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COMMITTEE IV.2

DESIGN METHODS

COMMITTEE MANDATE

Concern for the synthesis of the overall design process for marine structures, and its integration with production, maintenance and repair. Particular attention shall be given to the roles and requirements of computer-based design and production, and to the utilization of information technology.

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CONTENTS

1. DISCUSSION

1.1 Official Discussion by T. Moan

1.1.1 Introduction

It is an honor and pleasure for me to participate in the 19th ISSC in Lisbon and discuss the Committee IV.2 report.

I would like to congratulate the Committee and its chairperson, dr. Matthew Collette for producing a comprehensive review of developments of design methods through the last three years. The report is based on more than 200 publications and the considerations of committee members that no doubt will be of great value for the research community and for the industry.

According to the ISSC statutes my task is to critically assess the committee report in view of its mandate; referring e.g. to the synthesis of the overall design process and its integration with the other life cycle phases, and the utilization of information technology; and in view of the objectives of ISSC, namely:

- to make recommendations for design, production and operation
- to review research progress
- to identify areas of future research

The reference for my review is that a rational design framework, which seems to be favoured also by the Committee, should be based on:

- Goal-setting; not prescriptive criteria and methods relating to system integrity, sustainability etc
- Account of uncertainty: Probabilistic; not deterministic
- First principles; not purely experiential
- Integrated - total (life cycle phases); not separately
- Balance of serviceability and safety elements; not hardware only
- Robustness w.r.t. commercial opportunities and safety
- Design phases: conceptual, pre-engineering, engineering, detailed engineering

The actual approaches used in the different stages of design, however, need to be balanced with respect to accuracy and efforts, in integrated approaches for design. At the same time, I recognize that the voluntary nature of committee efforts, imply that limited resources are available for the Committee's work, which is very demanding in view of the fact that design requires knowledge about many disciplines and their integration.

On this background, I hope to provide comments on the report in a constructive manner – for considerations by the present Committee as well as the future Committee.

1.1.2 General Comments

In addition to chapters on introduction, conclusions and references, the report is organized in the following chapters:

- design methodology (6 pages)
- design tools (6 pages)
- optimization developments (17.5 pages)
- classification software review (14.5 pages)
- structural lifecycle management (8 pages)
- obstacles, challenges and future developments (2 pages)

ISSC refers to Ships and Offshore Structures; however, the Committee limits its treatment to ships, however, with sporadic mentioning of articles relating to other types of structures. Those citations might be of limited value since they are not placed in the context of a complete design approach for such structures. In the ISSC 2015 design of naval vessels, arctic technology (and related vessels), risers and pipelines, natural gas facilities and renewable energy devices are treated by other committees. Yet, important aspects e.g. relating to the design of offshore oil and gas facilities and very large floating structures would have been interesting to review in order to compare design approaches for different marine structures. Clearly, there is a vast literature for offshore and very large floating structures that is not referenced. Most of the following review is therefore based on the scope adopted by the Committee.

A brief account of design philosophy and principles is given in Chapter 2. In this context the Committee could have referred e.g. to ISSC IV.1 (2012), EU(2015) and the general literature in related industries relating to the background and the operationalization of novel design aspects that have not yet been adequately implemented for ships. Chapter 2 also provides an introduction to design methods. In general ships are designed for a certain mission of transport and other serviceability requirements to deflections, noise, HSE, access for inspection/repair, etc – sustainability and safety. The Committee touches upon design procedures and different targets, e.g. design for safety (risk based design), production, environment (al sustainability – water ballast treatment, emissions etc.), energy efficiency but refers to a limited extent to functionality aspects (architecture e.g. of passenger/cruise vessels, arrangement of propulsion), escape and evacuation issues, design for inspection and monitoring (i.e. access). Even if these aspects are "non-structural", they affect the ship layout.

Life cycle management with respect to system integrity (e.g. Norsok N-005, 2015), energy, environment (which obviously includes dealing with Big Data), is also highlighted.

For instance, a goal setting and probabilistic approach implies use of a risk based approach to safety, but the challenge is to operationalize it – in view of relevant hazards for ships (e.g. Lloyd's list: http://www.lloydslist.com/ll/sector/casualty/) and measures of risk amelioration – such as QA/QC, design for robustness (Accidental Limit State) etc., as e.g. done in the oil and gas industry (ISO 19900, 2013).

The operationalization of the design approach would depend upon the stage or nature of design; which for convenience here is splitted into

- Conceptual or Initial design
- Engineering or detailed design

Initial design can partly be a divergent process (exploring possibilities and constraints of inherited configurations by applying creative and critical thinking to establish – infer – new understanding – problem space – toward better design solutions) or a transformation of specifications of design into new solutions); and partly a convergent process by improving the originally inherited configuration, e.g. by optimization.

While the initial creative process is qualitative, the final documentation of the design is a convergent process. The focus of the committee is on the convergent process, but it would have been valuable if the committee could have devoted a section to notable new designs (prototypes), i.e. new ship designs. Levander (2012) presents many good examples in this respect. It would have been interesting to see examples on creative processes resulting in novel conceptual ship designs – e.g. driven by sustainability considerations (http://www.seaspeed.co.uk/, https://www.dnvgl.com/technology-innovation/revolt/index.html); or enabling materials technology – fiber composites not only for weight saving but also durability/longevity. Reduction of Capex and Opex is found to lead to a drive towards increasing ship size, implying new design issues and hence a demand for improved design methods.

