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Volume 3

Edited by

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and

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PREFACE

The 18th International Ship and Offshore Structures Congress (ISSC 2012) was held in Rostock, Germany, 09-13 September 2012.

The Proceedings of the Congress consists of three volumes. Volumes 1 and 2 contain the reports of the Technical Committees and the Specialist Committees. This volume 3 includes the discussion of these reports and the replies of the committees.

The Standing Committee of the 18th International Ship and Offshore Structures Congress comprised:

Chairman:	Wolfgang Fricke
	Jørgen Amdahl
	Yoo Sang Choo
	Weicheng Cui
	Chang Doo Jang
	Segen F. Estefen
	Carlos Guedes Soares
	Mirek Kaminski
	Merv Norwood
	Michel Olagnon
	Roberto Porcari
	Manolis S. Samuelides
	Ajit Shenoi
	Jack Spencer
	Yoichi Sumi
Secretary:	Robert Bronsart

On behalf of the Standing Committee, we would like to thank Germanischer Lloyd, Det Norske Veritas, American Bureau of Shipping, Lloyd's Register, Nippon Kaiji Kyokai and Bureau Veritas for sponsoring ISSC 2012.

Wolfgang Fricke	Robert Bronsart
Chairman	Secretary

Rostock, Mai 2014

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KEYNOTE LECTURE

GL-Group – Safer, Greener, Smarter

Mr. Erik van der Noordaa, CEO GL Group, Hamburg

The following presentation gives an update on the recent developments and activities of Germanischer Lloyd SE.

During the last years, Germanischer Lloyd has been transformed into a global operating group focussing on the Maritime Industry, Oil & Gas and Renewables.

The presentation focuses on this transformation. It gives a detailed service portfolio of all three business segments (Figures 1 - 4) and addresses a number of research & development topics relevant to the work of ISSC.

The focus of Maritime Research and Rule Development is based on three objectives: Safer, Greener, Smarter (Figure 5):

- *Safer* stands for reducing the risks in shipping.
- *Greener* stands for assisting our clients in reducing emissions and by doing so protecting the environment.
- *Smarter* means supporting our clients in operating their assets efficiently.

In addition to these three objectives, we distinguish between long-term research - exploring new technologies - and short-term developments focussing on product development and enhancement.

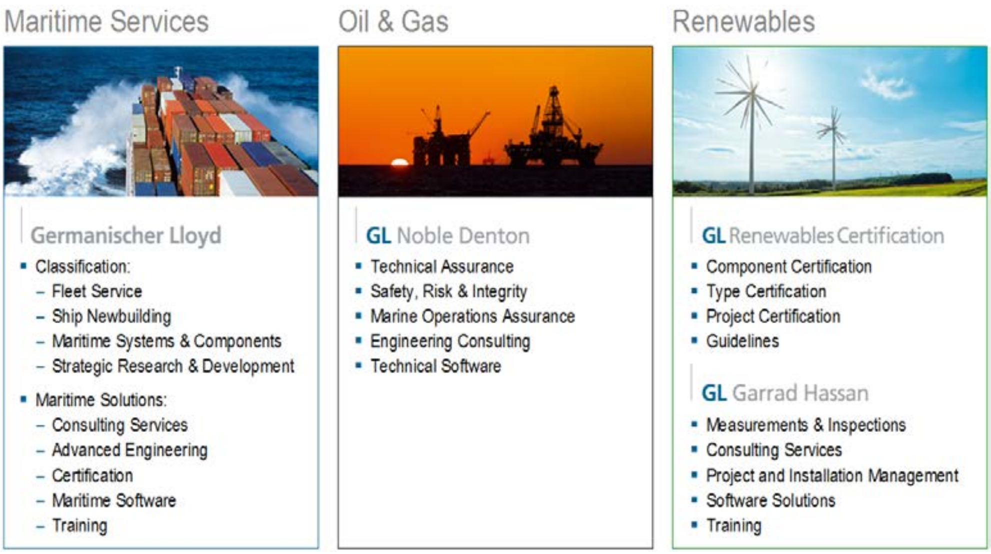

Figure 1: GL Group business segments

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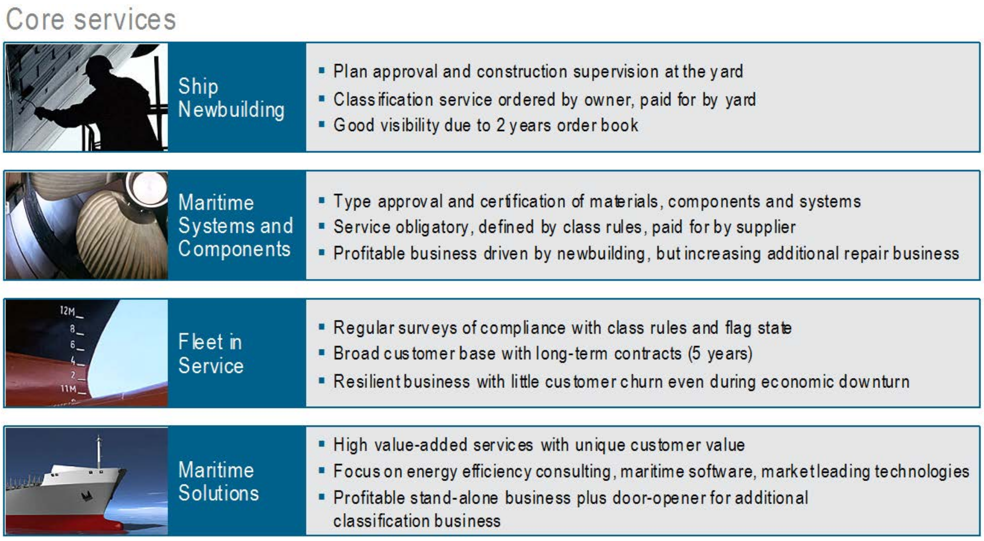

Figure 2: Maritime Services portfolio

All of the selected topics are supported by a project plan incorporating a timeline, deliverables and objectives. The selection of the topics was a result of an intensive exchange between our experts, the industry and knowledge institutes.

Traditionally, GL supports R&D for joint industry and public funded projects.

GL's typical objective in these projects is to explore new technologies for later implementation by our customers resulting in new rules & regulations, services or software tools.

GL focuses on all ISSC technical committee key areas. This applies to core competencies like predicting wave-induced loads on ships and the structural response of the hull.

Figure 3: Oil and Gas Service Portfolio

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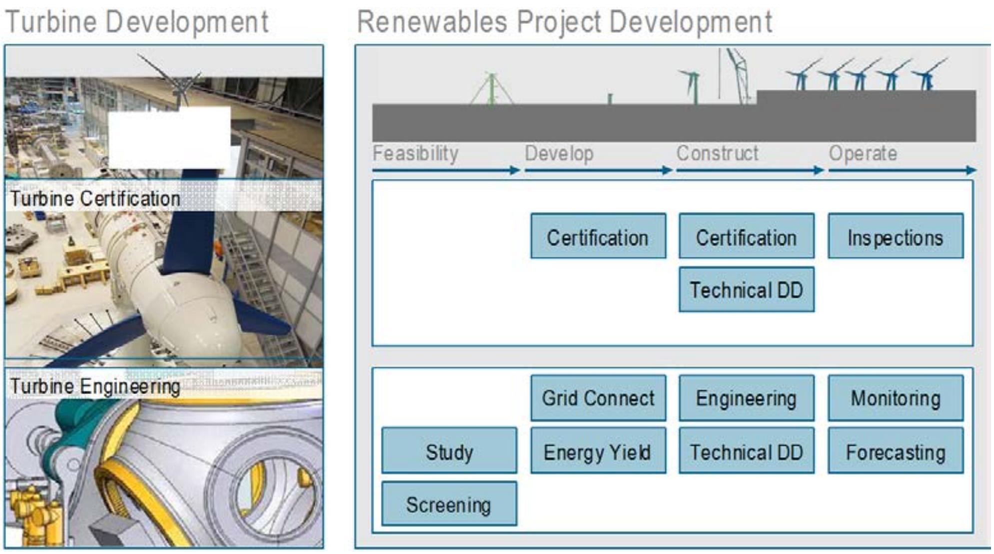

Figure 4: Renewables Service Portfolio

Recently, GL participated in developing concepts for future designs. Our focus in these projects is to integrate several technologies into one concept.

However, GL does not have any ambition or intention to develop designs. We will concentrate on concepts and improvements only.

ISSC also focuses on other topics through specialist committees, three of which are also addressed by GL: Damage stability of ships, LNG technologies and novel materials.

Additionally, GL pursues joint R&D projects addressing topics beyond ISSC's targets.

For example: Ship systems, which are of increasing importance to the performance of a ship, risk-based approaches including structural reliability assessments and onboard tools.

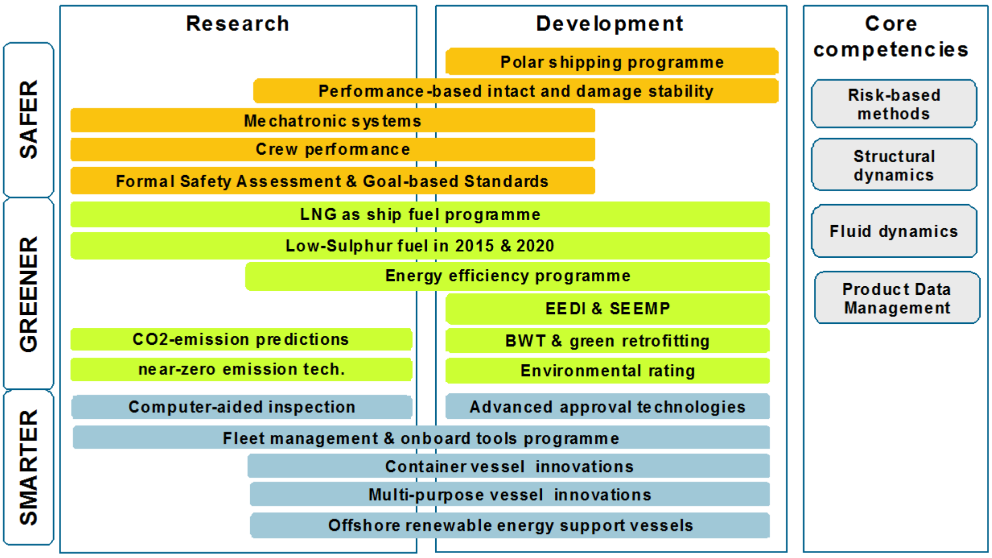

Figure 5: Maritime Service Innovation Map

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Figure 6: LNG as ship fuel – priority R&D programme at GL

LNG as ship fuel has priority at GL (Figure 6) since we consider this development one of the more important ones in this decade.

GL is actively engaged in advancing this technology in the following areas:

- Perform safety assessments of technologies for tank systems
- Contribute to the development of regulatory frameworks
- Assess the safety of new design concepts in cooperation with shipyards or designers
- Ensure the safety of the LNG supply and bunkering chain

As leading classification society for container vessels, our recent focus on LNG as ship fuel was dedicated to container vessel design concepts of various sizes (Figure 7).

Our first study was published in 2009 and it addressed a 1200 TEU feeder vessel.

Our latest joint development project resulted in an 'Approval in Principle' for a 13000 TEU vessel designed by IHIMU of Japan.

An 'Approval in Principle' documents technical feasibility for the addressed systems and outlines additional requirements which need to be addressed to achieve a final approval.

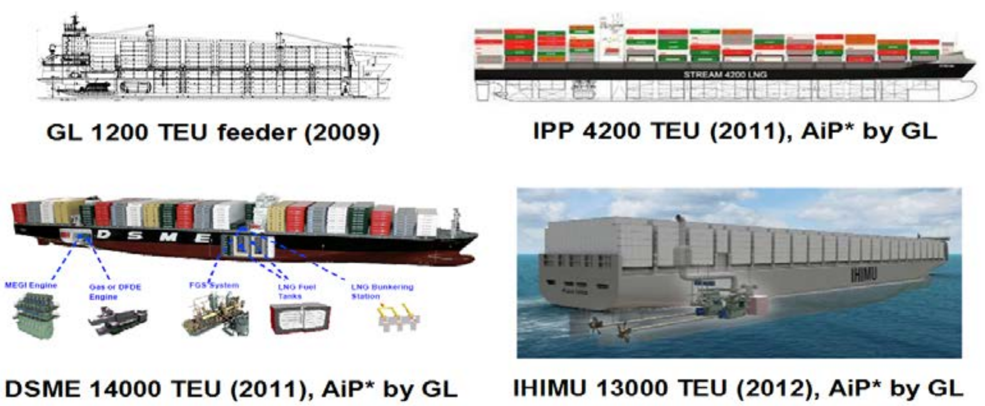

Figure 7: Projects exploring LNG as ship fuel for container vessels

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Ship and system design	Ship operation
• energy-optimal hull forms accounting for real sea states • performance of air lubrication and wind-power systems • energy-optimal ship system configurations • energy management systems accounting for multiple energy sources ("hybrid ships") • advancing the EEDI of IMO	• integrating real sea states into onboard decision-support tools • simulation of real-time energy consumption • collection and advanced analysis of voyage data

Figure 8: Ship efficiency - priority R&D programme at GL

In 2011, we participated in the conversion of the product tanker Bit Viking.

Delivered in 2007 by China's Shanghai Edwards shipyard, Bit Viking was built with double engine rooms, propellers, steering gears, rudders and control systems.

Having previously been powered by two 6-cylinder in-line Wärtsilä 46 engines running on heavy fuel oil, the conversion has changed these engines to Wärtsilä 50 DF dual-fuel engines capable of operating on LNG supplied from two 500-cubic-meter LNG storage tanks on the fore deck. The two LNG tanks enable the vessel to sail on LNG for 12 days.

The Bit Viking is the world's first vessel converted to run on LNG while in service.

After successful sea trials under GL supervision, the vessel has resumed commercial trading.

Another very interesting project is the newbuilding of an OSV at STX Finland for the Finnish Ministry of the Interior which will be launched in 2013.

This highly sophisticated vessel is incorporating three LNG-fuelled main engines as well as LNG-fuelled auxiliary engines.

Figure 9: New EU-funded R&D project CyClaDes – Crew-centred design and operation of ships and ship systems

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Increasing the efficiency of ships is another priority of our R&D, Figure 8. We are successfully advising our clients in optimising ship designs and running their vessels with optimal trim.

Our R&D department focuses on next generation technologies such as including real sea conditions in the optimisation; designing and running complex ship systems in an energy-efficient way; and looking at technologies to reduce required power or deliver additional power.

At the same time, we actively engage with IMO to advance the EEDI for other ship types and to have new technologies included.

With an increasing number of vessels sailing in ever more confined waters, performance of the crew is high on the agenda.

At the same time, new navigational aids are introduced and ship systems in general become more complex.

Under the EU-funded project Cyclades, GL teamed up with a large group of designers, suppliers, institutes and universities to explore, which technologies could support crews in reducing human failure (Figure 9).

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09-13 SEPTEMBER 2012
ROSTOCK, GERMANY

VOLUME 3

COMMITTEE I.1

ENVIRONMENT

COMMITTEE MANDATE

Concern for descriptions of the ocean environment, especially with respect to wave, current and wind, in deep and shallow waters, and ice, as a basis for the determination of environmental loads for structural design. Attention shall be given to statistical description of these and other related phenomena relevant to the safe design and operation of ships and offshore structures. The committee is encouraged to cooperate with the corresponding ITTC committee.

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1 DISCUSSION

1.1 Official Discussion by Sverre Haver

1.1.1 Introduction

As a member of this committee for the period 1994 – 2000, it is a great pleasure to have the opportunity to review and discuss the report of Committee I.1.

As stated in the mandate, the committee report deals with a broad range of environmental subjects being of concern for operation and design of ships and offshore structures. The mandate is very wide and involves topics well outside the area I am familiar with. In this discussion I will focus on the subjects I am most familiar with.

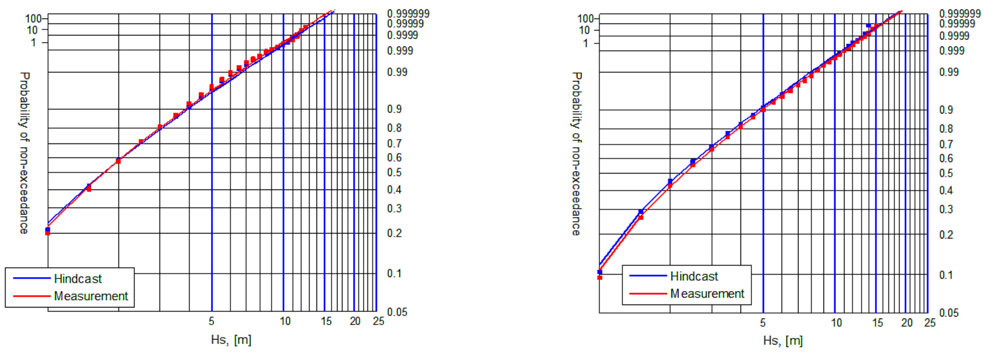
The present report fulfils the mandate with good margin. A large number of references are included for most of the subjects included in the mandate. The committee work is documented by a thoroughly written report.

I will congratulate the committee members with the report they have prepared. They have continued the ISSC tradition of solid review reports. In the end of this discussion, however, I will permit myself a brief discussion of the mandate for the committee and the interpretation of the mandate.

1.1.2 Sources of Environmental Data

This is an extensive review of availability of environmental data. I do not have much to add.

The committee correctly points out that the issue of data ownership remains a problem. In that connection I will draw the attention to the new Norwegian Hindcast Data Base, NORA10. This data base is also referred to by the committee. The reason for mentioning it here is that these data are to my knowledge open to all for a rather low cost. The data base provides wind and wave data at 3-hourly intervals from 1958 to present and covers North Sea, Norwegian Sea and Barents Sea. Comparisons with available measurements suggest that both wind and waves of the data base seem to be of good quality, see Figures 1 and 2. It is seen from Figure 2 left that when hindcast is compared to measurements from a weather mast, excellent agreement is observed. At the right of the figure results are shown when hindcast data are compared to measurements from a large platform. Hindcast data are apparently on the low side



Ekofisk, North Sea **Haltenbanken , Norwegian sea**

Figure 1: Comparison of distribution function for 3-hourly significant wave height for NORA10 and measurements (Ref. In-house Statoil report)

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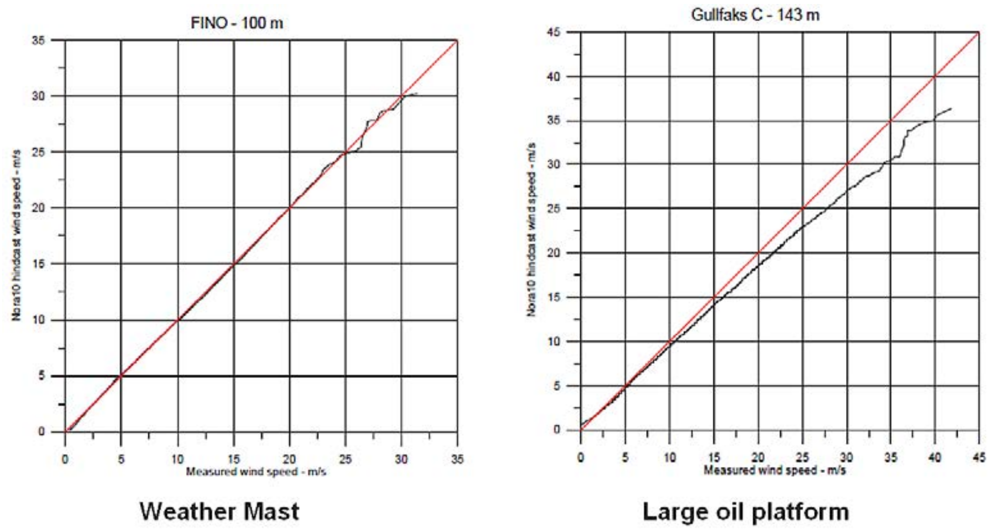

Figure 2: q-q plot for hindcast and measured wind speed at two locations. (Ref: Inhouse Statoil report)

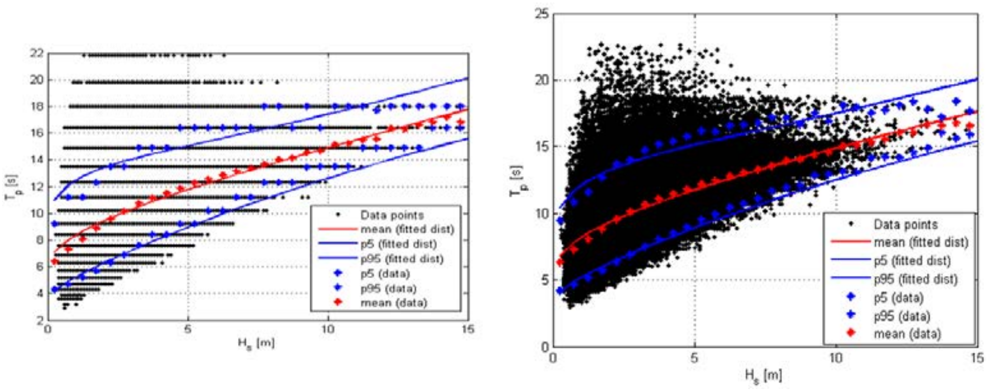

Figure 3: Scatter diagram for hs and tp before and after non-discretizing the spectral peak period.

regarding extremes. However, we think this is caused by the fact that the platform data are disturbed by the presence of this huge structure.

When using hindcast data for response analyses one should keep in mind that hindcast data bases usually will have a limited resolution regarding spectral peak frequencies. This is also the case for NORA10, see scatter diagram in Figure 3 left. If the problem under consideration has a critical frequency regarding amplification or cancellation, the spectral peak frequencies of hindcast data must be non-discretized prior to the response analysis, see Figure 3 right.

In Chapter 2.2.1 of the committee report, there is an interesting reference to an observation from Typhoon Krosa (Babanin *et al.* (2011a), see reference list of committee report). At 38 m water depth, a maximum wave height of 32 m and a significant wave height of 24 m were measured. These are rather extreme measurements in view of water depth. What type of sensor was used for measuring waves at this site? I guess that there must have been a considerable dissipation due to wave breaking in this area,

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ratio between maximum wave height and significant wave height is rather low if the time window associated with the observations at least is in the order of an hour or so suggesting that depth is clearly limiting maximum wave height. Are time histories for the surface process presented in the paper?

There is a comment at the end of Chapter 2.2.3 about bias in significant wave height when calculated from the zero-spectral moment as is done by the numerical wave models. Why is linearity referred to as the reason for this bias? The significant wave height calculated from spectral moment will be slightly biased (compared to the mean of the upper one third of wave heights) in a linear sea state also – I think? Is this bias (which must be rather small) of importance? As of today is it not most common to define significant wave height as 4 times the standard deviation (square root of zero-spectral moment)? At least I guess this is the case within the offshore industry? What would the committee prefer as the standard way of estimating the significant wave height?

I have a question regarding numerical modelling of current. Both wind - and wave hindcast have reached a level of accuracy making them applicable as data for design and operation of marine structures. Based on the review of papers and on-going research projects made by the committee is it is possible to give summary regarding the status of current modelling for the same purposes?

A final comment to this chapter is that data regarding marine growth is missing. Was this subject not prioritized (which I have full respect for in view of all subjects to be covered) or did not the committee find any data of interest? I think lack on marine growth data is a problem for design of slender structures in deep water? Will marine growth exist below $500\,m$ or $1000\,m$?

1.1.3 Modelling of Environmental Phenomena

This chapter gives a good overview of what has happened regarding this subject during the last few years. It is a rather extensive review. In view of my own primary interest, I found Chapter 3.2 very useful. I appreciate also that that several pages are spent on ice. I guess snow could also have been included. As the oil exploration moves into colder regions and ship traffic in the same regions also will increase, the future design and operation will definitely call for more and better information regarding ice, icebergs and maximum accumulated snow during heavy snow falls.

In this discussion, however, I will focus on the modelling of wind, waves and current. It is referred to in Chapter 3.1.3 that a joint modelling of significant wave height and wind speed have been presented based on the Nataf model. If one primarily is interested in rare combinations of these quantities, i.e. combinations corresponding to return periods well outside the time covered by the data, how adequate is the Nataf model for such an application? How close would contours based on CMA and Nataf be when applied to the same data set?

A considerable part of the wave chapter is devoted to freak or rogue waves. I appreciate that. The selection of references regarding this subject seems to give a very good overview regarding status. I think that the possible existence of wave events well outside our design scenarios is one of the few topics in Metocean for which the conclusion can have a significant impact on future design recipes and safety of existing structures.

Over the years, a number of reports have suggested the existence of wave events well beyond what is likely under the given weather conditions. The problem with observations of possible freak or rogue waves, however, can be illustrated by the following two

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questions: Is the observed event a very rare realisation from a typical, slightly non-Gaussian population of surface elevation processes (i.e. the observed value is merely a result of nature filling the tail)? Or: Is the observed event a typical realisation of a rare, strongly non-Gaussian population of surface processes? I think we will need an enormous amount of data before it is possible to conclude (with a reasonable confidence) to which question the answer is yes.

To me the solution to a conclusion regarding existence of freak waves lies in developing mathematical and physical wave models that have the potential of including freak waves among their population of solutions. Such models seem to be available, however, it is very difficult to anchor the occurrence of freak wave events to the physical quantities used in design. This should possibly not be surprising. A freak wave event is a rather local event (a spatial extension of some few wave lengths) and is also short lived (merely some few wave periods). So if the freak wave phenomenon exists, it is most probably a rare "instantaneous" combination of some sea state parameters within a limited area that is required to initiate a freak wave development. Sea state characteristics used in engineering are quantities averaged over 20-minutes – 3 hours, i.e. short living parameter combinations are smeared out over long time and – possibly – will not be recognised in the estimated engineering characteristics.

From adequate time domain simulations based on models including the potential of freak wave developments we could possible go back and identify some local governing characteristics immediately before the onset of the freak wave development. If we can identify a freak wave sub-domain of local characteristics, we could probably also empirically estimate the probability of being inside the freak wave sub-domain given the averaged sea state characteristics.

A forecast of freak wave occurrence directly based on averaged sea state characteristics (wave spectral shape or an associated kurtosis), I would not expect to be very robust.

In the end of the discussion of freak waves and breaking waves, the committee refer to a paper by Babanin *et al.* (2011b), see reference list of committee report), where it is suggested that the onset of wave breaking and freak waves are governed by the same physics. Onset of wave breaking is definitely governed by local characteristics suggesting that focus should also be on local quantities in order to explain onset of freak waves or rogue waves.

Breaking waves in deep water has got increasing focus in the offshore industry during the last few years. From model tests it is suggested that the impact pressure measured if a breaking wave hits a platform column is much larger than obtained using recommended practises and available standards, see Figure 4. The rate of breaking waves and type of breaking waves out in the open sea and the particle kinematics in connection with wave breaking is definitely of interest.

In Chapter 3.2.3 it is referred to the Crest JIP run by Marin. The last sentence of that paragraph could possibly be made more precise. I think Forristall 2. order crest height model was the best model also regarding field data? No better model was found, but the model was not the perfect model regarding upper tail. This can possibly be taken as an indication of the existence of crest heights beyond what is should be expected under a second order hypothesis regarding the surface elevation process, i.e. an indication of possible freak wave events.

Regarding current, I have mainly one comment. I would have appreciated some focus on joint occurrence of waves and current. Most joint data will be available for rather

		lower limit	upper limit	mean value
Sleipner	DNV	1076.5 kPa	1709.8 kPa	1393.2 kPa
	90% band	3273.1 kPa	3848.9 kPa	3561.0 kPa
	$\mathtt{err}_X$	+204.0%	+125.1%	+155.6%
Gjøa	DNV	892.0 kPa	2048.9 kPa	1470.5 kPa
	90% band	1336.0 kPa	4094.0 kPa	2715.0 kPa
	$\mathtt{err}_X$	+49.8%	+99.8%	+84.6%
Snorre	DNV	836.0 kPa	2079.9 kPa	1458.0 kPa
	90% band	1395.0 kPa	4782.0 kPa	3088.5 kPa
	$\mathtt{err}_X$	+66.9%	+129.9%	+111.8%

Figure 4: Comparison of 10^{-4} annual probability impact pressure estimated using a DNV-recipe and model tests, respectively. From: Clauss *et al.* (2010).

low and moderate sea states. In such conditions current speed and significant wave height appear to be more or less independent or very weakly correlated. When designing a jacket structure where extreme loads are governed by the drag term of Morrison equation, both waves and current are important. In Norway the standard approach is to combine 100-year wave and 10-year current in order to estimate the 100-year load. In other areas one shall use an adequate associated current together with the 100-year wave. How to extrapolate the conditional current statistics given the significant wave height estimated based on sea states up to $9\,m$ significant wave height to a significant wave height level in the range $15 - 20\,m$? This will be a challenge if it is to be based purely on observed data! Have the committee during their review of publications for the last few years seen any efforts regarding joint modelling of waves and current for extreme response predictions?

1.1.4 Special Topics

Climate Change

In next to last paragraph of Chapter 4.1.3 it is referred to a paper Vanem and Bitner-Gregersen (2012) (see reference list of committee report) suggesting an increase of significant wave height of about $2\,m$ during 21st century. Assuming this increase to refer to a 100-year return period significant wave height, we are talking about an increase of more than 10%. This result seems to deviate significantly from all other projected increases I have seen? How does this figure compare to other predictions? Is this methodology a pure statistical approach? Or is it anchored in a physical climate model? I think this result should be discussed relative to the various scenarios of IPCC. Does it reflect an expected change or is it a very pessimistic scenario?

CFD

Regarding CFD a computer code that is frequently used within offshore industry is COMFLOW developed by University of Groningen through a JIP. This program is using the VOF method. We have used the program for calculating loads on platform deck in case the wave crest height reaches the deck level. Compared to model test results, the numerical predictions seem to be significantly on the low side. However, we think this to a large extent is due to inaccuracies in the start conditions given to COMFLOW. We did specify a Stokes 5th order profile as start condition, but from the model test experiment it seems that the waves giving the largest loads are waves in the process of breaking.

This demonstrates that a critical part of a CFD analysis is the input conditions given. And realistic input is difficult to determine by simple tools. We will probably have to start the CFD calculations earlier while the target wave is reasonably close to a Stokes 5th order profile. This will significantly increase computation time.

The cases reviewed by the committee are they more or less idealised computations based on known initial conditions or are various approaches for determining proper start-up conditions discussed.

1.1.5 Design and Operational Environment

In 3rd paragraph of Chapter 5.1.1 it is said that generally the offshore industry considers instrumental data superior to model derived data. I think that statement can be questioned. At the Norwegian Continental Shelf this has been the case up to now, but with the introduction of NORA10 (the new Norwegian Hindcast Data base) we (Statoil at least) have changed our preference and are now using NORA10 for design purposes.

In the end of the paragraph the committee states that hindcast data for wind and waves are available for several basins worldwide. However, these data are generally not available for those that have not joined the JIPs paying for the hindcast. But regarding the Norwegian Continental Shelf and adjacent waters, NORA10 hindcast data are generally available for a limited cost.

In the 3rd paragraph of Chapter 5.1.2 it is said that uncertainties/errors in the estimated long term distributions often leads to gross errors in the predictions (of what?). What does the committee define as a gross error in the predictions? And how should we distinct between uncertainties and gross errors in the estimated long term distributions?

A joint long term environmental model will be difficult to establish if more than 3-5 weather characteristics are to be included. If more parameters must be included, a peak-over-threshold (POT) long term response analysis should possibly be adopted for estimating annual extreme value distributions for target response quantities. Instead of looking at 3-hour events (as is typical adopted when a joint environmental model approach is adopted) “short term events” are now represented by storm histories of the selected characteristics for the storms exceeding a selected threshold.

Regarding contours, I guess they can be prepared under various philosophies. It is. however, important to remember the main aim of the contours is to represent an approximate way for obtaining long term extremes without having to do a full long term analysis. The environmental contours by them self are not so interesting. It is therefore important that various contour formulations are accompanied by a procedure how to estimate load effects corresponding to a given annual probability of being exceeded.

In Chapter 5.1.3 designing for climate change and rogue waves is discussed. I think it would be useful to introduce planned structural life time as an important parameter when it comes to designing against effects of climate changes. If one shall design a structure to be in operation for 100 years or more, I guess one should account for best estimated effects of climate change. But for structures with a planned life time of 20-40 years, is there any reason to be concerned of climate changes regarding the design process? A discussion around this would be appreciated.

Regarding rogue waves, it is hard to make a rational design approach accounting for such events before we know more about their existence, frequency of occurrence and magnitude of amplitude. At present, all one can do from my point of view, is to take some actions ensuring some robustness against unexpected wave events. At the Norwegian Continental Shelf, the regulations followed for design of offshore structures require that the structure shall checked against wave crest heights corresponding to an annual exceedance probability of 10-4 as pointed out by the committee. This gives some robustness against rogue waves, because it is not very likely that the wave group including the 10-4 – annual probability crest height (predicted without accounting for freak wave mechanisms) also shall experience onset of a freak wave development.

In addition, Statoil has an internal requirement that a structure shall not be put at risk even if it is hit by a wave crest height 10% larger than the crest height predicted above. This is to account for a number of uncertainties and not only possible freak wave developments.

In last paragraph Chapter 5.1.3, the report refers to some few papers indicating that rogue waves may have to be accounted for by ship and offshore standards. Is it possible to briefly say what these indications are? Does the committee have any idea how one should account for them in standards?

In Chapter 5.2.2 it is said that kurtosis is a parameter accepted to be related to higher probability of rogue wave occurrences. I don't question that if kurtosis is high there is a larger probability for high waves. What I would appreciate to see is the correlation between a forecasted kurtosis and actual observed rogue waves at the site during forecast period. Have such a study ever been presented based on forecast and actual observations? How is the forecast kurtosis determined? I guess it must start with a forecasted wave spectrum, i.e. some average sea state properties. When estimating kurtosis from data, it is a rather uncertain quantity – in particular if one accounts for the fact the measured time series do not consist of independent data? How is confidence bands on the forecast values established?

1.1.6 Conclusions and Recommendations

The conclusions present a good summary of the previous chapter and I have nothing to add.

The recommendations are as precise as we can expect in this sort of a broad review report. I agree with all of them – in particular the one dealing with rogue waves. Recommendations like this, however, will not be explicitly of use in design work. I therefore consider the recommendations to basically be recommendations to the next committee.

1.1.7 Some comments to mandate and interpretation of mandate

The mandate of the committee is a far as I know defined by the standing committee. The mandate for the environmental committee has more or less remained unchanged for decades. During the same period the number of published paper has increased enormously. This is clearly illustrated by the committee early in the report by listing the number of conferences that they find of interest. In addition there are several journals that the committee should consider if a complete literature search should be performed. This report includes close to 400 papers! The selection of papers will to a large extent be committee dependent. There is no doubt in my mind that some of these papers will find (or have already found) their role as papers of permanent interest. However, most of the papers although they may well be important and

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useful in the context for which they are prepared, will not end up as being papers of permanent value.

What should we require for a paper to be included in the ISSC congress report? This question I will encourage the Standing Committee to discuss. There must be an element of new information and as far as possible, new findings/suggestions should be independently verified. Papers must have been through a review process – if necessary by committee members with adequate background. Furthermore, for a paper to be included in the report, maybe we should require that several committee members agree on this. There is no reason to believe that there are more than 50 papers of permanent value that are prepared within the fields and the period covered by the Metocean Committee. Maybe the Standing Committee should give a maximum number of references that can be included, for example 100?

I will also encourage the standing committee to narrow the mandate for the Metocean committee. There is for example no reason to have a full review of environmental data sources every 3 years. That goes also for the modelling of environmental phenomena. Our progress on complex problems does not progress that fast.

1.1.8 References

Clauss, F.C., Haver, S. and Strach, M. (2010): Breaing Wave Impacts on Platform Columns – Stoochastic Analysis and DNV recommended Practise, *Proceedings of 29^{th} International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2010)*, June 2010, Shanghai, China.

1.2 Floor Discussions

1.2.1 Shengming Zhang

The official discusser mentioned the breaking waves and associated impact pressure. My question is: What is the size of measured area which gives the impact pressure in the range of $3 - 4\,MPa$?

1.2.2 Ryuji Miyake

Thank you for your contribution and useful information. I belong to EEDI division of ClassNK.

In order to reduce CO_2 emissions from international shipping, EEDI (Energy Efficiency Design Index) regulation for new ships was adopted by IMO at MEPC and enters into force on 1st of January 2013.

EEDI is a factor of new ship's specification and shows 'maximum energy efficiency' which the ship can achieve. If the new ship does not satisfy EEDI requirement, the new ship cannot enter operation.

Especially, EEDI is governed by the ship speed. Therefore, it is important to verify the ship speed with accuracy. EEDI verification is carried out in accordance with 'Guideline for verification of EEDI'.

The measured ship speeds in sea trial are allowed to correct the effects of wind, tide, wave, shallow water and displacement. Especially, since waves significantly affect the measured ship speeds, it is important to measure the waves with accuracy. Therefore, the waves should be measured using devices such as wave buoys, wave radar and wave scanner. However, actually, it is difficult to use such wave measuring devices in sea trial. Therefore, EEDI verification guideline accepts visual wave observation by multiple observers including an experienced captain as the wave measurements.

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Because of this situation, I would like to ask you two questions about the wave measurements:

1. What is the best method for wave measurements with accuracy?
2. In the case where an experienced captain conducts visual wave observation, what is the percentage of errors?

Thank you for your response.

1.2.3 Bruce Hutchison

The Committee has presented results regarding a possible climate change increase to 99th percentile of H_s by $2\,m$ by 2080. The Committee's presentation observed that this might imply a 10% to 15% increase in the weight of the deck of a tanker.

Does this suggest that class societies should be offering an additional class notation for vessels with additional strength to meet the anticipated demands of climate change?

1.2.4 Carlos Guedes Soares

The Committee presented hindcast data. The problem with hindcast data is that they may not be validated against extreme measurements. I would appreciate to hearing comments on it?

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

2.1.1 Introduction

The Committee Members thank Professor Sverre Haver for evaluation of the Committee I.1 Report. The Committee appreciates to hearing that the Report I.1 fulfils the mandate with good margin and that the Committee work is documented by a thoroughly written report.

The Professor Haver's Official Discussion contains several interesting comments to which we will reply below.

2.1.2 Sources of Environmental Data

The Committee I.1 appreciates that Prof. Haver is satisfied with the review of availability of environmental data provided by the Committee and that he has not much to add.

Further, we are glad to hearing that the Official Discusser agrees with the Committee I.1 that the issue of data ownership remains a problem. We thank Prof. Haver for pointing out that the Norwegian Hindcast Data Base, NORA10 is open to all for a rather low cost. Several new met-ocean data bases mentioned in the Report I.1 are open to all (e.g. Argoss, Fugro-Oceanor database) but the price for using them is varying.

The Committee I.1 appreciates that Prof. Haver has included in his discussion the figures from the in-house Statoil report regarding the accuracy of the Norwegian Hindcast Data Base, NORA10. We fully agree that the resolution of the wave model is of great importance. It is mentioned in the report but due to limited number of pages the report could contain, this is not exploited in details. We agree that for some applications the discretization of the spectral peak frequencies of hindcast data should be removed prior to the response analysis.We would like also to add that the Norwegian Hindcast Data Base, NORA10 is used by the EC EXTREME SEAS project coordinated by DNV being the Chairman of the Committee I.1.

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The maximum wave height which occurred during Typhoon Krosa (Babanin *et al.*, 2011a) was recorded by a wave buoy. Three wave buoys were deployed in relatively close proximity and represent a standard long-term deployment by the Central Weather Bureau (CWB) of Taiwan. They are moored foam floats, 2.5 m in diameter, equipped with three-dimensional Watson accelerometers SHR-A1360-2A-30/105. The data buoy was patented by the Republic of China (Taiwan) (patent number No. 087358, their period of validity runs from 1997 to 2016, see also Kao *et al.*, 1999).These buoys have been operational since 1997, and data are recorded for 10 min every hour sampled at 2 Hz, thus providing 1200 values for each of the three accelerations and three angles. The vertical component is then double-integrated to obtain the surface elevation. As stated by the authors this is a standard data-processing routine, see also Kao *et al.* (1999). In the ocean area investigated by Babanin *et al.* (2011a) one can expect a considerable dissipation due to wave breaking. The time histories for the surface process are not presented in the paper of Babanin *et al.* (2011a). Prof. A. Babanin is a recognized expert on wave breaking but the paper is a bit controversial.It is difficult to prove that the measurement is accurate although the authors state that it is physically realistic. It was found by Babanin *et al.* (2011a) that neither SWAN nor WWMII model are able to reproduce the observed conditions, however, the wave models have also limitations due to the assumptions they are based on.

The original definition of the significant wave height is the mean of the upper one third of wave heights. Today $H_s = 4\sqrt{M_0}$ is commonly used, where M_0 denotes the zero wave spectral moment. The relation $H_{1/3} = 4\sqrt{M_0}$ is based on the assumption of the Gaussian sea surface (linear waves) and Rayleigh distributed wave heights, see Longuet-Higgins (1952), Cartwright and Longuet-Higgins (1956), also Thornton and Guza (1983). The Rayleigh distribution of wave heights is correctly applied only to linear waves and it is based on the assumption of the narrow-band wave spectrum. The latter will introduce additional uncertainty as real sea surface is for most of the conditions not narrow-banded.The bias between these two significant wave height estimators is usually rather small. However, when rogue waves are present it maybe of importance, see Bitner-Gregersen and Magnusson (2004). The Committee I.1 has pointed this it out so that a user is aware of this deviation between the two estimators. It will be up to the user to decide how important the bias is for an application considered. We believe that the significant wave height calculated from the wave spectrum will continue to be commonly used in the future, particularly as use of wave hindcast data in design and operations of marine structures is increasing.

Regarding the current modelling the Committee I.1 is referring to the GODAE project (see Section 2.3.3):

"An overview of the GODAE (Global Data Assimilation Experiment) project and the various products were introduced in the previous Committee I.1 report."

Further, in the "INTRODUCTION" section a link to GODAE Ocean View is given where additional information on current modelling can be found:

"Success of the global and basin-scale ocean models development with data assimilation under the GODAE (Global Ocean Data Assimilation Experiment) program opened a new era of operational oceanography. GODAE ended in 2008 and continues as GODAE Ocean View: `https://www.godae-oceanview.org/`".

Due to the requirement of the limited number of pages of the report the GODAE project was not exploited in details, however, reference is made to the ISSC 2009 I.1 Report where the GODAE products are discussed. The GODAE products sited in the

Committee I.1 report are still coarse for direct use in designing ocean structures; this is pointed out in Section 3.3 "Modelling of Environmental Phenomena". But these products can be used as a boundary condition for a fine-mesh model. The Committee expects that GODAE Ocean View will continue its effort in coordinating downscaled regional circulation model development. At the scale of ocean structures such as ocean energy converters, regional high-resolution models are developed individually. Interaction of ocean current (which is supplied by GODAE and GODAE-like products), tidal current and coastal topography gives us a challenge in modelling the regional circulation, see e.g. Wada *et al.* (2012).

The ocean current models are reviewed shortly in Section 3.3.

The marine growth data are not reviewed as the Committee I.1 has not seen anything in the literature on the topic that warranted specific mention in the 2012 ISSC I.1 Report. However, marine growth is mentioned in Section 5.1.3 in relation to climate change: "...The predicted increase in marine growth may increase loads on marine structures in some ocean regions, e.g. the Baltic Sea."

We agree that the lack of marine growth data for design remains a problem.The photosynthesis occurs only down to about $100 - 200\,m$, and sunlight disappears altogether at $1000\,m$ or less, while the ocean descends to a maximum depth of about $11\,000\,m$. Thus it is not expected to see marine growth below $500\,m$ or $1000\,m$. However, until recently the deep sea was largely unexplored, therefore more investigations are needed to reach firm conclusions. In any case an increase of ocean temperature will be a challenge in the future.

2.1.3 Modelling of Environmental Parameters

We are pleased to hearing that Section 3 gives a good overview of what has happened regarding modelling of environmental parameters during the last few years, and that Section 3.2 is very useful for the Official Discusser.

Professor Haver appreciates that ice has got several pages in the report but would appreciate to see also snow in the report. Snow is mentioned in the Committee I.1 Report, e.g. see Section 2.5.2: "...The authors produce a five year time series of freeboard elevation in the arctic, which in spite of uncertainties in snow thickness, indicates that overall sea ice freeboard has decreased during the considered observation period."

Snow is also mentioned in Section 2.5.3 dedicated to environmental data. There are several references regarding snow included in the reference list. However, the Committee I.1 has not seen anything in the literature on snow modelling that warranted specific mention in the 2012 ISSC I.1 Report. We expect that investigations dedicated to snow modelling will get increasing attention in the coming years.

When establishing a joint fit of met-ocean variables, if the available information about the simultaneously occurring variables is limited to the marginal distributions and the mutual correlation, then, as shown by Der Kiuregihan and Liu (1986), the Nataf (1962) model can be used. Applicability of the Nataf model to describe environmental parameters has been discussed in the literature for some time and is also discussed by Bitner-Gregersen (2012); the reference included in the reference list of the Committee I.1 Report.

The correlation between environmental parameters considered in the Nataf model can be computed in the physical space or in the normal space. The definition of the Nataf probability density function (pdf) is consistent with the given information, but the density function is not necessarily the "true" joint pdf. If the x-space variables are Gaussian, the Nataf model corresponds to the multi-normal distribution. If the x-space variables are random lognormal, the Nataf model corresponds to the multi-lognormal distribution. It thus follows that the Nataf model gives a good approximation for the distribution of the physical variables if the vector of the transformed standard normal variables is close to being multi-normal.

Bitner-Gregersen and Hagen (1998) applied the Nataf model to approximate the joint significant wave height and zero-crossing/spectral peak period distribution. The data from two locations: the Norwegian Sea (NS) and the Northern North Sea (NNS) have been used. For both locations the fitted Nataf models have been biased with respect to the significant wave height as well as the zero-crossing/peak wave period. It was concluded that the CMA (Conditional Modelling Approach) model is the superior to the Nataf model, and that the Nataf correlation model should be used with care. Applicability of the Nataf transformation has also been investigated by Sagrilo *et al.* (2008, 2011) for wave (wind sea and swell), wind and current parameters and direction. The statistical dependence between these parameters has been modelled by using concepts of linear-linear, linear-circular and circular-circular variables correlation. The joint probability established is taking into account the dependence between the intensity and direction of all variables. By improving modelling of correlation between environmental parameters a satisfactory joint fit has been obtained (see Sagrilo *et al.* 2008, Sagrilo *et al.* 2011).

The ISSC 2012 I.1 Report refers also to the ISSC 2009 I.1 Report where the accuracy of the Nataf fit is discussed. Therefore it was not repeated again in the text of the present report; mainly due to the requirement of the limited number of pages the present report should contain.

The Committee Members thank Professor Haver for the kind words regarding the section on rogue waves. We agree that the existence of these wave events can have a significant impact on future design recipes and safety of existing structures.

In addition, it needs to be noted that the conditional extremes model of Heffernan and Tawn (2004) is a flexible framework for general multivariate extreme value modelling which is easily implemented and extended. The major advantage of the Heffernan and Tawn conditional approach compared with previous conditional models, is that the functional forms for marginal fitting and conditional modelling are motivated by asymptotic arguments. The method is based on a parametric equation for the form for one variable conditional on a large value of another, valid for extremes from a wide class of multivariate distributions with Gumbel marginals. The conditional approach has been used as the basis for studies, including joint extremes of wave spectral parameters (Jonathan *et al.*, 2010) and extreme current profiles with depth (Jonathan *et al.*, 2012).

The Committee has noticed that Professor Haver raised the same questions: "Is the observed event a very rare realisation from a typical, slightly non-Gaussian population of surface elevation processes (i.e. the observed value is merely a result of nature filling the tail)? Or: Is the observed event a typical realisation of a rare, strongly non-Gaussian population of surface processes? I think we will need an enormous amount of data before it is possible to conclude (with a reasonable confidence) to which question the answer is yes.", in the last 10 years.

Some Committee members would say that an answer is "Yes" to both questions, others will say that these questions cannot be answered because the ocean waves will make a

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gradual transition from a state of slightly non-Gaussian population to a strongly non-Gaussian population. This should not be a question like: *to be or not to be.* At least for the mechanism of freak (rogue) wave generation based on weak nonlinearity, numerous research has now been conducted demonstrating the gradual transition from Gaussian to non-Gaussian waves, experimentally, numerically, theoretically and observationally. The hypothesis is that the sea states are changing in time and therefore at each instance of time different wave statistics are expected. The paper of Waseda *et al.* (2011) suggests that a strongly non-Gaussian population might be related to certain weather condition. Further, Waseda *et al.* (2012) have analysed recently numerous marine accidents in Japan and found that a lot of cases can be related to narrowing of the directional spectrum. Since direct causes of marine accidents are not known, it is rather speculative to use this result as an evidence of the relationship between narrowing of the directional spectrum and strongly non-Gaussian population, but, maybe good enough to illustrate how rapidly the wave spectrum can change in time in the ocean.

The occurrence of rogue waves, called also abnormal or freak is related to mechanics generating them. Today several physical mechanisms to explain the extreme and rogue wave phenomena have been suggested. These include: linear Fourier superposition (frequency or angular linear focusing), crossing wave systems, wave-current interactions, quasi-resonant interaction (modulational instability) and shallow water effects. In particular, it has been demonstrated that the contribution of high order nonlinear mechanisms such as the modulational instability of uniform wave packets, may give rise to substantially higher waves than predicted by common second order wave models.

Due to randomness of wave surface we can observe rogue waves satisfying the commonly used rogue wave definitions in the linear wave model as well as in the second-order wave models, if we simulate water surface elevation long enough. Rogue waves can also be observed in higher order solutions, beyond the second order, where the modulational instability is present. It should be mentioned, however, that the physics described by the linear and second order wave models is different from the one provided by higher order solutions of the water wave problem.

The Committee I.1 agrees that the solution to a conclusion regarding existence of freak waves lies in developing mathematical and physical wave models that have the potential of including freak waves among their population of solutions. Such models are available today and reported in the ISSC 2012 Committee I.1 report. A question remains how to link freak (rogue) waves to the physical quantities used in design. The EC EXTREME SEAS project is working on this topic and hopefully some answer will be able to be provided when the project is completed in 2013. Further, we do agree that a freak wave event is a local event while sea state characteristics used in engineering are quantities averaged over 20 minutes – 3 hours; this makes it more difficult to select the right wave parameters characterizing a freak event for design. We would like to mention also that intense time domain simulations of higher order solutions of water surface have been carried out in the last years in order to identify local characteristics of freak waves; they are published in several papers reported in the ISSC 2012 Committee I.1 Report. So far it has been difficult finding correlation between local freak wave characteristics and sea state parameters. However, it has been shown by Waseda *et al.* (2011) that characteristics of a weather pattern seem to correlate better with the observed freak wave occurrence (from the North Sea data).

A forecast of freak wave occurrence based directly on averaged sea state characteristics (wave spectral shape or an associated kurtosis) is a first step of freak waves' forecasting, and we can agree with Professor Haver, that such forecasting may not be always very robust. Further investigations are still called for.

Professor Haver states in his comment as following: "the committee refers to a paper by Babanin *et al.* (2011b), where it is suggested that the onset of wave breaking and freak waves are governed by the same physics." The Committee believes that Professor Haver has misunderstood the study. The paper of Babanin *et al.* (2011b) illustrates that with narrowing of the directional distribution the quasi-resonance (or the modulational instability) becomes more relevant in increasing the local wave steepness. For broad directional spectrum, the steepness of the wave was primarily due to random superposition of Fourier modes. These processes do not explain the breaking itself. When the initial wave steepness is high enough, the wave may steepen as a result of nonlinear or linear focusing, but locally the kinematics of breaking may be the same, as suggested by Professor Haver. The Committee I.1 thinks that freak waves may not necessarily be breaking. It is not clear to the Committee what Professor Haver means by "onset of freak wave." It may be clearer if the word "onset" is replaced with "generation mechanism".

We thank Professor Haver for valuable comments regarding wave breaking and offshore industry standards for the impact pressure on the platform, and for the reference to the paper of Clauss *et al.* (2010). However, the Committee I.1 regards that the paper being outside the Committee's I.1 mandate.

We can, however, mention that a paper regarding wave kinematics when rogue waves are present (without breaking) was presented on the last OMAE 2012 Conference in Rio, Toffoli *et al.* (2012). The direct numerical simulations of the Euler equations (the HOS method has been used) were applied in the analysis. A number of sea states with different wave steepness, spectral bandwidth and directional spreading were considered.

Sergeeva and Slunyaev (2012) has included in a simplified form a wave breaking in a 2D non-linear code; the results were presented at the EXTREME SEAS meeting but are not published yet.

Professor Haver is missing a statement regarding the Forristall (2000) distribution when the CresT project results are mentioned: "I think Forristall 2-order crest height model was the best model also regarding field data? No better model was found, but the model was not the perfect model regarding upper tail. This can possibly be taken as an indication of the existence of crest heights beyond what should be expected under a second order hypothesis regarding the surface elevation process, i.e. an indication of possible freak wave events. "

There is a theoretical 2nd order model of wave crest due to Tayfun (1980) which gives very similar results as the Forristall (2000) distribution based on curve fitting to the second order wave simulations. This model was not investigated by the CresT project. The Tayfun and Forristall models were compared, however, in several publications, e.g. Bitner-Gregersen *et al.* (2008), see Figure 5.

Fedele and Tayfun (2007) (see also Fedele, 2008 and the ISSC 2009 I.1 Report, 2009) suggested a crest distribution in a form that generalises the Tayfun model (1980). The authors show that for large waves the Tayfun model is an exact second order model for describing the crests and troughs of wind waves under general conditions at deep or finite water depths, irrespective of any directional and bandwidth constraints. Large

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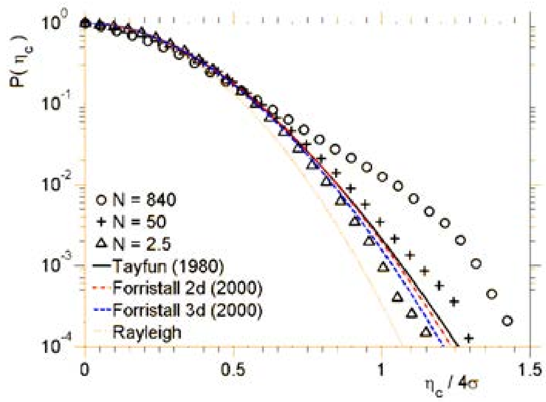

Figure 5: Wave crest distributions, Bitner-Gregersen *et al.* (2008).

waves are defined by the authors as waves characterised by $a >> M_0^{1/2}$ ($a = H_s/2$, where H_s denotes the significant wave height and M_0 is the zero-spectral wave moment). The model has been validated by wave measurements from the North Sea. The relative validity and accuracy of the generalised model in representing statistics of large wave crests is dependent on how a dimensionless wave steepness parameter is selected.

The Committee agrees that the Forrisall crest model is not a perfect one regarding the upper tail. It has been suggested at the last OMAE 2012 Conference in Rio by Bitner-Gregersen and Toffoli (2012b) an alternative crest model which gives better fit to the tail than the Forristall model does.

We agree with Professor Haver that for load calculations on a jacket structure joint occurrence of waves and current is of importance. There is an interesting paper of Winterstein *et al.* (2011) addressing North Sea current data set measured at Ormen Lange and probabilistic description of current. The paper should indeed get attention. However, the probabilistic description of current presented in the paper is closely related to the load procedure, therefore the Committee regarded the paper as being outside the mandate of the present Committee.

The current modelling work developed in the Safe Offload project coordinated by Shell did not produce anything conclusive, certainly nothing with respect to a joint relationship with either wind or wave. Even if we are able to model a joint relationship between current and wind or waves for extreme events, how can be confident that the relationship would also hold for very extreme conditions; it is an issue. From a purely statistical point of view of modelling joint extremes, the Heffernan and Tawn (2004) approach could be mentioned, well founded and quite easy to apply.

2.1.4 Special Topics

Climate Change

The results presented in the paper of Vanem and Bitner-Gregersen (2012) seem to be consistent with other investigations regarding climate change in the North Atlantic. Vanem and Bitner-Gregersen (2012) show the 100-year trend (by 2100) for the mean monthly H_s maxima of $1.6\,m$, and for the associated standard deviation of $0.39\,m$ in the North Atlantic location. It is stated in the Committee I.1 Report in the same section: "... Studies carried out before 2009 have reported increases of $0.35 - 1.15\,m$ in the seasonal maxima of H_s by 2080 and of $0.2 - 0.8\,m$ in the 20-year H_s in the 50-year period (2001- 2050) in the northeast North Atlantic. These positive trends have also been confirmed by later studies, e.g., Dragani *et al.* (2009), Wang *et al.* (2009), and Dodet*et al.* (2010). ...”

It is also stated in the report that uncertainties in climate change projection can be of the same size as the estimated extremes.

The model applied by Vanem and Bitner-Gregersen (2012) is a probabilistic model, the physics is included in historical data used in by the model. Further, the model includes terms reflecting the physics and uncertainties. This is a limitation of the model. The model is, however, more flexible to use by industry than physical climate models. The results presented do not reflect the most conservative IPCC scenario, scenarios are not included in this version of the model, only through the term reflecting uncertainty. A later version of the model (Vanem, 2012) includes terms reflecting explicitly different IPPC scenarios.

Due to the requirement about the limited number of pages of the report it was not possible to have extended discussion of the model. The intention was to mention the model as an alternative model to the climate/WAM models.

CFD

We thank you Professor Haver for the valuable comments. A discussion of loads is outside the Committee I.1 mandate. The intension of this section was to inform the shipping and offshore industry that CFD (Computational Fluid Mechanics) methodology is getting increasing attention in modelling of water waves and it is expected that this will continue.

The COMFLOW code is known to the Committee I.1. Both DNV and Shell have participated in the JIP projects where the code was developed. The code is used by DNV, but also other CFD codes are used by DNV.

We agree that the input conditions represent a critical part of a CFD analysis.

2.1.5 Design and Operational Environment

In 3rd paragraph of Section 5.1.1 it is said that *generally* the offshore industry considers instrumental data superior to model derived data. It does not exclude that some parts of the offshore industry may prefer the hindcast data for design purposes. Today hindcasts include assimilated satellite data (calibrated usually against buoy data) and hindcast data are commonly validated against measurements.

Some hindcast data for wind and waves are available for several basins worldwide (e.g. ERA40 data, Argoss database, Fugro-Oceanor), and not all where generated in the JIPs projects; some were developed by internal funding or within EC projects (e.g. Fugro-Oceanor database, HIPOCASS database). Use of some databases is free for research purposes (e.g. ERA40), however, not for the industrial applications.

It is stated in the Committee I.1 report: “It is recognised that uncertainties/errors in the estimated long-term distributions often leads to gross errors in the predictions.” We agree with Professor Haver that this sentence alone is not complete as one can ask what predictions one is talking about. However, the sentence is preceded by the sentence explaining which predictions the Committee is talking about:

“Long-term distributions of sea states are often employed in the prediction of met-ocean characteristics or various responses that a marine structure will experience.“

There are different definitions of gross errors in the literature. In the report “gross errors” referred to “biases”. An uncertainty will include both a systematic error (bias) and a random error (precision).

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The Committee I.1 agrees that a joint long term environmental model maybe difficult to establish if more than 3-5 weather characteristics are to be included. It will depend on a location and data available. A peak-over-threshold (POT) long term response analysis could be a good alternative.

We thank Professor Haver for the comments regarding environmental contours. Indeed, the contours represent an approximate way for obtaining long term extremes without performing a full long term analysis. This has been discussed in the literature for some time and it is also mentioned in the paper of Bitner-Gregersen (2012) referred in the present report. Therefore it was not repeated explicitly in the report. We agree that it is important that various contour formulations are accompanied by a procedure how to estimate load effects corresponding to a given annual probability of being exceeded.

The Committee fully agrees with the Professor Haver comment that it would be useful to introduce planned structural life time as an important parameter when it comes to designing against effects of climate change. There are still significant uncertainties related to climate change projections. The studies showing impact of climate change on marine structures, referred in the report, represent initial investigations only and not procedures for design. Therefore a discussion regarding a structure life time has not been mentioned. However, the studies clearly state for how long time periods the climate change projections are given. Due to the non-stationary nature of design criteria associated with climate change, the design criteria for a structure with a planned life time of 20-40 years will change as a function of when that 20-40 year life time occurs – e.g. the 100-year return-period significant wave height will increase with time, if we believe the predictions.

We thank Professor Haver for interesting comments regarding rogue waves. We agree that the Norwegian offshore standards (NORSOK Standard, 2007) taking into account extreme severe wave conditions, by requiring that a 10000-year wave does not endanger the structure integrity (ALS), give some robustness against rogue waves. The robustness is even increased by the Statoil internal requirement that a structure shall not be put at risk even if it is hit by a wave crest height 10% larger than the crest height predicted according to NORSOK.

Regarding the last paragraph of Section 5.1.3, there are indications e.g., in the paper of Bitner-Gregersen and Toffoli (2012a) that rogue-wave-prone sea states can actually occur more often than once in the 20-25-year period, which is currently used as a return period for ship design. Also the highest observed sea state within the 10-year time period analysed ($H_s > 15\,m$) is characterised by $k_p H_s/2 > 0.13$, the conditions which may trigger the modulational instability. The investigations carried out by Bascheck and Imai (2011) based, between on wave buoy data, support this conclusion. It is important to note, however, that hindcast data used in the study of Bitner-Gregersen and Toffoli (2012a) are generally subjected to a number of uncertainties, which may have influenced the authors' results.

How to account for rogue waves in standards is a subject of the EC EXTREME SEAS project coordinated by DNV and planned to be completed in 2013. Therefore it is too earlier to comment on it at present.

According to the knowledge of the Committee I.1 (see Section 5.2.2 of the report) a study showing the forecast kurtosis and the one calculated from the actual observations has not been published yet.These investigations are ongoing, e.g. in the EXTREME SEAS project. There are, however, several studies showing comparison of kurtosis evaluated from numerical simulations and model basin data. They are reported in Section 3.2.1 and 3.2.2 of the Committee I.1 Report. When analysing observed data, the correlation with freak wave occurrence and parameters such as kurtosis, Benjamin-Feir index, is rather low. It is probably because the sea states are rapidly changing in time and are affected by uncertainty due to sampling variability as pointed out by Michel Olagnon during the EXTREME SEAS Workshop in Geneva in 2011. Waseda *et al.* (2011) showed by analysing the North Sea data that if we make a conditional averaging for the "freakish sea state" only, the correlation becomes much clearer. It should be noted that the authors had to make use of the wave model to estimate directional spreading, which is a limitation of the study.

Forecast kurtosis can be evaluated from the directional wave spectrum, see Morri*et al.* (2011). We agree that kurtosis is an unstable parameter and it is more affected by sampling variability (uncertainty due to limited number of observations) than the integrated parameters like significant wave height and spectral/zero-crossing wave period. Estimation of confidence bands on the forecast values will be of importance. Data allowing estimation of confidence bands are available today, as ECMW and meteorological offices are providing ensemble forecasts.

2.1.6 Conclusions and Recommendations

The Committee members appreciate that Professor Haver finds that the conclusions present a good summary of the report sections and that the Official Discusser has nothing to add.

The presented recommendations are directed to both, academia as well as the shipping and offshore industry. They should not, however, be regarded as receipts for design procedures. They indicate the directions of future research needs being of importance for design and operations of marine structures.

2.1.7 Some Comments to Mandate and Interpretation of Mandate

The Committee disagrees with the suggestions of Professor Haver regarding changes of the Committee's mandate.It maybe sometimes very difficult to appreciate the full value of a paper right away: sometimes it reveals its usefulness not until many years later; an example can be the earlier work of Newton. Therefore it might not be a good idea to leave some papers out because of a limitation in the number of publications. Further, when focusing only on a small number of publications we might miss the "big picture". The Committee thinks that it is more useful if we give the reader a general overview (a short version of highlights) and leave it to the reader to get more detailed information from the originals. Further, sometimes only some investigations presented in a paper maybe of permanent value, and not the whole paper.

When papers are presented in the ISSC report the Committees' members have to agree on inclusion them; papers in press, or submitted, are already reviewed.

The Committee I.1 thinks that the present Committee's mandate covers well the needs of the shipping and offshore industry and by adopting it, directions for future research needs, being of importance for the marine industry, are also covered. Therefore the Committee I.1 does not see any reason for revision of the mandate. However, different Committee I.1 terms could have different topics in focus. This is to some extend taken care of already by the section "Special Topics".

We would like, however, to suggest increasing the number of pages required for the report.

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2.1.8 References

We thank for the reference of Clauss *et al.* (2011). The Committee I.1 finds the paper being outside of the Committee I.1 mandate.

2.2 Reply to Floor and Written Discussions

The Committee would like to thank the discussers for their valuable contribution to the floor discussion.

2.2.1 Shengming Zhang

The question was addressed to the presentation given by the Official Discusser Professor Sverre Haver and was answered by Professor Sverre Haver. In general, consideration of impact pressure in Clauss *et al.* (2010) is outside the scope of the mandate of Committee I.1.

The test for the Gjøa semi-submersible, presented by Clauss *et al.* (2010), was carried out at Marintek in Trondheim, Norway, while the one for the Snorre A TLP was done at Marin in the Netherlands. The model scales were 1:55 for Gjøa and 1:62.5 for Snorre. The impact loads from breaking waves were measured using force transducers. In case of Gjøa height transducers with a full-scale area of $10 : 89\,m^2$ were applied, in case of Snorre two with a full-scale area of $6.2\,m^2$ were used. In the case of the third platform, the Sleipner A GBS, the test model was built at a scale of 1:100. For measuring the wave-in-column loads 16 piezoresistive force pads with an area of $15\,mm$ x $15\,mm$ at model scale ($1 : 5\,m$ x $1 : 5\,m$ or $2.25\,m^2$ at full scale) were used.

2.2.2 Ryuji Miyake

The instruments measuring waves are under continuous improvement and their accuracy is also continuously improving. A recommended choice of an instrument will dependent on a wave parameter (or parameters) needed to be provided. For example,wave buoys are recognised as very good instruments for measuring integrated wave parameters like significant wave height and zero-crossing wave period but should not be used for measuring a wave profile. For getting accurate measurements of wave profiles lasers will be recommended to apply.

Visual observations of waves collected from ships in normal service are currently used in design and operations of ship structures.Wind speeds (Beaufort Scale) and directions, and wave heights in a coarse code have been reported since 1854. Observations of wave height, period, and direction have been collected from ships in normal service all over the world since 1949. Collection of visual observations is made in accordance with guidance notes from the World Meteorological Organisation (WMO). The utility of visual wave observations depends on appropriate calibration versus accurate measurements of the wave characteristics. Particularly, accuracy of visually collected wave periods has been questioned in the literature.Accuracy of visual wave height should be within 10%, when the guidelines of WMO are followed. It should be noted that visual observations include bad weather avoidance.

2.2.3 Bruce Hutchison

Classifications Societies are following closely investigations on climate change and their impact on met-ocean conditions. So far it has not been introduced an additional class notation for vessels with additional strength to meet the anticipated demands of climate change. There are still significant uncertainties related to climate change projections. However, the maritime industry has initiated studies aiming at quantifying potential impact of projected climate change and associated uncertainties on ship structures; see e.g. Bitner-Gregersen *et al.* (2011).

2.2.4 Carlos Guedes Soarres

Recently various hindcast and satellite databases have emerged and the work of comparing and of assessing differences and uncertainty level involved in their use is not yet properly explored, although significant progress has been achieved for some databases. The previous I.1 Committee Report noted a lack of validation of numerical wave models with instrumented data beyond 12 metres, but some studies have included such extreme data since that time. Cardone and Cox (2011) demonstrated that the current 3G models are capable of accurately hindcasting significant wave heights above 14 metres in very extreme storms. Similar studies are carried out at different met-offices world-wide.

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VOLUME 3

COMMITTEE I.2

LOADS

COMMITTEE MANDATE

Concern for environmental and operational loads from waves, wind, current, ice, slamming, sloshing, weight distribution and operational factors. Consideration shall be given to deterministic and statistical load predictions based on model experiments, full-scale measurements and theoretical methods. Uncertainties in load estimations shall be highlighted. The committee is encouraged to cooperate with the corresponding ITTC committee.

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1 DISCUSSION

1.1 Official Discussion by Atilla Incecik

1.1.1 Introduction

I am greatly honored to be asked to serve as the official discusser for the report of the Committee I.2 on Loads. The report of the Committee is a thorough review of the recent publications on sea loads on ships and offshore structures and I would like to express my congratulations to the Committee on their most interesting and excellent work. The work of the Committee is a most valuable contribution to the research and development community interested in the prediction of sea loads on ships and offshore structures as it covers the review of just over 361 recent publications of which 35% are journal and transaction papers and 65% are conference presentations. This large number of recent publications indicates the continuing importance of the research and development area concerning the load predictions for safe design and operation of ship and offshore structures.

The Committee in their report has not only highlighted the main contributions made by each of the paper that they reviewed but also identified the gaps in each of the research area that they have addressed and have proposed further investigations. In the following my comments on each section of the Committee's report are given.

1.1.2 Computation of Wave Induced Loads

Zero Speed Case

The papers reviewed in this section describe the prediction of the first- and second-order wave exciting forces, nonlinear wave diffraction forces, coupled motions and loads of an LNG considering the effects of sloshing with that are filled up to different levels and wave impact loads on gravity based multi column offshore structures. The numerical methods used in the predictions included:

- Computational Fluid Dynamics (CFD);
- Nonlinear diffraction modelling;
- MEL (Mixed Euler-Lagrangian) modelling in complex nonlinear ideal fluid domain.

The experimental investigation on the slowly varying motions of a floating body indicated a significant nonlinear wave force contributions in the low frequency range.

As the number of floating LNG terminals and LNG shuttle vessels operating in shallow water areas increase the Committee rightly focused on papers describing the effect of varying bathymetry on the wave excitation forces and resulting motions. The papers reviewed in this area are based on classical seakeeping and domain decomposition methods. It appears that there is a trend to modify the existing techniques like the Boundary Element Method (BEM) rather than developing new approaches. I would like to suggest that the inclusion in this Discussion Chapter of papers by Sutulo *et al.* (2010) on the development of boundary element method to calculate the added mass and damping characteristics of ship sections in variable depth shallow water areas, and Griffiths and Porter (2012) on the development of Green's function for waves propagating over variable bathymetry would be useful additions to the papers reviewed by the authors.

In recent years we have seen a significant increase in the design of multi-body systems with applications in offshore LNG shuttle tankers moored side-by-side or in tandem to floating LNG terminals or FPSOs. The operation of LNG shuttle tankers moored

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in the vicinity of large gravity based structures, offshore wave renewable devices and multi column structures also expanded. I therefore believe that the Committee in their report described the recent developments concerning multi-body hydrodynamics. Recent advances may be summarised as follows:

- The introduction of 'damping lid' method to reduce the over prediction of wave elevation in the gap between closely side-by-side moored vessels and of wave induced drift forces.
- Development of a hybrid 2D linear and nonlinear BEM to study the pumping modes due to ship to ship and ship to platform interaction.
- The application of a 2D viscous flow numerical modelling based on the solution of Navier-Stokes equations with a finite element method and a Volume of Fluid (VOF) method to capture the wave surface elevation between the closely spaced fixed two rectangular cross-sections.
- Development of an exact algebraic method to predict the linear diffracting and radiating waves by arrays of independently moving truncated structures.
- Application of a 3D diffraction code and a nonlinear coupled mooring analysis to predict the relative motions and mooring forces of two floating offshore platforms moored in tandem.

Forward Speed Case

The Committee report in this section addresses the advances made in the development of prediction techniques to determine the wave and motion induced forces on vessels with forward speed taking into account various levels of nonlinear effects. The majority of the papers reviewed in this section use methods that are based on potential flow theory. The linear or nonlinear wave exciting forces and resulting motions and structural hull girder loads are determined using numerical models based on the potential flow 2D strip theory, the 2.5D theory and the 3D theory. However, the prediction of roll motions near the roll resonance frequency, the heave and pitch motions of vessels with sharp corners and of slowly varying motions of moored offshore platforms require the inclusion of the viscous effects to ensure accuracy. Nonlinear time domain analysis is required in order to accurately predict, the motions, slamming and deck wetness as well as hull girder loads and forces on mooring lines and risers of floating offshore platforms in severe sea conditions. Figure 1 summarises various seakeeping theories and their ranges of application.

The Committee summarised (please also refer to Table 1) various levels of nonlinear time domain technologies used in the papers reviewed as follows:

- Level: 1 (Body linear solution): Both linear diffraction and radiation potentials and hydrostatic/Froude-Krylov forces are solved over the mean wetted hull surface.
- Level: 2 (Approximate body nonlinear solution): The linear diffraction and radiation potentials are solved over mean wetted hull surface while the hydrostatic/Froude-Krylov forces are solved over the instantaneous wetted hull surface.
- Level: 3 (Body nonlinear solution): Both the linear diffraction and radiation potentials and the hydrostatic/Froude-Krylov forces are solved over the instantaneous wetted hull surface considering the position of the hull with respect to the mean water level.
- Level: 4 (Body exact solution): Both the linear diffraction and radiation potentials and the hydrostatic/Froude-Krylov forces are solved over the instantaneous

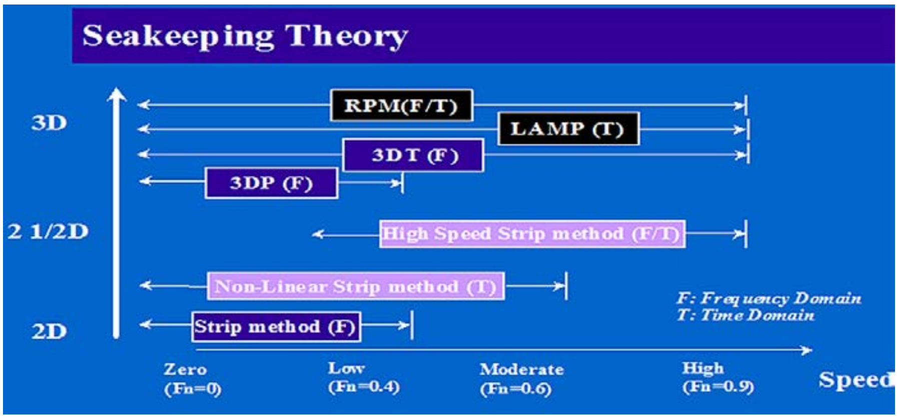

Figure 1: Seakeeping theories and their ranges of application

wetted hull surface considering the position of the hull with respect to the incident wave surface.

- Level: 5 (Fully nonlinear solution for smooth waves): Both the nonlinear diffraction and radiation potentials and the hydrostatic/Froude-Krylov forces are solved over the instantaneous wetted hull surface considering the position of the hull with respect to the incident wave surface. Level 5 solution assumes that the waves do not break.
- Level: 6 (Fully nonlinear solution): The solution in Level 6 is the same as in Level 5 but the breaking waves, sprays and water flowing onto/from the ship's deck are taking into account by solving the RANS equations.

In the future work of the Loads Committee it would be valuable to initiate a comparative study to find out how different levels of nonlinear time domain technologies correlate with each other and with available measurements for different ship hull forms, sea states and forward speeds. This may also be a joint task between ISSC Loads and ITTC Seakeeping Committees. In the future the committee may wish to include some review on the practical approaches available for the prediction of the long term assessment of loads based on nonlinear time domain technologies. Review of the papers by Bandyk and Beck (2009) relating to the review section on *Level 2 Body Nonlinear solutions* and Sclavounos (2012) relating to the review on *Level 4 Body Exact* solutions will be useful additions to the papers reviewed by the Committee.

Offshore Wind Loads

As the steady and time varying wind loading acting on moored ships and deep water floating offshore installations, and on bottom mounted and floating wind turbines play an important role in the design of mooring and riser systems for these structures as well as wind turbine blades the review of the recent papers on offshore wind loads is very timely. The conclusions reached from the review of the papers in this section indicate that:

- Wind tunnel tests are still the best option to evaluate wind loads;
- CFD methods are not yet mature to predict the wind loads with confidence.

The inclusion in this Discussion Chapter of a paper by Wnek and Guedes Soares (2011) describing the shadow effects between a floating LNG production platform and a LNG transportation ship will be a useful addition to the papers reviewed in this section.

Table 1: Summary of Methods used in various papers reviewed and their Applications

Author(s)	Radiation and Diffraction	Froude / Krylov forces	Restoringf orces	Body (rigid/flexible)	Special Features	Applications
Ibrahim et al (2009)	Linear Neumann-Kelvin	Nonlinear	Nonlinear	Rigid	Lift & drag	High speed Semi-displacement hulls
Bruzzone et al (2009)	Linear double body Rankine source	Nonlinear	Nonlinear	Rigid		Multi-hull vessels
Liu and Papanikolaou (2010)	Hybrid method Rankine source for inner region and 3D free surface Green function for outer region	Nonlinear	Nonlinear	Rigid	Hybrid method	Various ship added resistance and vertical motions
Wu and Moan (2005)	Linear strip theory	Nonlinear	Nonlinear	Flexible	2D momentum slamming model used also in hydrodynamic coefficients are constant	Whipping and springing
Lee et al (2011a, 2011b)	Linear Neumann-Kelvin	Nonlinear	Nonlinear	Flexible		Whipping and springing
Mortola et al (2011)	Nonlinear strip theory with relative vertical velocity	Nonlinear	Nonlinear	Rigid		Vertical motions and loads

The Committee may wish to comment on whether or not existing wind spectra formulations used for the analysis of deep water floating offshore oil and gas platforms can be used for the analysis of the future fixed and floating offshore wind turbines farms to be developed in shallow water areas to predict the dynamic wind loads and resulting responses.

Loads from Abnormal Waves

The Committee's review concerning abnormal waves can be grouped under three main headings:

- Observation of wave components which form abnormal waves and the resulting loads on ships and offshore platforms;
- Prediction of global loads using nonlinear time domain strip theories;
- Effect of nonlinear wave kinematics in the wave crest.

Given that there were a number of incidents which have been attributed to abnormal or freak waves the Committee may wish to comment on whether or not the present design guidelines and rules are adequate to cover the increase in loads due to abnormal waves with extremely large amplitude and steep crests or whether new design procedures are necessary for safe design and operation of ships and offshore structures.

Hydroelasticity Methods

A comprehensive review of literature on hydroelasticity and the conclusions reached indicate that the 2D hydroelasticity analysis is at a sufficiently mature stage to be

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applied to real ship design calculations. It would have been useful to include in the report a summary table of different hydroelasticity methods classified according to different hydrodynamic and fluid-structure interaction modelling with a comment on their validation.

