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Ice events and ice actions in ISO 19906

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ABSTRACT

Terms “design ice event” and “design ice action” (load) are frequently used in Arctic engineering practices. In the 2019 edition on ISO 19906, an attempt is made to rigorously define those terms and place them within the framework of the overall design philosophy of the ISO 19900 series of international design codes for offshore structures. This paper discusses how the Limit State Design approach employs the design situation concept where Extreme Level (EL) and Abnormal Level (AL) ice actions are calculated and combined with other actions to perform limit state design verification.

An ice event is an occurrence of ice-structure interaction for which ice actions can be calculated. A full probabilistic approach is the preferred method. Within this approach, an ice action hazard curve is constructed for a population of ice events. EL (and AL) values of ice action may correspond to several different ice events or, more often, to no any particular ice event.

ISO 19906 also allows for employing a simplified approach when a notional design ice event (ELIE or ALIE) is constructed directly, without full probabilistic analysis. Such an event typically involves interaction with an extreme ice feature and is usually constructed based on somewhat limited field data supplemented by expert judgment. It should be recognized that the simplified approach usually introduces a significant uncertainly in the probability of exceedance associated with calculated design ice actions.

KEY WORDS Ice event; Ice action; Design; ISO 19906.

INTRODUCTION

As many other design codes, ISO-19906 intentionally employs rather broad definitions of the key concepts to cover as many situations as possible. As a trade-off, some parts of the code may be general and seemingly vague, which makes it necessary to seek expert interpretation when used on a specific project. The informative part of the code (Annex A) provides more clarity and background to the provisions included in the normative part and hence make it easier to apply.

The intent of this paper is to provide more in-depth explanation of the concept and definition of ice event and the two types (feature-based and time-series-based) as employed by ISO-19906. There is focus specifically on the role and place of design ice events, characterized by Extreme Level Ice Event (ELIE) and Abnormal Level Ice Event (ELIE), and the derivation of design ice actions in the design process envisioned by the code.

After ice events are characterized and evaluated, design situations are established for which the structural design is verified. The actions arising from an ice event are combined with companion environmental actions and associated actions of other types (permanent, operational etc.) for use on the limit state design verification procedure.

ICE EVENTS

The concept of a discrete ice event is essential for ISO-19906. An ice event is one of the types of hazardous event addressed in ISO 19900. ISO 19900 requires that each hazardous event is characterized and evaluated in order to establish design situations with design actions at specified probability levels, which result in the calculation of design ice actions.

Design ice actions are the principal actions in the action combinations for use in extreme design situations and abnormal design situations. These are used in the limit state design verification procedure in order to verify structural integrity for such ice events.

This paper particularly addresses extreme-level and abnormal-level ice events (ELIE and ALIE).

Definition

The Barents2020 project, as reported by Moslet et.al., 2012, concluded that the term "ice event" as used in the 2010 edition of ISO 19906 could lead to different interpretations and that a definition, then lacking in ISO 19906, was needed. They proposed "ice-structure interaction event for which ice actions are calculated". They concluded that this concept of an "event" includes both discrete events and an extreme or abnormal peak or maximum within a continuous (stochastic) process arising from persistent ice conditions with no clear evidence of individual or discrete features.

The Barents2020 proposal formed the basis of the definition in ISO 19906:2019. In ISO 19906:2019, subclause 3.28, ice event is defined as:

- "occurrence of ice-structure interaction for which ice actions can be calculated".

Rationale for the changes are firstly that the event is an "occurrence" and ISO rules do not permit the term (event) to be used in its own definition, and secondly that it is possible but not always a prerequisite to calculate ice actions (therefore "are" is changed to "can be").

