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COMMITTEE II.1

QUASI-STATIC RESPONSE

COMMITTEE MANDATE

Concern for the quasi-static response of ships and offshore structures, as required for safety and serviceability assessments. Attention shall be given to uncertainty of calculation models for use in reliability methods, and to consider both exact and approximate methods for the determination of stresses appropriate for different acceptance criteria.

CONTRIBUTERS

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1. DISCUSSION

1.1 Official Discussion by Preben Terndrup Pedersen

1.1.1 Introduction

It is an honour to have been given the opportunity to serve as official discusser of the report of Committee II-1. As a long-time member of ISSC, I have continuously been paying interest into the efforts of ISSC committees in their critical evaluation of new research results and in presenting future directions for research and development of our field.

According to the mandate, Committee II-1 shall specifically deal with quasi-static response of ship and offshore structures as required for safety and serviceability assessment. Reliability methods as well as both exact and approximate methods for determination of stresses shall be considered. With this mandate the Committee becomes a very central committee for ISSC since it deals with the fundamental tools for structural analysis and design associated with ships and offshore structures. That is, prediction of structural loads, prediction of structural response, development of strength criteria, and development of reliability procedures. The only limitation imposed by the mandate is really that the loading and the response is to be considered as slowly varying functions of time such that time can be eliminated in the analysis.

The Committee has presented a comprehensive summary of current publications related to the mandate. The report has 76 pages of which 25% consists of the reference list which includes more than 300 references from journals and proceedings from meetings such as PRADS, OMAE, ISOPE and MARSTRUCT. Before a more detailed discussion of the content of the report it may be useful to recapitulate the purpose of ISSC.

1.1.2 The Role of ISSC

Traditionally the aim of ISSC has been to facilitate the evaluation and dissemination of results from recent investigations, to make recommendations for standard design procedures and criteria, to discuss research in progress, to identify areas requiring further research and to encourage international collaboration in promoting these aims. With this aim ISSC has through the years played a significant role for the development of marine structures.

When ISSC was first formed dissemination and critical evaluation of research results from various parts of the world was a very important task. At that time there were no web search possibilities and it was important that committee members were selected such that they had the knowledge and experience to perform critical evaluations. The members should also be selected such that they represented different parts of the world in order bring the most important research and development results to international awareness. This discusser finds that dissemination of titles and excerpts from abstracts of published papers does not seem to be nearly as important as before due to the excellent electronic literature search possibilities we have today. On the other hand, critical evaluation of published research results is now more important than ever because of the wealth of papers presented at conferences and in journals every year.

An important strength of ISSC is that the committees are manned by, in the case of Committee II-1 seventeen, active experts and researchers working for a period of three years. With such a set-up it is possible to give critical expert guidance on the status of our existing knowledge, to give design recommendations and also give directions for future research. Therefore, besides giving guidance on the state-of-the-art to the industry, the committee reports should ideally also be a source for graduate students and other researches to search for inspiration for new ambitious and relevant research topics. Finally, ISSC has been and hopefully still is a very valuable organization for advancement of networks among professionals within the field of marine structures.

Considering the aim of ISSC and since Committee II.1 is one of the central committees within ISSC with many experienced members, it would be interesting to hear the Committee's view on the future role of ISSC:

- Should ISSC continue to list most references within the committee mandates or should ISSC concentrate on more focused topics within the mandate and discuss these in more depth?
- Would it useful to focus more efforts on critical evaluation of the present knowledge situation?

- Should ISSC committees try to give more detailed design recommendations and guidance to future research directions?
- Should the Standing Committee recommend that the conclusions are backed up by benchmark tests applying the recommended practice?
- Would it be an advantage to have smaller committees (the statutes of ISSC specify a maximum of 15) which could meet more often and work more closely together to extract the most significant research results and give recommendations?

