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COMMITTEE V.6

ARCTIC TECHNOLOGY

COMMITTEE MANDATE

Concern for development of technology of particular relevance for the safety of ships and offshore structures in Arctic regions and ice-covered waters. This includes the assessment of methods for calculating loads from sea ice and icebergs, and mitigation of their effects. On this basis, principles and methods for the safety design of ships and fixed and floating structures shall be considered. Recommendations shall also be made regarding priorities for research programmes and efficient implementation of new knowledge and tools.

CONTRIBUTORS

Official Discusser — Professor Pentti Kujala, *Finland*

Floor Discussers — Agnes Marie Horn, *Norway*
Henk den Besten, *The Netherlands*
Jonas Ringsberg, *Sweden*
Ling Zhu, *China*
Mahmud Sazidy, *Canada*
Wengang Mao, *Sweden*
Gaute Storhaug, *Norway*
Thomas Choisnet, *France*

Reply by Committee Chairman: — S. Ehlers
A. Polojärvi
A. Vredeveldt
B. Quinton
E. Kim
F. Ralph
J. Sirkar
P.O. Moslet
T. Fukui
W. Kuehnlein
Z. Wan

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1. DISCUSSION

1.1 Official Discussion by Professor Pentti Kujala, Finland

1.1.1 Introduction

I first want to thank the committee for an extensive report to describe the current state-of-the-art related to the Arctic technology and especially safety of ships and offshore structures operating in ice-coverer waters. I agree that the focus of the committee "the objective of this committee report is to present the current state of the art in rules and regulations to be considered when designing ships and offshore structures for ice loads " is well chosen and important as there are number of topics that can be improved for these rules comparing, e.g. the current best practices for open water ship design. Research on ice loads is still behind research on wave loads. Wave-structure interactions can be described by using wave theories, strip methods, wave scatter diagrams, spectral methods, and other well-founded methods. There are no equivalent methods to describe the ice conditions and ice loads which is also well illustrated on the committee report.

As this is the 2nd period of this special committee, a short description on the beginning of the report could have been useful for the reader to illustrate shortly the differences between the focus areas of the two committees. I hope, committee can consider this in the answer to my discussion.

1.1.2 Remarks

Next I will discuss the report content following the structure of the committee report.

1. Introduction

This gives a good introduction to the report. My only comment is related to the 3rd section, where it I stated that "another aspect not addressed sufficiently for ships and offshore structures is the design ice load prediction resulting from ice rubble." I hope Committee describes in further detail what is meant by the word rubble here as typically the load level in the rubble field are not so high.

2. Design methods for marine structures

Here in section 2.1 is presented the FSICR rules and a statement "In terms of the FSICR rules, the possibility of damaging the vessels structure due to overloading from ice is apparent, because the return period of the design ice load is typically below 10 days." Here it has to be remembered that FSICR uses the first yield as a limit state and the load level is related to this design criteria, see e.g.(Riska and Kämäräinen, 2011). This means that this load level is achieved typically once a winter (assuming that typically ships are about 10 days in ice during one winter), but the loads to cause significant damage (ultimate strength limit state) must be in the range of lifetime maximum. I hope, committee agree on this statement.

On section 2.1 and under heading Consideration for probabilistic design there is a very good discussion how the time in ice should be used as one design parameter in future. It is stated that "A higher classed stronger vessel will cost more, but have reduced risk of downtime. A weaker vessel will cost less, but with increased risk of delay or downtime." I totally agree that the time in ice or distance traveled in ice should be the basis for future ice class rules as also stated by the committee. This topic has been also studied by Kujala and Ehlers (2014), which is missing from the reference list.

Section 2.1.3 includes a short description of the IMO POLARIS approach. This could have been given more space as it is a good approach to evaluate whether the ship has high enough ice class for the planned route based on the real ice conditions on the area. The numbers used to evaluate the risk index is based on practical experience, but it has been shown by Kujala et al. (2016) that it seems to give a reasonable risk level for the ships indicating properly if the navigation on the planned ice conditions is safe with the chosen ice class. This analysis was based on the real full-scale ice load data and analysis of the damage probability.

