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COMMITTEE V.1

ACCIDENTAL LIMIT STATES

COMMITTEE MANDATE

Concern for Accidental Limit States (ALS) of ship and offshore structures and their structural components during design. Types of accidents considered shall include fire, explosion, dropped object, collision and grounding. Attention shall be given to hazard identification and related risks, assessment of accidental loads and nonlinear structural consequences including residual strength. Uncertainties of ALS models for the use in design shall be highlighted. Consideration shall be given to practical application of design methods and to the development of ISSC guidance for implementation of ALS principles in engineering.

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1. DISCUSSION

1.1 Official Discussion by Gunnar Solland

1.1.1 Introduction

It is an honor to be invited to review the report by the ISSC Committee V1. I have for many years been engaged on the issue on how structures should be checked and designed in order to have the right strength to meet various accidental loads. So the topic is of great interest to me especially how code requirements should be formulated in order to facilitate an effective design process that results in safe designs.

The report points to the difference in design practice for ships and oil and gas platforms when it comes to how accidental loads are dealt with. Even if class rules do not explicitly require check of strength against accidental loads they do comprise prescriptive requirements that are formulated in order to give the necessary robustness against accidental loads. One example is the requirements of one or two damaged compartment stability. Some thoughts on the difference in code format for these two types of structures are given in the following.

1.1.2 General remarks

The committee has established a short list of definitions they see as important terms within their field of investigation. It will be beneficial for everybody engaged in structural engineering of these structures if precise definitions of terms are discussed in ISSC securing a more solid basis for the definitions. Terms that are well defined in major codes like ISO need not be repeated unless there is need for making the definition more precise.

However some of the definitions are strange to me. It is not clear that there is a need to introducing the new term "Dimensioning accidental load" as being something different from "Design accidental loads". Furthermore I disagree with the definition of failure strain being the limit when the "material no longer provide stiffness".

1.1.3 Comments to the various chapters

– *Fundamentals of ALS Design*

The Committee report presents a thorough review of codes and standards dealing with design of structures exposed to accidental loads. The report also presents the principle behind limit state design (LSD) and working stress design (WSD). In this discussion I will provide some additional thoughts on how design codes formulate requirements to structures in general and for accidental loads in particular.

Limit state design can be seen as a goal setting code formulation. It is in its purest form not giving requirements to how the structural analysis should be carried out, but only state that all limit states shall be checked including prescribed safety factors. The check of the limit state can be made in several ways: Linear analysis, non-linear analysis, testing etc.

Any identifiable failure mode represents a limit state that in the general case should be checked. For each failure mode there need to be defined a failure criteria and a characteristic load. The determination of the failure criteria is needed for all failure modes (limit states) and not only for non-linear analyses as mentioned in chapter 6.5.2 and 6.5.3. The failure criteria may be maximum loadbearing capacity, but other limitations can be needed. Examples are:

- Limiting the strain in the passive fire protection due to a blast pressure in order to maintain protection from a possible fire following the explosion.
- Limit of the traveling distance of a colliding ship in order not to interfere with wells etc.

The limit state formulation is valid for checking of the load carrying capacity of a structure, the maximum deformation in order to secure functionality of e.g. passive fire protections or stability of a floating platform.

My point is that limit state design requirements are versatile and can cover all aspects that need to be checked for a structure.

For practical design work it is necessary that the design requirements are formulated in a way that the structural integrity can be checked in an efficient way. Hence, often design codes give detailed rather than functional requirements. It can be useful to illustrate this as a pyramid with several levels and where each level represent a level of detail in order to meet the need of the designer, but at the same time meets the goal for the design as presented at the top of Figure 1.

The requirement pyramid illustrates that codes formulates requirements at different level of detail. In some cases the code formulates requirements at several levels. In the same code one can find functional requirements as well as more prescriptive requirements. In such cases the intent of the specific requirements should be to fulfil the requirements formulated for the level above in the hierarchy.

Detailed or prescriptive requirements are suitable for objects where the design is fairly similar from object to object. However, for one of a kind structures as often found in oil and gas developments it is necessary that the possible hazards are identified for the actual case and that the structure need to be properly checked for the resulting accidental loads identified.

Even if a particular code does not explicitly formulate the goal for the design it will in all cases be understood that a reasonable safety is wanted. The responsible engineer should always have this in mind and not using prescriptive requirement for cases he understand that the requirement was not intended for. He should then go one or more steps up in the pyramid and check out what is a reasonable modification of the prescriptive requirements.