1.1.3 Evaluation of the Report

According to the statutes of ISSC the Official Discusser shall critically assess the Committee's report as to its success in complying with its mandate, and that all significantly relevant progress in the subjects concerned have been addressed in the Committee report. With this in mind I shall in the following give my evaluation of the core of the Committee report and in the closure present suggestions for objectives for the future Committee work.

The structural design of ultra large or unconventional commercial vessels generally employs structural assessment procedures using direct first-principle methods. These methods augment the structural requirements expressed in traditional classification rules. It is the further development of these first-principle reliability based methods which are reviewed in the present report. In spite of the dynamic random environmental loads a quasi-static approach is normally preferred in a conceptual design phase due to the reduced computational efforts, shortage of time and structural optimization needs.

The main chapters of the report are devoted to: Strength Assessment Approaches, Calculation Procedures, Uncertainties Associated with Reliability-based Quasi-static Response Assessment, Ship Structures, Offshore Structures, and a Benchmark Study. This is a good disposition. Another strength of the report is some very worthy tutorial sections on the background for the new IMO regulation, on the Common Structural Rules, and some discussions of current class procedures.

– *Chapter 2: Strength Assessment Approaches*

Chapter 2 of the report gives a valuable general review to strength assessment approaches for response of ships and offshore structures. The strength assessment of marine structures is especially demanding due to the randomness or uncertainty in the expected environmental loads imposed on the structure and in the ability of the structure to withstand these loads. The sources of the uncertainties include phenomena that can be measured and quantified but cannot be predicted in a deterministic way, and also phenomena for which adequate knowledge is not available.

First in section 2.1 an excellent, but short description is presented of the existing computational methods for generation of hydrodynamic pressures and their influence on dynamic response of marine structures. This section is valuable since it reflects the perspectives from the ship classification societies and this section gives a good description of the state-of-art. In this subsection it would have been valuable if the Committee also had considered giving guidance on the inherent challenges, i.e. how to model the quasi-static effect of random dynamic loads such as slamming induced whipping loads which have been shown to be so important for ultra large ship structures.

When the dynamic time varying loading is approximated by quasi-static structural analysis procedure then important information is in most cases lost on the proper load combinations acting on the structural strength elements. Currently the dynamic loads are normally represented by a series of load combination factors which represent the superposition of the various dynamic load components to be applied at a given structural strength element when the major dynamic load component has a maximum value. For strength elements such as compressed longitudinally stiffened plates the load interaction strength relations may exhibit failure variations which make such an approach un-conservative. Therefore, also guidance or recommendations on how to improve procedures for modelling load combinations with the proper phase relations, such as the combination of longitudinal, transverse and lateral loads, on different parts of the structures would have been of value for our community. Recent accidents indicate that such load combinations are imperative for the structural integrity of important strength elements in large ships.

The second paragraph, 2.2, in this general introduction to strength assessment approaches deals with response calculations. Again the first part of this paragraph gives an excellent explanation of the state-of-the-art for response calculations of ship structures. It is evident that future response and strength criteria must be based on the development of improved formulations of collapse strength of thin walled stiffened structural elements, on the development of improved predictive theories of fatigue strength, and development of methods to determine the ultimate strength of intact and of damaged thin-walled marine structures.

In this section the Committee reviews mainly literature where the response calculations have been based on finite element analyses. The calculation methods include static implicit analysis methods as well as explicit time integration procedures to solve the algebraic equations. The most frequent application of the finite element method for response calculations associated with design is based on implicit linear codes and the results are used to verify stresses against strength criteria for yielding, buckling, and fatigue strength. This procedure is used by most designers and classification societies. However, ultimate limit loads and accidental limit loads cannot be dealt with in a consistent manner by such linear analyses.

The Committee therefore also includes in their literature review non-linear analysis procedures based on explicit time domain finite element analyses even if this type of analysis is on the borderline of the mandate. In principle these explicit procedures has the potential to model buckling and post-buckling behaviour of individual plate elements provided a sufficiently fine mesh is applied. However, reliable consistent computation of the global structural response through the onset of local structural damage to ultimate global failure is still not a reality for most mechanisms of structural failure. The foundation for predicting progressive damage such as buckling of structural components leading to global collapse, accumulated fatigue failure and brittle failure is still not well developed. This is an area where this reviewer finds that further research could be recommended.

