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COMMITTEE IV.1

DESIGN PRINCIPLES AND CRITERIA

COMMITTEE MANDATE

Concern for the quantification of general sustainability criteria in economic, societal and environmental terms for marine structures and for the development of appropriate principles for rational life-cycle design using these criteria. Special attention should be given to the issue of Goal-Based standards as concerns their objectives and requirements and plans for implementation. Possible differences with the safety requirements in existing standards developed for the offshore, marine and other relevant industries and of the current regulatory framework for ship structures shall be considered. Role of reliability-based design codes and requirements as well as their calibration to established safety levels.

CONTRIBUTORS

Official Discusser   Ole Christian Astrup, *Norway*

Floor Discussers   Jurek Czujko, *Norway*
Dan Frangopol, *U.S.A*
Frank Roland, *Germany*
Ekaterina Kim, *Norway*
Suquin (Sue) Wang, *U.S.A*
Abbas Bayatfar, *Belgium*
Rolf Skjong, *Norway*
Enrico Rizzuto, *Italy*
Mirek Kaminski, *The Netherlands*
Philippe Rigo, *Belgium*
Farshid Fardi, *U.K.*
Sheng Dong, *China*
Pablo Morato, *Belgium*

Reply by Committee
Chairman: Matthew Collette, *USA*
Zhihu Zhan, *China*
Ling Zhu, *China*
Vedran Zanic, *Croatia*
Tetsuo Okada, *Japan*
Toshiro Arima, *Japan*
Rolf Skjong, *Norway*
Han Koo Jeong, *South Korea*
Gennadiy Egorov, *Ukraine*

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1. DISCUSSION

1.1 Official Discussion by Ole Christian Astrup

1.1.1 Introduction

The Committee IV.1 mandate has remained the same as the previous ISSC 2015 mandate except for only one extra aspect; the role of reliability-based design codes and their calibration to established safety levels. The central focus of the mandate is a broader view of design criteria and principles phrased as general sustainability criteria in economic, societal and environmental terms. This was introduced in the mandate of the 2009 Committee IV.1 and has been present since. Previous reports have all followed the same general definition of sustainability defined by the UN (WECD, 1987).

Due to the broad nature of the mandate, it is difficult to identify a clear objective of the report. The target audience of the report is also unclear. Is it written for the academia, the industry or regulatory stakeholders? This discussion represents an industry perspective.

1.1.2 General feedback to the report

The Committee is credited for comprehensive reviews of the selected topics with useful references. However, it is hard to recognize the overall objective of the report based on its content and organization. The list of topics included in the report appear fragmented and the report contains few references and almost no discussions of acceptance criteria. Although design principles are discussed and referenced to some extent for different accident scenarios (like collision, grounding, fire & explosion and arctic), this is of limited practical use to the reader when design principles are not placed in a context of relevant acceptance criteria.

A very limited part of the report is dedicated to what seems to be the focus of the Committee mandate; appropriate principles and criteria for rational life-cycle design. As offshore structures and ships are becoming more and more complex, there is a growing concern that traditional risk assessment methods (IMO, 2015) are inadequate for comprehensively identifying hazards and adequately analysing risks in complex sociotechnical systems (Dallat, Salmon and Goode, 2016). Significant progress has been made in the past few decades surrounding our collective understanding of accident causation and risk. Evidence in the literature reveals that this evolution in thinking in relation to accident causation has not translated across to traditional risk assessment methods. A system thinking philosophy to risk assessment methods has demonstrated the ability to identify system-level factors (organisational, managerial, social and cultural), as well as their respective interactions beyond traditional risk assessment methods (Leveson, 2011). A criticism of methods based on Systems Theory is their lack of treating uncertainty (Bjerga, Aven and Zio, 2016). The information about uncertainty should be conveyed to the decision maker and is essential in rating the different RCOs (IMO, 2015). It would be very useful to discuss how methods based on system theory can be combined with existing risk methods. Some guidance is given by (Bjerga, Aven and Zio, 2016), but more research is needed. This can possibly be a topic for the next Committee.

The report is credited for discussing the role of human performance in engineering. However, the report would have benefited from linking this discussion to recent improvements in the understanding of accident causality and the role of human error. A discussion on standardization efforts for a transfer of design intent in engineering models and how this can improve information transfer and engineering performance is also missing.

The Committee shall have credit for opening a discussion on the role of on-board monitoring and collection of operational data as a potential feedback loop to design principles and criteria. It would have been interesting to discuss this in the context of the massive digitalisation taking place in the shipping industry. Data will be collected at an exponentially increasing rate and increased satellite bandwidth will ensure that the cost of transferring data to shore decreases at the same rate, see (DNV GL, 2017). How may this influence both design principles and criteria?

Many references date back more than 30 years for some of the content. While this may be justified from a completeness point of view, it is not the purpose of the report. The report should refer primarily to the publications from the period 2015-2018 as well as previous ISSC reports where necessary. However, some old publications may be justified, if they are fundamental references and new publications have not brought anything new.

The report is supposed to cover both ship and offshore structures. The report would have to recognize that ship regulations are largely international, whilst the offshore regime is regulated by the coastal state and therefore varying between states (end even more so for inland and coastal vessels). The reader would have benefited from a clearer separation between ship and offshore structures in parts of the report, and a discussion of similarities and differences are lacking. The report gives more attention to ship structures than to other marine structures. This bias is a continued trend from previous reports and should lead to reflections on how future committees are composed.

1.1.3 Specific comments on Section 2.1

A key point in establishing design principles and criteria using sustainability as a measure is a proper evaluation of the external costs (also called social or implied costs). The report documents how the inclusion of external costs may influence the choice of Risk Control Options (RCOs). The Committee has included the results of a cost-effectiveness analysis of a recent damage stability study of cruise ships under two approaches and the assumption that the criterion is either €7 or €8 million. As per FSA Guidelines (IMO, 2015), the criterion has not been updated and it is still $3 million, hence the recommendations (as per this value) between the two approaches are not identical and the number of recommended RCOs is reduced.

- A discussion is worthwhile why an increased criterion value should be used and what can be suggested so that the outcome of an FSA has increased validity as well as credibility?
- Would recommendations be different if other external costs were included (i.e. ballast water, bunker spill)?
- The Committee proposes that including other external costs in the IMO FSA Guidelines would have clear benefits, which will enhance further the FSA use as a regulatory tool. What actions does the Committee suggest so that this element is brought forward?

