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Rationale for development of design basis for Barents Sea field developments

O T Gudmestad

Department of Mechanical and Structural Engineering and Materials Science,
University of Stavanger, Norway

Corresponding author: otgudmestad@gmail.com

Abstract. Developments of hydrocarbon fields in the Barents Sea would normally include surface process units; thus, we must take into account the ice conditions in the area. Alternatively, smaller fields can be developed as satellites to existing production units. Full well stream to shore facilities may also be considered, in the case that one can document the flow conditions in the pipeline(s). Although glacial ice historically has been present all over the Barents Sea, the probability of meeting glacial ice in the southern part is very low, regarded by many as “negligible”. At which latitude one could expect sea and glacial ice in the future is, however, uncertain, as past experience has seen glacial ice on the Coast of Finnmark County and there are ongoing processes related to global warming which might increase the probability of iceberg encounter at the location. We will discuss concerns related to the selection of the design basis for the Barents Sea, including the Russian part of the Barents Sea, and discuss the term “negligible”. Of particular interest are criteria for the need for disconnection options for production units. The paper concludes with recommendations for thorough preparation of the design basis for the entire Barents Sea area.

1. Introduction

The importance of a design basis that adequately covers the relevant meteorological and oceanographic conditions for the design and operation of built facilities is of concern. The database of past events is normally used to statistically determine possible future events, with a certain annular probability of exceedance. The selected value of the annular probability of exceedance reflects the safety level chosen by the authorities. The exceedance probability for the “design event” is to be chosen with regard to the consequence of the event. Safety factors are, furthermore, included to cater for uncertainties related to the database and the possible consequences of the event. Standards distinguish between the importance (according to the importance class) of the facilities, by selecting a lower value of exceedance probability for the most important facilities. For example [1], hospitals, schools and the most important public facilities such as firefighting facilities are rated in a higher importance class than storage areas for nontoxic goods and houses for farm animals.

In the international oil and gas industry, the selection of a minimum safety level is set by the International Organization for Standardization [2]. Countries can decide to implement a higher safety level if desired.

During the process of selecting the safety level and safety factors and identifying design events, the database of past events is critical for ensuring that safe design is obtained. In this regard, the concepts

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of the known-knowns, the unknown-knowns, the known-unknowns and the unknown-unknowns play an important role [3]. In this paper the following terms and explanations will be used:

- Known knowns: Things we are aware of and understand (aleatory uncertainty like waves, wind…)
- Unknown knowns: Things we understand but are not aware of (hidden knowledge and hidden likelihood of occurrence like earthquakes)
- Known unknowns: Thing we are aware of but don't understand (epistemological uncertainty like elections)
- Unknown unknowns: Things we are neither aware of nor understand (ontological uncertainty like black swans)

We know about the waves in an area, and we can make statistical predictions about future wave conditions by using the present database. Data analysis shows that, using databases of past wave conditions, the extreme waves predicted for the south-western Barents Sea represent a stable estimate [4]. Using data assumed to represent future storms being caused by a presumed warming climate, the predicted extreme waves are higher [5]. So, we have a situation of known-unknowns: Should we use models which will give rise to larger design forces or should we base ourselves on data representing the known-known situation?

In this special case, it is difficult to give advice; however, the designer could choose to prepare a redundant design, which could be somewhat damaged, however, not to a level causing progressive collapse, should a worse prediction occur.

Alternatively, to ensure that all possibilities are covered, the designer could choose to implement a *Maximum Possible Event*, this would represent the maximum possible event restricted by physics. This event would be different from the *Maximum Credible Event* that is linked to a certain probability of annual exceedance, for example 10^{-4}.

For example for the wave condition, as based on physics, i.e. the geography and the extreme meteorology of the Barents Sea: Assume a low pressure from the west and a high pressure to the east. How large a gradient can be set up, and how large could the waves be in the area? A similar exercise was done for the northern North Sea [6], with a conclusion that the maximum possible wave condition is close to the wave found by using extreme statistics when selecting an annual exceedance probability of 10^{-4}. In this situation, the unknown-unknown situation represents an event we have no knowledge about, or we have no meteorological or mathematical model to predict it. In risk analysis, such an event is often called a "black swan" [7].