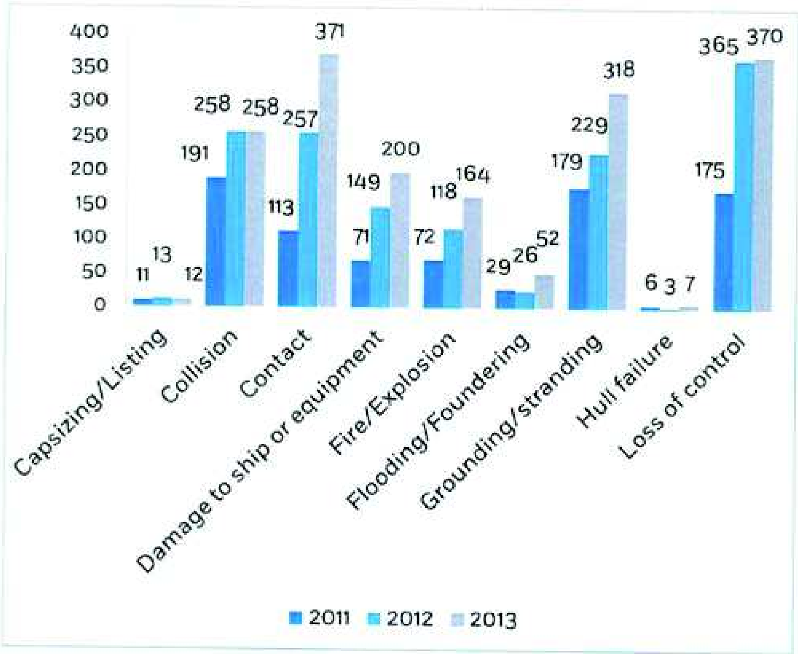

Figure 1: Statistics for casualty events from European Maritime Safety Agency (EMSA) for a three year period.

The Committee summarizes a number of publications dealing with the analysis of ship-ship collisions and ship grounding where explicit FEA has been applied. In order to improve ship safety this is an important area. It is seen from statistics for casualty events from European Maritime Safety Agency (EMSA), see Figure 1, that collisions, contacts, and grounding together is responsible for a very large percentage of casualties.

This chapter 2 on general introduction to strength assessment approaches also includes a one page summary of reliability assessment procedures. Again a valuable discussion on the approaches taken by the different classification societies and in the new common structural rules is presented.

– *Chapter 3: Calculation Procedures*

Chapter 3 constitutes the major part of the report. This chapter presents a comprehensive review of existing calculation procedures. It is a strong point that the report includes a large number of references related to the mandate of the Committee. This impressive list of references shows that research on marine structures is very much in focus around the world. On the other hand then this discusser would have appreciated a more critical discussion of the summarized papers.

Furthermore, the report contains several sections on listing of papers dealing with topics, such as purely dynamic procedures, which seem outside the mandate of the Committee. Examples are vibration of cabin deck structures in passenger ships, resistance optimization of round-bilges, etc. The information given in these sections may be useful but it is not clear why the Committee has included these references in the present report. These sections could have been handed over to the more relevant ISSC committees where the information is more readily picked-up by potential users.

Subsections 3.2.1 and 3.2.2 give excellent discussions of the application of rules versus rational or first principle ship design. Here the Committee really facilitates the aim of ISSC by evaluation and dissemination of results from recent investigations. Section 3.3 on structural modelling focuses especially on finite element procedures.

Marine structures are very large compared to the scales of the critical structural strength elements, and they are rich in complexity because of the many interacting structural-mechanical systems. Although finite element methods for these problems have reached a high stage of development, their application still poses several difficulties. The size and complexity of marine structures precludes direct modelling of the entire structure and important loads and environmental characteristics such as the sea surrounding the structure cannot be treated by standard techniques. The Committee report gives guidelines but more work should be encouraged.

