number, and as important, the spacing of the production wells could have an influence on the substructure design. For a production platform a high number of wells in combination with larger well spacing than used for non-Arctic areas (typical 2.5-3 m) could impact the substructure and neck design. For an exploration platform only a limited number of wells will be drilled from the same location, but this is not considered to have any impact on the GBS design.

To enable future tie-in of adjacent fields and sub-sea wells, J-tubes in the substructure walls and spare risers have to be included in the design which could have some influence on the substructure design.

Construction and Installation

Construction and installation drivers depend on platform type and are key considerations are summarized below for manmade islands and steel or concrete structures.

Manmade islands	Steel or concrete structures
• Gravel or sand source and quality • Proximity of source to island site • Accessibility of island site via winter ice road	• Yard or graving dock location • Access to skilled labor force • Tow of substructure or combined substructure and topsides

• Marine vessel availability for summer construction • Selection of slope protection including maintenance and repair considerations	• Maximum allowable tow draft and tow route selection • Marine vessel availability • Contingency planning for tow

Ice, Metocean, Geotechnical, and Earthquake

Each of these design drivers are important, but it is the combination that very often is the challenge to overcome, especially the combination of large ice loads and poor geotechnical properties. In regions with seasonal ice cover the wave loads are often not the dominant design element as the ice load, both local and global, normally is higher. Due to the nature of multiyear ice floes in the area which may have large embedded ice ridges, the global ice load on a platform could be very high.

Ice: Ice loads are discussed in detail later in this document.

Geotechnical: Soil properties are one of the most important drivers for determination of platform configuration as this has a direct impact on the foundation design sliding resistance and thus the size of the platform base area/structure. The foundation design may require skirts or alternatively piles/dowels to achieve sufficient sliding resistance to the large horizontal ice loads.

The following geotechnical data can be expected with reference to IMV's study entitled "Arctic Offshore Technology Assessment of Exploration and Production Options for Cold Regions of the US Outer Continental Shelf", 2008 performed for the former US Minerals Management Service (now BSEE):

> A top layer varying from relatively weak soil of 25-50kPa to a denser layer of 50-100kPa on top of a strong competent soil of 10-200kPa. The thickness of the upper layer can expected to be in the range of 1 to 13m

Metocean: Due to the short summer open water season the maximum wave height is limited in the area. Severe storms appear during the ice covered period and typical maximum Hs are in the order of 8.8m. (Reference IMV study for the former MMS). This Hs value is not considered severe and should not govern the substructure design as the ice loads will be significantly higher. However, wave loads and their effect should be calculated to confirm this for each project.

Current erosion: As described above the maximum Hs is relatively low for the area and wave erosion still has to be evaluated and mitigation means considered. The most common way to protect the structure from scouring due to erosion induced by waves or current is by dumping gravel/stones on the seabed along the perimeter of the structure. This activity will require mobilization of special vessels and has to be performed within the limited open water season.

The ocean current in the area is modest and not expected to be an issue with respect to erosion.

Earthquake: Seismic acceleration criteria for this area are relatively low and not considered a driver for design. ISO 19901 advises spectral acceleration values of 0.05g to 0.15g for 1.0 second and 0.2 second oscillator periods respectively. These values are somewhat higher than some of the most benign offshore areas such as the U.S. Gulf of Mexico, but mild when compared with highly active seismic areas such as in southern Alaska (Cook Inlet and the Gulf of Alaska). These acceleration values are only appropriate for early front-end planning, and ISO recommends site specific detailed investigations. Due to the general shape characteristics and large lateral design loads associated with ice, it is generally agreed that Arctic platform structures are unlikely to have their primary size and foundation configurations controlled by earthquake hazards..

Distance to Market and Evacuation Infrastructure

There is no local market for hydrocarbon products in the area as a result they have to be exported to market on the west coast of North America or to Asia either via an offshore offloading facility or through a pipeline.

Due to a lack of infrastructure, the platform design (both topside and substructure) has to be designed to handle an extended emergency situation. This could require improved hospital facilities on board as well as higher heat radiation shielding for the living quarters. Both of these elements will increase the topside weight and could lead to increases in size and weight of the substructure.