1.1.4 Specific comments on Section 2.3

The in-service reassessment for life extension must relate to different regulatory regimes depending on the asset type and geographic location. A list of guidelines/standards from different regimes/industries could be useful to provide an overview of the development.

1.1.5 Specific comments on Section 2.4

The Committee provides a review of how human performance can affect the conducted engineering analyses and the successful compliance assessment with the required criteria. In the introductory paragraph (2.4.1) two important and challenging questions are raised “How should the human engineer’s limitation be considered in criteria development” and “Are there any recommended standards or procedures for accounting for such error”. The Committee shall be credited for including this important subject in the report. The report focusses on two areas for performance on human engineering:

1. Errors due to a mismatch between design codes and numerical models
2. Errors in the communication of model assumptions between different individuals, teams and organisations.

The report argues that increased complexity in the design process puts a larger strain on the engineering design tasks, and hence, can lead to human error. The report points at increased complexity can lead to a “mismatch between engineer’s mental models, often leading to human engineering errors”. Also mentioned is the concept of “mode confusion” commonly used in aviation to describe mismatch of mental models. In this context, it is stated that “it is no evidence yet of researchers using these error frameworks to explore human error in engineering design”.

This is viewed as incorrect, as it is one of the objectives in the field of System Safety and System Theory (Leveson, 2011). Over the last decade, a framework has been developed in the form of Systems-Theoretic Process Analysis (STPA) and Systems-Theoretic Accident Model and Process (STAMP) to deal with the emerging complexities in safety-critical systems. STPA is a relatively new hazard analysis technique based on systems theory while traditional hazard analysis techniques have reliability theory at their foundation. STPA uses a new model of accident causation. In systems thinking accidents are multi-causal going beyond the traditional simple event-based thinking. STPA was designed to address increasingly common component interaction accidents, which can result from design flaws or unsafe interactions among non-failing (operational) components (Leveson, 2013).

An important concept of this framework is the feedback loop which is missing in the traditional event-based thinking, see Figure 1. The feedback loop becomes an integral part of the safety control system. Depending on where one sets the boundaries for the controller, higher level controllers may provide feedback loops for regulations, safety policies, standards, and procedures, and get feedback about their effects in various types of reports, including incident and accident reports. Lower levels implement those policies and procedures. Feedback provides the ability to learn and to improve the effectiveness of the safety controls.

System theory deals with human, and technical components of sociotechnical systems. In this framework, for a human controlled process, the process model is usually denoted a “mental model”, see Figure 1. In contradiction to what is stated in the report, this framework can address inconsistencies between individual controller’s process models. Part of the challenge is then to provide the feedback and inputs necessary to keep the controllers’ models consistent with the actual state of the controlled process and with each other.

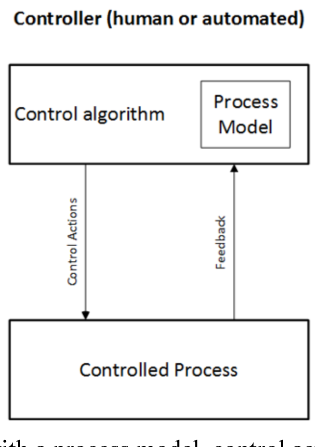
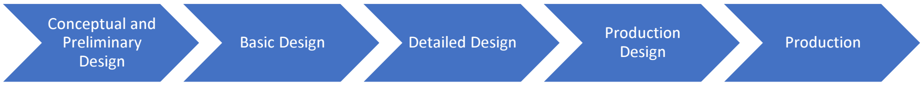


Figure 1: A controller with a process model, control actions and feedback loop.

The report is lacking a discusses of human performance related to these aspects, and especially in the context of the design process typically adapted for shipbuilding (the design process in offshore has its own terminology but represents similar design stages):



The information flow between the different design stages have interfaces involving all the three aspects above, each with potential sources of human error. The concurrent multidiscipline engineering environment in shipbuilding design and construction today, the challenge to control and minimize human error becomes even larger. The report does not address the role of standardization to reduce and control human error. Information standardization in the form of the ISO standards (ISO, 2004, 2005, 2014) addresses information flow in a product lifecycle context with the aim to reduce ambiguity and improve and automate information and data transfer. Standardisation enables automated data and information transfer between individuals/teams and functions inside and across organisations. Standardisation can also eliminate the error-prone process of manually building new calculation models. There are also initiatives focusing on standardising the information exchange between designer/yard and the Classification Society (Polini, 2011; Astrup and Cabos, 2017). The aim is to remove the need for providing design documentation in the form of drawings and achieve a fully model-based review process.

In the context of system thinking, this standard becomes the process model in the controller (see Figure 1), and hence, removes the danger of mental mismatch in models for this process.

The report references to research which indicates that third-party reviews and external audits have a positive impact on detecting and reducing engineering errors. In some sectors of the Maritime industry, third-party reviews are well established and taken on by the role of the Classification society (which represents a controller in the framework of system thinking). The Committee comments that this may have a significant influence on the rate of human engineering errors between classed and non-classed assets without documenting this any further. It would have been interesting to see if the postulated difference between these regimes can be documented by available research.

The Committee dedicate a large portion of the section to the use of spreadsheets in the design and engineering process. The use of spreadsheets is identified as a source of human errors in the design stage. Instead of discussing how errors in spreadsheets can be avoided or controlled, it would have been more interesting to reflect on why spreadsheets are still in so widespread use by the industry.

- Apart from the need of research, does the Committee have any proposal on how the results of such research could be integrated within the conducted engineering analyses and compliance assessment?
- In what way, the review could be used into providing advice and guidance on how to reduce the likelihood of errors in engineering design and approval?
- Can the Committee suggest a plausible answer (course) on how to deal with the two previous questions?

1.1.6 Specific comments on Section 2.5

The report builds on the previous report and contains a comprehensive reference list. However, the report does not address the main concern related to inland and coastal vessel safety; Why have not safety standards for passenger shipping in the domestic sector progressed in the same manner as for passenger ships in international voyages?

