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A Philosophy to Ensure the Safety of Floating Structures in Arctic and Cold Regions

Costas Makrygiannis[1], Oddgeir Dalane[2], Pavel Liferov[3], Richard McKenna[4], Per Olav Moslet[5], Kaj Riska[6], Brian Wright[7]

[1]KUFPEC Norway AS, Stavanger, NORWAY
[2]Equinor AS, Stavanger, NORWAY
[3]Equinor AS, Trondheim, NORWAY
[4]R.F. McKenna Associates, Wakefield, QC, CANADA
[5]Dr Tech Olav Olsen AS, Oslo, NORWAY
[6]Prof. TU Delft, THE NETHERLANDS
[7]B. Wright Associates, Canmore, AB, CANADA

ABSTRACT

The safety philosophy for floating oil and gas production systems in arctic and cold regions has been enhanced in the recent revision to the ISO 19906 (2019) arctic structures standard. Important changes since the initial publication of the ISO 19906 (2010) standard include the identification of different facility types, depending on whether ice management and disconnection/move-off capabilities are part of the design concept. Because operational procedures are such an important consideration for floaters, additional requirements include operating envelopes and non-physical barriers to ensure that these procedures are conducted safely and in a way that human life, structural reliability levels and the environment are preserved.

Arctic standards dealing with physical environmental data requirements (ISO 35106, 2017) and ice management (ISO 35104, 2018) have also been published since 2010. The new data requirements include verifiable data streams, particularly when dealing with weather and ice forecasts. Much of the material relating to ice management in the initial version of ISO 19906 (2010) has been moved to the new standard as well as numerous enhancements related to detection systems and performance requirements. Both ISO 35104 (2018) and the revised ISO 19906 (2019) provide increased focus on ice alert systems under which ice management activities are conducted.

INTRODUCTION

Floating drilling and production platforms have been in operation in sea ice and iceberg environments since the 1970s. The operational experience gained, combined with relevant experience in open water with disconnectable platforms, has resulted in the evolution of a practical operational philosophy for arctic and cold regions. The objectives of the philosophy are to ensure that the health and safety of personnel are not compromised, and that any adverse effects to the environment are minimized. This approach is the basis for the floaters provisions in the newly-revised ISO 19906 (2019) arctic structures standard.

A number of concerns were expressed by users of the first edition of the standard (ISO 19906, 2010) regarding the design guidance provided for floating structures. One of the main concerns was the lack of specificity in the design approach for floating structures, with particular reference to the quantitative determination of ice actions and action effects, the influence of ice management on these actions and effects, and the means of assessing reliability levels for different system configurations.

These configurations can include a range of floating platform designs and ice management support combinations, including aspects such as the stationkeeping capability of the structure, the configuration and effectiveness of the ice management system, and whether the platform is designed to be active or passive in terms of its capacity to suspend operations, disconnect, and move-off location.

Key issues addressed in the revised standard include (ISO 19906, 2019):

- a clear methodology for addressing the various types of floating systems, through flowcharts / decision trees, assisting thus the designer in establishing the appropriate design and operational philosophy;
- operational procedures used to reduce ice actions;
- streamlining ice management requirements with the new ice management standard, ISO 35104 (2018), with particular focus on ice alerts;
- the introduction of a safe haven concept, linked to the structural integrity and stability of the hull; and
- the concept of the operating envelope and safety barriers, to develop operational performance requirements (ISO 17776, 2016) in the context of ice alert system.

PHYSICAL ENVIRONMENTAL CONSIDERATIONS

A floating structure deployed in a sea ice environment will be exposed to a broad range of ice conditions, all of which are region and season specific. In most cases, there will be a high degree of complexity in the combinations of ice situations expected, including key factors such as ice age or type, ice coverage, floe size, presence and extent of deformed ice, consolidated layer thickness, drift speed, changes in drift direction and ice pressure events. Key considerations are stationkeeping ability and avoidance of ice features beyond the design limits of the hull and stationkeeping systems.

In an iceberg environment, ice conditions involve the frequency, size, drift speed and drift direction changes of the ice features. Also of potential concern is the range in source glacier characteristics that can influence iceberg size, draft and shape. Metocean and bathymetric conditions can affect iceberg drift, deterioration, impact criteria and grounding. Many areas where icebergs can be present are also subjected to sea ice incursions, which can affect iceberg drift, deterioration and management performance. For icebergs, the key consideration is the avoidance of ice features beyond the design limits of the hull and stationkeeping systems.