In this connection it is also of interest to exploit how well we can specify quantitatively all design targets.

In principle design tools need to cover the following items:

- Geometry representation, visualization of the relationship between the parts and the whole – while accounting for life cycle changes
- Describing environmental conditions for world wide or "restricted" operation, stability, calculating still water-, hydrodynamic-, accidental loads and load effects, structural resistance, code checks
- Optimization
- Reliability, risk with respect to structural integrity in the life cycle in a wide sense
- Measures of sustainability (energy use, emission,)
- Capex and Opex estimation

While there are several other ISSC committees that are dealing with the aspects mentioned under the second item (maybe except stability); and maybe the fourth item on risk and reliability, Committee

IV.1 has special responsibility for tools in the other areas, while at the same time reflecting the hierarchy of methods available at different fidelity levels in the other disciplines.

In the initial design phase simplified, efficient methods that capture the main features, are clearly needed; e.g. relating to global features like stability, global strength and robustness. Visualization, especially for consideration of functionality in use, arrangement is also important.

Chapter 3 deals with some apparently research oriented articles on CAD/CAM/CAE, while an overview of tools provided by classification societies is given in Chapter 5 – including the integration of the different tools. The link between design tools and production and operational phases is touched upon. In reality some design tools will also serve as tools for assessment during operation – based on design data complemented with data from the as-built structure and operation. Fabrication technology is dealt with by Committee V.3 but fabrication processes and data management is related to the design process.

The hierarchy of methods at different fidelity levels /efficiency needed for the different phases: conceptual via engineering to detailed design is touched upon. It is therefore important to highlight the need to carry out R&D to develop methods at different level of refinement.

Consistency in the accuracy of methods in design analyses is important. For instance, extreme wave-induced load effects for ULS design checks may be determined by a (complete) full long-term model of metocean data, selected sea states or even selected regular waves, clearly with different inherent uncertainties. Another example is how uncertainties in general are dealt with. While reliability methods clearly provides a tool for rationally handling uncertainties in design, it could very well be that semi-probabilistic methods which are calibrated by reliability analyses, are accurate enough for traditional ULS design, especially because application of reliability methods require an expert committee evaluation of the uncertainties in data and methods used to determine load effects and strength, as carried out in reliability based code calibration (ISSC VI.1, 2006). If not, the application of reliability methods gives a false impression of accuracy and should not be permitted used in design.

Production issues are addressed mainly through data transfer from design to production and data from the production process to support the life cycle management.

The committee highlights the need for life cycle data management and the challenges associated with property rights to data owned by different stakeholders.

In the following the different main sections of the report are commented upon.

1.1.3 Design Methodology

In Chapter 2 on Design Methodology the Committee provides well thought reflections on what design methods represent- and touches upon both the divergent (creative) and convergent (analysis oriented) design processes. The Committee also touches upon the different fidelity a level that is required at different design stages. There should be tools for the different tasks corresponding to different fidelity levels required.

In Section 2.2 the Committee elaborates on design for different targets (X). To a large extent design is about making compromises between conflicting requirements. Hence, an elaboration on the truly integrated design process, where all the targets could be addressed, is also of interest.

In line with the goal-based approach, the Committee especially highlights the risk-based approach, and also discusses uncertainty management in Section 2.4. This would in principle include assessment of hazards such as severe wave loads, ship collisions, fires …and their effect on failure modes such as: loss of stability and structural failure with targets expressed by acceptable risk level. In general it will be very demanding to carry out the iterative (detailed) design process to satisfy safety and serviceability in a truly goal-setting perspective with targets given by risk measures. Hence, simplified approaches are needed. While risk analysis is applied for safety assessment of individual facilities in the oil and gas industry, FSA has been applied to establish ship rules. For offshore structures risk analyses are particularly applied in conceptual design – as the implication on system selection have the largest safety benefit with the least costs, but are also used to determine design accidental loads for detailed design. However, experiences with risk analyses show that for instance the same magnitudes of fire and explosion loads result from risk analyses of different offshore facilities and can hence lead more specific load specifications. Hence, this result is in line with the FSA approach. The Committee reviews some research papers on risk assessment. How risk analyses should be implemented in connection with the different stages of ship design is still an open question. This is an area where ISSC Committees IV.1 and 2. could contribute.

Structural reliability methods are also touched upon, especially in connection with lifecycle maintenance, monitoring – in relation to fatigue and corrosion. Again it is a question how such approaches should be used – especially in a simplified manner – in a goal-based design setting, even considering both design, inspection/monitoring, maintenance and repair plans open for decision. It is extremely demanding since authoritative estimates of uncertainties are needed in the reliability analysis, and a vast number of fatigue prone joints needs to be considered. An additional complexity arises if fatigue of a large number of joints e.g. in the ship deck implies reduction of section modulus.