The finite element method is a tool of immense value to the marine design community. However, almost all current applications of the method provide solution estimates of unknown accuracy. This is especially so for large scale analyses involving geometrical and material non-linearity. Designers must rely on experience and judgement to determine whether or not the estimates are good enough to be useful. This implies a need for highly trained analysts to use such numerical tools. To solve this problem there is a need to develop computational methods that provide approximate solutions of known accuracy to boundary value problems. One needed ingredient is automatic mesh generation. The capabilities that exist today are of limited value, and alternatives such as meshless methods are still in their infancy. Does the Committee have a recommendation to solve problems related to the reliability of complicated finite element solutions? Should these preferably be compared to simplified solutions such as for example mentioned in NORSOK?

The report has a subsection, 3.3.3, on composite structures which includes laser welded steel sandwich plates and composite patch repair. However, several of the summarized papers in other parts of the report also deal with analysis of structures made of composite materials. In other fields such as the automotive and the aircraft industries composites plays an increasing role. We may expect a similar trend for marine structures due to high strength to weight ratios and the good corrosive properties. However, reliable design with composites is still in its infancy. Polymeric matrix with fibre composite materials can offer major advantages for life cycle cost effective applications in primary and secondary structures. Such materials, often in the form of sandwich structures, provide light weight load bearing components with attractive corrosion resistant properties. The characterization of strength and failure is probably the foremost barrier to reliable design with composites. This discusser finds that a recommendation to our community could be that research is needed on: failure characterization in a form suitable for design application, joining and bonding of composites to each other and to other materials, and establishment of a durability data base to make these promises a reality.

Throughout the report a significant number of studies of FEA procedures to calculate the ultimate strength of intact as well as damaged hull girders are discussed. Reliable procedures especially for the intact hull girder strength are important for estimation of the reliability of ships. However, related to the discussion of the improved residual strength of damage ship structures, then this discusser doubts that a cost benefit analysis will show that not much is gained by adding more structural strength than needed for the intact case. That is, these damage conditions will not be dimensioning. This could be an important object for further analysis. Of course, for post mortem analyses it is important to know the residual strength of damaged ship structures.

Chapter 3 has an excellent section 3.5 on validation of calculation results. This section presents a number of significant research papers where measured response values in model scale as well as full scale are used to validate numerical calculation results. For the full scale hull stress monitoring one of the reviewed papers show that the present IACS URS11 requirement for the wave bending moment seems to be too low to account for whipping and springing for the considered ships. A similar observation based on full scale measurements is made in Andersen (2014), see Figure 2, and Andersen and Jensen (2014). That is, there seems to be strong evidence that the present rules should be re-evaluated. This is indeed a significant observation which should lead the Committee to propose further research and/or propose improvements to our existing design practice.

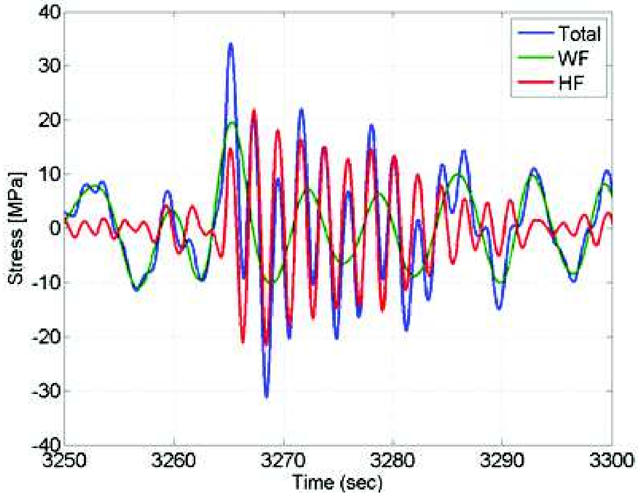

Figure 2. Stress measurements amidships on a large container vessel in a high sea-state. Direct wave-induced stresses on the rigid hull (WF), slamming-induced whipping stresses (HF) and the total combined stress, Andersen (2014).