Ice design situations with respect to global (and local) ice actions and effects (responses) are evaluated on a case by case basis. Clearly, uncertainty in the responses will be influenced by the complexity the particular floating system and its operation, of which an important aspect is ice management (which includes detection, threat assessment and forecasting). For ice management systems, factors such as wind, sea state, visibility, darkness, icing and precipitation can have significant effects on performance.

For floating structures, there is an expanded range of design situations that involves operational considerations. As a result, it can be more difficult to establish design situations than for fixed structures. Decisions made with respect to hull, stationkeeping and ice management capabilities at the concept and design stages will affect operability and downtime once implemented.

DESIGN AND OPERATIONAL PHILOSOPHY AND APPROACHES

The decision to use a floating production facility can be influenced by characteristics of the hydrocarbon reserves, processing requirements and water depth, among other considerations. A number of choices are available with a floater concept in ice regimes with regard to ice management and avoidance capability. Avoidance can involve a limited displacement of the facility without disconnection, disconnection of a drill string, production risers and potentially the stationkeeping system, and potentially a seasonal operation. Ice management can involve changes to the ice regime by means of deflection of potential ice hazards, their destruction, reduction in their size or other means of altering them such as relieving pack ice pressure.

The ISO 19906 (2019) standard categorizes floating structures as:

- Passive – Facilities with no avoidance and no ice management capabilities. The structure needs to withstand ice actions associated with the ambient ice regime through the design of the hull and the stationkeeping system.
- Semi-passive – Facilities with ice management support but without or with minimal avoidance capability. Ice management can potentially be used to reduce the ice actions used for design of the hull and stationkeeping systems.
- Semi-active – Facilities with avoidance capability but no ice management support. The hull and stationkeeping systems need withstand ice actions if they exceed design thresholds (i.e. ice actions used for design are non-zero).
- Active – Facilities with avoidance capabilities and with ice management support. Each of these can potentially be used to reduce ice actions used for design.

The range of options for floating systems is illustrated in Figure 1.

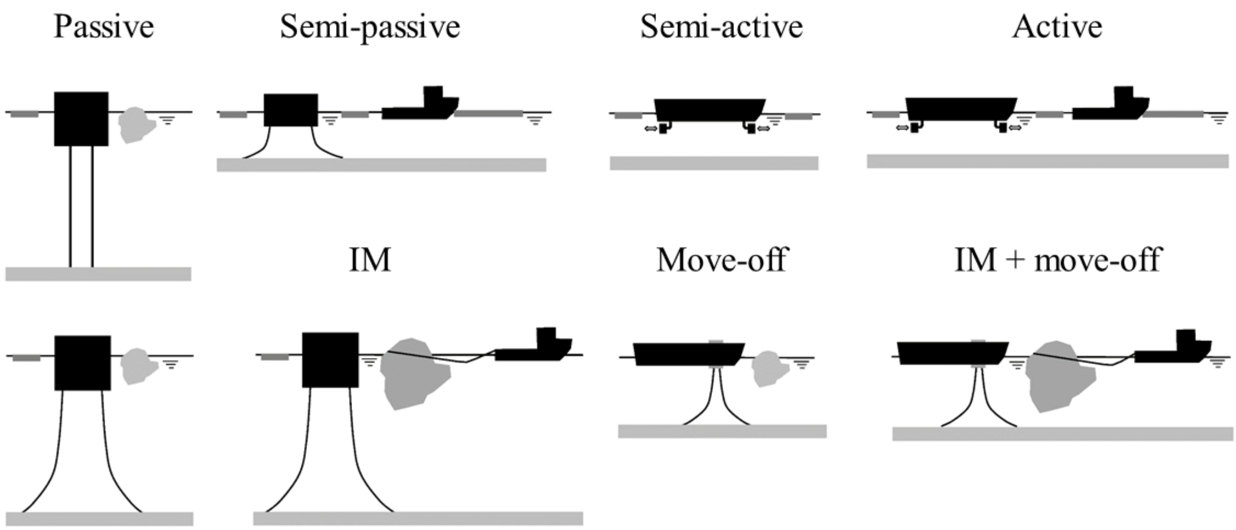

Figure 1. Floating system options depending on ice management (IM) and move-off capabilities

The revised ISO 19906 (2019) standard is more explicit than the initial version with respect to the definition and design strategy associated with these floater types. An important change in the new edition of the standard is the addition of semi-passive systems, which are envisaged for new developments off Canada's east coast and in the Norwegian part of the Barents Sea. At these locations, infrequent and light ice conditions can be dealt with using physical ice management support.