Non-Technical Considerations

Nontechnical considerations include:

- Marine Sound → drives consideration for insulation and isolation of rotating equipment; and may impact material selection for GBS
- Discharge: liquids, solid, cutting, etc. → drives consideration of process facilities and requirements for injector wells.
- Air emissions → drives topsides process and utilities functional design

Platform Types and Feasibility to US Arctic

Jacket Structures

Steel jacket structures are proven concepts for sub-Arctic environments like Cook Inlet and Bohai Bay, China. This structure is not considered feasible for the US Arctic due to insufficient resistance to withstand global ice loads resulting from interaction with multiyear ice. This conclusion is similar to that of the 2008 IMV study for the former US Minerals Management Service (now BSEE).

Manmade Islands

Manmade islands using sand or gravel fill with natural slopes or retained walls are proven technology for use in landfast ice and relatively shallow water conditions. Retained islands could work in deeper water depths. Design considerations for both structure types are access and proximity to sand or gravel resources. Additional considerations for naturally sloped islands are material quantity and quality and ice actions resulting from ice ride up and pile up. Design and construction practice developed in the US and Canadian Beaufort Seas has been refined by the manmade islands constructed in the North Caspian Sea.

Figure 1: Example manmade island in Beaufort Sea. (Photo: Shell)

Gravity Based Structures

Both steel and concrete GBS are considered the solutions for water depth from 15-20 m and deeper. The maximum water depth as described earlier is a function of the environmental loads (mainly ice) in combination with the geotechnical properties of the soil. Large areas in Chukchi- and Beauport Sea, at least those presently being considered for exploration and production, have water depth of less than 50-70m and a GBS alternative will be the most likely production platform solution.

Arctic GBS constructed to date include both monolithic, single shaft, and multi-shaft configurations.

- Monolithic examples include the Molikpaq (steel), Prirazomnaya (steel-concrete hybrid), and Orlan (concrete) platforms. The Molikpaq and Orlan platforms now located in the Sea of Okhotsk were originally installed in the US and Canadian Beaufort Seas, respectively.
- Single shaft examples include Hibernia and the Hebron platform under construction. Both are for sub-Arctic conditions, east coast Canada.
- Multi-shaft examples include the Sakhalin 2 concrete platforms (Lunskoye and Piltun-Astokhskoye-B) and recently completed Arkuntun-Dagi concrete platform for Sakhalin 1.

The preferential solution for the Chukchi and Beaufort Seas will be monolithic concepts like Molikpaq and Prirazomnaya to accommodate multiyear ice interaction with the structure.

Figure 2: Prirazomnaya monolithic GBS (picture: barentsobserver.com)

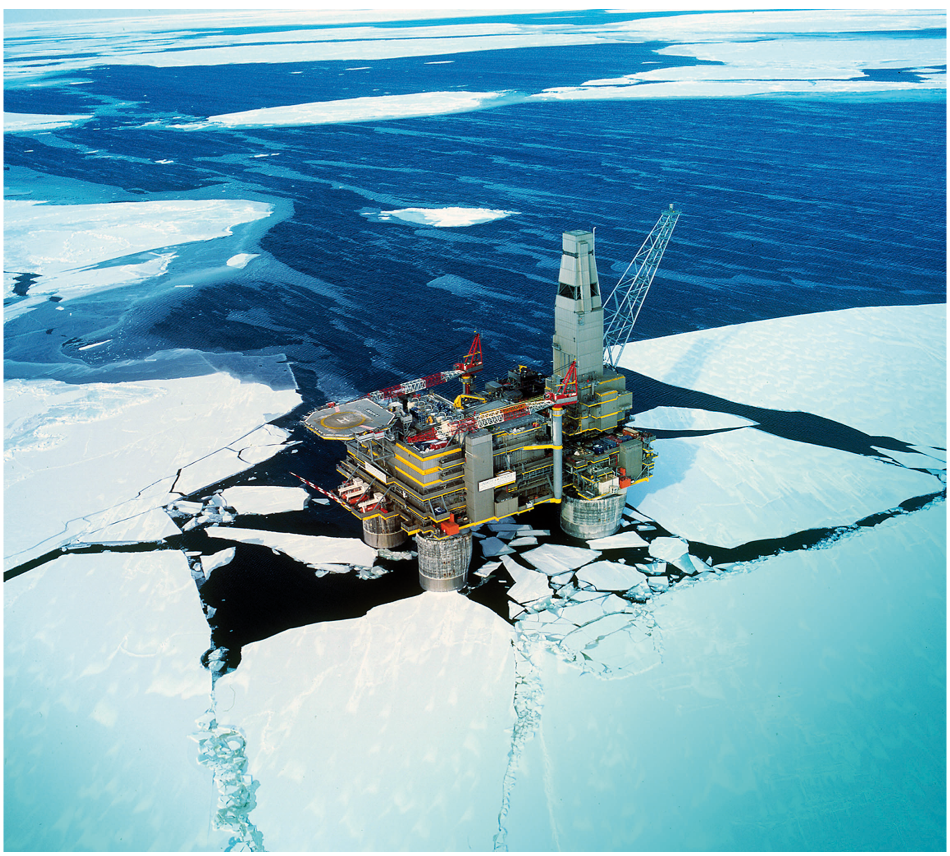

Figure 3: Sakhalin II platform with multi-shaft GBS in level ice. (Photo: Sakhalin 2)