1.1.7 Specific comments on Section 3

The report describes the accidents of MSC Napoli and MOL Comfort as examples of container vessels breaking in two due to hull girder collapse. Only minor reflections are included on design principles and acceptance criteria for how this should be handled in design. The rule application has been made quite clear through URS11A (IACS, 2015). What is not clear is the design principles for how whipping should be addressed. Some class societies include additional safety factors (ABS, NK and DNVGL) while others provide guidelines or Class Notations related to numerical calculations. Some Societies do not cover this in their Rules. Further research into how the different approaches are aligned and a comparison of their effects are needed.

It is also a gap between design requirements and what is required during operation of the vessels. Today, loading computers are required and cover still water bending. There exist no requirements for on-board monitoring of dynamic loading. So far on-board monitoring is only a voluntary notation. The report does do not discuss what should be the principles and criteria for these on-board systems.

The section on on-board measurements does not give a complete reference to the various existing rules and standards. It basically covers ships from a rule perspective, focusing mainly on wave bending for safety and maintenance, while other considerations as cargo securing and seamanship are missing. Monitoring is also relevant for offshore structures. This is not covered by the report.

The focus of the section on the full-scale measurement campaigns and decision support is mainly on fatigue. It would have been interesting to see reflections on how design principles and criteria are influenced if an on-board monitoring system is part of an active safety control system. The feedback loop between design and operation is necessary for establishing a link between requirements and performance (and vice versa). In this context, Systems Theory provides a framework evaluating a feedback loop in the context of safety systems.

- Has the Committee considered how feedback loop like on-board monitoring may influence the design principles and criteria?

Design principles and criteria are not clear, and guidelines and standards appear to be missing for routing systems. Research on this topic should address also the difference between good and poor systems to facilitate relevant development and faster implementation within the shipping industry.

1.1.8 Specific comments on Section 3.4

It would be appreciated if the Committee IV.1 referred to the reports of the ISSC 2015 I.1 and ISSC 2018 I.1 Environment committees (ISSC, 2015, 2018), where the accuracy of wave and other met-ocean data is discussed. This would increase the quality of the report. The presented discussion on data accuracy is poor and not sufficiently supported by references.

The Committee writes “There are many measures to identify encountering waves including visual observations, wave radar, wave forecast and hindcast.” Satellite data could also be mentioned even though their limitation is a very large sampling period. Therefore, multi-mission satellite data are presently used in applications, see (ISSC, 2015). It needs to be mentioned that satellite data do not include information about wave period, apart from SAR data, but SAR can register only waves with the wavelength beyond 100 m. However, significant wave heights recorded by satellites, being of high accuracy, could be utilized.

Wave description from measured ship motion using the analogy between a ship and a wave rider buoy has a limitation as it is based on a linear assumption. Further, application of this methodology is challenging when two wave systems are present, wind sea and swell.

The Committee should be credited for developing Table 3.1. The table is pointing out important factors which need to be considered when evaluating pros and cons of various wave estimation methods. However, the table is missing references. Further, wave forecast, not mentioned in Table 3.1, is also giving an opportunity for simultaneous post-processing of data, even though it is not as accurate as wave hindcast. The information provided regarding visual observations is not complete. The World Meteorological Organizations (WMO) collects not only visual wave and wind data from sailing ships but also simultaneously positions of ships and some ship characteristics, what allows also for simultaneous post-processing of data.

It is interesting to notice, but not mentioned by the ISSC Committee IV.1, that met-offices are developing now higher resolution hindcast, 30 km x 30 km and 5 km x 5 km. These data are being already partly available, e.g. from EMWF (European Center for Medium-Range Weather Forecasts) centre. Further, met-ocean data are starting to be freely available to the marine industry bringing new opportunities for engineering applications. This could be mentioned in the report.

For offshore structures, the reference is made by the Committee IV.1 to two publications: Bispo et al. (2016) and Mas-Soler et al. (2017). Data collection campaigns from offshore installations have taken place in several decades. In the North and Norwegian Sea, a length of data series covers today up to 30-40 years in some locations. Met-ocean data are continuously collected by buoys, radars, lasers, LASAR (array of lasers) and recently also by stereo cameras. These data are used by the offshore and renewable energy industry in design, planning of marine operations and operational services of marine structures. Further, wave forecast provided by met offices is utilized also today in operational services of oil and gas and renewable energy structures. Continuous wave measurements have been utilized in the development of procedures for evacuation of personnel from the offshore platforms, e.g. Ekofisk, Valhall platforms. Finally, it should be mentioned that the wave radar on fixed installations performs much better than the marine radar on sailing ships.

Nothing is mentioned on rule requirements related to weather surveillance systems.

The report does not discuss the challenges which rogue waves and climate change poses to the ship, offshore and renewable energy industry as well as the society in general. The topics are addressed by the ISSC 2015 I.1 and ISSC 2018 I.1 Environment Committees (ISSC, 2015, 2018), and are discussed in design perspective by, e.g. (Bitner-Gregersen *et al.*, 2014) and (Bitner-Gregersen and Gramstad, 2016). The carried-out investigations so far indicate that the range of possible changes of met-ocean conditions due to climate change is sufficiently large to influence the safety of marine operations and design of marine structures in some ocean regions (Bitner-Gregersen *et al.*, 2018). Although large uncertainties are associated with climate change projections at present adaptation processes to climate change have already started in the marine industry to support safe design. In the Norwegian Standard NORSOK (NORSOK, 2017), it is recommended to increase extreme significant wave height and wind speed by 4% on q-probability values due to climate change.

Further, it is worth to mention that some changes in industry standards have also been taken place to account for rogue waves. The oil company STATOIL (ISSC, 2015) has already included an internal requirement accounting in a simplified way for rogue waves when designing the height of a platform deck. This requirement is now implemented in the revised version of NORSOK (NORSOK, 2017). The nonlinear waves, beyond the second order, are starting to be implemented in Classification Societies codes, see e.g. (Bitner-Gregersen, 2017).

Reliable warning criteria for rogue waves may increase safety at sea and affect the planning and execution of operation of ships, offshore and renewable energy structures. The development of such criteria remains a high priority topic within the scientific community and for the marine industries.

1.1.9 Specific comments to Section 4.1

Admittedly, the Committee's mandate is on passive (design) measures which focus on the consequences of the accidents. It is also stated that life-cycle design (thus, consideration of operational aspects) of marine assets is of concern. However, for attaining risk control, frequency reduction is of equal importance.