One aspect of the different levels of detail, that codes may use, is the competence demand to the designer. Prescriptive requirements will make it possible for less experienced engineers to carry out the design. Less complex design rules will also reduce the danger of potential design errors, so prescriptive requirements may be beneficial also from a safety point of view.

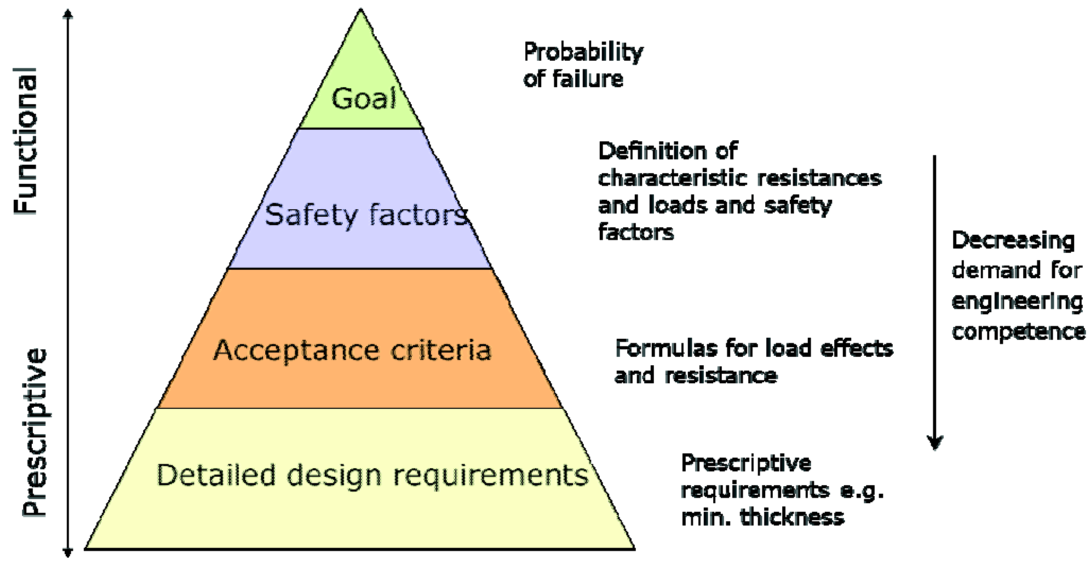


Figure 1: Hierarchy of code requirements.

As mentioned above any identifiable failure mode represents a limit state that in general should be checked. For each failure mode there needs to be defined a failure criteria and a characteristic load. The determination of the failure criteria is valid in all cases and not only for non-linear analyses as mentioned in chapter 6.5.2 and 6.5.3. The failure criteria may be maximum loadbearing capacity, but other limitations can be needed like limiting the strain in the passive fire protection due to a blast pressure in order to maintain protection from a possible fire following the explosion.

As there are lots of possible failure modes in a structure there are equally many limit states to be checked and it is therefore recommended to put the word state in plural when naming the various groups of limit states e.g. accidental limit states etc.

The leading star for defining the loads is that the characteristic load for an accidental limit state is the load that leads to a governing load-effect with the prescribed probability of not being exceeded. This means that for instance a plate between stiffeners may need to be designed for a higher load than the girder as the governing load effect in the girder (bending moment) is an integrated load from a larger area. Another example is the maximum pressure and duration as shown in Section 5.2.2 of the Committee report. The characteristic load for a dynamic sensitive structure will be defined different from a structural element with static response. It would be beneficial as this principle would be stated in the fundamentals of the ALS design.

Working stress design (WSD) does not represent a suitable method for documentation of structures exposed to accidental loads. For structures being designed according to the WSD method it will probably be required that prescriptive requirements are defined.

– *Hazard identification*

Hazard identification is given comprehensive coverage in the report which is good because all structural engineers that deal with design against accidental loads need to understand the background for the defined loads in the QRA. It is also useful to be reminded that the cause of accidents is rarely due to structural failure.

As the field of identification of hazards is a specialty in itself it may be required that a separate committee is looking into this area since structural engineers are not fully updated on all the topics relevant for the hazard identification.

A detail of interest is the statement that fixed units tended to have three to four times the number of fluid or gas spills and fires than mobile units. Is this number reflecting that there are several times more fixed units than mobile, and that the majority of mobile units are engaged in drilling rather than production?