Floating Structures

Floating systems would be of interest for development drilling where subsea production is planned. While year round operations are conceptually possible, the feasibility of such operations is deemed extremely low at this point in time. Multiyear ice is the limiting factor: creating loads that are beyond the feasible limits of present mooring systems and ice management. This is a similar view expressed in the 2008 IMV study that no floating production structures could be economically designed [for year round operations] to stay on station in the Beaufort and Chukchi Seas. Floating structures intended for exploratory drilling only are covered under TP7 – Exploration drilling – fixed and floating.

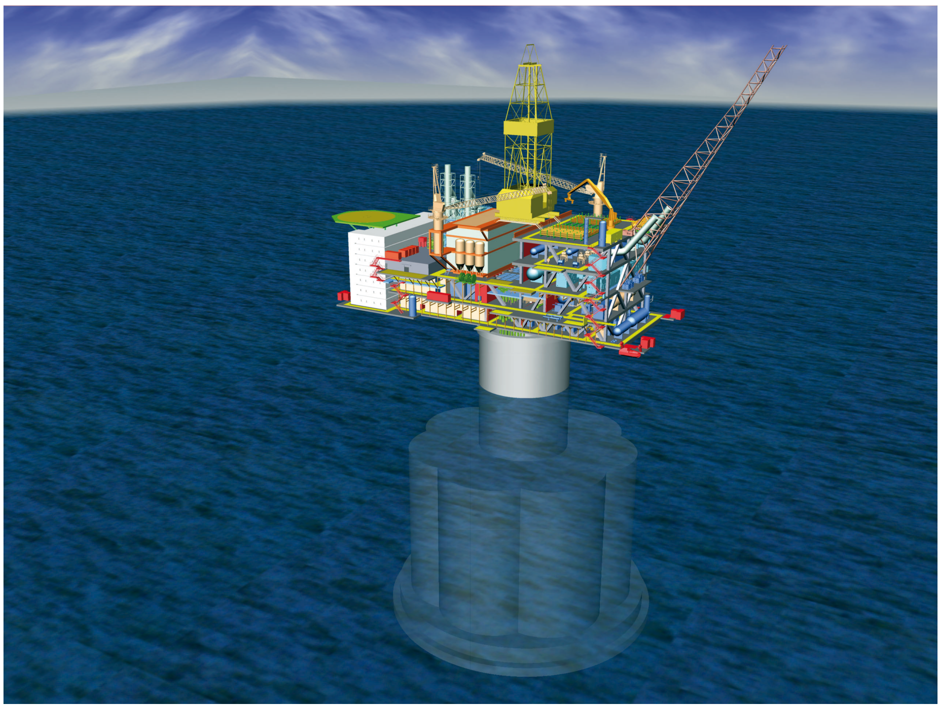

Figure 4: Artist impression of the Hebron ice berg resistant platform outside Newfoundland (ExxonMobil Canada)

Arctic Offshore Structure Design

The most important standard for Arctic offshore structures is ISO 19906. This standard, issued December 2010, codifies established practice based on input from leading experts across industry, contractors, government agencies, and academia. The scope of ISO 19906 follows in the table below:

Clause Number	Clause Title
1	Scope
2	Normative Reference
3	Terms and Definitions
4	Symbol and Abbreviated Terms
5	General Requirements and Conditions
6	Physical Environmental Conditions
7	Reliability and Limit State Design
8	Actions and Action Effects
9	Foundation Design
10	Man-made Islands

11	Fixed Steel Structures
12	Fixed Concrete Structures
13	Floating Structures
14	Subsea Production Systems
15	Topsides
16	Other Ice Engineering Topics
17	Ice Management
18	Escape, Evacuation and Rescue

Notes:

- ISO 19906 is divided into Normative and Informative sections. The former sets specific safety levels commensurate with the 19900 series and methods for ice action calculation, while the latter provides guidance with depth on calculation of ice action values.
- Normative and Annex A (Informative) have the same clause numbers for ease of reference
- Annex B provides data on the ice types and morphology, meteorological and oceanographic parameters found in Arctic and relevant sub-Arctic regions.