- Has the Committee discussed the effect of decision support systems (which are also mentioned in §3.3) in reducing the frequency of navigational accidents?
- It would be interesting to identify how much accident reduction can be achieved through passive measures and how much from active measures. Similarly, the effect of regulations. Both reviews are encouraged and could indicate if there is any balance between active and passive measures.
- With the establishment of risk-based approaches (including reliability-based) has the Committee considered the creation of a framework linking these approaches with the mentioned first-principles tools as well as simulation methods?

1.1.9.1 Comments to Section 4.2 Slamming

Most theoretical and experimental slamming assessments are based on deterministic case studies. However, extreme slamming loads are very sensitive to the concurrency of a wide range of stochastic time-dependent parameters. E.g. what is the likely concurrent roll angle and wave curvature when the big relative velocity and slamming occur. Such relations including frequencies of occurrence are not well understood for ULS conditions. Therefore, considerable uncertainties are related to calculations of the tail distribution of slamming loads. Methods to determine some of these relations including associated slamming effects considering linear seakeeping characteristics have been presented (Helmers *et al.*, 2012)

1.1.10 Specific comments on Section 4.3

The main principles are covered for the main explosion effects, however, the design criteria to set the load are not explicitly cited in the text. For a probabilistic assessment and QRA criteria, those are usually related to frequency acceptance criteria from 10^{-4} to 10^{-6} per year. The ALARP principle is also applied.

1.1.10.1 Explosion Load

Currently also 3D, dynamic explosion load pictures are developed for designs against high-risk vapour cloud explosions, especially in large process areas such as on FLNGs. When uniform pressure loads are applied on large decks or columns, the support forces become impossible to design against hence the size (width) of the pressure wave needs to be parameterized and applied when calculating the total reaction forces. By applying such techniques, the reaction forces can be reduced more than a factor two (Huser, 2017)

It can be mentioned that DNVGL has published an offshore standard (DNV GL, 2017a) where the explosion and fire loads are given explicitly for typical naturally ventilated offshore process areas. These loads typically become conservative for large and more confined process areas, and its tabulated explosion loads can be replaced by dedicated loads from explosion risk analyses for the individual process area

The report correctly states that near-field explosions are best based on experimental results. It can be mentioned that substantial work was performed after the Piper Alpha accident in 1988.

Full-scale experiments and CFD blind tests, referred to as the Phase II tests (Selby and Burgan, 1998) were performed after the accident revealed that most models at that time underpredicted near field explosion pressures grossly. All models were updated and showed largely improved prediction capabilities. A review of work performed after this can be found in proceedings of the Piper 25 conference (Burgan, 2013).

It is worth mentioning a Recommended Practice that considers linear and non-linear dynamic structure approaches and models to be applied in explosion design (DNV GL, 2017b).

1.1.10.2 Structure response analysis

The last paragraph is mentioning outcomes from QRA or probabilistic assessment. It could be mentioned that the normal outcome from a "NORSOK Z013 Annex G" analysis is a pressure exceedance curve giving the accumulated explosion pressure vs the frequency of occurrence. This is given together with a pressure pulse duration so that the pressure impulse can be found. It is as such, not common to develop PI diagrams directly from the probabilistic assessments. The Design and Dimensioning Accidental Loads can be decided based on such exceedance curves and a frequency acceptance criteria.

1.1.10.3 Leakage and ignition

Regarding liquid leak of more stabilized flammable liquids, it should be noted research post Buncefield accident (Wikipedia, 2018) leading to a theory and models for liquid sprays that can form large vapour clouds caused by low momentum liquid sprays that have a cascading "waterfall" behaviour. It shows that in such cases, significantly more vapour is generated compared to a quiet pool evaporation. If such leaks occur in a quiet atmosphere, at night in the open air (such as in Buncefield accident) or inside a pump room with poor ventilation, on e.g. an oil carrier, large explosions can occur. A model that is developed is provided by (Atkinson *et al.*, 2015). The source term models in Phast should also be mentioned as updated since 2010 (DNV GL, 2018)

The first statement in the last paragraph should be reconsidered. It reads "Immediate spontaneous ignition is considered to occur so quickly after the leak has started that the scenario results in a fire". As it is written, it is not considered correct. Most gas leaks are considered to develop to a gas cloud, and if it ignites, it will typically ignite after some time. Most leaks do not ignite immediately. Elaborate models to calculate the ignition probability are developed over the years such as the TDIIM model (called JIP Ignition 1998), the UKOOA Ignition model, and the MISOF ignition model that is under development.

1.1.10.4 Numerical simulation method

Current developments by DNVGL ComputIT involves 3D explosion risk mapping where a combination of 100ds of gas dispersion and explosion CFD simulations are used to establish localized zones where high explosion pressures can occur. Such detailed assessments reduce the need for conservative assumptions and can be used to reduce or fully eliminate the need for high explosion loads. Such methods can also be an aid to improving the design and reduce zones where hot-spot explosion pressures formerly could occur (Stene *et al.*, 2011; Witlox *et al.*, 2014, 2017; Stene, Harper and Witlox, 2016).

1.1.10.5 Principles and criteria for fire-induced hazards

Acceptance criteria seem to be left out of the text. Regarding acceptance criteria for fire loads, both probabilistic and deterministic "Worst credible fire" criteria are used. Traditionally, fire loads are given by a heat load and a duration, where (FABIG, 2014) gives fire loads for different types of hydrocarbon leaks.

Traditionally the high heat loads are applied over a large, conservative area. Recent developments by DNVGL ComputIT apply 100ds of CFD fire scenarios to develop risk mapping that is used to generate zones where fire protections are needed or improve design against fires.

A fire CFD code for assessment of fire and heat loads on offshore installations is current state-of-art when it comes to applications that can model the most important effects that are relevant for hydrocarbon fires. The DNV GL KFX code can simulate the dynamic development of high-speed jets, LNG and liquid pool spread and evaporation, gas cloud dispersion, ventilation, water deluge with fire, LNG spray and spray fires, LNG pool fires, and cryogenic LNG spray and pool spread.

The KFX code (ComputIT, 2018) can also export results to a code for calculation of dynamic temperature response in a frame-structures and for dynamic structure response (Reality Engineering, 2018) Significant research and experiments are performed to develop and validate these codes, see

1.1.11 Specific comments on Section 5

The section is named "Principles and criteria for arctic operations" but the chapter does not discuss or present any principles or criteria for arctic operations. It should either re-phrase the title or perhaps include an introductory text that explains how the content reflects the title.