Slamming Loads

Analytical and numerical methods to predict slamming loads are developing rapidly as can be seen from the review of recent investigations given in the report. Most of these methods employ traditional linear or nonlinear methods to determine the relative motions and the occurrence of slamming, and then potential flow based 2D analytical or numerical techniques or the results of experiments with 2D wedges or advanced CFD techniques are used to predict the slamming loads.

Experimental Hydroelasticity

The Committee described two major international joint industry projects (JIPs) which were carried out to investigate the effects of springing and whipping on the structural design of containerships. The conclusions reached from the two JIPs were:

- Fatigue damage increases if the hull vibrations are considered;
- Scaling techniques and torsional moment measurement methods require improvement;
- Numerical simulation techniques to predict wave induced vibrations of a ship hull girder need further validation with tank tests and full scale measurements before they can be used as a design analysis tool;
- There appears to be a large source of uncertainty in the prediction of slamming impacts.

The review of the various papers given in this section shows that:

- Vertical bending moment values can increase up to 35% due to hull vibration;
- There is a good correlation between full-scale measurements and model tests;
- Stern slamming events in following seas experienced by a cruise ship could be larger than bow slamming events in head seas;
- Linear springing of a container ship in oblique seas is much affected by its torsional properties;
- The results of experiments carried out with a high speed catamaran showed the dependency of the slam location on the forward speed.

Full Scale Measurements

The papers reviewed in this section described the results of full-scale measurements carried out with full scale ocean going ships. The review shows that the vertical bending moments values are increased by up to 38 % due to whipping and springing.

Specialist Structures

In this section the Committee reviewed a number of papers describing the hydroelastic behaviour various specialist vessels which include:

- A fast patrol boat with a small L/B ratio;
- Aircushion supported vessels;
- Underwater vehicles.

1.1.3 Ship Structures – Specialist Topics

Loads versus Operational Guidance

In order to enhance the operational safety modern ships are equipped with sensors for continued monitoring of the hull and engine performance. The papers reviewed in this section discuss developments on accurate tools and methods that could be employed to reduce hull girder stresses and loads on container fastening etc., by combining real time measurements with reliability based approaches.

Ice Loads

The review of papers by the Committee on ice loads is very timely. This is because in recent years the opening of the Norther Sea route and the subsequent major discoveries of oil and gas reserves in the Arctic raised the demands for improved design, construction and operation of a large number of ice strengthened ships and offshore structures. The development ice-structure interaction models validated by model and/or full scale measurements and the further development of guidelines and rules are essential for sustainable shipping, and oil and gas activities in the Arctic regions. Whilst the papers reviewed in this section will no doubt make invaluable contributions for the development of improved prediction models, the Committee's views on further research and development requirements for the establishment of design procedures, guidelines and rules will be welcome.

Loads on Damaged Ship Structures

The papers reviewed in this section addressed the following aspects in the analysis of damaged ship structures:

- The exposure time to environmental conditions between the damage occurring and the damaged ship arriving at a safe location should be considered as this may reduce the predicted loads on the damaged ship.
- Effects of internal free surface dynamics in the damaged compartment on the motions and loads acting on the damaged ship should be taken into account.
- Loading induced on a grounded ship should take into account soil-structure interaction between the hull and the sea bed in the grounding area.

Green Water

Similarly to slamming load prediction analysis techniques numerical techniques for investigating green water loads on floating offshore structures and ships are developing fast as can be seen from a large number of papers reviewed in this section of the Committee's report. The papers reviewed use mainly the multi-stage approach to predict the green water loads. Accordingly, traditional seakeeping techniques are used to determine the relative wave height at the bow and once the a freeboard exceedance is predicted the smooth particle methods or RANS techniques are applied to predict flow characteristics around the bow, on the deck and the green water loading.

Sloshing

Sloshing is a highly nonlinear phenomenon where free surface has the characteristics of wave breaking and air trapping. The papers reviewed in this section concern with the loading due to sloshing on the partially filled tanks and their support structure of LNG vessels. In addition, the hull girder loading due to coupling between the vessel motions and sloshing in the partially filled tanks are addressed in the papers reviewed.

Model Experiments

Model experiments to study the sloshing behaviour are important not only to understand the physics of this highly nonlinear phenomenon but also to validate the analysis techniques. The papers reviewed in this section concluded the following challenges associated with experiments:

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- Scaling issues due to the use of water and air are complex.
- Suitable representation of LNG liquid near boiling point and vapour in ullage space are difficult.

Hull Flexibility

The papers reviewed in this section concern with the interaction between a flexible ship and sloshing. The methodologies investigated in the papers can be divided into two categories:

- Decoupled Analysis: The fluid and structure coupling is one way only. This method is fast but less accurate;
- Coupled Analysis: The fluid and structure coupling in two ways. This method is more accurate but more computationally intensive.

In the future work of the Committee it would be useful to investigate the correlations between the pressure values as obtained from decoupled and coupled analysis.

Advanced Numerical Methods

The papers reviewed in this section indicated that:

- Potential flow methods are still commonly used to analyse the liquid motion and to predict pressures in an oscillating tank;
- Navier-Stokes solvers can be used to predict 3D liquid motion and pressures;
- Smooth Particle Hydrodynamics (SPH) method is good to predict the free surface shape but is not accurate to predicting the pressure values.

Coupling Sloshing with Motions

The papers reviewed in this section could lead to the conclusion that potential flow methods to predict ship motions taking into account viscous effects for roll motions can be coupled with RANS solvers to predict the sloshing motions and pressures with a good level of accuracy.

1.1.4 Offshore Structures – Specialist Topics

The papers reviewed regarding the offshore lifting and installation as well as cables, risers and moored structures emphasised the importance of coupled modelling for the accurate prediction of motions and loads of the systems analysed. The Figures 2 and 3 summarise uncoupled and coupled modelling. In the coupled analysis all interaction effects (stiffness, damping, mass and mean current loads) between moorings/risers and the vessel are modelled directly. Mooring and riser lines can be modelled by a finite element method.

The papers reviewed regarding the vortex induced vibrations and wake induced oscillations covered investigations on vortex suppression devices and the recent developments based on RANS solver to study the VIV phenomenon of a single riser or a cylinder in the wake of another. The last part of this chapter includes the review of the papers concerning the motion response analysis of Spars, TLPs and Semi-submersible due to wave, wind and current loading. The analyses carried out in these papers are based on linear potential flow calculations or semi-empirical methods or experimental measurements. One of the papers reviewed discusses the prediction of current loads on a semisubmersible using a CFD analysis. The effect of water depth on wave and low frequency motions and mean drift of moored vessels can be illustrated in Figure 4.

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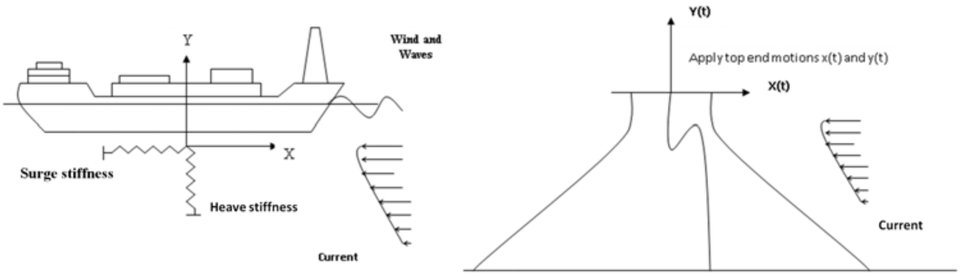

Figure 2: Uncoupled System analysis

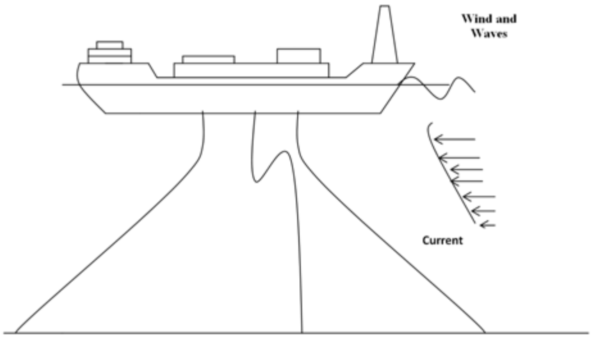

Figure 3: Coupled System Analysis

1.1.5 Uncertainties in Wave Load Predictions

In order to determine the safety of a ship or an offshore structure we need to properly account for the uncertainties associated with:

- Modelling of the wave, wind and current environment;
- Modelling of the loading and resulting dynamic or static response;
- Modelling of the strength and fatigue characteristics of the structure.

The papers reviewed in this section addressed the above uncertainties. In addition it should be noted that when benchmarking studies are carried out to validate numerical prediction techniques with model test data the uncertainty analysis of the test data should be carried out considering the possible sources of error from instrumentation, measurement technique, experimental methods and facility limitations.

1.1.6 Fatigue Loads for Ships and Offshore Structures

As there are still significant uncertainties in the prediction of fatigue damage of ships and offshore structures this chapter is very timely and includes the review of excellent papers on fatigue loads. One of the papers reviewed concludes that the only way to progress the understanding of fatigue phenomena is to combine all the available tools including model tests, full scale measurements and numerical models/simulations. The review also highlights the importance of combining high frequency and low frequency loading which are of narrow band Gaussian distribution in predicting the fatigue damage. Such methods are essential for the accurate prediction of fatigue damage when a ship hull is subjected to first order wave induced stresses as well as stresses due to

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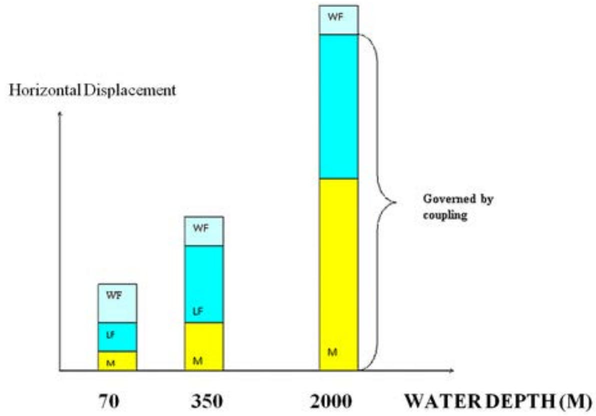

Figure 4: Horizontal motions of a moored platform

springing and whipping vibrations or when the hull of an FPSO is subjected to stresses due to wave frequency and low frequency loading as it loads and unloads cargo.

1.1.7 Conclusions

The conclusion section of the Committee's report gives a very useful summary of their very compressive report together with recommendation for future investigations. Once again I would like to congratulate the Committee on Loads for their excellent report which is a most valuable contribution to our community.

1.1.8 References

Bandyk, P.J. and Beck, R.F. (2009). Nonlinear ship motion computations using a time domain body exact slender-body approach, *The Proceedings of OMAE 2009,* Honolulu, USA.

Griffiths, L.S., Porter R. (2012). Focusing of surface waves by variable bathymetry, *Applied Ocean Research,* 34:150-163.

Sclavounos, P.D. (2012). Nonlinear impulse of ocean waves on floating bodies, *Journal of Fluid Mechanics,* 697:316-335.

Sutulo,S. J., Rodrigues, M. and Guedes Soares, C. (2010). Hydrodynamic characteristics of ship sections in shallow water with complex bottom geometry , *Ocean Engineering* , 37(10): 947-958.

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1.2 Floor Discussions

1.2.1 Celso Morooka

Referring to Chapter 4, sections 4.2 and 4.3, the Committee report gives a good review and basis for the state of the art regarding hydrodynamics of the Vortex Induced Vibrations (VIV). Valuable discussions are presented in the report, related to experimental work with rigid cylinders mounted into springs, stationary or with forced motions. The report also refers to CFD research works, not only for rigid cylinders but also flexible ones, including some cylinder curvature. The publications reviewed show successful and important results as steps for the VIV and associated motions. I would also like to mention that recent works present numerical simulations for slender cylinders in shear flow, in which combination of standing and traveling waves are demonstrated for the VIV (Bourguet, 2011). Multifrequency response and interaction of the response with vortex spreading, have been also discussed. CFD for curved cylinders with flow around have also been presented in literature (Vecchi *et al.*, 2009). I would like to offer the following suggestions on future research work:

- The development of numerical (CFD) simulation for curved flexible cylinder in shear flow is desirable.
- Carrying out numerical simulations for a flow with high Reynolds number, to represent, as much as possible, the actual problem faced by the oil industry, in particular, for risers and offshore pipelines would be very useful.

1.2.2 Giorgio Bacicchi

My first comment concerns the photos of the two cruise vessels given in the presentation:

- The photo of the Carnival vessel with the forward part completely submerged by a big wave is not true.
- People should be more afraid of masters than of ship structural reliability. So, before getting fun in a cruise vessel, take information about the master.

I agree that the combination of wave and whipping effects can easily exceed allowable values of shear forces and bending moments. Years ago we have made a comprehensive research campaign on the subject with Marintek and from that work we have defined a procedure for combining wave and whipping effects, at least for cruise vessels, understanding that whipping is strongly dependent by ship speed and heading. Is it really safe to simply install on board monitoring systems giving evidence of what is happening or should it be safer to install on board (as we did in some cruise vessels) 'Decision Support Systems' associated to a wave radar and to a software predicting the values of some critical parameters which you could experience without changing ship speed and heading?

1.2.3 Debabrata Karmakar

First of all I congratulate the chairman of the Committee I.2 for such a wonderful presentation. In subsection 3.2 the report discusses on the 'Ice Loads' in the area of Arctic and Antarctic region. I found some of the recent references could be useful to the readers for further study (Vaughnan and Quire 2011, Squire 2011). So, I request the chairman to add these references.

1.2.4 Enrico Rizzuto

Many compliments to the Committee Members for their very comprehensive work. I would like to raise a question on a subject that I might have missed from the presentation (and from the report, which I was unable to analyse in details so far). The subject is the availability of full scale surveys of loads on ships. It is now a couple of decades that news are around about load monitoring systems onboard ships, in particular dedicated to hull girder loads. The availability of these data would be of paramount importance to assess the prediction procedures for loads and their uncertainties. Has the Committee considered this kind of data, and was it able to have access to them? In case, can the committee provide information on sources for these information?

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1.2.5 References

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Evangelinos, C. Karniadakis, G.E (1999). Dynamics and flow structures in the Wake of rigid and flexible cylinders subjected to vortex-induced vibration. *Journal of Fluid Mechanics*, 400: 91-124.

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Squire V A (2011). Past, present and impendent hydroelastic challenges in the polar and subpolar seas. *Philosophical Transactions of the Royal Society. Series A*, 369:2813 – 2831.

Vaughnan, G.L. and Squire, V.A. (2011). Wave induced fracture probabilities for Arctic sea ice. *Cold Region Science and Technology*, 67(1–2):31–36.

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

We are grateful to Professor Atilla Incecik for his valuable comments, suggestions and additional contributions to our Committee's report. Professor Incecik, by and large, has been very complimentary about the range and depth of the coverage the report and supportive of the issues raised by the Committee. Our reply will not address these areas. With regards to specific questions or inquiries for additional discussion we reply to comments in the following sections.

2.1.1 Computation of wave induced loads

Zero speed case

We agree that there is clearly a need to address practical problems related with the undesired effects of water clearances on navigational safety and derive advanced numerical schemes able to derive the effects of bathymetry on surface waves.

The work by Sutulo *et al.* (2010) is a good example where inertial and damping characteristics have been computed for ship sections in way of multi-stepped and inclined bottoms using the boundary integral equation approach. This work has also some practical significance as the continuous growth of the average size and speed of vessels recently resulted in repeated problems related to insufficient water clearances affecting navigation safety and operational costs. Often these problems are related to the squat sometimes resulting in undesirable contacts with the ground which requires reduction of the ship's speed. The numerical investigation carried out by the authors for three characteristic ship sections shows that depending on the section's shape, oscillation frequency and mode, the influence of the local bottom configuration can vary from negligible to very significant. In general, near mid-ship sections with flat bottom are more sensitive to the seabed configuration details than typical bow and stern sections. The influence of the number of approximating steps may be systematic or of a quite unexpected character. Numerical results presented in this article can be used for qualitative estimation of possible errors caused by bathymetry approximations. The main practical recommendation is that the seabed surface should be approximated as accurately as possible.

On the other hand, the work by Grifiths and Porter (2012) addresses important aspects on computational modelling of scattering for a monochromatic train of surface gravity waves that may be incident on a finite region of arbitrary three-dimensional smoothly varying bathymetry. In this work the full three-dimensional linear water wave theory is approximated by the depth-averaged modified mild-slope equations and a Green function approach is used to derive an integral equation for the function relating to the unknown surface over the varying bed. The method is applied to bathymetries which exhibit focusing in the high-frequency Ray theory limit. They are used to illustrate that focusing occurs at finite wavelengths where both refractive and diffractive effects are included. The method of scattering of surface waves by a finite domain of arbitrary slowly varying bathymetry has been applied to focusing, but can be extended in a number of directions, such as interactions between multiple finite domains of varying bathymetry, near trapping - by long finite ridges - and edge wave excitation along semi infinite ridges. Other extensions may include shoaling domains on sloping beds, as considered by using Green function. Perhaps, it would be useful to follow on further developments related with this work over the forthcoming ISSC reporting period.

Foreword speed case

Professor Incecik provides very useful suggestions on the value of initiating an ISSC/ITTC benchmark study comparing, for a variety of hull forms and seakeeping conditions, the assumptions, numerical and experimental or full scale measurement results using various numerical schemes clearly referenced in the ISSC I.2 report and highlighted on Table 1 of this discussion paper. By all means a study of such kind would be welcome. Whereas further discussions between the relevant ISSC and ITTC committees would have to take place in the future before proceeding with such study, the committee would like to recommend that the issues on uncertainties related with theoretical concepts and calculation procedures as suggested by the ITTC (2011) would also have to be considered. With the development of the different direct calculation models and the possibility of even adopting probabilistically based direct designs, it is essential that the calculation methods are standardised to make sure that it is possible to make meaningful comparisons between calculated results.

It is the committee's opinion that Professor Incecik's comment on the need to review, in the future, practical approaches related with the prediction of long term assessment of loads is particularly valuable. A ship, during its operational lifetime, experiences a number of loads and the long term effects of those can be performed by taking into account the hull form, the mass distribution and the operational profile. A two- or three-dimensional linear hydrodynamic analysis, although fairly straightforward, may not be very useful for concept design, because of the lack of detailed data or detailed engineering expertise. As demonstrated by Ericson (2000) for a risk assessment involving thousands of different combinations of sea state and operational parameters even linear strip theory calculations might be too time consuming for routine applications. Naturally, computations may be even more complicated in those cases where partly or fully non linear hydrodynamic or hydroelastic methods are used. To this end, the development of rational and efficient procedures able to predict the design wave induced motions and accelerations with sufficient engineering accuracy in the conceptual design phase and in risk assessment procedures may be useful. Along these lines, a notable previous work worth mentioning is the one by Bhattacharyya (1978). More recent developments by Jensen and Mansour (2002) and Jensen *et al.* (2004) suggest the use of hull main parameters (e.g. length, breadth, draught, block coefficient, water plane area and operational profile) in deriving semi-analytical formulae. Similar formulas for the nonlinear wave-induced bending moment amidships have been presented in Jensen and Mansour (2002). The use of load combination formulas as suggested by Huang and Moan (2008) and Mohammed *et al.* (2012) may be also useful to consider, although rationalisation of the limitations of such approaches is pending. It is suggested that this committee will focus on reviewing such developments over the forthcoming reporting period with the aim to report on developments at the ISSC 2015 reporting session. Research in this area could provide updated information for new Classification Rules incorporating the effects of environment (e.g. Vanem and Bitner Grigersen, 2012) and new build vessel characteristics (e.g. Hirdaris and Temarel, 2009).

The original body of the committee's report discusses a number of numerical methods developed. The committee welcomes Professor Incecik's suggestion to review the work of Bandyk and Beck (2009) under Level 2 (Froude-Krylov nonlinear) methods and the recent work by Sclavounos (2012) under Level 4 (Body exact - weak scatterer) approaches. The former, presents a 2D body exact strip theory method used to solve the unified seakeeping and maneuvering problem in the time domain using direct pressure integration to compute forces. A frame following the instantaneous position of the ship by translating and rotating in the horizontal plane is used to solve the later. This has the advantage that the speed or heading does not need to be predetermined. A nonlinear 6 degree of freedom Euler equation of motion solver is used to find the new body position and velocities. Incorporation of the time dependent body wetted surface to integrate the forces and the use of 2^{nd} order terms in the Bernoulli equation ensure that non linearities associated with the high frequency seakeeping and low frequency maneuvering are captured without resorting to two separate time scales. However, the accuracy of the maneuvering results needs to be verified. In addition the assumption of linear maneuvering forces may be erroneous since nonlinear coefficients could play vital role during tight turns. On the other hand, the work by Sclavounos (2012) presents a new formulation of the nonlinear loads exerted on floating bodies by steep irregular surface waves. The forces and moments are expressed in terms of the time derivative of the fluid impulse which circumvents the time-consuming computation of the temporal and spatial derivatives in Bernoulli's equation. The nonlinear hydrostatic force on a floating body is shown to point vertically upwards and the nonlinear Froude–Krylov force and moment are derived as the time derivative of an impulse that involves the time derivative of a simple integral of the ambient velocity potential over the time-dependent body wetted surface. The nonlinear radiation and diffraction forces and moments are expressed as time derivatives of two impulses, a body impulse and a free surface impulse that represents higher-order wave loads acting along the body waterline. Numerical results are presented illustrating the accuracy of the new force expressions. Applications discussed include the nonlinear seakeeping of ships and offshore platforms and the extreme wave loads and responses of offshore wind turbines.

Offshore wind loads

We would like to thank Professor Incecik on his comment to reference aspects of wind effects between adjacent ships and floating offshore installations.

Indeed, the work by Wnek and Guedes Soares (2011) describing the shadow effects be-

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tween a floating LNG production platform and an LNG transportation ship is a useful addition to the papers reviewed in this section. The authors highlight that the effects of wind acting on ships can become critical in several situations of close proximity maneuvers. Two particular cases of models position have been taken into consideration namely LNG arrival and departure from the floating platform, in which the wind attacks prior the platform. Results obtained using commercial CFD code, compared well with experimental measurements performed in a wind tunnel. Numerical and experimental results, presented in a form of coefficients of the drag, lift components and yaw moment, reached approximate agreement.

The committee agrees that wind spectra formulations used for the analysis of deep water floating offshore oil and gas platforms can be used for the analysis of loads on fixed and floating offshore wind turbines farms operating in shallow water areas. Notwithstanding, wind turbines are made to utilise the wind and are consequently placed in areas where the wind climate is expected to provide a high density of kinetic energy. From a theoretical perspective, prior to the analysis, the spectrum of load conditions that a wind turbine experiences during its lifetime must be made discrete into a finite number of load cases and turbulent excitations should be incorporated in the model with the aim to account for fatigue and extreme stress considerations. Suitable modelling reproducing the atmospheric boundary layer over the sea surface, where part of the wind energy is transferred to waves, is another important point to consider. From a validation/experimentation perspective the scaling of experiments, where both water and wind loads are generated, is rather critical. Today, very few facilities can provide such kind of testing which is used mainly for sparsely validating or tuning numerical codes.

Loads from abnormal waves

The committee wishes to thank Professor Incecik on his comment questioning the adequacy of present design guidelines and Rules with regard to the inclusion of effects due to waves with extremely large amplitudes and steep crests. It is true that current Rules and design procedures do not address this matter and the topic has gained significant momentum over the last six years. However, Rules are derived on the basis of pessimism, they are based on operational experience and may well be considered satisfactory within the context of engineering practice. From a research perspective, categorization and collection of updated wave statistics including extreme events is clearly beyond the scope of this committee and lies within the broader interests of the ISSC committee I.1 on Environment. A recent paper by Vanem and Bitner Gregersen (2012) explains that the current state and future projections of wave height patterns and extreme events is subject to a large number of uncertainties that would have to be suitably understood before any actions on updating design Rules and procedures take place. Additional uncertainties are associated with the prediction methods (e.g. Levels 2 – 6) reviewed in the main body text of this committee's report, as well as the verification and validation of methods and tools. To this end development of updated Rules and procedures incorporating extreme events remains an inspiring, yet medium to long term research exercise.

Hydroelasticity methods

Professor Incecik refers to the important matter of assumptions and validation of hydroelastic methods. Over the last 40 years a number of theoretical concepts have been developed and have been reviewed in literature (e.g. Chen *et al.* , 2006 and Hirdaris and Temarel, 2009). On the other hand, validation studies remain sparse and incom-

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plete. Generally speaking two dimensional hydroelasticity theories incorporating the effects of slamming have been partly validated using full scale measurements. Steady state symmetric and antisymmetric loads have been validated under selected laboratory conditions for ships without deck openings. In this sense the recent International joint industry projects referenced under section 2.5.2 of this Committee's main report are pioneering. The committee agrees that it will be very useful for researchers to produce a relevant table and recommends that over the next reporting period such information is included in the main body text of the report.

2.1.2 Ship Structures – Specialist topics

We would like to thank Professor Incecik for his valuable comments on ice loads and the effects of hull sloshing versus hull flexibility.

With reference to ice loads the lack of detailed references on design procedures, guidelines and Rules has been somewhat intentional as aspects of ice loading are explicitly referenced by the ISSC Specialist Technical Committee V.6 on Arctic Environment. Taking this opportunity, the committee would like to highlight that Classification Societies over the last few years have been working on extensive research and development programs of relevance. For example, Lloyd's Register (2010) as part of their work on Ship*Right* design and construction procedures have developed a Fatigue Design Assessment procedure (Ship*Right* FDA ICE) to assess fatigue damage of ship structures induced by ice loads for ships navigating in ice covered regions. This work considers trading routes in ice regions, ice loads and impact frequencies, structural stresses, fatigue performance at low temperatures, fatigue damage and acceptance criteria (Zhang *et al.* , 2011). In addition, Lloyd's Register (2012) is currently developing Ship*Right* SEA(ICE) requirements for icebreakers. This work programme attempts to validate current Classification requirements for ice going ships and provide comparisons against operational guidelines and full scale measurements. Research includes understanding of ice dynamics and ice interaction scenarios. It is expected that as the roles and functions of icebreakers change and technological innovations are incorporated, Classification rules will need to adapt, to further define the ice performance envelope under a range of ice interaction scenarios. This will provide greater clarity of the ice conditions and reduce operational risk.

With reference to sloshing, the intention of the committee has been to provide a general outline of the developments in this area. We are in full agreement that future research work should highlight comparisons between the correlation of pressure values as obtained from coupled and decoupled analysis. Following the work undertaken under the MARIN led Joint Industry Project SALT (Gaillarde, 2004), more recent publications by Hirdaris *et al.* (2011) and Lin *et al.* (2009) demonstrate the importance of this issue. Today, in sloshing applications, even with the use of more sophisticated time domain models the fluid level is assumed static at calm water level and the treatment of internal tanks is more typically limited to a nominal reduction in metacentre height due to free surfaces. As explained by Hirdaris *et al.* (2011) results can be improved by considering that the fluids in tanks can be treated in a similar way as the fluid acting outside the hull, in a coupled ship motion and tank sloshing solution. The tanks can be modelled with a hydrodynamic mesh (see Figure 5), and the linear potential model may be applied to give the forces for each panel, in a similar way as for the hull. Predictions incorporating tank fluid actions can be significantly different from those that do not account for the effects of tanks. The most dominant effects appear as the roll ship motion changes from a single-peak to a double-peak response in way of

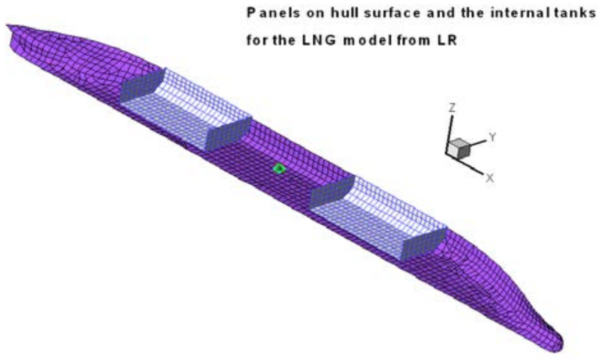

Figure 5: Hirdaris *et al.* (2011) hydrodynamic mesh for LNG carrier using Lloyd's Register FDWAVELOAD (tanks 2 and 4 are partially filled)

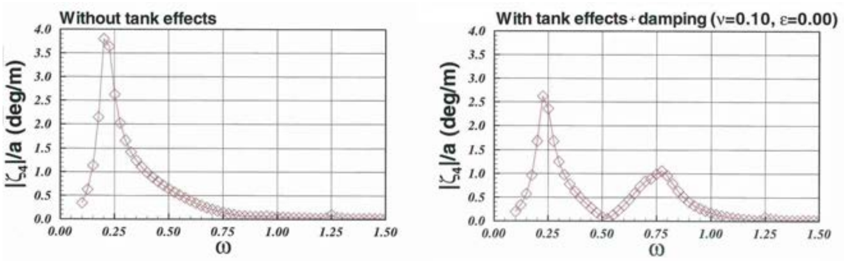

Figure 6: Roll motions of LNG carrier with and without tank effects - Hirdaris *et al.* (2011)

the natural frequency of the tank fluid (see Figure 6). Figure 7 shows the results of tank experiments of an LNG carrier compared with computational predictions in beam seas. The resonance in the roll motion at the tank's natural frequency is very well captured. Roll time series data based on this advanced model are the most appropriate for studies involving sloshing.

2.1.3 Uncertainties in Wave Load Predictions

The committee would like to thank Professor Incecik for his valuable comments. Enhancing safety at sea through specification and quantification of uncertainties related to description of the environment and predictions of loads and responses is currently one of the main concerns of the Shipping and Offshore Industry. These uncertainties play an important part in risk assessment for the design and operation of marine and offshore structures. Whereas measured values are used in the process of validating modelling techniques and associated assumptions both measurements and predictions in principle have errors associated with them. For example, high uncertainty of environmental description may lead to significant risk impact and several authors have previously been able to demonstrate the importance of modelling uncertainties in the calculation of loads and responses. To characterise the accuracy of a quantity it is necessary to distinguish between systematic (bias) and precision (random) errors with reference to the true value. Specification of uncertainties is not an easy task because the true value is usually unknown.

We would like to mention that as part of the mandate of ISSC and ITTC to encourage

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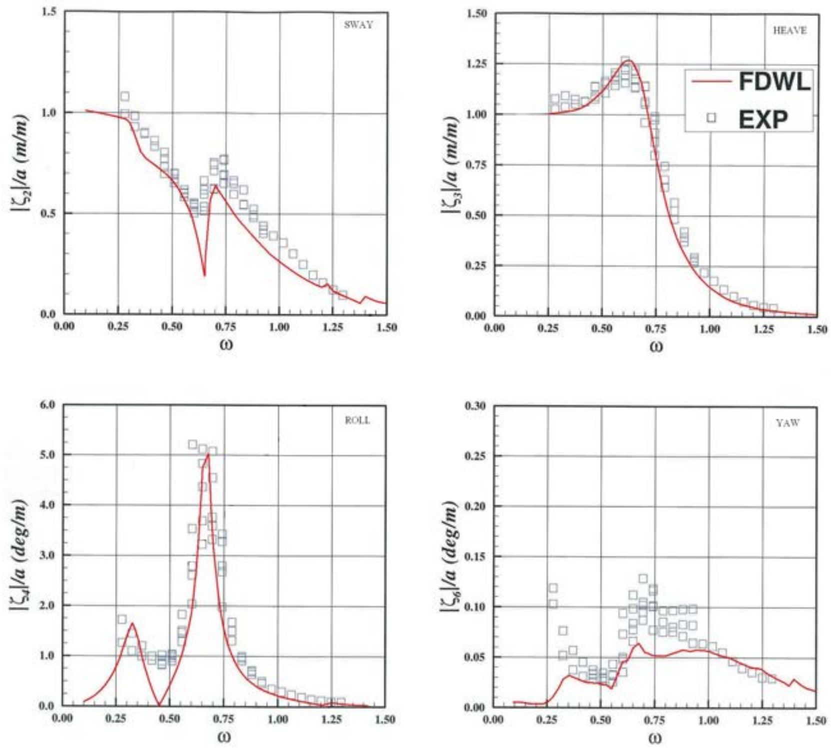

Figure 7: Comparison with model test results - Motions of LNG carrier at 0 knots, beam Seas (different loading condition compared with Fig 2) – Hirdaris *et al.* (2011)

cooperation in areas of mutual interest, the first international workshop on 'Uncertainty Modelling for Ships and Offshore Structures' has been organised as a pre-amble to the he 18^{th} ISSC by our committee in association with ISSC I.1 Committee on Environment as well as the ITTC Seakeeping and Ocean Engineering Committees. The workshop, under the support of Lloyd's Register Strategic Research, DNV Research and Innovation and the University of Rostock, aimed to facilitate the exchange of ideas on understanding the influence of improved uncertainty modelling in the design of Ships and Offshore Structures (Hirdaris, 2012). Topics discussed included model testing, full scale measurements, load prediction and experimental validation techniques, utilization of satellite measurements, extreme environmental phenomena, risk assessment and mitigation, goal based standardisation.

In furthering this work the main contributors of this workshop work on preparing papers for a special issue on uncertainties that will be published by the Ocean Engineering (Elsevier) Journal. These collated publications are expected to appear during 2014.

We sincerely hope that the afore mentioned initiatives will raise the interest of the maritime industry on the subject and will steer further collaboration between current and future members of the ISSC/ITTC community.

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2.2 Reply to Floor and Written Discussions

We are grateful to floor discussers for their valuable comments, suggestions and additional contributions to our Committee's report. Their comments compliment in further the breadth and coverage of our report. Our reply will not address these areas. With regards to specific questions we reply to comments in the following sections.

2.2.1 Celso Morooka

We thank Professor Celso Morooka for his valuable complementary comments and suggestions. All additional references suggested are useful additions for the relevant sections of this discussion paper. We agree that future research work could indeed focus on:

- development of numerical (CFD) simulation for curved flexible cylinder in shear flow
- numerical simulations for a flow with high Reynolds number for risers and offshore pipelines.

It is agreed that these research works may be particularly useful for practical applications.

2.2.2 Giorgio Bacicchi

We thank Mr. Giorgio Bacicchi for his comments. With regards to the photos of the two cruise vessels presented during the official presentation of the report we wish to clarify that there has been no intention to focus on specific operators or engage with discussion on broader maritime safety matters including human factors. We hope that you will kindly accept our denial to comment on aspects of hull integrity versus human factors as such discussions go beyond the overall scope of ISSC and this committee. The photos have been demonstrated to illustrate that in a case of an intelligent ship - like a cruise ship - the combined effects of damage stability and structural integrity would be worthwhile to be studied in the future. To date this has been difficult due to lack of computational resource and validated knowledge.

With reference to the comment on real time monitoring and decision support systems installations; the choice on the level of safety precautions in those cases that certain equipment is not imposed by the regulations of international bodies (e.g. IMO and flag states) is with the operator. New technology may, in occasion but not always, imply improved safety. Hence, structural monitoring and operator guidance systems may in general be useful. We would therefore simply like to highlight that furtherance of the knowledge in areas of knowledge that may enhance the credibility of these systems is valuable and should be continued as it will only help us to raise standards and our fundamental understanding.

2.2.3 Debabrata Karmakar

We thank Professor Debabrata Karmakar for the useful references provided. While targeted on specific sea-ice situations, many of the reported results are equally applicable to the interaction of waves with very large floating structures, such as pontoons, floating airports and mobile offshore bases.

2.2.4 Enrico Rizzuto

We would like to thank Professor Enrico Rizzuto for his kind words and valuable comments on full scale surveys. We agree that the availability of such data would be very useful for the verification and validation of computational tools, design procedures and Classification Rule development. The sources of information of these data are with the ship owner/operator and sharing of these data with the broader maritime technology world is quite challenging for commercial reasons. Nevertheless, we believe that members of the ISSC community and the broader academia would welcome an open access database including such information.

2.3 References

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COMMITTEE II.1

QUASI-STATIC RESPONSE

COMMITTEE MANDATE

Concern for the quasi-static response of ship 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.

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1 DISCUSSION

1.1 Official Discussion by Toichi Fukasawa

1.1.1 Preface

First of all, the discusser expresses his sincere appreciation to the committee members for their extensive research works on the Quasi-Static Responses. The quasi-static response is the fundamental bridge between the load and response of ships and offshore structures, and is directly linked to the actual structural design. With the progress of computers and the development of soft wares, nonlinearities of loads acting on ships and offshore structures are estimated in detail recently, and even the large scale dynamic stress analyses are getting to be possible in the structural analysis. In the structural design stage, however, it is still usual to adopt the quasi-static response analysis, rather than the dynamic response analysis, particularly in the early design stage. Mainly because the dynamic structural response analysis is quite time-consuming, it would be preferable to use such a method as the quasi-static response analysis in the structural design stage of ships and offshore structures.

In employing the quasi-static response analysis in appropriate way, it is firstly important to recognise the discrepancy between dynamic and quasi-static analyses, in particular the hypothesis in the simplification of the processes. It is then necessary to figure out the accuracy of approximation in the response calculations using a structural analysis technique with various loads acting on the structure. The individual topics with respect to the quasi-static responses are explained in detail in the committee report, including uncertainties associated with reliability assessment. The discusser therefore would like to make comprehensive comments on the report from the viewpoint of the application of quasi-static response analysis to the structural design of ships and offshore structures.

1.1.2 Quasi-Static Modelling of a Dynamic Problem

As a ship is sailing in waves and an offshore structure is used in waves, the behaviours of these structures are essentially time dependent and the structural responses should be analysed taking account of dynamic effects in a precise sense. The equation of motion of the structural response of such structures can be written in the following form in general.

$$[M]\{\ddot{q}\} + [C]\{\dot{q}\} + [K]\{q\} = \{f\} \tag{1}$$

where $[M]$, $[C]$ and $[K]$ are the mass matrix, the damping matrix and the stiffness matrix respectively, which can be obtained by means of structural modelling technique such as FEM. $\{f\}$ is the displacement vector in generalised coordinate. $\{q\}$ is the force vector comprised of several types of loads of different amplitudes, phase angles and frequencies. As the loads acting on the structure are mostly nonlinear, to be exact, Eq.(1) should be solved in time domain taking account of various nonlinearities of the loads; however, it is usual to reduce the dynamic problem to a quasi-static problem particularly in the ship structural design stage because enormous time and efforts are required to solve the dynamic problem strictly.

To reduce the dynamic problem to a quasi-static problem, the time variation of structural response is usually assumed to be a sinusoidal variation or its superposition; that is, the displacement vector is assumed to be

$$\{q\} = \{\overline{q}\}e^{i\Omega t} \tag{2}$$

where $\{\overline{q}\}$ is the response amplitude and Ω is the response frequency. Substituting Eq.(2) into Eq.(1), and ignoring the force vector, we have

$$\left([K] + i\Omega[C] - \Omega^2[M]\right)\{\overline{q}\} = 0 \tag{3}$$

Eq.(3) is an eigenvalue problem. The eigenfrequency of the structure can be obtained assuming the proportional damping for the damping matrix, or simply ignoring the damping matrix. With the use of the eigenfrequency ω, Eq.(1) can be reduced to

$$\left(1 - \frac{\omega^2}{\Omega^2}\right)[K]\{\overline{q}\}e^{i\omega t} = \{\overline{f}\}e^{i\omega t} \tag{4}$$

where the force acting on the ship is considered to vary in time with the frequency ω and the amplitude $\{\overline{f}\}$. In the case where the eigenfrequency of the structure is much higher than that of the external force, Eq.(4) can be approximated to be

$$[K]\{\overline{q}\} = \{\overline{f}\} \tag{5}$$

This is the basic idea of the quasi-static response analysis. The idea is sometimes extended to a general form as

$$[K]\{q\} = \{f\} \tag{6}$$

Eq.(6) will be solved in the quasi-static analysis. Different from the pure static analysis, the loads are mostly dynamic and sometimes nonlinear, and the load components which constitute the force vector in Eq.(6) have different phase angles in general as well as the different amplitudes and the frequencies.

It should be noted here that the basic assumption "the eigenfrequency of the structure is much higher than that of the external load" should be still kept in Eq.(6). In terms of this assumption, special attentions should be paid in the case where slamming, sloshing and other impulsive load are applied to the structure, because the duration of impulsive loads are very short in most cases comparing with the natural period of fundamental vibration of the structure. There are a number of research works on the impulsive loads as shown in the committee report, but the noteworthy point would be the practical treatment of impulsive loads, such as slamming, sloshing etc. in the quasi-static structural response and the effect of such treatment of the impulsive loads on the structural responses.

1.1.3 Load Characteristics and Structural Analysis

In the structural design stage of ships and offshore structures, the buckling strength, the ultimate strength, the fatigue strength and so on are evaluated mainly by means of the quasi-static response calculation. In these evaluations, the maximum or the minimum stress is usually needed for the design purpose. In order to obtain the maximum or the minimum stress by the quasi-static response analysis, to begin with, it is convenient if the moment when the stress becomes maximum or minimum in time domain is known. With the development of load estimation procedures recently, time variation of pressure or load acting on the ships and offshore structures can be calculated and it is possible to know the moment when the pressure at a certain point becomes maximum or minimum in time domain; however, the peak stress at a point of the structure does not necessarily occur at the same time as the peak load in general. One of the most obvious examples is the wave-induced pressure at a certain point and the resulting stress at other points. Thus, the moment when the stress

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at a certain point becomes maximum or minimum in time domain cannot be known without structural analysis a priori from the load information in general. This means that the structural analysis is inevitable to obtain the maximum or minimum stress in time domain; however, the structural analysis sometimes needs much time and effort. In this context, the number of structural analysis is the key in ship structural design from the viewpoint of efficiency.

As the number of structural analyses depends on the load type, the load component acting on ship's hull is firstly categorised. The load type would be categorised in the following 3 types, that is,

- Load Type I: A load corresponds one-to-one with stress in time domain, such as hull girder bending moment.
- Load Type II: A load of which distribution profile does not change in time but the magnitude changes, such as internal liquid pressure.
- Load Type III: A load of which distribution profile and magnitude both change in time, such as external pressure caused by waves.

It is easy to estimate the moment when the stress becomes maximum or minimum in time for the Load Type I, because the load and the stress correspond one-to-one in time domain; for example, stress due to hull girder bending can be calculated by dividing the bending moment by the section modulus of the ship. FEM analysis is not necessary in this case unless stress concentration is concerned.

Liquid cargo or ballast water of a ship acts on the ship structure as internal pressure. The internal pressure of a fully-filled tank can be treated as the inertia force of the liquid mass caused by the acceleration due to ship motions as shown in Figure1. It is well accepted that the grain or coal can also be treated in the similar manner, although the shearing stress component is to be added. The internal pressure is caused by the acceleration of cargo or ballast water, and the acceleration can be separated into x-, y-, and z-components. In each acceleration component, the pressure distribution profile does not change in time, but only the magnitude of the profile is varying time to time according to the accelerations. FE analysis is necessary to calculate the stress caused by internal pressure; however, the calculation effort is not so heavy, that is, the structural analysis is only necessary for 3 acceleration components assuming the load-stress linearity, and the pressures due to unit amplitude of each acceleration component can be used in the FE analysis. The amplitude and phase lag of the stress due to internal pressure can be determined by superposing the calculated stress components taking account of the phase angle of each acceleration component.

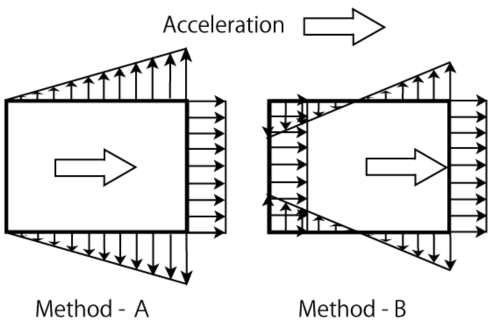

Figure 1: Internal pressure distributions

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On the other hand, in the case of external pressures in waves, not only the pressure magnitude but also the pressure distribution profile vary in time according to the wave profile as shown in Figure 2. It is easy to know when the pressure becomes maximum or minimum at a certain pressure point in this case; however, it is not possible to know the moment when the stress at a certain point becomes maximum or minimum without structural analysis. There are phase lags between external pressure of each pressure point in general, particularly in shorter wavelength cases. This means that so-called "maximum pressure distribution" or "minimum pressure distribution" cannot necessarily be defined to be exact.

In the case of external pressure in waves, moreover, the wave surface relatively moves up and down along the ship's side shell in a seaway as shown in Figure 2. As the relative magnitude of the wave surface movement could be the same order of the wave height, the wave elevation along the ship's side shell cannot be ignored in the estimation of the stresses caused by the external pressure in waves. The pressure at a certain point near the still water surface is positive when the point is submerged under the wave surface, while it is zero when the point comes out over the wave surface. This is known as the "pressure nonlinearity", and the distribution profile of non-dimensional pressure cannot be the same in time, different from the internal pressure case. The ordinary linear superposition technique cannot be used in this case.

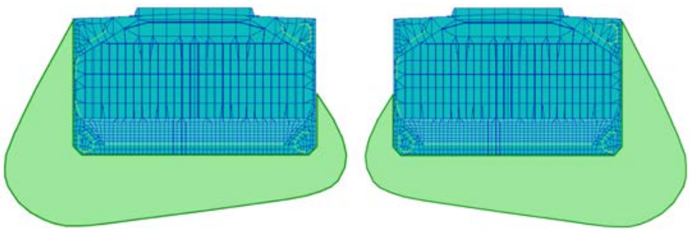

Figure 2: External pressure distributions

Strictly speaking, time domain structural analyses are necessary to obtain the stress amplitude and phase lag due to the external pressures in waves because of the "pressure nonlinearity". If the quasi-static analysis is adopted, rather than the dynamic analysis, the approximation would be as follows in this case. Assuming the response in regular waves for simplicity, the wave encounter period is divided into various points in time. The quasi-static structural analyses are conducted at given times applying the external pressure in waves at each instant. As the stresses are obtained at given times, the magnitude and the phase angle of the stress are calculated by interpolating the obtained stresses as a sinusoidal function in time. This procedure is rather strict and the pressure nonlinearity can be taken into account, but this would require too many stress analyses for the structural design purpose.

In order to simplify the above method, some assumptions are necessary. If the pressure nonlinearity is assumed to be insignificant, the wetted area on the ship surface can be considered to be unchanged. And also, if the external loads vary in sinusoidal manner in time, the pressure can be decomposed into sine and cosine components, and Eq.(6) can be written as

$$[K]\{q\} = \{f_c\}\cos\omega t + \{f_s\}\sin\omega t \tag{7}$$

Assuming that the structural response is in simple harmonic,

$$\{q\} = \{q_c\}\cos\omega t + \{q_s\}\sin\omega t \tag{8}$$

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the response amplitude can be obtained by solving the following equations.

$$[K]\{q_c\} = \{f_c\} \tag{9}$$

$$[K]\{q_s\} = \{f_s\} \tag{10}$$

This means that the structural analysis is only necessary for Eqs.(9) and (10), even if the phase angles of external pressure in waves are different from each other.

Another alternative way would be as follows. In the case where the structural response can be considered to be linear, a linear superposition method is available to calculate the stress amplitudes. Dividing the surface of ship's hull into a number of panels upon which the external pressure in waves is applied, the load-stress influence matrix is calculated at a certain stress point by applying the unit load on each panel one by one by means of stress analyses. Superimposing the load-stress influence matrix according to the distribution profile of the external pressure in waves, the stress due to any kind of pressure distributions can be calculated. This method is known as DISAM (DIScrete Analysis Method, see Kuramoto *et al.* (1991)).

The different approach would be that to approximate the "maximum pressure distribution" or the "minimum pressure distribution". As was shown before, the "maximum pressure distribution" or the "minimum pressure distribution" cannot be defined strictly, because the pressure at each point varies in time with different phase lags. In the approximation, the pressure distribution when the pressure at a representative point becomes maximum or minimum is assumed to be the "maximum pressure distribution" or the "minimum pressure distribution". An example of this method would be the design load provided by the classification societies' rule.

In any cases described above, the compromise between the accuracy and the number of structural analysis would be the key in the structural design stage of ships and offshore structures. Even in the quasi-static response analysis, FE analysis is necessary to be conducted to some extent. It would be important to know the merit and the demerit of each approximate procedure to obtain the maximum or minimum stress due to various loads, bearing in mind of the recent development of computers and soft wares.

1.1.4 Internal Load and Load Combination

The ISSC committee II.1 have reported on the various loads including ice loads, slam loads and accidental loads. These reviewed loads are mainly related to the external loads, that is, the loads acting on the ship structure from outside. In the ship structure, however, another important load, the internal load, is acting on the ship from inside. For example, the oil pressure is acting on tankers, the ore or coal pressure is acting on bulk carriers, and the container load is acting on container ships, as well as the ballast water pressure. The magnitude of the internal pressure is not small, but is comparable to the external pressure caused in waves. If the internal and the external pressures are acting on the ship in the same phase from each side of the ship's hull, the pressures are cancelled out and any stress may not be induced. On the other hand, the internal and external pressures are acting on the ship in the opposite phase from each side of the ship's hull, the magnitude of the pressure acting on the hull will be doubled. Because of this, the internal loads are very important in the ship structural design.

When the tank or cargo hold of a ship is partially filled with liquid, well-known sloshing phenomenon may occur, of which pressure can be estimated by numerical simulations or other formulae based on the experiment as was shown in the committee report.

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On the other hand, if the tank is fully-filled with the liquid, only the pressure due to the gravitational acceleration and the acceleration of ship motions occurs. In order to estimate these pressures, it is necessary to determine the "reference point" of the internal pressure, which is defined as the point where the pressure is always zero such as the free surface in a partially filled tank case; however, it is known that the reference point cannot be determines theoretically under the incompressible fluid assumption. Several methods to predict the reference point of pressure have been examined based on the experimental results (e.g. Ship Research Panel 228 (1999)); however, the results were not unique. In fact, the reference point is different, case by case, in the common structural rules for bulk carriers and double hull oil tankers. The internal pressure of the dry bulk cargo is also provided in the Common Structural Rules for bulk carriers. It is possible to treat the pressure of bulk cargo in a similar way as the liquid pressure except for the shearing stress. There seems to be a room to investigate further the pressure distribution of internal liquid cargo in a fully-filled tank particularly in a ballast tank of complicated shape and the behaviour of bulk cargos in a hold in detail.

As for the actual ship in a sea way, stresses of a certain structural member are resulted by multiple loads, for example, due to hull girder bending, internal pressure of cargo or ballast water, external sea pressure caused in waves, and so on. It is, therefore, necessary to superpose the stresses caused by such plural load component to obtain the total stress acting on a certain structural member of a ship. General superposition procedure of stresses due to several load components is shown in the followings.

Let the dynamic stress components caused by hull girder bending, internal pressure and external pressure be denoted as , and , and the static stress be. The superposed total stress can be given by

$$\sigma_t = \sigma_i + \sigma_e + \sigma_b + \overline{\sigma}_s \tag{11}$$

As the dynamic stresses have phase difference each other, the stress components in regular wave are given by

$$\sigma_b = \overline{\sigma}_b \cos(\omega t - \varepsilon_b) \tag{12}$$

$$\sigma_i = \overline{\sigma}_i \cos(\omega t - \varepsilon_i) \tag{13}$$

$$\sigma_e = \overline{\sigma}_e \cos(\omega t - \varepsilon_e) \tag{14}$$

where is the encounter frequency of the ship and wave. Substituting Eqs.(12), (13), (14) into Eq.(11), we have

$$\sigma_t = \overline{\sigma}_s + \overline{\sigma}_d \cos(\omega t - \varepsilon_d) \tag{15}$$

where

$$\overline{\sigma}_d = \sqrt{\overline{\sigma}_b^2 + \overline{\sigma}_i^2 + \overline{\sigma}_e^2 + 2\overline{\sigma}_b\overline{\sigma}_i \cos(\varepsilon_b - \varepsilon_i) + 2\overline{\sigma}_i\overline{\sigma}_e \cos(\varepsilon_i - \varepsilon_e) + 2\overline{\sigma}_e\overline{\sigma}_b \cos(\varepsilon_e - \varepsilon_b)} \tag{16}$$

$$\varepsilon_d = \tan^{-1}\left(\frac{\overline{\sigma}_b \sin\varepsilon_b + \overline{\sigma}_i \sin\varepsilon_i + \overline{\sigma}_e \sin\varepsilon_e}{\overline{\sigma}_b \cos\varepsilon_b + \overline{\sigma}_i \cos\varepsilon_i + \overline{\sigma}_e \cos\varepsilon_e}\right) \tag{17}$$

Eqs.(16) and (17) represent the amplitude and the phase angle of the total stress caused by the plural stress components. It should be noted here that not only the amplitude but also the phase angle of each stress component are necessary to estimate the stress amplitude of total stress. As was mentioned before, it is not easy to calculate the phase angle of the stress caused by the external pressure in waves. It may be necessary to adopt some practical techniques to superpose the multiple stress components in the ship structural design.

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1.1.5 Buckling and Ultimate Strength

One of the most important strength of ships and offshore structures is the buckling and the ultimate strength. The quasi-static response analysis is often applied to these problems because the dynamic effects can be disregarded in most cases. In the assessment of the buckling strength and particularly the ultimate strength of a ship, it is basically necessary to obtain the maximum load. In the case where a single load component is applied to the structure, a "design wave" concept is often adopted to estimate the extreme ship response. A regular wave train is usually adopted as the design wave and is properly calibrated by a stochastic analysis; the wave height and wavelength of the design wave are chosen so that the maximum load and resulting maximum stress are expected to occur. In the case where multiple load components are applied to the structure, however, it is not easy to define a single design wave because each load component has different phase angle generally. Maximum stress occurs in a certain structural member in the design wave for a certain load component, but this design wave may not cause the maximum stress for the other load component. It would be a practical way to use several design waves in this case according to each load component, although how to superpose the maximum stresses due to each load component may arise a new problem. In any cases, it may be possible to know the maximum "load" in the design wave method, but this does not directly lead to the estimation of the maximum "stress" as was mentioned before. The phase information of load and response is indispensable particularly in the above mentioned Load Type III or the multiple load case to estimate the maximum stress.

In conjunction with the buckling and ultimate strength of a ship, it is getting to be common to take account of the uncertainties associated with reliability based quasi-static response assessment as is shown in the committee report. In the reliability analysis, not only the magnitude of stress but also the statistical properties such as the variance of stress are needed. The exceeding values of ship response in her life can be calculated by a frequency domain analysis, or a spectral method, where statistical values of linear ship response in a short-term sea state are calculated based on the wave spectrum and the transfer function of ship response. The tail parts of the long-term prediction of the stress can also be estimated by using the statistics of extreme value, and recently the First Order Reliability Method (FORM) is also adopted extensively. Most of these researches, however, are carried out on the external loads or at most the stress caused by the above mentioned Load Type I such as bending moment of ship hull girder. As was mentioned before, the maximum load does not necessarily give the maximum stress in some load types. In this aspect, the important point in the quasi-static response analysis would be how to convert the useful information obtained in the "load" to the "stress". Future works may be necessary focusing on the reliability-based structural analysis technique to estimate the global and local stresses caused by multiple loads.

1.1.6 Fatigue Strength

In contrast to the buckling and the ultimate strength, the problem is more complicated in the fatigue strength. In the ship structural design, the fatigue strength is usually evaluated by the crack initiation: Adopting the linear cumulative damage law such as Miner's rule, the cumulative fatigue damage factor is calculated and is used for the judgement of crack initiation. According to the probabilistic approach, the stress transfer function is firstly calculated, and the short-term and the long-term prediction of the stress are carried out with the use of the wave spectrum and the wave scatter diagram. On the other hand, the fatigue strength is sometimes evaluated by means of the crack growth analysis according to Paris law. The reason is that the order of stress occurrence affects the crack propagation considerably, and such nonlinearity is one of the important factors in actual fatigue damages. Miner's rule may be unsatisfactory from this point of view. Crack propagation is to be simulated with the use of stress time histories of a certain structural member of the ship in waves. Although there might be several ways to estimate the stress time histories, a practical and simple way is to utilise a stress transfer function. Time-varying stress histories can be generated from the stress spectrum calculated by the stress transfer function and the wave spectrum.

In this way, the stress transfer function is actually useful in the estimation of fatigue strength of ships and offshore structures; however, it is not easy to obtain the stress transfer function caused by various load components. The stress transfer function represents the amplitude and the phase angle of stress as a function of wave length and wave direction. As several load components, such as hull girder bending, internal pressure of cargo or ballast water, external pressure in waves, are acting on the ship structure, enormous numbers of FE analysis would be necessary in general to obtain the stress transfer function exactly, as was already mentioned in the previous section. There are several research works to approximate the stress transfer function with the use of the load transfer functions, but it may be necessary to develop some ideas to boost efficiency with regards to the structural analysis in the assessment of the fatigue strength of ships and offshore structures.

1.1.7 Design Trends

The Committee II.1 have also reviewed the design trend of ships and offshore structures. The effects of global warming, the utilisation of renewable energy, the ballast water treatment and so on would be the key issues in the future design of ships, and there will appear several new types of ships in near future. The Committee II.1 concluded that "nowadays whenever a problem or question arises, the standard procedure is to either seek an answer from existing quasi-static references or to use any one of the many available finite element programs". The discusser thinks that it is inevitable to use a finite element program to design a new type of ship, and the key question is not "how is the function of the program" but "how to utilise the program" in the design stage. A lot of computational tools are now readily available even for the nonlinear dynamic response analysis, and the designers are being required to choose these tools efficiently and adequately in the structural design stage.

1.1.8 Summary of Discussions

In an actual ship sailing in a sea way, various external and internal loads are acting on the ship structure and the loads result in stress fluctuations in structural members. In the ship structural design stage, it is required to estimate the stresses attributed to such time-varying various loads. At present, it is usual to rely on the quasi-static response analysis, rather than the dynamic response analysis, to estimate the responses of the structure because of the convenience and the good prospect of the calculated results. In the quasi-static response analysis, the basic assumption is that the frequency of external loads is sufficiently lower than the eigenfrequency of the structure. The discusser would like to know the practical treatment of impulsive loads, such as slamming, sloshing and so on, in the quasi-static structural response and the effect of such treatment of the impulsive loads on the structural responses.

In the ship structure, not only the external pressure in waves but also various internal loads are acting on. The internal loads, such as the ballast water pressure, the oil pressure, the ore or coal pressure, the container load, are very important in the ship structural design. In the internal pressure of the liquid in a fully-filled tank, there is a problem of the "reference point. The discusser would like to know the recent trend in the estimation of internal pressures due to the ballast water, the liquid cargo and the bulk cargo from the viewpoint of quasi-static response analysis.

In the structural analysis using FEM, which is commonly used in the quasi-static response analysis, the number of FE analysis depends on the characteristics of the loads. The compromise between the accuracy and the number of structural analysis would be the key in the structural design stage. In the multiple load case, since each load component has each phase lag, the phase difference between load components and resulting stresses should be taken into account in the estimation of the total stress. In this respect, the discusser would like to have a comment from the committee on the practical structural analysis procedure using FEM to obtain the maximum or minimum stress due to various load components and on the superposition technique of the stresses due to each load component taking account of the recent development of computers and soft wares.

The maximum load does not necessarily give the maximum stress in some load types. With respect to the buckling strength, the ultimate strength, the fatigue strength, and the associated reliability assessment, it is important how to convert the useful information obtained in the "load" to the "stress" in the quasi-static response analysis. In the statistical approach, it might be easy to calculate the transfer function of a load, but it is rather difficult to calculate the stress transfer function from the viewpoint of time and effort of the structural analysis. The discusser would like to have a comment and a suggestion from the committee on the reliability based approach to the assessment of the buckling strength, the ultimate strength, and the fatigue strength of ships and offshore structures from the viewpoint of the quasi-static structural analysis.

As for the structural design of ships and offshore structures, there exists the classification societies' rule as a guideline, and someone may advocate that extra response analysis is not necessary beyond the rule; however, some kind of structural analysis would still be necessary in order to design a new type ship, to determine the details of scantling, to verify the structural integrity, to re-analyse damaged parts, and also, to improve the classification societies' rule. The quasi-static response analysis may be used sometimes, and the dynamic response analysis may be necessary in some cases. In such structural analyses, it is inevitable to use a finite element program nowadays, and a lot of computational tools are now readily available even for the nonlinear dynamic response analysis. In this circumstance, the discusser would like to have a comment of the Committee II.1 on the orientation and the role of the quasi-static response analysis in regard to the structural design of ships and offshore structures.

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1.2 Floor and Written Discussions

1.2.1 Bart Boon

The Committee Chairman stressed in his presentation that FEA requires efficient and effective modelling (e.g. shape of elements) and correct loading of the model. This discusser is of the opinion that optimal results of a FEA for structural design require in addition:

1. a good interpretation of the FEA results, and
2. special techniques (temporary modifications of the FE model) in order to understand correctly the cause of undesirable results of the analysis and to be able to optimise the structural concept and design.

Discusser feels that not sufficient attention is given to these points in literature. What is the opinion of the committee (chairman)?

1.2.2 Ahmad Zakky

In your final recommendations, you have some points which should review in future. One from the points is reliability based inspection and maintenance and life-cycle design concept.

My question: Could you explain, what do you mean about reliability based inspection and maintenance and life-cycle design concept in quasi-static point of view?

1.2.3 Adrian Constantinescu

First of all, I would like to say that it is a real pleasure to participate in this conference. The report of the 'Quasi-Static Response' committee was very interesting and, in this way, I congratulate all members of this committee.

My comments and questions concern the slamming phenomena. Firstly, I observed that the majority of researchers try to model and to validate the bottom slamming. But, the literature presents four main types of slamming. The first one is the bottom slamming, the second is the bow flare (lateral impact), the third is the bow-stem (frontal impact) and the last is the wet-deck slamming. The last is critical to the catamarans. In my opinion, it will be interesting to analyse more the other three types of slamming.

Secondly, I would like to add a comment on the vibration of the structures during slamming phenomena. According to the work of J. Paik, the report indicates that a quasi-static response is characterised by peak pressure duration greater than 3 times the fundamental period of vibration. I would like to know what you understand by 'peak pressure duration', because in slamming phenomena the peak pressure is characterised by very short duration.

More than that, we have to add another limitation of the quasi-static domain. Thus, this last involves the velocity of the peak pressure, i.e. of the wet surface, along the length of the structure, e.g. the generatrix of a wedge body, and the distance between the apex of the body (keel for ships) and the position of the antinode of the vibration mode.

The first question is: How can we estimate the loads, and then the quasi-static response, in case of flat bottoms knowing that simple theories (Wagner, von Karman) are not adapted due to air trapping complex phenomena?

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The second question concerns the classification societies' rules. Why is in these rules the term 'quasi-static' not mentioned? And why are there no explanations to indicate that the rules are used to obtain quasi-static responses?

1.2.4 Bart Boon

In his presentation, the Committee Chairman stated that greening of ships has little effect on the structural design other than allowing for instance an adaptation of the hull shape based upon hydrodynamic considerations.

This discusser is of the opinion that greening of ships (life cycle minimisation of negative effects for the environment) may have at least two direct influences on structural design:

1. The choice of material may be influenced by the footprint for the environment on a life cycle basis. For instance, aluminium may get a better position relative to steel because of its less energy requiring recyclability (without suggesting that aluminium already at this moment may oust steel).
2. Lightweight materials reduce fuel consumption of the ship and thus may get more important as a result of greening of ships.

What is the opinion of the Committee?

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

Professor Fukasawa provided comprehensive mathematical definition to the quasi static problem and discussed the simplifications and their accuracy. The Committee members are very appreciative of comprehensive comments provided by Prof Fukasawa. The committee members recommend that future committee is to consider, i.e. pay attention to the Equations 4 and 5 when reviewing the papers.

The superposition of stresses presented in Equations 11-17 is true, but extremely challenging task when different limit states are to be assessed (buckling, fatigue). Challenge is due to the fact that numerous simplifications are made. First of all, it can be that the analyses for different load components are done with different FE-meshes one modelling the global response, other secondary structures and yet another detail such as welds. Combining the stresses of these analyses has problems due to differences in scales of numerical models as well as making sure how the loads are actually occurring between these. Theoretically, it is an easy, but in practice is difficult task. Perhaps, the link between primary to tertiary local loads/response should be addressed better in future committee work. There are papers discussing on this effect both at naval architecture as well as solid mechanics (multi-scale modelling, homogenisation).

The Committee II.1 would like to respond to Prof Fukasawa's question on the practical treatment of impulsive loads, such as slamming, sloshing and so on, in the quasi-static structural response and the effect of such treatment of the impulsive loads on the structural responses by way of example of GL's simple procedure for consideration of slamming loads for container ships. GL addressed this with a relative simple procedure for consideration of slamming loads in a global strength analysis with an entire FE-model of the ship, Germanischer Lloyd (2011).

The procedure requires the generation of load cases from rule-based slamming pressures p_e - Structural Rules for a specific ship type, say container vessels, for bow and

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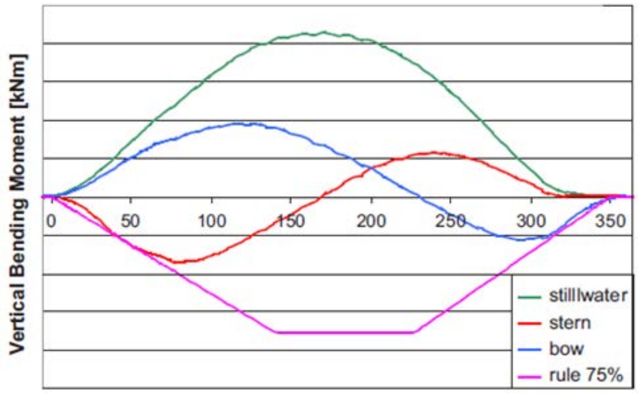

Figure 3: Vertical bending moments with and without inclusion of slamming load as per GL rules, Germanischer Lloyd (2011)

stern areas, respectively. Pressures p_e on bow and stern areas are applied in a way that, in combination with hydrostatic and weight loads, the resulting vertical bending moment (including stillwater loads) does not exceed the rule wave sagging bending moment (without stillwater loads). This restriction is imposed between 10% and 90% of the ship's length. Each slamming load case results from the combination of pressures p_e, hydrostatic loads, and weight loads. These loads are balanced by adjusting the acceleration factors for the weight loads. The evaluation is limited to permissible stresses and buckling strength only. The fatigue criteria are ignored for slamming load cases.

When discussing estimation of the internal pressure of the liquid in a fully-filled tank, Prof Fukasawa points out that there is a problem of the "reference point". He then requests the committee's view on the recent trends in the estimation of internal pressures due to the ballast water, the liquid cargo and the bulk cargo from the viewpoint of quasi-static response analysis.

In response, the committee II.1 would like to provide from ICAS (2012) the Common Structural Rules for Bulk Carrier and Oil Tanker which are published in July 2012 for external review as reference. Here the reference point is to be determined in respect of a maximum response, see Figure 4.

Under the assumptions that the tank or compartment of any type is fully filled with the homogeneous liquid of unique density, and the tank wall is rigid, the dynamic liquid pressure can be determined as a function of usage factors representing the difference between the tank pressure at 98% tank filling and 100% tank filling at the tank sides and the acceleration components that are measured at the centre of the tank. The reference point is defined as the point with the highest value of V_j. The technical background of IACS (2012) provides some possible examples for determining the reference point.

The discusser states that, in the multiple load case, since each load component has each phase lag, the phase difference between load components and resulting stresses should be taken into account in the estimation of the total stress. In this respect, the discusser would like to have a comment from the committee on the practical structural analysis procedure using FEM to obtain the maximum or minimum stress due to various load components and on the superposition technique of the stresses due

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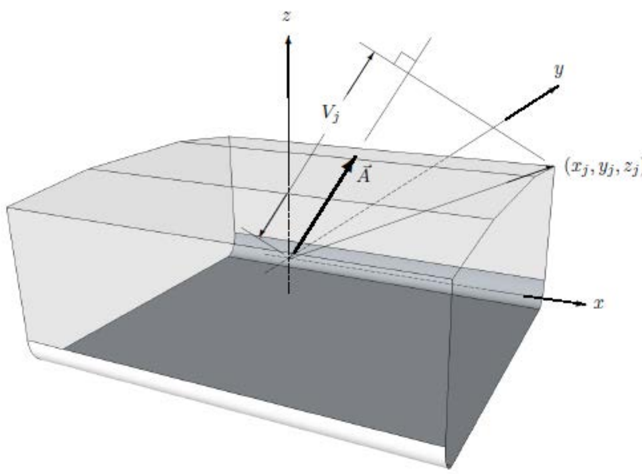

Figure 4: Definition of reference point, IACS (2012)

to each load component taking account of the recent development of computers and soft wares."

The application of the design wave load concept (see previous committee report Aksu *et al.* (2009) Section 3.1.2) by the class societies is to provide assurance of correct superposition of the different global load parts (Shear forces, torsion, horizontal- and vertical bending) and also with the local effects induced by the pressures. Therefore the maximum and minimum conditions can be selected directly by the stress response.

Prof Fukasawa requests for a comment and a suggestion from the committee on the reliability based approach to the assessment of the buckling strength, the ultimate strength, and the fatigue strength of ships and offshore structures from the viewpoint of the quasi-static structural analysis. There exist advanced numerical hydrodynamic tools, which do take into account highly nonlinear dynamic loads such as slamming. Application of such tools will provide pressures on hydrodynamic panels of the vessel. These pressures may then be transferred to a FE model at selected time steps. From the FE analysis, deflections and stresses can be determined and checked against failure criteria. Reliability analysis is carried out by considering statistical variation in pressures and the response. For example, the process may be repeated for a number of samples to have sufficient statistical representation, say, using Monte Carlo simulations. Importance sampling methods, such as response surface approach could be used to reduce the number of FE runs to a reasonable level. Even though the above mentioned procedure is primarily used to determine the deflections and stresses, a number of commercially available FE packages offer additional modules, which enable subsequent analyses and checks for adequacy of the structure against buckling, ultimate strength and fatigue.

Prof Fukasawa requests for a comment from the Committee II.1 on the orientation and the role of the quasi-static response analysis in regards to the structural design of ships and offshore structures. The Committee II.1 fully agrees with the comment that the problem nowadays is not the capability of different numerical tools, but rather how they are used efficiently during the design process. The role of quasi-static modelling is changing towards preliminary design where the scantlings are defined for example using optimisation; this is the way for example MAESTRO works. As the design progresses

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to change the main scantlings become more difficult, since the analyses may become non-linear as the discusser points out. To change the plate thicknesses, stiffeners, even the mesh is then practically unacceptable in large scale since the modelling and solution time, involving in worst-case optimisation or reliability analysis, increases too much. It is recommended that this topic is to be covered by the future Quasi-static Response Committee.

In conclusion, the ISSC Technical Committee II-1 members would like to thank, the official discusser, Prof. Toichi Fukasawa, for his comprehensive review and valuable comments and suggestions.

2.2 Reply to Floor and Written Discussions

2.2.1 Bart Boon

The committee fully agrees with Professor Boon's comment that the interpretation and the use of FEA results should be included as one of the key issues of the Finite Element Analysis. Williams (2004) supports Prof Boon's viewpoint and discusses a need for powerful and flexible tools for the FEA software to examine results and assess designs quickly, thoroughly, and accurately. Moreover, they advanced to levels providing structural optimisation automatically. The committee notes that over the years, commercially available FE packages have improved their post processing tools, which allow the FEA user to display and check the results easier than previously. However it is absolutely critical that the FEA user must be equipped with the necessary knowledge of structural analysis so that appropriate interpretation of the FEA results, and hence design modifications can be made.

2.2.2 Ahmad Zakky

The committee members would like to thank to Mr Ahmad Zakky for his question on risk-based inspection and maintenance and its relevance to quasi-static response. Maintenance, inspection, and repair are key aspects of managing the structural integrity of ship systems in a life cycle framework. The life cycle framework, in this context, refers to activities and resources associated with all stages of an asset from design, construction, operation and scrapping.

The traditional inspection and maintenance requirements by the classification societies and national and international regulatory bodies can be categorised as compliance-based or rule-based strategy, which is often translated to prescriptive time-based inspection and maintenance planning. Inspection plans derived from such a strategy have generally been developed based on years of experience gained from inspection and maintenance of many commercial ships. They tend to provide a minimum standard and proactive owners and operators may introduce additional or more frequent inspections.

The condition-based or performance-based inspection strategy is a step improvement from the rule-based approach. In condition-based strategy, the usage and degradation are forecast from the predictive models and input from subsequent inspections. This is then used to predict the condition of the structure. When the condition is estimated to reach a predefined threshold, inspections are conducted. The condition-based inspection approach is concerned with the occurrence of the structural degradation but is not explicitly concerned with the associated consequences of the structural degradation.

The risk-based inspection (RBI) and reliability centred maintenance (RCM) methods – a step progression from the performance-based strategy – are concerned with both

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the estimation of likelihood and the consequences of the structures degradation and potential failure Serratella *et al.* (2007). In this way, these methods potentially offer the optimisation of resources by identifying and focusing on towards inspecting those items, which have a greater risk. The implementation of these risk- and reliability-based techniques into the development of a plan provides an alternative to prescriptive time-based inspection and maintenance planning.

Both the performance-based and the risk-based inspection methods require predictive models in estimating the likelihood and the consequences of structural degradation. These predictive models are naturally linked with the quasi-static response.

RBI for hull structures has been widely used within the offshore oil and gas industry (API, 2002). Even though application of risk-based maintenance approaches in shipping industry is not widely accepted, there are few recent activities. Serratella *et al.* (2007) argue that proactive marine operators feel that significant benefits could be achieved in developing RBI plans that are tailored to their assets and started employing them. European Commission provided funding to the project RISPECT (Risk-Based Expert System for Through Life Ship Structural Inspection and Maintenance and New Build Ship Structural Design) within Framework 7 programme (RISPECT, 2008, Hifi and Barltrop, 2012). RISPECT project aims to bring the traditional rule-based approach based on long term experience and the risk-based approach based on first principles together and to develop and demonstrate an improved decision making method, based on a combination of experience-based and first-principles, statistical analysis, for safe, cost-effective structural inspection, repair and design rule improvement of existing ships. Bharadwaj and Wintle (2010) demonstrated a methodology using information generated by class inspection and/or historical operational data to optimise inspection such that the combination of the risk of failure of a structure and the cost of such inspection is minimised or reduced to an acceptable limit. The authors discussed the risk based optimisation of inspections with a two steps model. First step is a technique to prioritise sub-structures within the ship hull based on measures of risk, capturing risk profile information based on the likelihood of occurrence of failure, its severity and the effectiveness of current measures to mitigate the failure and/or its consequence. Second step of the model is optimising inspection actions, given the risk based order of priority established in previous step and the financial resource available.

2.2.3 Adrian Constantinescu

First of all, the committee members would like to thank Dr-Eng Constantinescu for his comments on the terminology and types of slamming. In regards to his first question on the issue of air entrapment for slamming of flat bottomed ships. The committee acknowledges that it is a difficult task to estimate the slamming pressures on flat bottomed ships. Kim *et al.* (2008) presented consideration of slamming impact design loads on large high speed naval craft by the classification societies' rules.

The classification rules contain certain level of conservatism to account for uncertainties in the loading and strength of the designed vessel. Quasi-static analysis often means a simplified approach with consideration of worst case loading scenarios (e.g. hogging and sagging conditions). It is in that sense fits well with classification society rule set development that quasi-static analysis provides a relatively quick and conservative approach.

Like other processes involving natural seaways, slamming is a strongly non-linear three-dimensional process, sensitive to relative motion and contact angle between body and

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water surface. Characterised by highly peaked local pressures of short duration, slamming peak pressures cannot be applied on larger areas to estimate structural response to slamming impacts. Moreover, the influence of hydroelasticity, compressibility of water and air pockets may have to be accounted for as well.

Classical approaches predict slamming peak impact pressures reasonably well (von Karman 1929; Wagner 1932), albeit only for two-dimensional sections without a flat bottom or large dead rise. Thus, these classical theories are hardly applicable for real ship geometries. Shortcomings of this method are the simplified treatment of three-dimensional effects, ship motions and wave steepness. Methods that directly solve the Reynolds-averaged Navier-Stokes (RANS) equations, including the two-phase flow of water and air, are better able to describe the physics associated with slamming. However, the computational effort for a three-dimensional RANS solver to simulate motions and loads on a ship at small, successive instances of time over a long-time period appears beyond current computational capabilities.

Payer and Schellin (2012) propose a method, which combines a fast potential flow seakeeping code with an accurate RANS solver. This has been found to be practical to obtain spatial mean slamming pressures suitable for design purposes of ships subject to slamming, El Moctar *et al.* (2004); Schellin and El Moctar (2007). The procedure consists of the following steps:

1. A linear, frequency domain code computes ship response in unit amplitude regular waves. Wave frequency and wave heading are systematically varied to cover all possible combinations that are likely to cause slamming. Results are linearly extrapolated to obtain responses in wave heights that represent severe conditions, here characterised by steep waves close to breaking.
2. Regular design waves are selected on the basis of maximum magnitudes of relative normal velocity between ship critical areas and wave, averaged over these critical areas.
3. RANS computations determine ship motions and wave loads for the identified critical parameter combinations.

The obtained average slamming pressures are applied as equivalent static design loads used to specify scantlings of the ship structure. This multi-stage procedure represents a compromise between attainable accuracy and computational effort.

2.2.4 Bart Boon

The committee II.1 agrees with Professor Boon's first point that if the use of different materials is encouraged / mandated by international regulations in future, this will have significant implications into the structural design of ships. Taking a ship hull as an example, a total life cycle analysis involves from the mining of the raw materials used in its construction, through to its operations, possible re-use of the material or recycling, and its eventual disposal. In this respect, a number of studies, Belair (2012), Burman *et al.* (2008) suggest that total cost of ownership of aluminium is lower than steel.

The committee II.1 notes that lightweight aluminium superstructures have been used in naval ships in order to manage the growth margin by lowering the vertical centre of gravity as well as reducing the overall weight of the structure, Lamb *et al.* (2011). In recent years, there has been significant interest in the application of steel sandwich panels with reduced weight to passenger vessel designs. The committee II.1 has provided a comprehensive review on this development.

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18th INTERNATIONAL SHIP AND
OFFSHORE STRUCTURES CONGRESS

09-13 SEPTEMBER 2012
ROSTOCK, GERMANY

VOLUME 3

COMMITTEE II. 2

DYNAMIC RESPONSE

COMMITTEE MANDATE

Concern for the dynamic structural response of ships and floating offshore structures as required for safety and serviceability assessments, including habitability. This should include steady state, transient and random response. Attention shall be given to dynamic responses resulting from environmental, machinery and propeller excitation. Uncertainties associated with modelling should be highlighted.