In Europe, ISO 19906 has been adopted (by vote of the relevant European committee) as a European Standard which is automatically adopted by the national standards bodies of all European (EU and EEA) states. These include Norway, Greenland/Denmark, Iceland, Finland, France, Germany, Netherlands, Sweden, United Kingdom etc. The relevant GOST-R (Russia) committee has voted to adopt ISO 19906 without modification, however challenges remain with the precision of the translation and the final approval steps to formal publication. In Canada, ISO 19906 has been fully adopted and issued. In the United States, the API is finalizing adoption of the ISO text essentially without change [1] as API RP 2N 3rd edition.

Ice Actions Overview

Sea ice is often not stationary, but moving. An offshore structure (fixed or floating) has to be capable of initiating a failure mechanism in the incoming ice while remaining stable. Forces exerted on the structure by ice interaction should not cause damage to the structure in this process. Design for serviceability criteria should allow for continuous operations on the topside during these interactions, except for action caused by abnormal ice features (such as icebergs in regions where they are not an annual occurrence). Collectively, these ice-structure interactions are termed ‘actions’ in ISO 19906.

Ice actions have both global and local effects. The global effect relates to platform lateral sliding loads and overturning moment. Local pressures have focused impact on plates (outer platform wall) and local stiffening elements, magnified by inhomogeneity of the ice (strong inclusions).

ISO 19906 Clause 8 describes ice action scenarios to be considered, while ISO 19906 Clause A.8 provides guidance on specific methods to calculate ice loads. This includes both vertical sided and sloped sided structures and addresses both first year and multiyear ice features. The basis for the calculation

[1] Last sentence of ISO 19906 Clause 7.2.2.4 will be deleted: sentence contains informative guidance of potential importance to an owner, but not necessarily pertinent to the designer.

methods in ISO 19906 is a combination of field measurements, analytical models based on field measurements and model tests, and engineering mechanics.

The art of predicting ice loads has been evolving since the first Cook Inlet Platforms were installed in 1964 and continue to evolve. The calculation methods in ISO 19906 represent established practice as circa 2008 when the responsible Work Group, ISO/TC67/SC7/WG8, finalized the document for the review process. In the last 6 years additional understanding has been created via numerous Joint Industry projects.

Significant ice structure interaction enhancement activities post-2008 include:

SILS (Sea Ice Loads Software): specialist software developed by C-CORE in a JIP funded by 6 oil companies as an Industry standard for ice load calculation. The software can be used in a deterministic mode (recommended for field platform concept studies) and in a probabilistic mode (recommended for platform design). The methods used in the code are in line with ISO 19906 recommendations.

ISO 19906 implementation guidance: Results from the DnV led ICESTRUCT JIP provide help to the non-specialist designer to comply with the normative provisions of ISO 19906, and (ii) to supplement ISO 19906 by addressing selected gaps that have been identified therein. Results provide a common and documented approach to achieve acceptable safety levels for offshore structure designs in cold climate regions, by adhering to the normative provision of the ISO 19906 Standard, and by supplementing it through the provision of practical design recommendations and case studies. Key issues addressed in ICESTRUCT will be incorporated into 19906 as it is being revised.

Re-analysis of 1986 Molikpaq multiyear ice loading events. This industry project had objectives to narrow uncertainty through application of lessons learned and enhanced understanding of ice structure interaction processes relative to the initial analyses. The work is summarized in the 2011 POAC paper: Overview of the Molikpaq Multi-Year Ice Load Analysis JIP, POAC 2011, R. Frederking, K. Hewitt I. Jordaan D. Sudom J. Bruce M. Fuglem R. Taylor.

Ice induced vibration: This industry project carried out by Olaf Olsen developed and verified a numerical tool for simplified analyses of ice induced vibrations for vertically faced fixed offshore structures. This is a design concern for steel and concrete structures and the project results enhance guidance provided in ISO 19906. The project involved leading experts from both industry and academia.

Ice Actions: Manmade Islands

In the Chukchi and Beaufort Seas, the principal design ice feature for near shore structures will be first year ice ridges and level ice. Global ice loads are an important consideration, but not normally a governing design condition, e.g., island footprint provides ample sliding resistance. Local ice loads can be an issue for retained islands (e.g., localized effects on sheet piling). Serviceability related issues including ice ride up and pile up on the beach or the island working surface and rubble generation are most important ice actions.