– *Safety levels in ALS design*

It is stated that ISO requires the design to either be checked by the partial factor design format LRFD or by a non-linear push over analysis. The LRFD method of ISO is similar to WSD, but with separate load and material safety factors. LRFD is then not a true Limit state design code as in such codes the requirements are generally formulated independent on how you decide to document the integrity. You can use linear or non-linear methods or testing to document your structure.

The report does not mention that ISO 19901-3 requires the design to follow the ALARP principle for design of offshore structures, but does also state same target level for the design accident load (10-4 probability level for the characteristic loads) as used e.g. by Norsok. It is interesting to note that in this respect ISO will be more stringent than Norsok if the ALARP principle is used in addition to that the structure should be checked for all loads with probability larger than 10-4.

The ALARP principle is the most logic and sensible design principle when it comes to loads with low probability of occurrence, but it is not very useful for engineering and construction contract on fixed price as the contractor and the buyer will have different views on what is reasonable possible.

The report presents a summary of the development of redundancy requirement to hull girders in case of grounding. This is a nice example on how prescriptive requirements can be developed in order to fulfil a functional requirement formulated as a maximum acceptable probability of failure.

– *Assessment of accidental loads*

The report focus only on recent achievements that are published as earlier ISSC report have dealt with various aspects of ALS design earlier. This is judged to be a reasonable decision.

The report distinguishes between deterministic and probabilistic determination of loads. I am not in favour of using the term deterministic and probabilistic to distinguish between simplified and more complex methods. All design loads are based on considerations of probability even if it is not explicitly stated. And all design methods will require loads to be simplified and a fully probabilistic model is never achievable.

– *Determination of action effects*

Simplified models are stated to be relevant for risk analyses. In my view simplified models also can be used for documenting structural capacity for various types of accidental loads dependent upon the problem at hand.

There is not given any reference for Table 6.1 and it not clear what is meant by “Elastic Effect” for “Ship collisions”.

The report discusses well the various difficulties by running advanced analysis. It would be nice if the report could spell out some general principles to be followed when conducting such analyses. For instance:

Accuracy check is the responsibility of the analyst

The failure modes that are intended to be represented by the analysis need to be validated against an empirical background.

The purpose of the analysis should be clearly defined as not all failure modes need to be or is possible to be represented in the analysis. The remaining failure modes need to be checked by traditional methods.

In Section 6.2 it is referred to Annex 3 which seems not to be included in the version of the document I received.

There are listed several tensile failure criteria but the tensile failure criteria given in DNV-RP-C208 are not mentioned even if this recommended practice is referred in several other sections.

– *Benchmark study*

The ISSC committee V.1 has made a huge effort in calculating a benchmark example for a part of a topside structure exposed to fire loads. The example taken is judged to be quite close to what can be found in reality. 8 different analyses from 7 analysts are presented in detail. The benchmark studies comprise both the structural response to a standard fire as well as fire load formulated as heat flux. The study provides an impressive number of result charts. The description of the analysis set-up is detailed and will be helpful to engineers performing such analyses.

For some of the result parameters shown, the results are quite uniform with a scatter as expected when different engineers perform independent analysis with different software. This yields typically deflections under ordinary loading etc. However, when the results from the fire loads are compared, the differences are significant and the report is silent about the reason for the large differences. For some of the results the differences are so large that one would expect that there could be given an explanation as the analyses results seems not to be comparable. In such cases it would be better to leave out results from analyses that differ considerably from the others. It may be that the difference in the assumptions made or in the methods programmed in the software are so large so comparable results cannot be expected. As it now stands the conclusion from the benchmark is that the industry is not yet ready to apply non-linear fire analysis as part of regular design work.

The geometrical details for the benchmark study are stated to be given in Annex 2, but this Annex was not part of the electronic version I received.

– *Material models for non-linear final element analysis*

As a bonus the report presents proposals for material models for a large number of different materials. Useful references are given for the different materials. However, the selected material model for an analysis will depend upon the problem at hand and the proposed material properties that are presented should only be regarded as an example. Furthermore it is a question if the committee is having sufficient background to recommend values for material models of the large variety of material that is presented. One should think that “exotic” materials such as ice, soil and explosives should require specialist competence which I would expect not to find among all the committee members. One should be careful with putting the ISSC authority stamp on recommendations if it has not been possible to undergo a thorough discussion.