The floating drilling operations (drillships and buoy-type platforms, see Figure 2) conducted in the Beaufort Sea in the late 1970s and 1980s involved extensive sea ice management and move-off capability. These are examples of active systems, although present-day drillships are superior with respect to stationkeeping and move-off. The ice-strengthened disconnectable FPSOs at Terra Nova and White Rose (see Figure 3, top and middle) on the Grand Banks are supported by a fleet of iceberg tow vessels and a comprehensive detection, tracking and forecast system. These are other examples of active systems. At Bay du Nord in the Flemish Pass off Newfoundland (see Figure 3, bottom), disconnection capabilities are envisaged so the system is classified as active. Another example of an active system is the disconnectable FPSO proposed for Shtokman in the Barents Sea (see Figure 4, top), an area where icebergs and sea ice are present. Active systems are used for the most challenging ice conditions, whether sea ice or icebergs.

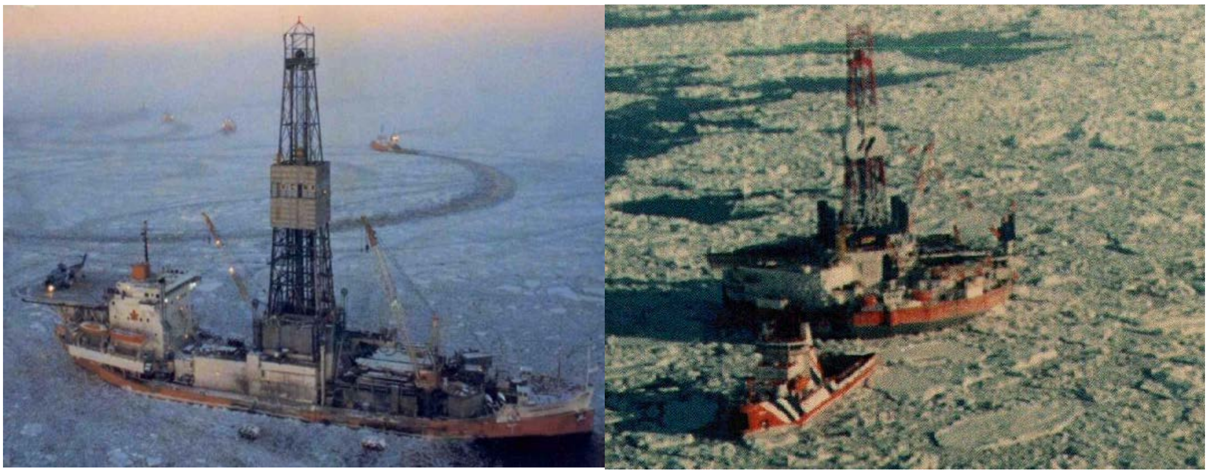

Figure 2. Drillship and Kulluk floating drilling platform operating in Beaufort Sea

At Johan Castberg in the Barents Sea, where iceberg occurrence is extremely rare, an FPSO without disconnection capability is under development (see Figure 4, bottom). This is a semi-passive system that involves ice surveillance. An example of a semi-active system is a seasonal platform operating during the so-called shoulder seasons when ice conditions are relatively light. Another example is a structure exposed to infrequent ice threats which would be impractical to manage physically. To prevent ice interactions that can exceed the resistance capabilities of the structure, the semi-active system can be moved off location in the context of well-defined ice alert procedures.

Unless the reliability of ice management systems can be ensured, fixed structures need to be designed for the ambient ice conditions. While floaters have more options for reducing the design ice actions, the revised ISO 19906 (2019) clarifies how to verify a reduction in ice actions.