In section 2.3 is presented very interesting mission-based approach to evaluate the design load levels on ships in ice. It gives a good approach how to evaluate the ice induced pressures based on the number of impacts with ice. Then the pressure values are e.g. compared with FSCIR rules. One has to be careful when comparing the pressure values as in all rules pressure is used to calculate the load by assuming some design contact area for the pressure. So pressures are difficult as such to compare without analyzing also the design contact area used in the rules. I hope the committee will discuss this in further detail in the answer to this discussion. This will discussed further in section 4 as well.

3. Structural capacity

Design process involves definition of structural capacity and there is a dedicated chapter to this. However, the subchapters seem imbalanced with regards to assessment of methods for the safety design as indicated in the mandate. I was particularly looking for a review of recent developments regarding plastic design methods and related limit states, as well as their possible integration with current set of rules. While committee has placed increased focus on response to moving loads (Ch.3.2), this is only a one, even though important, part of the limit state design. Several interesting papers have been published recently regarding the topic, from which some are brought out (Daley et al., 2017, Körgesaar et al., 2018, Yu et al., 2018). I am also interested to hear how committee sees the development of plastic design methods in the context of rules. In other words, this would involve opening the research challenge listed in the summary of the report: design procedures based on ULS as discussed further next.

Figure 1 below from recent paper (Kõrgesaar et al., 2018, 2017) shows the overload capacity of ice strengthened frames. There were two objectives in this study. First, to show the effect of load patch width & height on the response, and second, to show the effect of modelling on the entire grillage versus only a single isolated frame for response evaluation. Following findings are worth noting:

(i) They found that frame web fracture precedes plate fracture. Compared to first signs of plastic deformation in frames (also defined as three hinge load) load safety factor against plate fracture was three.

(ii) Besides length, patch width greatly affects the response. Thus, for overload response evaluation of critical patch length is of interest.

(iii) It is known that in the isolated frame analysis, the deformation mode is reminiscent of cylindrical bending. They found that in grillage analysis similar deformation mode in frame appears under longer patches (i.e. of several frame spacings). When they compared the load carrying capacity of a single grillage frame to an isolated frame under these conditions, it was found out that overload capacity is approximately the same. This is important since conventional assumption is that the frame in grillage has increased capacity to carry load compared with isolated frame due to the membrane effect.

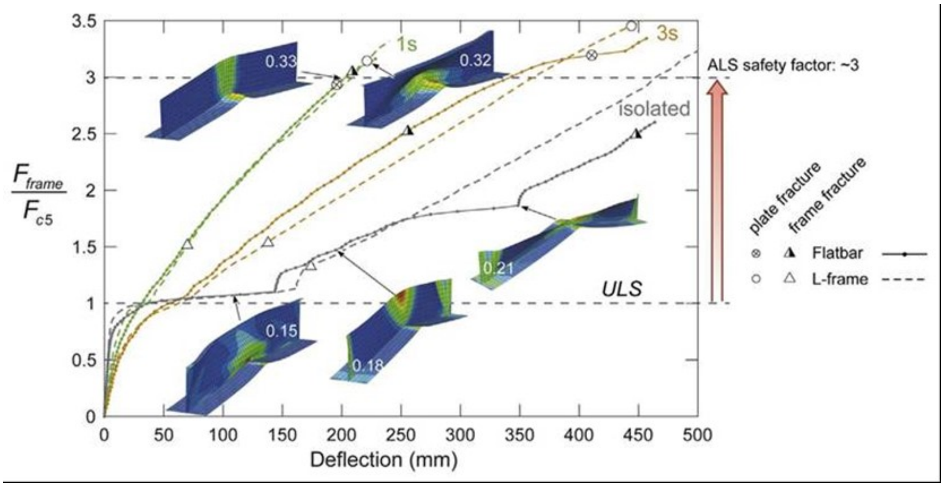

Figure. 1: Normalized frame response to show the safety margin for accidental limit state. Load height 0.1 m. (a) Flatbars and (b) L-frames. Inset figures show the contours of plasticstrain together with maximum plastic strain in the frame (Körgesaar et al., 2018)

The committee has done extremely good work by describing the latest development on the topics: temperature definitions, requirements of ductile to brittle transition and the effects of low temperature on fatigue and fracture properties. These are all new and important topics which are important to achieve the safe design of ships and structures on the demanding environments. Unfortunately, there is a number of missing references on the fatigue section as defined later in this report.