There is no way we can identify a "black swan" or an unknown-unknown; however, we can enquire amongst the local population and those using the area for fishing or other activities whether there have been events not reported in scientific or historical literature. Such events can be found described in historical archives, during interviews with "the elders" (see for example [8], where the author interviews sealer captains regarding the ice conditions in the Arctic Seas).

2. Examples of insufficient design basis

There are numerous examples of insufficient design basis. One example is the earthquake code of Kobe, Japan. Prior to the Kobe earthquake of 17 January 1995, the design basis for infrastructure was based on a comparison with US earthquakes [9], attempting to represent a known-known situation; however, insufficient attention was given to local historical information.

The Fukushima earthquake of 2011, which caused damage to the cooling system of nuclear reactors, might be considered in the class, unknown-knowns, as the combination of the earthquake and the huge tsunami (13 to 15 m high) following the earthquake was not considered in the design basis. The tsunami caused a large number of fatalities and damaged the cooling system of the nuclear plant, eventually leading to the escape of radioactive gasses and a large number of fatalities, caused by the radioactive exposure.

In intraplate areas around the world, large earthquakes are not expected; however, there may be local dormant faults, where historical records do not indicate any earthquakes. A devastating earthquake in any such an intraplate area might be considered an unknown-unknown event that it is absolutely impossible to warn against. However, large disruptions of geological formations, like water flooding or water injection into rocks, could trigger large earthquakes.

In Basel, Switzerland, a geothermal powerplant project was abandoned, as there were suddenly earthquake records with magnitudes up to Richter scale 3.4. There was grave concern that the project could trigger larger earthquakes, like the 1356 earthquake of magnitude 6.7, severely damaging the city [10]. It should be noted that one may in general not get a warning, as in the case of Basel, such that a known-unknown effect can be transferred into a known-known effect.

3. The safe design basis

In the oil and gas industry, the design conditions are given by the Ultimate Limit State (ULS) requirement [2]: "The ULS requirement ensures that no significant structural damage occurs for actions with an acceptably low probability of being exceeded during the design service life of the structure. Significant damage is associated with impairment of structure function". An annual probability of exceedance equal to 10^{-2}, with a factor of safety equal to 1.35 on the loading and a factor of safety of 1.15 on the material (steel) is selected in [2]. Furthermore, a condition for check of accidental collapse limit state (ALS) shall be investigated with an annual probability of exceedance equal to 10^{-4}, with safety factors set to 1.0. In the case of such an event, the structure shall still be able to withstand the 10^{-2} condition (with safety factors 1.0).

For fixed structures, the combination of these criteria should ensure that a complete collapse would have an annual probability lower than 10^{-5} [11]. The complete collapse of an offshore production unit would represent a very severe situation with respect to loss of life and environmental pollution. In the case of offshore structures exposed to waves, wind and currents, it is assumed that the extreme wave conditions are predicted by the use of statistical analysis of data from previous storms. It should be noted that the wave conditions give rise to loading on steel space frame structures that is proportional to wave height squared. There is no large jump in wave loading when the waves are increasing (as we will discuss later, the situation for interaction with ice floes is different, as the ice floes, and in particular glacial ice, vary greatly in size). Uncertainties related to possible future sea level rise and the effects of very large storm surges are implemented in the Norwegian NORSOK-N003 standard [12], by prescribing a certain air gap (higher than in previous versions of the standard), as wave-in-deck loading leads to excessive forces and moments.

Based on the above discussions, taking precautions for wave-in-deck loads, there should be no reason for selecting a wave design basis based on uncertain modelling of future wave situations [6] or on maximum possible events [7].

For physical load situations where the load, given a selected annual probability of exceedance, increases greatly when selecting a lower annual probability of exceedance, the situation is different. In this case, the ALS loading is much higher than the ULS loading. For the design of nuclear plants, where a very large number of people are at risk, the Maximum Possible Event [13] is selected as the design basis for structural design. This event is estimated with a basis in the potential size of maximum earthquakes on known faults. The local effects due to soil amplifications must be included. Although the estimates may be uncertain, the estimated earthquake accelerations may represent the best possible estimate to be used as design basis. It should be noted that the term Maximum Credible Event (MCE) is linked to a certain annual probability of exceedance [14] and is different from the Maximum Possible Event discussed above.