Note 1 to the ISO 19906 definition is an edited version of the Barents2020 conclusion It clarifies that ice events can be occurrences of interactions with discrete ice features such as icebergs, ice islands, ice ridges, stamukhi and ice floes (discrete feature-based ice events), or can be occurrences of peaks within a specified length or duration of the interaction process (time-series based ice events). The calculation of actions for a discrete feature-based ice event can be based on a time-series during the interaction, which can for example be a quasi-continuous (smooth up and down) action/time curve with an identifiable peak action between the start and finish of the event, or the calculation of actions can be based on a limiting process such as limit stress or limit energy. The calculation of actions for a time-series based ice event usually includes statistical analysis of multiple action peaks during the interaction.

Further elaboration

More discussion on what ice events are is provided in the informative part of ISO 19906, see for example the commentary subclause A.8.2.1. Ice events are derived from the various ice scenarios relevant to the ice environment at the geographical location under consideration.

Fundamentally, ice event is an interaction between an ice feature and a structure which generates an ice action above a certain threshold. The threshold is usually governed by the type of the structure and is usually high enough to eliminate a large number of “non-events” (i.e. interactions that produce ice action so low they are of no consequence to structure performance). By definition, ice event has a finite duration.

The peak ice action during an ice event is usually the most important manifestation of the event with respect to structural design. When statistical analysis of ice action is conducted, ice events are usually ranked by the peak ice action.

Event duration is often also important. For dynamic analysis of structural response, the rates of ice action build up and decay are important.

The geometry of ice-structure interaction is also important. This includes the location and consequences of the ice event, particularly with respect to local effects and local damage.

There are two different ways of elaborating ice events, which can be considered as two different classes: discrete feature-based and time-series based.

Discrete feature-based ice events

When the ice event is characterized as an interaction with a specific ice feature, its duration naturally lasts from the first contact between the two bodies (ice feature and the structure) to the time when the feature stops producing the action. Depending on the interaction scenario this can be either when the feature fails, or stops and rests against the structure, or when it loses contact with the structure and drifts away from it.

In a discrete feature-based ice event, there is typically a quasi-continuous (smooth up and down) action/time curve, with an identifiable peak action, and an identifiable start and finish. Figure 1 shows the well-known Hans Island event when a multi-year ice floe in otherwise relatively open water impacted the island (structure) and split at (or near) the moment of peak action.

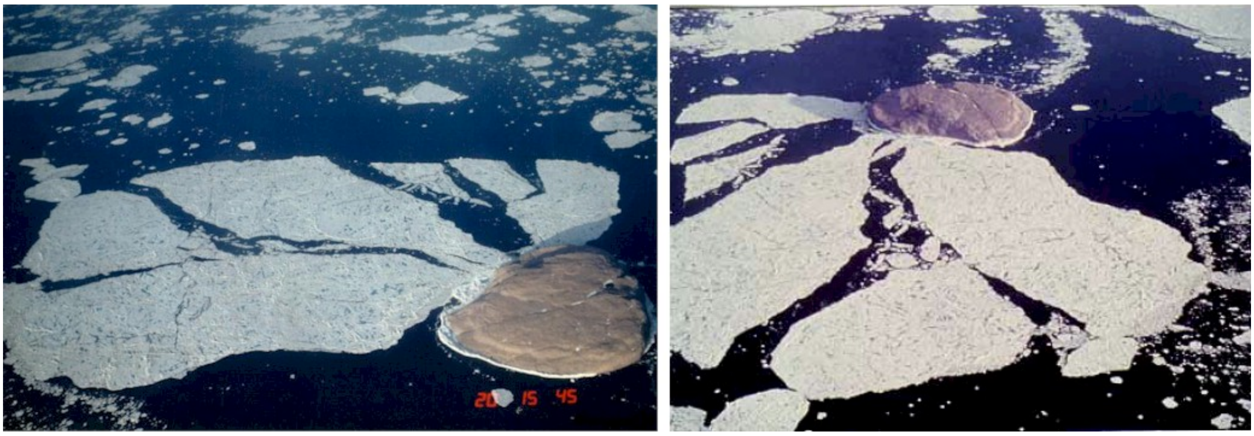


Figure 1 – Interaction of multi-year ice floe with Hans Island (example of discrete event)

Time-series-based ice events

When a long continuous record of ice action is available, individual ice events can be defined directly from the time series, using a threshold approach. The start and finish are often physically identifiable, for example the start and end of an ice movement, or instead they are chosen by the analyst from a longer continuous event record.