Finally, there is a short section of the repair limits and I consider this topic very important for the future to get a proper definition of the serviceability limit state as this topic has included limited research activities.

4. Ice load measurement and modelling

The full-scale measurement section (4.1) part does not refer that much to the actual measurements, but mainly describes that the problem is complex and simulations offer solutions even though there is a separate section for simulations. A reference to the previous Arctic committee of ISSC 2015 could also be done as there was an extensive description of the history of full-scale measurements.

To me, still the main challenge related to the analysis of the full scale measurements is how to define the real load patch on the ship shell structures. Recent thesis by Suominen (2018) illustrates this problem and as an example Figure 2 illustrates how the contact is moving along the ship shell. Earlier simulations (Su et al. 2011) have shown that the probability distribution of the local loading is different for short load lengths and for long loading cases. This has been confirmed by full-scale measurements (Suominen, et al., 2017). Furthermore, the recent full-scale measurements have shown, that the load level on a frame increases as a function of the load length (Suominen, et al., 2017). Again the comparison between the measured pressures and load cannot be compared without assuming some area for the load patch and this complicates the comparison between the used approach for the evaluation of the ice induced pressures in section 2.3 and the measured load in this section. I am happy to hear any possible comment from the committee on this complicated problem.

For other recent full-scale measurements, there are e.g. a number of papers related to the full scale measurements onboard SA Agulhass II in Antarctica (Suominen et al., 2015, Lensu et al., 2015, Nyseth et al., 2015, Suominen et al., 2015a, 2015 b, 2016, Suominen et al., 2017)

The process of ice failure is truly complex, but when the statistical methods are applied, the random nature can be analysed with statistical methods and connections between loads and prevailing ice conditions can be found, see e.g. Kujala (1994). Recent advanced statistical studies have been able to shed more light on the effect of the ice parameters on the loading characteristics, see (Kotilainen et al, 2017, 2018).

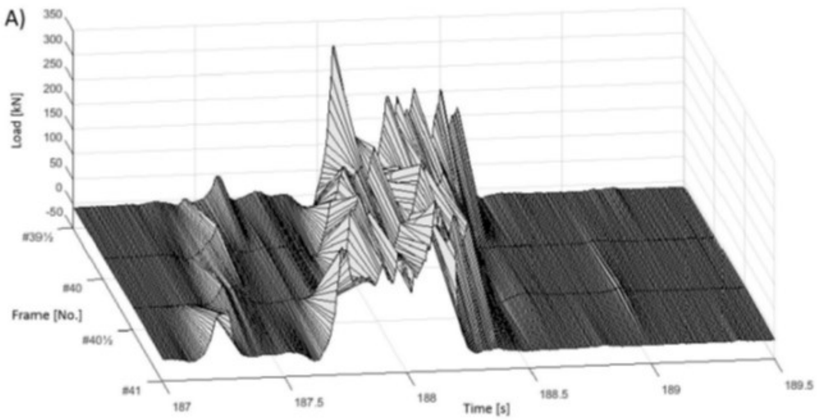

Figure. 2: . A short and long loading travelling over the instrumented area (Suominen, 2018)

Section 4.4. gives a very interesting idea that we need for validation purposes of the various analytical, semi empirical and numerical models a good full scale data base made publicly available and with detail definition of the measured load, prevailing ice conditions, ice breaking process etc. I strongly support this idea and hope that some of the bodies having this type of data can publish it in due course.

5. Summary and recommendations

The report ends with a short summary and a list of recommendations. The list of recommendations is comprehensive and covers a huge variety of topics. I assume committee has some idea about the importance of the various topics mentioned and may I propose that the committee makes a priority list i.e. what topics are most urgent to get new research.