Figure 3. Disconnectable FPSOs at Terra Nova (https://lubricants.petro-canada.com/en-ca/knowledge-centre/casestudy/terra-nova) and White Rose (http://wwrp.huskyenergy.com/Project_overview) on the Grand Banks, and concept for Bay du Nord in the Flemish Pass (https://www.naturalresourcesmagazine.net/article/frontier-no-more/)

Figure 4. FPSOs for the Barents Sea: active concept at Shtokman (http://shtokman.ru/en/project/about/offshore/) and semi-passive concept at Johan Castberg (http://www.ptil.no/getfile.php/1349762/PDF/Johan%20Castberg%20FPSO%20og%20isrisko.pdf)

Floating systems operating in arctic and cold regions need to comply with the provisions of ISO 19904-1 (2019), while their mooring systems need to comply with the provisions of ISO 19901-7 (2013). ISO 19906 (2019) provides additional requirements and guidance for floating systems in arctic and cold regions. Particular emphasis is placed on ice actions and hull design, cold weather materials, the design of marine systems, and disconnection. In addition, the provisions of ISO 17776 (2016) are referenced when operational measures are implemented for a floating system.

ISO 19906 (2019) can be applied to other temporary or permanent deployments of floating systems that are used as part of oil and gas operations in arctic and cold regions.

DESIGN AND ASSESSMENT PROCESS

Except for passive systems, the design and assessment process involves an iterative cost-benefit analysis for ice management, stationkeeping and move-off capabilities (where applicable), to achieve an optimal system. Feasibility and safety are key issues in this process.

The revised ISO 19906 (2019) standard is more explicit than the initial version with respect to the design strategy and detailed flowcharts are provided in Annex A.13. Particular consideration is given to the effectiveness and reliability of ice management measures associated with semi-passive operating approaches. Unless the reliability of operational measures can be ensured, stationary floating structures need to be designed for the ambient ice conditions. A simplified flowchart outlining a procedure for the development of an active floating production system is given in Figure 5. At the detailed design stage, the floater, stationkeeping and ice management systems are selected, while the marine operations and ice management plans/manuals are developed. This phase also involves training. During operations, the performance of all systems are monitored and operating envelopes can be increased when warranted.

HULL INTEGRITY

The hull of a floating structure is generally the most critical component of a floating system. As a result, its stability and integrity need to be maintained at all times. Attachments to the hull, such as risers, umbilicals and mooring lines and their connections, need to be weaker than the hull or contain weak links. Regardless of whether the due to ice or other actions, circumstances involving overloading should only lead to failure of the attachments, keeping the hull intact and avoiding capsize. Even for floating systems that are designed to disconnect when forecast actions and/or responses are above operational limits (semi-active and active), a failure to disconnect should not lead to failure of the hull itself. It is also important to recognize that the actions potentially causing overload generally act in combination with other physical environmental conditions and these should be included when developing design and assessment situations.

For most floating systems, design and assessment situations need to be developed for both ultimate limit states and abnormal/accidental limit states. For such efforts, extreme-level and abnormal-level ice actions and action effects relating to the integrity of the hull are considered. Both global and local actions can be important. Since models for the calculation of these actions have not been well verified for floating structures, the standard emphasizes the use of applicable full-scale experience.

In arctic and cold regions, distances to onshore or other offshore emergency response centres can be longer than in other regions. Since abnormal/accidental limit states criteria in the ISO 19906 (2019) standard involve damaged stability, prolonged rescue times in emergencies need to be factored into the hull design.