It might be convenient to apply a sequential approach for convergent structural design, starting with a global design based on stability, hull girder strength in view of accidental effects and corrosion management, followed by satisfying SLS and ULS component requirements. Finally, decision on management of fatigue can be made. If, however, fatigue design implies a need to reduce the nominal hull girder stress, it might lead to an additional iteration.

The committee also touches upon updating of wave-induced load effects based on measured responses. The measurements could be used to update the method for predicting wave-induced load effects, assuming measurements of the sea states etc. with good quality, but even for a measurement program lasting for a few years there will be a limited effect on updating of the environmental conditions; which still need to be based on longterm data.

The issue raised about designing for flexibility is interesting – and linked to the treatment of business uncertainties in connection with design.

Section 2.3 provides interesting, but brief summaries of research efforts on divergent design processes- i.e. creating novel designs. It would be interesting to know whether the approaches can account for all criteria and whether you could list examples of innovative designs.

Finally, I wonder which results from the recent research on design methodology that the Committee would like to highlight for improved practical design approaches.

1.1.4 Design Tools

Design tools are treated in Chapters 3-5. These computer aid tools for design can be categorized as:

- Product models (geometry ..), visualization of the relationship between the parts and the whole – accounting for life cycle changes
- Describing environmental conditions for worldwide or "restricted" operation, stability, calculating still water-, hydrodynamic-, accidental loads and load effects, structural resistance, code checks
- Optimization
- Reliability and risk analysis relating to failure modes relating to stability and strength
- Life cycle cost estimation
- "Monolithic naval architecture packages"

There are other ISSC committees that deal with the aspects mentioned under the second item (maybe except stability); and the fourth item on risk and reliability. The other tools, especially relating to synthesis, is within the scope of the Committee. In addition, I expect that the Committee also reflects the fact the all methods could be ranked in a hierarchy corresponding to different fidelity/accuracy levels. This is important to have design methods with consistent accuracy i.e. that also implies the desirable accuracy of synthesis.

It seems that Chapter 3 deals with a review of published papers on tools – but only a limited number of tools (e.g. MAESTRO, GL package, LR/MARTECH, Nauticus Hull/E4), while Chapter 5 provides an overview of the tools of 10 Classification Societies. These tools could have been assessed together.

The collected information is useful, but is a bit superficial. For instance, some papers dealing with structural fatigue assessment are mentioned, but not sufficiently in detail to provide understanding of the inherent features. Might be the relevant technical committees with members that are specialist on the relevant methods, e.g. II.1 (FEM), II.2, III.1, III.2, IV.1 (Reliability methods?)…, should be involved in comparative studies, and the Committee IV.2 focuses on the tools for product models, integrating tools ("monolithic naval architecture packages"), including optimization and maybe stability.

It is noted (in Section 3.3) that publications on tools for environmental impact analysis (LCA) of shipping are sparse despite the need for such tools and a significant (general) literature, ISO standards and applications in the petroleum industry. Maybe the Committee could stimulate further development of such approaches for shipping by bringing in relevant lessons from other engineering fields? However, it is more understandable that there is limited information about life cycle cost data, since fabricators need to protect their in-house data on costs.

The discussion in Section 3.4 on product models developed during design and updated during fabrication and operation and used during the life cycle – and, hopefully, feed-backed to designers, is important. It is therefore unfortunate, as mentioned by the Committee, that intellectual property rights cause problems in implementing the ideal system.

1.1.5 Optimization Development

A core feature of design is to determine a layout/arrangement, scantlings, that satisfy all design targets in an optimal manner according to a certain measure such as life cycle costs. Normally the solution space is given by a global layout – and to compare different layout require specifications of different initial layouts. Hence, formal methods of optimization are useful towards this aim. The Committee devotes a significant part of their report to Optimization developments.

To obtain reliable results by optimization, it is important that all serviceability and safety constraints as well as objectives are explicitly accounted for. While traditionally cost has been an important objective, call for sustainability implies that energy use, emission of GHG etc., need to be included as objectives or at least as constraints. Regarding cost criteria yards might be interested in production costs, while in principle for serious owners (not speculating in using the structures for a limited time, and hence, not focusing on longterm endurance) the costs in a service life perspective would be the relevant criterion. Life costs include inspection/ monitoring, maintenance, repair and offhire costs.

Even only considerations of optimal fatigue design of ship hulls in a lifecycle perspective for the owner or a regulatory body, is very challenging because it requires estimation of manufacturing, maintenance and repair costs as a function of detailed design and sometimes global design – affecting the nominal stress levels. Operational experiences are also crucial to "calibrate" e.g. structural reliability predictions of failure probabilities needed in such analyses.

If the design is based on direct analysis of load effects, resistance and use of a goal-based setting with safety in terms of reliability or risk acceptance, the computational effort becomes excessive. With reference to a 3D structural model, and a long term model for the wave conditions, and accounting for uncertainties in load effect models and resistance (in a reliability context) an analysis of a given vessel is very demanding; and even more so repeated analysis to find the optimum. Again it is important that the uncertainties in the design analysis methods used in the optimization, are sufficiently small to provide confidence in the optimization.