1.1.4 Summary

A summary of my review the important points are as follows:

- The report comprises a broad presentation of the methods and the principles of ALS design and in general this is in correspondence with my own views.
- The strength of the report is the detailed discussion of advanced methods in particular non-linear finite element methods. It should be pointed out that it is important that the use of such analyses in ordinary design work is limited to cases where the design decisions to be made require such analyses made.
- Simplified methods are not given close attention in the report even if it is specifically referred to practical methods in the mandate. Guidance is needed also for the non-specialist in non-linear FEM. For many ALS problems prescriptive methods are preferred. It would be good if ISSC could be a forum for initiating and discussing prescriptive requirements for cases where such are relevant. E.g. minimum deck thickness to withstand dropped objects.
- Requirements and methods for check of the residual strength of damaged structure are given little attention. In case of using non-linear FEM it is required that the capacity that can be documented are limited to the cyclic capacity of details subjected to plastic deformations.

The report includes important guidance on the material modelling of various materials for use in state of the art computer analyses. As a suitable material model always need to be considered in light of the purpose of the analysis, it is questioned if detailed material data should be provided in this report.

1.2 Official Discussion by the Committee

1.2.1 Introduction

The Committee members wish to thank Gunnar Solland for his efforts reviewing the Report, his comments and remarks.

Safety Design of offshore structures for potential accidents is a very challenging subject. ISSC have used two congress’ periods in the last 6 years to form a specialist Committee to work on this subject. In practical offshore development project, design for accidents is a source of a significant amount of discussion and disagreement. The objective of the Technical Report of Committee V.1 is to outline how ALS can consistently be implemented and applied in design projects. In this sense all necessary definitions, procedures and methods are revisited and explained.

Gunnar Solland's review of the ISSC 2015 Report "Accidental Limit States" identifies that here is still a significant number of topics and issues regarding ALS design that remain unresolved and open for discussion.

The Committee's main focus was on the application of accidental limit states for the safe design of offshore structures, with emphasis on the application of relevant international design standards such as ISO and NORSOK.

Nevertheless, in his first comment, Gunnar Solland writes that although class rules for ships do not explicitly require the check of strength against accidental loads, they comprise prescriptive requirements that are formulated in order to give the necessary robustness against accidental loads. In the Committee's opinion, however, this is misleading. Firstly, the necessary robustness is not defined in these rules and secondly, accidental loads are not identified. In this sense, the class rules for ships do not cover the safe design against accidental loads with respect to accidental limit state design.

As for the definition list included in the Report, the Committee members find it necessary to introduce basic definitions at the beginning of the Report to provide a reference for all potential readers.

The Discusser finds certain terms used in the Report new and strange. The Committee members claim the right to apply new definitions freely as a sign of evolving language in response to engineering advancements. The term "dimensioning accidental load", is a key definition used in NORSOK standards (S-001, Z-013), Dictionary of Science: http://www.crossdictionary.com/english/english/dimensioning_ accidental_load/. The term is based on using standardised assessment procedures taking into account uncertainties inherent in the use of parameters applied for load assessment. In this context "design accidental loads" are defined arbitrarily, being equal or greater than the "dimensioning accidental loads".

Based on the Discusser's remark, the definition of failure strain has been improved and reformulated to: "Strain at which failure is initiated when any of the principal material strains (or stresses) exceeds their respective specified failure levels".

1.2.2 Comments to the various chapters

– *Fundamentals of ALS Design*

Contrary to Gunnar Solland's remark, The Report does not present the principle behind limit state design (LSD) and working stress design (WSD). The Report is based on the limit state design as only where the accidental limit state is introduced. The working stress design methodology is not covered in the Report, which is explained in the Report introduction.

Several of the limit state definitions presented by the Discusser require some clarification.

For ALS design, it is necessary to understand the difference between design constraints and other factors. In particular, the travelling distance limit used to define a ship collision scenario is an operational issue rather than a design constraint variable and hence cannot apply to the ALS design process. Similarly, the stability of a floating platform is an environmental load issue rather than a design constraint variable and hence cannot apply to the ALS process.

While the Discusser's suggestions aim to improve safety in design, prescriptive requirements for ALS design are hardly possible since there are no prescriptive solutions to counter "unknown" extreme loads and hence the methodology is intended to facilitate functional rather than detailed requirements.

The Committee members must disagree with Gunnar Solland on his expectation that the responsible engineer will apply reasonable safety in design. There are no definitions of reasonable safety in design standards and as long as safety is not defined, the responsible engineer has no reference as to the requirements. In an attempt to address safety, accidental actions are studied for events with an annual exceedance probability of 10^{-4}, per installation. This annual exceedance serves as a metric to filter the relevant actions and action effects.