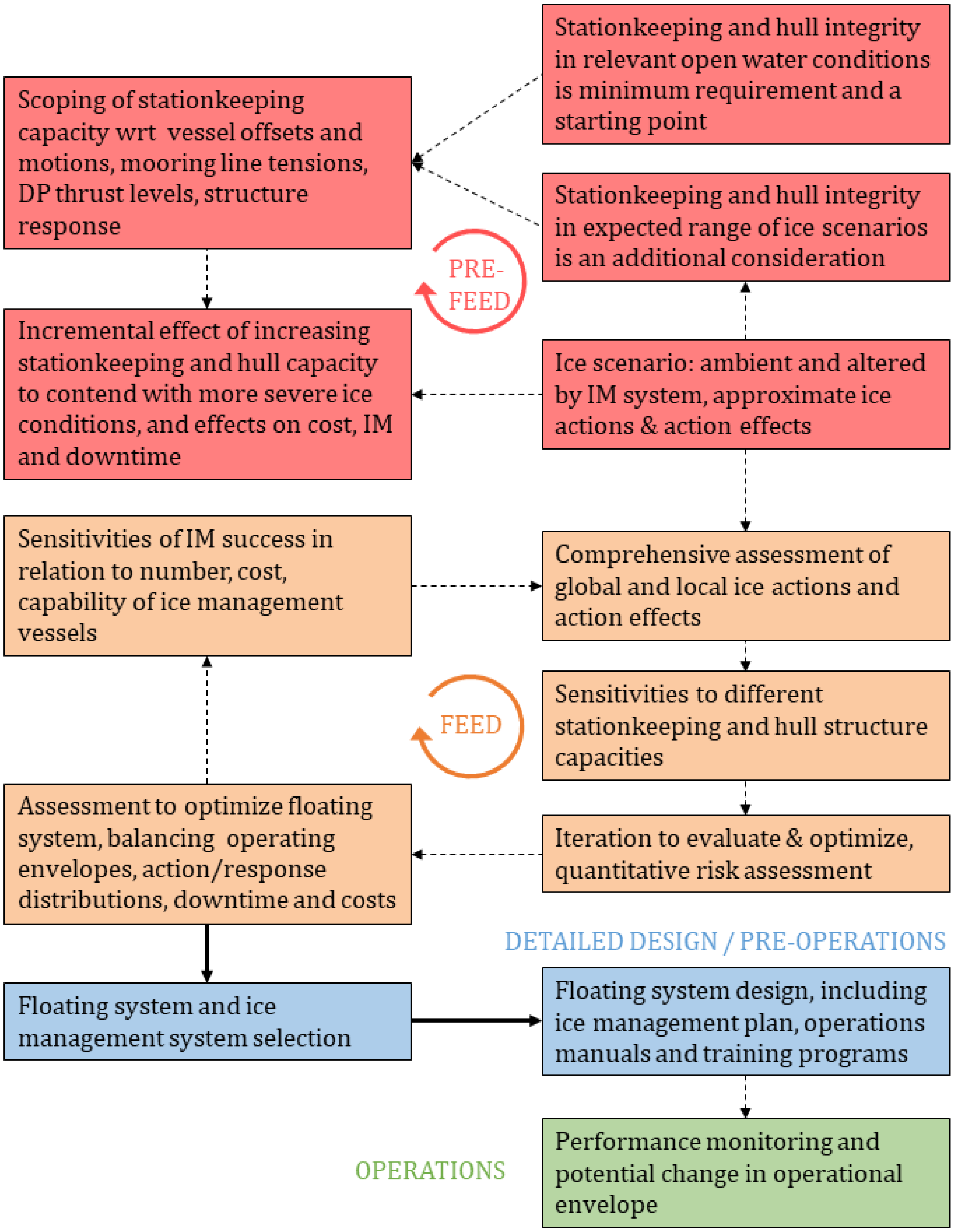

Figure 5. Staged design approach for an active floating system

If ice class rules are used as a starting point for hull design, the ISO 19906 (2019) standard can be applied to particular design and assessment situations for stationkeeping and additional requirements in ice. Although the rules can simplify the design process because they are prescriptive, they were developed for transiting ships where ice strengthening requirements depend on propulsion. While classification societies typically have several different ice classes for first year ice regimes and for Arctic ice conditions, ISO 19906 does not specify the choice of ice class.

OPERATIONAL ENVELOPES

For all except for passive floating systems, operational measures can be undertaken to mitigate ice actions in the context of an ice alert system, and potentially allow for a reduction in the design capacity of the hull. In spite of this, the design of the hull should take into account inefficiencies and the potential failure of these measures as discussed above. In some adverse situations, such as when pack ice is under pressure or during high sea states, ice management or disconnect operations can be impaired.

The capabilities of the hull and the operational measures together form the basis for developing operational envelopes of the floating system. The relationship between the design envelope and operational envelopes is illustrated in Figure 6. The operational envelopes should reflect design limitations and operational constraints of the stationkeeping system in all anticipated ice-operating situations. These situations might be more severe than the design and assessment situations for what the hull and mooring system is designed for.