Figure 2 shows a line survey of ice thickness over a 10 km length, gathered by the ArcticNet CCGS Amundsen field program in the southern Beaufort Sea (Canadian sector) in September 2009. If this were continuous ice moving past and interacting with a structure, ice actions can be calculated for the peak thicknesses above a threshold, and used together with other data in a statistical analysis to derive ELIE and ALIE.

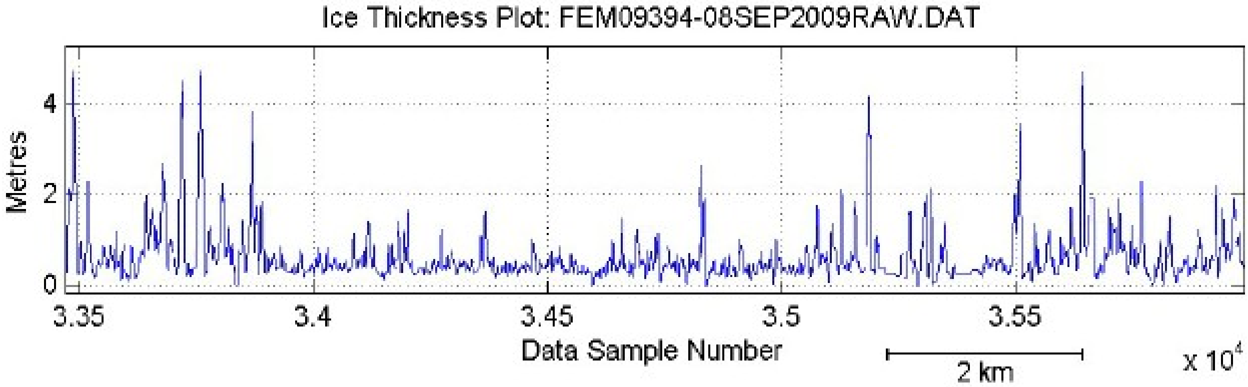


Figure 2 – Ice thickness plot from Field Data from the southern Beaufort Sea

DESIGN (LOW-PROBABILITY) EVENTS

Definitions of low-probability events are usually focused on the probability part (e.g. 100-year event has annual probability of occurrence of 1%). The “event” part is assumed to be obvious. But depending on the nature of the event, it can be ambiguous.

A flood is an example of a simple event. At any specific location it either occurs or it does not occur. The 100-year flood zone is the area defined by a boundary of locations where the annual probability of flood occurrence is 1%. But note it says nothing about the severity of flood event at any specific location within the flood zone. There can be an inch of water or 10 meters of water.

Wind events and temperature events are also examples of simple events. In such cases, wind speed or air temperature are the key adverse factors. There may be some nuances (e.g. gust speed vs 10-min average wind speed) but the action is characterized by the measurable physical quantity which defines the event. Statistics can be developed directly on the measured data (if such data exists).

Earthquakes are an example of more complex events. Earthquake magnitude (defined as energy released at the source) needs to be translated into ground motions (accelerations) at the structure location.

Ice events can be simple as well. An example is local ice actions, especially for a vessel hull. Individual events are usually determined directly from a time series of ice action. They usually have a well-defined start and well-defined end. Usually there is no attempt to relate individual events to a specific ice feature. Rather a group of events (which is typically large) is related to a certain range of ice conditions defined by level ice thickness, frequency of ridges, total ice concentration etc., see Frederking, 2003. There is a large database of local ice load measurements on vessel hulls. Statistical analysis of measured local ice action can be directly used to develop design actions. Models are needed to extrapolate results of such statistical analysis to significantly different ice conditions and/or structures where little or no local ice action measurements exist.