The question then arises as to whether an event larger than the MCE could be termed "*negligible*". The term "negligible" is defined as "so small, trifling, or unimportant that it may safely be neglected or disregarded" [15]. Aven [7] focuses on the probability of an event; however, the risk is often identified as the product of the probability of an unwanted event multiplied with the consequences. Thus, when using the term "negligible", one should consider both the probability and the consequences. Bearing in mind the term "black swan" or the term "unknown-unknown", we might not be in a position to predict the maximum possible event; however, we might be in a better position to imagine the maximum possible consequences. And when the maximum possible consequences are unbearable, the event should *not* be termed "negligible". Therefore, in such situations, measures should be implemented to reduce the consequences from "As low as reasonably practical" (ALARP) to "As low as possible", by introducing a sufficient number of barriers.

It should be noted that risk is at present e.g. in the PSA regulation [16] defined as "consequences of the activity with related uncertainty". PSA further indicate that if the uncertainty is large (unknown unknowns) the precautionary principle should be implemented. This statement is to a large extent a different way to express the same conclusion.

4. Design basis for Barents Sea oil and gas developments

We have discussed above the design basis for waves, wind and current relevant for all seas, including the Barents Sea. We have also discussed the handling of global warming effects, with respect to these meteorological and oceanographic conditions. The discussion reflects considerations related to unknown knowns and known unknowns.

We have also discussed the design basis for earthquake load effects and shared the concern that the ALS load effects are much higher than the ULS load effects for wave loading. A factor for ALS/ULS wave height of 1.3 (or 1.35) is normally quoted for harsh environmental seas, while a factor of 5 can be the case for earthquake load effects [14].

In the case of the Arctic Seas, and also for the Barents Sea, the question is whether sea ice is expected and in particular whether glacial ice is expected to occur. For a period of 30 years, the author has followed discussions related to a database for field development studies of the Stockman gas/condensate field at 73°N 44°E / 73°N 44°E in the Russian Barents Sea (where an estimated 3.8 x 10^9 Sm^3 of gas is in place). The design basis has been a matter of controversy. In the early 1990s, it was claimed that there was no need to design against icebergs, as drifting icebergs had not been sighted for many years. A fixed Tension Leg Platform (TLP) was suggested for processing the gas volumes. In 2003, however, a swarm of icebergs drifted into the area, due to winds and currents from the north east [16]. It should be noted that previous studies [18] had identified that drifting icebergs could be expected in the area. Short-term observations were considered sufficient to neglect the historical information. All assessments of a platform to support the processing equipment had to be re-evaluated after the 2003 events, and a dis-connectable production ship was selected for further design studies. In the case of a dis-connectable vessel, the vessel can leave the location should threatening ice conditions appear. This could be the case if the ice management implemented [18] is not capable of moving drifting icebergs away from a path where collisions may occur, or in the case of drifting sea ice threatening to cause the vessel to drift off location, causing damage to the anchor system. In this way (by ice management and the dis-connection option), there are several barriers to prevent the consequences of an unwanted ice event from escalating into a catastrophe.

Based on the experience with the Stockman development studies, the question remains regarding the parts of the Barents Sea in which one should consider the probability of drifting icebergs. According to [20], icebergs have even been located off the coast of Norway in historical times: in 1881, 1929 and 1939. Are these observations of relevance today? Could we expect icebergs all over the Barents Sea? The Atlas of Abramov [18] gives a positive answer to the question; however, it could be argued that the climate is warmer, so icebergs will melt more quickly as they are transported southwards. On the other hand, it could be argued that even an average temperature rise may not eliminate outbreaks of very cold weather. Furthermore, with an average warming, one could expect that more glaciers will melt and cause the calving of more icebergs in the future. For information, see also [12]. As a consequence of the uncertainty, the author recommends that the potential for drifting icebergs is evaluated for all developments in the Barents Sea, in accordance with recommendations in [12]: "For structures with annual probability of iceberg impacts in the range 10^{-4} to 10^{-5}, operational mitigations such as physical iceberg management and/or dis-connection should still be considered in accordance with the ALARP principle and actions from possible iceberg impact scenarios should be evaluated".