Ice ride-up and Pile Up: Both are hazards to people and equipment on the island working surface. They can also be hazards to slope protection for waves and currents.

Rubble generation: Generation of ice rubble, especially grounded ice rubble, effects platform re-supply operation as ships bringing in supplies might be prevented from coming close to the platform. In this case, ice management will have to clear the ice rubble.

The state of art of island construction is well established and proven. Examples include producing islands in the US Beaufort Sea (Endicott, Northstar, Nikaitchuq, and Oooguruk) and islands in the North Caspian. The latter has significantly advanced design practice. An overview of the current design practice from of the North Caspian is summarized in the following papers from POAC 2011 held in Montreal:

- Offshore Platforms and Deterministic Ice Actions: Kashagan Phase 2 Development: North Caspian Sea, K. Croasdale* I. Jordaan P. Verlaan
- Probabilistic Modelling of the Ice Environment in the NE Caspian Sea and Associated Structural Loads, I. Jordaan P. Stuckey J. Bruce* K. Croasdale P. Verlaan
- Ice Encroachment in the North Caspian Sea, R. McKenna* P. Stuckey M. Fuglem G. Crocker D. McGonigal K. Croasdale P. Verlaan A. Abuova
- Modelling of Ice Rubble Accumulations in the North Caspian Sea, R. McKenna* D. McGonigal P. Stuckey G. Crocker R. Marcellus K. Croasdale P. Verlaan A. Abuova
- Ice Issues Relating to the Kashagan Phase 2 Development; North Caspian Sea, P. Verlaan* K. Croasdale

Ice Actions: Gravity Based Structures

Ice interaction with vertical GBS will result in multi-modal failure including bending, buckling and compressive or crushing failure. For structures in the >15-20m water depth range multiyear ice floe and ridges will be the principal design ice feature. The latter failure generally results in the maximum ice loads. Ice interaction with sloping sided GBS will also result in multi-modal failure, but will predominately produce bending failure. Ice loads from bending failure are lower than those from crushing and therefore loads will be lower on a slope sided GBS than for a vertical sided structure for the same ice feature. Due to better ice clearing, ice will be less likely to ground in front of a sloped sided GBS than a vertical sided GBS.

Reliable calculation of ice loads requires a detailed understanding of the methods in ISO 19906 including the underlying weaknesses and uncertainties for each method. For multiyear ice interaction with sloping sided structures, where field measurements are minimal, prudent design would include physical model testing in an ice basin supported by engineering calculations based on the methods in ISO 19906.

ISO 19906 is based on limit state design and the use of load and resistance factors to achieve a target reliability. Load factors for the Ultimate and Abnormal limit states have been calibrated to achieve an annual failure probability of 1.0×10^{-5} for a manned platform with high consequence exposure level. Code calibration included determination of representative loads for Chukchi and Beaufort Sea GBS (reference OGP Report 422). OGP 422 shows a 100-year load of 1100MN for a vertical sided structure of 100m diameter. For comparison, the 2008 IMV study for the former MMS references a 100-year load of 1100 to 1500 MN load for a vertical sided structure of 75-90m diameter in 50m water depth.

Other ice related design considerations for GBS include:

Ice ride-up: To avoid ice loading of the underside of the deck due to ice ride-up on the side of the structure, the air gap between the sea level and the bottom of steel might have to be increased compared to what will be required due to wave run-up. A conical structure will have a higher ice run-up than a cylindrical/vertical structure and the platform deck elevation has to be increased accordingly

Abrasion: of structure outer shell materials due to ice action should be considered in the design of offshore structures for Arctic regions. Concrete abrasion can be an issue in highly dynamic ice environment as several thousand km of ice may pass an offshore structure per year. Measurements and inspections of lighthouses in the Baltic Sea in the 1980s and 1990s showed that some of the structures experienced significant abrasion due to ice action. Inspection of the concrete piers of the Confederation Bridge in Canada indicated a very low abrasion rate (0.3 mm/year). A number of laboratory and field studies were performed to investigate abrasion of different materials due to ice action. These studies found that the rate of material abrasion depends on a number of parameters: material and ice properties, ice pressure, drift rate, surface roughness and ice-material friction coefficient.
Use of high strength concrete will decrease abrasion significantly and was used as ice abrasion protection for the Sakhalin I GBS. An additional protection measure could be an application of low-friction coatings.