The overall impression is that the text seems to quote sources from the most active groups dealing with ice loads on marine structures. The report would have benefitted from a clear separation between text that applies to ships and text that applies to offshore structures. As it is presented the text is confusing when both ship and offshore structures are discussed in the same section. The reader would have benefitted from a clear separation even though there are some commonalities between the two regimes.

It is difficult to distinguish between much of the content in 5.2 and 5.3. Most of section 5.3 does not answer how to design (design approach) but is rather referencing research on ice loads on structures more.

The title of Section 5.4 "Assessment of Ice Class Rules" is quite misleading as the report both includes relevant Class Rules as well as ISO standards. Ice Class rules are in most cases not a concern for offshore structures. Again, these should be described in separate sections. For offshore structures, a reference to the ongoing update of ISO 19906 may be included (ISO, 2010).

1.2 Floor and Written Discussions

1.2.1 Jurek Czujko - Nowatec (Norway)

Chapter 4 – Principles and criteria for accidental loads. I would like to underline several issues here. I think that this chapter is describing the state of the art in the 50's and 60's and that the reference that are shown here are not relevant at all. The chapter is full of design practices that are mostly dedicated to industry.

In addition, we have a special situation regarding ISSC committee 5.1. For the past 3 ISSC conferences, Committee V.1 has produced very good reports, which are already functioning for 9 years. These reports have not been mentioned in the actual report. Committee V.1 of 2015 has issued a guidelines that has not been mentioned in this report. So I think that the report need an upgrade especially in chapter 4.

1.2.2 Dan Frangopol - Lehigh University (U.S.A.)

I want to point out some issues like life-cycle sustainability and life extension. Moreover there are other fields, like bridge engineering, in which a lot of work was done in the study of life extension. Commonly bridges are over 50-75 years old. I recommend to look into this field (references can be provided).

The field of monitoring should be studied: the relation between monitoring and cost should be taken into account. What is the cost of having more precise data?

The problem of system sustainability and reliability is a field that needs more work.

1.2.3 Frank Roland - Center of Maritime Technologies e.V. (Germany)

The question regarding the relation between condition monitoring and design approach was raised a couple of times. I think that this is a very important question because the cost of the sensors is decreasing and so we are going to have more data for digitalization. Following from this, also the cost of data will be less and less. The question is then: how does this reflect in the design procedures, rules guidelines and safety assessment for the new technologies like composite materials? I know that the committee cannot change the design procedures and safety assessment because that's the role of the classification society. The problem is that, especially for new technology, measurements and data acquisition could be done in the wrong way due to inexperience. Could the committee give anyway some best practice on how to conduct this condition monitoring analysis in order to avoid errors during the data acquisition for different kind of structural problems?

1.2.4 Ekaterina Kim - NTNU (Norway)

Chapter 5: Principles and criteria for arctic operation: The question regarding the combination between design and operation of ship and offshore structures and also with respect to the loads definition. Reading from page 585 Vol 1 "…determination of the accurate ice load acting on the ships requires a good understanding of the mechanism of interaction between the ice load and the ships to enhance the safety level of the ships in the Arctic." I'm wondering whether you think that this is a 1 dimensional problem or it's a multiscale problem. Example 1: An ice breaker may have a perfect design that comes from a perfect understanding of the interaction between ice and vessel (ice load). Anyway, if the same vessel would have a different crew, with different experience, then the load that act on the vessel may be very different. Example 2: Type of operation in the arctic environment. The vessel may sail alone or in convoy with another vessel. The following vessel, even if it is designed with the ice breaker rules, may also be damaged while sailing in the ice breaker channel. Could the committee comment on this?

1.2.5 Suquin (Sue) Wang - ABS (U.S.A.)

General question about the Recommended Practices. On board monitoring can be very useful for the in-service risk assessment and life extension in the integrity management. Quite a lot of activities in the offshore industry has been done by the API (American Petroleum Institute). This institute was working quite a lot in the field of RP for integrity management and on-board monitoring. Do you have an inner view on the RP's in the process of publication for structure integrity management, fixed platform integrity management, risers integrity management and mooring integrity management. Maybe the next committee can elaborate on this.

1.2.6 Abbas Bayatfar - Univeristy of Liege (Belgium)

Question relative to the presentation of the CC. I didn't get clearly your comment when you were talking about design tools and principles of design. In particular, when you were saying that "when a design tool stops, then a principle of design should start". I think that these two (design tools and principles of design) should go together. Please comment and clarify this.

1.2.7 Rolf Skjong - DNV GL (Norway)

Reply to OD: I would like to clarify the point raised by the OD about the 3 million USD for the cost of the loss of life instead of the 7-8 million USD considered by the committee. It is correct, in the guidelines the cost of the loss of life is set to 3 million USD, but a paragraph in front of that table describes a procedure on how to upgrade this number. This procedure has not been followed for many years. I did myself this new estimation and the value of 7-8 million USD seems to be the correct one to be chosen. Volume 3 should refer to this paragraph/formula.

1.2.8 Enrico Rizzuto - University of Naples (Italy)

Comment about accidental state and related design criteria. I think that this subject has been covered in different ways from different committees in this congress. What we tried to do in our committee (V.1 – Accidental Limit States) was to not only to concentrate on the limit state but also on the definition of general accidental state. What we tried to cover was also how to delimit the subject and how the concept of design is applied as regard accidental states. The feeling that I personally have is that so far the rational design approach for the definition of design criteria is not yet implemented fully in this field but it is implemented in a different way for different accidental situations. So there's a lot to be done on this subject but probably the role of this particular committee could be to set somehow a path for defining design criteria. I don't think that the role should be to define the criteria itself because this is a huge amount of work. The importance indeed should be given to the definition of the path for a rational design through a rational definition of design criteria.

1.2.9 Mirek Kaminski - Technical University of Delft (The Netherlands)

Question about future development of autonomous ship. The development of autonomous ship has to have an impact on design criteria because there are no people on board. My question is, how this will affect the criteria? Will it also modify the structural design criteria?

1.2.10 Philippe Rigo - University of Liege (Belgium)

Comments on the report: No pictures, it's difficult to follow, very academic and with lot of references.

What is the added value of the University with respect to the work done by the classification society? Is the University doing what the classification society should do or it's just a personal misunderstanding?