In principle, The Committee members agree with the Discusser's opinion on the failure criteria. However, it is important to mention that failure criteria in ALS design is a progressive collapse limit state and not the integrity of PFP that will be a functional requirement for the material.

The Discusser makes a comment that "the leading star for defining the loads is that the characteristic load for an accidental limit state is the load that leads to a governing load-effect with the prescribed probability of not being exceeded". The Committee members disagree and argue that ALS design is not addressing probability of failure but is based on loads with identified probability based on QRA. Further consideration regarding structure reliability in ALS conditions is given in the Report.

The statement that the characteristic load for a dynamic sensitive structure will be defined differently from a structural element with static response is considered wrong in the Committee's opinion. Design loads used within accidental limit state design are not defined differently depending on load type static/dynamic and load effect/responses, but are based on an evaluation of uncertainties of load parameters involved with predefined probability of exceedance.

– *Hazard Identification*

The Committee members disagree that the cause of accidents is rarely due to structural failure. There are examples of structural failures in pressure vessels, cabinets, foundations, enclosures, gun barrels, rope, hydraulic seals, gaskets, tires, brakes, and other items involving materials which yield beyond their ability to maintain their intended function. Other, more extreme examples, include the Alexander Kjelland and Deep Water Horizon accidents. This is in addition to other root causes of accidents such as explosions, dropped objects, ship-platform collisions and fires, which lead to structural failures. In response to the Discusser's suggestion on structural engineers' lack of relevant knowledge of hazard identification issues, the Committee members would like to express the opinion that structural engineers involved in ALS design need to be fully updated on hazard identification and risk assessment issues, as these are the main sources for definition of accidental loads to be used in design process.

– *Safety Levels in ALS Design*

The Discusser points out that the ALARP principle is the most logical and sensible design principle when it comes to loads with low probability of occurrence. As for the ALARP principle, the Committee's view is that this is not a design principle but rather a cost benefit analysis of how much additional cost is required to reduce risk. There is no evidence in engineering projects that ALARP principle has been used for design modifications within ALS design.

The reviewer makes some comments on the terms and requirements used in ISO documents, in particular in ISO 19902 (Fixed steel offshore structures).

In consideration of the ISO 19902 requirement for offshore structures and their components to satisfy ULS, SLS, FLS and ALS, the Committee considers that while each limit state can be verified using a number of design situations with appropriate action effects, the Report was intended to focus on ALS as the relevant limit state for discussion.

Accordingly, in ISO 19902 a suitable safety level is obtained using specific design equation that compares load effects and resistances based on either specified RSR values or partial coefficients.

Accidental design situations are treated by considering rare hazards with a low, but unneglectable probability of occurrence. Typical hazards are associated with abnormal and accidental situations. In lieu of better information, a return period of 10,000 years may be used for an exposure level L1 platform. It should be understood that this stipulates an order of magnitude rather than a strict figure since precise values are rarely available.

ISO 19902 gives procedures and requirements for the assessment of existing fixed steel offshore structures to demonstrate their fitness-for-purpose. The aims and procedures are also applicable for topside structures. Structures that comply with the design requirements for new structures clearly demonstrate fitness-for-purpose. For structures that do not comply with these requirements the owner shall seek to reduce the risk associated with a failure, as much as is reasonably practicable (Clause 24.1).

– *Assessment of accidental loads*

In the Report, it is not intended to distinguish between the deterministic and probabilistic analysis methods as simplified or complex.

The deterministic loads in this Report include nominal and prescriptive loads suggested by guidelines, rules or standards. As reviewer mentioned, these are also determined implicitly with statistic consideration of historical data, previous experiences, experimental data, and so on. However, these prescriptive loads are often conservative in order to include various types of facilities or situation. Otherwise, they are used for limited type of facilities or situation, that is, only similar structures because they are based on limited design data set and limited operating experiences considering accidental cases. Other deterministic loads from worst-case scenario, theoretical or empirical formula are also conservative usually with usage of limited range of design parameters.