ISO-19906 employs the notion of Extreme Level Ice Event (ELIE) and Abnormal Level Ice Event (ALIE), see Clauses 7.2.2.3 and 7.2.2.4 respectively in the 2019 edition. When working on this new edition of the code, it was recognized that ELIE/ALIE terminology may be confusing. An option to completely eliminate ELIE/ALIE from the code was considered but after much discussion the decision was made to keep these terms, although primarily in the informative part. ELIE and ALIE are introduced but deemphasized in the normative part,

The main argument for deleting ELIE/ALIE completely is that in reality the design deals with ice actions, not events. Moreover, the main characteristic of ice events is usually the peak ice action resulting from the event. In some sense, ice event and the peak ice action are synonyms in ISO 19906 context.

There were also multiple reasons for keeping ELIE/ALIE in the code. ELIE/ALIE terminology has been broadly used in the past both in the code and in the literature. Although it is not that common, there are design situations where ELIE/ALIE notation makes good physical sense. An example would be “air gap” design where the relevant primary characteristic of the ice event is the sail height of the ice feature and its interaction with the structure.

The requirement to establish ELIE/ALIE after EL or AL ice action is calculated from the hazard curve is a good design practice. It allows the designer to relate the results of a mathematical exercise with hazard curve back to physical reality and to conduct a reality check.

The ice action hazard curve is usually developed by the best fit to a large population of ranked ice action values calculated for corresponding ice events. By definition, EL and AL ice action are the points on the curve corresponding to specified probabilities of exceedance. There may be no specific ice events corresponding those ice action values. However, there always will be a number of ice events with ice action values within a certain range (for example within 5%) of EL or AL ice action. We call those events ELIE and ALIE respectively.

ICE EVENTS AND ICE FEATURES.

It is recognized that by continuing to use ELIE/ALIE terminology in ISO 19906, the distinction between ice actions, ice events and ice features can seem to some extent blurred. Ice features are hazards arising from, or in, the ice scenarios, and cause ice events when they interact with structures. Ice action is the primary manifestation (result) of an ice event.

Ice features are usually characterized by their geometrical and/or physical parameters. For example, keel depth for ice ridges, or mass for icebergs. Ice features usually cannot be uniquely characterized by a single parameter. In the case of a free-floating iceberg, for example, the following iceberg parameters influence the peak action during iceberg impact event:

- iceberg mass;
- impact speed;
- ice strength;
- local iceberg shape at the ice-structure contact
- local structure shape at the ice-structure contact.

Multiple combinations of different values of those parameters will result in approximately the same peak action. From that prospective, strictly speaking there is usually no such thing as “100-year iceberg” or “100-year ice ridge”.

Industry and Academia collected a lot of field data on individual ice features (such as icebergs, ice ridges, hummock fields, and multi-year ice floes). Examples are iceberg database for the Grand Banks, or IPS/SDCP data collected in the Beaufort Sea. Much less full-scale data is available on ice events, and especially global ice actions resulting from ice events.

In the 1990’s and early 2000’s, National Research Council of Canada (NRC) ran two JIPs to develop two databases: one for local ice actions and another for global ice actions measured in the field. A local ice pressure catalogue (CLIP) developed by NRC includes thousands of ice events [Frederking and Collins, 2005]. Many more local ice events were not included in the CLIP for a variety of reasons, e.g. because data was not available to NRC due to proprietary restrictions, or because the data was collected after the CLIP JIP was complete. It can be estimated that the world-wide inventory of local ice action events includes tens if not hundreds of thousands events. The other NRC database [Frederking et al 1999] includes only about 300 ice events where global ice actions were measured and associated ice conditions were documented reasonably well.

PROBABILISTIC APPROACH

ISO 19906 prefers a probabilistic approach to be used for design of Arctic offshore structures. ISO 19906 clearly sets expectation that full-scale data is preferred as the basis for the determination of representative values of ice actions on offshore structures when such data are available. The reality, however, is that there is very little good quality field data on global ice actions.