Ice seafloor gouging: Ice gouging at the seafloor will require any pipelines or cables to be trenched and buried for protection. The observed depth of ice gouging indicates that trenches may have to be several meters deep to ensure protection.

Structural icing: Mainly a floating platform issue

Ice Actions: Floating Structures

ISO 19906 covers floating structures in ice; however, the available design guidance is limited due to the lack of experience with floating structures. Key issues were summarized as part of Barents 2020 Phase 4. New capability to address the acknowledged limitations are the subject of significant improvement initiatives from industry parties, governmental authorities and research institutions as well as the development of a new ISO standard for floating structures.

The most relevant experience is from drilling with the Kulluk in the Beaufort Sea. After it entered the Beaufort Sea in 1983, the Kulluk drilling vessel drilled 12 wells at 7 different locations in water depths ranging from 25m to 50m. Its downward conical hull was made to force incoming ice to fail in bending rather than in compression, thereby minimizing ice loads. Its radially symmetric mooring system, in combination with the circular hull shape, provided an omnidirectional capability to resist ice and storm forces.

Improvement initiatives are summarized in the table below.

Project	Objectives
PRNL Station-Keeping In Ice (Confidential To Participants)	Advance understanding of the magnitude & nature of pack ice loads on vessels, including mooring and/or station-keeping forces; determine response actions necessary for maintaining station; and develop technologies to maintain station
PRNL Ice Management (Confidential To Participants)	Improve ice management system to improve safety, operational efficiency and capability in existing arctic and harsh environments. Research areas are

	• Ice/Iceberg detection • Threat Analysis & Drift Forecasting • Towing • Station-Keeping/ Pack Ice Management
European "DP in Ice" Program (Confidential To Participants) http://www.dypic.eu/index.html	Tool box which allows the prediction of station keeping capability of different vessel types and offshore structures under various ice conditions. For more details see:
PetroArctic Project http://www.ntnu.no/bat/petroarctic	The research project comprises the following tasks: • Task 1: Ice ridges • Task 2: Dynamic ice actions on structures • Task 3: Marine units in ice • Task 4: Ice gouging and protection of sub-sea installations • Task 5: Berm breakwaters and ice barriers in cold waters • Task 6: Ice actions on jack-ups • Task 7: Thermal stresses in ice and inhomogeneity • Task 8: Collection of ice pilot experiences from sealers • Task 9: Miscellaneous (workshops, printing of books)
NTNU SAMCoT (Confidential to Participants http://www.ntnu.edu/samcot	Ice Management and Design Philosophy is one of the principal areas of research for the Sustainable Arctic Marine and Coastal Technology (SAMCoT) program at NTNU other areas include • Collection & analysis of field data and properties • Material Modelling • Fixed Structures in Ice • Floating Structures in Ice • Coastal Technology
KMB Arctic DP (Confidential to Participants) http://www.marin.ntnu.no/arctic-dp/	Develop technology and competence to operate DP vessels in the Arctic. The project has the following main work packages 1. WP1: Project administration 2. WP2: DP control system redesign a. PhD #1) Guidance and control of a DP vessel to handle feasible ice loads. 3. WP3: Autonomous ice observation system a. (PhD #2) Autonomous aerial ice observation system. b. (PhD #3) Autonomous underwater ice observation system. c. (PhD #5) Image and sensory data processing for ice observation. 4. WP4: IM ice load reduction a. (PhD #4) Technology and methods to enable safe and low-risk arctic DP operations. 5. WP5: Demonstration and dissemination of project results
Global Maritime Arctic Mooring JIP http://www.globalmaritime.com/news/launch-of-arctic-mooring-jip-in-houston-	Project purpose is to advance design standards and operation practices for arctic and other cold regions mooring systems. Specific objectives include: • Develop a design and operation practice document based on existing technology, industry experience, and consensus building. This document can be used as: A foundation document for developing industry standards

	such as an Arctic supplement to API RP 2SK or ABS guidance note; A foundation document for developing company specific design and operation guidelines • Provide a forum for the industry and regulators to exchange information/ideas and work together to build consensus. • Develop proposals for further joint industry work

GBS Design

Substructure

Concept development work for the Chukchi and Beaufort seas has identified monolithic configurations like Molikpaq, Orlan, and Prirazomnaya as leading contenders. Single shaft concepts may be workable from an ice load standpoint, but will have substantially less storage volume. Ice load calculations for multi-shaft platforms are challenging particularly with regard to loading from multiyear ice.