References missing or given twice

As the state of art is important for the ISSC reports , it is also important that all the references are listed. Unfortunately, I did find out that at least the following references are missing:

DNV 2012, ILO 2014, Masterson et al. 1997 (I assume this should be Masterson et al. 2007), Kujala and Ehlers 2013, Jordaan et al. 1993, Trafi 2010, Kujala et al. 2009, Kujala et al. 2013, Alvaro et al. 2014, DNV 2013, Walters et al. 2014 and 2015, Miki and Anami 2001, Wahab and Sakano 2003, Goldak et al. 1977, Banister 1998, Palmer 1999, Määttänen 1986, Sanderson 2988, Cundall and Strack 1979, Cagnon and Wong 2012, Kellner et al. 2018, Kellner et al. 2017, Ehlers et al. 2012

In addition, the following are listed twice:

Braun 2017, Brian et al. 2016, Ralp and Jordaan 2013, Su et al. 2014,

I hope, the committee will correct these

1.2 Floor and Written Discussions

1.2.1 Q1

Ice build-up on ships is not covered in the report? How to deal with de-icing and the influence of human factor?

1.2.2 Q2

Related to ice induced fatigue; the mean stress has a significant influence on the accumulated fatigue damage. How about accounting for this effect in welded joints?

1.2.3 Q3

The report has an interesting section 4.3 on ice load modelling and validation. Accidental limit state committee Section 4.4 proposes a benchmark study set-up. It would be of great value to get the committee's view on a recommendation which type of ice models and methods (i.e. FEM, DEM, etc.) should be used in calculation of ice loads for various categories of ice. A summary table where in Vol. 3 where reference values to good examples could give us a good overview and guidance. Further, there are also ice models which are less useful. If the committee wishes, please specify which type of models or modelling that should be avoided in order to avoid research and development on the "wrong direction"?

1.2.4 Q4

I would like to thank the committee for a comprehensive report on this challenging topic. There are many papers on numerical simulations of ice action on structures. In the impact process, the ice will break. Perhaps how we model the failure of ice is the main uncertainty in the prediction. It may need more focused research. Ships operating in ice regions often suffer from repeated ice floe impact. In many ways, the repeated impacts responses differ from normal single impact. This is a scenario should be considered in the ice ship design. It is much appreciated if the committee could offer the expert view on these two observations.

1.2.5 Q5

In the flexural failure mode the load is not related to velocity. Shouldn't the effect of load vs. velocity be included?

1.2.6 Q6

The equations for the global impact loads in (polar) rules are a function of various parameters. Shouldn't the equations be a function of class factors to see where the fundamentals come from?

1.2.7 Q7

What about the consideration of velocity related to ice resistance and thus costs?

1.2.8 Q8

Only a few large ships have ice response monitoring systems on-board. What is the committee's opinion on ice response monitoring and would it be considered useful?

1.2.9 Q9

A number of offshore structures in ice-infested zones are made of concrete (for example Hibernia, Hebron, Pryrazlomnaya, Sakhalin, etc.) As the report mostly addresses metallic materials, I would like to know the committee's opinion on the main issues associated with the use of concrete in the artic environment, from a material point of view.

2. REPLY BY COMMITTEE

2.1 Reply to Official Discusser

The committee greatly appreciates the effort and the valuable comments and additions provided by the discusser. The detailed response is given as follows.

2.1.1 Introduction

While this report focuses on the current state of the art in rules and regulations to be considered when designing ships and offshore structures for ice, the previous report was primarily concerned with the determination of ice loads in a prescriptive, or rule-based, and probabilistic, or first-principle-based, fashion. Therefore, the motivation for mission-based design and the need to link the rules and regulations to the operational scenario was formulated.

Concerning our statement that design ice load predictions resulting from ice rubble are not yet covered, the committee agrees, that local loads in a non-consolidated rubble field, consisting of broken ice, are expected to be lower compared to consolidated or level-ice. However, these conditions may result in an increased resistance of the vessel dominated by friction, due to a possible increase in contact area. Therefore, the committee included corresponding references contributing to the identification of loads acting on ships and offshore structures in rubble fields.