The probabilistic loads in this Report reflect uncertainties of parameters affecting loads and are derived by numerical simulation and probabilistic processing techniques. Considering limited available accidental data, the application of the probabilistic approach enables us to better understand the design parameters and their physical influence on structural behaviour. In the context of the Report, probabilistic method is a term used to reference design actions that require a probabilistic analysis to determine the load. A probabilistic analysis does not represent more complex methods, it refers to a complex series of mathematical and numerical analyses to determine the most likely design actions during a particular period of time. Deterministic approach does not require a probabilistic analysis/complex series of mathematical and numerical analyses to determine the design actions.

A stochastic problem is one that may be considered completely random and as such must be solved using probabilistic methods. Examples of a stochastic design load condition are wave and current actions. NORSOK – N004 considers a stochastic wave description as, "…the short-term irregular sea states are described by means of wave energy spectra which are normally characterised by significant wave height (Hs) and average zero-up-crossing period (T_z) or spectral peak period (T_p)". The wave spectra defining characteristics (H_s and T_z or T_p) are defined probabilistically with a likelihood of occurrence determined using probabilistic methods from met ocean data measured and extrapolated or interpolated to meet design requirements.

Once the wave and current actions are determined probabilistically, they may be applied to the structure. If one considers the example of a hydrodynamic analysis of a containership, the pressures and accelerations of the ship are computed considering the modal response of the vessel. The modes are indicative of the vessel with very little simplification in the vessel numerical representation.

– *Determination of action effects*

The Committee members agree with the Discusser that simplified models can be used more broadly for risk analysis. They can surely also suit to describe accidental loads and responses for certain problems. It was meant to say that risk analyses often require very large number of analyses to be conducted and thus, for such analyses simple models are more suitable compared to detailed and time-consuming analyses.

As for the lack of reference for Table 6.1, it is a table that should be considered an expert opinion of the Committee. It presents rather general and wide limits and thus, it is hard to refer to any study that could confirm these limits.

The unclear term "Elastic Effect" has been changed to "Elastic-Plastic with material failure".

With reference to the Discusser's remark that accuracy check is the responsibility of the analyst, the Committee would like to refer to the new section 6.8 Quality Assurance. Additionally, at the end of Section 6.2 the responsibility of the analyst is discussed and the following explanation added: "Numerical modelling approach to capture a certain failure mechanism (e.g. material failure under tensile loads, structural collapse, tripping of stiffeners etc.) should be first validated using experimental studies or publicly available results to confirm that the selected approach (e.g. element type, material model, mesh resolution) is suitable to capture the mechanism."

The Committee members are of an opinion that the purpose of the analysis has been sufficiently explained.

The prospect of escalation is mentioned in Section 5.3.2 *Risk-based and probabilistic approach* as well as in the first paragraph of Section 6.1 *Introduction*.

As for DNV-RP-C208, it is discussed from the viewpoint of material curve and the ultimate strain values proposed by these rules are compared to the experimental values. The following additional clarification "Also DNV-RP-C208 suggests critical strain limits for tensile failure due to gross yielding of plates" is added to the end of Section 6.5.3.

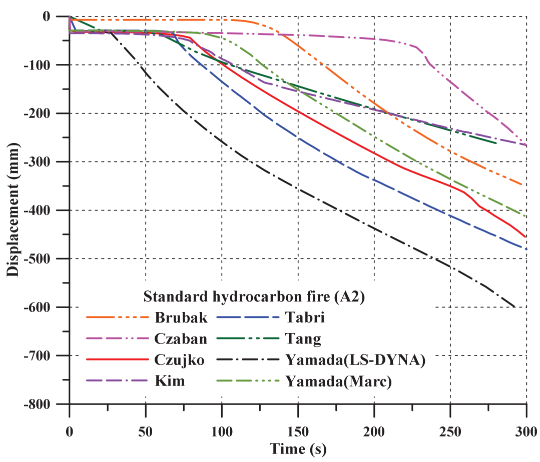
– *Benchmark study*

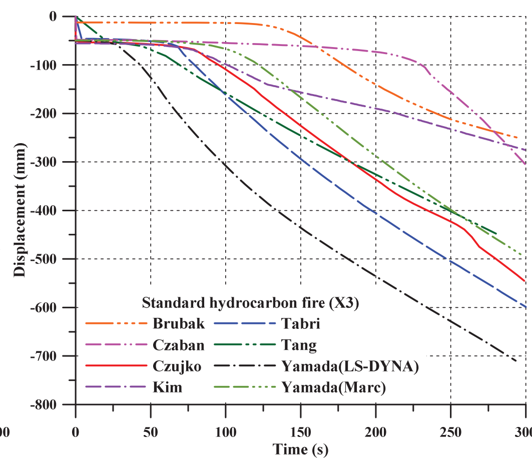
During the engineering phase of topside development projects, a significant amount of time and money is normally spent on risk assessment and a number of studies document fire resistance of topsides and the necessary amount of PFP. The knowledge in this area is under continuous development.