– *Chapter 4: Uncertainties Associated with Reliability-based Quasi-static Response Assessment*

This chapter discusses and reviews papers related to uncertainties related to loads, structural modelling, structural capacity and risk based inspection, maintenance and repair. The literature review shows that a large number of papers are being published on the development and application of reliability based procedures. The Committee does not make any recommendations or proposals for further research on these topics. In this section it could have been interesting if the Committee had made a comment or a discussion on the seemingly very high measured wave induced loads mentioned in Section 3.5 and the more theoretical studies reviewed in section 4.1, and on recent accidents such as the MOL Comfort accident. That is, this discusser finds that guidance and research is needed on structural design methodologies based on explicit probabilistic limit states for all failure modes, taking into account the new findings on dynamic wave-induced loads, structural deterioration such as crack growth, corrosion, and changes in residual stress and geometrical imperfection distributions. Of course, with reference to an acceptable risk level.

– *Chapter 5: Ship Structures*

The chapter discusses recent development in international rules and regulations for ship structures and includes a review of literature on some specific ship concepts. This discusser appreciates the review of the historic development of the new common structural rules for bulk carriers and oil tankers and the novel requirements to the direct strength analyses which will come into force from July 2015. Especially interesting is Table 2 which compares the different stress acceptance criteria which have been adopted until now by some of the current classification societies together with the new harmonized stress criteria. The Committee also presents a review of literature related to structural issues for offshore service vessels, container vessels, LNG/LPG tankers, passenger vessels and sailing yachts.

For the LNG/LPG tankers the report includes a summary of crashworthiness studies. With an increased focus on LNG as cargo as well as fuel then tank protections is an important issue. In spite of the fact that existing LNG tankers have had an excellent safety record there are good reasons to develop guidance on improvement of crashworthiness of cargo tank structures as well as LNG fuel tank structures. It seems appropriate that the research community tries to utilize the relatively large number of published research results on crashworthiness of ship structural elements to make recommendations on structural solutions which can limit the consequences of collision and grounding accidents and optimize the structural arrangements.

– *Chapter 6: Offshore Structures*

In Chapter 6 the published literature during the report period on structural assessment of various types of floating and fixed offshore structures are reviewed. The review shows that during the reporting period the research focus has been on assessment of consequences from extreme and accidental loads. The Committee has identified many references related to wave impact loads, spectral methods in the frequency domain, fatigue strength estimation, and progressive collision damage characteristics. This section contains many useful references, but few recommendations for future research directions.

– *Chapter 7: Benchmark Study*

The Committee must be commended for devoting a lot of effort in order to include a benchmark test in Chapter 7. The chosen problem relates to transforming a dynamic slamming load into a quasi-static load to be used for prediction of the structural response. This is indeed a challenge since the hydrodynamic loading time in the case considered is very short compared to the relevant wet natural frequency of the panels under investigation. Both a simple beam theory procedure with a very low amplification factor chosen from a textbook and comprehensive nonlinear transient dynamic finite element analyses were applied.

The amplification factor used to transform the dynamic slamming load to an equivalent quasi-static load for the beam analysis is based on the assumption of a pure triangular load impulse in time. This load history disagrees with the experimental measurements and the theoretical calculated load time histories. Due to the short loading period compared to the lowest wet natural frequency then another approach could be to base the choice of amplification factor on the impact momentum instead. For the assumed triangular load history the result will be the same but an approach based on impact momentum or induced initial velocity would be more general.

Another problem with the present analysis example is of course that the amplification factor approach to transfer the dynamic response to a quasi-static response will be difficult to apply when the structural response is non-linear as demonstrated with this benchmark test. The benchmark test indicates very well the challenges associated with the transformation of dynamic loading events into quasi-static analysis procedures.