2.1.2 Design methods for marine structures

The committee agrees with the statement concerning the FSICR rules and our statement concerning the return period and the design criteria. Nevertheless, the committee wants to point this out, because the consequence is that the tolerance to damage the vessel must be comparatively high for a ship owner and the ultimate strength limit state may be reached in the first and subsequent winters.

The committee agrees that the time in ice should be considered as a design basis and appreciates the inclusion the corresponding reference by Kujala and Ehlers (2014).

The committee appreciates the discusser's comment on the IMO POLARIS approach and the additional information provided.

The committee agrees that pressure alone is not meaningful nor correct without the corresponding area. Ice pressure for the interaction scenarios of interest in ship and offshore structure design scales with contact area. This topic was however discussed and presented at length in the previous committee report, therefore the committee only refers to it here also.

2.1.3 Structural capacity

The committee appreciates that the discusser widens the scope of this chapter here by providing additional insights into developments concerning plastic design methods and limit states and their possible integration into rules. The definition of clear and transparent limit states, similar to offshore standards, is of utmost importance for the further development of rules and regulations. The consideration of plastic limit states is one way forward and the references presented by the discusser clearly show the necessity and potential of their inclusion. On the other hand, the stakeholders need to define their targets and then we should address them with appropriate limits. In other words, we may use an elastic limit state with a very high design load and thereby account for various conditions including plastic limits – this was also addressed in the previous committee report. However, most important is the transparency and the influence of the design load, limit state and the consequences easily expressed in monetary terms. The latter must also include repair cost and thereby repair limits. As a result, a ship owner or operator may decide with a larger degree of freedom how to reach compliance to his target. The latter contains safety as well, which must of course be ensured at an agreed minimum level, but can then also be exceeded with potential monetary savings. The latter was also addressed by Kujala and Ehlers (2014).

The committee is not sure where the references got lost on the way to the final version of the document, but we are glad that the discusser spotted their absences and they are now included in the reference section of this document.

2.1.4 Ice load measurement and modelling

The committee agrees that section 4.1 does not refer much to actual measurements, as correctly pointed out by the discusser, this was included in the appendix of the previous committee report to a fine extent and therefore not included here. The references concerning the full-scale measurements pointed out by the discusser are a much appreciated addition to the report.

In line with our reply in the previous section the committee fully agrees with the discusser that the definition of the area under ice loading is very important. The previous committee report focused much on the definition of the design ice load as a result of large- and full-scale measurements. These measurements were often done with rather high spatial resolutions, i.e. strain gauge fields on the ship hull plating or tactile sensors covering large areas. As a result, it is possible in fact to determine instantaneous area under loading. However, it remains to be determined, which part of this area and to which lower pressure bound, the area shall be considered as a design patch, e.g. corresponding to a high pressure zone. Furthermore, it remains to be clarified what constitutes one event to identify both the spatial and temporal variation of the load and area consistently. The references and section provided by the discusser is a fine addition to these matters and well appreciated by the committee.

The committee very much appreciates your acknowledgment of our idea presented in section 4.4 and we too are looking forward to the first publications emerging here.

2.1.5 Summary and recommendations

The committee included a list of recommendations at the end of the report to pin-point the most important issues to be addressed in the future to improve the structural design for ships and offshore structures. The items are to some extent ranked resulting in the order shown. However, the majority of the items are closely related and the more important message is that they cannot be considered non-related items, since each of them will contribute to the desired improvements depending on the ability to account for the other items. In this respect, the committee would like to emphasize the complexity of these items and the need to have a fundamental understanding of each item prior to attempting to advance one individually.

2.2 Reply to Written and Floor Discussion

2.2.1 A1

Icing is mostly a problem of smaller vessels, i.e. fishing vessels and possibly large passenger ships. While smaller ships may suffer severe stability problems, larger ships, such as passenger vessels, may face a lowered reserve stability to maximum passenger due to the tall superstructures. On the other hand side, forecasting of critical weather conditions is reasonably good and especially passenger ships usually avoid such risk to passengers. Therefore, a threat to safety may not be given, but to operational limitations, i.e. ability to unload stacked but ice-covered containers. De-icing solutions, such as heating, are generally available, but current may not cover all operational scenarios or simply require to little heating energy to de-ice. Working in cold climate is typically limited in time unless protection is provided – for large offshore vessels this can include heated enclosures.