The objective of the benchmark study is to predict the strength of topside structures subjected to fires and compare different techniques assessing the strength of these structures. The capabilities of modern software to simulate such complex loads are evaluated and Passive Fire Protection (PFP) design using numerical predictions is assessed. The results of the Benchmark study presented in this report are achieved after a large number of modelling iterations and significant amount of discussions.

The Benchmark is based on a typical topside structure deck of an existing platform.

A sample of results of deck deflections for standard hydrocarbon fires is given below:





The results are significantly different, however representative to the modelling applied. The differences represent limitations of modelling and solver capabilities.

The Committee members disagree with the Discusser's comments regarding the necessity to omit the results with large divergences as these represent the upper limit of the software capabilities. The Committee members also disagree with the Discusser's conclusion that "industry is not yet ready to apply non-linear fire analysis as part of regular design work" but suggest that current Benchmark indicates the need for excessive Quality Assurance to be carried out during the ALS design process and the need for verification studies to be performed during the engineering phase of topside design.

The Committee members conclude that a significant amount of work needs to be done to control the consequences of accidental fire loads in the design process and for the improvement of design tools.

– *Material Models for Non-linear Final Element Analysis*

The "Material models" Section 9 contains a coherent and useful database of working examples of engineering materials. The numerical values presented in the section typically correspond to certain lab experiments, practices or to expert opinions. Most of the material properties include references to scientific papers or lab reports, thus the values have passed the scrutiny of scientific community in addition to the Committee members. Thus, especially for more common materials, the numerical values represent realistic material parameters used in everyday practice.

Obviously, users might apply the values of their own choice to correspond to certain lab experiments or desired material properties. In such situations the database still serves as a collection of working examples of different material models and their input parameters.

It is of course absolutely true that any selected material model required for any analysis will depend upon the problem at hand. Clearly however, material properties are, by definition, properties. As such, they cannot be considered variable. When selected for any particular application they will remain the same as they would for any other application. Ice is ice and explosives are explosives. A specific type of ice or explosive will retain its same properties regardless of what problem is being studied. It is important to maintain a correct and consistent material property database, particularly when considering dynamic load response of structures. That there exist numerous constitutive equation models does not mean that a particular material has inconsistent response characteristics. Instead, it simply means that numerous models are available for predicting material behaviour.

As more and improved modern tools become available to enable the study of material properties, it is to be expected that more precise and appropriate material models will evolve.

For example, materials research within the naval community (Czaban, Z.J., Norwood, M, 2014, On the Shock Response of Naval Steel, Canadian Department of National Defence/MARTEC Limited, 85th Shock and Vibration Symposium) has helped develop modern methods to characterize the response of steel and composite materials in response to a variety of threat weapon scenarios including shock, blast, fragmentation and fire loads using automated optical metrology with digital image correlation tools such as ARAMIS for optical 3D deformation analysis. The methodology allows a rigorous, yet economic and rapid characterization of material properties.

Such studies improve the body of knowledge available to the community for use in design and analysis. The data provided by the Report represent examples of such properties that have evolved from the authors' research and are being released into the public domain to facilitate improvements in the state of the art.

The Committee includes members with extensive experience in determination and application of materials properties, and would greatly appreciate if the official discusser could identify specific errors in the material properties data set so they could be corrected.

1.2.3 Summary

The Committee is pleased to hear that the content of the Report in general corresponds with Gunnar Solland's views.

The Committee members agree that indeed, ALS design is necessary to address those cases that require consideration of accidental limit states in design. It is, however, not appropriate for non-specialist practitioners to apply ALS design without appropriate qualification and knowledge. The only guidance in such cases would be for the non-specialist to seek qualified assistance, or to acquire the necessary knowledge through appropriate study and certification.

Prescriptive requirements, as mentioned previously, are not provided for ALS design, as there are no prescriptive solutions for extreme actions. The Committee members share the opinion that to recommend prescriptive solutions for highly non-linear, time- and space-dependent actions would be erroneous.

The Committee members consider determination of residual strength limits for damaged structures not to be the intent for ALS design. Rather, the methodology is intended to establish an inherent robustness for sound structure for it to survive a range of anticipated accidental load scenarios.