The only example where quality full-scale global ice action data have been collected continuously for a long time (over 10 years) is PEI Bridge, see Shrestha, 2012. When that much data is available for analysis, ice events can be identified directly from ice action time series, and then, if necessary, related to specific ice features. A large number (~20,000 between two piers) of global ice events was identified which allowed for developing the ice action hazard curve directly from full-scale data. Such a hazard curve can be modified to describe ice actions on a different conical structure in a different ice environment. A theoretical model describing the interaction of various ice features with a conical structure is needed for such modification to be sufficiently accurate.

In a more common probabilistic approach, ice features are studied for the geographical area of interest and statistical distributions of the key feature parameters are developed from field measurements. A theoretical model is used to calculate the global ice action from feature interaction with the structure of interest. An ice action hazard curve is developed using a probabilistic method. Monte-Carlo simulation is most commonly used to develop such curve. An example of such a curve is shown in ISO 19906:2019, Figure A.8-4.

Other probabilistic methods, for example FORM and SORM, can be used for this purpose as well. In this approach, the EL (or AL) ice action is in fact a value from the hazard curve corresponding to annual probability of exceedance of 10^{-2} (EL) or10^{-4} (AL for L1 exposure level). Even if Monte-Carlo simulation is used to generate the curve, there may be no any particular ice event on the hazard curve corresponding to 10^{-2} (or 10^{-4}) annual probability of exceedance. It is still useful to inspect a population of Monte-Carlo realizations producing ice actions close to the EL (or AL) ice action to understand what combinations of ice parameters produce such ice actions and if those combinations make physical sense.

DETERMINISTIC APPROACH

Guidance on the deterministic approach is provided in the informative part of ISO 19906, subclause A.8.2.2.3 and at the end of subclause A.8.2.3. The discrete feature-based approach, employs "building an Extreme (Abnormal) feature" that can produce Extreme (Abnormal)-level ice action. The recommendation is to pick one of the feature's parameters at Extreme (Abnormal)-level probability/return period and use appropriate (usually nominal or average) values for other parameters.

An example with CR for level ice actions given in subclause A.8.2.4.3.3 follows the same logic: combine extreme-level ice strength parameter with nominal ice thickness to get the ELIE action.

Due to the complexity of ice-structure interaction, the deterministic approach will usually produce only an uncertain estimate of the EL or AL ice action. Therefore the calculation usually employs conservative values of the parameters and the values of ice actions are probably over-estimated.

EXAMPLES OF PROBABILISTIC APPROACH

The probabilistic approach has been used to develop design ice actions for many years. Brown et al, 1996, describe an ice action hazard curve for the Confederation Bridge developed using a Monte-Carlo model. The design ice feature for the bridge piers is a first-year ridge. To develop the ice action hazard curve, the authors run Monte-Carlo simulations for 1000 years which included calculating ice actions for 5 million individual ice events.