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1 DISCUSSION

1.1 Official Discussion by Holger Mumm

1.1.1 Introduction

For three periods I have been associated now with the ISSC Committee on Dynamic Response. Its reports have been very useful anytime I have been confronted with a new problem or had to familiarize myself with some new development. Of course, such a report cannot deal with details of the respective publications but it provides a formidable overview of the recent technical progress in structural engineering for ships and floating offshore structures.

I am thus very glad and honored to join the 18^{th} Congress here in Rostock and would like to thank the ISSC 2012 Standing Committee and the Chairman of Committee II. 2 for inviting me to share some of my thoughts on the Committee report.

Here in Rostock and multiple other locations along the coast of the Baltic Sea we can find a long tradition in ship building and other maritime industries which had continuously to adapt to changing political and economic circumstances. More than 20 years ago the former East German shipyards underwent a mayor transition from government owned state enterprises to private companies. Even though this was combined with a drastic reduction of work force, the ship yards kept to construct merchant vessels in large numbers for quite many years. However, this development more or less ended with the financial and economic crises in 2009. Again German ship building industry had to reinvent itself by developing and building more specialized and customized vessels, a trend which was accompanied by continuous innovation and healthy market conditions for the German maritime supplier industry.

As pointed out in the Committee's report, the future trends within in the maritime industry can be supposed to be governed by the increased need of the world population for food, energy and raw materials on one hand and for sustainable living conditions on our planet on the other. Not surprisingly, a large part of recent R&D activities has been focused on these areas and it can be supposed that this will remain for decades to come. For the maritime industry this represents a huge opportunity to come up with new and innovative solutions for energy saving, emission reduction, and last, but not least, the development of new energy sources.

Here in Germany the government established an ambitious plan to drastically increase the share of renewable energy on the overall energy production. This will require tremendous investments and has triggered a lot of activities for realization of offshore wind parks already. The first offshore wind parks have gone into operation but multiple challenges need to be overcome. All over the world the interest for offshore wind energy has significantly increased and, certainly, interdisciplinary cooperation between ship building, offshore and wind turbine industry will be called for. Therefore, I am very happy to see that the Committee took up ISSC 2009's suggestion to devote more attention to offshore topics than it was done in the past.

I am very pleased that the Committee also succeeded in realizing another suggestion of the ISSC 2009 congress, to perform a comparative benchmark study on the analysis of whipping vibrations. This would not have been possible without the experimental results which have been provided by Cooperative Research Ships (CRS). It is greatly appreciated that CSR was willing to share the results of its extensive measurement program with the scientific world and thus enabled performance of the benchmark study which is considered as the ice on the cake of the Committee's excellent report.

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In my review I will follow the structure of the Committee's report. Where possible I will make some additions to the content but I will concentrate on where clarifications may be necessary, express a few recommendations and will make suggestions regarding what should be done during the next period.

The Committee's report is subdivided into the main topics *Ship Structures*, *Offshore Structures* and *Benchmark Study* making up for approximately 50%, 33% and 17% of the overall report, respectively. Considering that the benchmark study is treating a typical ship structure topic about 2/3 of the report are dedicated to the dynamic response of ships and 1/3 to the dynamic response of offshore structures. This suits very well with the Committee mandate and a similar approach should be followed in the future.

1.1.2 Ship Structures

The chapter on ship structures covers the topics *Wave Induced Vibration*, *Machinery or Propeller-Induced Vibrations*, *Noise*, *Shock and Explosion*, *Damping and Countermeasures*, *Monitoring*, *Uncertainties* and *Standards and Acceptance Criteria.* As can be concluded from the extensive coverage of wave induced vibration phenomena in the publications of the review period a lot of research has been done on this topic and a variety of open questions remains to be addressed in future. This opinion is supported by the fact that the benchmark study conducted by the Committee revealed a significant spread of results in theoretical whipping analyses.

Machinery and propeller induced vibration and research on ship noise phenomena did draw also some attention in the scientific community. Whereas vibration researchers focused on better prediction methods and practical vibration abatement measures aiming at an improved crew and passenger comfort, the research on noise has been triggered to a large extent by environmental concerns regarding noise emissions from shipping. This is true for airborne noise as caused in residential areas in vicinity of busy shipping lanes, ports or terminals, as well as for underwater noise from merchant vessels with its effects on the maritime fauna and human underwater communication means, as, e.g. required for remote control of autonomous underwater vehicles. However, also increased interest into the effects of noise on crew performance and habitability due to tighter regulatory schemes as to be expected in the next years can be observed.

Although included expressively in the Committee mandate the topic of uncertainties in modeling the dynamics of ship structures could not be treated to an extent which would have been desirable because few publications were found focused on this topic. The same is true for the research on damping and countermeasures. A reason for the reluctance to address these topics might be the maturity of approaches which has been meanwhile obtained, i.e. further improvements would require relatively high R&D investments for comparatively small progress.

Monitoring of ship structural dynamics was largely done to obtain more reliable full scale data concerning the extreme and fatigue loads resulting from wave induced vibrations. Research and practical applications directly affecting the operation and maintenance of ships are far behind those methods encountered in offshore industry. This possibly can be explained by the fact that in offshore deep water applications the use of conservative design methods would make certain projects unfeasible because much more economic pressure to push for the limits is given.

As recommended by ISSC 2009 only limited attention was paid to the topics of shock and explosion of ships because it is applicable to a small group of vessels only and,

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moreover, highly specialized experts are dealing with these topics in other organizations.

Wave-Induced Vibrations

The Committee's report extensively covers the topic of wave induced vibration. Due to the clear and systematic structuring of the chapter the various forms and consequences of wave induced vibration can be clearly understood. Due to the complexity of the phenomena involved, it appears that up to now a variety of questions could not be satisfactory resolved and that further extensive research is needed to fully understand the involved physics and derive consistent and reliable simulation methods. This observation is supported by the fact that academia presently does not fully agree on the grade of importance of wave induced vibration for the structural design of novel ships.

Extreme Loads Publications again confirmed that extreme hull dynamic response must be expected from whipping only, i.e. springing does not play a role in this context.

As cited by the Committee Zhu *et al.* (2010) found that compared to open sea condition the tank wall boundary conditions in model tests will substantially change the hydrodynamic values as being characteristic for the excitation of hull whipping vibration, i.e. the slamming pressures, the added fluid mass and the resulting overall hydrodynamic excitation forces. On the other hand the model tank results used for the Committee's benchmark study were obtained in such an experimental test set-up and similar influences must be expected. Could the Committee please clarify how these influences have been accounted for in the theoretical calculations or whether they have been considered negligible?

Ship designers, classification societies and maritime authorities have a great interest to reliably predict the extreme hull response statistics including whipping effects. Gaidai *et al.* (2010) have been cited to offer a method which is using full scale measurement data for this purpose. I would like to ask the Committee to explain in more detail whether the measurement data of the respective vessel must be used or whether some kind of generalization for certain ship sizes and principal dimensions might be possible?

In several publications of the review period on whipping loads on container ships it is stated that the computed and/or measured midship wave bending moments did exceed the IACS rule limit as defined in IACS Unified Requirement S11. Generally, this does not come as a surprise because the UR-S11 limit represents a design value rather than the expected long-term extreme value and, so it does include several safety factors. In the Common Structural Rules for Bulk Carriers and Tankers another approach than in UR-S11 is used. These Rules define for several hull sections the long term extreme value of vertical bending moment and shear force which must be compared against the ultimate strength of the respective hull section. I would be interested in whether in the Committee's experience there has been any evidence of exceeding container ship hull girder ultimate strength due to extreme whipping loads. Also the Committee might dwell a little bit on the question which operating conditions in terms of ship speed and still water loading condition might be considered suitable for dynamic response simulations as conducted in the design stage of a vessel?

The cited publication of Kim *et al.* (2011a) seems to describe a pragmatic approach how to translate *a priori* given extreme value load distributions into loads which can be used in non-linear time domain simulations. In comparison to the traditional design wave approach using regular waves and linear analysis the advantage that irregular design wave profiles can be accounted for will most likely come at the cost of drastically increased computation times. What is the opinion of the Committee regarding the applicability of such a method on an industrial scale in today's merchant ship industry?

Fatigue Loads The effects of whipping as well as springing on the fatigue loads on ships were investigated during the review period. Both phenomena can be easily distinguished in theoretical analyses, however, this is not true for the combined response which is measured in full scale. Did the Committee find any references suggesting methods enabling to differentiate between springing and whipping vibration response in full scale measurements?

Some publications during the review period suggest that torsional hull girder vibration might be of importance for the fatigue strength of structural details of large container ships because the natural frequency of the 1-node hull torsional natural vibration mode is known to be even lower than the natural frequency of the 2-node vertical bending mode and, thus, closer to wave periods with high energy content. The cited reference from Storhaug *et al.* (2011a) based its findings on model tests performed for a 13000 TEU container ship and concluded that this effect should be further investigated in full scale. Partly based on the same motivation full scale measurements are performed onboard a 14000 TEU container vessel in a Joint Research Project of DSME Heavy Industries and Germanischer Lloyd SE since 2010. As presented in Figure 1, about 30 sensors are installed onboard this vessel allowing for simultaneous monitoring of ship motions, slamming pressures in the bow and stern area, hull accelerations and the strains in structural areas presumably exposed to higher stresses in case of global hull girder deflections. The strain sensors are arranged in such a way that stresses resulting from vertical bending, horizontal bending and hull torsion can be clearly separated. Moreover, a wave radar is arranged providing information on the actual sea way conditions and via a connection between the monitoring central control unit and the onboard NMEA bus also the ship operational data (speed, revolution rate, course etc.) is recorded.

During periods of extreme events, e.g. severe bow slamming impacts, the simultaneous measurement of the detailed time histories of all sensors is automatically triggered by the monitoring system so that it can capture the interaction of ship motions, slamming loads, dynamic response and the actual stresses acting in the hull girder. During periods of moderate load levels the time series are of minor interest and so only the

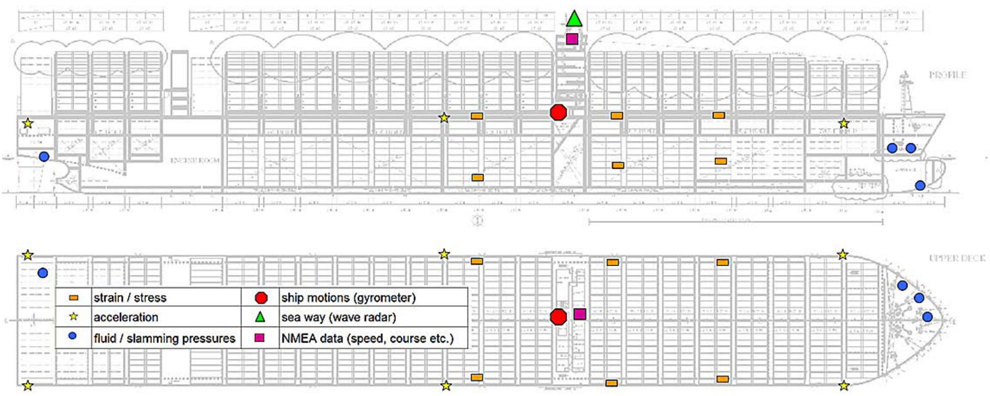

Figure 1: Whipping & Springing Monitoring System onboard 14000 TEU CV (courtesy DSME and Germanischer Lloyd SE)

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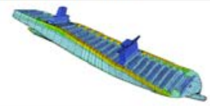
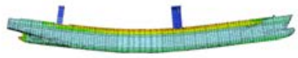
Natural Vibration Mode Shape		Ballast	Design	Full
1-node torsion		0,45 Hz	0,32 Hz	0,26 Hz
		2,2 s	3,1 s	3,8 s
2-node vertical bending		0,68 Hz	0,48 Hz	0,43 Hz
		1,5 s	2,1 s	2,3 s
2-node horizontal bending/torsion		0,75 Hz	0,47Hz	0,38 Hz
		1,3 s	2,1 s	2,6 s

Figure 2: Natural Frequencies and Natural Periods of Basic Natural Vibration Modes of 14000 TEU CV (courtesy Germanischer Lloyd SE)

statistical measurement data is saved to the database in 30 minute intervals including the rainflow matrices of the respective measurement signal.

In order to separate influences from low frequency wave loads and high frequency whipping and springing response on the fatigue strength, the rainflow matrices including and excluding the high frequency part are stored. For separation of the low frequency wave response from high frequency whipping and springing response the measured signals are low pass filtered before rainflow counting is applied. Thereby it is important to select an adequate filtering frequency based on the expected natural frequencies of the hull girder, which are listed in Figure 2 for three different draft conditions. For such long natural periods this is not a straightforward thing to do because setting the filtering frequency too high might result in insufficient filtering of the high frequency components and setting it too low might cause an unwanted filtering of sea way components with a short wave length. In order to shed some more light into the effect of the choice of the filtering frequency on the measured load spectra, the signals are filtered at a comparatively high frequency ($0.40\,Hz$) as well as at a comparatively small one ($0.25\,Hz$).

With this measurement arrangement it is easily possible to conclude on the relative importance of low and high frequency loads on the fatigue life of structural details exposed to load cycles from vertical bending, horizontal bending and torsional hull girder deflections, respectively. As an example the stress range spectra as obtained after 1.3 years of operation for two strain measurement points at a hatch corner radius in the mid ship area are presented in Figure 3. For both points the tangential stress in the radius is measured. It is important to note that the inner (blue) point is primarily exposed to stresses from hull torsional deflection and that the stresses at the outer (red) point will be determined by the grade of hull vertical bending deflection.

The measured stress ranges are presented for the overall combination of wave and vibration induced stresses as well as for the sole low frequency wave part for the two different filtering frequencies as explained above. Several conclusions can be drawn from the presented stress range spectra:

- the shape of the spectra is slightly hollow, i.e. usage of straight line spectra as normally done for the fatigue analysis of structures exposed to sea way loads represents a conservative approach
- for the measurement point exposed to stresses from vertical hull girder bending a distinct increase of the wave-induced longitudinal stresses by 2-node hull girder

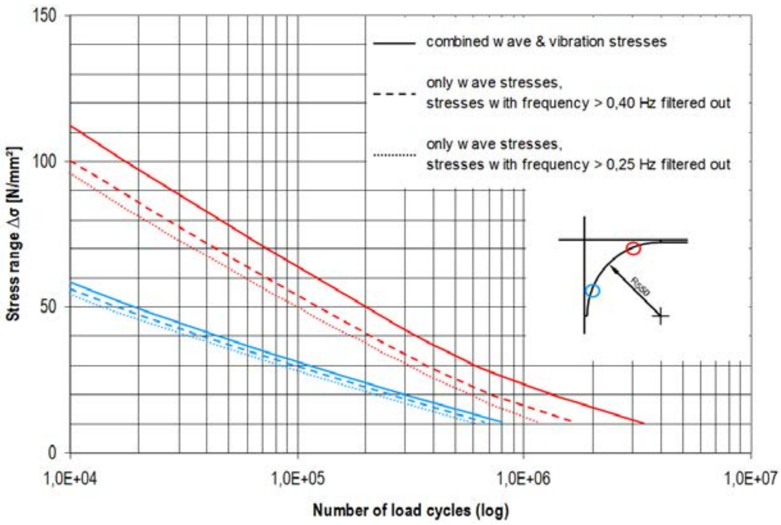


Figure 3: Measured Stress Spectra at Hatch Corner of 14000 TEU CV after 1.3 years of Ship Operation (courtesy Germanischer Lloyd SE)

vibration can be observed, amounting to approximately 10% and 13% for the high and low filtering frequency, respectively

- for the measurement point exposed to stresses from hull girder torsion no distinct increase of the wave induced torsional stresses by 1-node torsional hull girder vibration can be observed

In summary it can be concluded that the torsional vibration mode appears to be not effectively excited by the sea way despite having a natural frequency closer to the periods of longer waves with higher energy content. One possible explanation could be that, even in moderate seas, the intensity of the bow flare slamming impulses primarily depends on the magnitude of pitching motion of the vessel which will tend to cause an excitation of the symmetric hull girder vibration modes, i.e. of the 2-node hull bending vibration, but not of the asymmetric torsional vibration mode. Does the Committee have any further thoughts on this?

Also with regard to the fatigue damage/crack growth mechanism and suitable assessment criteria for a combination of low frequency and high frequency stress components still some uncertainty exists. Matsuda *et al.* (2011) are cited to have reported on their investigations regarding the combined effect of low- and high-frequency stress cycles on the crack propagation process. Could the Committee give a qualitative statement whether their approach will result in a shorter or longer fatigue life time compared to the simpler conventional methods neglecting this effect in fatigue life time prediction?

Machinery or Propeller-Induced Vibrations

Machinery and propeller induced vibration play a major role for the habitability of crew and passengers and the integrity of machinery and equipment. Therefore, it is somewhat surprising that coverage of this kind of hull dynamic response did get so small coverage in publications during the review period. Perhaps this can be explained by the fact that the methods involved in comparison with those for the analysis of wave-induced vibration have achieved a certain maturity and, therefore, less need for R&D in this field was seen by the industry. Does the Committee have further ideas why there have been so few publications in this field of dynamic ship response?

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In my opinion it will be very likely that the topic of propeller induced vibration will become again an important area of research in the next review period because regulations on vibration and noise levels on board ships and on the noise levels emitted into the sea are likely to become stricter. Therefore I would suggest for the next period that somewhat more focus is put on the research on propeller excited vibration and noise. Possibly, a liaison with the ITTC could also be helpful for this purpose.

The novel approach to qualitatively assess and grade the vibration risks of a new design as reportedly presented by Godaliyadde *et al.* (2010) appears very interesting to me for the application in the basic design phase. The used system will enable the engineer to identify the most promising ways to reduce the vibration levels to be expected. In this way it will be ensured that the improvement of the vibration characteristics during the further design stages will focus on the areas with the highest improvement potential.

As described in the Committee's report section on *Standards and Acceptance Criteria* the Maritime Labour Convention (MLC) 2006 does not define acceptance criteria regarding the crew's exposure to onboard vibration levels. As this will give room for different interpretations on compliance with the MLC, the Committee's recommendation to concretize vibration levels acceptance criteria is strongly supported.

The Committee report is citing a publication of Kirkayak *et al.* (2011) on systematic shaking tests of a two tier stack of 20 foot ISO containers. I did yet not fully understand the objectives of these investigations. Could the Committee please provide some information on this?

Noise

The subdivision of the Committee report's chapter on noise into the topics *interior noise*, *air radiated noise* and *underwater radiated noise* is much appreciated since it allows a clear distinction between the objectives, analysis and measurement methods related to these different fields of ship acoustics.

Regarding interior ship noise the focus of recent research was on the improvement of the numerical prediction methods being able to cover also the lower frequency range which can not be handled by statistical energy analysis methods with sufficient accuracy. The Committee reports that quite many hybrid methods have been developed which use finite element or boundary element approaches for the lower frequency range and statistical energy analysis for the higher frequency range. I believe the challenge that considerable computation power is needed to cover the lower frequency range will be solved soon, as we have observed for so many fields of numerical simulation in recent years.

The report's chapter on *Standards and Acceptance Criteria* describes that the IMO A. 468(XII) standard on maximum noise levels onboard ships has been under revision during recent years and it is more than likely that it will have become an amendment to SOLAS regulations until the next ISSC congress in 2015. This means in principle that a vessel which will not comply with the IMO noise limits during sea trial acceptance tests will not qualify to obtain its ship safety certificate and, thus, must not go into service until the deficiency has been rectified. This represents obviously a quite severe consequence and so it is important that the regulatory scheme will be applied in a consistent and uniform way. Has the Committee any suggestions how the risk that the regulations will be interpreted differently by the individual flag states can be minimized?

In combination with stricter regulations on air radiated noise from shipping it can be expected that reliable noise prediction methods and effective noise abatement measures

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will receive more attention from researchers and engineers in the coming years. This is also true for underwater noise radiated by shipping. Evidently, the background noise radiated from ships into the seas has considerably increased due to mankind's need for more and more transport capacity. This has not only triggered environmental concerns but also economic ones, as, for instance, from fishing industry. I am very pleased that the Committee addressed this development by reviewing publications on underwater noise prediction methods and also summarized the current activities to standardize the underwater noise measurement methods and to develop and introduce guidelines in this field. Even more activity can be expected in this area in the coming years and so I would like to encourage the Committee to keep this topic on its agenda also in its next term. Focus should be on the challenges and solutions concerning the underwater noise emitted from merchant vessels because underwater noise research for naval surface ships and submarines are too specific to be dealt with in this Committee.

Offshore Structures

The chapter on offshore structures covers the topics *Slender Structures*, *Very Large Floating Structures*, *Other Offshore Topics and Applications*, *Noise*, *Shock and Explosion*, *Damping and Countermeasures*, *Monitoring*, *Uncertainties* and *Standards and Acceptance Criteria*. The clear structuring of the chapter makes it a pleasure to read and allowed myself to safely navigate through this complex field of maritime engineering challenges.

As can be concluded from the Committee report's extensive coverage of the dynamic response of slender structures, as e.g. risers and underwater pipelines, a wealth of new knowledge has been gained in this field but also there remains a variety of open questions to be addressed in the future. Research and development activities have been mainly driven by the offshore industries' ambition to go for ever larger water depths. The same trend can be observed for the offshore wind energy industry and so it does not wonder that concepts which have been developed in the offshore industry are now transferred to offshore wind energy, as for instance, the use of tension leg supported or even floating wind turbines.

As the oil & gas industry goes for the limits regarding water depths there remains not much room for large design safety factors and thus monitoring of the loads and stresses acting in risers and pipelines has gained much attention in the recent years. The same is true for the interaction of ice and structures and the Committee's report provide an excellent overview on the developments in these fields. Again the experiences and knowledge gained from shipbuilding and offshore industry regarding the operation in polar regions are believed to benefit also the emerging offshore wind industry.

Slender Structures

Slender structures are very sensitive to vibration excitations and so excitation mechanisms are manifold. In cases of resonance, waves, currents or internal flow might cause structural motion or vibration with quite large amplitudes so that the respective structure is exposed to high cyclic stresses. Thus, the avoidance of fatigue damage is a very important design target and, consequently, the development of more reliable experimental and theoretical prediction methods stood in the forefront of research activities.

At the first glance it is a bit surprising that principally the same phenomenon, fluid flow around or within a circular shaped cross section, still revealed so challenging to the scientific community. However, this becomes understandable if the uncertainty

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of the boundary conditions, the high degree of fluid-structure interaction, the strong non-linearity and the sensitiveness of the predicted fatigue life time on the calculated or measured stress amplitudes are taken into account. Last, but not least, damage at risers and pipelines of offshore installations normally have a considerable economic impact and, additionally, bear the risk of environmental damage. Therefore, design safety factors can only be reduced if the gain in accuracy of new developed approaches has been clearly demonstrated and it is highly appreciated that the industry did put so much emphasis on this topic.

The Committee extensively addressed another important aspect in this context, the steady progress in the development of monitoring systems for risers, umbilicals, pipelines etc. In my impression a tendency can be observed to use such systems not only for failure detection but also in the framework of predictive maintenance or life cycle management concepts. Monitoring technologies might use conventional or fiber optic sensors but also magnetic or acoustic methods. Could the Committee please dwell a little bit on the question for which monitoring applications acoustic methods can be considered as the most suitable one?

The Committee's report is citing some references suggesting the use of tension leg foundations for offshore wind energy converters in larger water depths. Does the Committee consider this too as a feasible option?

It is also reported on publications on the 'VIVACE' which converts the kinetic energy of currents into mechanical energy by exploiting the forces originating from vortex separation at cylindrical sections at certain flow speeds. Since this invention is said to function also at rather low flow velocities it appears quite promising to me. How about the Committee's opinion about the potential of this device to harvest energy from currents?

Non-Slender Offshore Structures

Floating offshore structures as spars, tension leg platforms and semi submersibles are exposed to dynamic forces from waves and currents. In most cases the dynamics within the system is represented by the interaction of rigid body motions of the structure being in resonance with sea way components of high energy content, i.e. an elastic deflection of the structure is not involved. Therefore, I would suggest that these topics should be treated by the Committee on hydrodynamic loads in the next review period.

Monitoring of the motions, loads and strains acting within non-slender offshore structures got less attention from the industry than for risers and pipelines. The references on this topic are mainly dealing with cases where full scale monitoring served to validate load assumptions or dynamic response characteristics which had been computed by theoretical methods before.

Similar to shipping the offshore industry discovered new exploration areas in polar areas becoming accessible due to global warming. Both industries have to cope with ice induced loads and vibrations. The same is true for the offshore wind energy which also must secure its installations against the effects of ice covered seas. The report provides a concise overview on this topic and I consider it very valuable that also the recent standards on design criteria regarding ice loads have been discussed in detail.

Also in offshore industry the research on noise focused on two aspects; on one hand the protection of the crew against annoying or even harmful noise levels and on the other hand the emission of noise into the sea by seismic exploration, pile driving, dynamic positioning etc. The cited reference of Sadiq and Xiong-Liang (2008) is discussing

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the noise originating from a FPSO moonpool in waves. Could the Committee please comment whether this represents a typical phenomenon for moonpool arrangements or whether it can be considered as a singular case?

Pile driving for offshore wind energy turbines is a quite noisy activity but, finally, unavoidable if offshore wind parks shall be realised on a larger scale. Meanwhile some techniques have been developed to decrease the emitted noise levels but, as far as I know, there is no consensus on appropriate limit values. Can the Committee give any further information on this?

The Committee's report provides a concise summary of investigations regarding shock and explosions on offshore platforms. Since the cited references are of somewhat older date it appears that not much need for research is given in this field. Nevertheless, it is appreciated that the topic was reviewed in a systematic way so that this can be used as a very good starting point in case more detailed information is needed on the topic.

It is highly interesting that the topic of damping or compensation of structural dynamic response got quite some attention in the research of offshore wind industry. Mostly based on proven concepts from land-based industries different systems were designed to reduce the elastic deflections of fixed monopile offshore wind turbine towers and of the tethers of tension leg platforms serving as wind turbine foundation in case of resonant ringing vibration. Additionally, concepts have been developed to balance the dynamic response of floating wind turbines. Does the Committee know any examples where such systems have been successfully applied in offshore or offshore wind industry?

1.1.3 Benchmark Study

I strongly appreciate that the Committee succeeded in performing a benchmark study. In my opinion this kind of comparative investigation is extremely helpful for all participants because it offers the opportunity to recognize strengths and weaknesses of their own individual approach. Even more important, it gives some insight into the spread of results which might occur if different people use different numerical simulation methods. That should remind us on the value of empirical design methods and should also motivate to always benchmark computation results against what we know from experience.

One great advantage of benchmark studies is their limitation on simple problems which can be directly compared to experimental results. As we know, real whipping and springing does not take place in a regular design wave in the model tank under defined ship operating conditions but in natural seaway under operating conditions finally determined by the vessel's master. However, these uncertainties of the 'real world' can be ignored for the sake of simplicity and so our methods can be tested under clear and defined conditions.

The main purpose of the benchmark study was to address the uncertainties in the calculation of whipping vibration and, ultimately, to obtain an idea on the bandwidth of fatigue life predictions which might result from using different analysis codes and assumptions in the calculations. In the following I will comment on the results and conclusions according to the report's structure since its logic permits to clearly distinguish between the different challenges to simulate reality in this interesting field of fluid-structure interaction.

Modal Parameters

The quality of the respective analysis models with regard to stiffness and mass distribution was checked by calculation of the natural vibrations in dry condition. Since

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the geometrical dimensions of the test model's backbone and the weight distribution were known in detail, I would expect that the natural frequencies of the fundamental hull vibration modes can be calculated with a high degree of accuracy, at least for the 2-node bending vibration mode, which is well known as to be primarily excited by hull slamming impacts. In my opinion a deviation between calculated and measured natural frequency exceeding 2 to 3 % is a strong indication that the analysis model should be checked or the analysis method to be reconsidered because the numerical error can be expected to be much lower. The Committee took the same approach to ensure that all participants used a model of sufficient quality in proceeding with the next analysis steps.

Interestingly, the deviations became less pronounced for the natural frequency in *wet* condition. Possibly that can be explained by the reduced relative importance of the structural mass distribution. How about the Committee's opinion regarding this effect?

Response to Unit Impulse

Even though no experimental data was available for the comparison of the computed response to unit excitation impulses I consider this part of the benchmark very valuable because uncertainties relating to the calculation of the vessel's motions and the associated slamming forces could be disregarded, i.e. it was possible to clearly focus on the uncertainties relating to the computation of the dynamic response to a unit impulse. To further limit the spread of results originating from different assumptions the Committee also agreed on the same structural damping values to be applied in the calculations.

Taking the above into consideration the great variety of results is somewhat surprising. As can be concluded from the time series presented in the right part of Figure 4 of the report, the characteristics of the response computed by different participants varies strongly, not only with regard to the absolute magnitude of the predicted vertical bending moment but also with regard to the frequency content of the time series. Also the decay of vibration amplitude with time is quite different. This is particularly surprising because the same structural damping was applied by all participants. In my opinion the only explanation for this is that the magnitude of hydrodynamic damping was predicted differently by the participant's approaches. Could the Committee please dwell a bit on this phenomenon?

Taking into account the large differences in the computed amplitudes of vertical bending moment it is quite clear that also the comparison of computed fatigue loadings can be expected to reveal large deviations, particularly because they are very sensitive on the given stress range. This was confirmed by the simplified calculation of the fatigue damage as performed by the Committee for the computed time series of vertical bending moment response. For instance, for an impulse duration corresponding to half of the natural period of the 2-node vibration mode the predicted fatigue load was differing by a factor of 12 between the most pessimistic and optimistic approach and even by a factor of 2 for the results of the two participants being in best agreement.

Recalling that the uncertainties from hydrodynamic load calculations have been excluded from this part of the benchmark study, in my opinion the wide spread of obtained results should remind us that computation results must always be benchmarked against empirical criteria in order to judge their trustworthiness.

Response to Regular Head Waves

The first part of this comparison focused on the magnitude of bow slamming impulses computed with different approaches. For a realistic prediction an accurate calculation of the ship heaving and pitching motions as well as of the resulting slamming pressures was required. As can be seen in Figure 5 of the report an accurate prediction was only obtained by these two participants who applied a RANSE method, not only for the calculation of the slamming pressures but also for the computation of the vessel motions. Does the Committee think that this result can be generalised with regard to the calculation of impulses from slamming events?

The second part of the comparison referred to the vessel's response to a regular wave in terms of vertical bending moment. Again quite large differences were found and, in the end, only one participant achieved good agreement with the experimental results for low and high frequency response as well as the superimposed time series. Judging only on the measured and computed times series of the vertical bending moment one could tend to speak of an excellent agreement of the results of this participant, however, speaking in terms of fatigue load, and that is in the end what counts, the agreement is less convincing. Even for this participant the difference between measured and predicted bending moment range is approximately 15% corresponding to about 50% difference in the predicted fatigue life. In my opinion this illustrates very clearly the challenges we are still facing in this field of naval architecture.

1.1.4 Conclusions and Recommendations

Committee II. 2 has compiled an excellent report which I believe will be very helpful for the shipbuilding and shipping community.

As in the previous period the topic of wave induced vibration was the major research topic in the field of ship structural dynamics and I fully agree with the Committee's opinion that further research is needed in order to obtain reliable prediction methods.

Principally, I also agree with the Committee's recommendation that wave induced vibration should be considered during the design phase of the vessel, however, I doubt that current prediction methods are mature enough to turn this recommendation into reality. To illustrate this it might be helpful to leave the academic world and put oneself in the position of a design engineer on a ship yard being requested to verify a new hull design with regard to the risk of fatigue damage resulting from wave induced vibration. He might refer to tentative guidelines of various classification societies but all of them will require the use of some specific software considering fluid-structure effects to a larger or lesser extend. Naturally, each guideline will use its own assumptions on the vessel's operational profile, safety factors permissible stress ranges etc. because it was scaled to the individual experience with the applied computation methods. Some indication of the possible spread of results in this technical field we could observe from the Committee's benchmark study and in my opinion that should make us cautious to establish design requirements before more transparency on the used methods and assumptions has been achieved. That does not mean that whipping and springing vibration should not be addressed during the design stage but it should be recalled that there are also other options which have been used in ship design successfully for decades, i.e. model tests and experience with vessels of similar design. In this connection I would not underestimate the usefulness of performing a standard global strength analysis in the design stage of a vessel. Although a comparatively simple tool it enables the designer to identify those structural details which are exposed to high wave and vibration induced fatigue loads and to improve detail design accordingly.

Thus a well balanced structural design can be achieved where critical structural details have a similar grade of fatigue utilization.

I very much appreciate the Committee's suggestions to intensify research also on the improved consideration of the vessel's realistic operational profiles and the effects from combined wave and vibration induced stresses on crack growth because in design practice these are topics of great concern.

Naturally, vessel speed and wave encounter angle have a significant influence on the severity of wave induced vibration. Therefore, in my opinion, a monitoring system warning the vessel's master when under certain operation conditions too much fatigue life is consumed could also be a suitable approach to cope with wave induced vibration.

The Committee reported in several aspects on the likelihood of stricter noise and vibration regulations: ratification of IMO MLC 2006, inclusion of revised version of IMO 486 (XII) into SOLAS convention, legislation of local authorities on airborne noise emitted from vessels and last but not least IMO's activities regarding the impact of underwater noise from shipping on the marine fauna. Besides supporting the Committee's recommendation to concretize vibration limits in IMO MLC 2006, I would also hope that enhanced research activity will be put again on the prediction of propeller vibration excitation forces and propeller generated noise. As observed in recent years in many technical fields the enhanced use of CFD methods on an industrial scale might bring us a big step forward in this respect.

The extended coverage of offshore structures is considered very valuable because an increased need for offshore technologies can be expected to result from the world wide ascent of offshore wind energy and its potential need to go for greater installation water depths. The Committee realized a perfect balance between providing an overview and going into detail. The same can be said for the chapter on ice induced vibration and it is encouraged to pay the same attention on these topics in the next ISSC period.

Sometimes it is not easy to differentiate whether a certain topic is within the Committee's mandate or whether another one would be suited better for coverage. In this regard I would suggest for the next term to clarify whether research on wave and current induced motions of floating offshore structures should be followed-up by a Committee having more hydrodynamic focus.

Renewable energy can be expected to be one of mankind's major issues in the coming decades. Therefore, I was very pleased that the Committee observed the research activities relating to dynamic response in this field too.

I am sure that many readers of the Committee's report will share my experience to discover new methods and approaches for the solution of technical problems or, at least, get a good idea which publications they should refer to for more detailed information.

It was a pleasure to read this report. The Committee Chairman and the Committee Members are commended for their valuable and excellent work.

1.2 Floor and Written Discussions

1.2.1 Celso Morooka

Very nice report presented by the Committee. Main issues related to VIV are summarized, including inclined cylinders problems, traveling wave phenomena among others. Validations for the Shear 7 and VIV suppression methods are also mentioned.

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To contribute for discussions: the SCR among c shaped riser systems are becoming an important alternative system for oil and gas field production, particularly, deepwater with large flow rate of production, such as in offshore Brazil. However, few works touch the understanding of a SCR behavior due to VIV, not from experimental but also from calculation point of view.

In the past, Vandiver and Gonzales (1997) presented the modal superposition and frequency domain approaches to estimate the behavior of a SCR due to VIV, and Lie *et al.* (2001) used the time domain approach and demonstrated the importance of structural nonlinearities in the problem. Based on that, Morooka and Tsukada (2011) made numerical simulations in time domain following a semi-empirical approach for hydrodynamic coefficients and to predict the SCR VIV behavior. Main objectives of this study have been to reproduce experimental result obtained from reduced scale model experiment in the laboratory (Morooka *et al.* , 2009). Those results have shown traveling waves effect in the riser response, however, it was observed that the estimation of amplitude of the SCR still need more careful study, particularly related to the hydrodynamic coefficients for the VIV for curved cylinders, like in the SCR shape.

1.2.2 Celso P. Pesce

Congratulations for the excellent report and discussion! I would like to comment on VIM and its potential impact on user systems.

After SPARS, VIM of monocolumn platforms, as well as of semi-submersible platforms in very deep waters, have been focused these last five years. Particularly, even VIM in the presence of waves has been addressed.

Nevertheless, the report touches this point superficially, just citing *one* reference regarding a SCR (steel catenary user) case study. This seems to be a point deserving special attention in the next reviewing, for the 19^{th} ISSC.

1.2.3 Andrea Ivaldi

There are a couple of reminders in the committee's final report regarding active control of noise and vibrations.

Is this technology a real option today?

- If yes, how far is it from being commonly used on board ships?
- Up to which extent can it be used (small machineries up to propulsion engines)?
- How can the structural design be affected from the use of that kind of technology (e.g. foundations)?

1.2.4 Ionel Chirica

An important method developed in the last period for underwater blast loading (explosions) of ship hull structure is SPH (Smoothed Particle Hydrodynamics). This method was not treated in Committee II. 2 report.

SPH is used by dividing the fluid into a set of discrete elements, referred to these particles. These particles have a spatial distance, over which their properties are 'smoothed' by a kernel function. The contribution of each particle to a property is weighted according to the distance of particle of interest.

SPH is used in modeling the fluid motion, as well as the blast wave motion in fluid. The SPH method is used for underwater explosion modeling, which is very important for hostile attacks in immediately nearby a ship's hull. There are some papers published in various conferences in last years.

1.2.5 Enrico Rizzuto

First of all, compliments to the Committee Members for their work!

I would like to make a comment and raise a question about the specific subject of ship noise. This subject, incidentally, is covered by the project SILENV, funded by the EU within the 7^th Framework Programme, which deals precisely with the three aspects of noise mentioned in the report: internal to ships, radiated outside in air and radiated into water. Without going into more details about the results of the project, that will be available mainly during the next term of ISSC, I would like to point out an important aspect identified in the project, which is crucial for setting goals for the control of the noise radiated by ships. Such aspect is represented by the importance of improving the description of the noise effects in the various areas and on the various subjects affected. Only a proper quantification of the impact of noise, in fact, can provide means for an effective definition of the objectives of the noise control. The situation is pretty much different in the various area of ship noise radiation: knowledge on the effect of noise on humans is available and can be used to set requirements on internal noise and airborne noise radiation from ships, even though improvements are still needed in the quantification of the actual effects of noise on comfort. On the contrary, the actual impact of noise on the marine fauna and specifically on marine mammals is far from being known: at present, therefore, it seems possible to base requirements on best practice considerations only.

I understand that the subject is quite specific in the wide scope of the Committee analysis, but may the Committee Members expand a little on the formulation and the bases of the present normative framework in the various areas of noise impact control and on their view on the trends foreseen in the near future?

1.3 References

Vandiver, J.K., Gonzales, E.C.(1997). Fatigue life of catenary risers excited by vortex shedding. *International Conference Behavior of Offshore Structures (BOSS) 1997.*

Lie H., Larsen, C.M., Tveit, O. (2001). Vortex induced vibration analysis of catenary riser. *Offshore Technology Conference (OTC) 2001, 13115.*

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Morooka, C.K., Tsukada, R.I. (2011). Dynamic behavior of pipelines and risers due to vortex-induced vibration in time domain. *Marine Systems & Ocean Technology 6*, 17-26.

2 REPLY BY COMMITTEE

2.1 Reply to Official Discussion

2.1.1 Introduction

The Committee thanks Mr. Mumm for his generous appraisal of our report and for his thorough and enlightening discussion, which complements and amplifies many aspects of our report. Mr. Mumm has asked nineteen explicit questions. We have attempted to organize our responses to those questions according to the heading structure given in the official discussion.

2.1.2 Extreme Loads

Mr. Mumm notes there is great interest in reliably predicting the extreme hull response statistics. The Committee cited Gaidai *et al.* (2010) as offering a method to extrapolate

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extreme hull response statistics from full scale measurements. The extreme structural response depends not only on principal dimensions and ship class, but on the route served. It is the Committee's understanding that extreme values estimated using the methods of Gaidai *et al.* will only apply for the same class of ship on the same route and service. If data were collected for diverse ships in the same service, however, then it might be generalized using multiple regression methods similar to those of Kirtley *et al.* (2010), but only for that service.

Mr. Mumm also notes that a container ship may exceed ultimate hull girder strength due to extreme whipping loads. Other key factors may include operating conditions in terms of still water loading condition, speed, and heading that are appropriate for dynamic response simulations during the design stage. All could be key factors; however, speed reductions surely decrease the possibility of slamming.

The authors certainly believe that the Dynamic Load Generator (DLG) method of Kim *et al.* (2011a), can be practically applied in today's merchant ship design and construction industry. It is possible in five minutes, using a laptop computer, to generate 5000 sets of 301 phase angles for use in short time simulations leading to lifetime bending moments. Even when the number of Fourier wave components was increased to 1001, a little more than 12 minutes was enough to find 5000 sets of phase angles.

2.1.3 Fatigue Loads

The Committee did not find any references on methods to enable the differentiation of springing and whipping vibration responses in full scale measurements. It is one of the challenging aspects for the quantitative assessment of those two phenomena. From measured statistics like S-N curves, it is not possible to distinguish which load cycles come from springing and which from whipping. From a measured time series, however, it is possible to say whether the vibrations are resonant, without distinct vibration decay and induced without significant slamming impulse. At least from these indications, one could conclude whether the response should be classified as springing or whipping.

Mr. Mumm has presented some results which suggest that the torsional vibration mode does not participate strongly. Recent experimental and numerical investigations like Hong *et al.* (2012) studied and emphasized the effect of torsional and horizontal hull girder vibrations. The Committee agrees that those vibrations induced by asymmetric excitation mechanism are, so far, not significantly evident from full scale measurements. The Committee's benchmark study highlighted uncertainties involved in the numerical prediction of dynamic responses for symmetric excitation (vertical bending) by comparison with experimental results. The correlation of such hydroelastic predictions for asymmetric excitation (torsion), as well as with full scale measurements, is expected to be even more complex. Future effort should, therefore, also concentrate on studying uncertainties involved with modelling the asymmetric excitation mechanism by comparison with full scale measurements.

An advanced paper by Gotoh *et al.* (2012) investigated crack propagation based on an advanced elastoplastic fracture mechanics approach and clarified that superposed loading histories are not fully effective. This implies that rough estimation without consideration of fatigue crack propagation and fracture mechanics underestimates the fatigue strength and may result in a significant divergence from the actual fatigue damage. Technical literature over the last few years indicates that springing and whipping may contribute significantly to the computed fatigue damage of ships, although there

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is no supporting physical damage data. The fatigue assessments consider only the damage parameter of the Miner's Rule, and do not investigate the actual fatigue crack propagation behaviour when the vibration effect is superposed.

Recent technical literature from the 6th International Conference on Hydroelasticity in Marine Technology (*Hydroelasticity* 2012) mentioned that seamanship, both through weather routing avoidance and as applied through voluntary speed reduction, involuntary speed reduction, and heading changes, is revealed to be an important factor acting to mitigate wave-induced vibrations, particularly in whipping. Lifetime exposure analyses that do not account for these seamanship effects are likely to overestimate both extreme loads and fatigue damage accumulation.

2.1.4 Machinery or Propeller-Induced Vibrations

Mr. Mumm noted that few publications were reported regarding machinery and propeller-induced vibrations. Restrictions on the length of the report and resulting page allotments were a factor. Also, the global focus on ship engine machinery over the past few years has been on compliance with environmental regulation, and the Committee believes that research and publication has reflected an emissions priority over concerns regarding vibration.

The report cites a publication of Kirkayak *et al.* (2011) on shaker tests of a two-tier stack of 20 ft ISO containers. The Committee thought these tests might be of interest to the marine community because they were performed under controlled laboratory conditions that included realistic features, such as mechanical lash in the corner fittings.

2.1.5 Noise

IMO A. 468(XII) is under revision with the aim to incorporate mandatory noise level limits for work and living spaces via amendments to SOLAS Regulations II-1/36. These regulations may be interpreted differently by individual flag states. To minimize this risk, it ultimately falls to IMO to police and regulate their flag states members. Different interpretations could be avoided by unified requirements defined by international flag state organizations, like the *Paris Memorandum of Understanding*. In addition, the IACS, representing the major classification societies who act as recognized organizations on behalf of the flag states, could also define unified MLC requirements.

2.1.6 Slender Structures

The most suitable application of acoustic methods for slender marine structures is considered to be in relation to the monitoring of *metallic risers and pipelines.* Ultrasonic inspection is generally applied in connection with internal inspection by intelligent pigs (pipeline inspection gauges). Both characteristics of internal corrosion defects, as well as the variation of pipe wall thickness, can be measured simultaneously. Inspection up to the circumferential weld area can be performed; however, the weld volume itself is not inspected.

For *flexible risers,* the situation is more diffuse. Some examples of detection of a flooded annulus (i.e., the space between the different layers of the pipe wall) have been reported. Acoustic methods may also be able to detect wire defects in the metallic layers, but this does not seem to be well documented.

VIVACE clearly has the ability to harvest energy from currents. VIVACE has progressed beyond the laboratory to a field demonstration level, and appears to be a promising technology. It is not yet clear that the cost of VIVACE power is competitive with other alternatives.

2.1.7 Non-Slender Offshore Structures

Tension leg platforms are feasible for offshore wind energy foundations in larger water depths. There will soon be one or more demonstrator projects. Technically, tension leg turbine foundations in intermediate water depths are quite feasible. The challenge is to get the cost of power to a competitive level.

The Committee cited Sadiq and Xiong-Liang (2008) regarding noise originating from a FPSO moonpool in waves. The Committee believes this represents a singular case rather than a typical phenomenon. While moonpools are known to be a source of noise, it is not usually regarded as a problem.

Mr. Mumm points out that pile driving for offshore wind energy turbines is a quite noisy activity but, finally, unavoidable if offshore wind parks shall be realised on a larger scale. Some techniques have been developed to decrease the emitted noise levels. As yet, there is no international consensus on limits to underwater radiated noise. As regards offshore wind farms, they will be located, almost without exception, within the boundaries of the exclusive economic zones (EEZ) of individual nations and hence, initially, likely to fall under national regulation. As far as the Committee knows, Germany is the only nation that settled a limit value ($160\,dB$ in a distance of $750\,m$). However, the experience shows that, by state-of-the-art noise abatement measures, compliance with that limit is hard to achieve.

Damping or compensation of structural dynamic response got quite some attention in the research of offshore wind industry. This technology, which is mostly based on proven concepts from land-based industries, is comprised of different systems that are designed to reduce the elastic deflections of fixed monopile offshore wind turbine towers and of the tethers of tension leg platforms serving as wind turbine foundation in case of resonant ringing vibration. Additionally, concepts have been developed to balance the dynamic response of floating wind turbines. It is, however, as yet premature to judge which damping and countermeasures will be applied successfully in the offshore wind industry, particularly on floating wind turbine foundations in intermediate water depths.

2.1.8 Benchmark Study

As cited by the Committee, Zhu *et al.* (2010) determined that tank walls can substantially change the values observed during whipping model tests. The segmented model tests results used by the Committee in the benchmark study were potentially subject to such influence. The tank dimensions were not provided to the participants, so this potential effect was not evaluated by the benchmark study. The Committee is convinced that the uncertainties detected by the benchmark study are of considerably greater magnitude than those associated with tank wall boundary conditions.

Regarding the benchmark study, it is noted that the deviations of natural frequencies became less pronounced in the *wet* condition. Mr. Mumm suggests that this can be explained by the reduced relative importance of the structural mass distribution. The global parameters of the mass distribution of the segments were provided to the participants. Agreement with the specified mass distribution was not reported by the participants. Experimentation with the model of Participant B reveals that variations in natural dry natural frequency similar to that reported by various participants can result from small deviations in mass distribution. As surmised by Mr. Mumm, when the structural mass distribution is combined with the added mass, the relative impacts of any deviations in physical mass distribution are diminished. In addition, the relative importance of any possible error related to the stiffness will be smaller when the added mass is included.

Mr. Mumm noted surprise in the variability of predicted responses to the specified impulses in the benchmark study. The study organizers were also surprised by the significant variation in results. The differences in the vibration decay is all the more surprising since the modal damping, comprising the sum of hydrodynamic and structural damping of the experimental model, was provided to the participants. Hence, regardless of analysis method, participants had the opportunity to 'tune' their overall damping to match the modal damping. Results from Participants A and B are well in line. But, these differ significantly from those provided by Participants C and F. These participants were informed of the likelihood of an error in their computations. No corrections were, however, made. As this is also part of the uncertainty in the calculations, results were still included in the report.

For the benchmark computation of the bow slamming impulse in regular waves, an accurate calculation of the impulse, as well as ship motions, was only obtained by the two participants who applied a RANSE method. The Committee believes that this result can be generalised with regard to the calculation of impulses from slamming events. It is well known that the RANS solver predicts the vessel's motions more precisely than potential theory codes, which tend to overestimate ship motions. Nevertheless, the benchmarks showed that slamming loads were overestimated, as well as underestimated, by participants using potential theory methods. After the ship motions were provided to the participants, however, their agreement with experimental results improved.

2.2 Reply to Floor and Written Discussions

2.2.1 Celso Morooka

The Committee thanks Professor Morooka for his kind appraisal of our report, and especially for his additional references and observations regarding SCRs.

2.2.2 Celso P. Pesce

The Committee thanks, also, Professor Pesce for his kind appraisal. As to the question of VIM, this Committee has interpreted strictly rigid-body responses to waves as falling outside our mandate. However, where VIM induces modal responses in some other structure, for example in a riser, it is regarded as within the mandate of this Committee.

2.2.3 Andrea Ivaldi

There are a couple of reminders in the Committee's final report regarding active control of noise and vibrations. The Committee found that active vibration compensators are commonly used on board ships today. Typically these compensators have an operational frequency bandwidth from $1-25\,Hz$ and can, therefore, be used to counteract global ship vibrations or vibrations of slender superstructures. The location of the compensator depends on the vibration mode in question and its excitation source. For example, in case a torsional vibration mode of a superstructure is excited by the main engine's ignition frequency (H-type), the compensator could be placed directly at the engine or at the superstructure's top. In case of propeller-induced vibrations, the compensator could also be placed in the steering gear room. Before its installation,

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the location of the compensator and the correct compensator force should be carefully chosen, otherwise a compensator could also amplify vibrations. The only impact on the structural design by a compensator's installation is the need for a stiff foundation that is able to induce the compensation force into the ship's structure.

2.2.4 Ionel Chirica

The Committee determined that smooth particle hydrodynamics (SPH), as used for blast loads, fell outside of its mandate. The Committee suggests that the appropriate specialist committee, V. 7, Impulsive Pressure Loading and Response Assessment, explore this topic further.

2.2.5 Enrico Rizzuto

The Committee thanks Professor Rizzuto for his acknowledgement of our efforts. We thank him also for bringing the SILENV project to our attention. We look forward to the release of results from the SILENV project during the next term, which undoubtedly will be of interest to the successor Committee II. 2. Professor Rizzuto observes, quite correctly, that the ability to predict noise is only useful if there are suitable criteria for judging the impacts and consequences. Professor Rizzuto also observes that knowledge of noise consequences for humans is considerably more advanced than our knowledge of the impact on marine fauna, especially marine mammals. It is the appraisal of the committee that there is growing agreement on this point and that, as a consequence, there is quite a bit of active research into URN (underwater radiated noise) impacts on marine mammals.

It is perhaps beyond the mandate of this committee to consider the many research papers during the period that address impacts of URN on marine mammals, though we did mention Bailey *et al.* (2010) which concerned pile driving noise resulting in changes in marine mammal behavior. However, it is appropriate for this committee to note new agreed standards and in this we regard we did make mention of DNV Silent and ISO 16554. Aspects of DNV Silent were set on the basis of the International Council for Exploration of the SEAS (ICES) Cooperative Research Report No. 209 (1995), which is addresses changes in the behavior of fish resulting from URN. Conforming to the ICES (1995) standard is now a frequent goal for new research vessels but experience has shown that it is a challenging goal, which is not easily achieved.

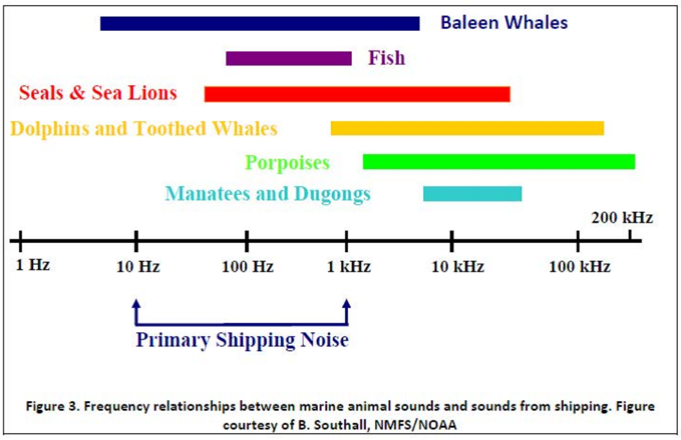

Figure 4: Figure taken from Okeanos (2008)

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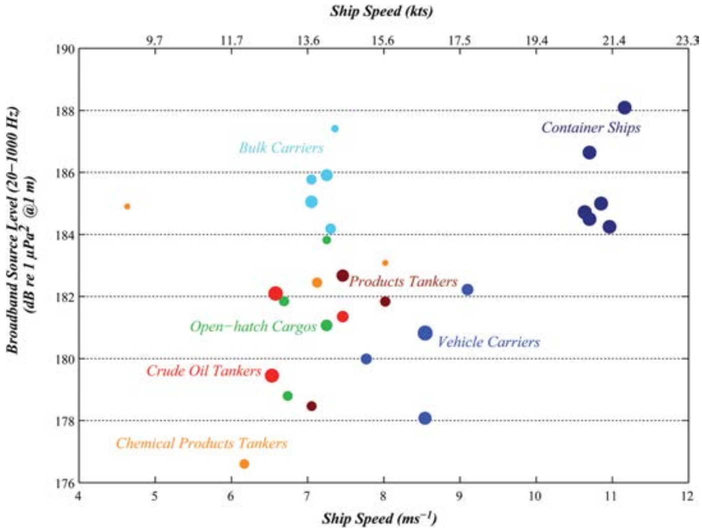

Figure 5: Figure taken from McKenna *et al.* (2012)

Those with interest in the state of research regarding URN and marine fauna may wish to consult Bradley and Stern (2008) or Okeanos (2008). The following is also a useful website for current research regarding URN and marine mammals: http://www. seaweb. org/science/MSRnewsletters/MSR_CP_UnderwaterNoise_8-2012. php

As shown in Figure 4, primary noise from shipping falls in the center of the range of greatest concern for baleen whales and fish, and the low frequency range for seals and sea lions.

Okeanos (2008) report that ocean ambient noise (inclusive of the effects of shipping) as measured at two sites, has been increasing at a rate of about $3\,dB$ per decade.

As illustrated in the Figure 5, McKenna *et al.* (2012) report on full scale measured noise from modern ships of various types and classes, operating at speeds between 9. 5 and 21. 5 knots, with some ships generating $188\,dB$ re $1\mu Pa^2$ at a $1\,m$ reference distance.

The Committee observes that airborne and underwater radiated noises are both of increasing concern. Underwater radiated noise has a potential adverse impact on marine mammals, and can also interfere with acoustic operations of the offshore oil and gas industry.

2.3 References

Bradley, D.L. and Stern, R. (2008). Underwater Sound and the Marine Mammal Acoustic Environment, A Guide to Fundamental Principles. Prepared for the U. S. Marine Mammal Commission.

Gotoh, K., Matsuda, K., and Kitamura, O. (2012). Numerical Simulation of Fatigue Crack Propagation under Superposed Loading Histories with Two Different Frequencies. *6th International Conference on Hydroelasticity in Marine Technology*, Tokyo, Japan.

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VOLUME 3

COMMITTEE III.1

ULTIMATE STRENGTH

COMMITTEE MANDATE

Concern for the ductile behavior of ships and offshore structures and their structural components under ultimate conditions. Attention shall be given to the influence of fabrication imperfections and in-service damage and degradation on reserve strength. Uncertainties in strength models for design shall be highlighted.

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1 DISCUSSION

1.1 Official Discussion by Paul Frieze

1.1.1 Introduction

The main sections of the report are:

1. Introduction
2. Fundamentals for Ultimate Limit State-Based Design and Safety Assessment
3. Rules and Guidelines
4. Definition of Parameters and their Uncertainties
5. Recent Advances
6. Benchmark Studies.

My report will address each section in turn, with varying degrees of attention to each.

1.1.2 Section 1. Introduction

Figure 1 of the report provides a very useful introduction to the various physical hazards to which ships and offshore structures are exposed and which can lead to nonlinear response. It is clear that some of these are beyond the control of the designer and/or operator, e.g. the low temperatures associated with arctic operations, cryogenic cargo conditions, but some are almost directly under the control of at least the operator if not the designer, e.g. impact loads from collisions or groundings, or age-related degradation, because these fall directly into the category of human factors.

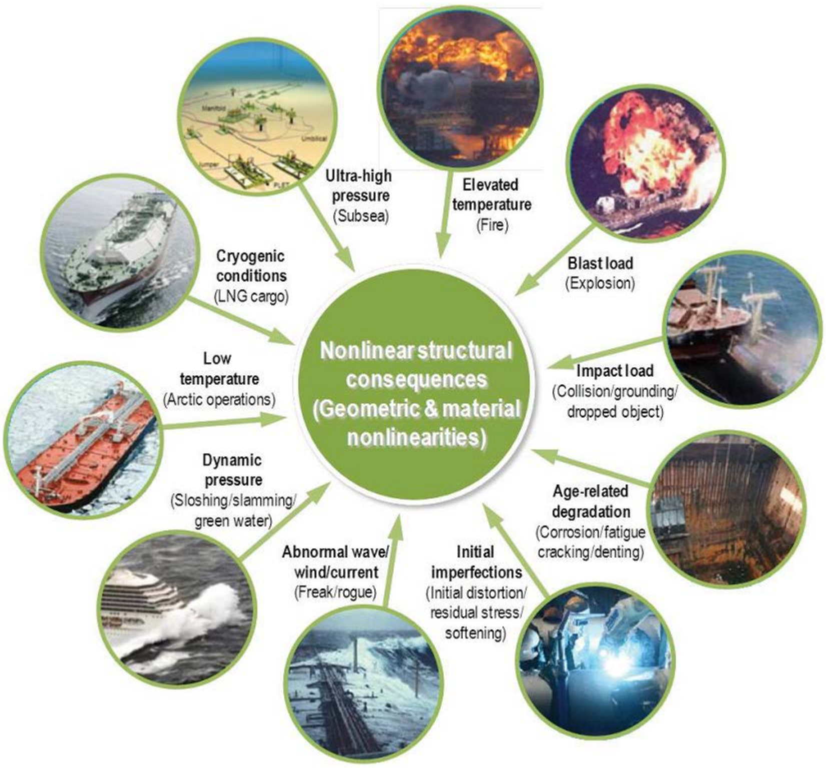

Figure 1: Figure 1 of Report (Paik, 2011)

As highlighted in an article by Paik (2012), Chairman of Committee III.1, human factors contribute some 80% to the cause of accidents which manifests itself as loading on ship and offshore structures. The human factors role is particularly important to recognize and deal with but it is not the subject of this committee's mandate so will not be considered further here.

1.1.3 Section 2. Fundamentals for Ultimate Limit State-Based Design and Safety Assessment

This section addresses, in particular, types of limit states and structural design formats. In the latter, both the partial factor and probabilistic formats are spelt out in some detail via Equations (3) to (11). However, these are all very standard equations which perhaps did not need repeating here but, instead, an appropriate reference to a suitable text book should have been made. Notwithstanding, it does provide an opportunity to comment appropriately on some of the parameters contained in these equations.

Consider Equation (3), which is:

$$C_d = C_k/\gamma_C \ ; \ D_d = \gamma_D D_k$$

This contains two parameters, C_k and D_k, which are described as characteristic values. In the terminology of International Standards, a characteristic value is defined as "value assigned to a basic variable associated with a prescribed probability of not being violated by unfavourable values during some reference period". While this might be the aim when initially determining such parameters, in the Discusser's experience particularly in connection with resistance parameters, such values are invariably not "associated with a prescribed probability". For example, Table 1 presents the modelling uncertainty parameters for the tubular member strength formulations contained in ISO 19902 Fixed steel offshore structures in terms of mean and standard deviation (sd). ISO 19902 assumes that strength formulations represent the 5% fractile which, for an infinite population is the mean minus 1.645 standard deviations. Applying this formula to the listed mean and standard deviation values leads to the numbers listed in the last column which should have a value of unity for consistency with the definition of characteristic value: clearly this is not the case.

There are a number of reasons for this departure from the prescribed requirement, such as:

Table 1: Modelling Uncertainty Parameters for ISO 19902 Tubular Members

Loading condition	Mean	sd	Char. value
Tension*	1.10	0.088	0.955
Local (compression) buckling	1.065	0.072	0.946
Column (compression) buckling	1.046	0.041	0.979
Flexure	1.109	0.094	0.954
Hydrostatic pressure	1.142	0.142	0.909
Tension and bending	-	-	-
Local (compression) buckling & bending	1.246	0.083	1.109
Column (compression) buckling & bending	1.030	0.084	0.891
Tension and hydrostatic pressure	1.075	0.105	0.902
Local (compression) buckling, bending & pressure	1.199	0.161	0.935
Column (compression) buckling, bending & pressure	1.197	0.109	1.018

*Based on API RP-2A LRFD Determined Values

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- As test data are added (or subtracted in a more up-to-date screening process), even if the original equation represented the proper characteristic value, changes in the test database will lead to changes in the modelling uncertainty parameters and, therefore, the characteristic value;
- When analytical models are used as the basis of strength formulation, and may be relatively accurate, the introduction of a factor (around unity) just to achieve the prescribed fractile does not necessarily seem logical;
- Some strength formulations were originally derived as lower bounds to test data and have been retained in their original format or only slightly modified form so will never match the required fractile;
- Some formulations are retained in preference to developing new equations because of their long-standing use.

Consider Equation (5) which is:

$$\eta = C_d/D_d = C_k/(\gamma_C \gamma_D D_k)$$

The parameter η is defined as a Structural Adequacy parameter. It is the ratio of Factored Strength to Factored Demand (Loading). If we take the inverse of this, i.e. the ratio of Factored Demand to Factored Strength, this is the ratio commonly used by Structural Engineers as the Utilization Ratio, i.e. the measure used when undertakings structural design checks, the upper limit for acceptability being unity.

1.1.4 Section 3. Rules and Guidelines

This section is completely devoted to Rules and Guidelines of relevance to ship structures with no reference at all to the topic which has equal weighting, not only in the Committee's Mandate but also in the name of the Congress, namely, Offshore Structures. Exactly the same issue arises in relation to the 2009 and the 2006 reports by this same committee although the latter does devote some space to jack-ups and to typical offshore space frame testing and analysis but not, however, anything on the standards. Perhaps there are good reasons for the lack of reference in which case it is hoped the Report would have indicated these accordingly. One obvious excuse is that none of the Committee members has any experience or exposure to offshore structures. On the other hand, all offshore standards, being international, are in the public domain so their titles and scope at least can be appreciated without the need to purchase the standard.

Given this lack of reference to offshore structures standards, it is useful to summarize these to ensure the wider audience is at least aware of their existence. Table 2 is the complete list of ISO offshore structures standards, the ISO 19900 Series as it is commonly referred to.

It can be appreciated that the top level document is ISO 19900, followed by the 19901 Series of Standards which sets out the provisions for the technologies underlying the structure-specific standards ISO 19902 to 19904. Whilst the same information can be applied to jack-ups (ISO 19905-1), they have evolved different practices for some of the main underlying technologies, particularly foundations, so it offers different approaches to these than specified in the 19901 Series. The standard on Arctic structures primarily addresses loading on these units and other cold-weather operating issues and says nothing about structural design which is the responsibility of the structure-specific documents 19902 to 19904.

Table 2: ISO 19900 Series of Standards and their Status

ISO Number	Title	Published	Status
19900	General requirements	2002	2nd Edition in preparation
19901-1	Metocean	2005	2nd Edition in preparation
19901-2	Seismic	2004	Work beginning on 2nd Edition
19901-3	Topsides	2010	None planned
19901-4	Geotechnical and foundation design considerations	2003	Work beginning on 2nd Edition
19901-5	Weight engineering	2003	2nd Edition in preparation
19901-6	Marine operations	2009	Corrigenda due late 2012, otherwise none planned
19901-7	Stationkeeping	2005	2nd Edition due late 2012
19901-8	Marine soil investigations	-	Due for publication 2013 with addition of Geotechnical site investigations in 2014
19902	Fixed steel structures	2007	Amendment due 2012
19903	Fixed concrete structures	2006	None planned
19904-1	Floating structures: Monohulls, semisubmersibles and spars	2006	2nd Edition under consideration
19905-1	Site-specific assessment of jack-ups	2012	None planned
19905-2	Commentary on 19905-1	2012	None planned
19905-3	Site-specific assessment of mobile offshore drilling units	-	In preparation, publication due 2014
19906	Arctic structures	2010	None planned

In Section 3.1, IACS, reference is made to the fact that harmonized CSR for tankers and bulk carriers is under development: it would be helpful to know who is carrying out this work.

Section 3.2 Classification Societies, the allocation of space to the various Societies is not well balanced with some 3.5 pages devoted to ABS, 2 pages each to Bureau Veritas and DNV but only one paragraph each to Germanischer Lloyd and Registro Italiano Navale. However, not one word on Lloyd's Register or ClassNK Rules. Perhaps it might have been more appropriate to have tried to include all the Class Rules but in a tabular format so that, firstly, all of the components addressed in the various Rules could be systematically listed and, secondly, the coverage in each set of Rules could be directly compared. Perhaps of more help to the reader would be a comparison between the various strength formulations in the different Rules, to highlight any differences and/or similarities.

At the top of page 296, when discussing compactness of Individual Structural Members, the definition of "noncompact" appears to be wrong because normally allowance for buckling is required for "slender" members, "noncompact" members being those in which yield can be achieved but not any plastic hinge capacity because of the possible occurrence of elasto-plastic local buckling.

On page 301, the 3^{rd} bullet in the first set of bullets refers to "panel ring buckling" in which "longitudinal stiffeners act as nodal lines" – this only occurs if longitudinal stiffeners are present which is not always the case.

On this same page, the description of "flexural buckling" (1^{st} bullet of 2^{nd} set of bullets), it is not quite correct because the failure is actually buckling in the direction of the larger slenderness ratio, i.e. effective length / radius of gyration.

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Just before leaving this section, it is just worth recording that the ISO standard referred to in subsection 3.3, ISO (2007), which is ISO 18072-1 Ships and marine technology - ship structures - Part 1: General requirements for their limit state assessment, was withdrawn after seven years of work following the cancellation of work on ISO 18072-2 Requirements for their ultimate limit state assessment. This is particularly unfortunate because the Offshore Industry considered ISO 18072-1 to be a fundamentally sound document.

1.1.5 Section 4. Definition of Parameters and their Uncertainties

Section 4.1 Introduction

At the end of this section, it is noted "that large/full-scale experimental data focusing on such practical aspects are rather limited, especially on aspects concerning hull girder strength". It seems to me possible that, because of their age, some very relevant test from the 1970s may have been overlooked when this view was expressed. A substantial number of stiffened steel ship-type cross-sections were tested as part of a major research programme into the ultimate and post-ultimate strength of stiffened steel box girders, precipitated by the collapse, primarily during construction, of four such box girders in the late 1960s. Most of this testing was in the UK but related tests were performed in Europe and Australia.

The main set of tests was performed at Imperial College, London, by Dowling *et al.* (1973), Dowling *et al.* (1977) and Lamas *et al.* (1983). Table 3 summarizes the pertinent features, in imperial units. The geometry was such that failure was precipitated by both plate and stiffener failure, and even cross-frame instability. Some of the models were subjected to pure bending (Figure 2) and some to combinations of bending and shear (Figure 3).

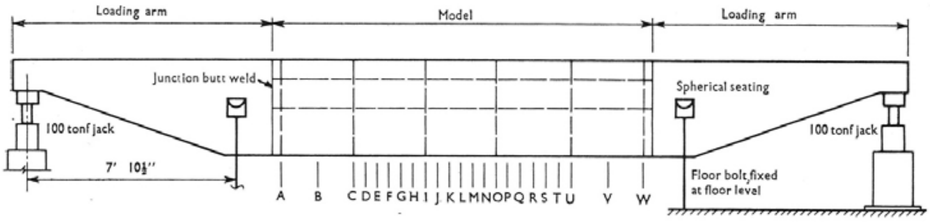

Figure 2: Figure 1b of Dowling *et al.* (1973) showing pure bending test set-up

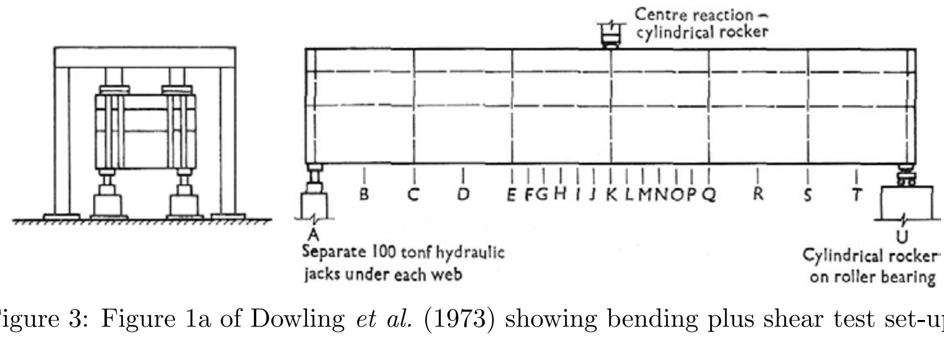

Figure 3: Figure 1a of Dowling *et al.* (1973) showing bending plus shear test set-up

Extensive initial geometrical imperfection and welding residual stress measurements were made with typical results presented in Figures 4 and 5, respectively.

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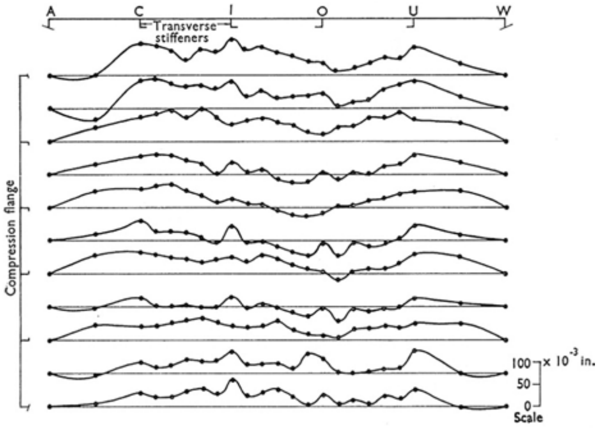

Figure 4: Figure 2 of Dowling *et al.* (1973) showing initial longitudinal profiles of Model 2 compression flange

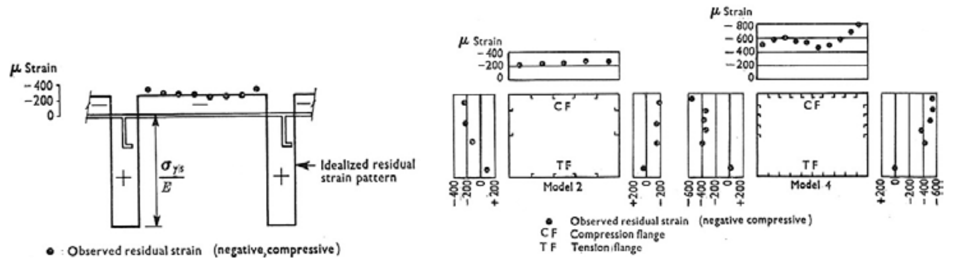

Figure 5: Figures 5a and 5b of Dowling *et al.* (1973) showing welding residual strains in compression flanges of Models 2 and 4

Some 500 strain gauges were fixed to each model to enable the growth of strain with loading to be carefully monitored whilst simultaneously, deflections were measured using the same transducer rig as deployed for measuring the initial shape – see Figure 6. Careful written records of the development of plate and stiffener buckling were made so the sequence could be mapped and numerous post-test photographs taken so as to highlight these buckling modes – see Figure 7.

1.1.6 Section 4.3 Modelling Uncertainties

Several papers are reviewed but only one measure of modelling uncertainty is reported. Considering the Mandate of this Committee states "Uncertainties in strength models for design shall be highlighted", the lack of reported values is felt to be a major omission.

Section 4.5 Conclusions on Practical Aspects in Ultimate Strength Assessment

An area not addressed in the Report, perhaps because its inclusion is borderline to the Committee's activities, concerns the residual strength of vessels that have suffered significant yielding and buckling as a result of grounding, incorrect cargo loading or large wave forces. In ultimate strength terms, the vessel hull girder is post-ultimate strength, i.e. on the falling path of the load-deflection plot and potentially involving gross strains. At sea, such vessels may be subject to salvage but what is the residual strength of the hull; can it sustain the forces associated with retrieval and towing to a safe have? It is not difficult to imagine that, practically, any procedure to analyze

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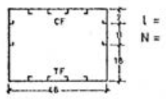
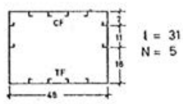
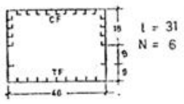
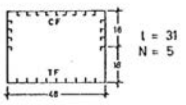
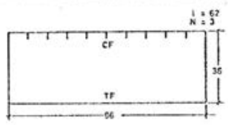
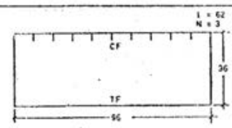
Table 3: Table 1 of Dowling *et al.* (1977) listing geometrical and material details

Model No.	Cross-section of model dimensions, in	Component sizes and material properties				
		Component	Nominal size, in	t*, in	σ_0 tonf/sq.in	E tonf/sq.in
1		CF	3/16	0.195	16.0	13000
		TF	3/16	0.195	16.0	13000
		W	1/8	0.133	17.7	13900
		LS	2 × 5/8 × 3/16 L	-	21.3	13000
		TS	3 × 2 × 1/4 L	-	20.3	12600
		D	1/4	-	16.5	12900
2		CF	3/16	0.192	19.3	13500
		TF	3/16	0.192	19.3	13500
		W	1/8	0.133	13.7	14000
		LS	2 × 5/8 × 3/16 L	-	17.9	12400
		TS	3 × 2 × 1/4 L	-	20.1	12700
3		CF	3/16	0.198	14.3	13400
		TF	3/16	0.195	14.0	13500
		W	3/16	0.196	18.2	13900
		LS(CF)LS(W)	2 × 5/8 × 3/16 L	-	18.6	12900
		LS(TF)LS(W)	2 × 1/4 Plate	-	19.7	13400
		TS	4 × 2½ × 1/4 L	-	19.7	13000
		D	1/4	0.258	19.4	13500
4		CF	3/16	0.198	14.3	13400
		TF	3/16	0.195	14.0	13500
		W	3/16	0.196	18.2	13900
		LS(CF)LS(W)	2 × 5/8 × 3/16 L	-	18.6	12900
		LS(TF)	2 × 1/4 Flat	-	19.7	12900
		TS	4 × 2½ × 1/4 L	-	19.7	13400
9		CF	3/16	0.192	21.6	13300
		TF	1/4	0.268	20.4	13900
		W	1/2	0.500	18.0	13500
		LS	2¾ × 5/16 Flat	0.312	18.5	13300
		TS	5 × 3 × 3/8 L	-	18.7	13200
10		CF	3/16	0.194	21.7	13400
		TF	1/4	0.242	22.0	13700
		W	1/2	0.500	18.0	13500
		LS	2¾ × 5/16 Flat	0.312	18.5	13300
		TS	5 × 3 × 3/8 L	-	18.7	13200

TF Tension flange; CF Compression flange; LS(CF) Longitudinal stiffener on compression flange
W Web; LS Longitudinal stiffener; LS(TF) Longitudinal stiffener on tension flange
D Diaphragm; TS Transverse stiffener; LS(W) Longitudinal stiffener on web

N Number of bays along span of model
t* Measured thickness

such a damaged hull would be simplified in nature. Does the Committee have any views on the matter?

One of the conclusions in this section is that "The available experimental data that can be used as target values for the calibration of structural models is very limited, which makes it almost impossible to estimate the related uncertainties." Given that the data on girder strength described above is only a part of what one suspects is quite a large database of information highly relevant to the ultimate strength of hull girders and the uncertainties associated therewith, I find it difficult to agree with this conclusion although it is acknowledged that the full set of necessary data does not necessarily reside in one institution.

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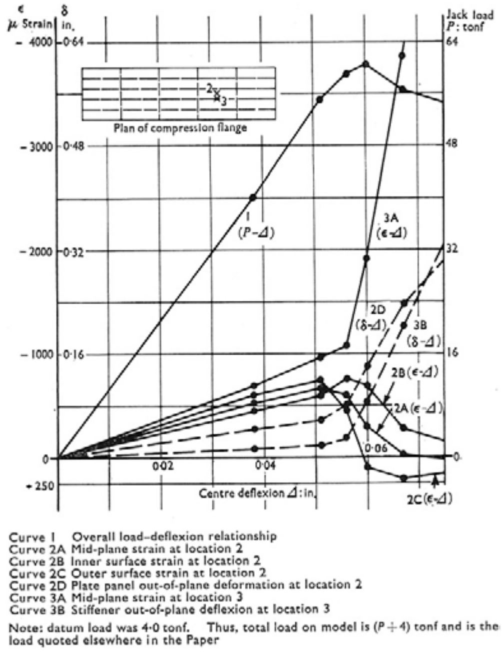

Figure 6: Figures 10 of Dowling *et al.* (1973) showing growth of deflections and strains with load for Model 2

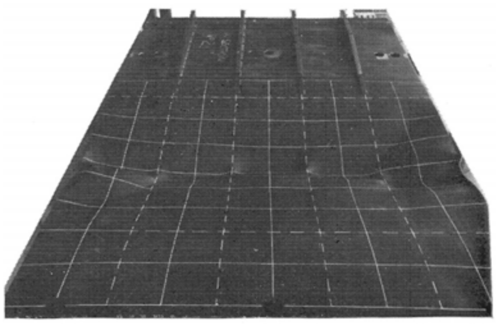

Figure 7: Figures 11 of Dowling *et al.* (1973) showing the post-test buckled shape of Model 2

1.1.7 Section 5. Recent Advances

This is divided into two main subsections, Components and Systems. Under Components, on this occasion, both components of ships and offshore structures are covered and, in keeping with the Mandate, subsections are devoted to (a) Influence of Fabrication-Related Initial Imperfections, and (b) Influence of In-Service Damage.