Further evaluations and analysis could be performed to evaluate the feasibility of a multi shaft platform for some of the areas with less ice exposure. These concepts may have some advantages with respect to float in draft and topside support. The reduced draft may also open up for alternative and possibly local GBS construction sites.

Steel: The extremely low ambient temperature down to -50 degree Celsius, do introduce additional requirements for the steel qualities to be used. Although equipment has been produced for and operated in the area for decades there is still a lack of international steel standards for suitable commodity “low cost” high strength materials. However, significant work has been and still is being performed to develop new steel qualities suitable for Arctic areas.

Concrete: For concrete the existing “standard” offshore quality (grades B55 or B60) is documented to handle the low temperature. Activities are ongoing to further develop light weight concrete to increase the ductility especially at low temperatures. This quality could be an alternative if the minimum platform draft for is an issue.

To overcome ice abrasion effects, concrete GBS shafts can be constructed with a special high strength concrete that was developed for the Sakhalin I platform. This concrete was used for the ice exposed area and will reduce ice abrasion over the lifetime of the platform.

Composite: The Russian platform Prirazomnaya is a hybrid solution where steel “form work” is filled with concrete. The concrete has the function of both increasing the capacity of the platform hull to resist larger ice load as well as providing the required on bottom weight for the platform to resist global ice load.

Improvement initiatives are summarized in the table below.

Project	Objectives
ISO/TC67/SC8	
SINTEF Arctic Materials (Confidential to Participants)	Establish criteria and solutions for safe and cost-effective application of materials for hydrocarbon exploration and

	production in arctic regions. Partners are Research Council of Norway, Statoil, Total, ENI, JFE Steel,Nippon Steel Corporation, Scana Steel Stavanger, Trelleborg, Bredero Shaw ,AkerSolutions, GE Oil and Gas, Miras, Norwegian University of Science and Technology (NTNU), SINTEF, Technip, Det norske Veritas, Brück PipeconnectionsIcing

Topsides

Topsides functionality would nominally include facilities for oil and gas processing, utilities including power and living quarters, and drilling rig(s). This functionality is similar to any oil and gas installation, regardless of location. Arctic specific requirements are associated with winterization and human factor engineering. Winterization includes heating or insulation of working and machinery spaces, tanks or compartments containing liquids (ballast, firewater, potable water), and possibly process related equipment for flow assurance. Winterization requirements are also important for HVAC air intakes to accommodate snow accumulation.

Heat tracing and insulation are required for piping exposed to the elements, including redundancy. Heat tracing may also be required around safety critical equipment such as evacuation craft and lowering appurtenances. Enclosures for process equipment create added complexity for explosion and fire design.

Human factor engineering is important for equipment exposed to the elements including valves, gauges, and communication devices to ensure functionality by workers having limited movement due to PPE. Human factor engineering is also an important consideration for exposed walkways and ladders.

A key implication resulting from the need for winterization is heavier topsides relative to temperate and tropical climates for the same functionality.

Tow from Construction Site, Offshore Mating of Topsides and Base

Towing a platform (substructure only or complete platform) is not considered to be a feasibility issue. A number of complete platforms (GBSs), the majority being multi legged, with topsides installed have been wet towed to final location and installed. The only challenge foreseen for Arctic Alaska is the limited ice free season which will require good operational logistics management to enable completion of all operations including any ballasting and scour protection within the available installation period. The wet towing distance from a potential construction site in Asia to the Chukchi or Beaufort Sea is relatively long, but feasible.

Figure 5: Towing of one of the Sakhalin II concrete GBSs from Vosthosny Port to field location outside Sakhalin Island (Photo: Sakhalin 2)

Offshore (or very often nearshore) mating of topsides and substructure is the preferred method as this will reduce the activities at the final location significantly. However, if there is no deep water area available allowing a mating, an offshore float over at the final location as was performed for the last three Sakhalin platforms is feasible.

Construction, Transport, Installation

Local construction of GBS has so far not been considered practical.

- The practice for all concrete GBSs constructed has been to perform this in a purpose built graving dock. Some evaluations have been performed to locate suitable areas where a dock could be established and a few potential areas in the Valdez and Anchorage area have been identified. These considerations have not been evaluated to a sufficiently detailed level to enable a final conclusion regarding feasibility.
- Local fabrication of large steel structures is not practical. No facilities exist and they cannot reasonably be expected to be developed.

From an execution and construction risk point of view but also taking into account economical consideration, the tow and installation of a complete platform including the installed topside is by far the preferred solution. By this the in-field activities will be significantly reduced compared to a float over of the topside after the substructure has been installed. The short ice free season increases the risk of not being able to float over the topside in the same season as the substructure is installed. The two Sakhalin 2 platforms were installed in two seasons (i.e. topsides installed the summer after the GBS base) due to this reason.