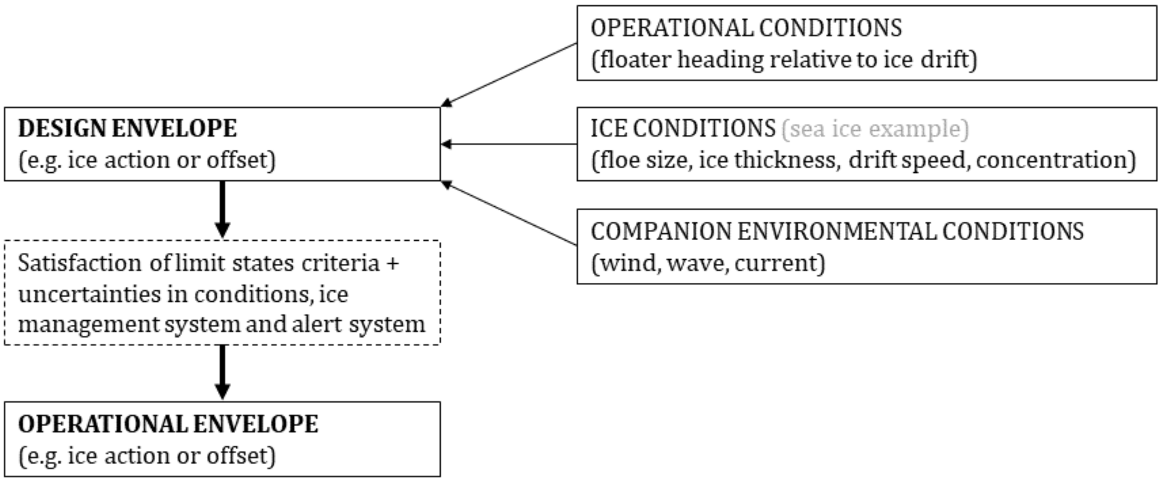

Figure 6. Relationship between design and operational envelopes

The implications of the operational envelopes concept have been addressed in the 2nd edition of ISO 19906 (2019) standard for the various floating structures:

- **For active and semi-active systems**; requirement for development of ice scenarios associated with design constraints for the stationkeeping system, including disconnection system capacities, mooring line capacities, anchor capacities, mooring line connection capacity, and dynamic positioning system thrust. In the case where the ice actions are limited by the capacity of the stationkeeping system, operational procedures are used to reduce the ice actions. The operational procedures define a set of safety barriers to ensure that the integrity of the floating structure is not impaired under any defined ice scenario. Barriers are designed, used, and maintained to ensure function over the design service life of the facility, see ISO 17776 (2016). These barriers, both physical and non-physical, are implemented to meet the alert system requirements. Operational performance standards are then developed, in accordance with ISO 17776 (2016), to ensure that structural reliability is adequate over the design service life
- **For semi-passive systems;** requirement to satisfy the structural reliability over the design service life, by mitigating local and global ice actions through the ice management measures applied (i.e. use of operational procedures to reduce ice actions).
- **For passive systems;** requirement to satisfy structural reliability over the design service life for the defined ice scenarios.

The envelopes should be part of the operating manual of the facility. This is equivalent to the operational criteria, design environmental condition and system with alpha factors used in marine operations (e.g. DNVGL-ST-N001, 2018). The alpha factor is defined as:

> *"the maximum ratio of operational criteria/design environmental condition to allow for weather forecasting inaccuracies".*

For ice environments, there is much less experience with forecasting and in understanding the uncertainties involved. A sound strategy includes multiple barriers. The specification of the operating envelopes and the design of the ice alert system should be done together to ensure a consistency between design and operations. For instance, ice conditions that exceed ice alert system criteria might need to be considered in the operational envelopes for the hull structure.

Another important consideration is the time for safe suspension or disconnection that is incorporated in the ice alert system. The alert criterion to suspend operations has to account for potential escalation of physical environmental conditions that might prevent suspension or disconnection. As a result, the criterion for initiating shut-in is dependent not only on the environmental conditions, but also the time to suspend operations.

As an example, three different cases are shown below where X_{OP} is the operational offset envelope, t_0 the time for initiating suspension, t_T the suspension duration which has to be lower than the anticipated time to exceed X_{OP} and B reflects the range of forecasted offset during the suspension period.

1) an acceptable system where shutdown is planned to be initiated and completed well before the operational envelope is reached (Figure 7);
2) a system or situation that is not considered acceptable (Figure 8), either because the suspension is initiated too late, the system is not robust enough, suspension time is too long, or the uncertainty in forecasting the conditions during the suspension period is too large; and
3) a system involving a staged suspension with multiple barriers (Figure 9), where a planned reduction of operations (i.e. production shutdown and preparation to disconnect) can extend the period the floater can stay on location before final suspension is carried out.