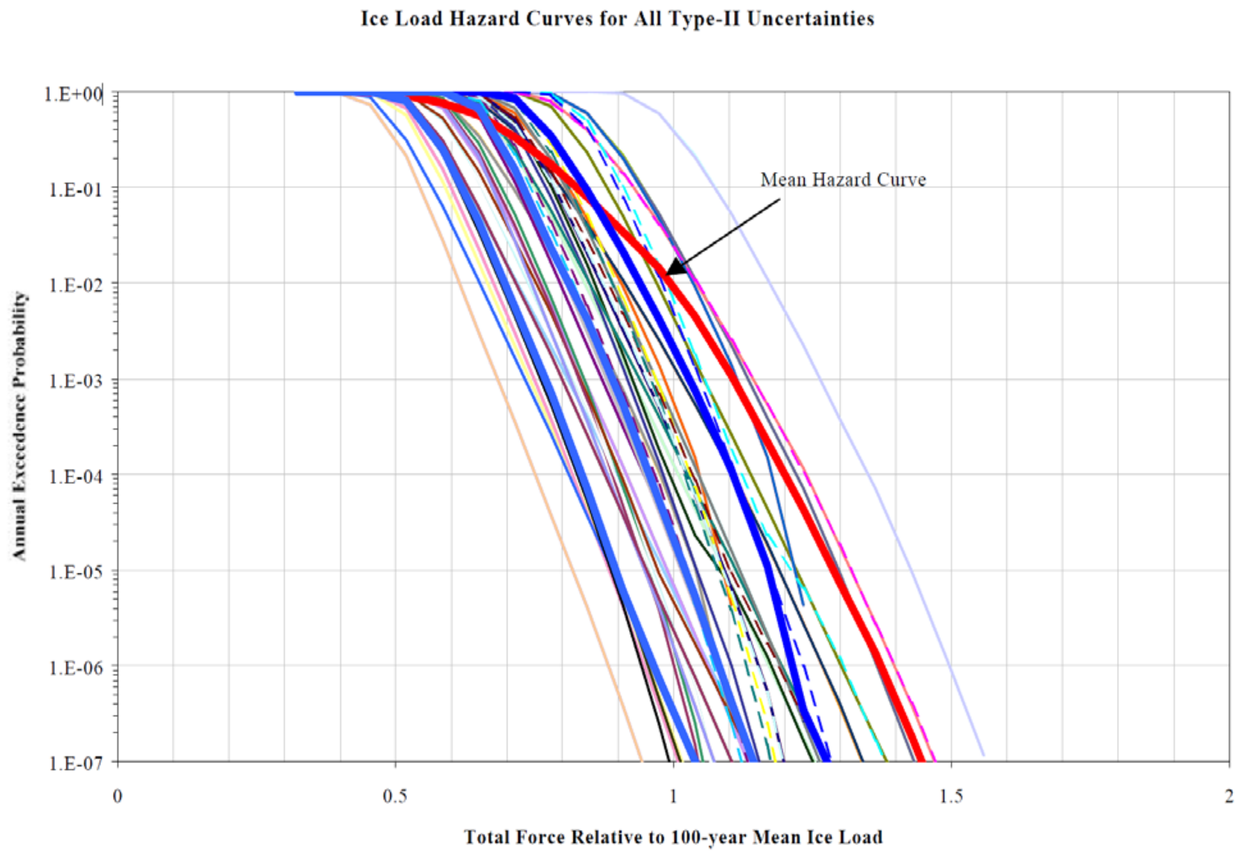
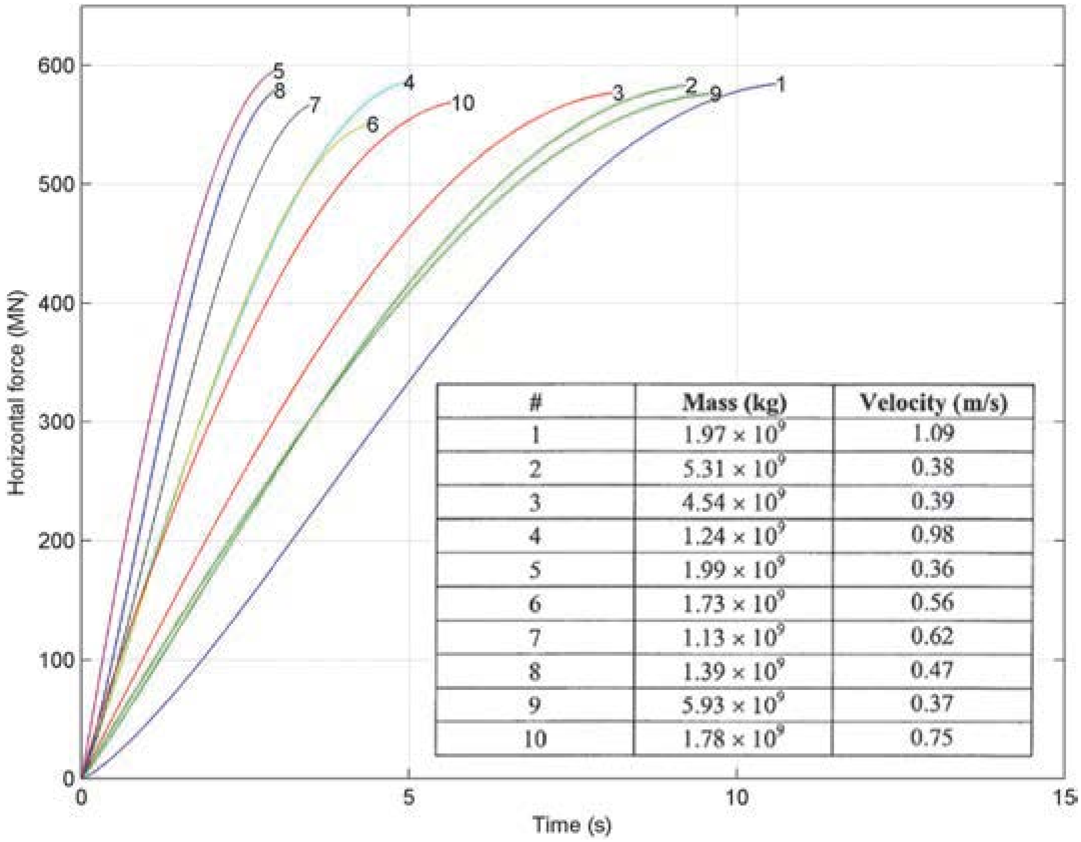