1.1.4 Closure

Marine structures of interest to the ISSC which includes ships, offshore structures and other marine structures used for transportation, exploration, and exploitation of resources in and under the oceans are very large compared to the scales of the critical structural strength elements. They are complex structures because of the many interacting structural-mechanical systems. For direct, first principle, quasi-static structural response calculations finite element methods for these problems have reached a high stage of development. However, their application still poses several difficulties related to modelling of the dynamic loads, degradation of strength, and accuracy. Most often the size and complexity precludes direct modelling of the entire structure with sufficient small mesh sizes. Therefore, guidance, procedures, and tools reviewed by Committee II.1 are essential prerequisites for practical design.

The Committee must be commended for having produced a report with a logical structure, a very large number of recent references, some good discussions of the new IACS Commons Structural Rules and IMO's Goal Based Standard, and for having embarked on a benchmark test. The final chapter on conclusions and recommendations is very well balanced and gives identification of areas requiring future research, review of research progress and to some extend also recommendations for improvements in design.

Where this discusser has been critical it is primarily in order to extract as much useful information as possible from the extensive committee work and to suggest fruitful areas and tasks for the coming Committee. This discusser's suggestions for the future Committee II.1 is to use the committee members' expertise and the available results from the literature to make even further efforts in:

- Making recommendations for improvements in design procedures;
- Being focused and critical in their selection and review of research results and in facilitating the dissemination of the most significant results; and
- Being specific in the identification of areas requiring future research.

1.1.5 Additional References

Andersen, I.M.V. & Jensen, J.J. 2014. Measurements in a container ship of wave-induced hull girder stresses in excess of design values. Marine Structures 37(1): 54-85.

Andersen, I.M.V. 2014. Full scale measurements of the hydro-elastic response of large container ships for decision support. Doctoral Dissertation, Technical University of Denmark, Kgs Lyngby, Denmark.

1.2 Floor and Written Discussions

1.2.1 Shengming Zhang (Lloyd's Register)

FEA on ship structures is becoming a design assessement tool/method. Element size will affect the results of stresses. What is the comment of the Committee on the current design practice of acceptance criterion of stresses?

2. REPLY BY COMMITTEE

2.1 Reply to the Official Discussion by Preben Terndrup Pedersen

The Committee would like to thank the official discusser Professor Preben Terndrup Pedersen for his effort and kind contribution to the assessment of the Committee Report. The Committee appreciates Professor Pedersen's (hereafter referred to as the "discusser") valuable and inspiring comments which we reply to in the following.

– *Introductory Comments and Questions Referring to the Future Role of ISSC*

In some chapters of the report, the discusser would have appreciated a more critical discussion of the summarized papers. The Committee agrees with the comment that the current report could have benefit from clearer discussions, statements, and recommendations. The next committee should consider this, and is recommended to include a "concluding remarks and future work" section in each chapter of the report.

The discusser's comments and questions regarding ISSC's future role and purpose are interesting but challenging for the Committee to reply on. It should be noted that the Committee's answers to the discusser's questions are subjective. The Committee is willing to participate in a broader discussion with the Standing Committee and other ISSC committees.

The Committee supports that a broad state-of-the-art literature summary should be presented on each ISSC congress by each committee. It should, however, be accepted that a committee be allowed to decide to limit the scope of its work during the mandate period. This flexibility would allow more in-depth discussions of subject areas that are clearly motivated in the report and on the congress. This will most likely result in work presented by the committees that focus more efforts on critical evaluation of the present knowledge situation instead of only presenting summaries of work presented in the public literature.