Section 4.1 deals with a generic approach to design support systems- coupled to optimization - based on a few publications. The description is centred on MAESTRO/OCTOPUS software. It would have been interesting to compare the methods described herein with those of the classification societies in Ch.6.

The continuous development of computer hardware is a basic enabling technology for analyses for design– initially for finite element methods, later for CFD and e.g. probabilistic approaches. In Section 4.2 hardware developments are briefly describing new developments such as parallelization, graphical processing units, addressed by exemplifying available hardware in some universities. Quantitative measures about the development of computational capability would have been interesting to see.

In Section 4.3 the Committee mentions that the practical use of optimization methods has been slow and that virtually no new method has been proposed since 2011; i.e. in the current ISSC period. However, the Committee lists 16 case studies which among others have been presented in 33 cited papers, illustrating the use of different optimization methods. Hence, it would have been interesting to know more specifically what has been achieved in terms of reduced costs/ improved environmental impacts in (some of) these studies – relative to those achieved by a "student designer" and an experienced designer, as well as an idea about the assumptions made in those optimization studies regarding constraints: ultimate strength, fatigue – mentioned for some cases; inspection/monitoring, maintenance and repair issues; environmental impact – during fabrication and operation.

The Committee also mentions an interesting thought of using optimization methods interactively with designers – knowledge. It would be interesting to pursue this thinking further – e.g. to establish an experience basis based on systematic optimization studies to guide "best" design without having to carry out the optimization analysis in detail. This approach would then be analogous to the simplified methods validated by advanced methods in mechanics. Considering e.g. structural design one might imagine to start with ultimate strength checks – for an intact and damaged structure and then fatigue design check (of structural details, welded joints) in a life cycle perspective, possibly with an iteration on the effect of global nominal stress level on fatigue.

Finally, it would be interesting to have the Committee's view on the further development of optimization methods for ship structures and their application in practice.

1.1.6 Classification Society Software Review

In Chapter 5 the Committee provides a useful overview of software for structural assessment (SA) and project lifecycle management (PML) by 10 classification societies (CS'). To some extent this software relates to that reviewed in Chapter 3. This link could have been elaborated on. The review deals with the functionality, global/local component assessment, input (geometry...) mode, capability of FE methods used, data communication of structural assessment tools. What about the availability of post-processing features– in view design checks? The assessment of PML includes information taken into account, database structure, communication between various stakeholders in the life cycle – and link design with fabrication and operation; e.g. relating to fatigue and corrosion. Even if the Committee devotes nearly 15 pages of their report on the software, it is still an overview, without going into many details on the actual features of the methods used.

Still this kind of review task is very demanding and depends on close interaction with the classification society – especially if the classification society is not represented on the Committee. The comparison might easily be biased also depending on the experience of those who do the study as well as the contact person in the CS. The Committee therefore also emphasizes that it is not a benchmark comparison.

It seems that the review touches upon both traditional Rule based and goal based design using first principles. A better clarification of what kind of approaches offered by classification societies for would have been useful – in view of the fact that goal based approaches are being introduced. There are limited details about metocean database, calculation of wave-induced loads, still-water loads, ultimate strength and fatigue analysis procedures possibly used in design based on direct analysis. Such methods are only specified by the name of the corresponding software. I also missed comments about possible structural damage tolerance and stability criteria (stability is only mentioned for some CS'). Mostly common ship types: tankers, bulk-carriers and cargo ships are covered. Some classification societies also deal with e.g. container vessels and LNG vessels. User friendliness would have been interesting to know but is of course difficult to objectively assess, without significant efforts.

Outfitting (machinery, propulsion, rudder,) and vibration and noise are only briefly mention for some CS' and it is hard to get an idea about the status.

Maybe a more focused benchmark exercise with a more narrow scope could be a future effort by this or other committees depending on the topic.

In general, the chapter on CS software only gives an overview of features in various modules (mentioned by their name) in the software packages. It would have been nice to have (scientific) references to the theories (theory manuals) implemented in the various software packages. Do the software packages contain this information?

In Chapter 5 there is no mentioning about reliability based design, not even semi-probabilistic ULS design check or reliability based structural integrity management, including e.g. fatigue considerations. This is in contrast to the mentioning in Chapter 2, 3 and 4. Could you comment on the status of reliability based design in practice?

The Committee mentions in the conclusions of Chapter 5 that some information about optimization capabilities was gathered. Could you elaborate on that statement and especially whether the CS' include such software?

1.1.7 Structural Lifecycle Management

Under the heading Structural Lifecycle Management (SLM), the Committee discusses some design aspects relating to tools, data interchange, standards as well as repair and health monitoring. Most of the text is devoted to some comments on selected research papers, relating to naval vessels, merchant vessels, diving vessels, offshore FSRU, pipelines, flexible risers and wind turbines. It is clearly interesting, say, to review merchant vessel SLM in view of practices e.g. in view of naval vessels and other marine structures. However, since the review involves only a few papers in each area and there is a limited discussion about the differences between the various structures and hence the need for different methods, it is hard to judge how new research results could be used to improve industry practice, e.g. for merchant vessels. Moreover, it would have been more clear if the discussion relating to merchant vessels had been separated into hull structure and propulsion/machinery system, because of their different features and modelling of such systems. Moreover, practices for hull structures could be compared to that of other structures while propulsion systems have resemblance with e.g. the drive-train of wind turbines, even if there are scale effects. It would also have been good to relate the research papers to the state of art practice e.g. by the classification societies.