1.2.11 Farshid Fardi - Lloyd's Register (U.K.)

You discussed about life extension of structures in the Gulf of Mexico. In fact, the structures there are reaching now the 20 years of lifetime. I'm guessing why you didn't took as example the ship and offshore structures that can be found in North Sea. In fact, some of them are reaching now almost 40-50 years. These structures have already reached the design lifetime and their life has been already extended. Moreover, a lot of monitoring is currently ongoing on these vessels/structures. Hence, this area can be a good source of data and benchmark study.

1.2.12 Sheng Dong - Ocean University of China (China)

Due to climate change, there's an increase in number and magnitude of extraordinary phenomena like storms, tornado or even tsunami. In general, the condition of the ocean environment seems to be more severe due to the climate change. Are these phenomena taken into account into the design principles and criteria? If so, are they included into the report?

1.2.13 Pablo Morato - University of Liege (Belgium)

How to relate costs with monitoring systems? A lot of this is going on in the offshore marine industry. I'd like to suggest a three spaces approach: How to quantify the value of the information for different monitoring schemes and how can we benefit from that. There are a lot of projects going on and I'd like to suggest to take this information into consideration also for the ship structure industry.

2. REPLY BY COMMITTEE

2.1 Reply to Official Discusser

The committee thanks the official discusser for his thorough review and interesting points raised around the committee's report. The committee agrees that the mandate is very broad. The resulting report reflects both the committee member's areas of expertise and a significant level of selectivity required given the limits of a nine-member committee faced with the broad mandate. The development of goal-based standards, and the strong tie with sustainability approaches has been well-documented in the committee's 2009, 2012, and 2015 reports. Hence the decision for this committee to focus on several areas of emerging concern to principals and criteria – primarily the impact of onboard monitoring, accident and off-design situations, and the continued emergence of the Arctic. We appreciate that this may seem like a change in focus from the more criteria-based reports in the past but felt that highlighting these areas was important to continue to explore the entirety of the mandate.

In terms of Systems Theory, we do agree that this is a fruitful area for future committees to investigate. However, the committee is also worried about both the capability of the individual methods that have been proposed (like System Theory) as well as the ability of IMO, flag states, and designers to have sufficient trained staff and resources to apply such methods. IMO (2015) provides high-level guidance in a UN organization. It does not attempt to describe all available types of tools and methods referred to as risk assessment. The guidelines frequently refers to 'other methods' that can be used, and there is nothing in the guidelines preventing the use of other methods that has been accepted by the scientific community. It is, however, unrealistic that an UN organization should maintain guidelines on the various techniques that may be popular to use for shorter or longer periods for some applications. FSAs are reviewed by the IMO Expert Group on FSA, and the uncertainties (and every other aspect of the FSA that may be critical for the final safety recommendations) are always discussed and often also quantified in the FSA.

In terms of Section 2.1, we fear there may be some confusion around the values used in the cost-benefit criteria for averting loss of life, as the limitations proposed by the official discusser is not fully correct. The full paragraph relating to the cost-benefit criteria for averting loss of life reads:

> "1.3.2 The proposed values for NCAF and GCAF in table 2 were derived by considering societal indicators (refer to document MSC 72/16, UNDP 1990, Lind 1996). They are provided for illustrative purposes only. The specific values selected as appropriate and used in an FSA study should be explicitly defined. These criteria given in table 2 are not static, but should be updated every year according to the average risk free rate of return (approximately 5%) or by use of the formula based on LQI (Nathwani et al. (1996), Skjong and Ronold (1998, 2002), Rackwitz (2002 a,b)"

The $3million has been updated many times based on the formula in Skjong and Ronold (1998). This is explained and discussed in detail in the referenced EMSA III documents. The €7 and 8€ million criteria is based on such an update. The reason such criteria need to be updated from time to time is also described in detail in the referenced documents. There has not been any question about the validity of these arguments at IMO. Most national governments issue updated guidelines on such criteria regularly. This is reviewed in detail in the EMSA III reports. In EMSA III, the most relevant external costs were included. Obviously, it is always possible to include other marginal external costs, which would not change the conclusion in any case. It is agreed that including other external costs in the FSA guidelines would be beneficial. However, there is nothing preventing including external costs in an FSA. Anyone is welcome to do this in a future FSA. In EMSA III it was done for the first time.

For section 2.4, unfortunately our report could be clearer. We meant that the models developed in aviation for confusion resulting from extensive automation have not yet been used as a framework to study engineers using increasingly automated tool suites to conduct advanced analysis. To date, we have heard only anecdotal stories of users of advanced analysis tools not fully understanding either defaults or interaction between complex settings in the application. Such errors are perhaps more likely in the naval domain, where the analysis tools are often at an applied research stage, each project may have unique aspects, and model documentation may not be fully established. However, the results of our literature survey in the civil engineering domain shows that there may be similar concern in the commercial domain. We would welcome more comprehensive studies of this area under any model, and the STAMPS model discussed by the reviewer is certainly a valuable lens to study this problem. Significantly, the automated transfer of models for approval mentioned by the official discusser may reduce common data transfer errors, but the interaction of such systems with larger conceptual thought transfer remains relatively unexplored. This is especially true when such systems are applied to novel ships where previous standardization may not perfectly represent the key challenges for approval.

At this point, the committee has relatively little guidance on the reviewer's questions around future interaction of human error modeling and approval criteria and ways to reduce human error. At present, the human error studies reviewed clearly focus on the civil engineering literature, and only hint that similar problems may be expected in the marine domain. A more exact study of the problem in the marine industry, accounting for the unique stages of marine design, and the deep involvement of classification societies in the approval process is needed first.

For section 3, the committee appreciates the comprehensive and insightful review of the official discusser. With regard to recent mishaps on large container ships, the committee focused on hull monitoring systems as a measure to enhance safety at sea. However, whipping is also important as it is pointed out to have been one of the major causes of the accidents. The committee appreciates the discusser's introduction of some approaches to this problem by classification societies and agrees to the view "Further research into how the different approaches (as to the design principles for whipping) are aligned and a comparison of their effects are needed."

In further regard to whipping:

- Some classification societies provide guidelines or Class Notations related to numerical calculations of whipping responses, but it is still considered to be difficult to accurately predict the magnitude of whipping responses in actual sea ways through numerical simulation.
- One of the measures to enhance reliability of whipping response prediction may be the statistical analysis of a large body of measurement data with regard to the whipping responses onboard. One example is a Japanese joint industry project (Niki, Chen et al. 2018), where continuous measurements on whipping responses onboard 10 sister

vessels are conducted and whipping factors (stress increase due to whipping) are collected according to different ship speed, wave heading, wave height, and so on.