Section 5.1 Components

On page 309, contributions on curved plates are discussed. Previously, curved plates for marine application have generally been as a subset of complete stiffened cylinders, as covered, for example by DNV-RP-C202 Buckling Strength of Shells. However, the curved plates discussed here appear to be isolated which, if this is the case, will not experience the hoop stress patterns associated with complete cylinders. It would be particularly interesting to see the difference between these findings and the strengths implicit in the DNV-RP-C202. Is it possible the Committee could include such comparison in its reply to this Discussion?

In Subsection 5.1.2 Stiffened Panels, it is instructive to examine the comparisons presented in the paper by Frieze *et al.* (2011) in a little more detail than presented in the Committee Report. Figures 8 and 9 are Figures 7 and 26 of this particular reference. The relevant results in the figures from the point of view of this discussion are those of ALPS/ULSAP and PAFA-SPS. Both are based on ostensibly identical equations yet, whilst in some cases they coincide exactly, in others they do not. They should, of course, always coincide but, unfortunately, the full set of equations on which ALPS/ULSAP is based are subject to copyright and so cannot be replicated exactly. The conclusion at the time is still relevant, i.e. "Thus, if the formulations are to be used more widely, particularly as they are extremely efficient compared with corresponding nonlinear FEA, then further dissemination of their details is necessary in order for users to gain the necessary confidence that they can be used for dealing with this very challenging topic, i.e. the ultimate strength of plates and stiffened panels."

Whilst this whole section seems fairly thorough, it is challenging to gain much appreciation of the papers covered because of the lack of figures or tables that present key findings from the considered papers. Whilst appreciating figures and tables take up space which is often at a premium, the adage that "a figure speaks a thousand words" is nearly always true so the next incarnation of the Committee is encouraged to give more space to the inclusion of figures, in particular, and tables, when appropriate, in its report. The following is hopefully an example of how figures aid the interpretation of findings compared with the approach adopted in the Report.

Consider the last paper addressed in Subsection 5.1.3 Shells, by Pan *et al.* (2010), which deals with the nonlinear analysis of titanium alloy spherical pressure hulls, the Committee Report states "based on their numerical result, the sensitivity of the ultimate strength to critical arc length, thickness to radius ratio, and structural imperfections were studied". One gains nothing from this. Compare that with the information that one can interpret from Figure 10 such as:

- the critical location of an inward deformation is slenderness dependent (although this is not a major influence) so, with inspections in mind, it is clearly far more

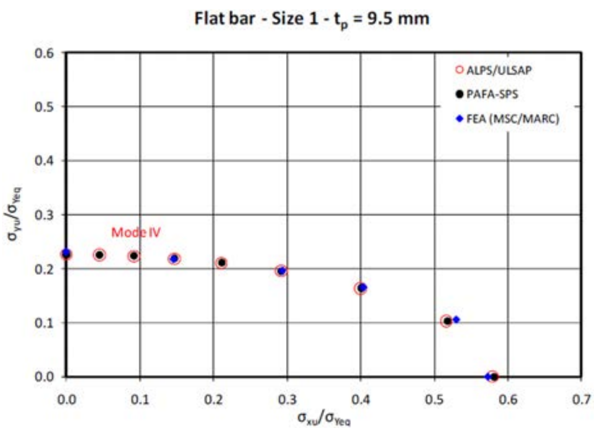

Figure 8: Figures 7 of Frieze *et al.* (2011) comparing ultimate strength interaction relationships between biaxial compressive loads for flat-bar stiffened plate

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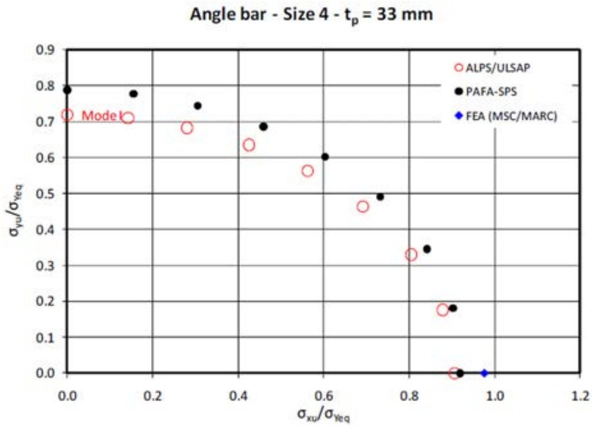

Figure 9: Figures 26 of Frieze *et al.* (2011) comparing ultimate strength interaction relationships between biaxial compressive loads for angle-bar stiffened plate

important to check out-of-sphericity near the top of a hemisphere than anywhere else;

- the same deformation located remotely from the pole can lead to strengths some four times the minimum value, and thus highlights the imperfection sensitivity of these structures;
- viewed another way, a small deformation near the pole could lead to the same reduction as a large deformation remote from the pole.

Another example of where a figure would have been most useful is in relation to the last paper reviewed in Subsection 5.1.5 Tubular Members and Joints. Here the topic is the new IIW (International Institute of Welding) strength formulations for circular hollow section joints, i.e. tubular joints. The review concludes “Detailed comparisons of the new IIW strength formulae to those of API RP2A were provided by Wardenier *et al.* (2009)”. How is one supposed to gain my benefit from this review. An engineer, presumably, has spent time tracking down this paper, reading it and preparing this view but no one has gained. Are the new IIW formulae better or worse than the API equivalents. We have no idea from this review, but because I have been heavily involved in the writing, editing and publishing ISO standards for Offshore Structures particularly fixed steel structures which have drawn heavily on API Recommended Practices, I was keen to know if some improvements on the API formulae were available.

The general conclusion was that “the capacities of the new IIW (2008) design equations for CHS joints are between the predictions of the previous IIW (1989) or CIDECT (1991) recommendations and those of the API (2007)”. Delving further, it appears that the strength formulations are based on extensive non-linear finite element analyses which give lower bounds to test results. Compared with the finite element analysis results, the new strength formulations give means for the main tubular joint strength parameters between 1.00 and 1.03 with corresponding COVs ranging from 4.2 to 6.8%. Clearly the new IIW formulations are accurate and thus are an improvement on the API equations but it is disappointing that such information is not included in the Committee Report.

In Subsection 5.1.6 Influence of Fabrication-Related Initial Imperfections, the second paragraph states: “Focusing on welded stiffened panels that are mainly subject to axial compression, the welding deformations are normally difficult to obtain from numerical

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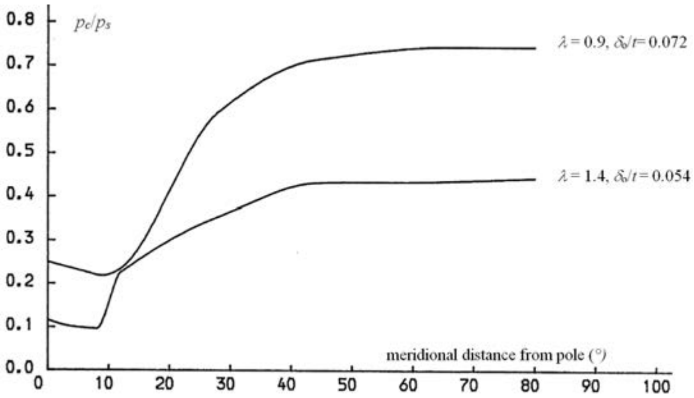

Figure 10: Figures 3 of Shao and Frieze (1989) showing hemisphere pressure sensitivity to initial deformation location as function of hemisphere slenderness and relative initial deformation magnitude

FE-analyses because the complete assembly and fabrication process and possibly the change in shape during overload under operation must be simulated. One option is to measure out-of-plane deformations during the fabrication and during service."

It then goes on to examine three ways in which such imperfections might be estimated in the absence of actual measurements. A major problem in adopting initial imperfections to represent both initial imperfection and welding residual stress effects is that, in the absence of welding stresses in the analysis, the adopted imperfections might be unrealistic. In one analysis conducted by the Discusser, independently derived geometrical imperfections and welding residual stresses for a stiffened plate were input into a nonlinear analysis and the plate buckled. It was not possible to achieve equilibrium with the given initial imperfections and the residual stresses in the absence of buckling indicating that the measurements were not compatible, i.e. they had been separately measured from different stiffened plates.

The conclusion from the paper by Gannon *et al.* (2011) that "only considering fabrication imperfections" and ignoring welding residuals stresses produced "an overly optimistic hull girder strength", apart from being a positive but perhaps not altogether unexpected finding, is also interesting because a study by Birkemoe at the University of Toronto many years ago on a tubular damaged by indenting and subject to axial compression to quantify residual strength, found that the omission of the damage-induced residual stresses in a non-linear simulation of the experiment, led to a significant underestimate of strength, in complete contrast to the present circumstances relating to an intact structure.

In discussing the Influence of In-Service Damage in Subsection 5.1.7, paragraph 4 refers to a paper by Paik (2009) in which the effects of crack location on strength are discussed, reference is made to "longitudinal-inside" and "longitudinal-end" cracks - unfortunately, this is fairly meaningless without a suitable figure to illustrate the location and orientation of such cracks.

On page 303, reference is made to Wang *et al.* (2009) and again on page 323. Naturally, one thinks this refers to the same paper but, no, because the initial of Wang in the first citation is G whilst that of the second is F. One clearly has to be careful using the adopted reference format to ensure the references are in fact uniquely cited because exactly the same problem occurs again with the surname Xu.

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Section 5.2 Systems

In the Subsection 5.2.2 Other Marine Structures, two studies on semi-submersibles are reviewed, one on an intact structure and the other on a damaged structure. They are particularly welcome because of the general lack of papers in the public domain dealing with this structural form. This dearth of papers on semi-submersibles became apparent to this Discusser in a recent review of RSR (reserve strength ratio = ultimate pushover strength / 100 year design return period loading) and probability of failure values of offshore floating structures designed to ISO 19904-1 Floating offshore structures: Monohulls, semi-submersibles and spars.

1.1.8 Section 6. Benchmark Studies

This section provides some very interesting reading. Some of the details have been excluded presumably in order to maximise the number of figures presented. Thankfully, the details will be available via another publication.

Section 6.1 Candidate Methods

Added interest arises from the use of different nonlinear FEA software systems to effect the analyses and, even more appealing, is the use of the same FEA software by different institutions to conduct the same analyses. The importance of this second point was brought home by jacket pushover benchmarking findings reported by Nichols *et al.* (1994) in which users of the same nonlinear analysis software showed a greater variation in results compared with variations between different software packages.

1.1.9 Section 6.3 Modelling Techniques

The first set of results presented addresses the issue of the most appropriate model to adopt for stiffened plate analysis - should it be a single span or a multi-span configuration. The results indicate that it is plate and stiffener geometry dependent. However, in both of the cases presented, the multi-span model generates the lower strength.

Single span models have frequently been used in the past in both stiffened plate and stiffened shell physical tests. In the case of stiffened plates, it is not normally practical to adopt fixed ended conditions because of the difficulty in generating the necessary end flexural/torsional stiffness, thus simply supported ends are the norm. However, the achievement of simply supported end conditions is particularly challenging because initial fabrication effects render the determination of the effective neutral axis difficult: the axial load must be applied concentrically to the ends of the model in order to avoid introducing any end moments. One way to do this in practice is to apply trial positions of the axial load until extreme fibre strains measured at mid span are the same.

Because of the difficulties associated with single span models, biases in the results derived from such tests can occur. Consider the following results for axially compressed cylinders which, based on the strength formulations developed by Cho and Frieze (1988), produced the modelling uncertainty parameter results shown in Figure 11. Two sets are shown, those for single bay tests (described in the figure as "unstiffened cylinder" and those for multi-bay tests ("ring-stiffened cylindrical shell"). The single bay results are seen to be skew with respect to the multi-bay values, reflected in the corresponding modelling uncertainty parameter COVs of 26.8% and 11.3%, respectively.

Because of the biases associated with single-span analyses, I feel the Committee should be more forthright in its recommendation that only these multi-span analyses should be used in practice, for both numerical and experimental studies, particularly in the light of some of the results presented in Figure 23.

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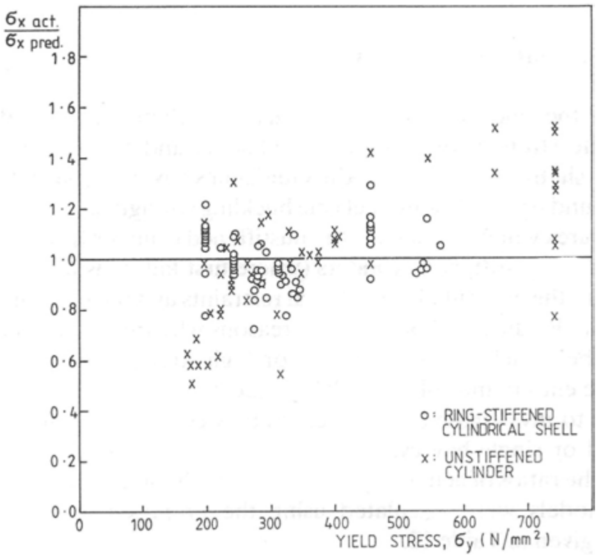

Figure 11: Figure 7 of Cho and Frieze (1988) comparing single and multi-bay axially compressed cylinders

Figures 13 to 15 illustrate some of the meshes used in the numerical analyses. Clearly they differ between the various institutions. Mesh convergence studies are essential even for elastic nonlinear analysis but even more so for elasto-plastic buckling analysis. Can we hope to see such details in the independent publication because the mesh refinement adopted for the stiffeners does seem inadequate.

1.1.10 Section 6.4 Results and Observations

Section 6.4.1 Plates

The results in Figure 16 are particularly encouraging in demonstrating that sophisticated analytical methods such as ALPS/ULSAP and PULS can give strength predictions very similar to those of nonlinear numerical analysis. Clearly some interesting buckling modes are occurring for panels dominated by longitudinal axial compression. Perhaps these modes could be included in the figure to aid understanding.

The results in Figure 17 confirm that the modes of initial geometrical imperfections are important in influencing strength particularly under longitudinal axial compression. It emphasizes the importance when generating strength values for design of ensuring that the initial imperfections adopted for the analysis are appropriate.

Section 6.4.2 Stiffened Panels

In Figure 19, it would be helpful to indicate just what is the changing parameter in each of the series marked Size 1, Size 2, etc: is it possibly plate slenderness β?

In Figure 18 and some other following figures, the controlling buckling modes as identified via ALPS/ULSAP are listed. This information is most helpful for giving insight to structural behaviour and which of course is available from any finite element analysis although one has the impression that, unfortunately, such information is not normally presented.

Figure 23 and some subsequent figures present results which are of some concern. The ABAQUS results in Figure 23 (a) appear to be the consequence of using single rather

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than multi-span stiffened plate models and adds weight to the comment made earlier on this issue. On the other hand, the reason advanced for the discrepancy in the BV results is less obvious because it is not clear whether it was the results of this study that found the BV method was "not applicable for some ranges of stiffener dimensions" or whether the results were generated by someone unaware of the limitations.

When considering the effects of pressure in Figures 29 and 30, can the Committee clarify whether the ALPS/ULSAP results have been generated for the pressure applied to the plate-side or to the stiffener-side because this is most likely to affect the buckling mode for some combinations of compression and pressure.

In Figure 32, it appears that the average level of welding residual stress has more impact on strength than the severe level. Can the Committee offer an explanation for this?

Section 6.4.3 Hull Girders

The Committee notes the considerable scatter in results obtained for hull girders subjected to sagging and hogging moments and attributes some reasons for this. Where numerical analysis has been used, it seems the limitation of analyzing only one bay between transverse frames could also contribute because this means that the analyses have exactly the same problem as raised earlier in connection with stiffened plates, namely, that single bay models are not adequate for representing compressed stiffened plates.

1.1.11 Conclusion

The Committee is to be congratulated on its report. The challenge of such a geographically diverse team completing this task is recognized, and where the discusser has been critical, it is primarily in an attempt to extract more useful findings from this extensive work, and to hopefully help the next generation of this Committee make the most of its opportunity.

1.1.12 References

Cho, S-R. and Frieze, P.A. (1988). Strength Formulations for Ring-Stiffened Cylinders under Combined Axial Loading and Radial Pressure, *J. Construct. Steel Research*, 9, pp. 3-34.

Dowling, P.J., Chatterjee, S., Frieze, P.A. and Moolani, F.M. (1973). Experimental and predicted collapse behaviour of rectangular steel box girders, *International Conference on Steel box girder bridges*, The Institution of Civil Engineers, London, pp. 77-94.

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1.2 Floor Discussions

1.2.1 Andrea Ungaro

Regarding chapter 5.1.3, and specifically the overview of current design practices for submarine pressure hulls, it is pointed out that the accuracy of conventional Submarine Design Formulae (SDF) for predicting pressure hull collapse is close to that obtained by nonlinear numerical models, which implies that the latter are not strictly necessary in the design phase unless a better representation of the geometric imperfections is used.

However, typical SDF do not take into account the effect of internal structures (tanks, decks, foundations, etc.) which, while having a mostly local (but potentially very significant) effect on stresses, can influence the failure behaviour of the whole compartment by significantly changing its deformed shape and instability mode shape.

At the same time, even computationally simple axial-symmetric numerical models can offer interesting information on the local stress and deformation close to transition areas (cone/cylinder, cylinder/end-cap), where a different scantling is often necessary and where SDF typically offer lower precision.

Therein, in its inherent flexibility, and in the possibility of accounting for a damaged structure, lie the main advantages of FE techniques in the design of pressure hulls.

Among the list of the non-linear factors in chapter 2.2, the "follower force" effect, that is the change of direction of the applied loads and pressure forces due to large structural displacements, is not listed. This effect can be considered implicit in the geometric non-linearities, however it would be proper to mention it separately in point d), loads.

1.2.2 Shengming Zhang

Regarding hull girder ultimate strength, the current mostly used methods included in the CSR, only longitudinal stress is considered. How important are other stress components such as transverse stress, shear stress and lateral pressure? Should we include all components in design assessment? Should the residual stress effects on ultimate strength assessment be included? Why?

1.2.3 Daisuke Yanagihara

In the benchmark of the unstiffened and stiffened plates, the comparison with CSR is only a few cases. Particularly, there is no comparison with the CSR-B which is the rule for bulk carriers. Does the committee have a clear reason for this?

In the benchmark, the FE analyses were almost performed applying the initial deflection of the buckling mode with 0.1ß^{2}t amplitude. I think that this deflection is very large and not realistic. But these FEA results are used as the reference values to verify the prediction method. Of course, I understand that the lower limit is necessary to provide the safety of the prediction. However, I think that the investigation on the model uncertainty of the prediction method is also the purpose of the benchmark. From this point of view, the average condition of the initial deflection should be considered, and the FEA results under the average condition should be used as the reference value for the comparison. Could you show the committee's view about this problem, that is, what should be used as the reference value in the benchmark?

1.2.4 Weicheng Cui

I like the way of Committee's representation of the ultimate strength problem as a function of several important parameters, in this case, eight aspects of factors (a – h), first I wish the committee chairman to confirm whether I can optimistically say that when eight aspects of factors are clearly described for a particular situation, then the current state-of-the-art method can predict the ultimate strength within 10% of error?

If that is the case, the future emphasis of this committee should be directed to the descriptions of these damage states such as fatigue cracking, corrosion, residual stresses, etc. and in particular the determination of human factors are extremely difficult to quantify their effect on ultimate strength. Do you have any suggestion on how to treat those problems, especially the human factors?

If the 10% of error cannot cover some of the problems, can you give some examples where the ultimate strength of the given structure cannot be predicted within that accuracy requirement?

1.2.5 Philippe Rigo

Let me first thanks the ISSC committee III.1 and his chairman Jeom K. Paik for their brilliant report and attractive presentation in Rostock.

My comments concern the need to integrate the assessment of ultimate strength (specifically the hull girder bending moments) within the optimisation procedure of ship structure (scantling).

In Rostock, the chairman of committee III.1 concluded his excellent presentation saying that, to his knowledge, ultimate strength has not yet been integrated, at industrial level, in the ship structure optimisation loop.

So it is my pleasure to highlight the fact that the LBR5 software (see references below) is an ship structure optimisation package, dedicated to early design, which target least weight and least cost optimisation (multi objective approach), and which is used since 2005 at industrial level by STX France (St Nazaire shipyard) for the design of their large cruise vessels and previously by ALSTOM for gas carriers. LBR5 considers as active constraints of the optimisation process the ultimate strength of each stiffened panel (bottom, decks, side shells, ..) and also the hull girder ultimate bending moments (using the simplified analytical method of JK Paik within the optimisation loop, and a progressive collapse module (PROCOL) as post-analysis (for validation)).

Running structural optimisation (ship scantling) is only meaningful at the conceptual design stage or at initial design stage. Later, there is no more room for significant changes in the structure. So, the challenge to include ultimate strength assessment of hull girder and its components (stiffened panels) within the optimisation process relates to the lack of detailed data to perform advanced ultimate strength analysis (as non linear FEA). The scantling details of the structure are not yet fixed; it is therefore challenging to make a FE model (too high uncertainties on the real geometry). In addition there is also a high uncertainty concerning the imperfection levels (deformation, residual stress) as details about the welding technology and assembling scheme are unknown.

So, there is an urgent need for researches to develop structural optimisation tools including ultimate strength capabilities that are integrated with design and production tools used at initial design stage (CAD, scantling tool, block splitting, ...).

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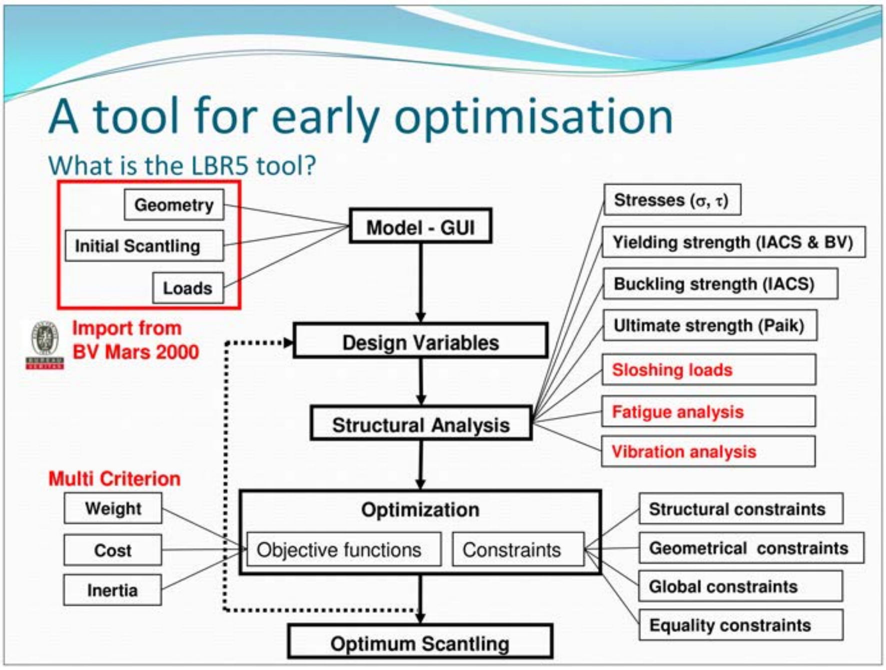

Figure 12: LBR5 Integration in Optimisation Process

1.2.6 References

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2 REPLY BY THE COMMITTEE

The Committee thanks official and floor discussers for their valuable comments and discussions related to our report. In the following, we respond to their remarks.

2.1 Reply to Official Discussion

Accidents are the result of a long chain of human error which is due to a lack of knowledge and engineering disciplines at various stages, including engineering and

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design, construction and operation. To prevent accidents, human error should be eliminated. Human error can be reduced by taking advantage of engineering disciplines in accordance with human factors engineering principles.

Our Committee deals with a key engineering and design disciplines for ships and offshore structures, and it is hoped that the uncertainty characterization of influencing parameters and the development of more refined ULS methods will help to reduce catastrophic failures of ships and offshore structures.

Two types of design format are usually applied in ensuring that a structure has an adequate degree of safety and reliability against ULS, namely partial safety factor design format and probabilistic design format in which the uncertainties are characterized.

In the offshore industry, substantial efforts have been devoted to the development of international standard guidelines associated with limit state assessment of offshore structures, and to extensive applications of such standards and guidelines to industry practices.

Residual strength of ships after significant yielding or buckling is treated by classification societies, e.g., Bureau Veritas (BV 2010), providing a service ERS-S which is an emergency response service corresponding to damage longitudinal strength and damage stability analyses. The structural model is generally very simplified, just removing damaged area from initial or intact model. The main investigations are focused on the additional load due to unexpected flooding. The aim is to determine the allowable still water bending moment and the allowable sea states. A more refined structural analysis would require a good knowledge on the actual state of the structure. Just to obtain accurate information on the actual structural integrity in emergency condition is a primary issue.

In the last decade, the shipbuilding industry has also tended to implement ultimate limit states principles into rules by IACS or classes, but such an effort is far from the level of the offshore industry. For example, 'critical buckling strength' of structural components determined by elastic buckling strength with a simple plasticity correction is regarded as an ultimate limit state, but this technique is not always true and is irrelevant in some cases.

Furthermore, neither international standards nor standard guidelines for limit state assessment of ship structures do exist. Large scale or full scale experimental studies are very lacking, especially in the sense highlighted by the Official Discusser that the limited available experimental data are not shared among involved parties. Moreover, often testing procedures and measurements are not comprehensively documented. Comparison and merging of such data, indeed very expensive to obtain, will be very beneficial and fruitful. The Committee agrees with the official discusser that there are still a lot of technical issues to be resolved.

2.2 Reply to Floor and Written Discussions

2.2.1 Andrea Ungaro

It is challenging to take into account the effects of all influencing parameters such as geometric imperfections and internal structures, among others, within a set of submarine design formulae. In this case, nonlinear finite element methods will be useful as far as their modeling techniques are adequate. Chapter 2.2 lists up the factors affecting the structural nonlinearities. The order or pattern of applied loading, e.g., lateral pressure or out-of-plane loading followed by in-plane loading, can cause different responses as well, and this issue can be classified into the quasi-static load case.

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2.2.2 Shengming Zhang

Ship hull girders are subject to combined hull girder loads which include not only vertical bending but also horizontal bending, shearing forces and torsional moments. Even though vertical bending moments are predominant component of hull girder loads, the effect of other load components on ultimate strength cannot be disregarded.

Welding causes geometric imperfections and residual stresses. In welded steel ship structures, it is known that the welding residual stresses can be released by cyclic applications of hull girder actions, i.e., hogging and sagging. In this case, remaining amount of welding induced residual stresses may be small and thus its effect on ultimate strength may also be small. However, this aspect is still uncertain and further studies are recommended to characterize the release of welding residual stresses by cyclic hull girder actions. It is important to realize that the welding residual stresses can reduce the ultimate strength and that its characteristics should be identified for robust design of ships and offshore structures.

2.2.3 Daisuke Yanagihara

The benchmark studies of the Committee have included stiffened panels of both tankers and bulk carriers with class rules, CSR, ULSAP, PULS and nonlinear FEA. Because of the page limits of the Committee Report, only the summary of the results was included. The conclusions of the studies obtained from the stiffened panels of tankers or bulkers are similar.

The geometrical imperfections in stiffened panels induced by welding include plate initial deflection, column type initial distortion of stiffeners and sideways initial distortion of stiffeners. We agree with Dr. Yanagihara that it will be better to consider an average level of initial imperfections in the benchmark studies. In this regard, we adopted the average level of plate initial deflection as $w_0 = 0.1\beta^2 t$, where β = plate slenderness ratio and t = plate thickness. According to Smith et al. (1988), it is noted that the maximum amplitude of the initial deflection of steel ship plates may be given as follows:

$$w_0 = \begin{cases} 0.025\beta^2 t & \text{for slight level} \\ 0.1\beta^2 t & \text{for average level} \\ 0.3\beta^2 t & \text{for severe level} \end{cases}$$

The effect of the initial deflection shape is also significant. The maximum initial deflection indicated in the above equation may actually not be the buckling mode of the plate, but rather it must be equivalent to a “hungry horse’s back shape”. We agree with Dr. Yanagihara that the uncertainties due to the shape of initial distortions needs to be further investigated.

2.2.4 Weicheng Cui

The Committee believes with a certainty that the clear characterization of all the eight aspects is very challenging and further studies are required. For some specific cases, however, we have various refined methods that are able to predict the ultimate strength within 10% error. As previously discussed in Section 3.1, human error is due to a lack of knowledge with uncertainties. Although it is theoretically impossible to totally eliminate human error, we could reduce human error to some extent by taking advantage of advanced engineering disciplines.

2.2.5 Philippe Rigo

The Committee thanks Prof. Rigo for sharing with us on the effort for developing full optimization of merchant ship hull structures. We absolutely agree with him that we will have to urgently develop structural optimisation tools including ultimate strength capabilities that are integrated with design and production tools used at initial design stage. This effort will eventually help to save design times, adjust structural scantlings for too strong and/or too weak members, improve structural safety, reduce structural weight and building cost, improve operational efficiency, and reduce CO_2 emission.

2.3 Reference

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VOLUME 3

COMMITTEE III.2

FATIGUE AND FRAGTURE

COMMITTEE MANDATE

Concern for Concern for crack initiation and growth under cyclic loading as well as unstable crack propagation and tearing in ship and offshore structures. Due attention shall be paid to practical application and statistical description of fracture control methods in design, fabrication and service. Consideration is to be given to the suitability and uncertainty of physical models.

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1 DISCUSSION

1.1 Official Discussion by Giorgio Bacicchi

1.1.1 Introduction

I accepted with pleasure the Standing Committee request to discuss the Committee III.2 report for the following reasons:

- having been active member of three different ISSC Committees (from 11^{th} to 13^{th}) between 1991 to 1997
- considering, on the basis of my personal experience, that the fatigue limit states are the most critical and challenging for a structural designer
- being interested in getting updated information about the latest developments in the subject both from the theoretical and practical point of view.

Having been for about 30 years responsible of the structural department of a major Italian shipbuilding company and being at present responsible of the Basic Design Department in the same company, I have always been convinced that fatigue problems can be greatly reduced in a ship and offshore structure:

- through a proper general design configuration paying attention to the possibility of achieving continuity and tapering of structural elements
- through a careful design of structural details based on proven experience
- by an adequate selection of different steel grades.

Nevertheless I have always been looking with interest at the new developments of new procedures for fatigue assessment paying however more attention towards those methodologies which had been calibrated by experimental work and seemed to be more practical in the application to a new design.

The present Committee did a great job in reviewing more than 200 papers and reporting about the developments of the latest 3 years in the:

- Fatigue Assessment Methods
- Unstable Crack Propagation
- Advances in Materials and Structural Details
- Damage Control and Risk-Based Assessment
- Design Methods for Ships and Offshore Structures.

In addition an interesting and extremely significant case study has been reported in the area of stress multiaxiality.

My discussion will generally follow the sections numbering of the Committee report with more attention and comments to the subjects which, from my own perspective and experience, seem to be the most relevant.

1.1.2 Recent Developments in Fatigue Assessment Methods

Most of the fatigue problems in ships structural details are occurring in my experience in the first years of service life (about 10^4 cycles): the recommendations given by Lotsberg (2010a) to assess low-cycle fatigue together with the ultimate limit state are shared and should be properly addressed by all Class Societies. In new designs, in order not to increase fabrication costs, ideas of new structural details, not always covered by available codes and tests, have sometimes to be evaluated. In these cases, the time available is normally not compatible with conventional fatigue tests: the thermographic method presented by Crupi *et al.* (2009, 2010) is a very quick approach to determine the fatigue limit and the entire S-N curve and has been successfully used

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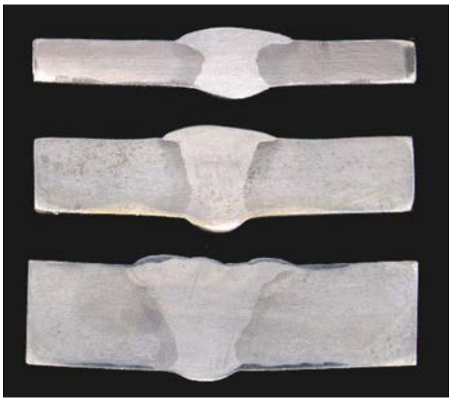

Figure 1: Macrographic cross sections of welds

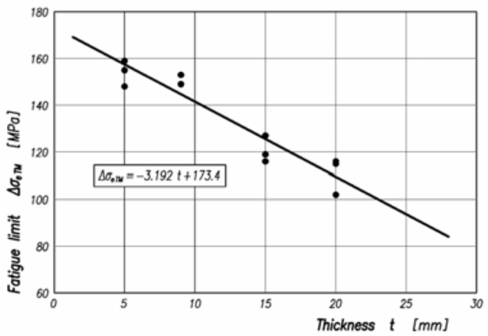

Figure 2: AH 36 steel butt-welded joints: Fatigue limit vs. thickness

also by my company proving that it is consistent with the conventional S-N approach given by IIW code. This method has all the characteristics to be considered as a valid and efficient alternative for quick fatigue tests.

Multiaxial stress states are rather common in ship structures especially in cases where important shear stresses are simultaneous to normal stresses. Although the problem of failure mechanism in mutiaxial fatigue has been continuously investigated and several criteria have been developed also in the recent years, a general applicable criterion is not yet available especially in relation to variable amplitude loading (see also the case study in Section 7). Further research work is therefore needed together with calibration by tests.

With reference to factors influencing fatigue, recent developments have been reviewed considering thickness, corrosive environment and temperature, CA and VA loading, residual stresses and mean stress.

Worth to be mentioned are the experimental results which show an increase of fatigue strength with decreasing thickness down to $3\,mm$. Although in contrast with the conclusions of the previous ISSC Committee III.2 and not yet considered by the present codes and Class Rules, the indicated tendency is also in line with the results observed in tests which have been commissioned by my company. These tests were carried out with the thermographic method on specimen of thickness ranging between 5 and $20\,mm$, applying axial cyclic loads at a frequency of $20\,Hz$ and with a stress ratio $R = 0.5$. The test pieces were AH36 steel butt-welded joints (full penetration), common for ship structures, having thicknesses of 5, 9, 15 and 20 mm (see Figure 1).

The fatigue limits, assumed as the stress ranges at $5\text{x}10^6$cycles, were predicted by test results quickly obtained with the thermographic method and compared to the corresponding limits calculated by the traditional procedure based on S-N curves obtained according to the ASTM E 739-91 Standard. The regression analysis performed on the experimental results showed a clear trend: the fatigue limit was increased by more than 40 % when thickness varied from 20 to $5\,mm$ (see Figure 2).

As for new cruise and RO-PAX vessels the thickness reduction is becoming a design target and recent hybrid welding technologies associated to an increased fabrication accuracy are allowing this trend, further experimental work is advised to confirm the positive effect of lower thickness in the fatigue strength, even if in relationship with fabrication accuracy.

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Developments in the definition of theoretical models for simulating fatigue crack initiation are reported considering both mesoscale (based on crystal plasticity) and continuum based models. Although these research works are aiming to increase the understanding of a crack forming, they seem however to be not yet mature to produce practical consequences.

Several recent papers have been dealing with crack growth assessment methods and models. Generally speaking, Paris law has been considered to give a reasonable estimation of the fatigue propagation life while crack initiation depends on the local notch stress. Some attempts are presented to remove the necessity of computing the stress-intensity factor for complicated geometries. References to experimental data and to practical structural details, which are often reported, are appreciated.

For strain-based designs (with stresses above 0.5% strain) extensive studies are reported together with results of full-scale tests.

1.1.3 Unstable Crack Propagation

The interest towards both brittle and ductile crack propagation is confirmed by the high number of recent developments in this field. This seems at present to be a topical subject due to the growing interest in design of new offshore structures for service in arctic regions and to the use of very thick steel plate for large containerships.

Extensive research has been done:

- in the standardisation of tests concerning crack arrest toughness, confirming CTOD as the most appropriate parameter and recognising the influence of constraint effects on fracture toughness
- in the evaluation of the effects of welding residual stresses in brittle fracture initiation although quantitative results are limited
- in the development of standard test methods for brittle crack toughness K_{ca} of steel plates.

However more interesting and practical are the results of the large scale tests made by Japanese researchers to investigate the behaviour of dynamic crack propagation and arrest for a typical hatch side coaming / strength deck welded connection of a containership, establishing at the end some guidelines to prevent brittle fracture. They concluded that a K_{ca} of $6{,}000\,N/mm^{3/2}$ is required for the structural elements and that a $300\,mm$ shift is recommended between butt welds of the two elements or, as an alternative, an area of unwelded breadth had to be provided. All these research works are confirming that the prevention of brittle fracture initiation and propagation can be achieved both with an improvement of crack arrest toughness of steels and with an improved weld geometry and reduced residual stresses.

1.1.4 Advances in Materials and Structural Details

The use of high strength steel to reduce weight and welding time has become normal practice and consequently the definition of the effects of yield strength on crack growth rate and on fatigue life is gaining increased interest.

Common fatigue design codes are not considering the influence of materials yield strength on fatigue. However steels produced by TMCP and microstructural control, recognised by Class Societies as FCA (fracture crack arrester) steels, have been subjected to several recent tests, confirming that they can guarantee an increased fatigue life compared to conventional strength steels. For sure, the use of this steel can provide a new alternative for fatigue life improvement. Moreover, on the basis of fatigue

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testing, a new design S-N curve has been proposed for FCA steels, concluding that the fatigue life could be increased by a factor of 3 for a typical ship structural detail subject to typical long term stress range. Additional testing is recommended to confirm the above conclusion and to consequently allow Class Societies to recognise the positive effect.

With reference to materials necessary for structures susceptible to brittle fracture (designed for instance for service life in the Arctic regions) limited recommendations are available for materials selection and structural design: therefore, development of new guidelines is recommended.

In the subsection referred to honeycomb structures, information concerning fatigue behaviour is missing and in general no "advance in structural details" (as mentioned in the title) is reported. Future Committees are recommended to collect data and reports on the possible development of new details, designed to improve the fatigue life.

1.1.5 Damage Control and Risk-Based Assessment

This section, discussed for the first time by the Committee III.2 report, is dealing with uncertainties in fatigue assessment from the design phase to the fabrication and to the service life.

In the first subsections new developments are reviewed with regard to the effects of workmanship, of weld quality and of internal defects, of welding procedures, of fatigue improvements methods and of NDE testing associated to the probability of detection of defects.

To produce a final structure consistent with the assumptions done in the design assessment of fatigue life, the welding process requires a high level of control in all the production phases: from the panels construction to the blocks prefabrication, from the blocks assembly into hull sections to the final assembly of sections in the drydock. In the initial phases, automatic welding processes are mainly used and thus the management of spot checks by NDE along the building process is normally sufficient to guarantee a constant weld quality. In prefabrication and fabrication of blocks and sections, visual inspection is required as normal practice together with "in phase" controls by RX (according to Class) and extended UT (normal or phased array) for butt joints and MT controls for fillet joints. The fatigue life of a welded joint is highly dependent on the local stress concentration that arise from the geometrical deviations and weld discontinuities (either embedded or at the surface) introduced during fabrication process. Geometrical imperfections could be misalignments, angular distortions, excessive weld or poor wed shape. Weld discontinuities are weld toe undercuts, cracks, overlaps, porosities, slag inclusions, lack of fusion/incomplete penetrations. Default values are given by rules for fabrication tolerances while the proposed S-N curves are assumed as inclusive of the weld discontinuities relative to the so-called normal workmanship. Although the presence of cracks and lack of fusion is more critical for a weld and these defects are to be corrected when exceeding acceptable values, on the contrary, the presence of embedded discontinuities like porosity and slag inclusion is less dangerous.

Nevertheless, being the present acceptance criteria defined with reference to limiting dimensions of defects of a certain percentage of thickness, in case of welding thin plates ($5 \div 6\,mm$), according to these criteria almost any defect of this kind should be corrected. To assess the effect of the presence of porosity and slag inclusion on the fatigue life of a butt weld, a comprehensive series of fatigue tests has been commissioned by

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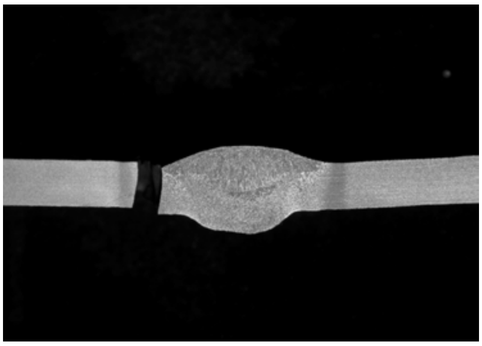

Figure 3: Specimen without defects

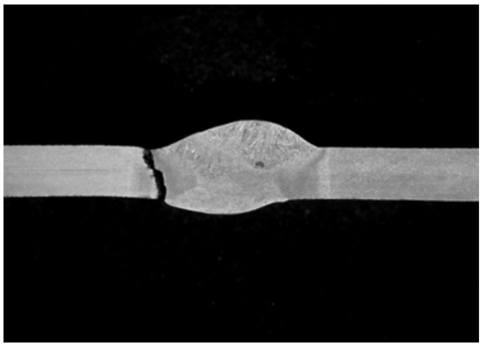

Figure 4: Specimen with slag inclusion

my company. The specimen ($5.5 \div 7\,mm$ thick) were taken from pieces cut from a ship under construction, containing either sound butt welded joints or with weld defects exceeding class limits. The results of the fatigue tests can be summarised as follows:

- for both categories of specimen, with or without defects, the failure mechanism was similar, starting in way of HAZ (see Figures 3 and 4)
- the fatigue tests have been carried out both with the traditional method and with the thermographic method
- elaborating test results according to IIW Fatigue Recommendations, the relevant S-N curves have been calculated (see Figures 5 and 6), deriving a detail category of $69.3\,MPa$ with the traditional method and of $71.5\,MPa$ with the thermographic method, with reference to a theoretical value of $71\,MPa$ (according to GL).

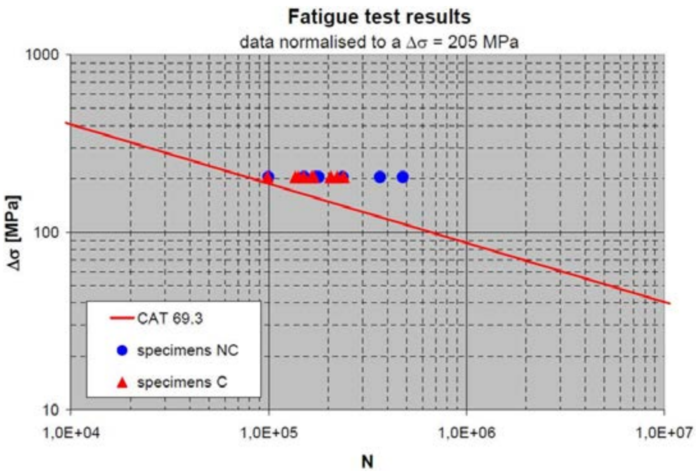

Figure 5: S-N curve from tests by traditional method

The conclusion was that the defects included in the examined welded joints had no influence in fatigue behaviour and strength. Further fatigue tests on specimen including weld defects of limited influence (i.e. porosity and slag inclusion) should be carried out in order to provide more results to support modifications of the present acceptance criteria concerning weld discontinuities.

Another subject to be addressed regarding the Class acceptance criteria of weld quality is that they completely disregard ship redundancy and margins in fatigue life calcu-

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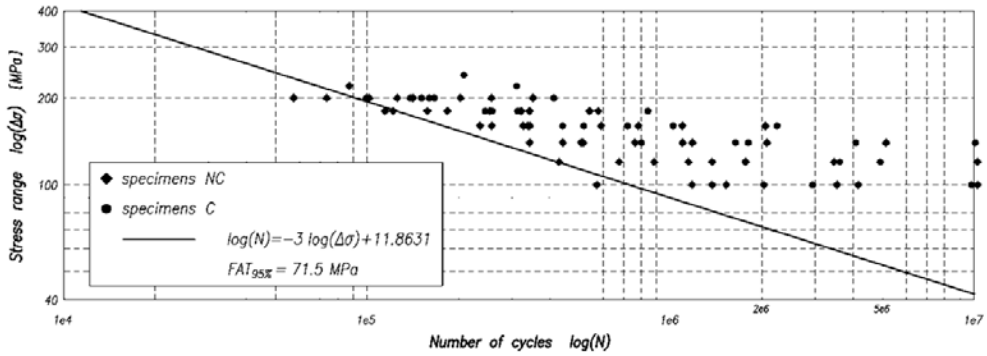

Figure 6: S-N curve from tests by thermographic method

lations. Traditional merchant vessels (tankers, bulkers, containerships) have lower redundancy in the longitudinal strength, if compared to a cruise vessel or a ro-pax vessel and, in the definition of the required number of check points and extension of NDE, reference should be made to the safety margin between the design stress range in a certain location and the corresponding allowable stress range. By these adjustments a constant safety could be guaranteed to structures of different types of vessels, avoiding to require corrections of welds which are not critical either for the limited design stress range or for the type of weld imperfections included.

With reference to the different uncertainties associated with fatigue life prediction, the reported studies concerning reliability and risk assessment, although interesting from a theoretical and scientific point of view, seem in general not to provide practical application except for the FORM/SORM technique based on the S-N approach.

Finally the information given on the problem of ageing ships and offshore structures seem really alarming for the dimension of the problem and its economical implications. The fact that important authorities are involved in defining requirements for Lifetime Extension of aged structures seems not sufficient to guarantee that priority will be given to safety rather than economical aspects. Engineering work should be commissioned to independent companies and the relevant authorities and class societies should support the required repair and improvement measures imposing obligations to owners.

1.1.6 Design Methods for Ship and Offshore Structures

This section is giving a complete overview of the recent developments in fatigue design methods and codes for ships and offshore structures and can be considered as an important and updated reference for designers.

With reference to CRS, the main differences in fatigue assessment between the present rules for Oil Tankers and Bulk Carriers are highlighted in view of the future Harmonized CSR-H which, including the recommendations of the IMO GBS and the experience so far collected in the present rules application, are scheduled for publication in 2014.

Guidelines are reported for fatigue assessment including springing and whipping effects which for some ship types are becoming an important issue.

References are given for fatigue assessment rules and codes dealing with risers systems, pipelines systems, FPSO installations and in general offshore steel structures.

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Due to the increased interest of the industry towards Arctic regions, new guidelines and procedures have been issued by Class Societies to specifically include ice loading and fatigue acceptance criteria for ships (Ship Right FDA ICE of Lloyd's Register of Shipping) and dynamic ice-structure interaction for fixed structures (ISO 19906).

1.1.7 Case Study

The proposed case study is very important in underlying the uncertainties of fatigue assessment procedures in presence of a multiaxial stress field and in calling increased attention of researchers towards a more reliable definition of methods to deal with stress multiaxiality. The idea of this case study and the relevant information have been supplied by my company's designers as one of the most significant example of multiaxial fatigue in a weld seam subject to parallel, normal and shear stresses.

In the superstructure of a cruise vessel the outer longitudinal bulkhead is one of the few longitudinal elements carrying shear forces from the lower hull to the upper decks and is commonly designed with repetitive openings to access from internal cabins to the external balconies. For this reason this bulkhead is normally continuous from a certain intermediate deck to the uppermost continuous deck. However sometimes, as in the proposed case due to production reasons, this bulkhead is interrupted by each deck which is passing through it although with a thickness which is about one half of the bulkhead thickness. Due to hull girder bending, amidships mainly longitudinal stresses are present in the bulkhead elements which are longitudinally continuous , while in the areas around $0{,}25\,L$ and $0{,}75\,L$, in presence of important hull girder shear forces, the vertical elements of the bulkhead develop an "S" deformation producing shear and normal stresses at its upper and lower ends which add to the longitudinal stresses consequent to the hull girder bending moment (see Figure 7). These stresses, which are higher above decks where the lower edge of the opening in way of the radius is closer, are transferred from the upper to the lower vertical element through a weld seam which is full penetration in the critical areas. Stress ranges producing fatigue are consequent to the difference between hogging and sagging wave. Longitudinal stresses are due to the vertical wave bending moment while normal and shear stresses are consequent to wave shear forces. The IACS formulations, which have been followed, establish along the hull girder the envelope of the maximum wave bending moments and shear forces which are not necessarily simultaneous at each frame. In the report there is no evidence of the adjustments which are required on the values of bending moments and shear forces before adding effects which are only partially simultaneous. Moreover in the case study, aiming to compare different approaches in fatigue assessment connected to multiaxial stresses, no misalignment has been considered between upper and lower vertical elements avoiding to increase the stresses by a concentration factor and thus remaining far from practical shipbuilding standards: in reality the structural detail has been built with a maximum misalignment of $2\,mm$ (0,17 x bhd. th.) in the critical areas (see Figure 8).

To calculate the local stresses on which the subsequent fatigue assessment has been carried out:

- an hierarchic modelling from the complete hull girder FE model to the sub-sub model of the cruciform joint has been performed with proper mesh sizes
- 2 hot spots have been selected both on longitudinal bulkhead and on deck, located, as expected, in way of the lower corners of the bulkhead openings
- the hot spot stress approach has been used as the most adequate.

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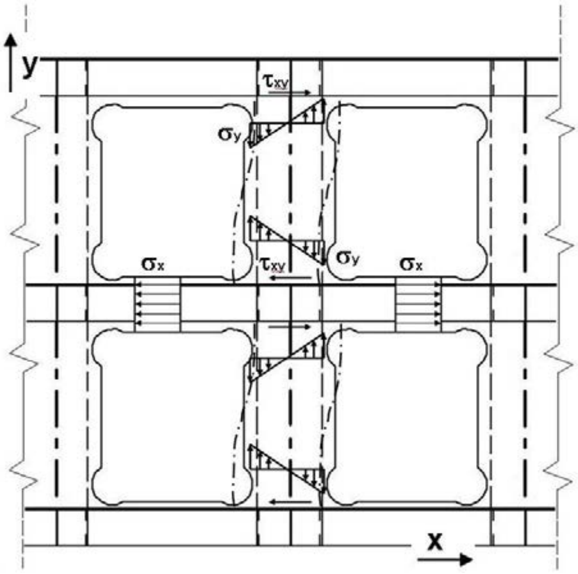

Figure 7: Stresses on the bulkhead

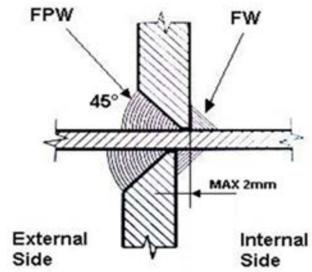

Figure 8: Weld detail

To take into account stress multiaxiality in a load-carrying weld, different formulations propose two ways: either by a reference principal stress or by the single components of the stress tensor (σ normal to the weld, σ parallel to the weld and shear τ parallel to the weld).

With regard to cumulative damage calculations and to fatigue life prediction, where long term wave loads are involved, all the methods:

- refer to a design life of 20 years (10^8 cycles) limiting to 1 the accumulated fatigue damage
- consider a simplified statistical approach assuming the stress ranges distributed according to a Weibull probability density function
- usually refer to a one-slope S-N curve (as normally designers would do) or to a two- slope S-N curve (as in the case study).

Traditional procedures given by Class Societies guidelines (GL, CSR BC, CSR OT, KR) do not take into account parallel stress to assess fatigue life of a welded joint and in this way the fatigue damages, calculated for the case study, are approaching a zero value. Among the Class Societies only DNV, in the Classification Note 30.7 of 2010, emphasizes the effect of the parallel stress either by a traditional method or better by an enhanced method which considers the maximum principal stresses approach and allows to obtain cumulative damages which seem to be more reasonable. The same DNV Classification Note, although in a previous release, has been used as a reference by the designers who supplied the structural detail for the case study. They assessed the detail on the basis of the addition of the cumulative damages produced by both the parallel and the normal stresses. In addition to DNV, also some IIW guidelines and some research works are indicating how to deal with multiaxial stress fatigue through maximum principal stresses or by summing the effects of shear and of normal stress or by referring to a resultant stress range: the application of these guidelines to the case study entail sometimes cumulative damages even exceeding the allowable limit for the longitudinal bulkhead.

The following conclusions can be derived:

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- in general the contribution of shear stresses is rather insignificant
- in general Class Societies approaches do not consider the effect of parallel stress converging towards a zero risk for both hot spot locations
- only DNV and some additional guidelines consider the effect of stress biaxiality in front of the weld. The calculated cumulative damages is low for deck hot spot, where the maximum principal stress is parallel to the weld toe line, while it is higher for bulkhead hot spot, where the principal stress is acting at about 30° to weld toe line
- the great divergence between the presented results is giving a clear evidence of the fact that fatigue problems in case of multiaxial stresses need further research supported by experimental work. More reliable procedures should be defined hopefully with the agreement of different regulatory bodies and Class Societies and at the same time these procedures should become more practical for designers' application.

Finally and luckily, notwithstanding all the difficulties involved in the fatigue assessment of the case study, the structural detail to which the case study is referred, has been used in a 90,000 GT cruise vessel which has been designed for worldwide navigation and is sailing with positive service experience since the delivery in 2007.

1.1.8 Conclusions and Recommendations

As highlighted along the sections of my discussion, the Committee report has properly covered all the subjects given within the mandate. A large number of interesting references is addressed and can be further studied by the persons who are interested to increase their knowledge in the recent developments on Fatigue and Fracture. Nevertheless, from my experience of designer, too few publications are written including practical application examples of the theoretical developments in the field and only in some cases theoretical works are supported and calibrated by experimental data. Fatigue life predictions are clearly associated to a certain number of uncertainties and any theoretical work contributing to reduce uncertainty, by producing more reliable and practical fatigue design procedures, would increase the confidence of designers in assessing fatigue as a normal design practice and would generally improve the structural safety. I have therefore to encourage researchers and people from different organisations and class societies, interested in fatigue assessment of ships and offshore structures, to think to designers' necessities adding practical examples and experimental calibration to any theoretical work.

With reference to possible recommendations for future Committees on Fatigue and Fracture, I summarise hereafter the comments already anticipated within the different sections of my discussion:

- additional fatigue tests are required to confirm the tendency of increasing fatigue strength with decreasing plate thickness
- additional fatigue tests are required to confirm the fatigue life improvement with the use of steels having Fracture Crack Arresting capabilities
- additional fatigue tests are recommended on weld details including discontinuities like porosities and slag inclusion in order to reassess the acceptance criteria of weld defects particularly for plates of limited thickness
- acceptance criteria of weld defects should be also revised to take into account the margin between design and allowable stress range
- guidelines are recommended for materials selection and structural design of ships and offshore structures designed for operation in very cold environments

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- guidelines are recommended for updated structural details, revised for fatigue life improvement, to support designers
- further research is needed in the field of multiaxial stresses defining the most appropriate approach and calibrating the theories with experiments in order to provide more reliable and practical fatigue assessment procedures.

1.1.9 References

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Crupi, V., Guglielmino, E. and Maestro, M. (2009). Fatigue analysis of butt welded AH36 steel joints: thermographic method and design S-N curve. Marine Structures, 22, pp. 373-386.

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Crupi, V., Guglielmino, E. Maestro, M. Marinò, A. (2012). Thinness effect on the fatigue strength of AH36 steel plates used in shipbuilding. *Under publication.*

Det Norske Veritas, DNV-CN30.7 (2010). Fatigue Assessment of ship structures, (June 2010).

1.2 Floor and Written Discussions

1.2.1 Bart Boon

The normally used design curve for fatigue is based upon the mean fatigue life minus twice the standard deviation. This means that any structural detail (theoretically) has maximum only 2.5% chance of failing during the life of the ship.

Presently the use of composite patches to prolong fatigue life is studied quite a bit.

What is the opinion of the Committee on the potential of such patches? Could they allow a higher risk of fatigue cracking provided that patches will be used when such a crack occurs?

1.2.2 Tetsuya Nakamura

In this report, peening approaches such as UIT have been mentioned as one of the fatigue improvement methods. I think these techniques are very cost-effective. However, in order to ensure peening is effective during the life of the ship, the compressive residual stress introduced by the peening must be maintained. From this point of view, I would like to make two questions. First, the compressive residual stress may be reduced by variable wave-induced loads. Do you think we have enough experimental data to guarantee the peening effect?

Second, it is about the peening procedure. It is difficult to confirm that compressive residual stress is introduced to the welded joints after performing the peening. What's your opinion with regard to this matter?

1.2.3 Cesare M. Rizzo

First of all, I would like to congratulate the Committee members for putting on the table some new issues that were not comprehensively dealt with by the previous Committees on Fatigue and Fracture. Significant advancements are reported. It means that the shipping industry is now ready to introduce somehow more complex fatigue assessment methods. Namely, multiaxial fatigue is still an open issue and matter for researchers. However, the report addresses the subject referencing a few multiaxial

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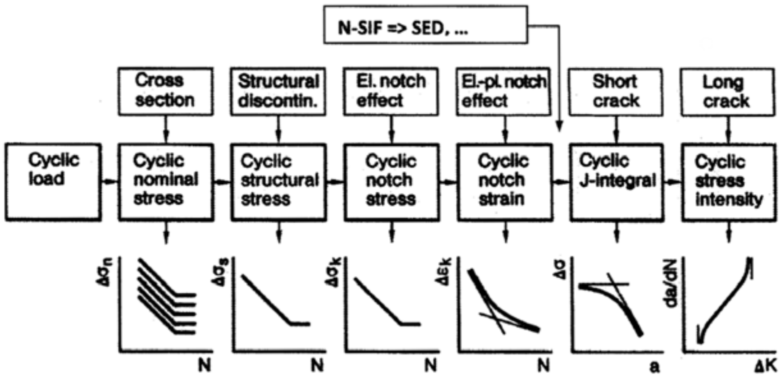

Figure 9: New fatigue assessment approaches added to the well-known figure reported in Radaj *et al.* (2006)

fatigue assessment approaches currently proposed in the literature and by guidelines of international bodies like the International Institute of Welding.

However, I would like to offer a small comment about assessment methods for multiaxial fatigue and the opinion of the Committee about this outlook would be very much appreciated.

Recently, a few novel approaches appeared in the literature and some of them are based on "energy concepts", i.e. those methods are assuming the deformation energy as the fatigue strength governing parameter. Actually, these new approaches may overcome at the root the multiaxial fatigue problems.

Indeed, it appears from recently developed researches (see ch. 7 of Radaj *et al.* 2006) that such methods represent the link between the stress or strain based approaches (e.g. the notch based approach) and the relatively complex crack propagation method (Fig. 1). In fact, it was demonstrated that the notch stress intensity factor in an open notch (N-SIF) is related to the strain energy density (SED) in a volume of the material, see Lazzarin and Zambardi, 2001).

While several questions are still open for the application of such N-SIF or energy based approaches to geometrically complex ship and offshore structures, it is believed that such methods can fulfil the needs of the shipping industry since their application can be easily automated in numerical analyses but at the same time their background is based on fracture mechanics concept. As a matter of fact, one can remember that the J-integral parameter used in fracture mechanics is basically an energy.

1.2.4 Ilson Pasqualino

Some issues related to fatigue have not been covered by the report. Fatigue under corrosion, under contaminants (H_2S, CO_2) or in damaged structures.

The review should be extended to composite structures, other materials for naval and offshore application and cladded linepipes.

The report did not mention the development of non-destructive techniques for fatigue damage evaluation like X-ray diffraction method.

1.2.5 Weicheng Cui

I have two brief questions. First, unstable fracture is basically the last stage of crack propagation which is not allowed from fatigue point of view. Why did your committee

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decide to emphasise this stage? Second: from your point of view, what are the physical quantities to decide unstable fracture?

1.2.6 Fang Wang

Unstable fracture is not important for commonly-used materials in normal conditions, but is significant for materials used in cold climates. How to determine the critical condition for unstable fracture is a problem. We always use static fracture toughness to replace fatigue fracture toughness, as the testing of fatigue fracture toughness is quite difficult. However, even the current testing method for static fracture toughness is facing challenge, especially the size criterion related to thickness. Could you give some comments on thickness and crack form effect on fracture toughness as the critical condition of unstable fracture?

Crack growth rate model is important for the fatigue assessment based on fracture mechanics. In the past 20 years there are many improved models proposed but most of them are based on cycle-by-cycle integration. That means the accuracy of calculation results is determined by counting method of cyclic stresses. In my personal opinion, if we would define the model by da/dt in time domain, the problem will be solved. The driving force can be expressed by stress and life integration can be done inside each stress cycle which would solve the problem brought by traditional loading cycle counting method. Could you please give some comments on that?

1.2.7 Wolfgang Fricke

Regarding the case study, it has simply been overlooked that in the weld considered two types of cracks are possible, (a) parallel to the weld line and (b) perpendicular to the weld line. Crack (a) may be assessed with the structural hot-spot approach, but crack (b) requires the assessment with the nominal stress approach with a fatigue class of FAT 90 -100 according to various catalogues of notch conditions. This would lead to much higher damage sums than given in the report. Insofar are the results misleading. A comparable situation exists, by the way, for cruciform joints with non-penetration welds, where also two crack types have to be assessed, one starting from the weld toe and the other from the weld root.

A closed form assessment based on the multiaxial stress state would of course be helpful, but is not unproblematic due to the different fatigue behaviour, calling for simplified assessments mentioned above.

The Official Discusser showed the "thinness effect" by a graph where the fatigue strength of butt joints steadily increases with decreasing plate thickness. This is in contrast to findings in a German joint industry project where specimens with butt welds from block joints were fatigue tested showing a decreased fatigue strength of 4 mm thick specimens compared to 6 and 9 mm thick specimens, see Figure 10. This was even true if the results are based on structural hot-spot stress which already includes secondary bending stresses due to misalignments. I would like to hear the opinion of the Committee about such contradicting results and possible factors affecting them.

1.2.8 References

Feltz, O. and Fricke, W. (2011): Einflüsse zwischen Bauteil- und Kleinprobe auf die Betriebsfestigkeit von Dünnblech-Montagestößen im Schiffbau. In: Schweißen im Schiffbau und Ingenieurbau 2011, S. 39-46, DVS-Berichte Band 277, DVS Media, Düsseldorf

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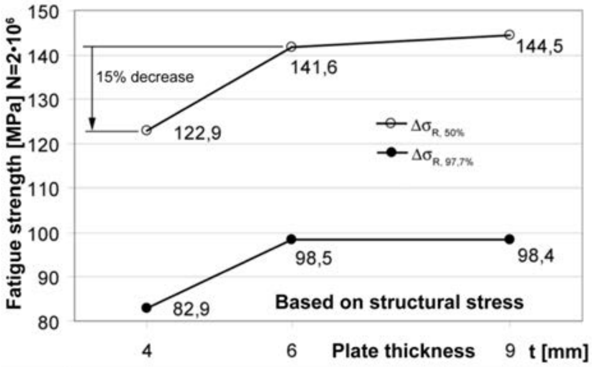

Figure 10: Mean and characteristic fatigue strengths found for block joints with thin plates (Feltz and Fricke, 2011 and 2012)

Feltz, O. and Fricke, W. (2012): Consideration of influence factors between small-scale specimens and large components on the fatigue strength of thin-plated block joints in shipbuilding. Doc. XIII-2418-12, International Institute of Welding

Lazzarin P., Zambardi R. (2001). A finite-volume-energy based approach to predict the static and fatigue behaviour of components with sharp V-shaped notches, Int. J. Fract. 112:275-98.

Radaj D., Sonsino C.M., Fricke W. (2006). Fatigue assessment of welded joints by local approaches (2^{nd} edition). Woodhead Publ., Abington, Cambridge.

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

The Committee would like to thank the official discusser Mr. Giorgio Bacicchi for his effort and kind contribution to the assessment of the Committee Report. The Committee appreciates Mr. Giorgio Bacicchi valuable and inspiring comments which we will try to answer in the following. The discusser also provides valuable supplementary contributions to the contents, including some interesting and important additional references and also suggests some essential future topics for the Committee to study within fatigue and fracture. These recommendations for further work is highly appreciated by the Committee, and will be studied and discussed in the ISSC 2015 report as far as possible based on available publications of these topics and the members' interest.

2.1.1 Recent Developments in Fatigue Assessment Methods (Chapter 2)

The Committee agrees with Mr. Giorgio Bacicchi comments that it is important to assess low-cycle fatigue together with ultimate limit state and this should be properly addressed by all Class Societies. The committee finds it interesting to note that the thermo graphic method in order to establish fatigue S-N data has been used successfully by Mr. G. Bacicchi's company and that the results obtained are in-line with the conventional S-N approach given by IIW code.

The Committee agrees that the developments in the definition of theoretical models for simulating fatigue crack initiation like mesoscale and continuum based models are not yet mature to be applied to practical applications and further research is needed. The Committee agrees that a general applicable criterion is not yet available for multiaxial fatigue especially in relation to variable amplitude loading and should be addressed

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further. Today some valuable guidance can be found in e.g. IIW design code (2009), Hobbacher. The Committee notes the increased fatigue strength obtained for thin plates presented by Mr. G. Bacicchi. However, further research is needed in order to investigate the applicability of the notch stress approach to the plate thickness below 5 mm in order to develop a sound basis for fatigue assessment of thin ship structures, see also comments by Prof. Fricke in section 2.7 and the Committee repay in section 3.2.7.

2.1.2 Unstable Crack Propagation (chapter 3)

The committee values Mr. Giorgio Bacicchi's interest and the importance of the research within brittle and ductile crack propagation presented in chapter 3 of the report.

2.1.3 Advances in Materials and Structure Details

The Committee fully recognises the importance of further testing and standardisation of TMPC and FCA steels in order take full benefit of these. It can be noted that some FCA steels have been applied to some ships and vessels. The developed steel plate has been approved as FCA in grades AH36, DH36, EH36 and AH40, DH40, EH40 by Nippon Kaiji Kyokai, Lloyd's Resister, Det Norske Veritas and American Bureau of Shipping.

The committee support the recommendation by Mr. G. Bacicchi that future committees are recommended to collect data and reports on the possible development of new honeycomb structures and their fatigue properties.

2.1.4 Damage Control and Risk-Based Assessment (chapter 5)

The Committee finds the conclusion from S-N test of thin welded sheets presented by Mr. Bacicchi where weld defects have limited influence (i.e. porosity and slag inclusion) on the fatigue behaviour, interesting and should be further investigated.

Mr. Bacicchi also points that "With reference to the different uncertainties associated with fatigue life prediction, the reported studies concerning reliability and risk assessment, although interesting from a theoretical and scientific point of view, seem in general not to provide practical application except for the FORM/SORM technique based on the S-N approach". The committee has demonstrated an example in chapter 5 to show how the uncertainties related to fatigue damage can be accounted for. There are many examples in the published literature how to use FORM, SORM, Monte Carlo and response surfaces for reliability assessment, which can be time-invariant or time-variant (Feng *et al.*, 2012).

2.1.5 Design Methods for Ship and Offshore Structures (chapter 6)

The committee agrees with Mr. Bacicchi that it is important to develop new guidelines for selection and qualifications of materials suitable for arctic application to account for low temperature and ice-loading, which is fully supported by this Committee. Initiatives have been taken by the industry lately as can be seen by Horn *et al.* (2012) and Østby *et. al.* (2013), in addition to a recent proposal for a working group within ISO "ISO/TC 67/SC 8 on Arctic materials.

2.1.6 Benchmark Study (Chapter 7)

Mr. Bacicchi points out that "no misalignment has been considered between upper and lower vertical elements thus remaining far from practical shipbuilding standards". However, the Committee decided to exclude gaps, misalignments and corrosion effects and discontinuities to make comparisons more reliable and forceful.

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Mr. Bacicchi points out that “Traditional procedures given by Class Societies guidelines (GL, CSR BC, CSR OT, and KR) do not take into account parallel stress to assess the fatigue life of a welded joint and in this way the fatigue damages, calculated for the case study are approaching a zero value.” The Committee wants to emphasise that a nominal approach widely accepted exists, which takes into consideration parallel stresses. Such an approach is based on the FAT class 90, applied to normal stresses parallel to weld toe line (see for reference detail No. 323 “Continuous manual longitudinal fillet or butt weld” in IIW design code, Hobbacher, 2009). A fatigue assessment has been carried out in the benchmark study making reference to this approach, obtaining a result aligned with those of the traditional approaches where parallel stress is disregarded.

2.1.7 Reply to conclusion (Chapter 9)

The Committee is happy to notice that Mr. Bacicchi values the work carried out by the Committee members. The Committee fully supports Mr. Bacicchi that it is important that by adding practical examples and experimental calibration to any theoretical work, will increase the confidence. In addition learning’s from ship and offshore platforms operating today should be traced back to researchers and designers in order to gain knowledge to better ensure the structural integrity in the future. The committee fully agrees with Mr. Bacicchi that preferably the research should end up in practical implementation (to large extend covered by the classification societies). The committee agrees that further research is needed in the field of multiaxial stresses and this is also addressed in our case study in chapter 7. Today some valuable guidance can be found in e.g. IIW design code, Hobbacher (2009). The understanding of fatigue is mainly based on observations from experiments or structural failure and the interpretation of these events. Hence, it is important to add practical examples and experimental calibration to any theoretical work, in order to increase the confidence. In addition learning’s from ship and offshore platforms operating today should be traced back to researchers and designers in order to gain knowledge to better ensure the structural integrity in the future. The Committee has also supported that preferably the research should end up in practical implementation covered by the classification societies and other rule makers.

2.2 Reply to Floor and Written Discussions

2.2.1 Bart Boon

It is the opinion of the Committee that the composite patch repair should be part of a “crack management” programme. A composite patch will be designed in order to stop/ significantly slow down crack growth. However, there are no inspection methods available today, that the Committee is aware of, which can easily check and verify the bonded strength between the patch and substrate surface. Hence, either the patch is used as a temporary measure to prepare a “permanent” repair or the patch and underlying crack are inspected at regular intervals.

Repairs often need to be carried out at short notice leaving limited time for qualification of the repair design. Hence, the client will need to balance the requirements for quick qualification against the reliability of the repair and hence the risk of having to upgrade or replace the repair in the future. In DNV RP C301 “ Guidens on Design, Fabrication, Operation and Qualification of Bonded Repair of Steel Structures”, repair classes have been designed (ranging from Class 0 repairs which are ad hoc repairs up to the most stringent Class III repairs, which are repairs where sufficient documentation is provided to quantify with confidence the reliability of the repair for the intended service life of the structure. Due to the limited service experience that currently exists with bonded repairs, the long term reliability of the repairs cannot be quantified with sufficient confidence. However, the RP provides some recommendations and the reliability of the repairs should in general be taken as $pf = 10 - 3$. In order to limit the risk, manual inspection can be replaced/supplemented by installing some kind of monitoring system based on e.g. optical fibres or strain gauges.

2.2.2 Tetsuya Nakamura

The effectiveness of peening methods has been confirmed in variable amplitude tests. However, overloads may reduce the effect. Reductions in benefits due to overload conditions are described by Haagensen and Maddox (2013). Other recent publications addressing the effect of the variable amplitude loading are provided by Yildirim. and Marquis (2012) and Miki and Tai (2012).

2.2.3 Cesare M. Rizzo

The Committee agrees with Dr. Rizzo's comments and reasoning and supports the statement that "... it is believed that such methods can fulfil the needs of the shipping industry since their application can be easily automated in numerical analyses ...". We recommend the next Committee to continue the work to demonstrate in comparative studies various multiaxial fatigue approaches with the aim to clarify their strengths, weaknesses and potential, respectively, when used in the shipping and offshore industry.

2.2.4 Ilson Pasqualino

Due to member's interests and limited pages allowed, corrosion fatigue, composite structures and cladded linepipes, are topic which have not been mentioned in the report. H2S / corrosive environments were discussed in the 2009 ISSC fatigue and fracture report. The Committee recommends that these topics are addressed further by the next Fatigue and Fracture Committee. Regarding development of non-destructive techniques for fatigue damage evaluation like X-ray diffraction method some information can be found in the group Committee V.3 Materials and Fabrication Technology 2012 report.

2.2.5 Weicheng Cui

Our mandate addresses unstable crack growth and was not covered in the 2009 report. For the recent increasing demand for natural gas, pipelines for natural gas transmission operate at higher pressures for ensuring higher transport efficiency. For realising higher pressure, higher strength pipes are used. Under this situation, risk of unstable shear fracture is increasing. On the other hand in shipbuilding industries, larger scale container ships are being constructed in recent years. In these ships, thicker steel plates are used at strength deck and hatch-side coaming structures. Under this circumstance, risk of cleavage fracture is increasing. One of the main challenges in order to select steel for arctic / low temperature applications is to ensure adequate material toughness in order to prevent brittle fracture to occur during operation. Due to this, the prevention of unstable cleavage fracture has become a big issue and extensive studies have been done for the last few years. Hence, the topic has been thoroughly discussed by the Committee.

The cleavage fracture can happen not only at a final stage of fatigue crack growth; it can also happen directly from defects in welds. Initiation of cleavage fracture takes

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place mostly at welds because it has a higher possibility of defects and higher probability of having a local brittle zone in addition that welds are often more prone to fatigue due to normally high stresses in a wild area. Although prevention of the initiation of cleavage fracture is essential to prevent unstable fracture, it cannot be prevented completely; the double integrity concept should be applied, in which crack arrest capability should be maintained assuming cleavage fracture initiation at the welds.

There are basically two types of unstable fracture, unstable ductile (shear) fracture and unstable cleavage fracture.

There are many factors which affect unstable cleavage fracture:

- material resistance to unstable fracture both at base metal and weld
- applied stress and welding residual stress
- plate thickness
- structural design including welding details.

See reply to Dr. Fang Wang for further discussions of cleavage fracture.

2.2.6 Fang Wang

As stated above in the reply to Dr. Weicheng Cui, there are many factors influencing unstable cleavage fracture. Because the plane strain condition is maintained in the interior of the thickness and plane stress condition prevails at plate surfaces. This is why cleavage fracture does not take place near a propagating crack; shear lips form near the surfaces. In this sense, thicker plate is more prone to unstable cleavage fracture propagation.

The crack arrest test should be done at an original plate thickness. Also, crack velocity is an important factor. To reproduce the crack velocity which can encounter at actual structural components, sufficient specimen size is necessary. From these viewpoints, a new testing standard has been proposed from Japan.

Regarding Dr. Fang Wang second question, the accuracy of the cycle-counting method, his hypothesis is that if ΔK is not representative of the true fatigue driving force in an incorrectly counted cycle, the fatigue life based on the cycle counting will not be accurate. Instead, Dr. Fang Wang asks whether it is possible to develop a fatigue crack growth model, which is expressed as da/dt instead of da/dN. It is the members' opinion that a fatigue crack growth model based on da/dt will create a lot of confusions among the practising engineers. There are a number of issues to be addressed for such a model:

- the da/dt model will unlikely converge into a uniform model, as the loading frequency varies for each structure and in different periods of the operating life. A simple example is the constant amplitude loading with two different frequencies. The da/dt model will somehow include the frequency into the model; however this requires a cycle counting method.
- time is an important parameter, but it is too general in describing the loading effects that cause fatigue crack propagation; By prescribing da/dt directly, the loading information will be missed (including magnitudes, frequencies, load ratios, etc.) in the model.
- the da/dt model will unlikely be able to describe the overloading effect.

2.2.7 Wolfgang Fricke

The case study has also looked at the assessment based on that nominal stress approach. In general, according to IIW, fatigue checking may be performed within the

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nominal stress approach by making reference to the FAT 90 S-N curve for computing fatigue damage of parallel normal stress $\sigma_{||}$ where reference classified detail is No. 323 "Continuous manual longitudinal fillet or butt weld" and to the FAT 100 S-N curve for shear stress $\tau_{||}$, (IIW-1823-07- "Recommendations for Fatigue Design of Welded Joints and Components" by Hobbacher (2009)). This procedure is only recommended for steel and in cases where sufficient experience exists. It is worth pointing out that some classification societies in their rules or guidelines also consider the case of a stress pattern predominantly parallel to weld line and define a proper fatigue checking approach based on the nominal approach. Such procedures give results in accordance to those of the DNV enhanced method and IIW.

With regards to the second question, the Official Discusser showed the "thickness effect" with respect to the plate thickness between $5\,mm$ and $20\,mm$ in Figure 2. In this range, the given results indicate the decrease of the fatigue strength as a function of the plate thickness. However, for the plate thickness between $3\,mm$ and $5\,mm$, the fatigue strength of butt joints may decrease with decreasing plate thickness, Feltz, and Fricke (2012).

The fatigue design of thin and slender structures is challenging due to larger distortions of the plate caused by welding. The recent results by Lillemäeet *et al.* (2012) and Fricke *et al.* (2013) show that the deformations are not only larger but also with different shape. In addition, the geometry of the weld in thin plate joints may be different from the one in thick plates affecting on the fatigue strength of the joints. Thus, further investigation is still needed to obtain a solid conclusion and recommendations for the fatigue design of thin marine structures.

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VOLUME 3

COMMITTEE IV.1

DESIGN PRINCIPLES AND CRITERIA

COMMITTEE MANDATE

Concern for the quantification of general economic, safety and sustainability criteria (as there are reliability, availability, maintainability, dependability) for marine structures and for the development of appropriate principles for rational life-cycle design using these criteria. Special attention shall be given to the issue of Goal-Based Standards as presently proposed by IMO in respect of their objectives and requirements and plans for the implementation, and to their potential for success in achieving their aims taking account of possible differences with the safety and sustainability standards in ISO and similar standards developed for the offshore and other maritime industries and of the current regulatory framework for ship structures. The IMO-related work shall be performed at a time scale consistent with that necessary for submission of documents to the relevant IMO committees.

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1 DISCUSSION

1.1 Official Discussion by Rolf Skjong

1.1.1 Introduction

The committee mandate is quite broad and general, and the topics described in the mandate are not closely related. It is therefore hard to identify a clear objective of the report. In this discussion document is it assumed that the main focus may be referred to as 'design for sustainability'?

ISSC does not have a consultative status as NGO at IMO and cannot submit documents to IMO. It is therefore unclear why the ISSC work shall be performed at a time scale consistent with that necessary for submission of documents to the relevant IMO committees.

The focus on the IMO Goal Based Construction Standards for bulk and tank (GBCS/BT), and the more general risk based approach to GBS (GBS/Safety Level Approach, GBS/SLA) is largely presented by referring to the ongoing process at IMO. The report is raising few questions as to the purpose and usefulness of the approach, and how this is linked to the design for sustainability approach.

The report is supposed to cover both ship and offshore structures. In regulatory aspects this is problematic, as the regulatory regimes are very different, and a 'design for sustainability' approach would require different adaptations. The report would need to consider that the ship regulations are largely international, whilst the offshore regime is regulated by the coastal state and therefore varying between states. The report also does not discuss the interesting development of a common EU regulation for the offshore sector in Europe (EU, 2011a), and other impacts of the Macondo accident.