In the section on Tools, the Committee reviews briefly many (research) papers on reliability based monitoring, maintenance etc., and conclude that this knowledge can be used for improved system performance, but it is hard to see how this will be realized – in view of current practices – for hull structures and propulsion/machinery systems.

In the section on Data the Committee highlights the data interchange between the design and operation phases, but the fabrication phase is also of interest – where initial design data will be modified;

based on the material and geometry of the as-built structure. While obviously data for each structure is needed, use of data (especially relating to failure and damages) of other (especially sister ship) structures, is also of interest. The challenges in striking a balance between sharing data between the stakeholders involved in the lifecycle and protecting the "IPR" of the data, and standardization of data bases, are well taken.

In the section on Integration with repair, the Committee touches upon research papers relating to very different types of structures and without separately referring to hull structures and propulsion/machinery. The challenge here is that damages and corresponding repair range from cracks/local corrosion to the damages e.g. associated with grounding. It implies that besides planning of repair at the design and when damages have occurred during operation, it could also be a matter of planning (emergency) actions to limit the progressive damage development. Obviously, linked to the mentioned issues, are also the design criteria applied to ensure damage tolerance or robustness.

Structural health monitoring (SHM) is concerned with structural damage detection and characterization. Often SHM is associated with continuous (instrumental) monitoring, as opposed to damage assessment by (human) inspectors. While monitoring (in that sense) is relevant for machinery and electrical systems, inspection is most relevant for hull structures. It would be interesting to have the Committee's view on possible monitoring of ship hull damage as such beyond say leak detection in connection with cracks. Another matter would be to apply hull monitoring of motions (accelerations) and "nominal" strains (stresses), which in combination with sea state forecasts, could be used to ensure ship operations maintain global loads at an acceptable level. Measurements of stresses could also be useful in controlling that the stillwater load conditions is according to the plan. In the section on Integration with SHM, the Committee reviews research papers relating to "electrical system", pipelines, riser and power umbilicals and briefly hull inspection. It would have been useful if the Committee had related the new knowledge provided through the research papers, to the state of the art within monitoring and inspection relating to structural damages in terms of cracks, corrosion and accidental damages, especially of hull structures, and possibly suggest improvements of the current practices.

1.1.8 Obstacles, Challenges and Future Developments

In Chapter 7 the Committee highlights the need for integrated life cycle analysis, risk- and goal-based design approaches, numerical models and classification societies'software. Many of the research topics dealt with have been researched for years. Yet the Committee mentions that most of the papers reviewed contain approaches in early stages. It would therefore be interesting to have a comment on to what extent the 200 + publications reviewed for the last ISSC period have contributed to the progress in those directions – i.e. especially life cycle approach, goal and risk based design.

Which contributions do you consider as the most significant R&D results in the last ISSC period – in terms of industrial application?

In this chapter the Committee also reverts back to the design-for-X principles that were mentioned in the introduction. However, a main issue is to accomplish a design in which a balance between all targets is achieved?

The Committee's comments on SHM in Chapter 7 are unclear. While e.g. accelerations and strains can be used – to monitor the overall ship hull, it would be interesting to have the committee's opinion on what kind of monitoring they envisage for various kinds of damages on the hull structures, possible special hull components and machinery, respectively, or whether they would rely on inspections ? What about monitoring by a leak (before break) approach?

In Chapter 4 the Committee discusses inclusion of risk and reliability measures and mentions in Chapter 7 that "many rules are moving toward a probabilistic foundation". However, such methods are not mentioned in connection with the classification societies' tools (Chapter 5). What is actually the current status and what is the next step – using recent research results?

The Committee also mentions the rapid development of numerical methods for determining hydrodynamic, accidental and other loads, structural load effects, ultimate and fatigue strength, structural reliability etc., by different organizations and especially classification societies. While apparently the same methods are used, there are differences that need to be identified by benchmarking. The growth of complexity in software also inceases the chance of errors in the software systems. Most of methods are subjected to scrutiny by other ISSC committees. However, stability criteria and analysis would probability be a topic for the design methods committee. In most disciplines there is a hierarchy of methods and modelling approaches. The issue raised from the design point of view by the Committee about the choice of level of refinement is therefore important. An assessment of the uncertainties inherent in different methods is also important – and actually the basis for reliability based design. The need for authoritative determination of uncertainties in the different methods may suggest use of expert committees and calibration of semi-probabilistic codes for use in design rather than using direct reliability methods.

The Committee also comments on the need for standardized data base models and efficient data transfer between different software, use of graphical processing units and hardware.

1.1.9 Conclusions

In Chapter 8 on Conclusions the Committee summarizes several trends in the development of design methods: risk- and goal-based design, life cycle system integrity and sustainability management.