Based on the above discussion and recommendation, it is unclear what is meant by a statement in the Plan for Development and Operations (PDO) for the Johan Castberg oilfield in the south-western Barents Sea [21], where the term "negligible" is used for the unwanted event "drifting sea ice and icebergs". It is, furthermore, stated that "An Ice Risk Management System (IRMS) shall be implemented according to the PDO. The ice conditions will be continuously supervised. In the case of sea ice drifting south of 73°N and the ice being forecasted to drift further south, the production shall be stopped temporarily and shall not be started up until all ice west of 30°E on the Norwegian Shelf is retracted to the north of 73°N" (author's translation of the document). In the case of any oil spill, an Emergency Response Analysis is prepared [22]. For this field, the requirements of the standard [12] are thus fulfilled; however, there is no possibility to move the production facilities, should there be problems associated with the ice management. On the other hand, the ice drift will be forecasted many days ahead; thus, it will be possible to mobilize the necessary vessels for ice management.

For future developments even further north or east, where the likelihood of drifting ice and icebergs is higher compared to the Johan Castberg field, it is very important that dis-connection of the facilities be considered. There are two possible design options:

- To consider a vessel that can be dis-connected and moved away whenever there is a possibility of drifting ice or icebergs. Such facilities exist on the Grand Banks on the Newfoundland Shelf (the Terra Nova and White Rose floating production and offloading vessels, FPSOs). A key consideration is the re-connection and start up of the facilities after a dis-connection. Ice management will be vital (as on the Grand Banks), to ensure that the vessel is moved only in the case of non-successful ice management. It should be noted that Equinor (formerly Statoil) has considerable experience with dis-connectable production vessels, through operations of the Lufeng FPSO in the South China Sea (1997 to 2009), where several dis-connections were carried out to avoid typhoon weather situations.
- To consider a vessel that can be disconnected the "hard way", by investing a minimum amount in a turret that would be damaged in case of dis-connection. The investments will be small; however, the repair costs and the value of delayed production can be large. Net present value analysis would be necessary to choose between the two design options.

In the case of future developments of oil and gas resources in the Barents Sea, there is a need to discuss safety measures to reduce the risk of a loss of production facilities, with the subsequent possibility of pollution of large parts of the Barents Sea area, possibly with oil pollution emerging under the Arctic ice. It should be noted that the direction of currents is towards the north east; thus, an Arctic disaster is the ultimate consequence. The ice conditions are regarded as being of the type, known-unknown, as global warming causes large uncertainties. The risk can in no way be considered "negligible"; however, for the ongoing development of the Johan Castberg field, plans are in place to ensure that the probability of an unwanted event is low and there is an attempt to mitigate the consequences to a large degree.

5. Conclusions

We have reviewed the design basis for oil and gas developments in the Barents Sea. The design basis for wave loading on offshore facilities is considered adequate, using present-day statistical analysis of wave data, provided we ensure that wave in deck of any fixed offshore structure is avoided. We have, thereafter, discussed the need to reduce the consequences of an unwanted interaction between any surface facilities (for example, an FPSO vessel) and surface ice or glacial ice (icebergs). It is recommended that dis-connection possibilities are considered as the last barrier, should ice management fail. The need to consider such an event is very relevant, as the future of drifting ice is unknown and as the historical database documents drifting ice in most of the Barents Sea. It will give us a false feeling of safety to conclude, before a thorough analysis, that the risk is "negligible".

For development of future design basis for the Barents Sea, we suggest that:

- To deal with unknown unknowns (high uncertainty) a Maximum Possible Event should be used as design basis

- If we are not able to predict the Maximum Possible Event the Maximum Possible Consequence should be predicted.
- If the Maximum Possible Consequences are unbearable the event should not be termed "negligible" and the Maximum Possible Event should be used as design basis.

As to whether any unknown-unknown situation could arise with respect to the physical environmental conditions, and in particular with respect to drifting ice, this is by the selected terminology (unknown-unknown) impossible to foresee. The characteristics of "black swans" are that they are impossible to predict. However, we must realize that known-unknown situations may appear in the Barents Sea.

6. Acknowledgements

The author acknowledges discussions with colleagues during the preparation of the paper. In the oil and gas industry, there is a concern that a "too high level of safety" might be disadvantageous for the competitiveness of the industry. There is, however, among both industry partners and authorities, a joint interest in reducing the probabilities and consequences of unwanted events to an absolute minimum, and the term "negligible" is being used, although not accurately defined.

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