Figure 3. Series of ice action hazard curves for Sakhalin GBS [Wu et al, 2002]

The approach developed for calculating design ice actions on Confederation bridge piers was advanced further and applied to the design of offshore structures for the Sakhalin-1 project. Wu et al, 2002, describe how ice action hazard curves were developed for a wide vertical-sided GBS platform exposed to first-year ice conditions offshore Sakhalin. In addition to Monte-Carlo simulations, the authors also used FORM/SORM methods to develop ice action hazard curves. A logic-tree based approach was used to develop a series of hazard curves for each structure to address model uncertainties (see Figure 3).

Development of design ice actions for Hebron GBS is a more recent example of the probabilistic approach, see Widianto et al, 2013. To our knowledge, this was the first offshore structure designed to ISO 19906. The design ice feature for GBS structures at the Grand Banks is a free floating iceberg. Similar to what was done for Sakhlain-1 structures, a series of ice action hazard curves was developed for Hebron GBS to address model uncertainties. A Monte-Carlo model was employed to generate those curves. Widianto et al, 2013 also provide a set of Abnormal Level Ice Events for Hebron GBS. This was also discussed in Thomas, 2017. And as discussed above, multiple combinations of iceberg mass, impact speed and strength result in ice actions close to the 10^{-5} event (see Figure 4).



#	Mass (kg)	Velocity (m/s)
1	1.97×10^9	1.09
2	5.31×10^9	0.38
3	4.54×10^9	0.39
4	1.24×10^9	0.98
5	1.99×10^9	0.36
6	1.73×10^9	0.56
7	1.13×10^9	0.62
8	1.39×10^9	0.47
9	5.93×10^9	0.37
10	1.78×10^9	0.75

Figure 4. Typical ice action-time curves for 10,000-year (ALIE) iceberg impact events on Hebron GBS structure [Widianto, et al, 2013]

DESIGN SITUATIONS

ISO 19906 requires that a design situation shall be established for each hazardous event, and refers to ISO 19900 for further description. Design situations in ISO 19900 and ISO 19906 are explained further in Thomas and Maes, 2019. The latest (2019) edition of ISO 19900 terms these “design/assessment situations” because assessment of existing structures is given more attention. But the revisions to ISO 19906:2019 were developed before the revisions to ISO 19900 were available, and therefore it, and this paper, continues to refer to “design situations”.

Each ELIE establishes an extreme design situation.

Each ALIE establishes an abnormal design situation.