The main focus is on convergent design – culminating with using optimization methods – to determine cost-optimal design with a given overall structural layout.

Besides the comments given to the specific parts of the report throughout my discussion, I have a few additional comments:

Maybe the Design Methods Committee can also address design methods for innovation, that create a divergent design space – i.e. with different layouts – and result in commercial, novel designs. At least it would be good to include in the review novel concepts that have appeared. The mentioning of novel concepts – form a basis for further developments of the methods used to assess convergent design of the novel concepts, and, hence, proving a marked pull for developments.

Research efforts to develop new and improve existing methods for design to deal with structural serviceability and safety as well as sustainability will continue. In this connection it might be useful to review design (principles and) methods in other engineering areas with the purpose of implementing relevant approaches to the ships and offshore area. This applies to LCA, LCC and risk- and reliability methods, structural life cycle management etc e.g. from the offshore oil and gas industry.

In general, it is one of ISSC committees' tasks to identify knowledge resulting from research which is novel, validated and relevant for use by the industry and regulatory bodies. It is important that the Committee highlight the papers of greatest potential value for the users. Besides providing information from research in terms of research papers, research results might be disseminated in a more easily accessible way for users, in the form of standards and guidelines for data bases and methods. Moreover, experiences, e.g. with the introduction of FE methods (for linear structural analysis) in practice, show that it is very important to include the new knowledge together with other documented facts in university curricula – so that graduates bring the new knowledge to the industry and missionize for its use. This is a challenge for educators.

I would again like to congratulate the chairman and the committee members for their comprehensive and insightful report and welcome their supplementary comments.

1.1.10 References

EU 2015. Horizon 2020 Work programme 2016-2017. Smart, green and integrated transport. Brussels.

ISO 19900.2013.Petroleum and natural gas industries – Specific requirements for offshore structures

ISSC IV.1, 2012. Report of ISSC Committee IV.1. Design Philosophy and Principles (2012), with Official discussion (2014). Proc. 18th ISSC, STG, Hamburg (W.Fricke, R. Bronsart, eds.)

ISSC VI.1, 2006. Report of ISSC Committee VI.1 Reliability based structural design and code development. Proc. 16th ISSC, University of Southampton. (P.A.Frieze and R.A.Shenoi, eds.)

Levander, K. 2012. System Based Ship Design, SeaKey Naval Architecture. Norwegian University of Science and Technology, Trondheim, Norway.

Norsok N-005. 2015 Integrity management of structures and marine systems, Standard Norge, Oslo.

2. DISCUSSION

2.1 Official Reply by Committee IV.2

The committee would like to thank Professor Moan for his detailed review of our report, and his helpful suggestions both for enhancing our report via this response, and for future IV.2 committees. We fully acknowledge his first comment that we restricted the scope of our report to ships, to the exclusion of offshore structures for oil, renewable energy, aquaculture, and other marine applications. This was a reflection of the composition of the committee, which unfortunately did not include experts in these areas able to add value to the literature mentioned. For future committees, we do recommend that they cover these areas and work with the standing committee to ensure the committee's membership covers such disciplines.

Several of Professor Moan's comments also relate to the mandate. More specifically the division of labour between Committee IV.1, on design principles, and our own on design methods is discussed. This is a tricky balance to get correct – of course the principles directly influence the development of methods, whether they are software tools or design approaches. It would have been better to more formally delineate our scope, and provide a few critical cross-references to the work in IV.1 in the introduction to IV.2, so that the reader would better appraised of where to find each type of information. Our intent was to cover major development in design tools, as well as broader issues that arise from the development in tools – such as IP protection in lifecycle models – while leaving the principles and regulatory framework developments to IV.1. In this approach, we intentionally did not review the work in goal-based standards, risk-based design, and sustainability except as it has been translated into specific design tools or published design methodology studies. From the chair's perspective, closer ties with Committee IV.1 through the initial period of ISSC would have made this division more distinct and understandable to the reader, and we will seek to do this in the future.

Professor Moan's comments on Section 2.2 of our report highlight this difficult division. The committee is fully in concurrence with Professor Moan's view that how to integrate risk-principles at different stages of design is still an open question. The continued focus on Design-for-X, where X is usually a singular discipline is a strong indication that design tools do not yet included holistic risk approaches – ones where different types of risks are balanced together. This is an area where both tools and processes still appear to be lacking. For offshore structures, a specific and detailed FSA may attempt such a balance, but the economic case for performing a specific FSA for each ship design appears unlikely to be made. The idea of applying FSA at the rule-making level has received much wider support, especially in the European research community. However, such approaches would fall under the mandate of Committee IV.1, not IV.2 in the current ISSC structure. Design tools could then be developed to suit these types of rules, if they end up differing from what we are using today. Structural reliability in design suffers from similar challenges – who will gather and validate all the uncertainty models and data? How often should such data be expected to change, from changing steel mills to changing global climate? It does appear that our ability to perform the reliability mathematics is now adequate for a wide range of design activities. However, validated and certified uncertainty model inputs to such calculations are largely lacking. And it remains unclear who should be gathering and certifying this data.