Another important new finding on whipping which may influence the design principles and criteria on whipping is that the whipping not only induces hull girder longitudinal bending stresses, but also it excites double bottom bending vibration, which adversely affects the hull girder ultimate strength. This phenomena was first revealed through 3-dimensional numerical simulation (Kawasaki, Okada, et al. 2017) and was recently confirmed through full scale measurement of double bottom stresses (Chen, Okada, Kawamura and Chen 2018).

The official discusser raises a question "Has the Committee considered how feedback loop like on-board monitoring may influence the design principles and criteria?" Firstly, one apparent benefit of on-board monitoring is understanding of actual hull responses leading to more rational rules and criteria, especially when the ships and offshore structures are not conventional and transcends past experiences due to the change in socio-economical circumstances. The recent rapid increase in the size of container ships is one such example.

In addition, when large amounts of monitored data are available, they can be statistically analyzed and used as sources of more rational design criteria. The monitored data reflect real operational decisions actually taken, and will fill a gap in pure theoretical assumptions.

Secondly, real time monitoring data can help officers' decision making for safer navigation. When it is combined with the design, more rational criteria will be established. DNV-GL's whipping criteria which can be relaxed when a required monitoring system is instrumented is one such examples as shown in the Committee report, but quantitative evaluation of the relationship between navigational decision making and ship structural design is still unclear and needs further research.

In future, "Digital Twin" will be an important concept, where advanced and extensive monitoring will be associated with digital representation of the ship systems and support all the life-cycle events of the product through design, production, operation, maintenance, and even conversion or scrapping.

The Committee appreciates the official discusser's comments about the measures currently available to estimate ocean waves. The Committee agrees that the report lacks comprehensive review on wave measurement, but leaving this to Committee I.1, the Committee focused rather on estimation of the exact sea state which each ship actually encounters, so that they can further contribute to establish design principles and criteria of ships.

The Committee appreciates the discussions on climate change. It is an important issue which may affect design criteria, but when it comes to the criteria of ships, it is also important to know how the climate change affects the navigational decision and actual encountering sea state. In this context, a recent study (Oka, Takami, and Ma 2018) has shown that the extreme wave load in actual encountered sea state obtained using AIS data and wave hindcast is considerably smaller than the extreme wave load obtained from wave scatter diagrams. Such effects should be further studied to establish more rational design criteria.

The committee thanks the reviewer for his comments on Section 4. In Section 4.1, There are plenty of researches about the decision-making methods in avoiding navigational accidents or just reducing their frequency, and it was reviewed in this report. The committee also agree that investigations about decision-making systems should focus more on monitoring & controlling methods than the structural design which is the emphasis of this section. The reviews about decision support systems are not covered in this section.

AIS (Automatic Identification System) data can indicate the effectiveness of active measures, but whether passive measures and regulations reduce the frequency of accidents should be based on the statistical data collected over a long time. It is noted that the probability of the accident is very low. The committee agree with the discusser that balance between active and passive measures should be paid attention.

Risk-based methods are gaining more and more importance. They have been adapted in the Formal Safety Assessment by IMO to lead the decision-making process. Two different approaches (a prescriptive approach and a safety-level approach based on risk-based methods) were mentioned in a discussion started by IMO in 2002. The discussion on the prescriptive GBS was finalized and that on the safety-level approach is still in progress (Hamann & Peschmann, 2013). These developments have been well captured in the past committee IV.1 reports.

In section 4.2, the committee agrees that the concurrent roll angle and wave curvature could have a significant effect on the deadrise angle and influence the slamming load.

For section 4.3, the probabilistic assessment and QRA criteria were considered but not in detail in this report, and the main concern is on the principle of explosion and the research of structural response. The supplements of many valuable and important studies by the discusser are acknowledged.

- **Explosion load:** Some analysis methods and design criteria to set explosive loads are given, especially in the work of DNV-GL. As discussed, all models were updated and showed largely improved prediction capabilities after the Piper Alpha accident in 1988. More studies on the simulation of near-field explosive loads can be covered in future. It is important to understand the recent findings on the “saturated impulse” and “saturated load time” in the determination of the design load level in explosive loading with various pulse shapes. The equivalent design load based on saturated impulse will reduce load uncertainties significantly and improve the standard.
- **Structure response analysis:** It is correct to point out that it is not common to develop P-I diagrams directly from the probabilistic assessments in the current practice. It is noted probabilistic approaches helped the engineering application and it may also rely on the core physical model on the phenomenon itself. The saturated impulse as mentioned above will help reduce the uncertainties for the design load and associated nonlinear response. It is useful to optimize the P-I diagram and use it combined with the probabilistic assessment. The P-I diagram when optimized by the above mentioned “saturation impulse” will give effective prediction of the structural response.
- **Leakage and ignition:** The research about the Buncefield accident is presented, which is useful for liquid leak of more stabilized flammable liquids. We agree with the discusser that most leaks do not ignite immediately, and the initial description should be revised as suggested.
- **Numerical simulation method:** The committee would like to thank the discusser for providing more information on the developments about DNVGL ComputIT.
- **Principles and criteria for fire induced hazards:** In the report more studies of fire loads and structural responses under the combined action of fire and explosive loads are covered. The discusser complements important information about acceptance criteria, especially the criteria in the developments of DNVGL ComputIT.

The committee values the overall comments on Arctic Operation in section five from the official discusser. The committee reviews recent work for the areas of ice load prediction, structural design approaches for arctic marine structures, and ice rules and regulations to deliver the latest research activities in the field of arctic operation. The review is performed in view of searching core arctic operation related research outcomes after 2014 to support design principles and criteria aspects.

The committee agrees with the official discusser on the separation between ships and offshore structures approaches for the benefit of reader. However, there are limited number of publications available for the period of the past 3 years, which lead the committee to pay attention to the commonalities between them in ice load prediction and arctic marine structural design approaches, as reflected in the corresponding sub-sections in the report.