The ISO sustainability standards mentioned in the mandate are not presented nor discussed. This seems logical as the relationship between these standards and the regulatory development at IMO or to 'design for sustainability' seems remote.

The report also contains quite a few pages about noise impact and ice loads on offshore wind turbines. Whilst the information might be useful, it is not at all clear why these topics are included, as this is not required by the mandate and not closely linked to 'design for sustainability'.

This review report is therefore largely limited to commenting on terminology, design for sustainability and GB(C)S.

1.1.2 Terminology

Systemic and Random Losses

There are some terminologies in the report that are found non-traditional. In particular this comment relates to the use of the terms 'systemic' and 'random losses'. The normal terminology is regular releases and accidental losses, which is understandable to most readers without any need for definition of terminology.

In a risk context, which is an important topic of the document, the term systemic is used in a different context and meaning. The term 'systemic risk' is much used in the finance sector. Systemic risk is the risk of collapse of an entire financial system or an entire market, as opposed to risk associated with any one individual entity, group or component of a system. It refers to the risks imposed by interlinkages and interdependencies in a system or market, where the failure of a single entity or cluster of entities can cause a cascading failure, which could potentially bring down the entire system or market. The word itself, simple refers to 'system' effects. The term is used a lot in the OECD book 'Emerging risk in the 21^{st} century' (OECD, 2003), which actually had the working title 'Emerging Systemic Risk' during its development, a title ending up as the title of Chapter 1 of the book. If the term 'systemic' is used about structures, it should be used in a systems reliability context.

Full Cost Accounting

Full cost accounting (FCA) generally refers to the process of collecting and presenting information about environmental, social, and economic costs and benefits/advantages (sometimes also referred to as the "triple bottom line") - for each proposed alternative when a decision is necessary. A synonym, true cost accounting (TCA) is also often used. Both terms may be problematic as definitions of "true" and "full" are very often subjective and subject to different valuation.

A large number of standards now exist in this area including Ecological Footprint, eco-labels, and the United Nations International Council for Local Environmental Initiatives approach to triple bottom line using the ecoBudget metric. The International Organization for Standardization (ISO) has several standards useful in FCA or TCA including for greenhouse gases.

However, the real subject in a regulatory context, which seems to be the scope of the report, is the classical concepts of internalization of the costs. Internalization is a policy instrument to correct market imperfections and the resulting inefficient allocation of resources that can occur when costs are not borne by those who incur them. Internalization of external costs such as those related to air pollution, noise and accidents should also reduce the environmental costs by providing incentives to reduce demand, which would be the effect if all external costs were born by the users and included in the evaluations done by the relevant decision-makers and/or regulators.

Net Present Value (NPV)

The concept of NPV is discussed in section 3.2.1. 'The conventional ship value assessment adopts the Net Present Value (NPV) ... approach, which only measures the tangible aspects of the ship, including ship's features and functions, discounted through time. NPV therefore fails to capture the importance of partnership and cooperation between the stakeholders of the shipbuilding industry'.

Net Present Value is mainly used to evaluate investment projects. It simply evaluates if an investment should be made or not, by depreciating the costs and economic benefits to present value using the corporate rate of return as the rate of depreciation. The corporate rate of return may be based on many considerations like return of alternative investments, risk premium of the project etc. (Skjong and Lereim, 1988). There is no problem including effects of sustainability considerations into this calculation if e.g. this is internalized in the calculations for example as a tax. The point is that NPV is a simple tool to be used by the investor, and any effect from sustainability considerations, taxes, future risks etc. can be taken into the consideration. Whilst the mathematical formula of depreciation is the same, the depreciation rate will be different in evaluating e.g. safety measures in a regulatory context or sustainability considerations where the aspects of the well-being of future generations are included. In any case it is not the NPV concept as such that fail to capture the importance of partnership and cooperation, it is the analyst that has not included it.

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Performance Based and Prescriptive Rules

In Chapter 2 it is stated 'A performance-based set of Rules implies a 'calibration' of lower level targets to targets at a higher level (and ultimately to the final target: sustainability). If this calibration is not performed, the term 'prescriptive Rules' applies, as the requirement is introduced in an 'axiomatic' way (i.e. without a proper justification in terms of achievement of the final target).'

A performance based rule specifies the performance, without prescribing a technical solution. The sentence about calibration seems more relevant for risk based rules. Prescriptive rules may also be risk based and calibrated. In summary, the paragraph quoted above is rather misleading and confusing.

The statement that 'Goal Based Standards' can be seen as a synonymous of 'Performance Based Rules' may be correct, but this is not clear yet and would only apply to GBS/SLA. For GBCS/BT only few of the functional requirements contain description of performance, and some 'functional requirements' are specifying design conditions and not functions. For example, functional requirement II.2 Environmental condition: 'Ships shall be designed in accordance with North Atlantic environmental conditions and relevant long-term sea state scatter diagrams'.

1.1.3 Sustainability

The Pure Rate of Social Time Preference

The ISSC report choose the following definition of sustainability: 'An activity is sustainable if it is proved that it adds value to the society, i.e. it improves the quality of life of the members and does not prevent future generations to achieve similar improvements.'

This is generally an adequate definition. However, in implementing the sustainability principle in any type of analysis to make the principle operational and useful in decision-making, the report should discuss how this may be achieved. In particular, when discussion relates to greenhouse gas abatements investments, where decisions now also affect future generations the pure rate of social time preference is an extremely important parameter. It is therefore a serious weakness of the report that this is not discussed.

Debates about discounting have a long history in economics and public policy. Discounting involves many related and often confused concepts. One is the idea of a discount rate on goods, which measures the relative price of goods at different points of time. Another is called the real return on capital, the real interest rate, the opportunity cost of capital, or the real return. The real return measures the yield on investments corrected by the change in the overall price level. In principle, this is observable in the marketplace. The Intergovernmental Panel on Climate Change's (IPCC) second assessment report discussed actual returns and reported real returns on investment ranging from 5 to 26 percent per year.

Yet another important discount concept involves the relative weight of the economic welfare of different generations over time. This is usually referred to as the pure rate of social time preference. It is calculated in per-cent per unit time, like an interest rate, but refers to the discount in future welfare, not future goods or dollars. A zero time discount rate means that, for *decisions now*, future generations into the indefinite future are treated symmetrically with present generations; a positive time discount rate means that the welfare of future generations is reduced or "discounted" compared to nearer generations.

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In the climate change debate there is a well-known case where differences in assumptions had drastic consequences.

The British government in November 2006 presented a comprehensive new study, the Stern Review on the Economics of Climate Change. Prime Minister Blair presented a dire picture for the future "It is not in doubt that if the science is right, the consequences for our planet are literally disastrous. Without radical international measures to reduce carbon emissions within the next 10 to 15 years, there is compelling evidence to suggest we might lose the chance to control temperature rises" (Blair, 2006).

This result of the Stern (2006) review was to a large extent the result of applying a pure rate of social time preference of 0.01%. As demonstrated by Nordhaus (2007) such assumptions would result in decision-making that are utterly irresponsible, since small consequences in distant future with small probabilities of occurrence could have direct consequences on resource allocation today. A number of illustrative cases are given in Nordhaus (2007, 2008).

For example Nordhaus (2007) in one example demonstrates that the modelling assumptions in the Stern (2006) review result in reducing per capita consumption for one year today from \$ 10 000 to \$ 4 400 in order to prevent a reduction of consumption from \$ 130 000 to \$ 129 870 starting two centuries from now and continuing at that rate till eternity.

Nordhaus (2007) calculates the optimal climate change policy using the in DICE-2007 model. The Dynamic Integrated model of Climate and the Economy has been continuously developed since the early nineties. In one run the model calculates the optimal trajectory of climate change policies.

The optimal carbon price in 2015 was calculated to be \$ 35 per ton C, rising over time to \$ 85 in 2050 and to \$ 206 in 2100 (all data are in 2005 U.S. dollars). It is claimed that this optimised path leads to a projected global temperature increase from 1900 to 2100 of around $2.3° C$.

The discussion between Nordhaus and Stern illustrates the importance of analysing modelling assumptions in detail. The fundamental idea is that such decision rules should follow the principle of generality 'A decision rule should be applicable to anyone anytime'.

In any case the IPCC (2007) report give a decision rule applicable today, for greenhouse gas abatement decisions, see below.

Safety Criteria in IMO (FSA)

At IMO the most important decision criteria for safety has been established since 2000 by a submission by Norway (2000) and based on cost effectiveness criteria: Net and Gross Cost of Averting a fatality (NCAF/GCAF), and also the Quality Adjusted Life Years (QALY) criterion for evaluating health and injury effects. This is now described in the FSA Guidelines (IMO, 2007). The implication is that internalizing costs to safety, injuries and ill health is made easy in any decision model.

The criterion used for recommendations based on NCAF and GCAF can be found in the consolidated version of the FSA Guidelines (IMO, 2007, page 54). The criterion that has been used for all FSAs submitted to IMO so far has been at \$ 3million, see Table 2, page 54 of IMO (2007). However, it is stated in the FSA Guidelines that the proposed values for NCAF and GCAF have been derived by considering societal indicators (refer to document Norway 2000). They are provided for illustrative purposes only. The specific values selected as appropriate and used in an FSA study should be explicitly defined. These criteria are not static, but should be updated every year according to the average risk free rate of return (approximately 5%) or by use of the formula based on the Life Quality Index (LQI), Skjong and Ronold (1998, 2002).

It is noted that the $ 3million is in reality derived from 1998 statistics for OECD member countries. If adjusted for US inflation rates until 2010, this figure should be updated to $ 4.14 million (2010). If adjusted for a 5% risk free rate of return the figure should be $ 5.39million (2010), and if a full update based on LQI for OECD member countries is carried out the result is $ 7.45million.

The main changes are due to the following: The number of OECD countries has increased, Gross Domestic Product per Capita has increased, life expectancy at birth has increased and we spend less time in economic activity. In addition the US$ has decreased its value against most other currencies.

The ISSC report chapter 3.3.1 is discussing this topic without mentioning the background documents and the concepts used at IMO, and is introducing the concept CSX for the well-established Cost of Averting a Fatality (CAF) criteria at IMO. Furthermore the concept is confused by referring to the large variability in actual decisions. 'The problem with this approach is that the resulting CSX values differ widely. The values reported in literature, ... ranges from $ 1 000 for investments in sport and recreation to $ 100 000 000 for investments in the nuclear industry'. By such statements the ISSC report is just confusing the reader. The point with cost benefit assessment is that resources reallocation could save many more lives. For example it was demonstrated in Tengs *et al.* (1995) that 40 000 lives could be saved in the US by reallocation of resources.

For health effects and injuries the IMO FSA Guidelines advocates the use of the QALY (Quality Adjusted Life Year) concept, which is promoted by the World Health Organization (WHO). For converting a CAF criterion to a QALY criterion it is simply assumed that a fatality correspond to $e/2$ QALY (where e is the life expectancy). It is worth noting that WHO maintain an evaluation of the QALY for various reduced health states.

The Cost of Averting a Ton of CO_2 Heating Effect (CATCH)

As pointed out in Skjong (2009) a similar approach may be used in prioritising reduction in greenhouse gas emissions. Actually, most of the high level analysis that is needed was carried out by Intergovernmental Panel on Climate Change (IPCC), and is reported in the Fourth Assessment Report, Contributions from Working Group III (IPCC, 2007). The report contains estimates of the risk reduction at different carbon price levels, both based on top-down and bottom-up studies and for two different scenarios. This is given in IPCC (2007), Table SPM.1 and 2. Reproduced here as Table 1 and Table 2.

The economic potential for emission reduction estimates is surprisingly consistent at all carbon price levels. The two scenarios are defined as follows:

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions

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Table 1: Global economic mitigation potential in 2030 estimated from bottom-up studies

Carbon Price ($US\$/tCO_2$–eq)	Economic Potential ($GtCO_2$ –eq/yr)	Reduction Relative to SPES A1 B (68 $GtCO_2$ –eq/yr) (%)	Reduction Relative to SPES B2 (49 $GtCO_2$ –eq/yr) (%)
0	5-7	7-10	10-14
20	9-17	14-25	19-35
50	13-26	20-38	27-52
100	16-31	23-46	32-63

Table 2: Global economic mitigation potential in 2030 estimated from top-down studies

Carbon Price ($US\$/tCO_2$–eq)	Economic Potential ($GtCO_2$ –eq/yr)	Reduction Relative to SPES A1 B (68 $GtCO_2$ –eq/yr) (%)	Reduction Relative to SPES B2 (49 $GtCO_2$ –eq/yr) (%)
20	9-18	13-27	18-37
50	14-23	21-34	29-47
100	17-26	24-38	35-53

of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Assuming that the politically expressed wish to reduce the emission by 80%, compared to the current level B2 scenario at 2030, and ignoring the uncertainties, this indicates that all measures that can avert a tonne of CO_2 – eq. emission for less than or about \$ 50 should be implemented now or in the near future. This is higher than the current price ine.g. the EU market and demonstrates that the current market based instrument fail to internalize the societal costs.At IMO this way of deciding to implement RCOs would be consistent with current decision making processes and FSA, e.g.

$$\text{Cost of Averting a Tonne } CO_2\text{– eq. Heating effect (CATCH)} = \$\ 50$$

It may obviously also be argued that due to the uncertainty in the estimates, and the long term irreversible effect of climate change, a safety factor should be introduced too. For EU and others, a reference to the precautionary approach would be of relevance, as this is also representing an agreed policy.

The CATCH concept has been applied in Longva *et al.* (2010) for setting the target Energy Efficiency Design Index (EEDI), but could be used in various ways, including introducing a fuel levy. The approach quantifies the cost of averting greenhouse

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gas emission, which indicate the costs that needs to be internalized in the decision processes, by regulators and individuals to achieve sustainability.

Economics of Marine Accidents

The section with this title in the ISSC report is really about the cost of averting oil spills. There are obviously other costs relating to marine accidents, like the loss of life and property.

In section 3.2.3 it is stated that 'The circumstances surrounding a spill incident are complex and unique. Predicting the per-unit costs of a spill response is a highly imprecise science since the factors impacting cost are as complex as the factors impacting the degree of damage the spilled oil will cause. Clearly, one universal per-unit cost is meaningless in the face of these complex factors. . . '

This is correct, but fails to address the real issue about ship 'design for sustainability'. Most ships are certified for global trade. The implication is that the implicit willingness to pay for averting e.g. oil spill in ship design and operation is not depending on circumstances surrounding a specific spill.

In any case, the ISSC report fail to cover the issue as debated over years at IMO, which focused on identifying a criterion for the cost of averting oil spill in FSA.At MEPC 62 this was largely concluded by preparing an annex to the IMO FSA Guidelines.

It was noted that the most appropriate conversion formula to use will depend on the specific scope of each FSA to be performed; a general approach to be followed was outlined.

The consolidated oil spill database is based on:

- IOPCF data;
- US Data;
- Norwegian data;

Figure 1 shows the data of the consolidated oil spill database in terms of specific costs pertonne spilled (Figure 5 of document Germany *et al.* (2011)). It should be acknowledged that the consolidated oil spill database has limitations and possible deficiencies.

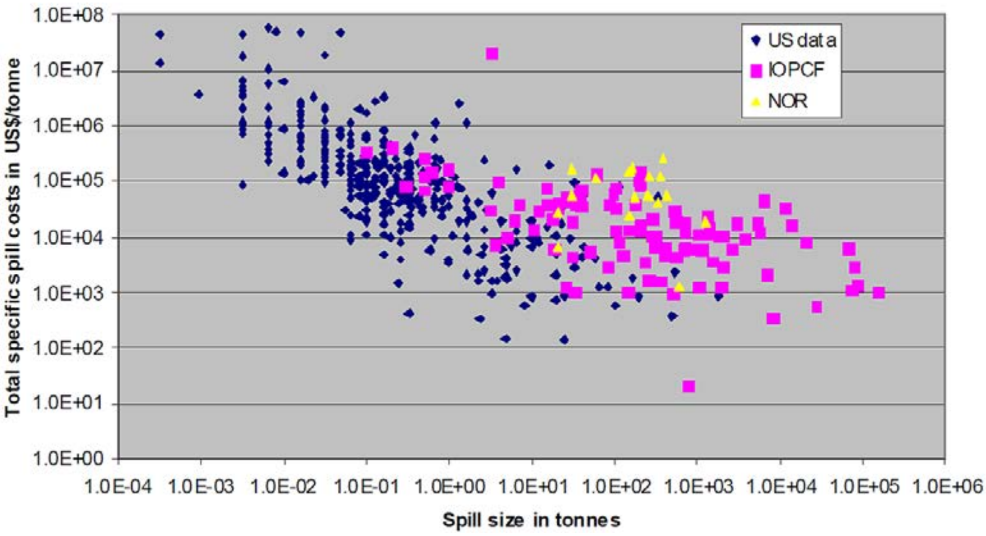

Figure 1: Oil spill costs as a function of spill size.

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Table 3

Dataset	f(V)=Total Spill Cost (TSC) (2009 US dollars)	Reference
All spills	67,275 $V^{0.5893}$	MEPC 62/INF.24
V>0.1 tonnes	42,301 $V^{0.7233}$	MEPC 62/18[6]

These are described in Germany *et al.* (2011) and may also involve incomplete or missing data on costs or other information.

The submitter of the FSA can amend this database with new oil spill data; however, this amendment should be properly documented.

Some regression formulae derived from the consolidated oil spill database are summarized in Table 3, in which V is spill size in tonnes.

The FSA analysts are free to use other conversion formulae, so long as these are well documented by the data. For example, if an FSA is considering only small spills, the submitter may filter the data and perform his or her own regression analysis.

It is recommended that the FSA analyst use the following formula to estimate the societal oil spill costs (SC) used in the analysis:

$$SC_{threshold} = F_{Assurance} \cdot F_{Uncertainty} \cdot f(V)$$

The assurance factor ($F_{Assurance}$): allowing for society's willingness to pay to averting accidents; Uncertainty factor ($F_{Uncertainty}$): allowing for uncertainties in the cost information from occurred spill accidents; and Volume-dependent total cost function $f(V)$: representing the fact that the cost per unit oil spilled decreases with the spill size in US$ per tonne oil spilled.

The values of both assurance and uncertainty factors should be well documented.

In order to consider the large scatter, the FSA analyst may perform a regression to determine a function $f(V)$ that covers a percentile different than 50% and document it in the report.

It is still unclear if the present formulations will be corresponding to the willingness to pay for averting oil pollution accidents that are implicit in the present MARPOL. This will presumably be analysed up to MSC91, and maybe $F_{Assurance}$ will be given a value in the FSA Guidelines reflecting the current willingness to pay for averting accidents that are now implicit in e.g. MARPOL. In any case, IMO is in a process of agreeing on how to internalize the societal cost of oil spill in the regulatory process, an approach that would be helpful for the 'design for sustainability approach'. This may be compared to the decision processes in EU on offshore regulations. The EU Impact Assessment (EU, 2011b) is largely a worst case scenario analysis estimating a return period for a Macondo type accident in Europe.

Other Criteria for Internalizing Costs in Decision Models

In general there is currently a large literature available on factors to be used in internalizing societal costs in decision models, and attempts to link this to sustainability concepts. Based on a review such costs are identified for NO_x, VOC, SO_x, Particular Matter, etc in Vanem *et al.* (2011). In general, there is a large literature available to support a 'design for sustainability' approach, and given the mandate of the ISSC committee it would be expected that such literature was reviewed.

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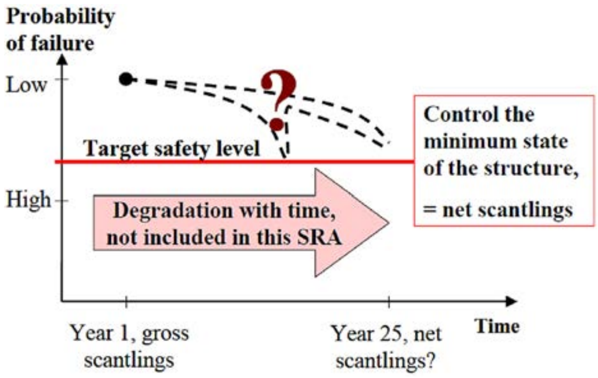

Figure 2: Safety Level as a function of ship age

1.1.4 Goal Based Standards

Goal Based Construction Standards for Bulk Carriers and Tankers (GBCS/BT)

The presentation of GBS development at IMO and the corresponding activities in IACS in the ISSC report is generally correct. However, there are few statements that represent a technical evaluation of the activity. For example the role of the regulator in the process may be questioned. This is reflected in the choice of the high level goals. As an illustration of this, the GBCS/BT is specifying a 25 years design life.

Figure 2 is an illustration of the questionable approach in defining goals in the GBCS/BT. The design life is specified to 25 years. However, the GBCS/BT does not indicate how safe the ship should be during the life. Given the role of the ship owner and the regulator, it would make more sense that the design life should be be a commercial decision by the owner, whilst the role of the regulator is to implement controls that the safety is acceptable during that design life. In structural reliability analysis this is traditionally done by specifying the target safety level, which may be derived from 'design for sustainability' approaches, using the criteria already defined by IMO.

This simple illustration may also serve to explain the current focus on the GBS/SLA or the risk based approach to goal based standards. The difference between GBCS/BT and GBS/SLA can be illustrated very well in Figure 2. In GBCS/BT the goal is represented by a *vertical* line indicating the design life, in GBS/SLA the goal is represented by the *horizontal* line specifying the safety level.

Potential Success of Goal Based Standards (for Bulk and Tank)

This is briefly discussed in section 5.3 focusing on the procedural consequences of having to go through an IMO audit process for the classification rules. It is worth noting that these issues were discussed, without being answered at the early development phase of GBS. This goes back to MSC78 (May 2003). In a society where decision processes are expected to be evidence based it is clearly of relevance for researchers to revisit these critical question from back in 2003 once this process has concluded and the first ship is built to the GBS standard in 2016.

In section 4.2.1 it is stated that 'It is the intention that the goals prescribed by IMO may be achieved by alternative designs that offer an equivalent level of safety, while promoting new technology and greater innovation within the shipping industry.'

This statement is a reasonably interpretation in general of GBS, but is not part of

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GBCS/BT at IMO. However, the IACS common structural rules for BT contain an equivalence paragraph.

Questions still remain. Are there going to be benefits from GBCS/BT? Could the result be a permanent end to innovation for these hip types? Are there any reasons class societies should improve the rules when they have finally been approved? Will classification societies have any incentives to carry out R&D activities on rule developments for bulk carriers and tankers? IACS (2003) voiced the following opinion early in the debate about GBS 'Proposals made for this Committee to consider the introduction of far reaching changes should be based on facts from sound investigation and should, at least, include a proper cost/benefit analysis as part of a Formal Safety Assessment (FSA)'. Such a cost/benefit analysis was never carried out.

Naval Ship Code

Given that the mandate of the committee was to look into GBS, it is somewhat surprising that the report does not consider the Naval ship code.

The vision of the International Naval Safety Association (INSA) is that the Naval Ship Code becomes established as a cost-effective goal based standard for naval ship safety benchmarked against statute, and accepted by the global naval community and intergovernmental bodies.

What are the benefits of a Goal Based Standard? According to INSA(2012) 'A "goal-based" standard, rather than relying on the existing rules, considers what the ultimate safety objective of the designer might be, and will consider a range of alternative design approaches that will reach this desired goal. Thus, whereas in the past the rules would have been specific over every detail, now, the over-arching objectives will be specified, giving the designer choice, and the freedom to innovate.'

It is worth noting that this is more in agreement with the GBS/SLA, and not in agreement with the GBCS/BT. The experience with the work with the Naval Ship Code was also communicated to IMO in order to influence IMO to develop GBS in a similar direction (Netherlands, 2007, 2008). Netherlands (2007) relates to Life Saving Appliances (LSA), where IMO now has started work on GBS on revising SOLAS, Chapter III on LSA (Denmark *et al.*, 2011).

Risk Based Approach to Goal Based Standards

Risk Based Approach and Goal Based regulations or standards are about two different issues. The risk based approach relates to justification of regulations, like described e.g. in the FSA Guidelines (IMO, 2007). As explained above, this may well be extended to include sustainability considerations.

Goal based relates to the style of writing and structuring the regulations. When risk based is combined with goal based the implication is that the goals related to safety and environmental protection is referring the acceptable risk levels, or the ALARP principle. At IMO (and elsewhere) the ALARP principle is gaining popularity and as described in the FSA Guidelines this result in decision making based on cost-benefit evaluations. As explained above, this can be linked to internalizing the societal costs in the decision process and to 'design for sustainability'.

The link between Goal Based and Risk Based was made already back in 2003, see for example Denmark *et al.* (2004), and the following years saw a number of submissions supporting what was later referred to as GBS/SLA. However, all focus until 2011 was on developing the GBCS/BT(for bulk carriers and tankers > 150 meters).

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The first working group at IMO that discussed the GBS/SLA was established at MSC90 (May 2012), and it is not at all clear which direction this development is leading.

The main proposal for MSC90 was the document submitted by Germany (2012), since this document again points to the fact that GBS standards will involve a restructuring of the IMO instruments. In principle it could be foreseen that in the long term the IMO instruments (SOLAS, MARPOL, Load Line Convention etc) are replaced by one instrument only containing the goals and the functional requirements. Tier IV of the regulatory system would consist of IMO Codes and Classification Rules. This is very different result compared to GBCS/BT, where SOLAS is amended by including some definitions and the entry into force dates, whilst the goals and functional requirements are included in a MSC Resolution 'International Goal-Based Ship Construction standards for Bulk Carriers and Oil Tankers'. The Guidelines for Verification of conformity with the international Goal-Based Ship Construction Standards for Bulk Carriers and Oil Tankers are yet another document (Tier III of GBCS/BT).

The working group at MSC90 agreed that SLA is an application of risk-based concepts in order to determine the safety level of the regulations, with a view to developing or changing international regulations, within or outside the GBS approach. With this in mind, the group developed the definition of SLA 'Safety-level approach is the structured application of risk-based methodologies for the IMO rule-making process.'

This agreement is somewhat difficult to interpret, because the SLA definition is in practice the same as the definition of FSA. For example in IMO(2007) FSA is defined as follows 'Formal Safety Assessment (FSA) is a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost benefit assessment' and it is meant to be used in the IMO rule making process etc.

It seems that SLA is the same as FSA. It would probably be better to say that GBS/SLA is the risk based approach to goal based standards, and that FSA is that risk based methodology. FSA is also the methodology to determine the safety level in current regulations. As a matter of fact, this is the outcome of FSA Step 2: Risk analysis.

IMO (2012) includes Figure 3, which clearly indicates that the goals relates to safety level. A Tier 0 is also included with the IMO mission statement.

In any case, the work programme for GBS/SLA approach that was agreed at MSC90 (IMO, 2012) is:

1. conduct relevant SLA exercises, as examples for further consideration, taking note of the experience gained within the DE Sub-Committee in restructuring SOLAS chapter III and other relevant experience within other organs, using a goal-based/risk-based approach; and
2. initially assess the current safety levels, taking into account the various FSA studies submitted to IMO, including:
   (a) developing risk models for SLA to assess the current regulations;
   (b) applying risk models to assess the current regulations; and
   (c) identifying the need, procedures, if necessary, and sources for collecting/improving data, taking into account the work of the FSI Sub-Committee and the GISIS database

Since the restructuring of SOLAS chapter III is an on-going work in the DE Sub-Committee, the group did not specify any time frame for the above issues, however, envisaged at least two to three years to develop interim guidelines for the safety level approach.

1.1.5 Some specific comments

Accidental Limit State

The topic discussed in Section 5.2, is also addressed in Hørte *et al.* (2007) using structural reliability analysis with the following clear conclusion:

'The cost benefit analyses show that the scantlings at the cost optimum target safety level for the damaged case are lower than those for the intact case. There is therefore not a need for a structural criterion for the damaged condition based on the case study reported here, the intact criterion is dimensioning.'

This is an important observation. A criterion may be excluded from a rule because the criterion is not dimensioning. Exclusion should therefore not be construed to mean 'not considered'.

Double counting

In section 3.2 'These figures indicate the efficiency of shipping. The ratio between the total freight rates and goods transported leads shows (sic) that on average less than 10% of the value of goods transported is required undertake (sic) that transportation using the shipping of the world. Even if the annual investment in newbuilding is add to this, in the order of 100 billion USD (SAJ, 2010), the overall system is still very lean.'

Presumably the annual investments are paid for by the freight rates, or shipping would not even be economically sustainable. To add investments would represent double counting.

Insufficient understanding

In section 3.2.1 'Wang (2008), building on this, found that currently there is insufficient understanding of the value of a ship by the ship owner and shipyard.'

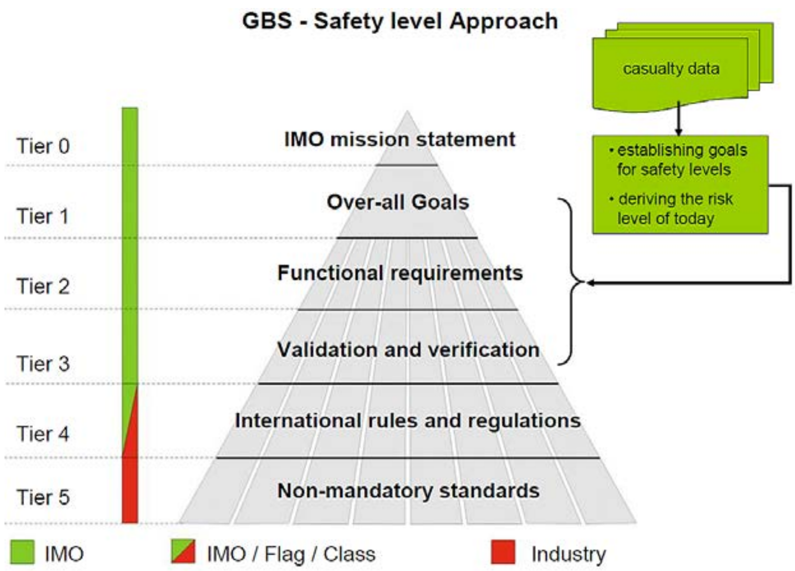

Figure 3: Structure of GBS/SLA (Denmark *et al.*, 2006)

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The statement and reasoning following the sentence is unclear. The shipyard will find out the value of the ship every time a contract with an owner is signed, and the owner will know the value when he tries to sell the ship in the market. Presumably Wang (2008) was concluding something else.

Learning from Aviation Industry

Chapter 6.2 of the report contains a very brief explanation of the design principles used in the aviation industry. The safe-life/fail-safe philosophy seems to be dealing with similar considerations as the GBCS/BT relating to functional requirement II.7 Structural redundancy (a 'systemic' effect) 'Ships shall be of redundant design and construction so that localized damage (such as local permanent deformation, cracking or weld failure) of any stiffening structural member will not lead to immediate consequential collapse of the complete stiffened panel.'

The purpose of Chapter 6.2 is rather unclear, and there would be added value to the report if there was a discussion and comparison of the ship and aviation approaches. Table (6) of the ISSC report also indicate that the aviation industry use a safety level approach. A discussion on how this is implemented and relevance to maritime would therefore be interesting.

Relating to fatigue, the main difference relates to the reliance on testing. Full scale testing is not feasible for ships, whilst this is the main approach within aviation. For an application of structural reliability analysis of aircraft fatigue see Sigurdsson *et al.* (1992).

References in the ISSC Committee report

The way of writing IMO references is confusing. At IMO, there are essential two types of documents: Submissions and resulting regulations, guidelines, circulars etc. Only the output from IMO should be referenced as IMO (yyyy). The submissions should be referenced by the organization submitting them (as done in the reference list in this discussion document).

Furthermore, the references (IMO, 2009f) and (IMO, 2010d) are wrong references (About Noise, not GBS.)

There is also a reference to an OECD report, said to be Endresen (2008), whilst the reference list only contain a reference to Endresen *et al.* (2008), which seems not to be an OECD report.

1.1.6 Concluding Remarks

The ISSC report on 'Design Principles and Criteria' seems to wish to describe a basic design philosophy referred to as 'Design for Sustainability'. This is a very good idea, and probably a better terminology than 'risk based design', which consists of many of the same elements (holistic, from design to scrapping etc.). However, although all ideas to promote the idea of 'design for sustainability' are available in the literature the report fail to describe the philosophy consistently, and rather fundamental issues related to sustainability, like the 'pure rate of social time preference' are not even mentioned.

The description of the regulatory systems with commonalities and differences are missing. If the 'design for sustainability' philosophy was adequately described it would be much easier to describe how this could be implemented in ship regulations through IMO and the Classification Societies. Likewise, implementation in the various offshore regimes would be possible, both in the prescriptive regimes and the goal based or safety case based regimes. Obviously, in the goal based or safety case based regimes implementation would be in principle strait forward, as long as the regulators would be prepared to define how externalities should be implemented in the decision processes of the operators. The Norwegian offshore regulatory regime is in this respect an exception, as also e.g. safety targets are specified by the operators.

The mandate of the committee is probably partly to blame for the lack of structure in the report. For example, there is a lack of fundamental principles to follow in the GBCS/BT, and it is hard to detect any useful information as relating to design principles and criteria in the ISO sustainability standards. The mandate is therefore not practical.

There are generally too many parts of the report that serves no purpose. What is the purpose of just quoting the result of the expert group on Formal Safety Assessment, without any discussion or conclusion? What is the relation between FSA and GBS/SLA? The heading under which FSA is mentioned is the SLA, and there have been many IMO submissions explaining the relation. Similarly, there is a chapter on design criteria for ice action on offshore wind turbines that seems unrelated to the topic of the report and to the mandate. Already in the introduction there is a statement that port authorities extend the international legal requirements for shipping. This is not followed up anywhere in the report. The issues described in Chapter 4.1.2 does not relate to international regulations, but to the fact that ports are regulated by national regulations and the municipal authorities. This is not a new development.

In any case the idea of developing an approach under the heading 'design for sustainability' is generally supported, and hopefully this discussion documents hints to the direction this goal should be pursued.

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1.2 Floor and Written Discussions

1.2.1 Paul James

Can a goal based standard cover only one system? Should it be more comprehensive and cover all ship systems? The NATO naval ship code tries to do this, has the committee considered this code?

1.2.2 Richard Birmingham

The Official Discusser correctly noted that the report of Committee IV.1 focused on "design for sustainability", however the wording of the mandate necessitated that much of the discussion was framed by goal based standards (GBS). This is unfortunate as the GBS debate is highly politicised and distorted by particular interest groups. The ISSC reports should make every effort to avoid participating in such political debate.

The discusser asserted that most of the specific issues of concern in design for sustainability had been dealt with, and had been considered since the 17^{th} century. This assertion misses the point. Sustainability is all about a holistic approach, where economic, societal, and environmental concerns are considered simultaneously. The fact that the tools for multi-criterion decision making have been developed many years ago does not mean that they have been successfully applied to the problem of addressing sustainability in design.

The issue of sustainability has only been recognized for a few decades, and methods to identify the most sustainable solutions are still being sought. Even this will only be the first step towards effective "design for sustainability", which, when achieved, will be very different from responding piecemeal to the codes that address specific issues in isolation which is the current procedure. I hope the Official Discusser recognizes that there is much work still to be done.

1.2.3 Berend Bohlmann

I wonder how it could happen that under the flag of Goal Based Standards we see sailing just another set of prescriptive rules. Can you comment on this?

2 REPLY BY COMMITTEE

2.1 Reply to Official Discusser

The committee members thank the official discusser for his contribution and critical remarks to the committee report. With his general comments regarding the broadness of the mandate and how the report has covered the task the discusser sheds light on the general difficulties that can occur in the ISSC committee work. Regularly the committees consist of experts from various fields of expertise that might not always match the mandate perfectly. As a consequence the members of the committee approach the mandate from their perspectives which can be different from the perspective of the discusser. Further the distribution of expertise among the committee members rules the focus of the report. Having in mind that no expertise from the offshore industry was available and no expertise regarding the activities at ISO it is self-explanatory why the report shows deficits in these fields as they were mentioned by the discusser.

The discusser's statement that ISSC does not have a consultative status as NGO at IMO is correct. In the past there have been opportunities for ISSC committees to present comments via RINA to IMO committees as the previous committee IV.1 has done. With this tradition in mind the mandate requested that the committee work

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should be done in line with the IMO schedules but finally the committee did not use this opportunity.

The basic assumption of the discusser is correct. The report wants to generally describe the efforts done in the maritime industry to increase sustainability, be it the local regulations to reduce emissions or any measures to avoid negative impact to society or be it the rules and regulations to build more robust ships which are assumed to cause less accidents with negative consequences for the environment.

The discusser expresses his concerns about the terminology that was used in the report. It was like a red line in the committee work from the very beginning, that the committee members discussed questions of terminology. From the committee members' point of view there was a broad variety in terminology in the literature reviewed which was discussed by the committee. Consequently the committee found it appropriate to propose a set of definitions which were coherent within the committee.

With regard to the definition of losses the discusser does not agree with the use of "systemic" and "random". It is the understanding of the committee that the word "loss" is overarching and describes any negative contribution to sustainability. According to the committee's understanding losses are divided into two categories systemic and random. In this context any kind of a regular release of e.g. exhaust gases or noise to the environment are defined as systemic. Accidental losses e.g. a release of oil to the environment as a consequence of a structural failure of a ship is defined as random.

With regard to the definition of full cost accounting the discusser mentions that "true" and "full" costs are very often subjective and subject to different valuation. This statement is not in contradiction to the definition of the committee. It may be that someone uses the term differently but in the context of the report full cost accounting is seen as an overarching concept related the economic evaluation of measures to achieve sustainability. However, in most of the studies reviewed by the committee the quantifications were dealing with partial costs only. Not all possible costs were included in the studies. Further it is agreed that the redistribution of costs by policy instruments is a possible measure to correct market developments that occur when the costs of the consequences of an action are not directly borne by those who are responsible for the action (e.g. costs of consequences of increased CO_2 emissions). It might be worth to describe the various instruments that exist in detail and their effects. However, the committee found this to be outside of the scope of the report and put focus on the criteria for design and to define the costs the society suffers from shipping activities.

Regarding the discusser's remark on the usage of the term "calibration" in context with performance based rules the committee respects the opinion of the discusser but disagrees. It is the understanding of the committee that in case of performance based rules there is a need to enforce coherence between the different levels by calibration, which by the way was set in quotation marks in the report. If a performance is introduced at a lower level (e.g. Tier 2) without showing that it comes from a more general requirement on a higher level (e.g. Tier 1) it becomes a prescriptive rule. Let's take an example. In case of GBS Tier 1 we have the general requirement that a ship has to be capable of operating under specified operating conditions. On Tier 2 we have the specific requirement that the North Atlantic spectrum has to be taken for the dimensioning of the scantlings. If the North Atlantic requirement would stand alone without the more general requirement of Tier 1one could say it is a prescriptive requirement. From the committee's point of view the term calibration is not limited

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to risk analysis where it has a specific meaning. If we talk about calibration in context of calibrating instruments we again have a very specific meaning. However, both cases are included in a more general definition of the term as used by the committee.

Further the committee does not see a problem in the fact that the present formulation of the GBS for some functional requirements contains reference conditions for performances and not performances in the strict sense. As long as one doesn't know better the reference condition North Atlantic can be seen as reasonable. The key point is that the performances and their reference conditions as described in GBS at Tier 2 should be consistent with those at Tier 1.

The discusser's remarks on the pure rate of social time preference are well appreciated by the committee and demonstrate the expertise of the discusser in this field. Together with the references introduced the remarks are a good supplement to the committee's work.

The section of the committee report dealing with the methodology of FSA and the safety criteria in IMO is a continuation of the previous report. In the previous report the committee presented the risk evaluation criteria related to safety of human life (GCAF/NCAF) and the cost effectiveness criterion related to accidental oil spills of tankers (CATS) in detail. Further the discussion and the methods to escalate the costs accepted by the society based on the different societal indicators have been presented in the previous report. In the present report the committee focused on the new criterion for the reduction of greenhouse gas emissions (Cost of averting a ton of CO_2 heating effect CATCH) as it was proposed by Eide *et al.* (2009). The decision parameter for emission reduction "CATCH" has been established using the same approach as adopted in the development of the decision parameter NCAF/GCAF as already included in the FSA guidelines and the similar parameter for assessing measures to reduce oil spills "CATS". These decision criteria (related to human life, oil spills and greenhouse gas emissions) indicate the costs that need to be "internalized" in the decision processes by regulators and individuals to achieve sustainability.

Regarding the discusser's comment that the report failed to address the recent discussion at IMO on costs related to oil spills the committee members admit that that there was no review done of MEPC documents published during this period. However, the previous report discusses the CATS issue in detail. The committee appreciates and welcomes the supplementing information on costs for cleaning up of accidental oil spills which come from recent publications.

With the comments on the section about goal based standards (GBS) the discusser expresses his concerns about the present development at IMO. The discusser uses the abbreviation GBCS as he has used it the first time in 2005 during a presentation at MSC (`http://research.dnv.com/skj/PRESENT/DNV-MSC80.pdf`) which was intended to support the paper MSC 80/6/6 submitted by Denmark and Norway. Presumably the author wants to differentiate between the now existing approach of GBS for oil tankers and bulk carriers and the GBS safety level approach which is still under development at IMO. However, in the meantime the abbreviation GBS is commonly used and the usage of the abbreviation GBCS in turn caused confusion among the readers of the discussion.

The committee members agree with the discusser, that there is a significant difference between the first expectations when the GBS discussion at IMO started and the final outcome.

One group at IMO expected that reliability methods or risk analyses would be introduced into rule development and that IMO would focus on their core activity of formulating acceptable limits of risk. On the next lower tier classification societies or other regulatory bodies would then formulate the rules for structures or systems in such a way that the systems would not expose humans or environment to a risk higher than that allowed by IMO.

However, the opposite group prevailed driven by commercial interests. Today it can be said that the driving factor for the GBS discussion was to get a single set of prescriptive structural rules which lead to ships with higher steel weight. Evidence can be seen in the lengthy discussions about the corrosion allowances that were lead in the various working group meetings at IMO or the discussion lead during presentations of the Common Structural Rules about scantlings and their increase compared to the former classification rules. The discusser in this context highlights the GBS requirement that a ship is to be designed for a specific design life of 25 years what can be seen as a pure commercial issue. At least it should be to the owners/investors discretion for what period of time he wants to spend an investment and to calculate the related return of investment.

The committee appreciates that during the floor discussion it was clearly expressed that the intention of the initiators of the GBS discussion at IMO was not to introduce risk analysis techniques into rule development but to just use a euphonic expression.

With regard to the future of the Common Structural Rules it is questionable if investments will be spent in further development. Presently the rules have to be submitted to IMO for validation and verification as described in the Resolution MSC 296(87). The classification societies have to pay a fee of $ 50 000. The verification will be done by means of an audit of the self-assessment that has been done by the classification societies prior to the submission and which is part of the submitted documentation. However the auditors are free to go further into details. Future changes of the rules will be subject to a continuous "re-verification" for which the classification societies have to pay again. Having in mind the required lead time for the verification procedure it is expected that significant improvements during the rule development will be delayed until they will be available for the market.

With this new procedure of approval the classification rules have become part of SOLAS and thus have a character of statutory rules. Consequently the latitude of judgement of the societies is rather limited. As soon as a society interprets a specific rule in a wider sense than a competing society the society is at risk of having approved a non SOLAS compliant design. As a further consequence unconventional or innovative designs might lead to an increased involvement of the flag state administrations during the early design phase. It can be expected that the acceptance of direct strength analyses as a support for unconventional or innovative designs might be limited.

However, the next committee should further follow and discuss the development of the safety level approach SLA at IMO and how this approach will influence the future development of IMO regulations.

The committee agrees that the report does not refer to the Naval Ship Code of INSA. This is due to the lack of expertise on this field among the committee members.

With regard to the section on aviation industry, on the one hand the committee utilised the expertise of one committee member coming from the aviation industry to describe their design principles, on the other hand the committee agrees with the discusser that there is a comparison of the approaches missing.

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With regard to the concluding remarks of the discusser it can be confirmed that the main focus of this committee was to discuss two important issues:

1. The concept of "design to sustainability"
2. How sustainability can be implemented in the various regulations

The committee agrees with the discusser that the mandate was formulated for a wider range of topics. However, with respect to the composition of the committee and the available expertise there were made limitations in the scope of the report. It is suggested that the mandate for the succeeding committee should be narrowed down.

2.2 Reply to Floor and Written Discussions

2.2.1 Paul James

To answer the first question one can simply say yes, the answer to the second question is also yes. With regard to the GBS for tankers and bulk carriers it was mentioned during the floor discussion the initiative to develop the so called goal based standard was driven by one interest group that was mainly interested to force the classification societies to develop rules for two distinguished ship types with the objective to build more robust hulls. A proof for this statement can be seen in the general allegations against the classification societies that were published in the past. As an example refer to Gratsos and Zachariadis (2005). A further example that GBS can be developed for only one system is the recent development of the goal based guidelines on framework of requirements for ships' life-saving appliances at IMO. However, assuming that the discusser would prefer a more general approach the committee would agree that the goal based standards should cover more than only structures but also other operational systems aboard which is in line with the recent new developments at IMO.

With regard to the NATO naval ship code the committee admits that it did not review the respective development.

2.2.2 Richard Birmingham

The committee welcomes the supplementing remark.

2.2.3 Berend Bohlmann

It can be said that the development of the Common Structural Rules for Bulk Carriers and Oil Tankers was the easiest approach to fulfil the requirements of GBS. Even though a few individuals at that time thought about the development of risk based rules and the Safety Level Approach it has been the understanding of the classification societies from the very beginning that GBS would result in a common set of requirements for ship structures which only could be covered by a common approach of structural rules. The later progress of the discussion at IMO affirmed this early assumption.

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VOLUME 3

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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1 DISCUSSION

1.1 Official Discussion by Christian Cabos

1.1.1 Introduction

The committee has made Lifecycle Management (LCM) the central focus of this report. This is a well justified move, as this methodology is slowly finding its way into the shipbuilding and shipping industries. It is evident that there is commercial benefit for a ship owner to not separately strive for a low price of the new-built ship and then later to optimize maintenance costs. Rather, the total cost over the lifetime of the vessel, i.e. the lifecycle cost (LCC) must be of concern. In this respect Lifecycle Data Management plays a central role. Referring to Marrall *et al.* (2011): "*The consistent use of information, data and knowledge along the entire life cycle can drastically increase production performance and the competitiveness of all actors along the chain.*" Since after the warranty period, the newbuilding shipyard typically has no commercial link to the delivered vessel, the ship owner has the task to make sure that the design of his vessel and the choice of systems and components installed on it will lead to an efficient operation over the lifetime. The situation is further complicated by the fact, that a significant part of the operational cost is not covered by the owner but charterer of the ship.

The reviewed report gives a comprehensive overview about methods and software which are today applied in ship design and which have a lifecycle focus. The conduction of a survey performed by the committee members gives the report a solid foundation, even if a higher number of respondents to the survey would have been helpful. This review will try to add additional information on Lifecycle Management and its connection to design methods where this is possible. A particular focus will be put on Lifecycle Management in ship operation as this is less covered in the report. Each section of this review will refer to a corresponding section in the report.

1.1.2 Section 1. Introduction

The reviewed report gives a breakdown of the cost types making up Lifecycle Cost. In fact, there are numerous activities in the industry for reducing a single cost component in ship operation. Examples of these are given in section 2.1. Further examples can be added here, such as

- Services offered for energy optimization such as the Ship Energy Efficiency Management Plan (SEEMP), trim optimization or hull form optimization,
- Software for optimizing maintenance and repair,
- Procurement software for shipping companies,

which all contribute to reducing cost in a particular discipline. These are services and software aiding in ship operation directly. The market for such systems today is quite extensive and an overview on software supporting ship management and operation would be helpful and could be a mandate for a future committee report.

A publication covering such systems is e.g. Jahn (2011). Approximately 35 software providers today offer software for shipping companies, most of them covering only few of the relevant processes. Regarding fleet management –used here as the term for the comprehensive and integrated support for most of these processes through an integrated system– one must state that there is today a lack of such an integrated system.

Although the named software systems typically support the operational processes of a ship management company, they hardly follow the idea of lifecycle optimization

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which would require data integration and long-term analysis capabilities based on the information stored in this integrated model. This model would encompass technical as well as cost information. Such functionality would be the target of an ILCM system as described in section 2.1 of the report. An ILCM would in particular integrate cost models from design *and* operation. As described in the report, PLM would be the methodology supporting knowledge acquisition with regard to performance and cost of the ship and its systems and components over the lifetime.

Although actual cost information is typically difficult to obtain, there is some published information available concerning e.g. the breakdown of the operating cost of container vessels, see HSH Nordbank (2009).

1.1.3 Section 2. Design for Life Cycle

Section 2 takes up the subject of design for lifecycle. An Integrated Lifecycle Management System would be the tool to support optimization for maximal benefit in terms of safety, low environmental impact and high profitability. The disciplines to be covered are well described in the report, additionally cargo handling and voyage management systems should be mentioned as systems supporting ship operation. The reason is that cargo history e.g. can give valuable information concerning loads acting on the vessel during its lifetime which again can be used for fatigue assessments. Voyage data is e.g. helpful for computing a vessel's efficiency with respect to environmental issues. Systematic evaluation of such lifecycle data could then feed back into design of future vessels.

Section 2.2 touches the important aspect of passing information between design and operation. Here the GBS are named which set standards for the exchange of required information for the maintenance of innovative ships. As mentioned, it will only apply to bulkers and double hull tankers. Obviously, the need for more detailed information from design is already apparent, as ship managers are today requesting software and associated models for maintenance procedures based on the actual condition of the hull and systems and components for all ship types. This need is particularly pronounced for floating offshore installations. There, the direct cost for towing the unit to a repair yard and also the connected loss of income due to downtime is often significantly higher than in shipping. Innovative maintenance schemes are therefore requested and developed e.g. for FPSOs. Consequently, transfer of building information from design to operation is performed more frequently for offshore units due to owners' requests.

The building yard's IPR concerns must be balanced with the request for more detailed information on vessel design to be used during the lifecycle. IMO discussions on the SCF will set standards here. Nevertheless, the level of information passed from design to operation does significantly depend on the negotiations performed between the ship owner and the yard during contract phase.

As reported in section 2.3, drivers for ILCM are cost savings such as energy efficiency measures and maintenance schemes. Apart from positive environmental and safety effects, condition based maintenance schemes typically have more direct cost saving consequences. For machinery equipment, they are in particular due to avoidance of unnecessary inspection and maintenance activities, to avoiding component breakdown and to avoiding damage due to unnecessary open-up inspections. In the case of hull maintenance, also repair preparation –both concerning time and scope– can benefit from better information derived from inspections.

Other drivers for LCM in the emission field are industrial initiatives such as the Clean Cargo Working Group (CCWG), which represents a significant part of world wide

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container transport. The aim of this group is to make transparent the environmental impacts of global goods transportation through measuring, evaluating, and reporting. This helps ocean freight carriers to track and benchmark their performance and report it to their customers in a standard format. On the other hand, cargo owners (shippers) can review and compare carriers' environmental performance when reporting and making buying decisions.

An additional driver for LCM could be ship safety. E.g. capturing and tracing the status (expiration date, service letters, observed condition, ...) of onboard Safety Equipment such as Lifesaving Appliances will further help to ensure that this equipment is fit-for-purpose when it is needed.

1.1.4 Section 3. Available Design Methods

Section 3.3.3 refers to Design for Environment. With increasing awareness towards environmental issues the efficiency of design, maintenance and operational options with respect to e.g. CO_2 reduction have been examined in recent years. Although this is not directly a design method, it is a good example of taking the lifecycle impact into account for decisions on e.g. design/retrofit options. One such study is published in Appendix 4 of IMO (2009). It reports on the marginal abatement costs, i.e. the maximum achievable CO_2 reductions against estimated cost-effectiveness, for measures such as propulsion system upgrades, hull coating, main engine tuning, air lubrication, etc. It therefore helps to decide on technical measures from a lifecycle cost and performance perspective.

1.1.5 Section 4. Available Modelling and Analysis tools

This section summarises well available CAD and naval architectural packages. Clearly most vendors of such systems are following the path of integrating more analysis capabilities in their packages. Here figures about the actual application of these tools on yards and in design offices (such as market shares) would be interesting – but possibly difficult to acquire.

The typical strategy of CAD vendors is to offer some specific analysis capabilities integrated in their CAD package. Nevertheless, rather than investing too much in own analysis capabilities, interfaces to specialised analysis toolkits are the preferred development direction when aiming at higher coverage of analysis capabilities. Taking FE strength analysis as an example, vendors like NAPA and AVEVA have invested in functionality for either directly generating FE meshes or for preparing geometry output ready to be meshed by an FE-pre-processing package from another vendor.

Typically, the calculation of loads, the assessment of the FE strength analysis with the help of buckling, yield and fatigue codes, the dimensioning of the structure according to class rules is then left to specialised packages. In that sense, there is today no comprehensive CAD and analysis package covering all design aspects. Rather, the expectation is that the future development direction will be the manifestation of interfaces between such packages and the integration of software from different vendors. Currently, no standards appear to emerge for such interfaces but rather they are specific to the respective CAD and analysis tools.

With regard to future optimisation capability the expectation (and hope) is, that a central model held in a CAD package will hold all information necessary for such optimisation. An optimisation engine connected to the CAD tool would then control a number of external analysis codes. The challenges in developing such an integration of packages are still manifold. To name a few

1. The CAD model will require a significant amount of additional meta-information in order to pass this to the analysis packages. Examples are main dimensions of the vessel, design intent such as lifetime, loading, expected operational profiles, etc. If this information is not held in the CAD package but rather entered in the analysis software no automatic update of the analysis would be possible. CAD vendors work in this direction, but the multitude of analysis codes and lack of standardization in the sets of additional required analysis parameters makes this difficult.
2. The topology of the CAD model must be sufficient to allow for FE meshing. This in particular requires additional effort on the side of the person building up the CAD model. I.e., the training requirements for the CAD modelling staff is increasing significantly.
3. Analysis post-processing –and in particular rules for assessment– typically require a definite level of abstraction. E.g. finite element sizes and used element types must be in accordance with the assessment rules. Again training is necessary to allow proper application of analysis codes in an optimization run.
4. Volumetric CAD models (as opposed to surface models) add another level of complication, since FE analysis models typically require surface elements.

The result of this is that the maritime industry is still by far not in the situation that the required analysis capabilities can be controlled from a CAD package holding a model which covers all topology, geometry and required meta-information e.g. for optimising a structure with respect to seakeeping, fatigue strength, ultimate strength and also other disciplines from the Design-for-X catalogue. In particular, there are high additional requirements with respect to knowledge on the side of the person controlling such an optimisation as compared to the skills in CAD construction work expected today.

Since interfacing is a central topic in the above named strategy, a survey on current developments in this area (in particular any standardization efforts) would be an interesting subject of a future report.

The inventory of hazardous materials (IHM) is the subject of section 4.1.3. Although optimally already set-up with the delivery of the ship, the IHM could not be regarded as a design and analysis tool but rather a tool for supporting the operational phase of the ship. The name "green passport" should be omitted here, as it is not connected to the IHM. Another relevant development in this area is e.g. the CDX service offered by HP in the non-maritime field but which is carried over to the maritime industries.

The conduction of a survey to report on the state-of-the-art (as performed by this committee) is very helpful and it is a pity that not more companies replied to the call to answer the questionnaire. Results of the survey could be complemented by the results from a similar survey on Lifecycle Management in the maritime industries conducted in 2010 and reported in Cabos (2012). The result of the latter survey in shipbuilding was that adoption of PLM in shipbuilding is considered important to achieve higher competitiveness and is expected to promise a good Return On Invest (ROI). Commercial PLM solutions available today offer a lot of potential that is not exploited yet in shipbuilding because most companies are only in an early stage of adoption. The situation is different in the supplier industry where several of the equipment manufacturers belong to the early adopters of PDM and PLM technology.

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1.1.6 Section 5. Optimisation and Decision Support Tools

Section 5 reports on current optimisation and decision support tools. This part of the report is very comprehensive and this review will not be able to significantly add to its content.

1.1.7 Section 6. Product Lifecycle Data Management

Section 6 has a focus on the technology applied in the design phase and on the question on how information can be transferred to the operations phase of the vessel. It would of course be very relevant to also report here on tools and techniques for Lifecycle Management after delivery of the ship and on how information from operations phase is fed back into the design phase of new vessels.

In recent years, LCM techniques have appeared in several technical disciplines of ship operation. Lifecycle Management can be interpreted as a method for increasing the benefits of information gathering through efficiently making it available. This is done by connecting the information in a multitude of ways. Information is put in context from different views: in the system context, the fleet context, the temporal context, etc.

In this way a number of approaches which are finding their way into shipping can be seen as being parts of a Lifecycle Management methodology. Some of these approaches which have come up in recent years are

1. Hull maintenance
2. Condition based maintenance of ship equipment / machinery parts
3. Emission reporting
4. Damage databases leading to information regarding component reliability

It has to be noted although, that there is currently no integrated data management solution available which would cover all the named approaches in a single environment. Thereby there is no emerging integrated Lifecycle Management platform available in shipping. One implication also is that there is no systematic flow of information from operation to ship design. Nevertheless, e.g. for specific components, the manufacturers use experience from maintenance to improve component design or to adapt recommended maintenance schemes.

Maintenance in shipping is today in most cases based on the Planned Maintenance scheme. This means that inspection and maintenance activities are derived from a fixed number of running hours or elapsed time since the last inspection. Since the date of the next inspection does not rely on previous inspection outcome, no systematic storage of past inspection results need to be accessed. For that reason, current Planned Maintenance Systems (PMS) do not allow for a storage of this information such that automatic evaluation (such as trending) of the results of past inspections become possible. Typical data held by such systems are descriptions of necessary inspection activities, lists of components to be inspected, inspection dates and inspection outcomes (which might be free text). There is typically no connection of the inspected components in a PMS to its representation in the PLM system from the building phase.

It is the ShipDEX initiative which partly aims at closing this gap (in one direction) through providing information on component maintenance procedures from design phase to the operation phase. There is currently no standard however, to pass maintenance information back to design.

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In the case of hull maintenance, the first step of an efficient maintenance scheme is the passing of hull design information to the ship manager. As described in section 2.2 of the report, this is supported to some extent by the SCF required for bulk carriers and double hull tankers from 2016 onwards (although still mainly based on drawings). Currently hull information available in ship operation is limited to the drawings passed over to the ship manager by the yard. Additional information such as CAD models are only passed on in rare cases, in particular if this has been negotiated between yard and ship owner during contracting.

Similar to ShipDEX, a standard is emerging for passing on information on hull condition in the lifecycle. It is the OpenHCM format which is currently developed further by some classification societies, software manufacturers, and other stakeholders in hull maintenance, see also the ISSC report 2009 of committee IV.2 and OpenHCM (2012). Using OpenHCM, also hand-over of structural models from yard to ship manager could be standardized.

As can be seen from recent conference publications, the offshore industry is very active in promoting Integrity Management programs for their fixed and floating structures (in this case called Floating System Integrity Management, FSIM). Refer e.g. to Wisch *et al.* (2009) or other papers of that conference for data and document categories to be maintained over the lifetime of a floating structure for an effective Asset Integrity Management.

Subsection 6.2.3 reports on the results of the survey. This confirms that only in specific cases information is exchanged between design and operation today. Also, in many cases, native formats are being used. Shipbuilding STEP protocols are today hardly applied, at least in the European and Asian shipbuilding industries. This is different e.g. from the widespread use of STEP AP 214 in the automotive industry, so this standard might in future also find its way in to shipbuilding (as it is not specific to an industry).

XML formats are indeed increasingly being applied in the shipbuilding and shipping industries. Nevertheless, they should not be compared to a STEP standard, because the latter describes a data model, whereas XML is a format specification being able to hold data of any data model (with certain restrictions).

1.1.8 Section 7. Obstacles, Challenges and Future Developments

The survey findings, namely that AutoCAD, Excel and Rhino are the design tools in use in most cases, shows that there are still a number of steps to go on the way to an integrated PLM model of the vessel. The reason is that these general purpose tools lack any common data model (with the exception of geometry) being able to represent a ship during its lifecycle.

As described before, the major obstacle is in particular, that there is no such standard Lifecycle data model. So even while there are initiatives in certain areas, such as ShipDEX or OpenHCM for data exchange in the lifecycle, there is e.g. currently not a widely agreed standard for classifying the components, systems and structural parts of a vessel. While European yards often apply the SFI classification scheme, Asian yards apply different schemes and these are in the most cases not carried over into the operations phase of the ship. Such a classification system would have to be implemented in a data model being able to describe the ship and its components over the lifetime.

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Once such common classification schemes and data models implementing them become available, general purpose LCM tools could more easily be used to set up an integrated Lifecycle Management.

As mentioned in subsection 7.3, the automatic derivation of analysis models, in particular FE models, from CAD pose an obstacle to comprehensive optimisation in the design phase. For that reason current approaches focus on common parametrisation of the CAD and a semi-automatically generated FE model. Using these parameters, an optimisation can be performed. Although not giving the full flexibility, this seems to be a pragmatic approach which will be present for some years to come.

1.1.9 Section 8. Survey on IT Tools and Data Exchange

Comments on the results of the survey have been given in the above sections.

1.1.10 Summary

In the opinion of the reviewer, Lifecycle Management has rightly been chosen by the committee as the central subject of this report on design methods. Through interconnecting information (which might already be available today) future technology will help the industry to achieve cost benefits from a holistic, i.e. life cycle, perspective. The difficulty will lie in the changes of processes and procedures which are required to successfully apply such technology. For that reason, development and introduction of LCM as a methodology applied in the marine industry will accompany us for many years to come. Hopefully, future reports will report on its evolution.

Regarding today's situation, it would be helpful to gain more insight into the actual application of the reported technology on ship yards and also in the shipping industry. This was the intention of the survey, but due to the lower number of responses no clear picture yet emerges from it regarding a quantitative assessment of applied technologies. The situation is more difficult in shipping, since the survey did not cover ship management companies. A survey covering these stakeholders would be a valuable addition to a future report.

The committee has taken significant effort to report on the state-of-the art and future direction of design methods for marine structures. The reviewer would like to thank the members of the committee for successfully delivering this informative, very comprehensive and insightful document.

1.1.11 References

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1.2 Floor and Written Discussions

1.2.1 Masanobu Toyoda

With regard to lifecycle management data during lifecycle of a ship, it is considered that monitoring data after delivery, such as wave height, ship's speed, hull girder stress and cargo weight distribution, will be more important in the near future.

For instance, there are many ships and they have different route from heavy weather route to calm weather route. And some operators need to sail through a harsh weather with higher speed in order to keep their timetable, or some operators have enough time to reroute or wait to avoid rough sea. So wave load history and resulting cumulative fatigue damage on each ship would be quite different, and UK MAIB report on *MSC NAPOLI* accident mentioned the large effect of sailing speed under harsh weather and the difficulty to know accurate weight of each container. Therefore, these monitoring data will be beneficial to maintenance, second hand value, safety operation and feedback to design and rules.

I would like to know your opinion about the monitoring data mentioned above.

1.2.2 Igor Ilnytskyi

My congratulations to chairman Mr. Jean-Yves Pradillon and all Committee members for the very interesting report.

My first comment to Section 3.3.5. Design for Retrofitting and Refurbishment regarding problem of making passenger vessels more flexible to changes in the market.

For new generation of river passenger cruise vessel just on concept design study we apply general arrangements with functionally divided vertical zones:

- passenger cabins – "Hotel" zone with similar modular cabins on each verticals;
- restaurant/entertainment and recreation zones

When necessary in design stages or during operation of the vessel to change level of comfort due to changes on cruise market in future (to reduce/increase area of standard passenger cabin with changes of passenger capacity):

- Standard passenger cabin areas may be varied (in our case from $13\,m^3$ to $18\,m^3$) depending on required level of comfort. Passenger capacity of the vessel is correspondingly varied without changes of cabin's (hotel) zone borders;
- Restaurant/recreation zone have also constant borders – increasing/decreasing capacity of restaurants, saloons etc. and changes by specific area per passenger corresponding to the level of comfort (furniture changes);
- Fire protection zones and main hull structures and systems not necessary to change.

My second comment is to the Section 4.2.4 Computational Fluid Dynamics design method in application to ship design.

We agree that CFD tools require highly specialised engineers and high computational power. Really most of design bureaus and shipyards are not equipped with appropriate computer platforms and have not the necessary skilled staff.

We will see the solution of the problem in cooperation with design bureaus which are specialised on CFD tools.

Our bureau has experience of works with a design bureau specialised on CFD tools to have results of this cooperation on a very early design stage (concept design).

Using CFD tools instead of tests in a Ship Model Basin will allow to reduce time and design costs.

1.2.3 Adrian Constantinescu

First of all, I congratulate the committee for the great work and also for the presentation. During the presentation, Mr. J.-Y. Pradillon talks about HCM which stands for Hull Condition Model. The HCM seems to become the base (main) language implemented in Condition Monitoring software. It will be interesting to present more these kinds of software, and maybe to try to select a common format data (common language) based maybe on HCM for all Condition Monitoring software. It will allow the exchange more easily the maintenance and repair data between actors.

1.2.4 Ionel Chirica

A lot of terrorist actions and accidents due to human errors took place in the last decade.

The effects of these actions are very huge damages, so from point of view of human losses and of ship structures, why not the specific organizations as class societies, ship design companies and other organization did not introduce in the design philosophy new certain methods or methodologies in this topic?

The results of these activities can be certain coefficients aimed to penalise the scantling selections, or certain special risk coefficients.

These activities can have an important impact on the future ship design philosophy.

2 REPLY BY THE COMMITTEE

First of all the Committee would like to thank all the ISSC members, who provided the Committee with official, floor and written discussions, for their very aware, wise and interesting comments. From our point of view this is a strong sign to demonstrate that ISSC is really relevant and a "place to be" for the ship structure experts of the world.

2.1 Reply to Official Discussion

The Committee would like to specially thank Dr. Cabos for his Official Discussion. It is not only a cross check between the mandate and the report contents. It is rather a comprehensive complement of the report that provides the reader with several valuable additions.

Dr. Cabos agrees the Committee's choice to make the Life Cycle Management the backbone of the report. He does insist on the key role the LCDM (Life Cycle Data Management) will have in the very next future for all the stakeholders of the ship industry. We are convinced that LCDM is a main challenge for ship design in the next decades. We also agree that the meaning of "ship" in that respect must be taken as usual in ISSC reports: All structures at sea - including offshore platforms dedicated to Oil & Gas industry or Marine Renewable Energies (MREs). The rules and control authorities may vary from one sector to another but the final goal is the same in all cases: Reducing OPEX (even with a higher initial CAPEX), minimizing impact on human life and environment and taking the sustainable growth into account. In that respect we do agree that all life cycle management data gathered from ship operation is of a critical importance to support the report. We thank Dr. Cabos for the interesting references he provided the reader with in this specific area. The Committee experienced many obstacles to reach such data during the literature review, thus the data from Dr. Cabos is very welcome.

In the Committee's reply, we decided to select three main comments of Dr. Cabos regarding the ship operation:

- Regarding the need to assess and optimise hull form and trim together with ship performances, the Committee fully agrees and some ongoing projects deal with this topic at national and international funded levels in various countries.
- The need to get consistent data on real load conditions to help fatigue damage assessment is also acknowledged by the Committee.
  - Benefits from monitoring systems have already been highlighted in previous reports of this Committee.
  - MONITAS (International JIP project) is an example of an ongoing project
- The Committee agrees Dr. Cabos regarding his comments on relatively different way of undertaking LCM in shipping and offshore industries.
  - It is in turn very different with MRE and civil engineering at sea but with the same goal as already highlighted in this reply.

The Committee also would like to clarify what the Official Discusser tells regarding the difference between the Inventory of Hazardous Materials (IHM) and the Green Passport:

- Green Passport Inventory was the name of a recommendation in a resolution of IMO dated 2004,
- IHM is a requirement in the Hong-Kong Convention (HKC) adopted by IMO in 2009,
- IHM is analogue to his ancestor and is often referred as Green Passport,
- Officially, HKC entered in force mid 2010:
  - After having been ratified by 15 States,
  - Representing 40 per cent of world merchant shipping by gross tonnage.

Finally, the Committee would like to come back on three other comments from the Official Discusser review:

- STEP & XML
  - The STEP & XML standards were described so many times in previous TCIV.2 reports. The Committee found no significant advances to report.
  - Thus, the Committee decided to cover it only in pages 547-548 of the report.
- Reference to ShipDEX and OpenHCM
  - It is a very valuable comment: We recommend that this topic must be covered in the next TCIV.2 report.
- Not enough replies to the survey
  - The Committee regrets and also acknowledged so few replies.
  - Answers were difficult to get but are enough to show a consistent, even if incomplete, figure.

Once more the Committee would like to thank Dr. Cabos for his very valuable complement to the report. We do recommend the reader who wants to have a comprehensive view of the covered topics to supplement the reading of the report with the Official Discussion.

2.2 Reply to Floor and Written Discussions

2.2.1 Masanobu Toyoda

Dr. Masanobu Toyoda raises a very interesting point during the congress. He mentions the importance of various monitoring (and especially hull condition) to be installed on board on a systematic basis. This Comment is fully consistent with what the Official Discusser presents. The Committee fully agrees that this will help to get decision making tools for the crew to select the better route, a valuable data collection for maintenance purposes and critical information for retrofitting (i.e. conversion of a tanker into a FPSO). We also think that we will have to face the reluctance of the crews and owners to make such a valuable initiative a reality. From our point of view, the only way to get it in force is to let authorities (flags, IMO, ILLC, IACS. . .) to make it mandatory.

2.2.2 Igor Ilnytskyi

Mr. Igor Ilnytskyi provides a very interesting input on passenger ships dedicated to inland navigation. We agree that the two main differences with open seas passenger ships are:

- Rather different load conditions and then specific rules and associated hull design,
- A more versatile market leading to a specific way of design allowing latter changes several times during the product life,
  - Thank you for such an input which has not been covered in the report.

The Committee also thanks Mr. Ilnytskyi for underlining the present situation in using CFD tools. These tools need very experienced engineers to carry out reliable computations and the regular ship yards usually have not enough studies a year to justify a full time team in this area. This is the reason why many ship yards (all over the world as demonstrated by the survey) are still subcontracting such studies to specialized design offices. What the survey also demonstrated, when compared to a similar survey the Committee carried out for ISSC 2003, is that 10 or 15 years ago the ship yards also subcontracted the FEM analyses but conduct it internally nowadays. Do we have to expect the same progress for CFD? The question is raised.

2.2.3 Adrian Constantinescu

Dr. Adrian Constantinescu proposes the Committee to look HCM-based software more in details. It is a good idea to be included in the next report. As far as the new chairman of this Committee for ISSC 2015, Matthew Collette, is a member of this Committee for 2012, he will be the key person to get the link alive.

2.2.4 Ionel Chirica

Prof. Ionel Chirica wants to bear in mind of the Congress attendees that perils of the sea, especially terrorism acts, is not yet taken into account by ship designers for civilian ships and that the rules will probably change in the future to take it into account. The Committee fully agrees this comment. The rules continuously changed over the centuries to include new safety ratios to take into account better knowledge or new situations (switch from wood to iron, brittle fracture, buckling, fatigue analysis. . .). But it will be impossible to make the ratios larger and larger making ships to carry more steel than cargo. That the reason why, the Partial Safety Factors entered in force within the IACS members rules these last years. We are convinced that these new design criteria will be addressed in such an approach. The Committee would like to thank Prof. Chirica for raising this topic that could be addressed in detail in a future report of the ISSC TC IV.1 "Design Criteria" as an addition to what was discussed in the ISSC Specialist Committee V.1 since 2009. These reports discussed design criteria to be applied to the damage assessment after accidental events as well as accidental limit states.

2.3 Acknowledgement

The Committee would like to thank all the attendees of the Congress in Rostock for their attention during the session and for all the interesting and informal discussions we had during the breaks. Finally, the Committee would like to thank all the people who made ISSC 2012 a success and especially the Chairman Prof. Fricke and the Secretary Prof. Bronsart.

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VOLUME 3

COMMITTEE V.1

DAMAGE ASSESSMENT FOLLOWING ACCIDENTS

COMMITTEE MANDATE

Concern for the structural integrity of offshore structures exposed to hazards. Assessment of risk associated with damage, range of repair required and the effects of temporary repairs and mitigating actions following the damage. The hazards to be considered include hydrocarbon explosions and fires, wave impact, water-in-deck, dropped objects, ship impacts, earthquakes, abnormal environmental actions and possible illegal activities like the use of explosives and projectiles.

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1 DISCUSSION

1.1 Official Discussion by Preben Terndrup Pedersen

1.1.1 Introduction

It is apleasure to have been given the opportunity to serve as official discusser of the report of Committee V.1. As a long time member ISSC, I have been paying great interest into the efforts of ISSC committees in digesting new research results and presenting future directions for research and development of our fields of interest to the benefit of the maritime industry.

According to the mandate Committee V.1 should deal with assessment of risk associated with damage, range of repair required and the effects of temporary repairs and mitigating actions following the damage.

The report covers a wide range of hazards which can lead to structural damage, i.e. hydrocarbon explosions and fires, wave impact, water-in-deck, dropped objects, ship impacts, earthquakes, abnormal environmental actions and possible illegal activities like the use of explosives and projectiles.

With the mandate as background the committee decided that the focus of the report should be on:

1. Safety measures to be taken during the design phase and in case of accidents.
2. Assessment of the level of damage and of the residual strength of the structure.

To give a complete review of the advancements within these areas is a tremendous task and since this is the first ISSC committee to deal with these topics the committee has been forced to prioritise the topics to be included. As the committee will see there are only a few points where I disagree with the committee but there are a number of items where I would like to see further work to be done.

In addition to the review of published work the committee must be commended for carrying out a benchmark study concerning the response of stiffened plates subjected to hydrocarbon explosions.

1.1.2 General Remarks

Safety Measures to be Taken during the Design Phase

Risk analysis is a tool that is increasingly applied during the design phase in the marine and offshore industries to manage safety, health and environmental protection. For rational design of safety measures it is important to apply a comprehensive risk analysis, i.e. to estimate accident frequencies and to determine the probabilistic distributions of accidental loads given a specific hazard in order to perform rational consequence analyses.

Probability of Occurrence All the accidental damages considered by the committee are low probability, high consequence events. For this reason it is a challenge to develop procedures to estimate frequencies for the hazards such as those presented in the committee report.

From Table 1 it is seen that most of the structural analysis tools presented in the report can be considered as elements of comprehensive risk analysis procedures.

Except for the section on hydrocarbon explosions and fires the report gives very limited information on procedures for estimation of the probability of the different hazards and the load distributions given a hazard takes place. If this reflects the scarcity of research work in this area there are good reasons to recommend such work in the future.

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Table 1: Approaches for determining incident occurrence frequencies (from OMAE 2007-29760)

Approach	Main Advantages	Main Disadvantages
Statistics of incidents	Long been regarded as the only reliable sources	Limitation with incident reports, difficulty in application to the future
Expert opinions	Long been used when limited by data	Subjective
Predictive calculations	Predict unfavorable conditions, inexpensive	Targets known scenarios, limits choice of software/programs, restricted to occurrence probability
Comprehensive risk analysis	Rational, includes consequences	Relies on accident data for benchmarking

Risk Control Options The consequences of the hazards considered by Committee V.1 can be measured in terms of structural damage, the number of fatalities and injuries, the amount of material released to sea, the immediate impact on environmental resources, and the subsequent costs of restoration. An important part of a safety design procedures is to reduce these consequences by considering risk minimising measures or Risk Control Options (RCOs). That is, to include a combination of actions that reduces the frequency and consequences of accidents. Those assessing the risk normally prioritise Risk Control Options that are adopted to reduce the number of hazardous situations that may cause an accident. On the other hand, because the consequences of incidents are so serious for offshore structures, we must develop damage tolerant structural designs and develop consequence reducing arrangements, regulations and requirements.

The tools presented in the report are essential elements for analysis of damage tolerant structures. Future committee work could preferably also give attention to consequence reduction, i.e. possible RCOs for the different hazards.

Rules and Regulations Most design codes reflect a number of distinctive risk assessment steps in the design process. For instance API Recommended Practice 2A-WSD specifies the following assessment tasks for evaluating the events (fire, blast, and accidental loading) that could occur to a platform over its intended service life and service function(s):

- Task 1, assign a platform exposure category for the platform
- Task 2, assign risk levels to the probability of the event
- Task 3, determine the appropriate level of risk for the selected platform and event
- Task 4, conduct further study or analyses to better define the risk, consequence and cost of mitigation
- Task 5, reassign a platform exposure category and/or mitigate the risk or the consequence of the event
- Task 6, assess structural integrity if the platform is considered high-risk

In Section 15 “Design and Assessment Process” the committee has a section on Codes and Standards. For designers this is an important subject. A number of codes are mentioned. But no systematic listing of relevant codes is presented. For instance the above mentioned API code is not included in section 15.2 even if this code is often used in the industry.

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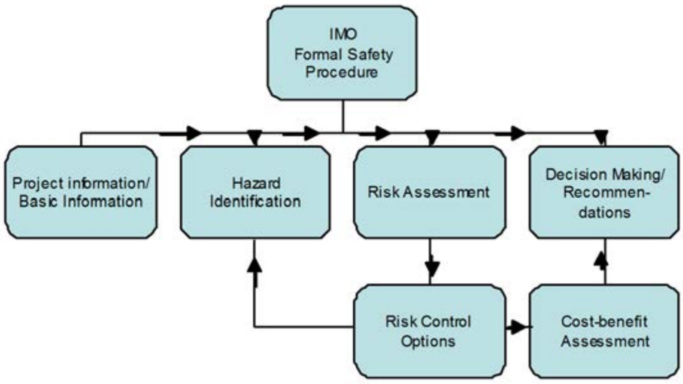

Figure 1: IMO's Procedure for Formal Safety Assessment

Perhaps the report could have summarised relevant codes in a tabular form to the benefit of designers.

It is my experience that for a consistent design process for safety it is of considerable value in a formal way to go through steps such as those from API presented above in order to document the procedure and to make a risk summary. A similar approach has been taken by IMO's Formal Safety Assessment procedure for evaluation of proposed new regulations. See Figure 1.

Assessment of the Level of Damage and of the Residual Strength of the Structure

When an emergency has happened on a platform the crew is often overwhelmed by tasks. There is little time and not often the expertise available to produce a residual strength assessment and safety evaluation onboard the platform.

For commercial vessels the concept of "Emergency Response Service" has been established to provide fact based assistance to a vessel in distress immediately after an incident.

Has Committee V.1 any thoughts about the use of the tools and procedures presented in the committee report to be applied as integral parts of a similar Response Emergency Service for offshore platforms to assess the level of damage and the residual strength of structures given an incident has happened?