In our committee's discussion, a similar area which seems to be neglected in terms of frameworks, tools, and data, is the end-of-life phase for the structure. Ship structural optimization is primarily based on operational requirements formulated by the ship owner, classification society's rules, international regulations such as IMO codes etc. and technological requirements specified by the shipyard. The final phase of a ship's lifecycle i.e. recycling is usually not included into this process. Ideally, both design tools and optimization methodologies would be able to quantify if the design is environmentally friendly, safe and easy to recycle. Additionally, tracking information about the quantity of materials available non-hazardous, hazardous materials; steel, non-ferrous metal and other scraps for example) on an end-of-life ship as well as their spatial distribution should be linked to PLM approaches.

Professor Moan's comments on Chapter 3, dealing with design tools, are also welcome. We understand that the division between Chapters 3 and 5 may appear artificial. However, we selected the classification tools for particular analysis in Chapter 5 for several specific reasons:

1. While yards and owners have wide latitude in choosing software used for design internally, once a classification society is selected, both the owner and yard are locked into that society's software toolset. Hence, a more detailed review and comparison of these tools seems warranted.
2. Class has a unique role, operating through design, construction, operation, and disposal of the vessel. Class is also nominally independent of many of the IP issues raised by owners and shipyards. Thus, in confronting the data exchange and IP issues surrounding lifecycle structural management, it is natural to pay extra attention to class.
3. This committee had previously reviewed class software in 2000, just after class societies transitioned to supporting automated application of design rules and automatic FEA model construction. Given the current focus on lifecycle support, it seemed appropriate to see if class is responding with similar tools for the lifecycle problem.

In the 2012–2015 review, we concentrated on a wide but therefore shallower review of the software offerings. This approach yielded information on which topics are now well supported, and which topics are lacking consistent support. It is our hope that future ISSC IV.2 committees would use this overview to select specific topics to perform a more detailed comparison.

The committee does not agree with Professor Moan that the design tool focus should be restricted to "product models, integrating tools ('monolithic naval architecture packages'), including optimization and maybe stability". While it is true that the committee cannot perform in-depth reviews of the specific analytical models in all tools reviewed, we do find value in looking at the bigger picture of how the tools interact in design. Specifically, from our report it is apparent that designers are seeking simplification, not higher fidelity, from spectral fatigue analysis tools. Several different organizations proposed such simplifications in the 2012-2015 period. Similarly, while we did not delve into the details of geometry representation in our work, we did comment that many practitioners are rebelling against NURBS surface. This revolution is another example of a high-fidelity approach (NURBS) struggling to support rapid changes and the low information environment in design. The balance between the amount of information required to use a tool and tool fidelity is constantly in flux. We hope that experts in specific technical communities and ISSC committees will find such commentary useful as they consider benchmark studies, tool development, and future research tasks.

We appreciate Professor Moan's remarks on optimization. In the structural domain, the impact on the structure for sustainability has been debated. In terms of contribution to hullform resistance and GHG emissions, the importance of structural weight varies with vessel speed but is generally small. However, in accidental situations, the structure's ability to withstand accidental limit states is highly significant to the ecological impact of the accident. As the committee has noted, the ability to trade between different areas of environmental performance has not widely been explored. In the move from prescriptive to risk-based approaches this gap is a potential stumbling block. While it is tempting to convert all negative effects into monetary or life-impact terms, such a conversion requires another set of assumptions and calculations. More research and proposals for evaluation frameworks in this area would be most welcome, and is a natural area of cooperation between Committees IV.1 and IV.2.

We fully support Professor Moan's comments about the evaluation of optimization results. While we did present 33 papers, these papers did not form a comprehensive or comparable set of benchmark results. When each author develops a variant of an optimizer, and compares it to a limited number of design problems unique to the author (often without listing the performance of a design made without optimization but with an experienced designer), it is very difficult to compare optimizers and formally assess the progress of the field. This is an area in which an ISSC benchmark would be most welcome. Even setting out a family of problems to be solved or used in future papers would be a major advancement for the optimization community.

In terms of future development in optimization, the committee sees a number of growth paths at the present time:

1. **Focus on decision support, not providing final structural designs directly:** We are seeing increasing attention paid to efficiently displaying trade spaces, including decision uncertainty, and post-processing of optimization results to reveal underlying trends and relationships in the design space. Collectively, these techniques mark the end of the era of trying to build all the design intelligence into the optimizer, so the optimizer directly synthesizes the final structural design. Now it appears that allowing the optimizer to educate the design team about the design space being explored, and collectively making better design decisions is the goal.
2. **Expansion of optimization beyond structural configurations:** Increased interaction with hull shape, internal layout options, and wider aspects of the vessel design are now becoming common. These developments are exciting as they are showing that there is significant room to improve structural efficiency when additional design variables are involved (e.g. number of decks, gross dimensions).
3. **Increased interest in lifecycle performance optimization:** Following the increased interest in lifecycle modelling from all phases of the design process, there is increased interest now in optimizing such models. Despite this, shipyard-driven optimization is likely to still focus on new build cost unless a standard for evaluating lifecycle performance is both adopted and requested by owners during the design process.
4. **Novel decomposition of the problem:** The overall ship and structural design problem is of such as scale that monolithic optimizers struggle to operate efficiently. There is growing interest in applying collaborative optimizers or other decomposition-based optimizers to the problem, and then solving the resulting series of coupled sub-problems. Formal evaluation of the efficiency of such approaches is eagerly awaited.