One of the main differentiators between a concrete and steel GBS would be that the steel version most likely will require some additional solid ballast to obtain sufficient on bottom weight to be able to resist the ice load. If this can be installed prior to float in to the final location this should not have any impact on the in-field activities. However, if the solid ballast has to be installed after installation this would be another operation that has to be completed in the short open water season.

Figure 6: Construction of the Hebron concrete GBS at the Bull Arm site, Newfoundland (Photo: ExxonMobil Canada)

Figure 7: Towing of the Hibernia platform from Bull Arm, Newfoundland, to final location (Photo: Hibernia Management and Development Company)

Successful near shore mating such as for Hibernia and the North Sea GBS's and offshore float over of topsides as for the three latest Sakhalin platforms have been performed. For both methods a number of the topsides have had a weight of more than 40,000 tonnes.

During concept studies the possibility to carry a topside weight of close to 100,000 tonnes has been verified while still keeping the tow-in draft in the range of 20-25m. If an offshore float over installation method is used as for the three latest Sakhalin platforms, the topside weight limitations will be given by the marine equipment used in combination with the geometry of the top of the substructure.

Decommissioning

The basic requirement when designing a GBS substructure is that it should be possible to remove it when the field life has come to an end. This has been the case for large GBS structures designed and built for the last 30 years in the North Sea. Removal of the platform is in principle a reverse installation process and the same systems used for installation will be in operation. This does require that all the applicable systems like ballast and skirt evacuation/soil drain system have the same design life as the platform. To obtain this will require high quality stainless steel or titanium material to be used for some equipment and piping systems. The large GBSs that so far have been taken out of service were designed and built prior to implementation of the decommissioning requirement and the substructures of these platforms have been left after removal of the topside. Examples are the Frigg Field Center at the border between Norway and UK in the North Sea and the Ekofisk Tank in the Norwegian sector of the North Sea.

Figure 8: Remaining concrete structures at the Frig Field Center, North Sea (photo: Norwegian Petroleum Directorate)

Decommissioning in areas with short open water periods may lead to decommissioning/removal activities to last for more than one season.

Other issues

Non-Technical Design considerations include

- Marine Sound
- Discharge: liquids, solid, cutting, etc.
- Air emissions

Well Systems Topical Paper TP6 – Arctic well integrity and spill prevention methods and technology addresses both surface and subsea wells including drilling, completion, and source control.

Resupply The resupply philosophy will influence the platform and substructure design. If long resupply periods are expected the platform has to be self-supplied for a long period which will increase the required storage volume and operating weight. It is important to include this element as a part of the design basis at an early stage in the project to avoid potential changes late in the project.

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Human Factors

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- ISO 5349-1:2001 Mechanical vibration -- Measurement and evaluation of human exposure to hand-transmitted vibration -- Part 1: General requirements
- ISO 5349-2:2001 Mechanical vibration -- Measurement and evaluation of human exposure to hand-transmitted vibration -- Part 2: Practical guidance for measurement at the workplace
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    - Basic information on human performance and health hazards when working in Arctic conditions
    - Guidance for design or selection of clothing
    - Design of equipment to be operated in cold conditions
    - Information that can be used to help generate cold weather operations safety and operating procedures
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- IMO Guidelines for Ships Operating in Polar Waters (2 December 2009)
- Work of Charles C. Ryerson

Non-Technical Issues

The IMO Guidelines (IMO, 2002a) make a strong statement in this regard by referring in a considerable number of its sections to the need for preventing pollution from ships navigating the Arctic Regions.

- IMO, 2002a, Guidelines for Ships Operating in Arctic Ice-Covered Waters, MSC/Circ. 1056, MEPC/Circ. 399. International Maritime Organization.

Emergency Response

- Guide to Cold Water Survival, 2012 Edition

- OCIMF – Guidelines on Capabilities of Emergency Response Services (very general)

Live-saving appliances and navigational equipment - This addresses requirements for various life saving appliances. They are based in part on the following International Maritime Organization (IMO) documents:

- MSC Circular 1056/MEPC Circular 399 (IMO, 2002a), Guidelines for Ships Operating in Arctic Ice-Covered Waters.
- IMO Life Saving Appliances Code (IMO, 2003) (from MSC.81(70) (1998) and MSC.48(66) (1996)).

Other

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