After these more general remarks some comments will be offered to the sections on the specific hazards considered by Committee V.1.

1.1.3 Hydrocarbon Explosions and Hydrocarbon Fires

These two sections of the committee report focus on hazards involving sudden loss of containment, fires, explosions, or combinations thereof. Even though the theoretical foundation for the physical and chemical processes involved is reasonably well established, then the complexity of realistic offshore problems limits direct use of basic theory for predicting the outcome of potential accidents. Practical engineering solutions rely on empirical correlations or phenomenological models. The current up to date procedures are based on the use of computational methods for evaluating the relevant partial differential equations in the form of algebraic equations. However, caution should be exercised whenever computational (CFD) models are used outside their validation range. There are not many large-scale experiments suitable for model

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validation, and the quality of the available measurements varies significantly. Furthermore, the repeatability of large-scale experiments is rarely investigated. There is a need for further research within this important area.

It is obvious that design explosion loads derived from the worst credible event is far too large to be accommodated by any structure. Thus the focus of these sections has been on comprehensive risk based approaches as mentioned in the last lines of Table 1. Nearly all elements are touched upon. Quantitative risk assessments of the risk associated with hydrocarbon explosions and fire are still in its infancy and as the committee points out different analysts will often come to quite different estimates. But a thorough and critical review of the latest literature as presented here will help to standardize risk analyses in this area.

These two sections of the committee report give excellent reviews of current knowledge and are of value for designers of offshore structures. They give a good introduction to the physics of the problems where the different structural load mechanisms are described. Based on an overview of recent research, a probabilistic explosion risk model is presented together with design exceedance curves for overpressure. In these two sections the committee has managed to give a lot of information in a limited number of pages.

The only topic I could miss is a description of possible risk control options. But this could be a good topic to be included in a future committee report.

1.1.4 Underwater Explosions, Illegal Activities Like Use of Explosions and Projectiles.

It is not clear to me why Section 5 "Underwater Explosions"and Section 14 "Illegal Activities like use of Explosives and Projectiles" have not been combined. From a structural point of view these subjects are closely related.

The source of underwater explosions is often the result of acts of terrorism. For this reason it is of course difficult to make any probabilistic predictions on frequencies and load distributions.

The committee has chosen to describe different procedures to determine the structural response associated with different given underwater explosions. Unfortunately, most of the research results within this field are probably not available in the open published literature.

Design against structural damage due to underwater explosions could be a subject for further work by the committee. The analysis procedures reviewed by the committee have in the past been used to improve the failure resistance of underwater structures. For instance, after the USS Cole incident, research was initiated to find structural configurations which can sustain higher underwater explosion loads. Some of this literature has been published and the results can probably be used to design more explosion resistant structures.

1.1.5 Wave Impact, Wave-in-Deck, Freak waves and Tsunamis

Wave impacts and slamming loads at the underside of superstructures is different from the other hazards treated by the committee. These loads and their effects are considered in the normal design process for fatigue limit loads as well as for serviceability load effects. They are not normally considered as accidental loads. I assume that one of the reasons why the ISSC standing committee has included these subjects in the mandate has been to look for procedures for assessment of the residual strength of

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offshore structures subjected to damage from these loads and/or some guidance for emergence response for consequences of these load types.

Again it is not clear to me why Section 6 "Wave Impacts" and Section 11 "Abnormal Environmental Actions" have not been combined to one section.

1.1.6 Dropped Objects and Ship Impact on Offshore Structures

Together with hydrocarbon explosions and fire, ship collisions are among the most costly accidental loads. As stated in section 9.1 the offshore industry has a risk management concept for these accidental loads. For this reason it would be helpful for designers to get guidance for generation of an absorbed energy spectrum that shows the cumulative collision frequencies versus the impact energy generated by the collision. Such load and energy distributions are needed for rational consequence calculations. Again it does not seem reasonable to base the design against dropped objects and ship collisions on some deterministic worst case scenarios.

The probability of the occurrence of impacts due to dropped objects and collisions may be computed from historical data, expert opinions and predictive calculations as indicated in Table 1. Historical data provide realistic figures which nevertheless are difficult to use for future predictions since they are not relevant to offshore structures which may differ from those used today and they do not take into account the actual geographical location, the operational procedures, new navigational equipment, etc. For these reasons mathematical models for prediction of the frequency of hazard occurrence is an important first step for a rational risk assessment procedure for impact loads. Such probabilistic analyses must involve identification of a number of different impact scenarios, each one associated with a probability level. A number of frequency prediction models have been developed during recent years which together with external energy analyses can be used to determine probabilistic distributions of energy released for crushing of structures. The final step in that part of the risk analysis is then to determine the consequences given that an event takes place.

The focus of these two sections of the committee report is on analyses of consequences given that a well described impact incident has taken place.The Committee mainly concentrates on explicit FE-methods for consequence assessment of the large number of possible scenarios related to high energy impacts and structural configurations.

In addition the committee recommends basing the consequence calculations on an integrated approach where the external mechanics of the impacting ship (or dropped object) is solved together with the structural response analysis.

For comprehensive risk based analyses of damages to be expected due to ship impact I am not so sure that nonlinear explicit FEM simulations using coupled fluid dynamics always should be preferred. Even if significant progress in software and hardware has been made it seems to be an unattainable task to get the statistical consequence distributions needed for a risk based procedure by these coupled procedures. The loss of accuracy by separating collision problems into an external dynamic analysis and an internal analysis is normally quite small. The statement in Section 9.2 that in ship collisions mooring can give different external mechanics characteristics does not correspond to my experience.

Of course, for specific analyses of accidents that have taken place the proposed advanced analysis procedures are very relevant.

For future committee work within this area it is recommended that the committee reviews risk based assessment approaches which makes it possible also to evaluate risk control options in the form of increased crashworthiness of offshore structures.

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1.1.7 Flooding

The report includes a section on the effect of flooding on the structural integrity of a ship or a floating offshore structure.

Mitigation of the further consequences of ship-ship impacts is to day usually achieved by controlled flooding, i.e. through defining a certain distance between inner and outer watertight barriers, defining appropriate subdivisions for survival in case of flooding, appropriate arrangement of cargo and fuel tanks etc.

Two effects of flooding are considered in the committee report:

The first is the global effect on the hull girder. Here Figure 11 in the report shows the RAO for torsional moments of an intact and a damaged ship in beam waves. The choice to include this figure is somewhat surprising since hull girder torsional moments in FPSOs and other ship shaped offshore structures usually play a very small role for the overall stress level. It may have been of more interest to see similar curves for longitudinal bending moments and shear loads, even if analyses show that flooding does not normally increase the wave-induced hull girder sectional forces.

The second effect considered is sloshing loads in flooded compartments. This load type is similar to the sloshing loads from liquid cargoes. The latter may be of more concern due to the more frequent partial filling ratio conditions during normal operation.

1.1.8 Material Models for Structural Analysis

When Benchmark Testing and Joint Industry Projects involving advanced structural analyses are carried out then it is quite often found that the results deviate considerably and can fail to model the physical tests in a reasonable way. One reason for these poor results can be the material models used for the numerical calculations.

For this reason the committee must be congratulated for including a quite comprehensive section on material models.

The committee first gives a review of existing guidelines and standards. It is shown that these existing guidelines fail to provide clear guidance for material modelling to the analysts.

This section of the Committee Report is then followed up by a thorough discussion of properties for relevant materials such as steel, aluminium, foam, rubber, ice, air water, explosives, composites, soil, etc. The report even contains example input cards for the recommended material properties to a commonly used explicit finite element program. A section like this is new for ISSC, and I am sure that this will be used by structural analysts in the future.

1.1.9 Benchmark Study: Stiffened Panel Subjected to Explosion Loads

The committee has performed a valuable benchmark study where calculated structural response results are compared for a stiffened steel panel subjected to explosions loads using different numerical procedures. The benchmark is based on a full scale test experiment subjected to a hydrocarbon explosion load. The time variation of the deflections and the permanent plastic deformation of the panel are measured and numerically predicted by five different participants.

The benchmark study is very illustrative. It shows that even if the panel and the physical set-up is quite simple and the test conditions are such that fracture has been avoided there is a considerable scatter in the results.

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Adding to this spread in structural response results also the uncertainty in explosion load prediction in the current design process then it is obvious that much more work is needed before reliable procedures for damage assessment of offshore structures subjected to explosions hazards is a mature field.

1.1.10 Closure

Accidental loads on offshore structures cause loss of lives, economic losses, environmental damages and other unwanted events every year. It is indispensable that such hazards are considered to be so rare that the benefit of the operations to the owner and the public exceeds their sensitivity to risk. Therefore, one of the many performance goals during the design phase of offshore structures should be to ensure that serious accidents and service disruptions are low enough to be acceptable to all stakeholders, i.e. owners, the public and those responsible for public safety. On the other hand, the required risk levels should still allow construction and operation of these structures at feasible cost levels. To obtain this equilibrium structural damage assessment following accidents is an integral part of any risk assessment and serves to evaluate consequences of different hazards.

That is, the procedures and tools reviewed by Committee V.1 are essential tools for balanced design against hazards and for estimation of survivability after incidents have taken place.

The committee must be commended for presentation of a very valuable overview of different hazards for fixed and floating platforms, an excellent review of design principles for hydrocarbon fires and explosions, a new and rather complete material model database, and a benchmark study of the response of a strength element subjected to explosion loads.

Hopefully the Standing Committee decides to continue this committee for another three year period. During a coming term the committee will have a chance to place more focus on procedures to estimate the probabilities for the different hazards, to probabilistic distributions of the associated accidental loads, to recommend Risk Control Options for the different hazards, to give a schematic overview of current regulations and recommendations, and to include a final section which gives advice on needed future research and development to improve safety.

1.2 Floor and Written Discussions

1.2.1 James Underwood

Section 5 refers to three incidents of either UNDEX or surface explosions. In fact all three are the result of surface explosions alongside or from within the vessel. The same events are used again later in section 14, where it is clearer that none were damaged by UNDEX. Section 5 is entitled "Underwater Explosions" and I believe it is misleading to include these examples here. The most obvious source for examples of UNDEX damage would be military conflict torpedo or mine strikes. Possible examples include sinking of merchant vessels attempting to reach the UK during WWI, strikes during the Pacific War post WWII; sinking of ARA GENERAL BELGRANO, 1982.

Section 11 refers to a Wikipedia reference for defining freak waves. More recognized references are listed below and may be more appropriate.

Kharif and Pelinovski (2003): The amplitude criterion of freak waves: its height should exceed the significant wave height in 2 – 2.2 times.

Clauss (2002) presents published wave data where $H_{max}/H_s > 2.15$.

Bennett *et al.* (2002) utilises the assumption that the freak wave height is at least twice the average wave height for experimental investigation of freak waves on ships.

In Section 13.1, it is noted that information on the effects of flood water on the loads seen by a vessel is not very extensive. Although not currently published, PhD research work being undertaken by Mr Daniel Fone at UCL (University College London, UK) under the supervision of Dr Kevin Drake may add to this area in the near future.

1.2.2 Mirek Kaminski

My question refers to Figure 28 of the report. It seems that in all cases, the frequency content is the same. This indicates that the stiffness and mass were modelled in the same way. A good practice is to carry out a non-linear, transient analysis step-by-step in order to understand the source of possible differences. My question is if the committee did a step-by-step analysis e.g. by carrying out first a quasi-static response. If so, was the difference already present at this level of analysis?

1.2.3 Kristjan Tabri

Figure 28 in the report presents significant difference between the simulations conducted by different parties even though often the same software is used. Is the difference due to the different application of loads or is it rather due to this response?

1.2.4 Erkan Oterkus

Finite element analysis is not a suitable tool for failure analysis and damage analysis, because of its mathematical structure. There are some available tools such as VCCT, cohesive zone model, X-FEM, etc. These techniques are either questionable or require very talented engineer. Even the Abaqus cohesive zone element implementation is not accurate. I personally recommend a new technique called "perdynamics" which is a natural way of doing failure analysis. Although it is a new technique, it has been used at Boeing, Sandra National Laboratories, etc.

1.2.5 Enrico Rizzuto

While complimenting the Committee Members for their work, I note that, in my view, they concentrated more on the phases of the damage generation (and the preceding ones) more than on those following the accident and generating consequences. The name of the committee is a bit misleading in that, but the text of the mandate covers also the phases following the accident, containing an explicit reference to risk assessment.

Prof. Tendrup Pedersen in his official discussion pointed out the need for a probabilistic characterization of loads at accident to assess risk. My point is that, to assess consequences (i.e. the other 'ingredient' of risk assessment) it is also needed to identify the scenarios in which the postaccident situation may evolve. This would imply to characterize, in addition to the damage, also other relevant parameters (and inherent probabilities). For example: duration and severity of the exposure to sea loads (after the accident), the wind and its direction, the residual capacity of operation of the unit, etc.

These scenarios are quite important from a design point of view and it is crucial that they are identified as those generating the larger risk contribution for the system under analysis. An inadequate selection may result into checking unrealistic situations (possibly with low probability of occurrence and therefore non-significant contribution to risk).

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The definition of these design scenarios could be the result of an overall risk assessment, comparing different escalating situations and identifying those contributing more to the total risk for the system. May I ask if the Committee supports this viewpoint?

1.2.6 References

Bennett S, Hudson D, Temarel P. (2012). A comparison of abnormal wave generation techniques for experimental modelling of abnormal wave-vessel interactions. *Ocean Engineering*, Vol. 51; pp. 34-48.

Clauss G. (2002). Dramas of the sea: episodic waves and their impact on offshore structures. *Applied Ocean Research*, Vol. 24; pp. 147-161.

Kharif C, Pelinovsky E. (2003). Physical mechanisms of the rogue wave phenomenon. *European Journal of Mechanics - B/Fluids*, Vol. 22, Issue 6; pp. 603-634.

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

2.1.1 Introduction

The Committee members wish to thank Prof. Pedersen for his efforts reviewing the report, his helpful comments and his kind remarks.

The report covers a wide range of hazards which can lead to structural damage. To give a complete review of the advancements within these areas is a tremendous task. The Committee has been forced to prioritise the topics to be included and its members agree that there is a lot of further work to be done.

2.1.2 Safety Measures to be Taken During the Design Phase

In the last two decades risk analysis has become an advanced engineering tool. In offshore development projects it plays a key role in joining identification of hazards and guidelines for design against these hazards.

2.1.3 Probability of Occurrence

The Committee members agree that except for the section on hydrocarbon explosions and fires the report gives very limited information on procedures for estimation of the probability of the different hazards and distributions of the loads involved. Only very limited information on the determination of probabilities for other hazards than hydrocarbon explosions and fires currently is available. Therefore, Prof. Pedersen's recommendation to focus on such work in the future is supported and welcomed. This committee's focus was on damage assessment following accidents rather than on the estimation of probabilities of different hazards.

2.1.4 Risk Control Options

The problems associated with risk control options raised by Prof. Pedersen are an important observation. These issues should be included in a next committee mandate in the future.

2.1.5 Rules and Regulations

As for design codes specifying assessment tasks for evaluating accidental events, it is agreed that the risk assessment steps mentioned by Prof. Pedersen are useful for the designer, and they are also part of the ISO 19902 standard which is thoroughly reviewed in the Committee's report.

Recent international development is to use semi probabilistic design standards such as ISO 19902 and Norsok N-004, while the use of WSD standards is discouraged. This is also reflected by API which now uses the ISO 19902 standard with additional national information as their API LRFD standard in an API wrapper, and further by their decision to discontinue the API WSD design standards.

Recommending certain design standards over others will always be somewhat subjective. However, the committee has carefully reviewed and commented on the Norsok N-004, and in particular ISO 19902. These are the committee's recommended design standards for fixed steel offshore structures. Generally, the recommendation is to use the ISO 19900 series of offshore standards whenever relevant.

It is agreed that the IMO procedure for formal safety assessment presented by Prof. Petersen can be a useful tool for the designer. It is interesting to notice that quite a similar procedure is recommended in ISO 19902 but in a somewhat different context (Clause 23 In-service inspection and structural integrity management).

Additionally, the fact that the suggested risk assessment steps are an integrated part of risk assessment and are based on national laws and regulations irrespective of design standards cannot be overlooked.

2.1.6 Assessment of the Level of Damage and of the Residual Strength of the Structure

Residual strength assessment and safety evaluation is not carried out by the crew onboard platform because, as Prof. Pedersen remarked, there is no time for it in case of accident. It is the platform operator who assesses the damage based on the engineering resources from the design phase. It needs to be verified if the accident has been covered by the design hazard report. In case of larger accidents the structure is probably damaged and the crew evacuated, and the focus must be on the possibility of saving it or the necessary repairs.

2.1.7 Hydrocarbon Explosions and Hydrocarbon Fires

The Committee agrees with Prof. Pedersen about the need for large-scale experimental sites providing computation model validation.

As for the problem of discrepancy between the contractor dependent estimates that different analysts come to, more benchmarking needs to be done to verify differences and standardize quantitative risk assessments of the risk associated with hydrocarbon explosions and fires.

2.1.8 Underwater Explosions, Illegal Activities Like Use of Explosions and Projectiles

It was the Committee's opinion that Section 5 “Underwater Explosions” and Section 14 “Illegal Activities like use of Explosives and Projectiles” should remain separate due to the added load possibilities from terrorist events. It would be highly unlikely that an UNDEX event would be used in a terrorist attack. The more likely attack would be in the way of an air blast or a surface blast, as was used on the USS Cole.

Frequencies of underwater explosions are very difficult, if not impossible, to accurately predict. However, the load distributions could be determined from a series of analyses with various charges and standoffs. It is true, though, that the sources of an underwater explosion could be numerous especially in offshore oil platforms, as was seen with the Deepwater Horizon. It is very unusual that a terrorist attack would include an UNDEX event, surface would be the most probable with fast crafts or air blast.

Describing procedures to determine the structural response associated with different given underwater explosions is challenging due to limited literature, but not impossible. It is a concern that the experimental results are fairly limited. However there are

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several sources, such as DRDC which will, and has, openly published experimental results in journal papers and reports. There has been very few UNDEX experiments pertaining to definite structures, such as ships or offshore platforms, and they are generally performed with plate and panel specimens. This is mainly due to cost and environmental considerations.

The Committee supports Prof. Pedersen's view that design against structural damage due to underwater explosions could be a subject for further work by the committee. There is a move toward looking at stiffened panels in different configurations. Stiffeners can actually reduce the UNDEX resistance of a panel and this is an area which could be further developed.

2.1.9 Wave Impact, Wave-in-Deck, Freak waves and Tsunamis

The Committee has not seen it as a central matter to decide whether the wave impact (mainly floaters), wave-in-deck, freak waves and actions from tsunamis should be presented in one or two sections. The thinking behind using two sections in the Committee's report has been that freak waves and actions from tsunamis represent a special group of potential hazards characterized by the most immature understanding. However, the Committee may consider merging the two sections in future work.

2.1.10 Dropped Objects and Ship Impact on Offshore Structures

The load assessment follows a case-by-case risk analysis, which certainly includes a probabilistic assessment. However, due to the page limit of the chapter only the overall procedure and the available tools are presented, as well as conservative measures to treat such events.

Concerning the ship impact only the analysis relevant steps are presented as well as a discussion on the complexity of the event and the need to analysis all phenomena involved unless it is known that certain aspects can be neglected. The chapter does however not claim that the worst case scenario needs to be analysis, moreover this is typically not know and therefore it shall be identified in order to design the structure against the most probable actions.

The focus of this section lies with the as accurate as possible assessment of the incurred consequences considering the relevant effects. Hence, an integrated approach should be favoured over the uncoupled simulation, especially because a fully coupled dynamic collision simulation can be run using LS-DYNA in a couple of hours today. However, simplified procedures will be needed for a while to limit the amount of high-fidelity assessments as much as needed. Consequently, this will allow the identification of the highest energy scenario and thereby allow designing the structure for the most probable actions, which must not necessarily be the highest energy case.

The Committee supports Prof. Pedersen's suggestion that for future committee work within this area it is recommended that the committee reviews risk based assessment approaches which makes it possible also to evaluate risk control options in the form of increased crashworthiness of offshore structures.

2.1.11 Flooding

The Committee reports the RAO for torsional moments of an intact and a damaged ship in beam waves and torsional loads, according to Prof. Pedersen, usually play a very small role for the overall stress level on hull girder. However, a reference was found which reported a significant change of the hull girder load especially with respect to the torsional moment. The Committee would also like to state that in case of a

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severely damaged structure the cross section of the hull girder, in way of the damage, loses its 'closed cell' properties and may therefore become more vulnerable to torsional loads.

Another effect of flooding considered in the report is sloshing loads in flooded compartments. The Committee considered it interesting to report on these as in some flooding cases it may be beneficial to deliberately flood an additional compartment in order to improve the hydrostatic stability of the ship or reduce the still water hull girder loads. When this involves a relatively large compartment, e.g. an engine room, apart from the water head on bulkheads the dynamic effect due to sloshing is worth considering because it may significantly increase the momentary load on such bulkheads. The importance of sloshing in partially filled cargo tanks, marked as worth consideration by Prof. Pedersen, is acknowledged in the report.

2.1.12 Material Models for Structural Analysis

The Committee thanks Prof. Pedersen to clearly outline the potential of using material models in numerical simulations. The intended purpose of this section was to provide structural analysts with example input cards for the recommended material properties to a commonly used explicit finite element program and the Committee hopes that it will find its users.

2.1.13 Benchmark Study: Stiffened Panel Subjected to Explosion Loads

Recently a significant amount of time and money has been spent on risk assessment and a number of studies document explosion and fire loads. The knowledge in this field today is complete and precise. In the same time design processes are very much underdeveloped and in most cases use rough and imprecise techniques – linear tools. The Committee observe that the gap between accuracy of predicting loads and predicting structural consequences of these loads.

The Committee concludes that work needs to be done to control consequences of accidental loads in design process and improvement of design tools.

2.1.14 Closure

The Committee fully supports Prof. Pedersen's view that the work needs to be continued, with the mandate shift from the assessment of damage after accidents to damage prevention by the implementation of risk analysis results into structural design. There is still a lot of work to be done in the field of hazard engineering.

2.2 Reply to Floor and Written Discussions

2.2.1 James Underwood

The examples of USS Cole, Superferry 14 and Limburg are mentioned clearly as surface explosions in the first sentence. The Committee do not suggest that these attacks were underwater detonations, they are solely mentioned in order to stress the extent of capability on behalf of the perpetrators; their modus operandi. The remaining part of the first sentence says: "...very likely to predict similar attacks on offshore structures and platforms" in order to bridge the introductory sentence with Par. 5.1 where the reader embarks on the specifics of UNDEX. Detonations at the waterline and below the waterline (at close proximity only) share similar characteristics, like cavitation, brisance, and focusing, hence the aforementioned examples in the introduction. If perpetrators can get close enough to the target to detonate at the waterline, it is fair to say that UNDEX is well within their capability although it is much more complicated to deploy hardware underwater. It is believed that this scenario would likely include SCUBA divers who would attach the explosive charge to the hull/leg. It is difficult to imagine perpetrators towing a mine as these are bulky and difficult to transport. Failed attacks where the dingy sank under the weight of its own explosive charge have been reported.

Examples where naval vessels were hit and sunk by limpet mines or torpedoes are numerous, but they were not included here as the focus of Committee V1 is on damage assessment following accidents. Acts of war are not accidents. Some may even argue that the attack on USS Cole was not a terrorist attack as explosive loads are among the design loads of warships.

The Committee wishes to thank Mr. Underwood for additional references regarding the freak waves and flooding.

2.2.2 Mirek Kaminski

Finite Element models used in the study (developed by all members separately) were based on the same 3D CAD model ensuring the same stiffness and mass of the models. The step-by-step approach/benchmark study performed is presented in the report. Static analysis was carried out to document sensitivity to different FE sizes. This was not reported in the benchmark study presentation.

2.2.3 Kristjan Tabri

For the same solvers used in the benchmark study, the differences in transient and final deformations are mainly due to different approximation of pressure load and slight differences in the boundary conditions applied.

2.2.4 Erkan Oterkus

The Committee wishes to thank Dr Oterkus for his comments. Establishing specialised committees to further investigate advantages of this new method and report results to the ISSC will be suggested.

2.2.5 Enrico Rizzuto

The Committee wishes to thank Prof. Rizutto for his comments. All the comments and suggestions are supported by the Committee.

Indeed, Committee on Damage Assessment Following Accidents was mainly concerned with damage that can be controlled during design phase. In order to assess and quantify the effects of different hazards a Quantitative Risk Analysis is carried out that delivers Design Accidental Loads. These loads form basis for damage control and ensuring required residual strength. During accidents loads are rather undefined and the extent of damage is normally assessed by accident investigation. The requirements and scenario to be considered for the post-damage strength such as duration and severity of the exposure to sea loads (after the accident), the wind and its direction or the residual capacity of operation of the unit have recently been defined by design standards like ISO, Norsok or DnV.

We support the view that the post accidental loads scenarios could be assessed within the total risk analysis of structures. This concept has been successfully implemented into the design process of offshore installations. However, for the ship structures we still need international consensus for implementing these methods into design.

The Committee wishes to thank Prof. Rizutto for additional references for the subject.

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VOLUME 3

COMMITTEE V.2

NATURAL GAS AND TRANSPORTATION

COMMITTEE MANDATE

Concern for the safety and design of containment systems for the storage and transportation of natural gas in connection with floating platforms and terminals, and on board ships. This is to include assessing the performance of various containment systems for gas under compression (CNG), liquefaction under cooling (LNG), and combination of the two methods. Particular attention shall be given to the integrity and safety aspects of containment systems under pressure and thermal loads, and the interaction between fluid and structure under static and dynamic conditions. Needs for revision of current codes and regulations shall be addressed.

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1 DISCUSSION

1.1 Official Discussion by Marcos D. Ferreira

1.1.1 Introduction

It has been a great pleasure the opportunity to serve as the official discusser of this Committee V.2. The Committee members have written a very throughout and comprehensive report addressing a multitude of aspects involved in the natural gas storage and transportation activities.

I will review the subjects in the same order that the chapters were presented in the report and include comments, my personal point of view, and suggestions that I consider relevant and should have been addressed in this review. All sections were commented and suggestions proposed, but not for all subsections, as some of them have recommendations that I considered already established as a current practice and needed no further comments.

1.1.2 Background

By showing the safety records of the LNG industry, was clear for the reader that this market can be considered safe, in fact with a much better safety record than general ship transportation. The difficulties associated with the large increase of the fleet during the last ten years and the impact this may have in order to keep the crew well trained and the fleet maintained at the same high standard among a multitude of LNGC operators were also well pointed. LNG handling difficulties associated with future offshore operations and the use of LNG as fuel was also anticipated. These comments motivated remarks that I will present in section 3.3 (Operation and Human Error).

When the committee identified the LNG markets and trends, the FLNG near future possibility of use was pointed but existing challenges, mainly associated with the offloading operations related to the FLNG unit could have been mentioned. I will detail this point in the discussion of section 4.2 (Floating LNG, FLNG, and Floating Storage and Regasification, FSR, Units).

1.1.3 Safety and Design

In the description of this section it could be mentioned that LNG is not the only available choice for gas transportation, as there is the CNG (compressed natural gas) alternative, as well as other approaches like the so-called CGL (Compressed Gas Liquids), described for instance in ABS Editor (2008), and proposed by SeaOne, where a hydrocarbon solvent is added to the natural gas stream after it is cleaned of impurities. When this mix is cooled down to -40 degrees Celsius and pressurized to 1400 psi, it will liquefy. Nowadays the market sees the LNG solution as the most attractive approach for ship transportation, and therefore should have the focus of the research, but the other existing possibilities could have been mentioned.

Cargo Containment Systems

As the committee report details the existent cargo containment systems, it could have mentioned the difficulties associated with inspection and maintenance for some of the concepts. As an example, the FLNG unit concept using membrane tanks as its CCS would require concept changes in the original membrane tank design to allow their offshore inspection if a small leakage is identified in the primary barrier. The installation of scaffoldings inside this type of tank in an offshore environment would not be a simple task. There are proposals of articulated arms that would enter the tanks transporting workers for the execution of the needed tasks, but this solution would probably use deck area that would not be available in the middle of a liquefying plant. Suggestions regarding possible solutions would be welcome.

Another issue may be identified also with inspection and maintenance for some of the CCS presented in the report for the CNG alternative. A Coselle system would not allow a human inspection to be carried out, and fulfilling all inspections using special instrumented pigs is not yet a common practice, nor an established approach.

Unrestricted Filling

The reason there is a restriction regarding the CCS usage at any filling level is to avoid, or at least mitigate, the possibility of sloshing occurrence. In my opinion this item would be better located inside the "Sloshing" section.

As mentioned in the committee report, the use of large tank dimensions that arrive from the membrane concept will increase the exposition to the sloshing phenomena, and it could be added that the membrane tank designer (GTT) now proposes different levels of reinforcement to be used in order to stand higher impact loads and allow unrestricted filling, but this has yet to be approved by the classification societies.

Operation and Human Error

This is an important issue many times neglected in our industry. Operators in general do not enjoy exposing their incidents or assume that an improper behaviour may occur during the conduction of specific operational tasks. Sometimes even from one unity to the other of the same operator fleet, we may find different procedures for the conduction of similar tasks.

In the oil industry, there is today a JIP (Joint Industry Project) being conducted by Marin called "Offloading operability 3" where the focus will be not only on the measurement of real time metocean conditions and the FPSO and Shuttle ship responses, but also to follow the crew behaviour and choices taken during simulation sessions and possibly also during the real operation. This sort of initiative can lead to an identification of the amount of training that should be required for the crew, as well as a discussion (through debriefing sections) of the actual procedures and possible alternatives for conducting these operations.

A similar initiative could be planned in order to better understand the human activities during the FSRU operations. In the near future, this approach would also be carried involving FLNG operations. Training requirements would be a possible manner to enforce an adequate operational response from the units personnel.

Structural Integrity Management

There are activities in the oil industry regarding the life cycle management of FPSO structures (LCM JIP, as a recent example conducted by the main Classification Societies with participation of many operators), looking for possibilities of a rationalization of regular inspections and required maintenance of existing FPSO structures (mainly analyzing the impact of corroded structures and the possibility of crack management instead of repair).

This sort of approach may be tried in connection to FSRU's and in the future FLNG world. Today there are no FLNG units in operation, so for now it will only be possible to plan how similar programs may be developed until the experience with respect to FLNG structural response starts being built.

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Sloshing

If unrestricted fillings are allowed, wave induced vessel motions will excite liquid motions inside their tanks. Today there are three tank types used as CCS in the LNG transportation by ships. The SPB technology allows the use of internal bulkheads, and sloshing occurrence can be prevented or mitigated. Moss type tanks have a spherical geometry that allows the liquid to sway without causing large impacts on its walls. It should be mentioned that this internal liquid motion will cause cyclic loads on the tank supports, and fatigue stress should be checked for these conditions.

As pointed in the committee report, the motions of fluid inside internal tanks will have significant effects on the dynamic response of the vessels in waves, mainly if the LNG has tanks with large dimensions (as the membrane type in general), partial fillings, and their sloshing critical periods lie in the range of the unit natural periods. This coupled problem has been studied by Kim (2001) and Rognebakke and Faltinsen (2001, 2003) among others, with nonlinear analyses of the interior flow in the tanks, and by Molin *et al.* (2002) and Malenica *et al.* (2003) using linear analyses. The tank dynamics are computed separately from the exterior radiation and diffraction problems. Combining the hydrodynamic forces for the tanks with the floating unit hydrodynamic coefficients and exciting forces, they could solve the coupled equations of motion.

The free-surface panel code Wamit was extended as described by Newman (2004, 2005) in order to analyse the coupled liquid in tank / unit motions, using a more unified approach where the interior wetted surface of the tanks are included as an extension of the conventional computational domain defined by the exterior wetted surface of the body. The same exterior free surface Green function is used for each domain (tanks and exterior flow), with vertical shifts of the coordinates corresponding to the free-surface elevation in each tank. The main advantages of this approach is that any tank geometry can be easily represented by flat panels, and that this representation is the only requirement for carrying the analysis, with no necessity of determining the displacement modes of the internal free surface with periods in the same range of the floating unit responses. In Newman (2004, 2005) a comparison is made between the use of this approach and model tests and computations presented by Molin *et al.* (2002) for a barge with two large internal tanks with rectangular cross sections in both longitudinal and transversal directions.

Table 1: Main Dimensions of Barge with Two Internal Tanks, with a description of the Loading Conditions 1 and 2

Description	Condition 1 (m)	Condition 2 (m)
Barge length	3.0	3.0
Barge beam	2.0	2.0
Barge draft	0.108	0.108
Tank1 length	0.25	0.25
Tank1 beam	0.8	0.8
Tank1 depth	0.19	0.19
Tank2 length	0.25	0.25
Tank2 beam	0.8	0.8
Tank2 depth	0.19	0.39

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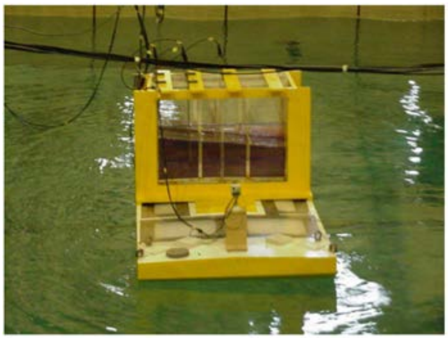

Figure 1: The reduced model used by Molin to compute the coupled motion of liquid and barge. Representation of loading condition 1.

I will present some of the results obtained, in order to claim that this is the best approach for the determination of the coupled response for a wide range of incident wave periods. The main dimensions of the barge and internal tanks are defined in Table 1 for the two conditions simulated. In the first loading condition the two internal tanks have the same filling ratio, and as the tests were performed for beam sea waves, the tanks will present the same response. For the second loading condition, one tank will have a higher filling ratio and we can see a more complex system response.

The barge used in Molin's model tests is shown in Figure 1, for the condition 1, when the two internal tanks have the same filling level. For the tests performed the tanks were located on the deck of the barge. It is easy to notice that the liquid inside both tanks behave in the same manner, as if the test was performed with only one tank.

The roll responses of the ship are presented in Figure 2. It can be observed that the tank acts as a dynamic absorber for the roll motion of the barge, and the roll RAO now presents two peaks instead of one, as it would be expected for the uncoupled barge roll response. The comparison shows experimental results against Molin and Newman linear numerical results, and it can be observed:

- The peaks obtained from the linear numerical computations are in close agreement with the model tests, presenting similar amplitudes. The model tests also

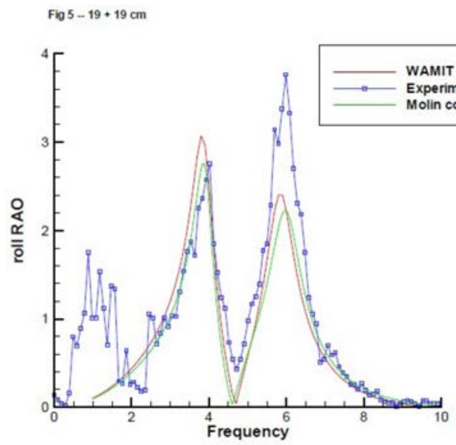

Figure 2: Coupled roll response of the barge (degree/m) under the influence of the liquid motion in the tanks. Loading condition 1.

present some response at lower frequencies, which could not be recovered by the linear simulations, but low frequency vessel motions are not responsible for the most critical sloshing loads.

- These numerical simulations based on potential panel codes are much faster then non-linear CFD computations, and can show the influence of the coupling of the internal liquid motions and the ship dynamics. Linearized damping can also be added to the liquid motions and vessel responses, if needed.

Another loading condition, when the two internal tanks would have different filling levels, was also considered using this approach, and this new arrangement can be seen in Figure 3.

Under this situation, the liquid inside the two tanks will present different resonant periods, leading to a more complex situation for the unit roll response, which will present three response peaks. A similar loading condition can easily occur for the case of a FLNG with large internal tanks, or for a LNG carrier while receiving the LNG load from the FLNG.

Figure 3: The reduced model used by Molin to compute the coupled motion of liquid and barge, representing loading condition 2.

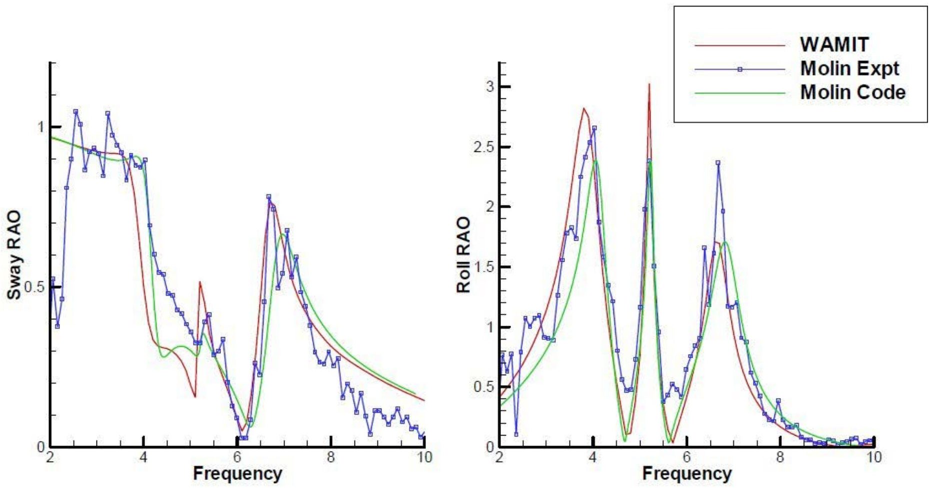

Figure 4: Coupled sway (m/m) and roll (degree/m) responses of the barge under the influence of the liquid motion in the tanks. Loading condition 2.

It can be observed from the results shown in Figure 4 for the sway and roll motions, the good agreement between Molin approach representing the liquid motions by its resonant modes and Newman approach representing arbitrary tank geometries extending the panel method, and that both codes show good comparison against the model tests.

From these comparisons and the nonlinear CFD simulations presented in the literature and summarized in the committee report, it can be concluded:

1. CFD nonlinear simulations have improved in the last years and give great contribution for a better understanding of the flow characteristics and computation of the impact loads.
2. Performing uncoupled ship motions computation and using the RAO to obtain the movements of the tanks for a posterior nonlinear CFD simulation of the internal liquid motions is not adequate, as these liquid motions have large influence on the ship responses.
3. Carrying coupled ship time domain and CFD nonlinear analysis is time consuming and in many cases will be a difficult task for obtaining good convergence of the overall coupled motion response.
4. The best approach would be to solve the linear coupled problem and as this analysis can give reliable results in the wave excitation range, select the possible critical cases with respect to extreme ship motions (in general sway and yaw). For these selected cases a nonlinear CFD analysis can be performed and results compared to further validate the linear approach.

Also mentioned in the report was the need for a better understanding of the local flow behaviour, through drop tests and breaking waves in a flume. In this context, the ISOPE 2012 conference presented an extensive programme entitled "Sloshing Dynamics and Design", from which interesting papers can be selected, contributing to a better understanding of the sloshing impact phenomenon. In particular there were articles in connection with the Sloshel project, as Lafeber *et al.* (2012b,a), that defined elementary loading processes (called ELP) that could describe the local effects, and could be defined as (ELP1) the direct impact characterized by an instantaneously loaded area, the subsequent (ELP2) building jet along the structure and finally, when there is entrapped air, the (ELP3) compression of this entrapped or escaping gas, giving rise to a pulsating load with a loading area that will be a function of the amount of entrapped gas. Physically, ELP1 is related to liquid compressibility, ELP2 to liquid change of momentum and ELP3 to gas compressibility.

The work of Lafeber *et al.* (2012b) and Pasquier and Berthon (2012) also researched in the scaling effects of sloshing studies, and so far the general conclusions are that the global flow can be well represented by the reduced $(1:40)$ model, but deviations have been found in some of the records and further research is still needed.

Temperature Control of Hull Structures

The discussion about the use of longitudinal bulkheads in FLNG design is an interesting topic raised in this subsection, and I will comment in section 4.2, as the committee report concentrated most of this discussion in this section.

Spillage Control

Research must be carried for a better understanding of a large LNG spill in seawater, in the case of future FLNG units, and how realistic it would be to guarantee that the LNG spill would be diverted far enough from the side of the hull, inside coamings or scuppers, and also taking in account the possible motions of the unit at this time.

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1.1.4 Safety and Design for Specific LNG Applications

In this section the committee report concentrated in new applications to the gas market, by making a description of the complete Offshore LNG Chain and later concentrating in some links of the chain, mainly the FLNG and the FSRU possibilities.

Offshore LNG Chain

The description of the FSRU only mentions the possibility of locating it at offshore, exposed areas. But there are a number of operating FSRU that have been installed in sheltered areas, as Guanabara bay (Golar FSRU, operating in Rio de Janeiro, Brazil), Pecem (Golar FSRU, operating in Ceara, Brazil), Bahia Blanca (Excelerate FSRU, operating in Bahia Blanca, Argentina) and Dubai, among others. In all previous locations the FSRU remains moored to a jetty and the LNG carrier can moor to the jetty in opposition to the FSRU, or side by side to the FSRU. When the carrier moors to the jetty, cryogenic loading arms will be employed, and when the carrier moors side by side to the FSRU, cryogenic hoses with specialized supports are employed. Both technologies are field proven technologies.

Floating LNG, FLNG, and Floating Storage and Regasification, FSR, Units

Probably due to the vast number of subjects being covered by this committee and their connection, some were addressed a number of times in different parts of the report. One of these subjects is the need of longitudinal bulkheads in FLNG units. On this topic, I would mention that:

- The large deck load due to the liquefying plant put a strong requirement in favor of the use of a longitudinal central bulkhead (addressed in the report).
- There is actually one FLNG design using this longitudinal bulkhead (Shell's FLNG for Prelude field, in Australia), and its size is huge (total length of $488\,m$ and a beam of $74\,m$), which also puts a pressure for the use of at least one longitudinal central bulkhead (partially addressed in the report).
- For the Prelude FLNG, it was decided to employ membrane tanks, which are not allowed yet to operate at unrestricted filling levels, but will have to show that its use is possible taking into consideration (1) the metocean conditions at the site and (2) a detailed sloshing computation. Aside from the possibility of hurricanes, the wave conditions in the Prelude field can be considered benign, and the use of a central bulkhead will favour the mitigation of the sloshing phenomena in its tanks (not explicitly mentioned in the report).
- A central longitudinal bulkhead will have to be designed as a cofferdam, and heated like today's transversal cofferdam bulkheads in existing LNG ships (as suggested in the report).

One interesting point that was raised in this section of the committee report is the offloading operations. There are some issues related to offloading operations involving FLNG units that were not fully covered, like:

- As the FLNG will be located offshore, the side by side offloading strategy will not be an option in general, unless the sea state is very benign. Simulations and model tests carried out in different JIPs (as Safe-Offloading, or Offloading Operability 2), indicated a maximum sea state condition with significant wave heights around $1.5 \sim 2.0\,m$, for peak periods in the range of $8 \sim 18\,s$. The behaviour will vary depending on the size of the units involved (FLNG and LNG carrier), and this statement can not be taken as a rule, but as an indication that extensive simulations and tests should be conducted if significant wave heights larger than 2.0 m for typical wave periods are expected to occur during side by side offloading operations.

- The use of tandem offloading approach will also require detailed simulations and analyses of the operations involved, associated with the use of cryogenic hoses, which can be either aerial or floating. In both cases the distance between the FLNG and the LNGC participating in the offloading operation will not be as large as the distances used for tandem oil offloading operations today (around at least 160 m), staying in the range of 70 to 90 m. This limitation is imposed by the size of the structure needed to lift the aerial hoses or due to current loads in connection with the large diameters required for the floating hoses.
- If a tandem configuration is required for the offloading, the best LNGC configuration will include a bow loading system and dynamic position facilities, which associated with the partial filling conditions pointed in the last item, will require a dedicated ship that most probably will only operate between a gas terminal and the FLNG, and will have a larger cost than a similar size ordinary LNGC.
- During oil offloading operations in tandem, using DP oil shuttles, from time to time there are occurrences of DP incidents, like drive-off, in general due to a failure in the evaluation of the relative positions (sensor problems) or any less common failure. The reduced distances between shuttle and FLNG will magnify the chance that such incident become more serious. Research on this subject is required.
- The LNGC ship receiving the LNG load will be subjected to partial filling conditions in the tanks during the offloading operations, which will have to be considered. Also if any contingency occurs interrupting an offloading operation, this partial filling condition will remain until the carrier arrive at the discharge location.

As stated in the committee report, there are different products produced at the FLNG (LNG, LPG and condensates), and there are projects that involve the use of different carriers for the LNG load and LPG and condensates load. This will increase the number of offloading operations, and the risk involved. We should also consider that the LPG carrier will in general be smaller than the LNG carrier, and present larger motion responses in waves, imposing another challenge for the operation. One possibility to mitigate the risks involved during offloading is to increase the size of the tanks, allowing the operation to abide longer for favourable weather conditions. The total number of offloading operations will be the same as if the tanks were smaller, as they only depend on the production amount and size of the shuttle ships, but there may be more time available to choose more adequate weather conditions.

The other unit mentioned in this section of the committee report is the FSRU. There are units of this type operating offshore (in general Excelerate FSRU using the STL disconnectable turret system), but also FSRU moored to a jetty in shallow waters, receiving LNG loads from carrier ships mooring to the other side of the jetty or side by side to the FSRU. In both situations, if there is the possibility of the occurrence of some wave excitation, despite the FSRU remaining moored inside a bay or a region with breakwater protection, there is the need of a good estimate of the local sea states, because:

- Wave drift forces and second order slowly varying forces increase significantly when the water depth becomes shallow.
- The FSRU mooring natural periods will be in the range 20 ~ 100 s, so these

drift forces will probably be the main source of excitation close to the mooring natural periods.

- Not only the water depth may be important to define the wave action, but also the local bathymetry, which can affect substantially the wave profile close to the FSRU.

In the last years there have been some activity regarding a more accurate estimation of the wave action in shallow waters in the presence of variable bathymetry, and its influence in the mooring of ships. I would mention the work presented by Buchner (2006), which motivated further research like Ferreira and Newman (2009) and Pinkster (2011). This is still an area of research, and so far most analyses indicate that considering a constant local mean water depth as an approximation of the detailed bathymetry can lead to first order motion responses that are close to the real situation, but some discrepancies can occur to the drift forces estimation, mainly in the low frequency range.

Second order slowly varying forces computed from the complete first and second order wave potentials in the presence of a bathymetry have not yet been accomplished. This is still a research topic.

The JIP HAWAI (and its sequel, HAWAII) coordinated by Marin with the participation of Bureau Veritas, Deltares and SBM, had focus on (1) the estimate of the local wave activity by propagating waves from offshore locations, where supposedly there are more accurate information about the sea states distribution and on (2) the ship response to the waves at the moored location.

One problem arriving from this situation is that as the waves progress to shallower waters, there will be an increase on the amount of second order bounded (set-down) waves, which can be computed through the idealization of the sea state as composed by first order linear components, and the subsequent evaluation of the second order components that arrive from the interaction of pairs of this first order waves. This waves will be bounded to the pair of the first order linear waves, but as the waves become too steep, encounter discontinuities at the bottom, or reflect at barriers, some part of their energy can get free from this constraint, and travel with the celerity of a free wave obeying the dispersion relation.

The correct calculation of the amount of second order wave energy that will become free is a challenge, and Olaf (2009) showed in the HAWAI JIP that this mechanism may also be the source of spurious waves in model tests, generated by the presence of the wave maker, the beach, and possible bottom discontinuities, inducing a higher amount of free waves in the model tests than would be expected in full scale situations, and this must be adjusted.

The best practice, or the recommended computationally feasible way to proceed with this computation is still in debate.

1.1.5 Conclusions

The areas of investigation raised by the committee are consistent with the subjects covered throughout the report. I would complement, based on the points I mentioned in the discussion, the need for research on:

- With respect to the CCS sloshing computation, I would suggest to establish the use of a linear panel method with the definition of the tanks to be used as a first step in order to evaluate the coupled ship response under the influence of the internal liquid motions. This analysis can be also checked against coupled CFD results and model tests, for the most critical conditions. I understand that the critical situations for the ship motions coupled response will be better defined using this approach than starting with a nonlinear analysis.

- Also in the CCS alternative using membrane tanks, there is nowadays a proposal of different types of support boxes, under the name of various reinforcement alternatives, with the claim that this approach would allow partial filling utilization. Research must be conducted to relate coupled ship motions, sea states, computed sloshing loads for a partial filling condition and the allowed membrane reinforcement type, if any.
- Regarding spillage control, also in connection with the FLNG possibility, research should be carried regarding the efficiency of diverting the LNG spill and also on the design of the coamings and scuppers, as their location may subject them to wave impact loads during rough weather conditions.
- Definitions on the requirements for longitudinal cofferdam bulkhead alternatives for the FLNG unit.
- FLNG offloading operations including definition of allowed cryogenic hoses and suggested requirements for the offshore operation (minimum distances and relative positions) and numerical simulations in different conditions (side by side and tandem).
- Determination of wave conditions on shallow waters based on the sea state characteristics on deep waters, including an estimate of bound and free waves amount and bathymetry influence on the wave loads computation.

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1.2 Floor and Written Discussions

1.2.1 Masanobu Toyoda

With regard to sloshing, the report describes countermeasures for damage from sloshing by avoiding resonance. The successful safety record of LNG carriers due to the restrictions of LNG filling level at almost full or empty in tanks was also reported.

Avoidance of resonance is fundamental approach for structural design. For instance, VLCC is requested to confirm the effectiveness of a swash bulkhead with the CSR rule formula and the resulting opening ratio of the bulkhead.

Furthermore, new precautions designed to protect people and port facilities against the effects of tsunamis are discussed. When a ship carrying dangerous cargo moors in a port and loading/unloading is in process, the ship should stop that process and leave the port within 1 hour of an earthquake's occurrence. It is possible that the shuttle tankers for FLNG will need to move away quickly in the process of loading and unloading in case of emergency.

It is more beneficial to ship's operators and port authorities for the safety level or operational instructions against sloshing including the emergency case to be indicated in something like a unified notation.

With regard to the safety level of independent tank type (3.1.2 Independent Tanks), the IGC code requests both a relatively safe side and unsafe side prescriptions for each tank type with good balance, and for all tank types have comparable safety levels including redundancy for possible events considered by the industry.

Type A

- Safe side: Full secondary barrier required
- Unsafe side: Complete strength analysis not required

Type-B

- Safe side: Extensive large-scale analysis, leak before failure, etc., required
- Unsafe side: Partial secondary barrier accepted

Type-C

- Safe side: High-pressure design and reduction of fatigue damage risk, increase of safety level with simple structures
- Unsafe side: Secondary Barrier not required

These measures for each tank type are compensatory such that the resulting safety levels including redundancy are comparable.

1.2.2 Rene Huijsmans

I would like to point out recent developments on wave climate computations in shallow water which are important for mooring LNG carriers. They were reported by JIP HAWAI and HAWAII. It was shown that complex wave–wave interactions from different wave directions could also be included in the computations of the QTF's of LNG carriers.

1.2.3 Spyros Hirdaris

The committee is congratulated for their report. I would like to mention a couple of issues for general information:

- An extended review of the Sloshel project was provided under the review of committee I.2 on loads. Equally, a very good report is provided by the ITTC Seakeeping Committee. I should like to suggest that your group refers to these references.
- Lloyd's Register published a Keynote in the IMDC 2012 Conference on "Green Shipping Technologies". The paper co-authored by Hirdaris and Cheng refers to a recent Lloyd's Register study on the cost of implementation of LNG as a fuel and the appetite of the market to make use of this technology for LNG fuelling.

1.2.4 Yukichi Takaoka

I appreciate your efforts to summarize and discuss such a wide range of technical issues on natural gas storage and transportation.

New IGC and IGF codes are now being developed at IMO. Thus, the committee should also discuss the necessity of these rules from the results of your study. Please show us your viewpoints on these new rules.

Finally, this is a comment. At the explanation of Type-C, although the report noted that the type-C tanks are usually not used for LNG transportation, I would like to add that Type-C tanks are suitable for domestic LNG transportation and Ship-to-Ship LNG transfer using small-size LNG carriers due to the advantage of the easiness of keeping the boil-off gas.

1.2.5 Byeong Seog Kang

This presentation give several old agenda such as sloshing of LNG, longitudinal BHD issue for very large FLNG, steel grade of T. BHD and heating and interaction between liquid (LNG) and CCS (Cargo Containment System). Discusser, however, ask that more advanced method or technology or design proposal be given in spirit of better and richer contents of presentation. And the other side, big FLNG project design already started. And in some aspect, the technology relating to these practical solution is being matured. I would propose that next committee is kindly asked to investigate in deep insight and practical aspect.

2 REPLY BY COMMITTEE

2.1 Reply to Official Discussion

First of all, the Committee would like to thank the Official Discusser, Dr. Marcos Ferreira, for his valuable comments and supplementary contributions, including some important additional references that helped us to clarify some of the technical aspects of our report.

I would like to reply to Dr. Ferreira's discussion step by step.

2.1.1 Safety and Design

As pointed out by the Official Discusser, some alternative concepts for the sea transportation of natural gas have been proposed in addition to LNG and CNG. Dr. Ferreira mentioned CGL (Compressed Gas Liquid). In the committee report, we reviewed some of the new concepts only very briefly due to page limitation. Besides CGL, there are other concepts that appear to have advantages, for example, NGH (natural gas hydrate), a method by which we can transport natural gas at $-20^\circ C$ and at ambient

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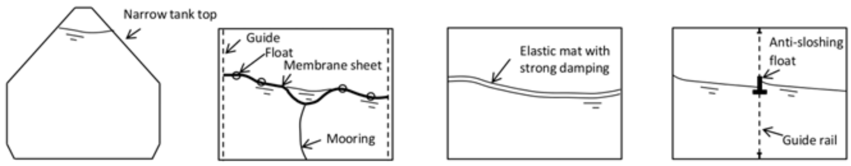
pressure, a very favourable character in cargo handling, although the weight efficiency is less advantageous.

2.1.2 Cargo Containment Systems

The Official Discusser correctly pointed out that there is difficulty in the inspection and maintenance stages of FLNG, for example, the need to inspect the primary barrier of the membrane tank. As indicated in the conclusion of the committee report, we believe that innovation is certainly required in the inspection and monitoring of the containment tanks.

2.1.3 Unrestricted Filling

As the Official Discusser mentioned and we also stated in the committee report, a membrane tank with large tank dimensions will increase the exposure to the sloshing phenomena. The Official Discusser introduced the notion that a new measure of reinforcement, designed to withstand higher impact loads and allow unrestricted filling, is being developed in the industries. We think that this is one of the ways to solve the problem. Another possible solution may be to minimize sloshing events, rather than trying to design structures to withstand the sloshing load. Recently, several research groups have proposed ways to mitigate the sloshing in membrane tanks. Figure 5 shows a few examples.



(a) Noble et al., 2005 (b) Anai et al., 2010 (c) Chun et al., 2011 (d) Arai et al., 2012 (IMDC)

Figure 5: Anti-sloshing concepts

2.1.4 Operation and Human Error

The Committee would like to thank the Official Discusser for introducing the Joint Industry Project called "Offloading operability 3", where the focus is not only on the measurement of real-time metocean conditions and the FPSO and Shuttle ship response, but also on examining the crew behaviour.We agree with the Official Discusser about the importance of such research and application of the obtained results to the crew training, and hope the application of a similar approach to the FSRUs and in the future FLNGs will lead to a better understanding of the human activities during operations of those facilities. Decreasing the possibility of human error will certainly upgrade the safety of such facilities.

2.1.5 Structural Integrity Management

The Official Discusser mentioned the Joint Industry Project called "LCC JIP", which pertains to the life cycle management of FPSO structures. Much like our response to the Official Discusser's comments about the "operation and human error", we think this type of approach for FPSO can be a good reference for the FSRU and FLNG cases.

2.1.6 Sloshing

The Official Discusser pointed out the possible problem in the fatigue strength of the tank supports in the Moss system that may be caused by the cyclic internal liquid motion during partial filling condition. This is a new topic to be studied if unrestricted filling becomes a regular practice.

The Official Discusser introduced several important research reports about the Sloshel project that appeared at the ISOPE 2012 conference. We certainly regret that we could not review them, since the committee report was submitted to the ISSC secretariat before the ISOPE conference was held. We believe that the next Committee will review the advancement of the project.

The Official Discusser proposed a process of sloshing analysis to take into account the coupled ship motion. The Committee agrees with the proposed process utilizing the linear theory for screening the critical condition. However, we would also like to point out the importance of the non-linear analysis in sloshing. For example, as shown in Figure 6, the free surface motion in the fore tank becomes very complicated if the tank has this configuration. And even for an ordinary shaped tank if the tank has almost the same tank length and tank breadth, so called swirling motion may occur. It is difficult for the linear theory based method to reproduce these highly non-linear free surface motions.

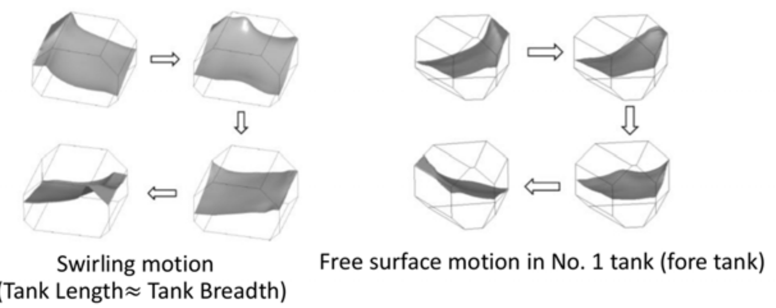


Figure 6: Highly non-linear free-surface motion (Wang and Arai, 2011)

2.1.7 Floating LNG, FLNG, and Floating Storage and Regasification, FSR, Units

The Official Discusser pointed out that there exist many challenges in the offloading process of FLNGs. The main focuses of our committee's discussions were safety aspects of the cargo containment systems, and we did not discuss deeply the operation of the facilities. However, as the Official Discusser indicated, there are some important items related to the offloading process, such as collisions between FLNG and shuttle tankers, problems related to the use of cryogenic hoses, and so on. We would like to encourage the next committee to start with a review of the offloading operation.

The Official Discusser's proposal of increasing the tank size of FLNG to allow the operation to abide longer in cases of favourable weather conditions is very interesting. However, we would like to comment that there may be an opposite idea about the tank size. That is, if the tank size is smaller, it would allow a quicker passing of the "danger" filling levels during offloading operation. Optimization of the total system must be carried out.

The Official Discusser indicated the importance of the good estimation of the local sea states, which will affect the response of FSRU moored in shallow water. The possibility

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of the increase of the wave drift forces and second-order slowly varying forces when the water depth becomes shallow was pointed out. This problem was also pointed out by the previous 2009 ISSC Committee I.1 "Environment". We would like to encourage the next Committee V.2 to cooperate with the Committee I.1 in evaluating the recent advancement related to this topic.

The Committee would like to thank the Official Discusser for his fruitful discussion. The discussion is certainly very interesting addition to our report and it also provides us with some motivations for future work.

2.2 Reply to Floor and Written Discussions

2.2.1 Masanobu Toyoda

For the first comment of Dr. Toyoda, we fully agree with his concerns about the emergency that may occur during the loading and offloading operation. If unrestricted filling is applied in not calm weather conditions, some kind of measures are necessary which are effective in the case where loading or offloading is discontinued due to some unexpected reason. Increasing the strength of the tank system might be one measure but there might be other alternatives such as the anti-slosh devices we showed in Figure 5. Another practical way might be the use of batch tanks, which are small tanks used as buffers for the loading and offloading process. This would allow a briefer time spent at the "dangerous" filling levels during such operations. Research group in Norwegian University of Science and Technology studied the optimisation of operation based on this idea (Rokstad *et al.*, 2010).

About the second discussion for the safety level of independent tanks, as Dr. Toyoda mentioned, the three types of the tank have different advantages and disadvantages. If the tank has a particular safety disadvantage, a proper measure is introduced. One example is the second barrier concept. After applying the various measures, the three tank types are considered to have equivalent safety levels. This is our understanding about the IGC code. Therefore, if we introduce a new storage system in the future, the new system should have equivalent safety performance to the conventional ones.

2.2.2 Rene Huijsmans

Thank you for your comments, which provide valuable input to be evaluated during the next term of this committee.

2.2.3 Spyros Hirdaris

We appreciate your information on the review of the Sloshel project and the Lloyd's Register's study about LNG as a fuel.

2.2.4 Yukichi Takaoka

Dr. Takaoka asked us our viewpoints on future IGC and IGF codes. As we showed in the presentation, there are some items which are not covered by the IGC code. For example, there are many new LNG containment systems proposed and they do not fit into the IGC code. New offshore applications such as FLNG also request some modification and addition to the code. One example is the design of the longitudinal cofferdam. As for fuel, LNG can be applied for any type of ships and LNG fuel tanks may be located in other areas than cargo area. As shown in the conclusion of our report, this may challenge the established safety philosophy of an LNG containment system. Safety aspects should be carefully evaluated during the code development of IGF.

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2.2.5 Byeong Seog Kang

Our committee's main tasks are to review the published information and discuss the state-of-the-art technologies according to the obtainable information. It is very difficult for an ISSC committee like ours to access and evaluate technological developments inside the industry.

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COMMITTEE V.3

MATERIALS AND FABRICATION TECHNOLOGY

COMMITTEE MANDATE

The committee shall give an overview regarding new developments in the field of ship and offshore materials and fabrication techniques with focus on trends which are highly relevant for practical application in the industry in the recent and coming years. Particular emphasis will be given to the impact of welding and corrosion protection techniques on structural performance, on the development and application of lighter structures and on computer and IT technologies and tools, which link design and production tools and to support efficient production.

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1 DISCUSSION

1.1 Official Discussion by Anto Tusun

1.1.1 Introduction

As it was mandated the report contains an overview of new developments in field of ship and offshore materials and fabrication techniques written in clear and understandable form. Review of new trends in material and fabrication methods worldwide was done with reflection to the effects of global economic crisis and the recovery period from year 2010 onwards. Fabrication technology has focused on welding thick steel, aluminium and corrosion protection techniques. Significant part of report has been reserved for composite materials and its potential for practical applications and still with some actual obstacles for wider application. Standards comparison has pointed out some differences and evidently some points that are causing confusion with interpretations by surveyors and shipyards. At the end of the report, most important topic was reviewed; the issue of linking design and production, through computer applications with a goal to increase efficiency.

1.1.2 New Trends in Material and Fabrication Methods

World

Current state of world market is showing signs of recovery, but the effects of crisis will be still visible for some time, therefore it is very important to point out some issues.

The report has mentioned for most shipyards very unfavorable position with great number of deliveries and just a few new orders. But still, those shipyards must consider themselves very lucky, when compared with situation of no job at all. From one side we have to keep production operation at highest possible level to achieve deliveries deadlines, and on the other side have to maintain preproduction activities in top form with no challenges, new orders. With that respect it is obvious that the positive approach is to try to find new and innovative products and to try to find some more reserves and possibilities inside companies by applying new methods. Yards are looking for new opportunities and trying to adjust their technology in order to compensate for new requests. Probably it can be investigated that each company has unique reaction time in which it can adjust itself to new requests, also we can say that larger companies have shorter reaction time, and the reason is that they invest more effort in innovative technologies, but there are still opportunities for smaller companies, since they can transform themselves faster.

Second issue that needs to be addressed is market disturbances caused by national interventions in order to keep strategic status for their own shipbuilding industry. It is obvious that interventions of this kind do not help recovering from economic crisis and we have false sense of market competition. Market share shifts and changes are partly related to this issue.

For each shipyard we can say “you are what you build”, and your size and location are key parameters when discussing production technology. In short, European yards sophistication for wide range of complex ships and Asian productivity through mass production lead to two different approaches toward innovative technology methods.

Asia

Japans record production of 20 million GT in year 2010 is very significant as a great pressure on shipbuilding industry to try to compensate lack of new orders.

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The report has mentioned that one of goals is better ship building accuracy. That is to be achieved by application of laser cutting, 3-D measurements, deformation simulations and by better block division. This is clear example how to find some more reserves inside company, and effect of this is not only related to hull production. The word simulation is used in context of welding distortion prediction, but it can be used in context of improvements in block splitting.

The real power of world largest Korean shipyards can be seen in actual development areas of distortion control, welding automation, welding equipment and plate forming. But market share changes are forcing change of direction toward technically complex ships, and above-mentioned power will be surely used to developments in area of green ships and green energy.

Expansion since year 2000 has evolved into respectable 185 million DWT in year 2010, the expansion has changed market share in Chinas favor. Recent information's about wages, steel prices are pointers that situation will develop in direction of expansion slowdown.

Europe

The sustainable growth has yielded with better business results with stabile capacity. What is most important there is respectable orientation toward innovative technology and innovative ships. Scarce natural resources are pushing Europe toward sophisticated ships.

America

Brazil's great reserves of oil and gas are economy booster, emerging but closed market, with shipbuilding of strategic importance. In some way as China, in last 10 years the capacity has increased, but not fully supported to last, what can be seen through fact that they need to come to the level of development to recognize that they need orientation toward innovation.

1.1.3 Fabrication Technology

Discussion about fabrication technology in recent years has become related to reacting to changing requirements and demands, which are reflected to fabrication technology fields like welding and corrosion protection. On one side fabricator needs to develop, prepare, approve and efficiently use welding technology for new material type or range; for new requirements on force by Contract and sometimes new production standard when switching between shipbuilding and offshore production. On the other side growing ecological awareness has been reflected in rising level of acceptable primary and secondary surface preparation for painting process for wet spaces. Moreover, we are experiencing rising requirements for dry spaces also.

In short, in order to accept new materials you need to invest and develop, and in area of surface preparation you need to find opportunities where to reduce rising production costs.

Welding Thick Steel

It can be discussed why we see rise of usage of thick steels, but again we come back to differences in approach for shipyards around the world "you are what you build". For Asian part we can see developments related to the container ships, LNG carriers. But it must be pointed out that usage of thick steel is also related to the special applications on sophisticated ships, since most of them have certain parts of ship construction heavily stressed and therefore it is necessary to make decision to use thick high tensile steels.

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Welding Extreme Thick Plates Report starts with three important areas of investigation; brittle crack initiation, propagation and NDT technology. It is necessary to point out that there are some other important aspect, like joint preparations and welding technology with preheating and post weld heat treatment, that are very important factors to complete picture of welding extremely thick plates. Let us mention that on sophisticated vessels these plates are often related to functions that are requiring strict tolerances for dimensions, so we need to consider that the aspect of deformations and shrinkages are also involved.

Nevertheless, it can be seen that differences and challenges are recognized and development is being done in area of investigation of brittle crack propagation arrest, mentioned new method for brittle crack arrest toughness. It is also stated in report that crack initiation mechanism is closely related to imperfections in welded joint, so they need to be addressed in combination. Extensive effort and developments in this field include advanced FEM analysis for prediction of residual stresses, usage of new materials and testing procedures.

Thickness Effect to Fatigue Strength Fatigue strength investigations and developments for thick plates are showing progress toward better understanding of what lay behind its mechanism, and it is good to see that some of new discoveries are becoming part of current rules and regulations. Good engineering practice to keep asking questions will help clear out areas where we use some assumptions based on small number of samples.

Special attention has been paid to the FCA steels, and UIT method. Both of them are examples of engineering answers to problem, loss of fatigue strength when welding thick steel, on their unique way; Fatigue Crack Arrestor steel and Ultrasonic Impact Treatment method.

Welding Aluminium

Aluminium, with its all advantages and disadvantages with respect to the steel is very well known material, but it can be seen that there is still lot of effort needed to change present state of welding technology, full introduction of friction stir welding method, FSW.

Corrosion Protection Techniques

In terms of corrosion protection techniques described in report we can see engineering approach to the subject; understand, apply and analyze in order to confirm and improve. Understanding the subject as always proves to be difficult taking into consideration different materials used and influences that paint is subjected to. In recent years we are witnessing to diversity of paint systems applied to the ship and offshore structures, and it is very important to know to estimate and predict its long term condition.

Corrosion Behaviour This subject starts with aluminium, material which in general isn't so much related to corrosion, but has one important issue to be respected, that is stress corrosion cracking. All developments in that area will find application easily. Usage of titan and super austenitic steels in diesel engine exhaust system is good example of development when corrosion issue is solved by application of material with superior corrosion resistance, but actual application involves also some usual production difficulties. Erosion corrosion proves to have real difference from regular corrosion in certain conditions; therefore reaction was to search for material with natural higher tolerance to wear and corrosion, like elastomeric composite materials.

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Corrosion Protection IMO's PSPC – Performance Standard for Protective Coatings can be described like standard that has made significant impact to shipbuilding production. Report explains fundamental requirement for NaCl in primary and secondary surface preparation, but let us keep in mind some other like relative humidity and temperature. It is mentioned that sum of all requirements has resulted in increased costs, but that in small extent, cause most shipyard has already moved step forward and set a goal that paintworks must be done in controlled conditions friendly toward workforce and to the nature.

But cost have risen because of other requirements, like increased level of inspections, introduction of certified coating inspectors (CI), and above all requirement of allowable percent of paint damage after painting, less than 2%, 25 m^2 maximum area, excluding erection joints.

That requirement has to be incorporated into Inspection schedule and has putted additional pressure to outfitting, steel preparation and pressure testing altogether. For some instances even block splitting was subjected to some changes in order to have ballast spaces as completed as possible before final assembly take place.

Further developments, like air mixed high pressure water blasting, on field of primary surface preparation will find their application in future, because it is connected to waste reduction and better working condition, but it still must match abrasive application.

Flush rust and surface roughness investigation are making insight toward real boundaries for requirements for paint application on surface and therefore must have deserved attention. Like mentioned before, we need to keep asking questions and finding answers, this is the way to improvements.

The development of new innovative highly efficient anticorrosion paint systems is underway, and self-healing coatings are things to come. But technologies like thermal spray coating and direct metal deposition are technology of today and have potential for further development. Thermal spray coating, coming to shipbuilding and offshore industry from civil construction applications, must be mentioned for its application for sacrificial anodes and barrier coatings.

Corrosion Analysis Theoretical and practical achievements in this field are important in order to correct the way for further developments. Efforts in developments of Structural Health Monitoring system will help to gather more information about the subject from actual ships.

1.1.4 Composite Materials and their Practical Application

Composite materials in their real wide sense are materials of future, but their way into real-world applications is rough, at least for commercial applications, even if we have in mind their supreme corrosion resistance, light weight, freedom of shape and other advantages. For sake of introduction there are some disadvantages like high initial price and fire safety issues.

Fire safety issues, SOLAS rulers, are most important obstacle for composite material wider application, so this is most important filed of investigation when composites are concerned. But there are some other investigations related to strength under different conditions, and usage of composite materials for repair of steel constructions, especially in events that is not allowed to use hot methods of repair.

We still need some more time collect real-world data regarding usage of composite material before we start optimizing design.

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Recycling is important aspect of composite material, and therefore development has been done to find and optimize method for scrapping composite material and to maximize its reuse.

Hybrid composite materials like metal sandwich panels are finding their way into industry for decks, balconies, stair and hatch covers. Real advance will be to come to the level that composite material can be used as a part of global strength, which development is left to the future.

1.1.5 Standards

Production standards have their important role for many aspects of ship functions and behaviour during its service life. The fact is also that during ship construction we are facing inevitable imperfections that are controlled under standards like IACS, JSQS, CSBC, VSM or IRCN.

In some occasions company must for one product follow one production standard, and for the other different one, as part of Owner request. There is no big or fundamental difference between them but still some differences exists.

The nature of standards is that they are collection of rules and regulations that have been collected from ships in service. In general this system works, but when we are dealing with some specific issues it comes out that standards are simple and do not take into consideration some important factors.

Example of fatigue cracks and its influencing factors show us good correlation with standards in issues, like production tolerances, alignments and shape of welded joint. But, because of the nature of the standards presented before, there are some aspect that can be improved; like usage of high tensile steels.

Experience shows us that in some situations we have mix of requirements from production standard, general tolerances and special demands for accuracy on production drawing, what can be confusing.

Measurements techniques are becoming more and more advanced, possibilities to measure and present the measurements are endless, but we still see no sign of them inside production standards.

Standard Comparison

Standard comparison has pointed out several important aspects and several different views to the subject. In this report we can find elaborated issues like distance between welds, fairness of frames and deviation of rudder from centreline.

Distance between Welds This aspect of production standard comparison is most confusing, so it deserves first position, since some standards do not have this limitation at all.

There are lot of examples where we come across with this requirement, and one of them is interference between structural welds and flush container foundations on container ship. A lot of effort has to be paid so that all fit in requirements, by adjusting block division, by development of full ship accuracy measurements for container foundations close to the structural welds.

In some other examples some simple solutions become complicated since one requirement leads to another and final arrangement can be described as complex.

It is good to see that there are efforts to change this limitation since materials are constantly developing as well as welding.

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Fairness of Frames Fairness of the frames on car carrier is good example where we see that requirements are not refined to take into account all instances that can happen in the real world. Distortion of primary supporting members like deck girders is one instance where we have very long slick structural element which is very hard to keep in required tolerance, but its function is not in question.

Another instance are liftable deck guides at the ship sides, heavy web frames with great height, more than adequate for structure reasons and for functional reasons with very well proven system of connection between liftable decks and the web frame.

In this case also is good to see that there are efforts to change inadequate requirements.

Deviation of Rudder from Centreline Discussion about this requirement can start with 8 mm required, but can also start with mentioning all influences to the accuracy. Doesn't matter are you big or small shipyard, you are facing the same problem, how to assemble key elements of propulsion and steering system in required tolerances, in workshop or at the building position.

You need to incorporate some finished elements into functional system and your situation becomes more complicated if instead of rudder you have nozzle and propeller working inside, and you try to reduce amount of machining on site. The only way is to start from this point as a reference point, to do all necessary arrangements with rest of elements in steering and propulsion system. The effort has to be well supported by measurements during all construction phases. In that case the required 8 mm can be satisfied, but for good reason.

1.1.6 Linking Design and Production in Computer Applications for Increased Efficiency

Engineering efforts to perfect the design are reflected in paradigm Design for X. Design for production is most known, but just one of important factors that can be used as X, with Manufacturing, Assembly, Cost, Simplicity, Maintenance, Environment, Safety, Life cycle cost, robustness or Six sigma etc..

When we think about the Design we must understand that it is like iceberg, most of it is hidden from the eyes in first sight, we must be aware of all factors. Like report states; challenge of the future is to incorporate simultaneously as much factors as possible.

We need to take into consideration that world is rapidly changing so its markets also experiencing changes. The decision which factor will prevail needs to be done on basis of solid facts.

Design for Production and Design for Manufacturing (DFP)

Productibility as a design attribute has been pointed out, since ship must be manufactured and assembled efficiently on basis of adequate design. It is very well-known engineering fact that good decision or change in early design stage can save a lot of effort and reduce cost in production stage.

Designs have to promote simplicity and they have to be adjusted to production facilities capabilities. If we take simplicity for start we can make connection to ease of production, standardization and modularization.

Ease of production have to be considered with due respect like the report has elaborated. Flat versus curved where ever applicable; reduce extremes in thicknesses; when using thin plates have in mind work that needs to be done to make them fulfil required tolerances; make good sense when designing plating with different thicknesses; force automatic welding; use symmetry; optimize welding.

Standardization is very old tool to make things less complicated and a tool to make things easily producible. Modularity where ever possible to be able to separately create some parts of project in order to reduce production costs.

Computer Applications

Computer integrated manufacturing represents integration of parts of business process that can offer possibility to increase productivity. Computer aided design, Computer aided manufacturing are basic parts that in basic used to translate engineering idea and requirements into usable data. Product data management is needed to be able to efficiently use vast amount of data. Enterprise resource planning, Computer aided process planning are tools for planning the project execution. And at the end power of today computers has to be transferred into applications able to help us make predictions and decide applicable strategies.

Difficulties to Link Design and Production Abovementioned vast amount of data still represent problem, since it is generated by applications that are self-oriented, like report states, no interoperability. It seems unimaginable that we still need to do compatibility by manual work, but it is a fact and a position for improvement. In all shipyards we can find mixture of applications from different sources starting with small applications related to the specific calculations in early design stage, toward to CAD solutions that shipyards use internally, and CAD solutions that are forces to use to exchange information's with outside word.

One other view to the subject of was amount of data is from perspective of initial design, detail design, engineering technology and production data. All is connected but not all is necessary for each stage. The basis is the same, but time of data generation is different.

Let us mention sensitivity to changes, how system reacts on changes, is it easy or hard to see effect of changes to product that we design. Some changes are unwanted errors but some changes can have different reasons, like improvements or additional functions. System must be able to handle changes of any reason, and we know that it is not always easy.

Examples like Digimaus and 3-D catalogue are applications trying to deal with mentioned difficulties, like in-house solutions.

Linking CAD/CAM to Production CAD/CAM because of its characteristics has become standard, modern shipbuilding already work with 3-D CAD models prepared for CAM use. Approaches are different depending of shipyard history and ability to adapt to modern trends. Goal is to reduce time to product, make production efficient and reduce costs. The fact is also that simulations are not the standard and that all parts of design process iterations are not covered by simulation but just some parts of it.

Application of simulations are endless cause 3-D model for the ship is already present, so the real work has to be done to prepare model of production of other parts of process that needs to be simulated. Linking data to simulations and retrieving simulations results back to the design is part of mentioned vast amount of data that needs to be handled in real time.

Optimization of Schedule, Flow and Resources Shipbuilding operations are complex and are asking lot of work in planning and scheduling. In that respect computers

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are enabling us today to be more efficient when planning and modern concepts like linear programming, concurrent engineering, critical path method, program evaluation and review techniques, discrete event simulation and enterprise resource planning are helping to integrate all important factors when planning.

To have an overview of project with all its aspects, to be able to optimize and forecast, simulate some scenarios means that you have more confidence in meeting the deadlines.

Simulation model of production facilities is important part, but unfortunately amount of work needed for usable model is a task fit for larger shipyards with specialists appointed to the task.

Simplified methods are widely used, scheduling with optimisation, or by using PERT methodology, or combination of linear programming and optimisation algorithms to solve scheduling issues. They are not so expensive and easier to maintain then expensive discrete event simulations.

To be able to simulate influence of product characteristics from earliest design time we must have usable information's to apply them on positions where we do not have exact data, because of early project stage. That usable information's can be gathered by using simulations from previous projects and probably making combinations between different projects.

Discrete event simulations that are developing in direction of simulations of development and production simulations for existing projects and there is still space for improvements in all stages of shipbuilding process.

Outfitting as well as hull production, offer their unique difficulties to simulation tool for optimizing effort that is involved.