The committee tries to focus on ice load prediction in section 5.2, although some of its contents are inevitably difficult to distinguish from section 5.3 - arctic marine structural design approaches. Ice load prediction is reviewed within numerical, experimental and ice field test regimes, in which the modelling of ice behavior subjected to various arctic operation environments, full scale experiments of hull structure responses, and actual ice load acting on icebreaking research vessels are summarized. The committee investigates the state-of-the art structural design approaches for arctic marine structures in section 5.3. In this section, a focus on evolving structural design approaches in the context of ice-structure interactions using various capabilities like FEM, DEM, FEM+DEM, CEM / rule/probabilistic based design / multi-model-based simulator / risk and reliability-based design / full-scale impact test on arctic vessel are the focus.

The committee agrees with the official discusser on the title of section 5.4: revision of the title containing “ice rules and regulations” seems more appropriate. This section tries to cover the current artic operation related rules and regulations regardless of a ships and offshore structures focus to the rules. The section also briefly introduces divergent rule development approaches among different Class rules and ISO standards with new design formulae/procedure proposals. The committee report includes a reference to ISO 19906 (2010) for arctic offshore structures. The committee recommends further investigation of ISO 19906 to provide any on-going update of ISO 19906 for future committee work.

2.2 Reply to Written and Floor Discussion

2.2.1 Jurek Czujko - Nowatec (Norway)

We appreciate the comments on Section 4. The goal was to look at the principles and criteria that underpin current regulations, which, of course, are less advanced than the state of the art in research explored by Committee V.1. However, we fully agree that better connections with the work of Committee V.1 should have been highlighted in the report.

2.2.2 Dan Frangopol - Lehigh University (U.S.A.)

We fully agree with Professor Frangopol, sustainability and reliability criteria are topics in need of further work, and that stronger ties between the civil engineering community and the marine community would be beneficial in this regard. Professor Frangopol’s presence at this event is a great step forward to bring this communities together. At the moment, cost as not featured into many of the monitoring campaigns reviewed, however, industrial operators have certainly indicated that cost considerations are important for future wide-spread adoption of monitoring technology. This is an area that future committee IV.1 should continue to explore – which principles and criteria will give cost advantages if more intense monitoring is used.

2.2.3 Frank Roland - Center of Maritime Technologies e.V. (Germany)

The committee did not specifically research composite materials in the current congress period, but we appreciate and agree with the overall spirit of this comment. There is a very real danger in all monitoring systems that a large amount of data will be gathered, but that the data will not prove useful in changing decisions or the design and maintenance approach for the structure. This is an area where emerging standards instrumentation and data analysis and collection are needed. Unfortunately, the committee did not find any broad evidence of work in this area from classification societies or others in the period of 2015-2018. However, a more hopeful view of the future emerges from the extensive monitoring campaigns that we did report on – such as those for the new generation of ultra-large containerships. Hopefully, the lesson distilled from such campaigns will be made available in such guidance in the future.

2.2.4 Ekaterina Kim - NTNU (Norway)

For details of the vessel-ice interaction, we would refer the specialist committee on Arctic Operations. From the point of design principles and criteria, such ice loading shows the requirement to include ongoing experience with polar operations in the criteria. Polar navigation is new, and we fully expect that emerging standards and criteria will need to include both operational and physical considerations.

2.2.5 Suquin (Sue) Wang - ABS (U.S.A.)

Expanding the on-board monitoring discussion to include related work in the offshore industry is a very logical next step for this committee. However, in the current mandate period we did not compare API approaches to other approaches.

2.2.6 Abbas Bayatfar - University of Liege (Belgium)

The division between the scope of committees IV.1 and IV.2 will probably always be a bit blurry, indeed the availability of tools also shapes principles and criteria – for example without the rapid advances in finite element analysis over the last thirty years, structural approval criteria would look far different. In the current congress, IV.1 shared draft report outlines with IV.2 and attempted to find a reasonable division point. This is likely what was referred to in the presentation, however, the statement did not have a broader significance other than marking where we were attempting to divide the discipline.

2.2.7 Enrico Rizzuto - University of Naples (Italy)

We agree that moving from analysis of such situations to criteria is very much needed, and hope that future ISSC IV.1 committees can look into this aspect of the problem.

2.2.8 Mirek Kaminski - Technical University of Delft (The Netherlands)

Removing life safety concerns will of course change criteria, for example our work in Section 2 demonstrates that the cost to advert the loss of life is currently being used as a yardstick for comparing risk control options. However, significant risks to both property and environment will persist even in the era of autonomous vessels, so a major relaxation of criteria seems unlikely. As autonomous ships develop, rational criteria will be needed to balance the changing risk profile.

2.2.9 Philippe Rigo - University of Liege (Belgium)

We are sorry that there are few pictures in the report, and the broad scope of the work does make it difficult to follow. Ideally, the university would be handling fundamental research, where the classification society would handle more applied research. However, the boundary between these two domains is sometimes fuzzy, and given the increasingly strong relationships between universities and classification societies (such as LR's new Southampton campus), clearly there is the potential for strong collaborative benefits if the two can work together.

2.2.10 Farshid Fardi - Lloyd's Register (U.K.)

Unfortunately, the current committee did not have the resources to conduct a benchmark or comparison between the North Sea and Gulf of Mexico platforms, but such an approach would be a great idea for future committees. The focus on the Gulf of Mexico platforms was mainly owing to the large number of new criteria produced during our mandate period for this region. While the North Sea has been investigation life extension for several decades, this mandate period marked the first time the new generation of deepwater platforms, such as the first-generation spar platforms, in the Gulf of Mexico needed to be considered for life extension. Hence, there was significant publication and development of criteria for this novel problem.

2.2.11 Sheng Dong - Ocean University of China (China)

Climate change could significantly impact the loading on structures and is clearly an ongoing concern for the industry. During our mandate period, we did not find significant evidence of "climate change aware" criteria or principles. However, our exploration of recent platform extension criteria in the Gulf of Mexico did reveal the impact of changing climate – wave and wind criteria for the life extension of certain platforms needed to be revised to be significantly higher owing to more data and more extreme storm events reported over the last 20 years. This is perhaps an indication of what future criteria and future mid-life adjustments may look like.

2.2.12 Pablo Morato - University of Liege (Belgium)

Clear criteria for cost assessment of monitoring systems is currently a challenge. More information sharing and a basis for the design of such systems including cost would be most welcome. A comparison between different sectors of the industry would be also be welcome, and a structured approach like the one you are discussing would be valuable.

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