2.2.2 A2

In design, the mean stress effect for ice induced fatigue would be taken into account in the same way as for open water wave loading. Herein high welding related residual stresses at welded joints as well as stress concentration due to the joint geometry are assumed. Consequently, material data is gathered in test with high stress ratio or by correcting data to a stress ratio of R = 0.5 according to the IIW recommendations for example. However, mean stress effects at sub-zero temperature and due to ice induced loading are an ongoing research topic at TUHH. The results will be shared as soon as all test have been completed.

2.2.3 A3

Currently simulations may be considered to serve either global or local load estimations, but not necessarily both. The DEM approaches mentioned in the report can serve a fine purpose for process simulations and global behaviour potentially including loads. Simulations for local loads where ice is specifically modelled as a volumetric body currently fail to capture the entire process found in ice-structure interaction. Various models exist, which can only describe certain parts of this process, most commonly until the intact ice body disintegrates due to fractures and damage.

Overall, a material model for local loads must be able to capture the visco-elastic material behaviour of the ice with temperature dependency, creep and damage. The time dependency is crucial, because the rate of interaction will dictate the failure of mode. Highest pressures (design pressures) result from the occurrence and failure of HPZs of which failure is time dependent. This is in addition to suitable numerical procedures to account for damage, fragmentation, interaction between the broken ice fragments, etc. Naturally, ice-structure interactions take place in water at temperatures close to the melting point, which adds to the complexity. Current numerical simulation models are not suitable for design load predictions. Therefore, we do not want to include a comparison and guidance presenting existing methods beyond the current contents of the report at this point.

2.2.4 A4

Repeated service level impacts at a given location, in general, are likely for ice-strengthened ships (e.g. waterline bow-shoulder impacts). As IACS PC ships will suffer plastic damage when subject to the design load, it is reasonable to assume that plastic damage begins at a load level somewhat less than the design load; implying that there is, at least, some potential for effects of repeated impact induced hardening. Consequently, it is nice to hear that effect of repeated impact induced hardening was investigated experimentally. Generally, the topic is worthwhile to be considered in a future committee on Arctic Technology.

2.2.5 A5

Load and velocity are indeed correlated but it is still not clear how exactly. This is the result of other effects which also play a role. Until this correlation is clarified it is assumed that the phenomenon is velocity independent.

2.2.6 A6

The fundamentals behind these equations can be found in the PhD Thesis by Freeman Ralph provided in the reference list of the report. Furthermore, the background to IACS PC by Claude Daley should be consulted (Daley, 2000).

2.2.7 A7

Ice resistance is the time average of the instantaneous loads resulting from the interaction of the ship and the ice. At low velocities, i.e. below 3 knots, the frictional component of the resistance dominates and increases towards zero speed. Consequently, ships are at risk if their installed propulsion power is insufficient to overcome this initial resistance, e.g. due to compressive ice loads. Therefore, it is advisable to maintain a minimum velocity and thereby momentum in ice with the vessel. On the other hand side, a high velocity may lead to structural damages when ice features are approached too fast. The upper limit, or a safe ship velocity, also considering economics, must be identified based on the underlying design consideration proven in the ice trials and maintained by the ship operator. Further, for operation along the Norther Sea Route, the vessel is required to have an ice passport where the safe speed is defined for different ice and operation conditions.

2.2.8 A8

For ice monitoring the vessel has to be instrumented to identify the loads on the hull. This is also advised by the committee. However, ice typically causes an instant impact load. Due to the fast load increase, any mitigating response (e.g. slowing of the vessel) from an early warning is difficult if practical. It is indeed considered useful to perform such monitoring, as it gives insights and helps to learn and understand ice failure and loading.

2.2.9 A9

For gravity based structures the appeal of concrete is certainly given. Local ice loads can reach very high local pressures potentially eroding the concrete surface. Therefore, some means of protection might by necessary, since concrete repairs are nearly impossible.

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