1.1.7 Conclusion

The report has been prepared with understanding and good elaboration, so it was very hard to find questionable or even debatable fields.

1.2 Floor Discussions

1.2.1 Naoki Osawa

I congratulate the committee for the great work of publishing a comprehensive and valuable report. Researches and developments related to corrosion protection technique, including new developments in anti-corrosive coatings and thermal spray coatings, are summarized.

In these days, ship's ballast tanks are constructed with ordinary steels, and they are coated by epoxy coatings following the IMO PSPC/WBT standards. This system guarantees an average coating life of 15 years, if applied correctly. Because ship's economical life cycle is around 25 years, it is needed to develop innovative solutions which improve the corrosion resistance of ballast tanks. The application of corrosion-resistant steel (CRS) is a promising technology for this purpose (e.g. DeBaere *et al.* 2011).

Researches and developments of CRS for ballast tanks are carried out by many researchers in recent years. In these works, it is often the case that the corrosion resistance improvement is achieved by the combined uses of a protective coating and a new steel (e.g. Shiotani *et al.* 2010) because the corrosive environment in a ballast tank is so severe that bear steels cannot endure it.

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The quantification of the improvement effect of these new steels in service has not been achieved yet. The incomplete understanding of the mechanisms responsible for the coating failure and under-film corrosion in ballast tanks hinder the progression of technical innovation.

Therefore, I propose followings as a possible contribution for future research work:

1. Understanding and quantification of the mechanisms responsible for the failure of anti-corrosive coatings and under-film corrosion in water ballast tanks.
2. Development of corrosion-resistant steels for water ballast tanks.

1.2.2 Andrea Ivaldi

1. Friction Stir Welding: Despite a large number of publications regarding several different applications of this technology, the actual status is limited to thin aluminium plates, butt welding. What is the trend for the future?

2. Please provide some more references about the matter of distance between welds (ref. 5.1.1 of the Proceedings).

1.2.3 Fang Wang

With the increasing use of thicker and higher tensile strength steels, the synthetic characteristics of the new material must be considered enough. But the characteristics of a certain material may go in absolutely different direction. For example, the increase of yield strength of the material may lead to the decrease of fracture toughness and fatigue strength. Furthermore, the weldability, corrosion resistance, impact resistance, etc. should be considered. So my question is that, is there any synthetic criterion or standard used for evaluation of a new material? Or should we adopt some other analysis methods such as damage tolerance analysis method instead of criterion simply based on strength?

1.2.4 Erkan Oterkus

What is the necessity of technology transfer from aerospace industry in the area of composite materials? Problems regarding the utilization of composite materials, how about the issues related with moisture since ERP's generally made of polymer based materials. In addition to anti-corrosive materials, how about the development of anti-fouling materials? Thank you.

1.2.5 Mirek Kaminski

The report includes macro-properties and effects of materials. I think we should also look outside our field by reviewing research of e.g. material scientists. They are changing chemical composition, tempering process temperature in order to get materials with new microstructures that satisfy our requirements w.r.t. corrosion, resistance, strength and toughness. Would you recommend to modify the mandate and include review of these developments.

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

We would like to thank Mr. Tusun for his clear and complete review of our committee report. We appreciate your comments to our report.

We agree with you that due to the current market situation it is necessary for yards to find new and innovative ways to open up new opportunities. An open market with

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little national intervention would create a more realistic view on competition and also help the industry to innovate more, since yards then have to be competitive.

Mr. Tusun mentions a use of thick steel plates in sophisticated ships. We agree that large thicknesses can be used in these ships for some local areas. However, large application of thick plates for structural longitudinal strength is mostly seen in container ships and LNG carriers. The thick plates require special welding requirements, but in general it will be easier to prevent deformation and shrinkage in thick steel plates than in thin plates. The latter are more prone to welding deformations.

The increasing diversity of paint systems that the industry is seeing indeed calls for more research and testing of the long term behaviour of these systems. We appreciate the insight of a yard that the cost rise in corrosion protection is mainly due to the restrictions on limits of paint damage and the increased inspections. We believe that experiences like this combined with research on the effect of e.g. the strict requirements should be used to improve/adapt regulations in the future. Although there are many developments in coatings, such as the mentioned self healing coatings etc. we support the statement of Mr. Tusun that the current systems should also be developed further. Within all developments the practical application should be the main point of focus.

The committee fully supports the statement that more time is needed to collect information of the use of composite materials in real structures. It is good that experience is now gained in non-structural elements, such as balconies etc., since this will provide valuable insight in for example the long term behaviour and connection issues with only limited risk. The real advantage of composites will become apparent with the application in global strength. However, this also requires a change in design. Looking at the design from a traditional material approach and applying composites in that design will not show the real benefits.

Standards will probably always be based on experience with ships in service. This makes the incorporation of new materials and technologies sometimes difficult. However, with the trend towards goal based standards, first principle analyses and proof via experiments is normally accepted now. This makes innovations easier. This application of first principles and experimental proof or measurements should not only be applied in the design, but also in production and in in-service conditions.

We fully agree that the requirements in standards should be functional. The safety of the vessel is the first priority, but unnecessary complexity and limitations have to be avoided.

The amount of data on shipyards is indeed a problem. Not only from the amount of manual work that the lack of interoperability causes, but also by the increased possibility of errors due to the switches between programs, different definitions used in programs and adaptations during the building process.

It is true that full production simulation techniques require a lot of effort and simplified methods are more widely used. It can probably be expected that this will change in the future similar to the use of finite element methods (started as a very sophisticated tool used by only a few people, now almost common in designs). The main issue that will remain is the input required, input that is not always known in the early project stage but that can influence the success of the simulation. Learning from experience, but also sensitivity studies can improve the quality of the input and the knowledge on the most critical parameters.

Again we would like to thank Mr. Tusun for his comments and additions to our report.

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2.2 Reply to Floor and Written Discussions

2.2.1 Naoki Osawa

We appreciate the remarks of Prof Osawa on the importance of research in the area of CRS and on the mechanisms responsible for the failure of anti-corrosive coatings and under-film corrosion in water ballast tanks. We advise the next ISSC committee on materials and fabrication technology to include important development in these areas in their report.

2.2.2 Andrea Ivaldi

1. Indeed the largest application now is on butt welding of thin aluminium plates. However, research is done on the use of Friction Stir Welding for stiffener plate connections or corner welds (Figure 1, Martin *et al.* 2011). Also there is some work being done in the welding of steel with this technique. The committee saw some examples of corner or stiffener welds and other materials during their visit to the CEWAC research center in Belgium.

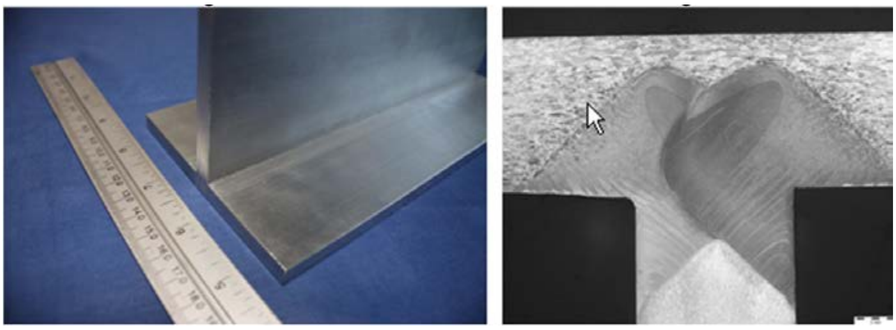

Figure 1: Example stiffener friction stir welding (Martin *et al.* 2011, TWI)

2. This matter about the distance between welds was raised based on shipbuilder's practical observations that overlapped welds cause no structural problems nowadays, although in old days it used to cause problems such as cracking of welds. No references have been found regarding this issue, and one of the reasons why we raised this issue is exactly this lack of research activities into this matter.

2.2.3 Fang Wang

We completely agree with the discusser's point that when a new material is to be actually applied, it is necessary to evaluate the strength and properties of the material from wide varieties of aspects, including facture toughness, fatigue strength, weldability, corrosion resistance, and so on. Some of them can be covered by the Rules of Classification Societies. Anyway, at first, necessary testing and its procedure and criteria must be established in consultation with Classification Societies.

2.2.4 Erkan Oterkus

The committee beliefs that it is important, especially for materials as composites that are often still only used in niche areas of different industries, to learn from each other. Since the application of composites is still relatively limited indeed more long term effects such as moisture, but also uv degradation etc, still need to be studied. It is important that these aspects are studied further in the near future to increase the application of these materials.

As for anti-fouling materials, a lot of research is still going into the anti-fouling coatings, ultrasonic system and electrolytic anti-fouling devices. Traditionally, self-polishing coatings were used to prevent bio-fouling on marine vessels. Since organotin and copper compounds have a detrimental impact on the environment; some of them have already been banned. Foul-release coatings also have been extensively studied for marine applications. Toxin-free systems such as (a) hydrophilic antifouling coatings (b) low energy, hydrophobic foul-release coatings (c) enzyme-based systems and (d) coatings with covalently attached toxins have been updated. Especially, two types of toxin-free, environmentally benign antifouling coatings: hydrophilic polymer brush and hydrophobic low-surface energy coatings have been developed.

There is an ongoing need to improve the performance of antifouling coatings and to increase environmental safety. More durable systems for hydrophilic polymer brush coatings will be the topic of focus.

2.2.5 Mirek Kaminski

The new steel materials mentioned in the report, such as as YP460 steel, large heat-input extreme thick plate, high arrestability steel, FCA steel and corrosion resistant steel, are all results of microscopic material research activities, and we agree to the discusser's view that reviewing research of material scientists is also important. Nevertheless, our committee believes that the emphasis of the mandate should be practical application of developments to ship and offshore structures and as such would recommend maintaining the mandate and limit the review of material developments to the viewpoint of these practical applications.

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COMMITTEE V.4

OFFSHORE RENEWABLE ENERGY

COMMITTEE MANDATE

Concern for load analysis and structural design of offshore renewable energy devices. Attention shall be given to the interaction between the load and structural response of fixed and floating installations, taking due consideration of the stochastic nature of the ocean environment.

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1 DISCUSSION

1.1 Official Discussion by Finn Gunnar Nielsen

1.1.1 Introduction

Let me first congratulate the committee with an extensive and well written report. The development within offshore renewable energy is rapid, in particular within offshore wind. The report gives a very good overview of the latest developments in this area.

Last year IPCC issued the special report on Renewable Energy Sources and Climate Change Mitigation (IPCC, SRREN, Arvizu et al. 2011). Here Ocean Energy is defined as "...energy derived from technologies utilizing seawater as their motive power or harness the water's chemical or heat potential." The six distinct energy sources are by IPCC listed as: Wave energy, Tidal range (rise and fall), Tidal currents, Ocean currents, Ocean thermal energy conversion and Salinity gradients. Wind energy is treated as a separate source of renewable energy, including both on- and offshore wind turbines. From a technical point of view the differences in terminology between IPCC and ISSC should not be a problem, but may cause some confusion, in particular when discussing the energy potential. According to IPPC, SRREN 2011 Ocean energy and wind energy in 2008 contributed with 0.002% and 0.2% respectively to the global primary energy supply. (Coal, oil and gas contributed with about 85% of the primary energy supply). Despite these almost negligible contributions from ocean and wind energy, the estimates on technical potential show that wind energy alone can supply almost an order of magnitude more electricity than the present global demand. The estimates on the technical potential of electrical energy from near shore and shallow water offshore wind alone ranges from 15 EJ/year to 130 EJ/year as compared to the present (2008) global demand of electrical energy of 61 EJ/year. The estimates on the technical potential for ocean energy show an even wider span. This is mainly due to the immature status of the technologies. The estimates range from 7 EJ/year to 331 EJ/year. So independent of which estimates to rely upon it may be concluded that ocean energy and offshore wind may supply a very significant portion of the global electrical energy demand. To make this happen, however, the cost per produced kWh must be significantly reduced. Here the competence of the ISSC community can provide significant contributions. However, even if the ocean environment is the same for ships and offshore structures as for offshore renewable energy devices and the basic physics is the same; we have to rethink our approaches in design and computational methods.The committee has very well addressed some of these challenges, as will be commented upon in the following.

1.1.2 General

The committee has in the present report decided to focus on the status and challenges related to offshore wind as this technology presently is the most mature and of greatest commercial interest. I support this prioritizing as there still are several severe challenges to be addressed to make large scale deployment of offshore wind farms a commercial success. It could however be argued that there are even larger challenges related to the various ocean energies. Thus the research community should help finding the path forward towards commercial deployment of these technologies. Also, as e.g. is the case for wave power, there are very many proposed technologies. It is unlikely that all of these may have a future commercial potential. Based upon physical insight and engineering experience, the ISSC community could consider more actively help sorting out which technologies that have the potential for success, not only comment upon the technology applied for the proposed concepts.

The committee has devoted much of the report to give an update on current activities with respect to concept developments, testing and analysis. This is useful, however, I would recommend that future reports puts more effort on the discussion of various challenges related to dynamic analysis and testing of the structures. If possible also specific recommendations should be provided.

1.1.3 Offshore Wind Turbines

The offshore wind market is still only a small fraction of the total wind energy market. Within EU only 4% of the installed wind power in 2011 was installed offshore (EWEA, 2012). In a global perspective this fraction is even lower. A key challenge is thus to secure that the special requirements related to the offshore environment are taken care of in the design of standardized wind turbine products. The special requirements relates to materials (salt and humid atmosphere), dynamic loading, reduced access opportunities (requires better reliability), installation as well as replacement of major components. These challenges are partly outside the mandate of the committee, but have certainly implications on the design of offshore wind turbines.

The offshore wind industry has developed from a land based industry, via very shallow water to increasing water depth. Thus the wind industry is following some of the same path as the oil industry went down about 60 years ago. The oil industry initially used jacket foundations, a very logical solution for shallow water, but the technology was extrapolated to deep water and, one may argue, beyond reasonable limits to more than 400 m water depth. This trend was broken by the introduction of floating platforms. We now see an extrapolation trend also in the offshore wind industry. The water depth limits for monopoles as well as jacket foundations are pushed.We must contribute with solutions that are optimum from a total cost perspective, i.e. construction, installation and operation. The committee addresses some of the design challenges related to the various substructures, but also point on the problem of limited experience with most of the newer designs.

Most offshore foundations, fixed or floating, are designed to carry an almost standard wind turbine tower.We must think of the complete support structure as one unit that shall carry the nacelle- rotor assembly, i.e. not only design a foundation that can be used as support for a standard tower. Such an integrated design approach will challenge the wind turbine and tower manufacturers.

With respect to the future size of turbines we now see a discouraging trend: The weight per MW is higher for the larger turbines than the smaller ones (Verhagen, 2011). This combined with higher nacelle level for large turbines challenges the design of offshore support structures. Thus we may see an increase in expenses for the support structures that may be greater than the benefit of using fewer units. One should also keep in mind that on a given area of an offshore wind park, the total installed power is approximately independent of the turbine size. This is under the assumption that the ratio between of the distance between turbines to the turbine diameter is constant.

Various alternative turbine concepts to the 3 bladed horizontal axes solutions are discussed. It would have been useful to address which challenges these solutions imply to the foundation design and analysis, e.g. the implications of the large dynamic variations in horizontal thrust that may be experienced by a vertical axis turbine.

In the discussion of costs of offshore wind turbines it is observed that generally the cost per ton of steel for the substructure is considerable higher than for the tower. It seems like here is a potential for significant cost reduction. The reasons are probably both related to design and market issues.

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Among the concepts discussed are the downwind turbines on a floating foundation. One of the basic ideas behind these concepts is the weather-vaning capability, i.e. a forced yaw control should not be needed. One should however be aware that the weather-vaning capabilities downwind turbines may be dubious.Neither is the turbine necessarily directional stable, nor does it always align with the wind direction, see e.g. Verelst and Larsen (2010), Corrigan and Viterna (1982).

The report does not discuss issues related to installation of offshore wind turbines. Present installation techniques are highly weather sensitive and costly. In the evaluation of concepts one has to consider the "as-installed" costs. The installation costs are highly dependent upon number of units considered. If very many similar structures are to be installed, special purpose installation vessels may be justified, thus reducing the marginal costs of the marine operations significantly. Maybe future reports should look more into the marine operation issues.

Analysis tools

As the committee states, there are several numerical codes available for analyzing offshore wind turbines. A trend is observed that the traditional wind power community have advanced turbine models on which they add simplified wave load models. Similar the offshore community makes simplified aerodynamic load models and couple them to the state of art wave load computer codes. Such simplified modeling of either the wind loads or the wave loads can be justified in some cases. However, if new concepts are to be studied, and new and maybe unexpected phenomena revealed, we should encourage the use of fully coupled aero-hydro-servo-elastic simulation tools, at least for verification of the more simplistic approaches.

Validation techniques

The committee refers several concepts that have been developed to various technical maturity levels and being tested. It is observed that testing of concepts may have several objectives and take place at various levels of concept maturity. We see testing at very small scales at an early idea stage, model testing with fairly advanced models and controlled environment as well as open sea tests at reduced or full scale. It would be useful to address these test options in more detail and discuss at which development stages the various tests are relevant, the challenges related to scaling, control of environment as well as the information that can be expected to be extracted from such testing.

The discussion of testing and validation should reflect the findings from numerical analysis of the concepts. E.g. if the wind forces are the most important forces to the dynamic response of a foundation, it has no meaning to make a combined wind and wave scale testing with great simplifications in the modeling of wind forces. Likewise for floaters that can be sensitive to negative damping induced by the turbine control algorithm, scale testing without this effect properly modeled will be of limited value or even misleading.Performing model scale tests, scale effects on the loads are always a concern and should be considered carefully. However, the advantage of model testing is the excellent control of the test conditions. Also model testing is well suited for testing extreme events rarely occurring in real life. Full scale tests on the other hand will reveal the "correct response" without scale effects. However, accurate assessment of the environmental conditions during the tests is always a major challenge, and one has to wait long for the extreme events to happen. The costs of full scale tests might be prohibitive.

1.1.3.1 Details, fixed structures

For the fixed foundations there is a challenge related to assess the natural periods of the elastic bending modes. I particular the first bending mode is sensitive to the soil properties.One may raise the question if state of art methods both with respect to soil testing and implementation in integrated numerical models are sufficient to accurately represent the restoring, damping and inertia effects of the soil. Also the change of properties over time may be a challenge. These are areas where the experiences from the offshore oil and gas industry are important, but may be not sufficient.The committee's viewpoints of these issues are welcomed.

It is observed that for most engineering applications the beam element momentum (BEM) method is used for computing the aerodynamic loads. This method is well established, but relies heavily upon several correction factors, as the Glauert correction for large induction factors, Prandtl's tip loss correction, correction for skewed flow, and e.g. a Beddoes-Leishman type dynamic stall model. The various BEM implementations should thus not be expected always to give similar results for the aerodynamic loads. Frequently CFD computations based upon Navier-Stoke's equations are considered to be the alternative to the BEM method. However, it would be nice to hear the committee's viewpoint on other methods as e.g. vortex sheet methods. Such methods account directly for most of the effects added as corrections in the BEM approach and are much faster than most CFD methods.

With respect to hydrodynamic loading, most codes use a Morison equation approach. This is an approach with long tradition in the offshore oil and gas industry. Most oil and gas platforms are located in deeper water than wind turbines. Care should therefore be taken when using the same Morison equation approach to offshore wind turbines as for the offshore oil and gas platforms. Some of the important phenomena that should be considered carefully are:

- Effect of shallow water.
  - Steep waves, non-linear wave kinematics, more frequent breaking waves, intensified by interaction with strong ocean currents.
  - Non-linear loading, e.g. slamming.
- Small draft to wave height ratio.
  - Nonlinear wave loads due to variation in submerged volume, "water entry" effects.
- Large diameter structures (monopoles)
  - Diffraction effects may be important.

A more comprehensive discussion of these effects would be welcomed as the implementations of some of these effects in standard engineering tools seem to be very simplistic.

In the report the committee refers to Veldkamp and van der Tempel (2004) that concludes that linear wave kinematics with Wheeler stretching is sufficient for fatigue calculations. High and steep waves may contribute significantly to the fatigue damage. Based upon the results by Johannessen (2010) one may thus question if the simple use of Wheeler stretching is sufficient. Johannessen claims that to obtain correct estimates of the kinematics in the wave, one has to ensure that the spectrum used for the wave elevation contains linear components only.The velocity profile is obtained by including second order terms in the potential and an exponential profile above the mean free surface, and using a truncation criterion to exclude the contribution from the shortest waves. I assume that accurate modelling of the wave kinematic close to the free surface

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is more important to the assessment of fatigue loading on wind turbine substructures than on most oil and gas platforms. Thus I support the committee's recommendation on more work on these issues, and in particular to implement the effect in integrated analysis tools. The statistical properties of the wave kinematics and loading must also be considered.

The use of response surfaces and contour line approaches are discussed to establish the ULS response for wind turbine. I agree on the warning the committee issues with respect to use of the contour line method for wind turbines. The method assumes that the most severe responses are to be expected along the contour of the most severe environmental conditions.Wind turbine maximum loads under operation occur at rated wind speed and the most severe structural wave loads may have significant contributions from resonant response, thus violating the inherent assumptions in the contour line approach. However, it would be worthwhile to investigate more carefully the applicability of this method for wind turbine design.

In the discussion of coupled versus decoupled fatigue analyses the committee seems to advocate the use of coupled time domain analyses. I support that recommendation. At the same time, quick, early phase engineering tools are always useful in concept screenings etc.A recommendation on how to use coupled or decoupled frequency domain analyses for such applications would be useful. In the coupled analyses the aerodynamic loads will contribute to damping of structural resonant response. But do we know if the most common implementations of the BEM model give correct damping estimates? This may be an important issue as the resonant response becomes more important in deeper water and higher waves.

The wind industry has used 10 minute simulation time as standard in their time domain analysis. When wave loads becomes important this is far too short to establish reliable extreme value estimates. The offshore oil and gas industry has typical used 3 hours simulations. Even this is too short when highly non-linear events control the extremes. More reliable procedures for extreme value estimates for combined wind and wave induced loads should therefore be an area for further investigation.

1.1.3.2 Details, floating structures

As mentioned in the report, most of the floating foundations suggested for the wind industry are well known from the offshore oil and gas industry.However, one should not underestimate the new challenges related to smaller sizes, need for mass production and low costs, and a very different load pattern. An example is the TLP design. An offshore oil and gas TLP has large deck area and are carrying large weights. The environmental loads are dominated by waves. The large horizontal distance between the tethers combined with the wave loads acting at a low level, results in relatively small dynamic variations in the tether loads. For TLP wind turbines the situation is different.Large static and dynamic wind loads are acting at nacelle level, causing large pitch moments. To counteract these moments the distance between the tethers should be as large as possible to avoid too large dynamic variation in tether tension. However, most TLP wind turbines have fairly small horizontal distance between the tethers. Thus the wind turbine TLP is a very different design than a TLP for oil production.Similar consideration can be made for the other concepts.

In the report, the wave induced heave response for different concepts is presented. One should rather present pitch/roll motion responses and accelerations as these are the quantities most important to the fatigue of the tower.

As stated in the report, the longest natural periods for most floaters are much longer than the wave periods, in the order 25 seconds and more. At the same time the elastic modes have similar natural periods as for fixed structures. Thus the challenges related to time domain simulations, fatigue assessment and extreme value estimates mentioned above for fixed foundations becomes even larger for the floating structures.

The importance of coupled analyses was commented upon above. This is even more important for floaters. Here the interaction between e.g. nacelle motions and thrust forces, gyro effects, nonlinear restoring and damping forces due to mooring lines etc. all interact.

I miss a discussion of the applicability of the various floater concepts with respect to water depth. The draft of each structure obviously constitutes a limit. But the cost related to mooring in shallow water seems to be underestimated by many designers. The mooring system shall have both sufficient strength and compliance yet not being too expensive. Also the power off-take cables must have sufficient compliance. These factors may call for a certain minimum water depth depending upon the site specific wave climate.

1.1.4 Wave Energy

A nice update on the most recent activities within development and testing of wave energy devices is given. The overview demonstrates that still it seems to be a way to go before commercial scale wave power devices are deployed. Any convergence in technology, as for the wind turbines, has not yet taken place.

A lot of new ideas and inventions of wave energy devices have been presented during the last decades. Not all are based upon a firm theoretical insight in the basic principles for capturing wave energy. The book by Falnes (2002) and his review article (2007) are useful references where the basic principles are formulated.Falnes and Budal (1978) formulate the basic requirement to a wave power device: *"In order for an oscillating system to be a good wave absorber it should be a good wave generator".*

For most wave power devices it is not possible to distinguish between the power off-take system and the support structure. Thus, analysis to assess fatigue end extreme loads must also consider the power off-take. With respect to analysis of wave power devices, two critical issues seem to be important; handling of non-linear resonant response and inclusion of proper control algorithms. This calls for advanced non-linear analysis. The use of linear analysis may help in understanding the system properties and behavior, but can hardly provide exact estimates on power take-off or extreme loads. A more in-depth discussion of the applicability of the various numerical tools available and the most important effects to include in the computations would be welcomed. Similar the role of scale testing would deserve a thorough discussion as the design of tests obviously depends upon what purpose the tests is to serve, e.g. demonstration of principle,validation of computational tools, assessment of power off-take, extreme load estimation or optimization of geometry and control system.

A problem that frequently occurs is that each new wave power device requires modifications of existing computational tools or tailor made programs to be analysed. This makes evaluation of the concepts costly and time consuming. A module based computational system for analysing various basic systems for wave energy conversion would thus be very welcomed.

Testing wave power devices in small scales implies not only challenges related to hydrodynamic scale effects, but even more so challenges related to scaling of the power off-take system. The power off-take system should provide the correct system damping to be able to study the system performance.

In the description of the Penguin concept there seems to be a printing error.It does not capture the rotational energy, but converts wave energy into rotational motion, as most wave power devices attempt to do.

1.1.5 Tidal, Ocean Current and Ocean Thermal

The report gives a good review of various concepts for tidal current and ocean current energy conversion.The ultimate wish is to be able to utilize the energy in low speed currents at a reasonable cost. In the discussion of the new ideas that aim at solving this challenge, it would be useful to look upon the ideas in view of the basic principles, considering limits on available energy. From such considerations and rough estimates on the size of the structures involved, one may obtain a first impression of the proposed concept likelihood of success.As stated in the report, the resources are very site dependent. So will most of the support structures be. As a consequence the cost of energy will be very site dependent.

It is nice that the committee includes a discussion of ocean thermal energy converters in the report. They give a brief review of some of the conversion principles. However, I am missing a more thorough discussion of the load challenges, e.g. by deploying large diameter vertical pipes of several hundred meter length in an ocean environment with waves and current.

1.1.6 Summary and Conclusions

The committee summarizes very well the status and challenges within offshore renewable energy.

The basic principles for energy conversion are well known and several practical concepts exist. To make offshore renewable energy realized at a commercial scale, the cost of produced energy must be reduced. This must realized by combining increased efficiency, high reliability and low costs.

I will encourage future committees to, in addition to describe principles and concepts, also discuss how the various concepts address the fundamental challenges related to both energy conversion, support structures , analysis and testing. Thus the report could to a large extent provide a guideline for the professional community with respect to promising concepts as well as analytical and experimental challenges.

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1.2 Floor and Written Discussions

1.2.1 Ivan Ćatipović

Since the wind turbine blades are very flexible associated natural frequencies are low. Moreover, complete structure of fixed wind turbine also has low natural frequencies. This information can be found in ISSC (2012) Committee Report V.4, chapter 2.2.3 along with example form Jonkman et al. (2009). Mentioned author states that the lowest natural frequency of the tower plus the rotor is about 0.32 *Hz*, while the blade natural frequency ranges from 0.67 to 2.02 *Hz*. So, corresponding natural periods are: 3.1 *s* (tower plus rotor), from 0.5 to 1.5 *s*(blade).

According to API-RP-2A-LRFD (2003), in seismically active areas, fixed offshore structures are to be designed to resist earth ground motions. To describe ground acceleration amplitude API recommends normalized design spectra such as Figure 1 for use in structural design.

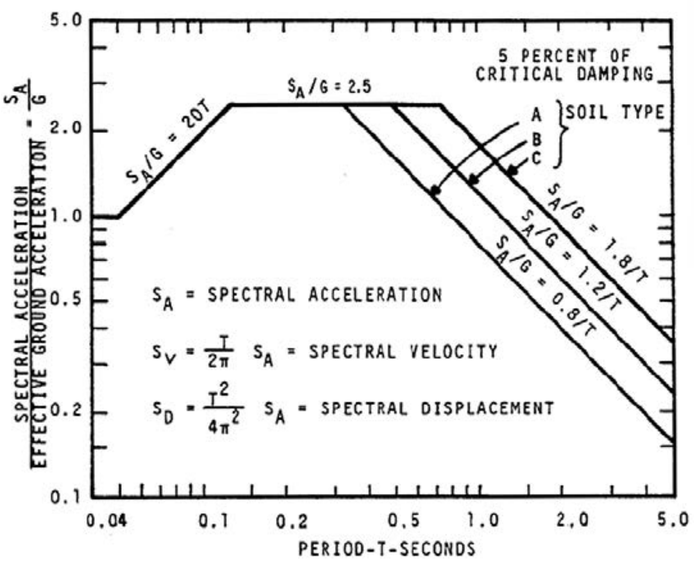

Figure 1: Normalized (response) spectral function of ground acceleration

As can be seen on Figure 1, natural periods of turbine blades (0.5-1.5 *s*) are partly overlapping with peak of spectral function of ground acceleration during earthquake. Also, natural period of the tower plus the rotor (3.1 *s*) is very near to the peak. Therefore, the occurrence of resonance can be expected. Part of this problem is low overall damping of fixed wind turbines; see ISSC (2012) Committee Report V.4, chapter 2.2.3.

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Since DNV (2011) in “Design of Offshore Wind Turbine Structures” considers earthquake as environmental load, this topic should be considered in the future work of the committee to fully cover design problems of fixed wind turbines.

1.2.2 Rachel Nicholls-Lee

1. During the presentation wave and tidal energy were said to be “less important” than wind. Surely this is very location specific as many countries have both environmental (national parks, protected areas etc.) and political problems with wind energy and cannot implement it. We are very interested in wave/tidal/river/current energy!

2. In the report, wave is said to be less important than wind due to the steady progression of wind from onshore to offshore. Surely this is not the main reason – the extreme environment WEC’s operation is usually avoided by most industries and creates huge issues with regard to through-life-design and reliability!

3. Section 3.2.2 and 4.1.5 would be useful to reference the development of Marine Renewables Road maps. Recommended reference: Johnstone, C.M.; McConkes, T.; Bahaj, A.S., Myers, L.E.; Holmes, B.; Koefoed, J.P.; Bittencourt, C. (2011): “EquiMar: development of best practices for the engineering performance appraisal of wave and tidal energy converters”. In the 9^{th} European Wave and Tidal Energy Conference, Southampton, UK, 5^{th} – 9^{th} Sept. 2011.

4. Comment was made in the conclusions regarding the prohibitively high CAPEX costs relating to installation of tidal energy devices. This is correct, however it is being addressed in the industry and academia currently with several TSB and EU projects funded to develop methods of installation and bespoke installation vessels.

5. While the tidal section was short, I feel it would be enhanced by mention of TGLs tripod, gravity base installation and also the quick and relatively quiet method used by MCT of pre-installation of pin piles.

6. Section 4.1.4: Environmental modeling of tidal flow and the effect of tidal turbines is being undertaken. There are several papers by Ross Vennell, Otago University, NZ, on the subject as well as Turnock at al. (University of Southampton).

1.2.3 Pengfei Liu

1. Informal update on organizational structure of *National Research Council Canada* (NRC) and *Institute of Ocean Technology* (NRC-IOT)

I am glad to see that IOT has been mentioned/acknowledged during the talks and several places during the presentation of the committee. However, since April 1, 2012, NRC-IOT does no longer exist. I felt that I should give an update on this.

1. NRC is undergoing a restructuring/reform: it has been changed from institutional-based to portfolio-based management. For example, NRC-IOT has combined with Canadian Hydraulic Centre (NRC-CHC) into *Ocean, Coastal and River Engineering Portfolio* (NRC-OCRE). NRC-IOT now is called NRC OCRE St. John’s or NRC St. John’s for short and IRC-CHC is called NRC OCRE M32 or NRC M32 for short.
2. NRC OCRE currently consists of several programs: Marine Vehicles, Marine Safety, Arctic, Marine Infrastructure, Inland Waterway Resources and Marine Renewable Energy.
3. Programs are not permanent: Current programs may be discontinued and new programs may be deployed.

2. Questions to V.4, Offshore Renewable Energy Committee Report

Congratulations to the Committee for its excellent work and contribution to the renewable energy community.

1. Among the three technology areas waves, tidal and river hydro-kinetic energy systems, which one has been or will be the technology of highest priority (of course all three energy resources are assumed equally available)?
2. For renewable energy technology development, for these two aspects: 1) technology development and 2) project (site) development, which one should be given more effort, concentration or focus?
3. River turbine technology development was not seen to be discussed in the committee report. Is there any reason for this – is it out of the scope/mandate of the report, or is it not important enough to be considered/included? Canada is placing strong emphasis on the development of river turbine technologies – would you expect it to have a reasonable or a large global market opportunity?

1.2.4 Wim de Boom

The committee has reported from published research that costs of offshore wind have to come down considerably to make the industry survive.

At conferences several times statements have been made “if we do not half the cost of offshore wind this industry will be dead”. The reality is that costs have shown an upward trend the last couple of years, rather than going down.

Has the committee, from reviewing many publications, got any feel for where the desired significant cost reduction could come from?

1.2.5 Spyros Hirdaris

From the presentations it becomes obvious that in this area technology is extremely important. My question is:What do you believe is the role and associated responsibilities of independent assurance bodies’ with respect to the implementation and assurance of technologies in the area of offshore renewable systems?

Would the process be the same as for oil and gas? Do you see any dangers if the industry proceeds with self-certification? Do you see immediate scope in clustering technology providers/manufacturers class societies with detailed rule making or certification via implementing existing standards is adequate?

Congratulations for the presentations and the excellent report.

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

The Committee appreciates Prof. Gunnar Neilsen’s valuable contribution to this Specialist Report and in particular his broad and balanced perspective of the subject matter. The committee is obviously pleased with the general conclusions made. Prof. Gunnar Neilson adds a very valuable commentary on the relationship between IPCC and ISSC.

The main points of the Official Discussion as we see it and where we agree entirely are:

- That our report was correct to focus on Offshore Wind;
- That cost reduction is the primary driver for Offshore Renewable energy;
- There is a fundamental need to consider integrated solutions;

- There is a pressing need for appropriate Standards and Guidance;
- Future committees should expand the mandate to include consideration of installation, access, inspection and repair in addition to describing principles and concepts.

Specific remarks made to the committee to be addressed are as follows:

Prof. Gunnar Neilsen'sstates that it would have been useful to address the challenges of Novel solutions e.g. VAWTs on foundation design and analysis. The view the committee took was that it needed to be careful not to inadvertently stray into areas which might be commercially sensitive and that the committee doesn't have the wherewithal to research ripple effects in two-bladed turbines and compare to three bladed configurations or to study HAWT versus VAWT for that matter. We reported as objectively as possible the peer reviewed literature concerning these concepts without conjecture. Having said this, there is a good point to be made here and that is that by taking a systems or integrated design approach including the turbine with the foundation as a single structural solution then the structural advantages or otherwise of certain configurations on the structure should become apparent;

That the report does not discuss issues related to installation of offshore wind turbines and making the observation that present installation techniques are highly weather sensitive and costly. We agree with the Official Discusser's observations in this regard and that installation might be dealt with by the new committee;

Prof. Gunnar Neilsen advocates a need for fully coupled aero-hydro-servo-elastic simulation tools to study new wind power concepts. The committee agrees particularly for the development of floating wind concepts however expresses caution in encouraging development of numerical and analytical tools in the absence of an empirical knowledgebase for verification and validation of these new tools. Dimensional similarity is very difficult if not impossible to achieve through model tests and once information starts to become available from field tests on large/full-scale devices then is the time to encourage refinement of such methods. The next point leads well from this;

The Official Discussion devotes significant time to discussing the merits and difficulties in full/large-Scale Testing. The committee agrees that not only is this important for the reasons expressed above (i.e. combined aero-hydroelastic aspects) but also for structural integrity purposes including the effects of corrosion, residual stresses and size effects on the fatigue performance of steel foundation structures;

The question is posed whether or not Soil-Structure interaction models developed for Oil & Gas are sufficient? The committee response is that they are not and that it is well documented the difficulties encountered in extrapolating small diameter pile models to those currently used in monopile wind foundations. The industry is exploring "heavyweight" monopiles up to nine metres in diameter and these certainly will require a new understanding of pile-soil interaction.

Prof. Gunnar Neilsenmakes the observation that in the report the wave induced heave response for different concepts is presented and explains that it is better to present pitch/roll motion responses and accelerations as these are the quantities most important to the fatigue of the tower. The committee agrees and included the Heave Figure for illustrative purposes.

Finally Prof. Gunnar Neilsen poses the question at what point do floating Wind Turbines become more economical and makes the observation that many academics and concept studies underestimate the cost of moorings in shallow water. The committee

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agrees that shallow water moorings can be complex and expensive. It would add that the depth of water is not the only parameter but also the size of the turbine needs to be significant to offset the size of the floater.

2.2 Reply to Floor and Written Discussions

2.2.1 Ivan Ćatipović

The committee thanks Dr. Ćatipović for his contribution and agrees that seismic effects need to be considered in certain parts of the world and that the new committee may see fit to investigate this further.

2.2.2 Rachel Nicholls-Lee

The committee is grateful to Dr. Nicholls-Lee for her comments. Taking these in turn:

1. It is not the view of the committee that Marine energy is less important than offshore wind but that at this time there is by far more economic activity and technical research and development work focused on Offshore Wind applications and therefore this needed to take priority and our report and presentation reflected this. The committee agrees that Marine Energy has enormous potential and is certainly site specific;
2. Again there was no suggestion that Wave Energy is less important than wind. The committee agrees that the manner in which wave energy is imparted to a WEC structure is in the main more severe than for Wind and Tidal and WECs subjected to impact loading need to be designed very carefully;
3. We agree this is an important reference and are grateful for its inclusion in these proceedings;
4. It is encouraging that these projects are underway to help reduce costs, certainly it should be possible to greatly reduce installation costs;
5. The committee is restricted to reporting peer reviewed publications and whereas members are aware of such developments we could not find any public domain objective publications to detail these concepts; ISSC must remain independent and the committee was careful not to be drawn into stating an opinion that might be used by one developer over another for commercial advantage;
6. Again this is a useful contribution to these proceedings.

2.2.3 Pengfei Liu

The committee is grateful to Dr. Liu for his update concerning the Canadian NRC and its former IOT. Responding in turn to the questions posed:

1. The committee would point to the discussion above with Dr. Nicholls-Lee and stress that each technology needs to be considered in detail given the local resources available. No one technology will always be better than another and the performance or otherwise will be site specific;
2. Again this is an interesting question and one without a definitive answer. Many island and distributed communities would be quite happy with a 1 - 2 MW single turbine and therefore an appropriate technology will be the primary focus; for large arrays (or parks) generating several hundred megawatts or greater, then site development and array design becomes more important than the component turbine technologies;
3. River Turbines like Hydroelectric Power is important but deemed to fall outside the mandate of ISSC.

2.2.4 Wim de Boom

The committee thanks Mr. de Boom for his insightful question. The Committee believes that so far despite the growth in Offshore Wind the sector has not yet benefited from the economies of scale largely due to the fact that an offshore wind turbine is still manufactured and installed in the same way be it a single installation or part of a wind array. The cost reduction must come from greater automation in manufacturing and special purpose installation vessels that allow installation without competing with Oil & Gas and other users of the sea.

2.2.5 Spyros Hirdaris

Dr. Hirdaris poses a number of very important questions concerning the roles of Classification Authorities in this developing sector. We believe the role and associated responsibilities of independent assurance bodies' with respect to the implementation and assurance of technologies in the area of offshore renewable systems is one of partnership with the developers. No one has been here before and all of us are learning as we research and develop such technologies. It is important for developers and their investors to appreciate this and not to expect independent assurance bodies to be able to provide cost-efficient solutions to new technological solutions but to provide a guiding framework to allow the design and testing of new systems in a safe in manageable manner. We expect the process to be largely the same as for Oil & Gas however the risks of unmanned installations are far less and should allow for a greater tolerance of adventure. Risks associated with self-certification would be to fragment the healthy friendly criticism that often exists between developers and certification bodies and developers would stand to lose access to the immense body of knowledge available through these relationships. It certainly makes sense to cluster technology providers/manufacturers and class societies with detailed rule-making as incremental development of implementing existing standards brings with it baggage that may not be appropriate for this industry.

2.3 References

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COMMITTEE V.5

NAVAL VESSELS

COMMITTEE MANDATE

Concern for structural design methods for naval ships and submarines including uncertainties in modelling techniques. Particular attention shall be given to those aspects that characterise naval ship and submarine design such as blast loading, vulnerability analysis and others, as appropriate.

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1 DISCUSSION

1.1 Official Discussion by Paul James

1.1.1 General Discussion

Historic and future development

The different approaches taken by classification societies and naval ship designers can be seen in their historical approach to global bending, the class societies traditionally relying on an empirical formulae such as IACS Unified Requirements URS7 to derive wave bending, and the navies utilising a static wave balance, Chalmers (1993). This fundamental load along with a design wave height for local structure defines the primary loads for structural design and, in conjunction with an assessment criteria, determines the structural steel weight.

Validation work undertaken by the classification societies demonstrated that the wave bending moment was similar if an allowance was made for a naval vessel's fine hull form. However, naval ship designers tended to use different assessment methods involving a greater degree of structural optimisation, for example use of grillages, and in some areas less conservative criteria. However the most significant factor which impacted steel weight was the use of a net scantling approach for naval ship design.

The development of the High Speed Craft (HSC) Code in 1990's and the subsequent classification society rules written for these ship types meant that an approach existed which was more akin to naval ship design. A net scantling approach, with rules that were transparent that could also facilitate structural optimisation.

It is probably fair to say that commercial ship design and naval ship design have met somewhere in the middle.

The future of naval ship design will probably be in two directions

- High value highly capable assets for specific roles and purposes. Submarines, Aircraft carriers or Air Defence Platforms. These will have highly specialised equipment and the platform is basically the casing around a weapon system. These vessels will probably be in the minority.
- Less capable but flexible semi-militarised vessels which carry a variety of equipment for a variety of roles. LPDs, RFA, OPVs or Corvettes. These will have the ability to transport, launch and recover a wide range of unmanned and manned equipment.

Both will rely on classification society rules for the basic structural scantlings because fewer naval ship design standards will be available; even now a designer's choice is limited as many naval standards are not maintained. Many navies are using class society's survey services and have configured their own procurement and certification processes accordingly.

It is likely that only the high value vessels will require design features for specific military loads. Even then designing structure for military loads is often a last resort as it is seen as the most expensive and least convenient option. Significant advances in capability can be achieved through careful placing of equipment, redundancy/duplication and separation, all of which can cost very little if implemented early in a project's life. In addition, the preference will be to spend money on not getting hit rather then dealing with the after effects of a hit, so the focus will be on reducing signatures and adding countermeasures.

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This means that there will be less focus in the future on the military load aspects of ship structural design and fewer projects on which knowledge and experience can be developed.

Similarities between naval and commercial ship design

There are a large number of similarities between naval and commercial ships' design because the fundamental physical environment is the same, for example the similarity of global loads derived from the long term wave environment. However, there are some important differences, these arise because of the way in which a naval ship is used in its environment. With more equipment being derived from the commercial supply chain, the lack of appreciation for the way a naval ship is used can lead to incorrect specification and ships that are not fit for purpose.

Some examples of this for the ship design elements chosen in the paper are:

- Hull bottom, sides and main deck forming the hull girder. These may require assessment against a higher wave bending moment because a naval ship may be subject to extreme bending loads from different operational scenarios, for example, sailing in extreme sea states for a rescue mission or hull whipping from an underwater explosion. Commercial ships are typically assessed to a 10^8 probability of encounter whereas some naval ships may need to be assessed to a higher probability of encounter to account for extreme sea loads.
- Watertight bulkheads, will usually be assessed against a much higher load from extreme flooding events due to multiple compartment flooding, see Sarchin (1962) for the definition of watertight structure, however the plastic collapse criteria used for assessment is generally the same as commercial ships. This has been important for ships that were originally commercial ships and converted into naval ships which are then expected to withstand greater levels of flooding.
- Foundations and supporting structure for equipment and the design of equipment such as cranes, ramps and lifts need to reflect the operational requirements. Stern ramps may get used as slipways, docks, and swimming platforms, all of which may not be appreciated by the equipment designer. This equipment is also used in a variety of sea states, whereas merchant ships usually use their cargo handling gear only in harbour. Munitions will also impose higher safety factors and test loads which need to be addressed in the design of the supporting structure. These requirements must get passed down the supply chain to the lowest tier.
- Weapon systems can also place unusual constraints on the structure for example, some weapon systems such as a CIWS require a certain seat stiffness which is usually easy to achieve locally but it may require global stiffening of superstructure which could be more of a challenge.
- Tanks in classification society rules are designed with certain allowances for the settling of fluids in pipes and filling systems, these may not be appropriate for a naval ship fitted with filling trunks which place a large static pressure head on double bottom tanks when replenishing. For the supplying ship operation with slack tanks may lead to significant sloshing loads which need to be addressed.

The NATO Naval Ship Code ANEP 77 attempts to address some of these issues by requiring a concept of operations to be defined, in short this document should define what a navy is going to do with to ship and be used as a reference for all subsequent design and approval activities and also all future operational guidance when in service.

Scope of Military loads

Whilst the major difference is the military loading, it is clear from the above that this is wider than just the "military action" loads listed in the paper. A navy uses a ship in a way which will impact on the "normal" structural loads too. It is these less obvious military operation aspects that are often overlooked and lead to the majority of problems in naval ship design and they are often discovered late in the build process.

Consideration of the military loads discussed is important and they can have quite a significant impact on structural arrangements, scantlings and steel weight. Therefore it is important to assess their cost and benefit through a formal survivability analysis. However as discussed in 1.1 the output from this is usually centred around equipment layout, and improvement of strength is usually the design team's last resort.

When assessing the survivability of a ship and the military loads to design for, it is important to understand the range of naval ship types a navy operates. This can be very varied and include: harbour tugs, research ships, auxiliary supply vessels, corvettes, frigates and landing platforms. All will have some form of Military role to a greater or lesser degree and this will determine the applicability of commercial ship approaches to design.

It is also interesting to note that some of the assessments and processes applied to naval ships are being applied to commercial ships too. Cruise ships are reducing underwater noise signatures Linden (2008), and the new common structural rules for tankers and bulk carriers LR (2011) Ch. 5 Sec. 2 require an ultimate strength assessment which is further discussed in section 5 of this report. Following the USS Cole incident in the Persian Gulf (October 2000), a number of commercial ship operators undertook analysis against military threats, especially those operating LNG ships.

Commercial and naval design conclusion

The narrowing of the gap between commercial ship design and naval ship deign has a number of good outcomes for the industry in particular the opportunities for joint research mentioned in the paper. Colleagues in both industries should look for more opportunities to collaborate and co-operate; one area of common research currently developing is in assessment of damaged ship structure. Underwood *at al.* (2011).

It is important to recognise that the way in which a navy uses a ship may impose fundamentally different loads on a ship which the designer must take account of and this is wider than just the direct military action type loads. Efforts to capture the manner in which a ship is used in a common format should be encouraged.

Ensuring that these routine naval load scenarios are correctly specified will allow classification societies to take up this work and allow Navies to focus scarce resources on the ship types with the greatest military role and concentrate on military action loads. In doing so they can determine the most effective means of enhancing the military capability of a ship.

Therefore the future direction of the committee should be on the military action loads including residual strength but it should also identify areas where the use of a naval ship can impact the more routine loads.

1.1.2 Optimisation of Naval Structures using Lightweight Materials

Why consider using lightweight materials?

It is important to put the weight equation into perspective, around 50-60% of a ship's weight is from the structure and there are significant gains to be made in the use of lightweight materials, but the full impact on the material system should be considered when evaluating the different technologies. It is quite correct that it is often the non structural performance of alternative materials that restricts their use in naval vessels, e.g. fire resistance or production costs.

Requirements and decision criteria for naval vessels

The total value of a change in a material system should consider the whole structural system. For example for relative capital investment, the structure and its protection systems e.g. Fire or corrosion, and the full costs of purchase and manufacture also need to be taken into account. Manufacturing costs will vary for each place of manufacture depending on the skills and experience available.

In-service costs should also take account of likely volume of in-service defects, for example use of high strength steels typically leads to increased fatigue fractures because of the higher field stresses in the structure. The cost of work in-way can be many times more than the cost of the actual steel work repair.

The costs of recycling and environmental impact also need to be taken into account when considering the full costs of a material system and FRP may not perform as well as steel and aluminium in this respect.

Light weight materials as a means of optimisation

The low modulus of Aluminium and FRP tends to restrict their use. However, some of this is due to traditional approaches being taken to panel stiffening. The use of some novel materials such as steel sandwich allows secondary stiffening to be omitted, and extruded close spaced thin walled aluminium sections can provide very rigid panel structures. Neither of these structures looks like the conventional stiffened steel panel but they can provide efficient structural support. That said, the limitations of flexural rigidity under global loads means that steel will continue to be used for frigate type ships and larger, though discrete structural elements such as hull appendages and superstructure blocks may use aluminium or FRP.

In Table 4, the impact of high ambient temperatures which can be encountered in normal operations in the Gulf should be noted in the performance characteristic for FRP. Enhanced scantlings may be required to provide sufficient flexural rigidity in hot weather.

Further challenges for mitigation of weight in naval vessels

Fire protection is rightly identified as a key issue for non steel materials, and several projects have investigated fire protection issues e.g. EUCLID RTP3.21. However there is also potential for a steel structure to fail in an extreme fire scenario where a single point of failure exists for a particular load path. It is not normal to insulate a steel ship structure for preservation of strength as it rarely sees maximum load coincident with an extreme fire event. However, it is common to provide protection for a building's structure as defined in EN 1993-1-2. Protection of steel may be relevant for a naval ship where the expectation is to regain use of the ship following a significant fire and expect the structure to carry load. The new edition of the Naval Ship Code requires critical structure to be identified for all materials and suitably protected.

Whilst FRP structures will require fire protection to limit smoke and toxic products, some navies have stricter requirements than the IMO criteria which could restrict a number of FRP materials.

For the other challenges raised in Table 7 the impact of production, coatings and consequences for ship signatures should be considered

- The corrosion resistance of unprotected steel is poor but there are efficient paint coating systems that are enduring which would elevate steel to an average or good corrosion performance. Corrosion resistance is typically addressed through improved coatings rather than steel thickness as this is more cost effective through life. Few naval ships have substantial corrosion margins. The Superior corrosion resistance of FRP is tempered somewhat by the long term degradation due to water absorption and UV attack.
- For FRP production, the quality of the material is very dependent on the environmental conditions for manufacture; it may be more costly to produce a good product. This also means repairs are more difficult as controlled conditions may be required.
- One important property of metallic materials is the ability to screen electromagnetic emissions and this often leads to FRP materials having metallic screens added. Conversely, metallic materials need insulation, to improve thermal signature.

Hull monitoring

Hull girder monitoring has taken place historically on naval ships to help validate design assumptions such as long term wave bending moments, and on commercial ships for real time feedback to ship operators. In light of the discussion in 1.1 above, there is likely to be less measurement on naval ships in the future as classification societies are used to provide the routine ship design loads. If continued validation is required, it may be necessary for navies to engage with classification societies collaboratively through organisations such as Co-operative Research Navies.

Currently, there is more interest in the use of hull monitoring systems on local structure of naval ships to monitor crack growth in order to validate crack growth predictions and justify the delay of repairs.

1.1.3 Military Loads

With military loads being an essential and integrated part of the ship structural design, it is necessary for the classification societies to begin developing expertise in these areas. Most of the classification society naval rules have notations or requirements for military design of the ship's structure and where these notations exist, classification societies need to have specialist resource to undertake assessments. In most cases, it is the loading that is different, the structural analysis undertaken has similarities with the non-linear methods used by classification societies for non-military engineering applications. Once the threat has been translated into an engineering load time history, the process of analysis or review of test data is relatively straightforward.

There are some advantages to applying the classification process to a military feature which will require the plan approval, assessment of material characteristics, survey of production, installation and through-life monitoring. The classification process can be used to provide assurance that the capability specified is designed, built and maintained in a naval ship. Classification societies are currently issuing type approval certificates for blast doors, shock mounts and appliqué armour panels, and this will provide assurance in the supply chain.

1.1.4 Residual Strength after Damage

As discussed, the subject of residual strength after damage is becoming an increasingly popular topic for both commercial and naval ships and common assessment methods are used. Whilst the overall approach to progressive collapse is the same, using beam elements and load shortening curves, there is a degree of variation in the determination of the beam element load shortening curves. The introduction of common rules for commercial ships has standardised this to a certain extent but there will be a variance, with results derived from a navy's traditional database of load shortening curves, many of which will have been derived from experimental and analytical data. Alternative approaches are being developed which may look at panel collapse rather than beam element collapse, Underwood (2011).

For a naval ship, it is important to assess the damage from peacetime events as well as those from a military threat. Development of reliable peacetime damage extents is difficult, Zhu (2001), and quite often naval ship designs are assessed to determine the capability inherent in a ship designed for normal environmental loads. It is rare that a residual strength assessment will be allowed to drive the scantlings of a ship design. Similarly, the commercial ship common structural rules stop short of mandating a residual strength assessment against a prescribed peacetime damage.

Military damage extents are either prescribed based on past experience and analytical methods, or they are derived from the extent of damage described by a vulnerability analysis which identifies the number of compartments damaged for a given weapon threat. Empirical calculations can be used to determine the effectiveness of structure in resisting damage propagation.

Whilst flooding may not be explicitly addressed by the residual strength calculations of the classification societies, the use of a damaged waterline or "V" line to determine bulkhead and deck strength will ensure that internal structure is adequate for the damaged condition, provided the damaged extent assumed for structural calculations does not exceed that assumed in stability assessments.

1.1.5 Conclusions

Commercial ship design and naval ship design have clearly been moving towards each other and are nearly at the point of meeting. This is certainly the case for normal sea loads. However, it is important to recognise that the way in which a navy uses a ship may impose fundamentally different loads, which the designer must take account of, and this is wider than just the direct military action type loads.

Opportunities for joint research should be sought so that there are more opportunities to collaborate, co-operate and understand some of these naval differences.

This delegation of some areas of design and assessment should enable navies to refocus on the military loads and retain a specialist core of experts in these areas. If this is done, it is still important for navies to develop joint projects, attend conferences and encourage secondments with the classification societies so that knowledge and experience can be shared.

Lightweight materials do have potential to provide savings in weight, but at a cost, and the full impact of the material across all other ship systems, features and requirements needs to be rigorously assessed. The full costing of a material system from manufacture to disposal is difficult to determine and some standardisation of criteria would help in any objective assessment.

The focus on military loads and residual strength is supported but there may be some benefit in looking at the impact of naval operations on normal ships' load scenarios to ensure that classification rules provide adequate scope for structural safety.

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1.2 Floor and Written Discussions

1.2.1 Matthew Collette

I thank the committee for an excellent and interesting report. On the comparison between commercial and naval structure design, I wonder if the committee can comment it they examined differences on methods for predicting costs, outfitting impacts and other aspects of the "wider" design problem between commercial and naval vessels, and if we have adequate tools to support such analyses?

1.2.2 Albert Frederiksen

DNV's experience is that the military loads, such as shock and blast, have to be treated differently from the ordinary loads. The reason for this is that the military loads are related to the vessel *performance*, and are therefore more an optimisation issue than a question of "pass/fail".

In DNV, military loads are treated as verification of "owner's requirements" instead of "class requirements".

1.2.3 Stuart Cannon

Firstly I would like to congratulate the committee on a very good report. I have a comment and a question. Naval vessels cover a spectrum of requirements depending on the role they are intended for. This ranges from the constabulary role for patrol boats, which are dominated commercial rules, through auxiliaries to front end warships and aircraft carriers which are predominantly warship rules. If we use this approach we may need to include thermal loads from aircraft, such as the J.S.F. on flight decks.

My question is related to ageing warships. We have seen a general increase in the life of warships – some being 40 – 50 years old. This means corrosion and cracks of varying size and sites. Is this included in the analysis of shock and residual strength?

1.2.4 Akihiro Yasuda

I would like to congratulate the Committee in producing a very comprehensive report. I have two comments:

1. As suggested in the report, it is concerned that how the technique and knowledge about naval vessel design are taken care of. Especially for military loads, it is well known that almost all the results and experience about ship shock trials are confidential. In this situation, it seems difficult for class societies to review such results.

On the other hand, recent progress of numerical simulation makes it possible to predict large and complex phenomena including full-scale ship shock trial. As for the structural

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response to an underwater explosion, the analysis results of full ship shock trial are gradually conducted and published by the researchers. Therefore, it seems realistic that the class societies should clarify the phenomena which can be predicted by the numerical simulation or cannot be predicted in the present computational resources. In addition, the numerical results are to be validated through the model scale testing.

2. It is well known that strain rate effects on yield stress affect material behaviour when the material deforms in high rate under large impulsive loads like blasts. In the section about the benchmark of the blast analysis, the description about the strain rate effects on the results, are there any comments for that?

1.2.5 Mirek Kaminski

I have found the committee recommendations very short. Probably this is caused by the restriction of number of pages of the report imposed by the Standing Committee. I think the ISSC community needs more directions for the future research from the committee. Would it be possible to include these directions in Volume 3 of the ISSC Proceedings?

1.2.6 Stuart Cannon

The report does not comment on classification society rules for submarines. Where do you think this will go in the future?

1.2.7 Glenn Ashe

One significant challenge we face as a community is the realisation that naval vessels are primarily manned with younger and less experienced personnel. As a result, we must consider two realities when we do naval structural design:

- We must expect unusual loadings resulting from operation of the vessel outside of its expected design envelope, and
- we must expect the possibility of unforeseen corrosion or structural degradation resulting from inattention to maintenance.

2 REPLY BY COMMITTEE

2.1 Reply to Official Discussion

2.1.1 General Discussion

The members of committee V.5 would like to thank Mr James for his interesting and valuable discussion of our committee report, it is always difficult for an official discusser when he has not seen the content of the previous reports of this committee. Mr. James's discussion makes a number of valuable contributions to the report of our committee and we consider this to be a valuable addition to the committee report.

The discussors comments on chapter 1 of the committee report are generally supportive, the official discussion provides some excellent supplementary information which is of relevance to the committee report and would have been included in the committee report had it not been for page restrictions. The discussors report comments on the similarity between naval and commercial ship structural design and physical environment this supplements the information contained in the committee report.

2.1.2 Similarities between naval and commercial ship design

The difference in usage as mentioned by the official discussor is covered in the report but could perhaps have been given more weight, here we thank the discusser for his input. Usage is covered in the report as part of the 'Concept of Operations' statement, (CANOPS) as defined in the new Naval Ship Code (ANEP77).

The committee agrees with the discussers comments on the limitations of the use of lightweight materials, but the discussion in 2.1 of the report is intended as a general discussion on the possible advantages of these materials.

The committee agrees with the discusser that when looking at requirements and decision criteria for lightweight materials both initial procurement and through life cost considerations should be taken into account.

The committee agree with the discusser about the resistance properties of Aluminium and FRP which inhibit their use in general ships structure for larger vessels. We would also like to draw attention to the example within the report as a representation that sound engineering practice could still yield beneficial weight savings using alternative materials.

One of the major unspoken reasons for the continual use of steel in ship construction is realistically the comfort level among Naval Administrations, Classification Societies, designers, shipyards, etc. with known behaviours of steel naval ships through service history. Pioneering efforts for naval ship designs using alternative materials to steel will always be strongly resisted and highly scrutinized because of the uncomfortable idea of deviating from the norm.

The committee also agrees that there are considerations, other than fire protection of the structure, which are challenges facing the use of alternative materials that can and should be considered, these have been highlighted in previous reports of the committee and are in broad agreement with the discussers comments.

2.1.3 Scope of Military loads

The committee think that the comments on Military Load effects are overly simplified by the discusser, he comments that more effort should be spent in avoiding taking a hit rather than investigating how we mitigate the effects of a hit. This is a simple thing to say but unfortunately weapon designers tend to lead defensive systems design and ships will get hit, therefore to protect people and equipment detailed studies on vulnerability have to take place.

This committee fully agrees with the comments to this chapter 4, mainly based in the idea that Class Society (CS) involvement in the definition of the military loads will be beneficial for the design process and classification of a naval ship. The need of CS to develop as much expertise as possible on the definition of such loading is also agreed. The committee also would like to make reference to committee report for ISSC 2009, where the role of CS in naval ship design were deeply revised including recent advances in military loads definition.

The committee is also less optimistic than the discusser that class rules can handle military loads " just like any other loads". The levels of damage inflicted by weapon effects are varied and improving weapon yield and weapon design means that damage levels will become more severe leading to the need to improve the ships structural design to mitigate these effects.

Characterisation of data this complex in simple expressions is difficult if not impossible Also the underlying data used to develop the rule based criteria is old and based on experimental data, these experiments are expensive to reproduce and new data on more modern weapon effects is being developed, based on the use of multi-physics, models to investigate the effects of the weapon loads.

2.1.4 Residual Strength after Damage

The calculation of the residual strength of damaged structure from a naval vessel point of view is a critical technology which is required to assist in the recoverability phase when a warship is damaged in action. This assists in the captain's decision as to whether his vessel is capable of continuing with its mission or has to seek shelter and undergo repairs.

The assumption that we can use the same empirical models to calculate the strength of damaged ships that are used to calculate the strength of undamaged ships, with some assumptions about the extent of the damage, could be both incorrect and non-conservative. More up to date methodologies are being developed which improve our ability to predict the damaged strength of a ship taking into account different modes of collapse due to the presence of the damage. Some of the references to this work are included at the end of this discussion. These methods need to be further considered and incorporated into rule based design for all ships, never mind just naval vessels.

2.1.5 Conclusions

The official discusser's conclusions are in broad agreement with the committee's own conclusions and make a very useful addition to the conclusions of the report. Again I will take the opportunity to thank Paul James for his considered discussion of our committee report. The committee think his discussion of our report makes a very useful addition to the committee' own report on naval vessel design.

2.1.6 References

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2.2 Reply to Floor and Written Discussions

2.2.1 Matthew Collette

The costs of naval vessels are heavily influenced by weapon and equipment outfitting, the vast majority of the costs lying in this area. With commercial vessels there is more of an influence on cost from structural design and production. It is therefore very difficult to compare the costs of producing these vessels, there are tools available for carrying out this type of comparison but whether they are adequate or not is open to discussion.

2.2.2 Albert Frederiksen

The committee agree with Mr. Frederiksen comments about military loads having to be treated differently from ordinary environmental loads. All structures will have some capability to withstand military loads and local as well as global structural designs can be incorporated to improve this military load capability. I think current design techniques are not accurate enough to produce a straight forward pass/fail criteria but will give a relative measure of the level of improvement in the structural performance when certain design changes are made.

This can be implemented as either a class requirement or an owner requirement I think both approaches can be made to work for improving designs for military loads.

2.2.3 Stuart Cannon

The committee thinks that for Progressive Collapse and Residual Strength of a Naval Vessel current approaches can account for both the effects of corrosion and cracking. In the case of shock loads where the loading will excite both local and global natural frequency response of the structure that corrosion effects can be dealt with but fatigue cracking and propagation of the fatigue crack due to shock loading is not adequately dealt with and requires further research.

2.2.4 Akihiro Yasuda

The committee agree with the comments of Dr. Yasuda about the lack of availability of shock trials data, which have been carried out on naval vessels, due to classification reasons. It is also true to say that commercially available codes are now available which have the potential to carry out complex analysis involving fluid structure interactions for shock, blast and UNDEX loading events. That is why the committee said in reply to Mr James that the role of the classification society in the area of military loads will be severely limited and may remain an area which is dealt with by specialist researchers.

As Dr. Yasuda comments the effect of high strain rate on the material yield stress is well known, and has been used in a number of areas of research such as collision and grounding modeling, the effect of the much higher strain rates involved in shock and blast loadings will have a much more marked effect and these have to be included in any analysis involving shock, blast and UNDEX loadings.

2.2.5 Mirek Kaminski

The committee acknowledge Professor Kaminski's comments and would suggest that this comment would be better addressed by the next Naval Vessel design Committee.

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2.2.6 Stuart Cannon

The committee is aware that some Classification Societies already have rules for Submarine Design and other Classification Societies are actively pursuing the development of Rules for Submarine design. The committee assume that these developments will continue and in the future a number of Classification Societies will have Rules for Submarine Design available for use.

2.2.7 Glenn Ashe

Mr Ashe has made some valuable comments on the future considerations for the design of Naval Vessels and the committee are in agreement that these have to be taken heed of.

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COMMITTEE V.6

ARCTIC TECHNOLOGY

COMMITTEE MANDATE

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

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1 DISCUSSION

1.1 Official Discussion by Walter Kühnlein

The Official Discussion was presented by Jørgen Amdahl.

1.1.1 Foreword

The ISSC Committee Report V.6: Arctic Technology gives a very good overview over the wide range of ice related issues like definition of ice forces, major ice projects and also about codes and standards. The report references quite a substantial number of papers, but due to the limited size of the report (27 pages without references) all topics could only be touched and a few main research projects have been not mentioned at all, i.e. the two main EU founded research projects LOLEIF and STRICE (www.strice.org). As these two projectswere the first and so far only ones where besides the ice forces acting on an offshore structure (light house tower in the Northern Baltic Sea, close to Lulea) also ice conditions like ice thickness, ice drift speed, ice density, ice strength, ice temperature history, etc. have been measured in conjunction with the ice loads. These results have been extensively used for the generation of the new ISO Code.

As mentioned in the report, the Arctic, i.e. ice covered waters are one of the biggest challenges of the next decades, as it is estimated that not only oil and gas, but also mineral resources are to be found in these areas. On the other side these areas are extremely sensitive to any change of the environmental equilibrium. All this information which has been collected during the last 3 to 5 decades are collected and nicely presented in this report.

But what is missing in this report is the fact that "ice is totally different than any other environment where we operate". This even includes deep sea, air and space. Researcher and engineers are used to design systems/units which are in general able to survive by its own, i.e. systems/units that are designed in order to withstand the environmental forces. As an example offshore platforms in the North Sea are designed that they can withstand 100 year waves (waves with a return period of 100 years) without any support from outside, they are just stronger than the waves. Of course this is not a new statement, that is well known and actually, how engineers design everything, so far.

But when going into ice covered waters, especially into heavy ice this approach does not work anymore. At a sudden, structures in ice need to rely on supporting operations, i.e. ice management and this is a total new and sometimes frightening approach for many engineers. I experienced a few times how reluctant engineers reacted when I presented new concepts and philosophies for field developments in ice where ice management was and need to be a substantial part of the entire concept. But if this new operational based approach is considered this will also give a lot of new possibilities to scope ice related challenges. Therefore I would suggest that design philosophies in ice should be included at least as a foreword to the ISSC Committee Report V.6.

The following discussion of the ISSC Committee Report V.6. is using the same section numbering as the report itself. Only section "13 MISING TOPICS" has been included at the end of the paper and is intended to mention topics which should be included in the final (next) committee report. The topics are briefly mentioned and addressed as it is not the task of the discusser to complete the report.

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1.1.2 Introduction

It should be also mentioned that the Arctic development in the late 1970's and early 1980's was mainly caused by the search for oil and gas and it dropped in the late 1980's because of falling energy prices and also the status of the technology at that time was not sufficient for safe operations in these areas.

1.1.3 Environmental and Climate Change

This section gives a short introduction to climate change (or global warming) and how it would influence the current design practice. It is also mentioned that the ice becomes in general thinner but also more movable, which might even increase the ice load on fixed or moored structures in this area. This is in general the right approach, but could be also described a bit more detailed. I personally do not like charts where the y-axis does not start with 0 (as used in Frig. 2) , as this shows always much steeper trends as they are in reality. But this is my personal opinion!

1.1.4 Arctic Ships

In general I agree with section 3, but I would also include operability of vessels in ice. Because in some cases it can become much more economically if a bigger engine as needed is installed.

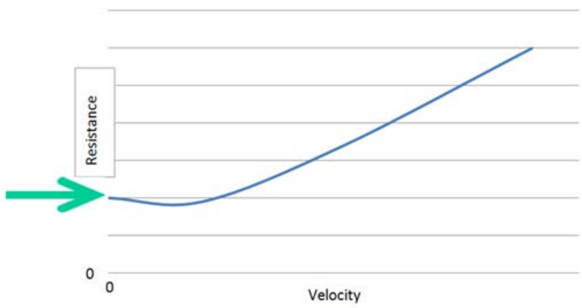

Figure 1: Resistance versus ship velocity (schematic chart)

As a simple example, as the resistance of a vessel in ice does not start with zero for zero speed it can be advantageous (depending on the vessel) if a larger engine is installed, i.e. with 20% more power you might get more than 20% more speed when breaking ice (at low speed). In most of the cases the installed power should be anyhow higher as required by class or rules if the vessel is supposed to operate sufficiently in ice. Operational aspects need to be considered. In ice it is anyhow mandatory that concepts are optimized from an operational point of view and not from an engineering point of view. This also leads back the previous mentioned necessity of having good defined design philosophies where operational aspects governing the design.

Ice classes and rules can and should be only considered as absolute minimum requirements for sufficient operations in ice.

1.1.5 Arctic Offshore Structures

This section is giving quite a good and complete overview of structures in ice. The North Caspian Sea with its challenging requirements due to the limited water depths and extreme ice in winter time could be added to this section. As an example ice management in the shallow waters of the North Caspian is quite different compared to deeper areas. Sucking water in the limited areas of the North Caspian is also quite challenging as the sea chest need to be deep enough not to suck ice and get blocked, but not too deep in order to suck water with soil and erode pumps and nozzles. Again, operational aspects could be considered much more in this section.

As mentioned earlier, ice management should more in the focus of this report. Also operational aspects should be considered when it comes to disconnectable solutions. In most of the cases, where a quick release mechanism has been defined in the design premises, the resulting costs have been not defined. Because, different than in open water where you might disconnect a structure when a hurricane approaches and you come back a week later, in ice covered water you might need to wait up to 18 months prior the unit is connected and can start to produce again. This should be a high motivation to spend extra efforts and costs in order to push the limits and make the system safer.

Operation of moored structured in ice should be explained. As an example "weather vaning" and all related problems for moored structures with a turret should be included in the report.

As mentioned in the report SPAR Buoys are quite a good concept for ice covered waters with sufficient water depths. One of the main advantages would be having a summer and a winter draft (cone shaped in winter draft - in order to reduce ice forces and vibrations). Additionally, the limitations of a turret and problems with "weather vaning"are not existing.

1.1.6 Rules and Regulations for Ice-Going Ships

This section is giving a very good overview about ice rules and general approaches to ice loads and ice design on vessels. It is also with more than 7 pages the most detailed one. Operational aspects could be also briefly mentioned.

1.1.7 Guidance for Arctic Structures

This section is compared to the previous section for ice going vessels rather short (1/2 page) and gives just a brief introduction into ISO 19906 and API standards. This section needs to be much more extended.

Operational aspects should be also included. Some decision guidance what kind of structure shall be used in what kind of environment would be also helpful!

1.1.8 Ice Loads

This section is giving a very brief introduction how to determine ice loads and the definition of local and global ice loads. This section also needs to be much more detailed as some paragraphs are not really giving any detailed information, as an example: "Model basin tests have been reported for moored Spar (Evers and Jochmann, 2011; Bruun *et al.* 2009, 2011), ice ridges (Dalane *et al.* 2009), level ice (Wille *et al.* 2011), moored FPSO (Chernetsov *et al.* 2009), and interaction between ice and ship's bow (Aksenes 2011)."

Especially the problems of fixed platforms with vertical walls causing ice induced vibrations and also the advantage of a cone or a sloped shaped structure, that the ice fails instead of crushing in bending which reduces the force (significantly – only applies for sloped structures) and also eliminates the possibility of ice induced vibrations.

Also some operational aspects should be included, like the reduction of ice loads using ice management.

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1.1.9 Structural Response

This section is giving a brief overview of structural responses. But it does not really go into details. As mentioned earlier the STRICE project should be also mentioned here (www.strice.org) as this allowed extensive investigations of ice induced vibrations which have been published in various papers and journals.

In section 8.2 it is mentioned that a cone has been introduced to various monopile constructions.

Please note as the diameter of a cone is rather large compared to the monopile itself, especially if large tidal variations occur, the force on the much wider cone might be in the same magnitude or even higher compared to the original monopile, but as the ice fails now in bending instead of crushing the risk of ice induced vibrations is eliminated.

1.1.10 Numerical Simulation of Ice

This section gives a brief introduction to numerical simulation of ice. An overview should be given why ice is so complicated to model, i.e. because of the bridle and ducktail failure. The section makes references to very actual papers and publications, some more information from these papers should be presented.

Section 9.3 should first explain what ridges are. Readers who know what ridges are, also know about the rest of this small subsection. Ridges are quite an important design feature for structures in ice, as in most of the cases they are defining the maximum design load and also the mooring design, as they can be quite deep (> 30 m).

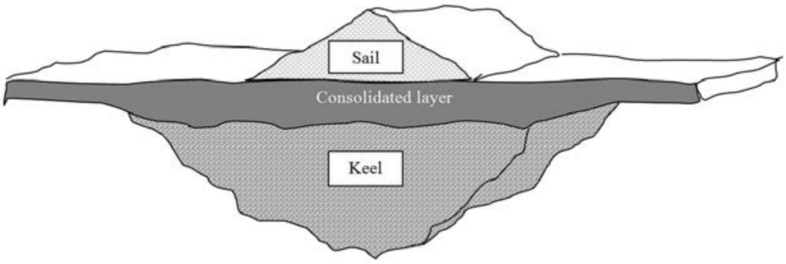

Figure 2: Principle sketch of a typical ice ridge (sail, keel and consolidated layer)

1.1.11 Structural Reliability Analysis

This section is giving a much more detailed overview about structure reliability analysis as the previous sections. This section is rather complete and is going deep enough for such an overview paper. Similar detailed descriptions should be given for sections 6, 7, 8, and 9.

1.1.12 Summary and Recommendations

I fully agree that the committee recommends that ISSC continues this committee, as quite some substantial efforts need to be put into the document in order to make it a good working document. The actual version is not very homogeneous and different sections have been developed and described on rather different levels concerning completeness and information depth.

The extensive list of referenced papers shows that the authors (committee members) are on the right way, but they should transfer more statements/information of the referenced papers into the ISSC Committee V.6 report.

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1.1.13 Abbreviations

In general ice related expressions should be also defined:

- Ice
- Ice failure modes
- Crushing
- Buckling
- Bending
- Ridge
- Rafted ice
- Ice floe
- Ice concentration
- First year ice
- Multi-year ice
- Bridle
- Ducktail

1.1.14 Missing Topics

The following main topics should/need be also included in the final (next) ISSC Committee V.6 report. The topics are just briefly mentioned and explained in the following subsections.

Design Philosophies in Ice

As mentioned in the foreword "ice is totally different than any other environment where we operate". Therefore a section about design philosophies in ice including ice management should be included.

Ice Model Tests

A section about ice model tests including advantages and disadvantages should be added to this document. As the parameters of ice can be modelled in ice model tests, these tests are rather different than open water tests, therefore this would be quite an important section of the report.

Ice Management

Ice management, i.e. pre-breaking the ice with ice breakers in order to reduce the ice loads on the fixed/moored/DP operated platform is an essential factor when operations in ice shall become successful.

This section should also include spraying ice in order to create artificial ice reefs protecting structures or increasing the weight of ice barriers.

The use of ice barriers in shallow waters like in the north Caspian Sea should be also included in this report.

Ice Movement Simulation (numerical experimental)

The movement of ice including the overrunning of structures and island should be integrated in the next version of the report. Especially in shallow waters the ice movement around structures including grounding of ice can and will cause quite some problems.

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Figure 3: Ice Approaching an Artificial Island (left model test – right full scale)

Dynamic Positioning in Ice

DP in ice introduces quite some new challenges which are totally different compared what is known from DP in open waters. In the following the main challenges for dynamic station keeping in ice are summarized:

- Capability of continuous ice breaking (no ramming is possible).
- No (immediate/direct) interaction between thrust and motion.
- Rotating the vessel on the spot is not possible (large turning circle).
- The vessels needs to be orientated always against the drifting ice with the bow or the aft end, as sidemotions are very limited or even not possible.
- If the ice drift stops, a pre-broken ice flow area needs to be generated, in order to be able to turn quickly into the new ice drifting direction.

DP in ice had two special sessions during OMAE 2012 in Rio de Janeiro.

Evacuation in Ice

Evacuation in ice is one of the most urgent problems to be solved. Evacuation vessels which can operate in open waters, brash ice, thin and thick ice are needed in order to evacuate platforms at any time. Risk based approaches are needed in order to lower the risk if evacuation is limited.

Figure 4: Arktos amphibious vehicles evacuation crafts (left: full scale – right: model tests)

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1.1.15 Oil Spill Recovery in Ice

Oil spill recovery in ice is also a problem that needs to be addressed in such a document. At present oil booms have to be put on the ice in order to allow fuel transfer. I think it is quite obviously that they would not work in case of a spill. Even if no perfect solution can be described it should be mentioned in an such an report.

1.1.16 References

The list of papers is rather comprehensive and give a very good overview of ice related research issues during the last 3 decades. As mentioned before the committee should transfer more information and statements from the cited papers into this report.

Also papers concerning operational aspects and philosophies for ice projects should be included. As ice is so different, it should be worth it to mention, why it is so different!

1.2 Floor and Written Discussions

1.2.1 Koji Terai

I think that collecting and sharing ice loads data is needed in order to promote the research efficiently. So, I have one question:

Do the experimental results and measuring data of ice loads that we can use currently have enough quantity and quality to promote the research?

If we do not have enough, what kind of program is needed?

1.2.2 Wolfgang Fricke

Regarding fatigue, we have seen measurements showing that cyclic loads are of a magnitude that cracks may occur. Are the committee members aware of such damages and if so, what are the structural details affected?

1.2.3 Shengming Zhang

1. Comments: A question whether fatigue of ships by ice loads is a problem or not, Lloyd's Register's Damage Data Base showed that about 57% of ice class ships have cracks/fractures at an average of 13 years. Thus, LR has released ShipRight FDA ICE procedures to address this concern and make sure ships have a sound fatigue performance when navigating in ice regions. A number of LNG ships have been assessed using FDA ICE procedures and are currently under construction.
2. A question on engine power requirement: Baltic Rules require minimum engine power while Polar Ship Rules do not. Can the committee comment on this difference? Thanks.