The definition of ice event suggests that companion environmental actions, such as actions due wind and ocean current on the structure in addition to the ice, are not part of the ice event itself. Although the environmental event as a whole could be considered to include all contributing environmental phenomena, ISO 19906 and ISO 19900 are clear that, in these design situations, the ice action is the principal action, and it is associated with the ice event. Companion values of other environmental phenomena which could occur simultaneously should be evaluated and added in order to obtain the total environmental action E, which is used in the limit state design verification procedure.

CONCLUSIONS

In ISO 19906:2019, ice event is defined as “occurrence of ice-structure interaction for which ice actions can be calculated”. When considering an ice event, two levels are relevant for design verification to ultimate limit states: extreme-level ice events (ELIE) and Abnormal-level ice events (ALIE).

The definition of ice events can be elaborated by considering two classes of ice events: discrete feature-based ice events and time-series based ice events. Design ice actions are calculated either probabilistically or deterministically for each design ice event and are applied in relevant design situations.

Probabilistic methods are the main way for calculating design (EL and AL) ice actions. They typically involve construction of an ice action hazard curve from the joint probability distribution of the most important ice parameters, and calculating ice actions from that curve with the appropriate probability of exceedance. Deterministic methods, which include construction of ELIE and ALIE directly, from the data on individual ice parameters, are also permitted.

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REFERENCES

ArcticNet, 2009. *ArcticNet/IORVL Partnership CCGS Amundsen 2009 Field Program: MetOcean Data Report*. Centre for Earth Observation Science (CEOS), University of Manitoba, December 2009.

Brown, T.G., Croasdale, K.R, and Wright, B, 1996. *Ice Loads on the Northumberland Strait Bridge Piers – An Approach*. Proceedings of the Sixth (1996) International Society of Offshore and Polar Engineers conference, ISOPE-I-96-139, Los Angeles, USA.

Frederking, R., Timco, G., and Johnston, M., 1999. *Technical Report HYD-CTR-058.* Canadian Hydraulics Center. National Research Council Canada.

Frederking, R., 2003. *Determination of Local Ice Pressures from Ship Transits in Ice*. Proceedings of the Thirteenth (2003) International Society of Offshore and Polar Engineers conference, ISOPE-I-03-073, Los Angeles, USA.

Frederking, R., and Collins, A. 2005. *NRC Catalogue of Local Ice Pressures (CLIP)*. Proceedings of 18th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC05), Potsdam, New York, USA.

ISO 19900, 2019. *Petroleum and natural gas industries – General requirements for offshore structures*. International Organization for Standardization.

ISO 19906, 2019. *Petroleum and natural gas industries – Arctic offshore structures*. International Organization for Standardization.

Moslet, P.O., Eide, L.I., Mansurov, M., Onishchenko, D., Liferov, P., Gürtner, A., Thomas, G.A.N., 2012. *Barents 2020 - Working group 02 - Design of floating structures in ice. OTC 23709*. Arctic Technology Conference, Houston, Texas. December 2012.

Muggeridge, K., McKenna, R.F., Thomas, G.A.N., 2019. *ISO 19906:2019- an International Standard for Arctic Offshore Structures*. Proceedings of the 25th International Conference on Port and Ocean Engineering under Arctic Conditions, POAC19, Delft, The Netherlands.

Shrestha, N., 2012. *Ice Action Database for the Confederation Bridge Piers*. A Thesis Submitted to the Faculty of Graduate Studies, University of Calgary, Alberta, Canada

Thomas, G.A.N. and Maes, M.A., 2019. *Design Situations and Limit State Verification for Arctic Offshore Structures*. Proceedings of the 25th International Conference on Port and Ocean Engineering under Arctic Conditions, POAC19, Delft, The Netherlands.

Widianto et al, 2013. *Design of Hebron Gravity Based Structure for Iceberg Impact*. Proceedings of the Twenty-third (2013) International Society of Offshore and Polar Engineers conference, ISOPE-I-13-036, Anchorage, Alaska, USA

Wu, X. et al, 2002. *A Reliability-Based Method for Determining Design Ice Loads on Offshore Structures*. Proceedings of 21st International Conference on Offshore Mechanics and Arctic Engineering, OMAE’02, Oslo, Norway