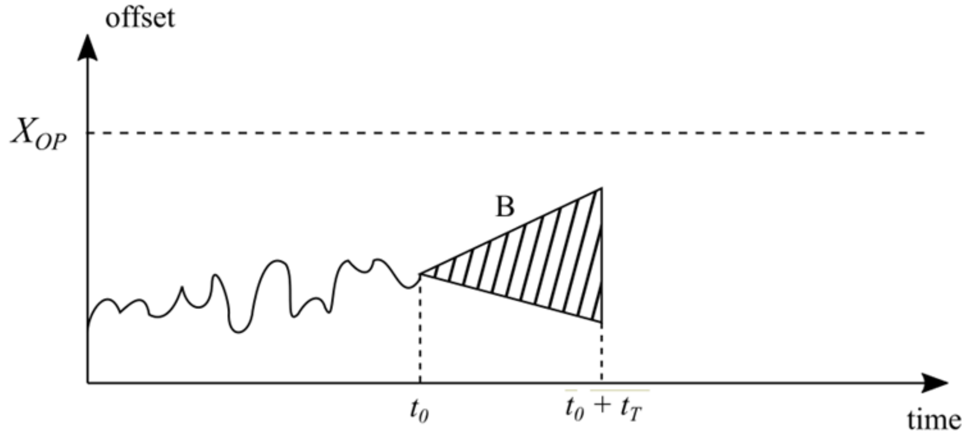

Figure 7. Example of acceptable operational envelope for offset

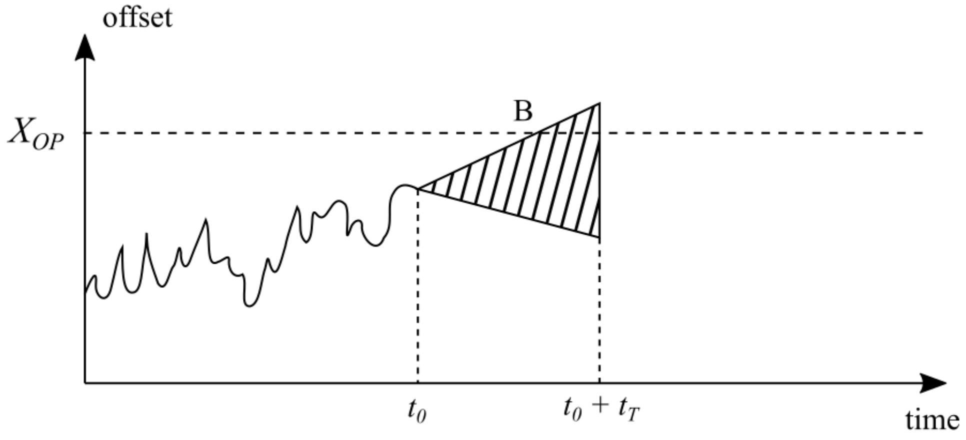

Figure 8. Example of inadequate operational envelope for offset

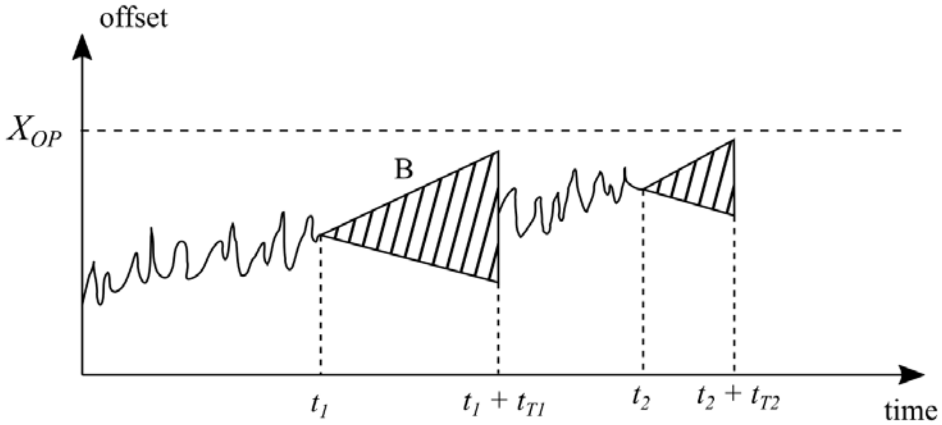

Figure 9. Example of operational envelope for offset based on staged suspension with multiple barriers

In practice, an operator wants clearly defined criteria for when to initiate production shutdown, disconnection and other suspension measures. To ensure reliable operation, the criteria should involve easily measurable quantities that depend on the type of facility, the ice conditions and other aspects of the physical environment. In addition, there are still challenges to quantifying the uncertainty in future offset (*B* in the figures above) and decisions to suspend operations will be based on a best estimate of offset at the end of the suspension period (at time $t_0 + t_T$).