All ISSC committees review, reflect, and summarise results from literature studies on recent advances related to the committees' mandates. Due to the vast amount of publications published annually, significant amount of work is spent on reading and selecting key references which have resulted in new knowledge and findings. But, we can always improve. This Committee agrees with the discusser that all ISSC committees should strive to give (detailed) design recommendations and guidance to future research directions, preferably as concluding remarks in the report. The concluding remarks should form the basis to the conclusions from the Committee's work, which can also be backed up by benchmark tests applying the recommended practice. Many committees work according to these suggestions today but there is always room for improvements.

The Committee's impression is that today, many committees have an ambition to carry out and present benchmark studies. Since the ISSC work of each member is voluntary and on top of all other work-related duties, it is understandable that it can be difficult to allocate time and effort to contribute to both critical assessment of literature and participate in benchmark studies. One solution could be to change today's committee structure into several smaller (number of committee members) committees which could meet more often and work closely to extract the most significant research results and develop recommendations. But, it should be noted that this framework can be achieved already today with the current size of today's committee structure. The chairman has the freedom to organize the work and manage work groups within the committee and establish subgroups with special task assignments on dedicated focus areas.

– *Chapter 2: Strength Assessment Approaches*

The Committee appreciates the discusser's positive feedback on this chapter. The Committee agrees with the discusser that an extensive description of how to model the quasi-static effect of random dynamic loads such as sloshing or slamming-induced whipping loads could have been presented. The next committee is advised to include this in their work.

On the topic of guidance and/or recommendations on how to improve procedures for modelling load combinations with the proper phase relations, such as the combination of longitudinal, transverse and lateral loads, on different parts of the structures are of value for our community. The Committee agrees with the discusser that the understanding of how to model load combinations is imperative for the structural integrity of critical strength elements in large ships; see Alfred Mohammed et al. (2012) and Ćorak et al. (2015). The Committee did not emphasize on this topic during the mandate period, but recent accidents provide a justification for the next committee to review it as one of its focused topics.

Section 2.2 presents a general introduction to strength assessment approaches. The Committee appreciates the discusser's positive feedback on this section and also the recommendations for future work. Prediction of progressive damage such as buckling of structural components leading to global collapse, accumulated fatigue failure and brittle failure still require additional development. The Committee agrees with the discusser that this is an area which the next committee is advised to engage its efforts. However, it overlaps with areas and mandates of other ISSC committees. Hence, a collaboration or interaction with other ISSC committees should be encouraged; hence, bridging gaps and transferring knowledge between committees.

– *Chapter 3: Calculation Procedures*

This chapter is the core chapter of the Committee's report which is reflected in the number of references presented in the chapter. The Committee reviewed a large number of papers which in many cases dealt with purely dynamic procedures, which is outside the Committee's mandate. There are, however, in general limited studies that model FSI using parametric idealizations leading to closed form quasi-static formulae. This is a strong trend in research and development and inevitably the quasi-static committee suffers from this. The Committee wants to clarify that the majority of the references which in their titles may indicate that they deal with purely dynamic procedures actually suggest quasi-static analysis by simplifications in either load modelling or response calculations.

Section 3.3 on structural modelling using finite element procedures is identified by the discusser as a topic which should have deserved more attention. The Committee deliberately decided to limit the scope of the work and postpone this subject to the next mandate period. It was discussed thoroughly in the ISSC2012 Committee II.1 report and the current Committee did not have sufficient members with knowledge within the field.

The Committee agrees that FE analysis of complex structures requires highly trained engineers. To ensure that the models are properly made, traditional automatic mesh generation procedures must be controlled/overruled by existing guidelines for FE modelling of marine structures. Therefore, the traditional "automatic mesh generation" concept may advantageously be replaced by automatic generation of FE models in accordance with best practice and existing guidelines.

On the topic of composite structures, they are mentioned briefly in section 3.3.3 of the report. The topic has been reviewed and discussed thoroughly by Committee II.1 in the ISSC2009 and ISSC2012 reports. Hence, the current Committee decided to present recent research work on this topic as part of several chapters, i.e. not in a separate chapter. The Committee agrees with the discusser that the next committee should address among others: composite failure characterization in a form suitable for design application, joining and bonding of composites (primary, secondary, adhesively bonded), and establishment of a durability database to make these promises a reality.