As noted above, for the classification society review, we focused on an overview of the current state-of-the-art. Given the broader ISSC's mandate, we excluded stability, machinery systems, and outfitting from our review. It is apparent from the review that there is a community consensus on what tools a classification society should offer. Performing initial rule-based designs with semi-automated rule support was first seen in the 2000 committee's review of these tools. Support for such rule-based calculations continues to be a consensus position today. As such designs are often the starting point for optimization and more detailed analysis, clearly the continued development of rule-based approaches matters to industry. Linear FEA, spectral fatigue, and some sort of lifecycle PLM support are now offered in some capacity by all societies. Support for optimization is frequently mentioned but uneven at this time between class societies. Optimization for cost or performance clearly crosses a boundary between class as an impartial regulatory or approver, and class as a consultant helping the owner or yard increase profitability. Many societies are attempting to separate this consulting from approval, yet seek streamlines software capable of working across both sides of this divide. Future ISSC committees could conduct more focused benchmarks – e.g. on the optimization, PLM features, or the FEA modelling approach, of the tools within the time and scope allowed for the committee. We hope our overview here will help guide future detailed benchmarks in this area.

The Committee appreciates Professor Moan's comments on lifecycle management and SHM systems. It is clear from the literature that monitoring of rotating machinery and mechanical systems is more advanced than monitoring of ship structures. This is especially true when it comes to diagnosis of condition and prognosis of future failure. Hence, we attempted to blend a bit from each domain in our report, as the developments in machinery monitoring can help forecast how structural monitoring and diagnosis may develop. We do agree that long-term prognosis and short-term damage/accident response are different, and there is an active need in industry for each. We appreciated the close tie with inspection and online crew feedback systems; here we left further development of these areas to specialist Committee V.7, Structural Longevity, after discussion with their chairman. However, like the ties with IV.1, we do agree that future reports should explicitly cross-reference other committee's reports where it makes sense.

In future developments, Professor Moan makes the point that many of the topics both within the report and specifically discussed for future developments have been around for some time. This is indeed true; progress in structural design tools is generally slower than a single ISSC period given the complexity of the problem. However, we do believe that we are seeing several major developments come to fruition. Multi-objective structural optimization appears to be gaining traction, and in academic settings, addressing problems whose scale and complexity is increasingly relevant to industrial problems. There is increasing focus on lifecycle models, and fusing such models with large amounts of inspection data. While the papers reviewed do not outline a comprehensive strategy for implementing such fusion today, this is clearly a topic of growing interest. This interest can be seen in the large number of papers from shipyards, class societies, and academic institutions all focused on aspects of this problem. Indeed, this large-scale date fusion could replace classical reliability-based approaches to inspection interval planning. Classical models typically use limited inspection data and consider a smaller set of the overall structural failure modes. Such classical models for risk-based inspection are clearly more mature and robust today. However, even their uptake is limited, owing to complexities involved in deploying such a risk-based solution. This does raise the interesting question of whether the data fusion approaches being researched today are really a product of industrial need, or a product of having vast amounts of data and trying to figure out what to do with it.

These concerns tie into our comments on Chapter 7 which we regret seemed unclear. The committee does see a central challenge in structural lifecycle management is turning the data that can be gathered into improved decisions. At the present time, there are robust methods to monitor and record strains, accelerations, temperatures, sea conditions etc. onboard vessels. However, the committee still sees a gap in processing this data so that information relevant to the operation and maintenance of the vessel emerges – data is not yet useful information! For rotating machinery, spectral vibration signatures and temperatures can be used to diagnose machinery faults – e.g. bearings beginning to fail. Such methods are now commonplace for rotating machinery. However, given a one month or one year record of hull girder strains, the marine structures community lacks established and validated methodologies to forecast future structural failures or update hull integrity models. We adopt the term "data-to-decision problem" for this situation following the lead of the civil engineering monitoring community (Collette and Lynch 2013). We see this as an area where more work needs to be done.

The committee appreciates Professor Moan's comments on the importance of cross-discipline comparisons – e.g. with other industrial sectors, and hope that future IV.2 committees will attempt such a comparison. We also see the value in highlighting critical papers – in our report, we attempted to do so by distilling themes we saw present over multiple papers, and then only including references to the most relevant papers in our work. Perhaps owing to the scope of the problem of design tools, we found few papers that readily gave such a high-level view of the evolution of the design systems, and instead attempting to use our report to provide this information. We thank Professor Moan for his detailed and comprehensive review of our report.

2.2 Reply to Floor Comments

No written floor comments were received.

2.3 Reference

Collette, M., and J. Lynch. 2013. "Lifecycle Support for Naval Ships Based on Structural Health Monitoring: Data to Decision Strategies." In *ASNE Day 2013 Proceedings*. Crystal City: ASNE.