The Committee members agree that material properties, such as those included in the Report, remain important and necessary for the public domain to support more transparent and consistent assessment by the engineering community. The Committee members find the proposed data to have no technical error and stands by the decision for it to be published.

Once again, the Committee members would like to thank Gunnar Solland for his efforts reviewing the Report, his comments and remarks.

1.3 Floor Discussion by Dr Ekaterina Kim

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(VOLUME 2), Committee V.1 Accidental Limit States, pp. 519–590

I would like to thank authors for this report. The report is not only disseminates the results from the recent studies but also provides an interesting and important benchmark study on the resistance of structures subjected to fire. My only two concerns are about the information provided in Section 9 (Annex 1) on “the hazard simulations utilizing the recommended material models and input parameters”.

1. *One concern is about using the term ‘ice’ in the Table 13*. In nature, there are different types of ice, i.e., first-year, second-year, multi-year, shelf or glacier. There are also different ice features such as icebergs, ice islands, rafted ice, rubble fields, leads, pressure and shear ridges, level ice, pack (broken) ice, etc. Furthermore, there are different ice failure mechanisms. For instance, a ship advancing in level ice (or impacting an ice floe) will introduce several failure processes to the ice, i.e. localized crushing, bending failure, in-plane splitting failure. When level ice, in turn, interacts with a floating (or fixed) offshore structure, the ice can accumulate in front of the structure resulting in higher ice loads. First-year sea ice in the Baltic Sea is different form the multiyear sea ice in the Barents Sea. Mechanical properties of icebergs (freshwater ice) are different from those of sea ice. Taking aforementioned into consideration, the model parameters (and the introduced assumptions of the constitutive ice behavior) will depend on the ice type and the parameters of the hazard scenario, including ice temperature and the interaction speed.

To have better clarity in Sec. 9.3.4, it would be beneficial to highlight early in the text that the ‘recommended ice model’, including the model parameters is for the Baltic Sea ice (level ice), for situations in which the flexural strength of an ice sheet is of interest.

2. *Other concern is whether the ice model, which is only valid when the flexural strength of an ice sheet is of interest, can adequately represent accidental–level ice loads resulting from ice crushing failure.* Reasons for this concern are the following: (1) the ice crushing strength is normally higher than the ice strength in bending. A realistic ice–structure interaction always starts with localized ice edge crushing at the ice–structure interface. (2) Lack of published literature that uses the ‘recommended ice model’ for the analysis of the accidental limit state due to ice actions.

In addition, a minor comment: For end-users of this report, it would be good to provide a couple of references where the ice model assumptions and ice model parameters are established and/or used.

1.4 Response to Dr Ekaterina Kim by the Committee

Response to Question 1:

It is obvious that ice properties vary a lot depending on several issues such as ice type, temperature variations etc. Report clearly emphasizes the conditions when the presented ice model can be used and also points out that the proposed model can only be considered as a first attempt:

> *“Hence, unless material model data is not available explicitly for tension and compression including an appropriate failure criterion for brittle ice failure based on micro-crack growth, a simple elastic model may be employed. The latter is however only valid to some extent, if, e.g. the flexural strength of an ice sheet is of interest.*
>
> *Therefore, as a first attempt, ice may be modelled as a volumetric body following non-iterative plasticity with a simple plastic strain failure model (mat_13). However, therein the*

yield- and failure stress is note rate or pressure dependent and the temperature is assumed constant. An example input card following the LS-DYNA nomenclature for Baltic Sea ice is given in Table 13."

Therefore, we find that the questions raised (the Baltic Sea ice (level ice), only flexural strength considered) are covered by the report.

Response to Question 2:

Report states that the suggested material parameters can only account for flexural failure. Indeed, the ice crushing required much more elaborate approach that cannot only be covered by material database, but requires deep discussion on contact definition, element erosion etc. However, such simple material model is suitable for first estimates on ice loads. It is obvious, that the suitability of the material properties and modelling approach for the problem in hand should remain the responsibility of the user.

It is agreed that the reference should be presented together with the ice parameters. The ice parameters are evaluated via laboratory experiments and an optimization routine presented in Sören *Ehlers, Pentti Kujala (2013) Optimization-based material parameter identification for the numerical simulation of sea ice in four-point bending. Proc IMechE Part M: J Engineering for the Maritime Environment, Vol. 228(1), 70–80.*