Analysis of ultimate strength of intact and damaged vessels using FEA procedures are presented to a large extent in the public literature. The discusser has raised an interesting question regarding "cost benefit analysis of strengthened ship structures". This could be an important subject for further analysis. The next committee is therefore advised to include it in the next report as a complement to the structural integrity analysis, both for intact, damaged, and corroded conditions.

The Committee appreciates the positive feedback from the discusser on section 3.5 – validation of calculated results. It is important that both model and full scale testing is continued in order to provide researchers with data for model validation. This can also enable simplification of models related to the mandate of this committee. The Committee agrees with the discusser that the next committee should use the present knowledge to propose further research, recommend improvements to our existing design practice, and possibly application to a benchmark study.

– *Chapter 4: Uncertainties Associated with Reliability-based Quasi-static Response Assessment*

The chapter presents a review of literature spanning many areas of research. The discusser's recommendation is that "… guidance and research is needed on structural design methodologies based on explicit probabilistic limit states for all failure modes, taking into account the new findings on dynamic wave-induced loads, structural deterioration such as crack growth, corrosion, and changes in residual stress and geometrical imperfection distributions. Of course, with a reference to an acceptable risk level". The Committee supports this recommendation; however, this topic is vast and could possibly be an ISSC committee by its own. In the next ISSC report, development of a focused scope with motivation to the limitation is suggested.

– *Chapter 7: Benchmark Study*

The Committee is grateful for the positive feedback on the benchmark study. It should be noted that the benchmark study presented in the committee report has been extended with results from non-linear plate strip models. The results are described in Heggelund et al. (2015). For the investigated case, the non-linear plate-strip models were found to be the most realistic. Therefore, it was recommended to use such models in an initial design assessment. Further elaboration on this topic will be given in a paper to be submitted to the international journal of Marine Structures.

– *Final remarks*

The Committee thanks the discusser for valuable and thoughtful feedback on the Committee's work. The next committee is advised to consider the final remarks from the discusser:

- Make recommendations for improvements in design procedures.
- Be focused and critical in the selection and review of research results and facilitating the dissemination of the most significant results.
- Be specific in the identification of areas requiring future research.

2.2 Reply to the Floor and Written Discussions

2.2.1 Reply to Shengming Zhang (Lloyd's Register)

The Committee thanks Dr Shengming Zhang for the interesting question. Finite element analysis has indeed become a tool/method in assessment of marine structures. It is crucial that the element size is chosen appropriately and suitable to the objective of the analysis. To the Committee's knowledge, there is no common design practice of acceptance criterion of stresses in e.g. the strength assessment. This issue is highlighted in the Committee's report. With regards to the stress acceptance criteria, most of the current classification rules have criteria for yielding checks of local stress concentrations, assessed by means of direct calculations and modelled by fine meshes. However, due to differences in approach, not all stress acceptance criteria are the same. An overview of the stress criteria as defined in the main class rules is given in Table 2. It should be noted that the table only contains an excerpt from the actual stress criteria and is therefore not complete. What can be observed in Table 2 is that there is a variety of mesh sizes to be used.

2.3 Additional References

Alfred Mohammed, E., Chan, H.S. & Hirdaris, S.E. 2012. Global wave load combinations by cross-spectral methods. Marine Structures 29(1): 131–151.

Ćorak, M., Parunov, J. & Guedes Soares, C. 2015. Probabilistic load combination factors of wave and whipping bending moments. Journal of Ship Research 59(1): 11–30.

Heggelund, S.E., Li, Z., Jang, B.S. & Ringsberg, J.W. 2015. Quasi-static assessment of response to slamming impact of free fall lifeboats. In Proceedings of the 34th International Conference on Ocean, Offshore and Arctic Engineering (OMAE2015), St. John's, Canada, 31 May–5 June 2015. (OMAE2015-41810).