ICE ALERT SYSTEM

One area relating to floaters that has seen significant changes involves requirements relating to ice alert procedures. The ice alert system ties operational responses of the facility or the ice management system to ice hazards. Ice alert system requirements are found in ISO 19906 (2019) and in ISO 35104 (2018).

The first stage of an alert system can involve an initial warning of ice hazards for which responses might only involve a particular state of readiness. Subsequent stages can involve iceberg towing, icebreaking, changes to drilling or production status, depressurization of lines, shutting of safety valves, de-manning, disconnection and move-off. Vessel operations could also involve weathervaning or other facility displacements, or changes to the mooring and ballast systems.

The different stages of an ice alert system, sometimes referred to as alert levels, can be assigned colours that become more vivid as the risk increases. An example from the Beaufort Sea is given in Makrygiannis et al (2011). Alert levels involve the state of the facility, while changes to the alert levels typically involve thresholds in the state of the ice, such as ice hazard proximity or pack ice pressure for which operational responses are required. Since operational responses are usually expressed in terms of the time required for their completion, the proximity of ice hazards is expressed in terms of a travel time. Ice hazard travel times can be calculated from the travel distance to the facility divided by the component of the forecast ice drift speed toward the facility. Correspondingly, errors in drift forecasts can be estimated by relating the component of the actual and forecast drift speeds along a line between the present ice feature position and the location of the structure.

An ice alert system can also involve a de-escalation of risk, in which the alert level can be decreased if the severity of the ice hazard falls below a critical threshold.

An ice alert system can potentially fail to provide the intended level of safety if:

- the operational envelope does not meet the limit states criteria, which could be due to unexpected environmental conditions that were not considered in the design of the system;
- hazardous ice conditions are not detected;
- the ice management system does not perform as intended;
- an ice hazard arrives faster than forecasted;
- suspension procedures are not completed successfully; or
- where avoidance procedures are part of the strategy, anticipated side-tracking or disconnection measures cannot be completed as planned.

Because no system can be 100% effective, each of the above circumstances is possible. As a result, realistic probabilities of failure for these circumstances should be reflected in the design the ice alert system and when establishing the operational envelope.

ICE MANGEMENT

A new ice management standard, ISO 35104 (2018), has been published recently, covering many of the ice management requirements that were previously in ISO 19906 (2010). As a result, the new ISO 19906 (2019) document has been revised to include only high-level requirements.

Ice management encompasses physical management activities involving towing and icebreaking, the detection and tracking of potentially hazardous ice features, and the forecasting of ice and metocean conditions. Forecasting sea ice or iceberg drift is a key aspect of any ice management system.

Changes to ice management requirements in the new ISO 35104 (2018) document include the need to demonstrate ice management success based on previous experience, that ice management operations be tested prior to use in protecting a facility, and that sufficient data be collected and recorded during operations to allow IM success to be assessed. Furthermore, ice management protocols need to be subjected to a continuous improvement process. The importance and characteristics of the ice alert system has been clarified in the revised standard, as is the requirement for ice management operations to be conducted in the context of the ice alert system.

SUMMARY OF CHANGES IN THE REVISION TO ISO 19906

Important changes since the initial publication of the standard in 2010 include the identification of different facility types, depending on whether ice management and disconnection/move-off capabilities are part of the design concept.

Significant effort was made to provide a stepwise methodology for designing and planning a floating system, including the structure, stationkeeping capability, ice management support, and the important trade-offs involved.

This methodology can also be used to streamline the design process for floating structures, particularly when considering different levels of ice management support. Hopefully, the proposed methodology will help demonstrate safety for all types of systems in a fully justifiable and controllable manner.

Because operational procedures are such an important consideration for floaters, additional requirements include operating envelopes and non-physical barriers to ensure that these procedures are conducted safely and in a way that human life, structural reliability levels and the environment are preserved.

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