1.2.4 Sören Ehlers

- Concerning the design philosophy, it would be nice to see a discussion with respect to the applicability of the FSICR, being economic measures, to the arctic sea.
- Design support to the choice of fleet, ice class and entrance time to the arctic sea should be included to give guidance to owners and operators.
- What should be the required safety level for arctic vessels?

1.2.5 Jørgen Amdahl

Ultimate limit state assessment of ice actions

- Design rules should have clear separation of loads and resistance, as is the case for offshore codes

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- Loads in IACS PC rules difficult to interpret and compare with ISO19906
- Resistance assessment of plates, stiffeners and girders based on plastic mechanisms is fully adequate as loads are not reversible- corresponds to moderate plastic deformations (this is OK in IACS PC)
- Finite plastic deformations of shell plating may be considered – then based on acceptable strain levels not deformations

Accidental limit state assessment of ship–iceberg collisions

- Large elastic accelerations/displacements reported
- Significant structural damage accepted - but no penetration of cargo tank
- Integrated ice-structure-fluid analysis is required!
- Continuum mechanics modelling of iceberg a challenge
- What local ice-berg shape to use?
- Design guidance needed!

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

The Committee appreciates the extensive discussions. Dr. Kühnlein has added a lot of interesting aspects from his experiences in the industry and R&D. We think these comments are valuable and would help everyone understand the breadth of the issues.

Dr. Kühnlein wanted to include design philosophies in the committee report. We fully agree. The Committee discussed formulations of loads and responses in ice class rules. Section 5 clearly shows that existing ice class rules differ in their framework, which is also quite different from the practice of modern ship designs. There is a strong need for re-visiting the way ice class rules are based upon. As Dr. Kühnlein pointed out, Arctic is a very challenging environment and ice is totally different than any other environment. This unique situation calls for ice management as an integrated part of operation. Consequentially, we need to think differently and adopt new design philosophies.

The Committee report covers ice management for Arctic offshore structures though our coverage is rather brief. We agree that ice management should be given more attention.

Operations related to disconnectable moorings are not covered in current Rules or Regulations (to our knowledge). As stated by the Official Discusser, disconnectable moorings in open water are mainly designed to allow the offshore facility to escape from hurricane conditions. These conditions allow a certain pre-warning time. In Arctic environment disconnection can be required if an iceberg is heading towards the facility. That will also allow a certain warning time. However, in the current thinking, it may also be required to disconnect a facility from its mooring once the ice loading from level ice appears to reach the maximum capacity of the mooring (if ice loading was underestimated, such could happen without much warning time). This requires disconnection under load, which imposes quite different design requirements on the disconnectable mooring. So this example confirms that operational scenarios are needed to make proper designs. This technical reason for requiring clear operational scenario's comes in addition to cost evaluations of capacity of moorings versus availability of the moored unit.

As for the design guidance of arctic structures, we agree that the industry needs to have more guidance. The current standards are certainly insufficient. The ISO standards are a good step forward. But there is a lot of room for further development.

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The discussions on ice loads are well taken. The Committee has already listed ice loads as a highly recommended area for further research. Additional topics that worth investigation are – Up to what extent is an offshore floating structure allowed to be dependent on ice management?What level of reliability and availability should the ice management be required?

Dr. Kühnlein has a valid comment on the numerical simulation of ice. We agree that this is a fast developing area of R&D, and we included this section to give a general view of the related studies. Our committee was tasked to look at the practical side of design analysis of structures, and we placed our emphasis accordingly.

The Committee thanks Dr. Kühnlein for pointing out a few items that the report overlooked, including North Caspian Sea, EU funded projects of LOLEIF, STRICE.

We are pleased that the Dr. Kühnlein agrees with the Committee's conclusions and recommendations. We thank him for suggesting additional topics for the next committee, especially the topics of ice management, dynamic positioning in ice, evacuation in ice, ice model tests, ice simulation.

Our Committee had tried our best during a challenging time. We wish we could have done better if we have had a stable committee during the last three years. We are glad that the ISSC Standing Committee has started identifying new committee members and we are sure that the new committee will be able to provide more data and information about the state of the art technology, which is evolving very fast and is becoming more and more sophisticated.

2.2 Reply to Floor and Written Discussions

2.2.1 Koji Terai

We think that there is a general lack of measurement data of ice loads. Ice loads measurement taken during the FSICR development is still extensively used now when there is a need for re-visiting the ice loads. As we are well aware of, ship designs have been greatly changed during the last few decades. We should have accumulated enough experiences about the structural performance of modern commercial ships, and these experiences must be fed back into the design codes. A very important step is to systematically collect ice loads and ice damage data so that analysis of these data will become possible.

The Committee also notes that some owners and ABS are collecting ice loads information from instrumented tankers trading regularly to the Arctic region. We expect that many such data will become available in the near future.

2.2.2 Wolfgang Fricke

The Committee was not aware of the fatigue study mentioned by Prof. Fricke. We agree ice-induced fatigue needs to be further studied.

We do agree that ice-induced fatigue deserves more attentions of research. We think that the focus should be ice-induced fatigue of side longitudinal end connections and other structural connections at and around waterline.

2.2.3 Shengming Zhang

The Committee noted the study by LR about the ice-induced fatigue. Statistical data of structural damage is always welcome, and a key aspect of statistical study is interpretation of data. We expect that statistical data will be made available to the research community.

As for the minimum engine power in the Baltic Ice Class Rules, the Committee noted that the industry and research community are well aware of this issue. Classification societies have established supplemental guidance on this issue. For example, ABS (2012) specifies an alternative method for rationalizing the minimum power requirement for FSICR.

The Committee is not fully aware of the rationale behind IACS Polar Class Rules.

2.2.4 Sören Ehlers

Prof. Ehlers raised questions about the design philosophy and safety levels. The Committee agrees that these are very important topics that deserve discussion in depth and by all stake holders.We were pleased to note a few research papers on this topic, and we expected to see more research in this line.

The FSICR is the de facto industry design code that is basis of the majority of ice classed ships built up to date. As mentioned in our committee report, the IACS Polar Class Rules and RMRS IR are also important ice class rules. However, what code is the most appropriate to ships sailing to the Arctic regions will be decided not only on the technical aspects. The decision is often influenced by economy, trading region, period of time during the year, local regulations, accessibility of infrastructure supports, among others.

2.2.5 Kaj Riska

We thank Prof. Kaj Riska for the critical review of our committee report. Prof. Riska pointed out the needs of understanding the basic theory behind the IACS longitudinal strength requirement and associated data, the origin of ice-induced vibrations (and the several different theories presented). We will pass these valid comments to the next term.

Though our Committee had tried our best, our committee report still has room to improve. I am very glad to hear that Dr. Riska has agreed to join the committee, and I am looking forward to a much improved committee report in three years.

2.2.6 Jørgen Amdahl

The Committee agrees in general the comments by Prof. Amdahl. The long list of topics by Prof. Amdahl only demonstrates that our knowledge and practice is far from perfect. We would recommend the coming committee to take Prof. Amdahl's suggestions. They are good directions for continued research and development.

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VOLUME 3

COMMITTEE V.7

IMPULSIVE PRESSURE LOADING AND RESPONSE ASSESSMENT

COMMITTEE MANDATE

Concern for direct calculation procedures for evaluating impulsive pressure loadings, namely slamming, sloshing, green water and underwater explosion, and their structural response. The procedures shall be assessed by a comparison of tests, service experience along with the requirements of the rules for relevant classification societies. Recommendations for structural design guidance against impulsive pressure loadings shall be given.

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1 DISCUSSION

1.1 Official Discussion by Odd M. Faltinsen

1.1.1 Introduction

The committee has given a broad review on the subject and I agree with many of their statements. A more specialised but challenging problem which is not mentioned in the report is launching of free-fall lifeboats from offshore platforms which has created attention in Norway due to the economic consequences of operational limits. Safe launching must be possible in as high sea states as possible. The concern is slamming loads as well as acceptable accelerations for the passengers. The design constraints of the lifeboat are, for instance, sufficient volume for the passengers, small weight and good propulsion.

The committee's introductory description of the effect of impulsive pressure on ship structural response is an important message which historically has not always been realised. One must not focus on the impact pressures when the high pressures have a short duration relative to structural natural periods of modes that give dominant contributions to large structural stresses. A good illustration of this fact is the theoretical analysis of vertical drop tests of horizontal aluminium and steel plates on waves and calm water reported by Faltinsen (1997) that was compared with the experiments by Aarsnes (1994) (see also Faltinsen *et al.* 1997). The bending stiffness of the plates was Froude scaled in the model tests to give representative values of the lowest natural structural frequency. For a given drop velocity the maximum pressure showed very large variations for different tests with varying wave conditions including calm water. The maximum pressure varied from below 10 to nearly 80 bar for the largest tested drop velocity of about 6 m/s and was probably influenced by the presence of air cavities and acoustic waves. If the size of the pressure gauges had been even smaller, even higher pressures may have been measured. The maximum stresses were not sensitive at all for the different impact scenarios for a given impact velocity, i.e. there is poor correlation between maximum pressure and maximum stress. The reason is that the main contribution to high stresses comes from oscillations with the natural frequency of the lowest structural mode and the fact that the time duration of the large impact pressures is very short relative to the highest natural structural period. The fluid dynamic details of the pressure loading are insignificant for the maximum structural stresses. The theoretical model is very simple. At the end of the initial slamming phase the sum of the impacting velocity and a space-averaged elastic vibration velocity of the structure is zero. This, together with the fact that the initial deformations of the plate are zero, provides initial conditions for the free elastic vibrations of the plate. The maximum structural stresses occur during this free vibration phase. The time dependence of the generalised coordinate of the lowest mode after the initial impact phase can be described as a free vibration of a mass-spring system of a plate which is fully wetted on the lower side. The mass term is the sum of a generalised structural mass and added mass term. The spring term is due to the bending stiffness. One does not need to know the slamming pressure in the theoretical analysis of structural stresses. The important parameter is the impact velocity. The stresses have according to the theory a linear dependence on the impact velocity. The latter tendency is experimentally confirmed. The case illustrates the need for close cooperation between structural mechanics and fluid dynamics.

When considering global response due to slamming, it should be noticed that both

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the water entry and exit phase may matter. The water entry and exit phases are associated with increasing and decreasing wetted surface, respectively.

1.1.2 Local Slamming

General

Section 2.1 mentions the importance of the relative impact angle which means that the roll angle can be an important parameter. The latter fact implies that more attention should be given to oblique sea. Structural damage in oblique sea due to bow-flare slamming has been reported by Yamamoto *et al.* (1985). Large-amplitude rolling was an important contributing factor.

Fundamental Hull-Water Impact

Section 2.2 deals with fundamental hull-water impact. 2D flow assumptions are typically made. The fact that experimental errors exist is often ignored when numerical calculations are compared with experiments. Both bias and precision errors may matter. Investigation of precision errors requires repetition of tests. Bias errors can, for instance, be due to 3D flow in experiments that were intended to be two-dimensional. Other possible bias errors are mentioned later in this section. One procedure is to use endplates to achieve 2D flow. The latter fact implies that the size of the end plates should be investigated. I have seen tests with obviously too small end plates. Another technique is to measure on a midsection of a 3D structure with constant cross-section. The length-to-“beam” ratio may become too small at the end of the drop for the 2D assumption to be true. Here the “beam” refers to the breadth of the instantaneous water plane area (Zhao et al. 1996). Zhao *et al.* pointed out an inconsistency in measured vertical force and pressures for the bow flare section referred to in Figure 1 in the committee report. This indicates measurement errors and has relevance for the comparative study between different numerical methods with the experimental pressure at one position that is presented in Figure 1 in the committee report. The boundary element method used by Zhao *et al.* (1996) agreed very well with measured force while it over predicted the pressure. Since theoretical results for slamming are normally for constant water entry speed, it is important during the tests to have as constant water entry velocity as possible in order to minimise the effect of the acceleration dependent force.

There exists a broad variety of CFD methods. Some methods use approximate free-surface capturing methods such as the volume-of-fluid, level set and color-function methods. Verification and validation are basic requirements. Verification involves benchmark testing, convergence studies and satisfaction of global conservation of mass, momentum and energy. A good example on benchmark testing is comparison with the similarity solution results presented by Zhao and Faltinsen (1993) for water entry of upright and rigid 2D semi-infinite wedges. The water entry velocity is constant, gravity and air flow are neglected and potential flow of an incompressible liquid without surface tension is assumed. The fact that inviscid liquid is assumed is an unimportant error. Anyway, it is easy to set the viscosity coefficient equal to zero and neglect turbulence in the input to a CFD code solving the Navier-Stokes equations. I can refer to two examples were a benchmark test as that was done. Two master students independently used two different commercial CFD codes. Each student used only one of the computer codes. Both of the CFD codes were based on the finite-volume method to solve the governing equations and the volume-of-fluid method to capture the free surface. Since human errors due to the user happen, I will not mention the names of the commercial computer codes. In one case good predictions were obtained

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for very low deadrise angle while the other student obtained good results only for deadrise angles larger than 45 degrees. A small deadrise angle is challenging for a CFD code. The same is true for a boundary-element code with correct free-surface conditions. The rapid change of the flow at the spray roots requires locally small cells/elements or many particles depending on which numerical method is used. The committee report presents in Figure 1 a comparison of pressure between different numerical methods and experiments for impact of the bow flare section mentioned above. The case is relatively simple and does not prove the applicability of the methods to more challenging cases with small local deadrise angles such as during the initial water entry of a bulbous section. One of the SPH calculations presented in Figure 1 show large pressure oscillations which often happen with particle methods. Marrone *et al.* (2011) have modified the original SPH method where the undesired effect of spatial and temporal pressure variations is minimized. I would have appreciated that convergence tests of the numerical code were discussed in connection with Figure 1 in the committee report. It is relevant in this context to mention comparative seakeeping tests of the S-175 ship that I was involved in as a member of previous ITTC seakeeping committees. The experiments done by different organisations showed non-negligible variations. Calculations done with the same strip theory showed also non-negligible variations. Comparative tests of slamming pressures for difficult cases should be encouraged. The experiments and the use of a given method should involve different organisations. This is the type of work that can be organised by ISSC and ITTC.

A challenging problem during water entry is ventilation which may cause non-viscous flow separation from curved body surfaces. An example is during water entry of bulbous sections. Rolling and transverse velocity of ships combined with water entry can also cause flow separation. Sun and Faltinsen (2009) studied numerically the free water entry of a rigid bow-flare ship section with strongly nonlinear free-surface effects. The effects of the roll angle on the forces and pressure distributions on the ship section were investigated by a boundary element method with exact free-surface conditions within potential flow theory without surface tension. The non-viscous flow separation model is described in detail by Sun and Faltinsen (2006) (see also Sun, 2007) and involves detecting pressures smaller than the atmospheric pressure on the body surface next to the free surface. Sun and Faltinsen (2009) found, for the ship section studied, the vertical forces did not change much with the roll angle when the roll angle was small, whereas the horizontal force clearly increased with increasing roll angle. As the roll angle becomes larger, there will be a stronger impact on the flare surface, which can cause very high localised pressure in the flare area; the latter effect may cause hydroelastic effects. Non-viscous flow separation from the section bottom can occur for large roll angles, which was demonstrated numerically by an example. Flow separation significantly influences the pressure at the section bottom while the free-surface elevation and pressure distribution on the windward side are not apparently affected. Comparisons between the calculations and the model test results by Aarsnes (1996) are affected by experimental bias errors, induced, for instance, by the oscillatory motions of the rig and the upward force effects of the elastic ropes. 3D flow effects may not have been important in the tests.

Hydroelastic Interaction

It is good to see the many reported hydroelastic studies involving different materials. I would have appreciated more discussion on when hydroelasticity matters for local response and for which structural members it has primary importance, i.e. similar to

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Faltinsen (1999) who studied the relative importance of hydroelasticity for an elastic steel hull with wedge-shaped cross-sections penetrating an initially calm water surface. Stiffened plating between two rigid transverse frames was examined. A hydrodynamic strip theory with a Wagner-type method in combination with orthotropic plate theory was used and the focus was on stresses in the second longitudinal stiffener from the keel. It means that the studied problem cannot be analysed as a 2D problem. The stresses in the longitudinal stiffeners are more important to study than the stresses in the plating. Non-dimensional parameters were used to show when hydroelasticity matters. The importance of hydroelasticity for the local slamming induced maximum stresses increased with decreasing deadrise angle β and increasing impact velocity V. The bending stiffness but not the structural mass is an important parameter. Using realistic structural dimensions and relative impact velocities for ships implies that hydroelasticity may have to be considered for local slamming for deadrise angles less than about 10 degrees.

Sun and Faltinsen (2006) have also studied the water impact of an elastic cylindrical shell by coupling a boundary element method for the water flow and a modal analysis for the structural responses. It was shown that the initial water impact, the flow separation from body surface and the ventilation near the free surface can affect the structural responses at a later time of the water impact.

Wave Impact

Section 2.4 deals with impact loads on both the columns and the underside of large offshore platforms. I would add to the description on the use of a numerical wave tank with a CFD code that dispersion errors in the incident waves may happen when a CFD code with a free-surface capturing method is used. The latter difficulty is dealt with by using small cells in the free-surface zone. The committee refers to numerical calculations that include viscous effects. Viscous effects are normally considered secondary in impact problems. However, if propagating waves hit the vertical front of a horizontal deck, the flow will separate from the front edge when the water subsequently moves downwards from the front. A viscous code is beneficial then.

An air cavity may be formed during wetdeck slamming such as in Abrahamsen's (2011) (see also Abrahamsen and Faltinsen, 2012) tank-roof impact studies. High-speed compressible air flow matters in a small time period prior to the closure of the air cavity and is difficult to numerically solve. There is a singular tendency in the numerical velocity and pressure predictions at closure. The closure problem has similarities with the "water hammer" problem. The impact causes inwards water jets to the cavity which are also challenging to handle.

Wetdeck slamming on catamarans and offshore platforms are similar problems. Wetdeck slamming has also similarities with slamming on a nearly flat overhang at the transom of a container vessel. Both local and global effects should be considered. An example on the importance of both water entry and exit phases for global effect of wetdeck slamming was illustrated by Ge *et al.* (2005) for a high-speed catamaran by means of experiments and simplified theoretical analysis involving frequency-domain strip theory without hull interaction. The magnitude of the negative forces during the water exit phase can be as large as the maximum force during the water entry phase. Since the Wagner method does not apply during water exit, a von Karman method was used. Using the Wagner method partly during the water entry phase had a small influence on the global response. The fine details of slamming occurs on a very small time scale relative to the time scale of global response and are therefore not important for global response. The nonlinear Froude-Kriloff and hydrostatic forces did also contribute. Both the water entry and exit forces must be considered for properly studying the global response. The latter fact can easily be illustrated for heave and pitch response where the duration of the deck wetting is smaller than one quarter of the natural heave and pitch periods. The force impulse determines the response and only considering the water entry phase would obviously lead to highly conservative response.

The global analysis by Ge *et al.* (2005) does not consider the fact that local hydroelasticity may have an important effect on the local slamming induced stresses when the angle between the impacting free surface and the body surface is small. Since the time scale of the local response problem is much smaller than the time scale of the global response problem, the local response problem would require a separate analysis.

Helmers *et al.* (2012) recently developed an efficient Monte Carlo simulation approach to perform the stochastic analysis of slamming loading on marine structures in irregular seas, while a simple Wagner method was used to evaluate the impact force. The probability distributions of the maximum impact forces were addressed. It was found that the deadrise angle, up-crossing level, flow separation from the knuckle, vertical motions and roll motions can influence the maximum impact force at the high probability level.

After the section mentioning the model test performed by Baarholm (2009) and the consecutive CFD computation by Kendon *et al.* (2010), the following can be added:

Vestbøstad (2009) also performed CFD computations comparing with this model test, using the CIP method following Hu and Kashiwagi (2004). The focus of this work was to obtain as accurate wave kinematics as possible for the incoming wave. A numerical wave tank was therefore used to generate the waves. However, only regular waves were used in both experiments and simulations. This is also the case for the work performed by Iwanowski *et al.* (2010), and is common practice for this type of studies performed by the offshore industry. However, recent model tests (see Scharnke *et al.*, 2012) show that the forces obtained using regular waves differ from loads obtained using extreme wave crests generated from irregular waves. This is a major challenge for the CFD methods, as only deterministic, regular waves are usually generated. 5^{th} order wave kinematics are often used as input at the inflow boundary in such simulations. The wave kinematics beneath a steep irregular wave may differ substantially from 5^{th} order Stokes kinematics, leading to increased loads.

Concurrent Modelling of Waves, Ship Motions, Slamming Loads and Structural Responses

The limitations of CFD methods due to the required CPU time are clearly illustrated in the committee report. Recent examples on coupled CFD and structural analysis of whipping and springing of ships are provided by El Moctar *et al.* (2011) and Oberhagemann and el Moctar (2012).The 2D generalised Wagner method presented by Zhao *et al.* (1996) has been popular to use as a time-efficient numerical tool in combination with a ship response analysis. The 2D generalised Wagner method is able to handle sufficiently accurate larger local angles between the impacting free surface and the body surface than the Wagner method. It is worthwhile to mention some of its limitations. It requires that the instantaneous breadth of the water plane increases with time, i.e. the complete water entry of a bulbous section cannot be considered. The latter fact implies that fictitious body shapes are introduced in practice. The assumption

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of 2D flow is an important limitation for some bow-shapes. The 3D generalised Wagner method was presented by Faltinsen and Chezhian (2005). However, it is not clear in general how to apply the 3D method to a ship in waves. Further, the forward speed effect on slamming has to be incorporated. A quasi-steady approach of forward speed effects on slamming has been reported, i.e. the steady wave elevation at different instantaneous submergences was accounted for. The error in neglecting dynamic effects on slamming due to the forward speed needs to be studied. We should ideally solve the slamming problem as a fully integrated part of the ship response without doing a separate slamming analysis. A fully integrated analysis was done by Sun and Faltinsen (2011) for a planning vessel by using a 2D+t theory based on potential flow with a 2D boundary element method in head sea. Fully nonlinear 2D cross-sectional flow problems were solved and the flow separation from chine line can be simulated. The predicted heave and pitch motions were compared with experiments and the agreement was good. Nonlinear effects were shown to be more important when the incident wave encounter frequency is close to the heave and pitch resonance frequencies. Large vertical vessel accelerations occurred as a consequence slamming. The 3D flow effect near the transom stern, which is neglected in a 2D+t theory, shows non-negligible influence on the predicted bow acceleration near the resonance wavelength. A 2D+t theory is also relevant for semi-displacement vessels but not for the vertical response of displacement vessels.

Further studies are needed to incorporate slamming as a fully integrated part of the calculation of wave-induced ship response in a time-efficient way and such that e.g. 3D flow and forward speed effects are correctly accounted for. It is appropriate to assume potential flow of incompressible water in such an analysis. However, using state-of-the-art nonlinear boundary element methods is presently too time-consuming. We are now working on developing a more time-efficient potential flow solver which we have called the Harmonic Polynomial Cell (HPC) method. It implies that the water domain is divided into cells. In each cell a set of polynomials that satisfy Laplace equation is used. Exact nonlinear free-surface conditions are satisfied. The method has been shown to be very time efficient and accurate for idealised problems (Shao and Faltinsen, 2012 a). However, there is some way to go before we can prove the efficiency and accuracy in concurrent modelling of waves, ship motions, slamming loads and structural responses.

1.1.3 Global Slamming

In section 3 on global slamming it is stated: "In recent years, the research on nonlinear wave load calculations has made some progress. Many methods have been introduced, including first order theory, second-order theory and the body nonlinear theory. The nonlinear factors include the speed square of pressure expression, wet surface and free surface. Through a large number of studies it is shown that the dynamic nonlinearity is mainly due to the body nonlinearity together with the free-surface nonlinearity." First of all, what are the references to these studies? Further, I would appreciate more precise definition of terms used. Is the framework for the investigations an approximate theory, e.g. is one referring to so-called blended methods? Does second-order theory mean that it is only the incident waves that are described by second order theory or is some approximate methods used to account for the second order effect of the ship? It is relevant to refer to a somewhat different case examined by Shao and Faltinsen (2012 b) that does not involve slamming but illustrates the importance of nonlinear free-surface effects. Second-order springing excitation was studied. It was demonstrated by a complete second-order theory accounting for wave-body interaction

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that the second order potential gave clearly the dominant contribution. A so-called blended method does not account for this fact. Generalising such a method to include higher order than second-order hydrodynamic effects would be impractical and I can therefore not make a firm statement about a scenario with combined whipping and springing.

1.1.4 Sloshing

General

Faltinsen and Timokha (2009) describe the many different hydrodynamic impact scenarios that may happen in a tank as a function of the filling ratio. Shallow liquid cases and high filling ratios may involve flip-through or gas cavities.

I agree with the committee's statements about the many fluid dynamic parameters that may matter in analysing slamming induced structural response due to sloshing. By fluid is meant gas and liquid. Thermodynamic effects may also matter for LNG and NG. Further, hydroelasticity is of concern. Sloshing-induced slamming in LNG tanks is for me the most challenging slamming case. I agree with the committee that CFD has limitations which reflect the fact that model tests are the basis in design. However, model tests are also limited due to the fact that all fluid dynamic and thermodynamic parameters that may be important are not considered. Further, the tank model is normally assumed rigid. It is challenging to properly model the structural properties of a membrane tank in model scale. The time scale of a fluid dynamic phenomenon such as acoustic effects relative to natural periods of structural modes contributing to large structural stresses is important in judging if a particular fluid dynamic effect matters. If a fluid dynamic effect occurs on a time scale much shorter than important structural natural periods, the details of the fluid dynamic effect do not matter. An idea about important structural natural periods can be obtained from the numerical studies by Graczyk (2008) who examined slamming load effects on a part of the Mark III containment system. The hydrodynamic part of the analysis was strongly simplified while the structural modelling was complete. Typical main dimensions of the tank could be a length of $43\,m$, a breadth of $37\,m$ and a height of $27\,m$. Because the corners complicate the analysis and structural details were not available, the studied segment of the containment system was not adjacent to corners. The lateral dimensions of the panel were. This corresponds to an assumed span of girders and stiffeners in two perpendicular directions. The thickness of the segment was approximately $300\,mm$. The resin ropes, the steel plate and two layers of plywood with a layer of foam in between were included. These components are the most important in a dynamic analysis.

The lowest modes are governed by the steel-plating response. The bending response of the plywood next to the resin ropes matters from about $300\,Hz$ dependent on how the added mass was estimated. Because the steel bending causes tension/compression of the plywood, there is also important plywood response associated with the lowest mode.

A slamming case is analysed numerically in terms of response spectra. An average slamming pressure of 10 bar acting on the considered segment was assumed. The time duration of the loading was $3\,ms$. The effect of added mass was included in a very simplified way. The maximum response values were of significance for the evaluation of the structural strength. Four different locations were studied. It is not only the lowest modes, governed by the steel response, that matter. There is a significant influence from modes with a range of natural frequencies from about 100 to $500\,Hz$.

An important effect of these higher modes is compression of the foam and local bending of the plywood plate adjacent to the resin ropes. The effect of liquid compressibility is believed to matter for frequencies of the order of 1000 Hz and higher if the influence of bubbles in the liquid is neglected. A mixture of gas and liquid can significantly lower the speed of sound and thereby increase the time scale of acoustic effects (Faltinsen and Timokha, 2009). Even though the committee refers to a publication by me saying that the change of the speed of sound due mixture and gas are likely to be of secondary importance, I must confirm that I am uncertain about my statement.

If the ratios between the impact duration and important natural periods are small, the fine details of the hydrodynamics are not needed in describing what the maximum structural stresses will be. In the introduction we briefly described the analysis by Faltinsen (1997) when the ratio between the impact duration and the important natural period is small. The situation for the membrane structure considered by Graczyk (2008) is different. Significant response of the lower plywood occurs already during the slamming impact, i.e. before the free vibration phase. This is both due to the slamming duration and the higher natural frequency of the lowest important mode ($125 - 165\,Hz$).

Model tests of slamming and sloshing are typically done with prescribed tank motion which may be found by calculations as a realisation of the ship motions in representative sea states. The calculations must account for the mutual interaction between ship motions and sloshing. The 2D numerical calculations and experiments by Rognebakke and Faltinsen (2003) with forced harmonic sway motion illustrate the mutual interaction between sloshing and wave-induced ship motions and the fact that nonlinear sloshing matters. The external flow can to a large degree be based on linear potential flow. However, nonlinear viscous roll damping must be accounted for. There are different linear potential flow methods such as a 3D method where the forward speed effect is only accounted for through the frequency of encounter. The accuracy of the latter 3D method is unknown to the author due to the fact that, for instance, the explicit forward-speed dependent terms considered in strip theories such as the Salvesen-Tuck-Faltinsen (STF) method are not included. How much the latter 3D method differs from the STF method when the STF method is an appropriate approximation needs to be investigated. An example of a more complete 3D potential flow theory involves solving the so-called Neumann-Kelvin problem in the frequency domain by using a Green function satisfying the radiation condition and the free-surface condition with explicit forward-speed dependence. There is no interaction between the local steady and unsteady flow. The complexity of the Green function and a line integral along the intersection between the mean free surface and the ship surface in the representation of the velocity potential makes the method numerically challenging. Rankine singularity methods are used when the interaction between the local steady and unsteady flow is accounted for. If an inertial coordinate system is used, the so-called m_j-terms in the body boundary conditions are numerically challenging and fundamentally wrong for sharp corners. The latter problem was avoided by Shao and Faltinsen (2012c) by using a body-fixed coordinate system. The sloshing effects ought to consider nonlinear effects which can cause 3D flow such as swirling, diagonal waves and chaos in prismatic tanks with length-to-breadth ratio around one (Faltinsen and Timokha, 2009). The latter can occur even though the forcing is along a tank wall. A linear theory will then only account for 2D flow. Tank roof impact may also affect the global sloshing induced forces and moments (Faltinsen and Timokha, 2009). Even though CFD is not recommended in general for sloshing-induced slamming, it may better describe the global effect of sloshing. However, the computational speed of CFD methods make it in practice unrealistic for long time simulations in a sea state. The nonlinear multimodal method (Faltinsen and Timokha, 2009) is a fast method which from a CPU point of view can realistically simulate the effect of a sea state. Assumptions are potential flow of an incompressible liquid without overturning waves. 3D effects can be considered. However, the method has not been developed to the stage where it can be used in engineering calculations. One drawback is the difficulties in handling shallow liquid cases with realistic tank excitation amplitudes. Then we are left in practice with linear sloshing theories which are fast and are commonly used. What errors are caused in slamming induced structural stresses by using calculations of tank excitations as a basis for model tests should be investigated. An issue is also the statistical analysis of the response.

Since sloshing-induced slamming causes filling restrictions in prismatic membrane tanks, a natural question to ask is if there are ways to reduce the load level. Swash bulkheads are a possibility from a hydrodynamic point of view. However, it seems impossible to use in membrane tanks. The IHI SPB self-supported prismatic type B tank with aluminum-alloy as material and used for LNG cargo is equipped with swash bulkheads. A swash bulkhead is typically placed in the middle of the tank perpendicular to the main flow direction. The opening area ratio of the swash bulkhead is a main parameter. If it is small, an important effect is the change of the highest natural sloshing period to a level where sloshing is less severe. The latter effect depends on the excitation level. Flow through the holes causes flow separation and thereby damping of resonant sloshing. It is illustrated by 2D calculations in Faltinsen and Timokha (2009) how the wave amplitude response depends on the sway excitation of a rectangular tank as a function of forcing frequency and solidity ratio. The solidity ratio is one minus the open area ratio. Comparisons between experiments and theory for non-shallow depths of rectangular tanks with nearly 2D flow and sway excitation are presented by Faltinsen *et al.* (2011a and b) for a wide range of solidity ratios and frequencies. Germanischer Lloyd states that the total area of perforation of swash bulkheads should not be less than 5% and should not exceed 10% of the total bulkhead area. The hydrodynamic studies mentioned above indicate that minimum wave response for realistic tank excitation occurs for higher open area ratios; let us say an open-area ratio in the order of 0.2. However, final conclusions from a hydrodynamic loading point of view require that realistic tank excitations are considered together with focus on sloshing-induced slamming.

Experimental observations in shallow water depth for sufficiently large harmonic excitations reveal impact events on the swash bulkheads caused by steep wave profiles hitting the bulkhead (Firoozkohi, personal communication, 2012). Most of these impact events are seen for large solid area ratios and frequencies clearly larger than the lowest natural frequency for the clean tank. In the absence of pressure measurements on the bulkhead, qualitative calculations using visual photographs and pressure impulse theory give pressure values comparable to slamming pressures that take place on vertical tank walls due to sloshing impacts. Direct pressure measurements and further theoretical analysis are needed to prove the qualitative calculations.

Model Tests

It says on line 4 in the 3rd paragraph on page 18 in the report that: "Authors conclude that the leakage is not the main cause of decay and that the heat transfer between air and water might be important." This is unclear and can be written: Authors

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conclude that air leakage was not present after the first period of oscillation and is hence not a source of the general decay in their experiments. Based on a simplified analytical model, it was found that the heat exchange between the air inside the air pocket and the surrounding water and tank wall contributed to the decay of the air pocket oscillations. In the same paragraph it can be stressed that air and water were used.

1.1.5 Green Water

I would like to add some supplementary material to the report. A systematic and comprehensive description of the green water-on-deck phenomena is provided by Faltinsen and Greco (2011) on the basis of experiments (directly performed or from other investigators) and of 2D numerical simulations based on a Boundary Element Method (BEM) and on a field method solution. The main water-shipping scenarios were identified as: dam-breaking (DB) type, where the shipped water propagates similarly as the flow generated after a dam breaking; plunging-wave (PW) type, where the water invades the deck in the form of a large scale plunging wave hitting the deck or superstructures; initial plunging plus dam breaking (PDB) type, where the water enters the deck in the form of a small scale plunging wave hitting the deck near the bow and then propagates as in a DB event; hammer fist (HF) type, where a rectangular-shaped liquid mass rises obliquely above the deck and then splashes violently against it. The PDB appeared as the most common scenario, PW and HF the less common but also potentially the most severe. All types of water shipping can lead to water impacts against obstacles on the deck. The PDB, PW and HF cause also impacts against the deck and lead to more or less pronounced air entrapment which can affect the resulting green-water loads. From the study, in general the numerical analysis of green-water occurrence and severity appears rather difficult due to the complex phenomena possibly involved and the intrinsic nonlinear behaviour.

The DB large-scale features can be simulated coupling a suitable seakeeping solver with a shallow-water approximation for the in-deck liquid evolution, as proved by the promising numerical and experimental studies by Greco and Lugni (2012) and Greco *et al.* (2012). The adopted solver combines a weakly nonlinear external solution for the wave–vessel interactions with a 2D in-deck shallow-water approximation, and a local analytical analysis of the bottom-slamming phenomenon. It can handle regular and irregular sea states and vessels at rest or with limited speed, expected in rough seas. The solver was compared with 3D model tests on a patrol ship at rest or small forward speed in head-sea regular waves. From the investigation the wave-body interactions can lead to slamming loads with different features depending on the location of the impact: on the hull bottom, the pressure evolution was typically characterised by a church-roof behaviour, with the first short peak due to the water impact against the structure and the second mild rise due to wave-reflection effects; on the ship deck, the pressure has a double-peak behaviour near the superstructure, with the first peak due to a water-wall impact and the second peak caused by water falling and impacting on underlying liquid, and a single-peak behaviour near the bow, due to the new liquid entering the ship deck; on the side hull, the pressure has a church-roof behaviour for mild conditions and a double-peak behaviour for severe conditions. Recently Greco and Lugni (2012) have used the same method and 3D experiments on a FPSO model to investigate the occurrence of parametric roll with water on deck. Numerically it is found that the green-water loads support the parametric roll excitation for the studied cases. As expected the instability develops after a transient phase where the roll motion is characterised by both the excitation (incident-wave) frequency and the

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roll natural frequency that eventually dominates the signal. As a result the water on deck is first periodic with the excitation period and then with the roll natural period, say T_{4n}, which is affected by the nonlinear wave-body interactions. For the examined cases, T_{4n} tends to reduce as the incident wavelength-to-ship-length decreases.

To handle general water-on-deck scenarios the shallow-water approximation is not suitable and numerical methods able to handle breaking and fragmentation phenomena are needed. On the other hand, the state-of-the-art solvers are not able yet to provide accurate results and reliable statistical investigations of the local and global green-water loads in the case of realistic geometries due to the demanding memory-space and CPU-time requirements. A compromise between capability, accuracy and efficiency could be represented by hybrid methods based on Domain-Decomposition (DD) strategies, where the problem solution is split in time and/or in space among different solvers. Each solver is chosen as the most efficient among those accurate and capable which are available. Recent attempts in this direction are represented by the 2D work of Colicchio *et al.* (2011) handling also air entrainment, and by the 3D investigation of Colicchio *et al.* (2010).

1.1.6 Underwater Explosions

Although underwater explosions have been studied over a century, a large part of the results have limited access. Many physical effects matter. The following additional references should be noted (Zong, personal communication, 2012). Zhang and Zong (2011) decomposed the motions of a ship subjected to underwater explosion into two parts: rigid-body motions and elastic deformations. The effects of rigid-body motions have consistently been neglected in the current literature based on the assumption that they are small. Zhang and Zong (2011) clarified that the effects of rigid-body motions are negligible if the ship under consideration is long, corresponding to longer than approximately $200\,m$ in their study. The effects of rigid-body motions are dominant for small ships, corresponding to about $60\,m$ in their study. Based on their theory and investigations, one can conclude that rigid-body motions reduce the amplitudes and vibration natural periods of the bending moments of the hull girder. This investigation is useful in design of mine-sweepers.

Zong *et al.* (2012) tried to establish an analytical method to consider the dynamic viscoplastic behaviour of a circular plate subjected to underwater shock. Although this is a classical problem, accurate prediction of plastic deformation in the centre of the plate is not easy, if we notice the fact that the earliest prediction in the World War One had an error over 100%, improved to the order of 30% a decade ago. Thanks to the introduction of a double-scale double-phase model which considers the effects of time-scales, local cavitation resulting from rapid plate motion, the prediction error has been reduced to within 10%.

Li *et al.* (2012) continued the work of developing a specialised boundary element method for simulating non-spherical bubble in the presence of a free surface. The trick lies in introduction of a vortex ring when the bubble experiences topological change at the stage of collapse. Numerical results show that the bubble collapse behaviour is more complicated than previously expected near the free surface, exhibiting different jetting formation patterns.

1.1.7 Damage to Structures

An accident involving wetdeck slamming happened 24 March 2010 with MS "Sollifjell" in Norway. A drawing of a longitudinal cut of the wetdeck is shown in Figure 1. The

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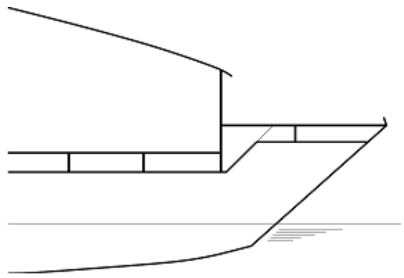

Figure 1: Illustration of the wetdeck of MS "Sollifjell" containing a 45° front panel

wetdeck is flat in the cross-sectional plane. The design of the front panel of the wetdeck was special. It had an 45° angle relative to the rest of the wetdeck. The consequence is that the forward speed can contribute significantly to the relative impact velocity on the front panel and thereby to high loading on the front panel. The loading on the front panel may have initiated the damage on the rest of the wetdeck.

Design procedures of wetdecks considering the slamming load effects have to be improved. The details of the vessel dynamics as well as the slamming load effects have to be accounted for. The wetdeck geometry (bow ramp angle, deck flatness etc.) and material ought to be reflected in the rules. Aarsnes and Hoff (1998) presented full scale experiments of wetdeck slamming on a 30 m long catamaran. The measured maximum strain corresponded to about half the yield stress. This occurred in head sea with significant wave height $H_{1/3} = 1.5\,m$ and ship speed 18 knots. The ship was allowed to operate up to $H_{1/3} = 3.5\,m$. The classification rules did not predict well that the ship had sufficient height of the wetdeck above sea level to avoid wetdeck slamming. It should be investigated if simple formulas for sufficient height of the wetdeck above sea level could be exchanged by direct simulations with state-of-the-art computational tools that properly predict the hydrodynamic effects on the trim angle which is an important parameter for wetdeck slamming on high-speed vessels.

1.1.8 Conclusions

General

I agree with most of what is written in the report. Most of my comments are supplementary. Some concluding remarks relative to my additional contributions are given below.

Local Slamming

Challenging benchmark tests are encouraged for numerical methods. A good example on benchmark testing is comparison with the similarity solution results presented by Zhao and Faltinsen (1993) for water entry of upright and rigid 2D semi-infinite rigid wedges at small deadrise angles.

Sloshing

Attention should be given to the accuracy of prescribed calculated tank motions used in model tests of sloshing-induced slamming.

Underwater Explosions

New numerical and analytical methods are urgently needed to clarify the mechanism and properly capture the physics behind an underwater explosion (Zong, personal communication, 2012).

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Rules

Rules for wetdeck slamming on ships should better reflect the physics.

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1.2 Floor and Written Discussions

1.2.1 Mirek L. Kaminski

First I would like to comment on the classification of the Sloshel project as the model test. It was a full scale test as it included a real containment system and a wave breaking impact having height of ten meters. Second I would like to know the committee opinion about the relationship between local pressure measurements and strains. In my opinion careful preparation of the experiment including the whole data acquisition system and pressure gauges results in a very good correlation. This has been proven in the Sloshel project (Kaminski *et al.* 2011).

1.2.2 Sergiy Baskakov

I thank committee for interesting report. I would like to add followings:

1. It is necessary to specify procedure of generalisation of results of simulation of a slamming on a real vessel. It demands shaping of corresponding similarity parameters.
2. Effects linked with behaviour of a vessel on a wave can be considered only in a complex. For example, lowering of punching shears can be reached having lowered speed. However, having diminished speed we expos a vessel to risk of a stopping by wave. From practical positions it means necessity of installation of minimum admissible speed at a course on a wave. It is especially actual taking into account tendencies of slowing of speed for fuel saving.

1.2.3 Shengming Zhang

Sloshing of LNG carriers is a repeated phenomenon. Some LNG carriers have experienced damages in the containment systems. Can the committee give comments on whether such damage is due to a single peak load or due to the repeated sloshing loads causing fatigue problems? Thanks.

1.2.4 Sharad Dhavalikar

In sloshing experiments or numerical simulations can we distinguish between sloshing pressure and impact pressure? If yes, how? Because classification societies give different formulations for sloshing pressure and impact pressure.

Can the experimental and numerical results be used/validated against rule values?

1.2.5 Sören Ehlers

Concerning structural analysis and the definition of design pressures for LNG sloshing I would like to see the actual material stiffness and ultimate strength measurements of the containment systems to allow for the actual definition of the safety margin. Please comment!

1.2.6 References

Kaminski, M.L, Bogaert, H. and Brosset, L. (2011). Full and large scale wave impact tests for a better understanding of sloshing - Results of the sloshel project. *Proc.* 30^{th} *Int. Conf. on Ocean, Offshore and arctic Eng. (OMAE2011),* Rotterdam, The Netherlands.

2 REPLY BY THE COMMITTEE

2.1 Reply to Official Discussion

2.1.1 Introduction

First of all, the committee members would like to express our sincere thanks to the official discusser, Prof. Odd M. Faltinsen for his kind appraisal of our report and valuable and constructive comments not only on the introduction but also on the other contents of the reports. The committee will reply to each comment or discussion one by one.

The official discusser points that the report did not cover 'launching of free-fall lifeboats from offshore platforms'. We agree that should have mentioned in the report. We are happy to hear that the official discusser agrees on the importance of the effects of impulsive pressure loadings on ship structural response which historically has not always been realised. He also mentions the necessity of close cooperation between structural mechanists and fluid dynamists for further progress in the area of impulsive pressure related.

2.1.2 Local Slamming

General

Regarding local slamming, the committee is satisfied with understanding that the official discusser agrees with the majority of the committee's statements. The official discusser stresses the importance of proper verification of numerical methods including convergence studies and assessment of conservation of mass, momentum and energy. On the Local slamming the mechanics of the system explained by Prof. Faltinsen do make sense, in terms of pressure duration and relation to natural period and the problem being one of initial condition.

Fundamental Hull-Water Impact

The point Prof. Faltinsen makes on systematic computations, in terms of convergence is right, in general. Most of the time we rely on our experience to generate a refined enough mesh and hope it will be all right. However, the computing times involved make it difficult to follow a proper convergence analysis.

He is also right in pointing the example of the ITTC seakeeping committee study where same experiments and same numerical methods (at least on paper) produced differences. We must be aware of such possibilities, both in terms of experimental and numerical uncertainties.

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Hydroelastic Interaction

The official discusser comments that he would have appreciated more discussion on when hydroelasticity matters and for which structural members. It is the understanding of the committee that the official discusser primarily considers dynamic effects and the relation between load period and structure natural period when discussing hydroelastic effects. However, by definition hydroelastic effects are the effects of the response of a flexible structure on the fluid around it and the mutual coupling there between. The committee agrees that the peak pressure is a poor reference for determining the response, since the peak pressure is a sensitive measure. Instead it is the complete pressure distribution that matters.

Wave Impact

The official discusser refers to several studies which the committee, however, considers as relating to global slamming rather than to wave impact even though some mechanisms and aspects of course are in common for these two problem areas.

Concurrent Modelling of Waves, Ship Motions, Slamming Loads and Structural Responses

Prof. Faltinsen discusses planning hulls a lot in this subsection, which we did not consider at all. The point he made on Harmonic Polynomial Cell (HPC) is interesting, but probably more valid for loads or dynamic response in terms of nonlinear potential flow. The use of pressure gauges will provide a measure of hydrodynamic pressure. As such, these pressures are not that useful with respect to the design of local structure. A better way of determining design pressures is to utilise pressure panels where the panels are designed to respond at the same natural frequency as the actual ship structure. The committee is finally glad to understand that we share with the official discusser the view that the development of methods for concurrent modelling of waves, ship motions, slamming loads and structural responses is an important concern for future work.

2.1.3 Global Slamming

The committee should have paid more attention on precise definition of terms regarding global slamming in the report. As mentioned by the official discusser the paper presented by Shao and Faltinsen (2012b) would be very useful to understand the effects of the nonlinear free-surface and second-order hydrodynamic force on global slamming response.

2.1.4 Sloshing

General

As stated by the official discusser in the structural impact problems, together with the amplitude of the impulsive pressure the ratio of the impact duration to important natural periods can represent the physical phenomenon of the impacted structure. However, except unstiffened plates, it is difficult to analytically obtain natural periods of impacted structures. In that regards, the committee expresses thanks to Prof. Faltinsen for introducing Graczyk's paper (2008), in which the important natural periods of the cargo containment panel was estimated.

Model Tests

The committee also thanks to Prof. Faltinsen for his correction of the expressions regarding the decay of the air pocket oscillations.

2.1.5 Green Water

The committee thanks Prof. Faltinsen for pointing out a few references that the committee missed. He describes a more fundamental study dividing the green water phenomenon in a number of different types. The main water-shipping scenarios were identified as: dam-breaking (DB) type, where the shipped water propagates similarly as the flow generated after a dam breaking; plunging-wave (PW) type, where the water invades the deck in the form of a large scale plunging wave hitting the deck or superstructures; initial plunging plus dam breaking (PDB) type, where the water enters the deck in the form of a small scale plunging wave hitting the deck near the bow and then propagates as in a DB event; hammer fist (HF) type, where a rectangular-shaped liquid mass rises obliquely above the deck and then splashes violently against it. Of course, the different types of green water might give rise to different extrapolations from model scale results to full scale.

We fully support the opinion of Prof. Faltinsen that state-of-the-art CFD solvers cannot yet be used for the statistical investigations, excessive CPU requirements and numerical stability are the key problems. Blended methods that split-up the problem and apply different solvers for each sub-problem might indeed be the solution for at least the next period.

2.1.6 Underwater Explosion

Referring the calculation results of Zhang and Zong (2011) Prof. Faltinsen states that the effects of rigid-body motions are negligible if the ship under consideration is long, corresponding to longer than approximately $200\,m$ in their study. The effects of rigid-body motions are dominant for small ships, corresponding to about $60\,m$ in their study. This investigation is useful in design of mine-sweepers. However, when the local rupture due to underwater explosion is considered, we believe the effects of rigid-body motion may be negligible. The committee thanks Prof. Faltinsen for introducing newly published references (Zong *et al.*, 2012 and Li *et al.*, 2012), which can be added to our report.

2.1.7 Damage to Structures

The committee thanks to the official discusser for providing another slamming accident happened 24^{th} March, 2010 with MS "Sollifjell" in Norway. The wetdeck of the catamaran was damaged due to high slamming pressure loading on its front panel which initiated the damage on the rest of the wetdeck. He also comments on full scale experiments of wetdeck slamming on a $30\,m$ long catamaran which was conducted in 1998. The committee would like to support his proposal to investigate the adequacy of the relevant classification rules for wetdeck height above sea level.

2.1.8 Conclusions

General

The committee is happy with the Prof. Faltinsen's appraisal of the report conclusions by agreeing with most of what is written in the report.

Local Slamming

Prof. Faltinsen has encouraged performing benchmark tests for various numerical methods and he also provided an example with which benchmark testing results can be compared. The committee should have conducted benchmark calculations. The committee seriously discussed the possibility of performing new benchmark tests with the test models reported by Mori (1977), which provides the measured pressure histories and permanent deflections of drop-tested aluminum alloy stiffened plate models. However, unfortunately, it was concluded by the committee not to perform for this time due to limited resources.

Mori, K. (1977). Response of bottom plate of high speed crafts under impulsive water pressure. *Jour. of the Society of Naval Architects of Japan*, 142, 297-305 (in Japanese).

Sloshing

Considering the structural design practice of LNG cargo containment systems where their model test results are utilised Prof. Faltinsen's comment on paying attention to the accuracy of prescribed calculated tank motions used in model tests is very timely and by which more reliable structural design of LNG containment systems can be achieved.

Underwater Explosions

The official discusser points out the urgent necessity of new numerical and analytical methods to clarify the mechanism and properly capture the physics behind an underwater explosion. Furthermore, practical design guidance should be provided for close proximity underwater explosions where the shock wave and bubble effects can be coupled.

Rules

The committee agrees with the official discusser requiring the betterment of the present rules regarding the wetdeck slamming on ships to reflect the physics.

2.2 Reply to Floor and Written Discussions

2.2.1 Mirek L. Kaminski

Prof. Kaminski is correct to classify the Sloshel project as a full scale test. The committee agrees on Prof. Kaminski's commenting that careful preparation of the experiment should provide very good correlated measurement results of local pressure histories and strain histories.

Second I would like to know the committee opinion about the relationship between local pressure measurements and strains. In my opinion careful preparation of the experiment including the whole data acquisition system and pressure gauges results in a very good correlation. This has been proven in the Sloshel project (Kaminski *et al.*, 2011).

2.2.2 Sergiy Baskakov

The committee thanks to Dr. Baskakov commenting on slamming from navigational view point. Unfortunately, no committee members have experiences of navigation and it is difficult for us to provide any practical guidance regarding how to practically avoid severe slamming damage in rough sea. However, it has been reported to experience several slamming impacts before changing the heading angle and reducing the ship speed. We believe that if any practical guidance of manoeuvring of ship is provided the number of repetition of slamming impacts causing severe structural damage in a single storm can be reduced.

2.2.3 Shengming Zhang

The committee fully agrees with Dr. Zhang saying that the sloshing of LNG carriers is a repeated phenomenon. Of course, repeated impacts due to sloshing might cause fatigue

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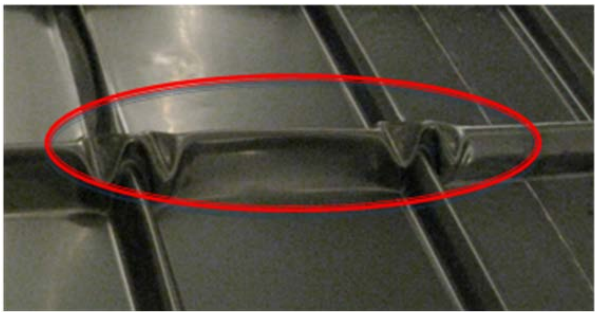

Figure 2: Damaged corrugation of LNG cargo containment due to sloshing

problems. However, more relevant cases can be accumulated plastic deformations due to repeated sloshing loadings as be seen in Figure 2. The figure shows the plastic deformation of the corrugation of an actual LNG containment probably due to repeated sloshing.

2.2.4 Sharad Dhavalikar

Mr. Dhavalikar is asking whether we can distinguish between sloshing pressure and impact pressure. It seems difficult to distinguish sloshing pressure and impact pressure, because sloshing is also an impact loading. The committee agrees on Mr. Dhavalikar's opinion saying that the present classification societies rules regarding the structural design of LNG cargo containment systems need to be more rational considering the nature of sloshing phenomenon.

2.2.5 Sören Ehlers

In replying to Prof. Ehlers the committee would like to categorise the sloshing of LNG cargo containments as a Serviceability Limit State problem rather than an Ultimate Limit State one. Of course, if the impact loadings due to sloshing are severe the structure can be collapsed. However, the reported damages of LNG cargo containment systems reported so far are very localised and not causing the collapse of the whole system.

We believe that in order to treat the sloshing impact of LNG cargo containment systems more rationally the design load needs to be defined not only the peak pressure but also its duration. Furthermore, the allowable extents of damage also need to be provided in the relevant classification society rules for the Serviceability Limit State analysis.

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VOLUME 3

COMMITTEE V.8

YACHT DESIGN

COMMITTEE MANDATE

Concern for the structural design of sailing and motor yachts and similar craft. Consideration shall be given to the material selection, fabrication techniques and design procedures for yacht hull, rig and appendages. Attention should be given to structural issues associated with special fittings as large openings, inner harbours, pools etc and with security requirements. The role of standards, safety and reliability in the design and production processes should be addressed.

CONTRIBUTORS

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Floor Discussers: Simon Benson
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1 DISCUSSION

1.1 Official Discussion by Paolo Moretti

1.1.1 Introduction

I would like to thank the Standing Committee for inviting me to this congress and to review the report of the yacht design committee V.8 as the Official Discusser (OD).

Even if I am not a yacht designer, I feel confident that my contribution from a different point of view – in this case as a Classification Society representative and former yacht surveyor – could be appreciated.

1.1.2 Historical Background

Despite the fact that the yacht industry can take advantage of modern technologies (CAD, CAM, CFD), most probably old yacht designers and builders were able to have a better understanding of their professional tasks. Rules were simpler, level of craftsmanship was higher and the yachting standards were based on a professional top level of quality. Yachting was at that time defined as "the king of sports and the sport of kings". Royal yachts were built using the best materials, rigorous procedures and up to date know-how. In many cases these luxury vessels were designed, built and crewed in accordance with contemporary naval standards. Being also a naval architect by training, a yacht designer was involved in the design and building of warships, cargo sailing ships or steamers, and high speed craft such as steam destroyers or fast motor torpedo boats.

In the first half of the nineteenth century the last objection to steam yachts was removed by the Royal Yacht Squadron rescinding all of the rules which had prohibited these craft being owned by members of the club. It had been decreed in 1827 that any man who owned a steam yacht should automatically disqualify himself from the membership. In 1844 the following minute was approved: "*No steamer of less than 100 horse/power shall be qualified for admission into, or entitled to the privilege of the Squadron*". Although a condition had been imposed, the steam yacht was now acknowledged. In 1873 George Lennox Watson founded the world's first yacht design office. Watson's most famous design, "HMY Britannia", was commissioned by Edward Prince of Wales, subsequently King Edward VII. Among his work in yacht designs Watson designed extensively for the Royal National Lifeboat Institution (RNLI) with his boats becoming renowned for their seaworthiness and durable qualities. High speed steam boats were designed and built by legendary names, such as Herreshoff's yard, working at the same time on luxury yachts and early naval torpedo boats.

By 1900 the gasoline engine was taking place of the steam engine in the smaller launches and the so called "automobile boat" was coming into use. A few years later (starting form WWI) fast motor torpedo boats have been built by the following yacht builders too:

- Elco and Higgings in the United States;
- Thornycroft and Vosper in Great Britain;
- Lürssen and Abeking & Rasmussen in Germany;
- Baglietto and Picchiotti in Italy.

Recently new boat-builders have been created from nothing and, in many cases, this lack of tradition and skill has been marketed as "new concept" proposals in order to attract new potential customers. Lack of professional skills may lead, sometimes, to projects that are either unfeasible or very far from real seaworthiness.

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1.1.3 Motor Yacht Basic Design and Typologies

The term "yacht" has been used in a very broad sense, ranging from a rowing kayak to a three masts sailing ship. In order to have a better understanding of the subject, a more detailed classification (depending on yacht size) could be useful and the authors have managed to provide a comprehensive view of the terminology currently in force to categorise pleasure vessels.

Even if there is no firm lower-end cut-off for the size of a yacht, it can generally be said that a vessel or conveyance used on the water for pleasure, under approximately 30-34 feet (9–10 meters) in overall length is not a yacht but a "pleasure boat" or "recreational boat". Insurance companies define "yachts" as vessels of 27' or more in length, while "boats" are 26' or less (yacht and boat insurance policies are quite different).

According to a common perception a yacht is technically any recreational vessel greater than 20' with an enclosed cabin. The European Directive text considers:

- boats shorter than 24 m as "recreational craft";
- Yachts exceeding 24 m are classified (according to many Flag Administrations) as "large yachts";
- Yachts exceeding 30 m are usually defined as "super-yachts"
- Yachts exceeding 45 – 50 m are usually categorized as "mega-yachts"
- Yachts exceeding 100 m are commonly referred to as "giga-yachts".

1.1.4 Rules and Regulations

The authors made a very accurate analysis of the standards currently applicable to pleasure vessels. Class rules are not harmonized through common IACS (International Association of the Classification Societies) requirements. Statutory regulations may vary depending on which flag the yacht is flying, the intended service (private or commercial) and the dimensions (length and gross tonnage), as per the following examples.

Private Yachts

The mandatory requirements are very light; for the vast majority of Flags a registration survey and a tonnage measurement, carried out by an authorised surveyor, are the applicable standards. The only mandatory international conventions are those relevant to the marine environment (such as the MARPOL Annexes).

Commercial Yachts

Nearly all major Flag Administrations require commercial yachts to be certified in accordance with a specific large yacht safety code. The most popular of these safety codes and the first to be developed is, without any doubts, the MCA Large Commercial Yacht Code (LY2) that has replaced the former Code of Practice for the Safety of Large Commercial Sailing and Motor Vessels (LY1) published in 1997. This Code is applied by the Red Ensign Group Flags (UK, Cayman Islands, Isle of Man, Bermuda, Gibraltar, BVI, etc.) and it is recognised as a reference standard for all the yachting industry. Other Flags have developed similar codes: Luxembourg, Italy, Marshall Islands, Malta, Belize and Holland are some examples. While introducing a stricter set of rules and regulations, if compared to private yachts, the commercial registration is offering to yacht owners the possibility of making profits from the chartering activity of their boats and to take advantage of all the other benefits coming from a commercial operation (in particular VAT exemption on the purchase, sale, bunkering, provisions,

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Table 1: Gross Tonnage and mandatory certification

CERTIFICATE	Over 24 m any GT	$300 \leq GT < 400$	$400 \leq GT < 500$	$\geq 500GT$
LARGE YACHT SAFETY CODE	X	X	X	X
SAFETY CONSTRUCTION				X
SAFETY EQUIPMENT				X
SAFETY RADIO		X	X	X
LOADLINE	X	X	X	X
TONNAGE	X	X	X	X
MARPOL 73/78			X	X
CLASS CERTIFICATE	X	X	X	X
ISM (Safety Management)				X
ISPS (Security)				X

dry-docking and others). The number and type of the mandatory certificates depends on the size of the vessel; those reported in Table 1 is an indicative list.

Main technical features of the commercial yacht codes:

- new ships are usually obliged to strictly adhere to the provisions of the Code;
- existing boats can be granted with dispensations or equivalencies;
- the severity of the safety requirements decreases in case of reduced navigation and imposed operational limitations;
- the safety requirements increase when the yacht has a gross tonnage equal or exceeding 500 GT (corresponding to a full displacement motor yacht of $45-50\,m$ in length);
- the safety codes apply to vessel who are 24 meters or over in load line length;
- yachts are certified to carry on board a maximum number of 12 passengers.

Passenger Yachts

Since the average size of the yachts has dramatically increased over the last five years, it appears evident how limiting the “12 passenger”’ upper threshold is. For this reason the MCA and all the Red Ensign Group has recently adopted a new code, the so called “Passenger Yacht Code”, which allows yachts to transport up to 36 passengers. In accordance with the provision of this Code, the yacht shall have a class certificate as passenger ship (hull, machinery and electrical parts) and a statutory document in line with the requirements of the SOLAS passenger ship with less than 36 passengers, which implies stricter requirements on fire load, means of escape, lifesaving and damage stability.

Recreational Crafts

This category includes all boats having a length below 24 m. The main reference standards are:

- European Directive 94/25/EC as amended by the 2003/44/EC: mandatory regulations, applicable to recreational crafts and components that are intended to be commercialized within the EU, based on ISO standards relevant to hull construction, fire protection, electrical, bilge, stability, etc.

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- American Boat and Yacht Council (ABYC), voluntary standards for boats intended to be used within the USA national waters.

The above mentioned standards have similarities and in this respect it is to be highlighted the commitment of ICOMIA (International Council of the Marine Industry Associations) in establishing an international working group with the mandate of publishing "Global Conformity Guidelines" with the aim of assisting the boat-builders to comply with either ISO or ABYC.

1.1.5 Vibration and Noise

Vibration and noise are crucial topics in the motor-yacht design and the authors have carried out a very accurate comparative study of the comfort class rules published by the major classification societies. Comfort on board of motor yachts is usually associated only with noise and vibration levels. Both these parameters can be predicted, measured and – if needed – reduced taking advantage of several engineering methods. Last but not least, it is possible to assess and certify a "comfort merit factor" based on purpose made class society surveys. Comfort class notation, if not mandatory, can even add resale value to luxury yachts, or it can be used as a reference standard in the contractual specification.

Sea-keeping, intended as the capability to operate in severe weather conditions seems to be an almost forgotten factor within a yacht's basic design. Due to the fact that on fast motor yachts, maximum speed is still considered as a key selling point, many yacht designers adopt very small deadrise angles to gain a few knots, keeping the same power/weight ratios.

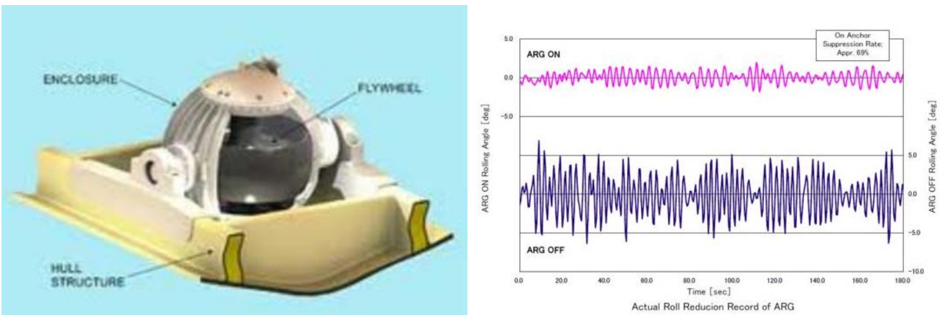

Figure 1: Anti rolling gyro (ARG) stabilizer; Roll reduction records with and without ARG system.

Unfortunately small deadrise angles, even if very efficient from a propulsion point of view, lead to unbearable vertical accelerations and slamming pressures when weather conditions are not perfect. Taking into account the fact that sea-keeping is usually higher on the priority list of professional small craft, these kinds of boats use deep-V hulls, shifting the focus from speed to seaworthiness. Roll stabilization seems to be the only sea-keeping parameter that is currently being considered on board luxury yachts. Uncomfortable roll angles can be effectively reduced using anti rolling gyro (ARG) stabilizers (Figure 1) or through active stabilising fins.

1.1.6 Structural Arrangements and Production Methods

The authors have correctly identified the main technical aspects related to the different type of construction:

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- wood;
- steel;
- aluminium;
- composite material.

Wood

This type of construction is mainly limited to Italy (North Tirrenic and Northern Adriatic areas) and Turkey (in particular in Bodrum and Marmaris). While in Italy there are at least five builders of top class wooden motor yachts, the Turkish tradition is more focused on the traditional schooners built with lamellar wood hulls. Class rules usually have specific structural requirements for wooden vessels up to 40 m; over this size a direct calculation approach is to be adopted.

Steel

This material of construction is commonly used for yachts over 50 m, always in conjunction with aluminium built superstructures. Limited niches of smaller size steel built full displacement motor yachts are still "en vogue" in Holland. The structural criteria set by the class rules are almost the same of the merchant ships of similar size. FEM calculations are often required for the large side openings enclosing garages and other recesses and global strength verification mandatory for all yachts having a length over 50 m. It is to be highlighted how small is the influence of the hull construction on the build of very large yachts, due to the fact that:

- the construction process lasts at least 36 months for a 60 – 65 m yacht, the large majority being spent in the outfitting and finishing activities;
- the direct cost of the steel hull production is very low compared to the overall cost of the yacht;
- a "sub standard" welding and assembling process is, at a later stage, covered by filler and paint.

Aluminium

Aluminium construction is still considered as a valid option for fast planing hulls in the range between 35 and 50 m. Also for this kind of material it is imperative to remain within the 500 GT, otherwise the entire hull and superstructure should be insulated to a "steel equivalent" fire rating, compromising the weight reduction effect and the efficiency and speed of the hull construction process. Aluminium boats represents a very good compromise between high performance and production costs (the mould construction investment being avoided).

Fibre Reinforced Plastic (FRP)

FRP construction is by far the most used in the yachting market, in particular for serial production. Due to the fact that moulds are quite expensive, boat-builders are oriented to spread this fixed cost on as large number of hulls as possible in order to improve the process cost effectiveness. Modern use of large moulds leads to the following effects:

- yacht models lives can be "extended" taking advantage of re-styled superstructures using old hull moulds;
- hull lines, and – in turn – mould shapes, are engineered in a modular way to enable building of longer, wider or deeper hulls inserting only small additional mould removable parts;

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- if needed, yacht moulds can be used to laminate workboats, small passenger ships, or patrol boats;
- owner's freedom to choose a customized project is reduced, and yacht builders are now offering "semi custom" yachts where buyers can request specific interiors based on a basic standard hull layout;
- some boat-builders are now starting to produce yachts of around $50\,m$, made with FRP hulls and aluminium superstructures, in order to combine the serial production advantage of a standard hull mould construction with the greater flexibility and cost savings induced by a customisable superstructure built in aluminium alloy.

Composite materials on large yachts are now used for hulls up to a maximum of 165-170' ($48-50\,m$), the upper threshold being determined not only by the market request but also by the statutory regulations which prescribe that a pleasure vessel engaged in charter activities and over $500\,GT$ should comply with the SOLAS requirements and therefore being built with a "steel equivalent" hull.

The use of new lamination techniques under vacuum, the so called infusion, is granting a significant reduction of the weight and a more controlled and environmental friendly production process.

Yacht Structural Failures

As already mentioned, pleasure vessels are not covered by IACS requirements and furthermore class is not always maintained through the operational life of the yacht, not being a mandatory safety standard: this issue, associated with an almost total absence of Port State Control inspections on yachts, implies a certain lack of databases containing casualties and accidents reports related to the boating industry. Anyway class reports, insurance statistics, legal claims and other institutional sources such as the U.S. Department of Transportation's statistical database on marine accidents, indicates that swamping, fire and explosion, collision, and drowning are the principal causes of casualties within the yachting community.

In the entire history of the Office of Boating Safety, the USCG has imposed a recall for reasons of structural inadequacy on only two boat companies. It seems that there is no significant pattern of hull failures or hazard to human life deriving from an inadequate construction process of recreational crafts or large yachts. Most structural problems seem to be limited to gel-coat cracking and de-lamination of frames in GRP boats. Total structural failure in pleasure craft is rare, because fibreglass hulls give plenty of warning before failing catastrophically.....or may be because boats are almost never used under severe weather conditions.

1.1.7 Outfitting

As clearly identified by the authors, this is the most crucial topic for a large yacht construction, also due to the fact that very important and basic areas of the outfitting are built and surveyed without having in place well defined international standards. Apart from the structural challenges, the two areas of major concern, from the class perspective, are the fire integrity and the stability requirements.

For commercial yachts having a gross tonnage of less than $500\,GT$:

- structural fire protection: machinery spaces, decks and boundaries are to be properly insulated in order to reach A-30 standard in unrestricted service and B-15 standard in short range navigation.

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- fixed fire detection systems should be fitted in machinery spaces, control stations, service and accommodation spaces (smoke detectors and manual call points);
- upholstery composites and suspended textile materials used through the vessel shall be certified non combustible in accordance with IMO FTP Code. As an alternative a sprinkler system or equivalent should be installed on board;
- two separate means of escape for each machinery space or accommodation spaces are mandatory.

For commercial yachts with a gross tonnage equal or over 500 GT:

- structural fire protection: the requirements are derived from the SOLAS passenger ship rules applicable to ships carrying less than 36 passengers; this apply to the subdivision in main fire vertical and horizontal zones, fire integrity of bulkheads and decks;
- fixed fire detection systems should be fitted in machinery spaces, control stations, service and accommodation spaces (smoke detectors and manual call points);
- automatic sprinkler system is always fitted;
- two separate means of escape for each machinery space or accommodation spaces;
- restricted use of combustible materials for the interiors.

All yachts shall comply with intact stability requirements and, if commercial yachts in unrestricted navigation, shall meet the damaged stability criteria and being subdivided in watertight compartments bounded by watertight divisions without any openings except for type-approved watertight doors.

In addition to those areas covered by class rules and statutory regulations (hull, machinery, electrical, automation, lifesaving, etc.), even if not harmonized, there is a huge gap of standards related to very important aspects in the contractual specification of a pleasure vessel such as:

- coatings;
- interior quality and finishing;
- large windows;
- innovative composite materials and production technologies;
- gangways, ladders, balconies , cranes and other deck equipment;
- security equipment.

Boat-builders and refit shipyards have recently developed international associations, like the SyBass (Superyachts Builder Association), with the mandate of cooperating in identifying and developing new standards applicable to the yachting industry, in particular in those areas not covered or vaguely addressed by the international and national regulations currently in force. One of the most important project, in this respect, is being done through the ISO/TC8/SC 12 – Large Yachts, that has the mandate to develop international standards on:

- hull coatings – measurement and analysis of the visual appearance (already published);
- strength, security and water-tightness requirements of windows and port-lights in large yachts (currently under review);
- structural standards for deck cranes and gangways (currently under review);
- other work projects such as noise & vibration, steering and control systems, anchoring equipment and new fire protection standards on large GRP yachts.

Another important trend of the yachting industry is represented by the so called "environmental challenge". Whilst the mandatory international and local environmental

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regulations apply to yachts in the same way as they do to cargo ships, some owners are prepared to invest in the most innovative green technologies to ensure their yachts achieve the highest levels of efficiency and the lowest possible environmental impact, going beyond the compulsory requirements and introducing innovative technologies.

This is where the voluntary based certification comes in. Some Classification Societies have recently developed internal standards to certify the environmental sustainability of ships and yachts, some of these being prescriptive rules while other goal-based standards. The key criteria of the "goal-based" standards, are that a yacht should reflect a significant investment in design solutions, on-board equipment and operational procedures aimed at contributing to an environmental performance above the minimum levels required by the regulations, covering, as far as possible, all the different ship pollution sources concerning emissions into the sea and into the air: oil from machinery spaces, sewage, grey water, ballast water, garbage, ozone-depleting substances, greenhouse gases, NOx, SOx, CO2, particulates, building materials and recyclability.

1.1.8 Sailing Yachts

The authors' contribution on this topic is an interesting upgrading of the V.8 ISSC Committee on Sailing Yacht Design (2009). It is to be once more highlighted how Classification Societies have always excluded mast and rigging from the scope of class, Germanischer Lloyd being the only institution involved in this plan approval activity. In parallel, the new edition of the MCA-LY2 code (the so called MCA-LY3), coming into force in 2013 is expressly requiring the classification society in charge of the approval of the hull structures to take also the responsibility of reviewing the mast and rigging calculation in accordance with an international recognised standard.

1.1.9 Conclusions

The authors have evidenced the singularity of super-yachts: a very special and unique marine product falling outside the common criteria of conventional ships, due to their high intrinsic value. The main areas of interest and research trends of the yachting industry have been correctly identified and addressed:

- ship weight reduction through lighter structures;
- on board comfort (noise and vibration);
- performance;
- innovative construction materials and production techniques;
- outfitting design and production methods.

1.1.10 Final Remarks by the Official Discusser

This report gives a very complete description of the yacht design and the authors are to be congratulated. Through this reports some criticalities have emerged such as:

- errors in the basic design project due to a relatively poor knowledge of rules and regulations, which are often very complex and not harmonized;
- aesthetical aspects often in contrast with technical and functional requirements: designers versus naval architects.

These issues should be addressed and dealt with by the yachting community through:

- harmonization of class rules and statutory regulations. In particular it should be adopted a common approach to the structural scantling, based on the material of the hull, the speed and the operational profile;
- involvement of notified bodies and Class Societies at the very early stage of basic design;

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- minimum mandatory qualification skills for builders and designers;
- dissemination of guidelines for the correct interpretation of the mandatory regulations, such as the ISO rules for the compliance to the European Directive.

There are a growing number of professionals coming from other industry sectors (such as automotive, fashion, civil architecture) into the yachting industry, bringing with them new concepts and ideas that in some cases do not match the complexity of a marine product, thus causing delays and additional costs for the boat-builders.

1.1.11 References

Despite the lack of availability of specific papers about yacht structures, the authors succeeded in collecting a wide number of related articles very useful for designers and researchers.

1.2 Floor and written discussion

1.2.1 Simon Benson

My comment relates to the continued growth in the size of the new generation of mega-yachts. At various points in the report and presentation, reference was made to the similarities to commercial ship design. Although it is stated that a mega-yacht is a very special structure which falls outside conventional design, it is also emphasised that design principles are not so different to commercial vessels such as passenger ships. In certain respects I disagree with this statement.

Mega-yachts are highly specialist ships from a structural design point of view and in many aspects are closer to naval vessel design than a commercial ship. There is a huge quantity of research, experience and history in naval ship design. Could the Committee comment on how this experience may be important for the mega-yacht industry and how this may influence and improve motor yacht design?

1.2.2 Andrea Ivaldi

How is the trend in the Classification Societies in order to tune the requirements of the market in the mega-yachts world (to have yachts classified as passenger vessels) with the actual status of the rules that are suited to commercial vessels like passengers and cargo ships?

Moreover, I suggest to keep the committee alive also for next editions of ISSC.

1.2.3 Jerolim Andrić

1. At page 362 of the report you referenced using an expansion joint to control level of hull girder stresses at decks of naval vessel. From my knowledge it is not design practice to use expansion joints in very large yachts ($> 80\,m$) design. Can you comment this issue?

2. What are methods (besides the FEM) to calculate natural frequency of decks (grillage) and superstructure in the early design stage, especially if structural optimisation is performed?

2 REPLY BY THE COMMITTEE

2.1 Reply to the Official Discussion

2.1.1 Introduction

On behalf of all Committee Members, first I wish to thank Mr. Paolo Moretti for his kind availability to be the Official Discusser of the Yacht Design Committee. His

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experience in the field of pleasure boats and super-yachts, gathered in many years of activity as surveyour and manager of the Italian Classification Society, makes the Official Discussion a valid and precious completion of this Report, especially from the Regulations point of view, which is a fundamental hinge of the whole design procedure of super-yachts.

An example of this formulation is the contribution given by Mr. Moretti on the historical background of the motor boat and motor yacht development from the first steam machines in the early 1800, up to the introduction of gasoline engines, at the beginning of 1900.

2.1.2 Motor Yacht Basic Design and Typologies

Even if the interest of the Yacht Design Committee has been mainly devoted to large yachts (length over 24 metres), being this category more subject to structural problems, smaller yachts and pleasure boats have been considered as well for some aspects, given their great diffusion and importance from the commercial point of view. Nevertheless, as stated in the Report, we have not subdivided motor yachts into commercial categories such as “mega-yachts”, “giga-yachts” or “dream-yachts” because these terms have not an official acknowledgement by any technical institution. So we classified motor yachts exclusively according to the MCA-LY2 definition: yachts with freeboard length below/over 24 metres.

2.1.3 Rules and Regulations

For what the Rules and Regulations is concerned the Official Discusser added many specific and useful information about classification and certification, gathered from his long experience in this field. Particularly appreciated is the reference to the American Boat and Yacht Council (ABYC) and to the International Council of the Marine Industry Associations work (more well known as ICOMIA) in establishing an international working group with the mandate of harmonizing the present Rules for the design and construction of recreational boats.

2.1.4 Vibration and Noise

About noise and vibration, the “comfort merit factor” quoted by the OD, is released by the Classification Society as a function of the noise and vibration level measured on board and compared with those “suggested” by their rules. In the Report, at page 363, 364 and 365, three synthetic, comparative tables are presented with vibration and noise maximum levels extracted from the Classification Society rules.

A short account in the Report is also provided on seakeeping problem, quoting some important papers on this subject by Dallinga and Van Wieringen (1996), Van Wieringen *et al.* (2000) and Stevens and Parsons (2002).

2.1.5 Structural Arrangements and Production Methods

The OD agrees with the general planning of this section and its content and provides a comprehensive set of information about materials and outfitting from the Classification Society point of view, dividing the yacht fleet into vessels with less than 500 GT and more than 500 GT. Some points have been assessed in the Report as well, but just from the structural point of view.

A final remark is devoted to yacht structural failures where he asserts that this is not, fortunately, a recurring concern. Structural failures have not been covered by the authors because of the lack of available data. Classification Societies obviously consider this kind of information very confidential and the shipyards, even more obviously, don’t

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like to spread them. As a matter of fact no important examples of structural failures exist in the yacht field other than those due to fires and groundings.

2.1.6 Outfitting

While the analysis made by the Committee of this subject covered mainly all those aspects which have a direct influence on yacht structures, Mr. Moretti focused the attention on fire integrity and stability requirements, giving additional information about the main requirements super-yachts should comply with. The fleet has been divided into two main classes, that is yachts below 500 GT and yachts exceeding 500 GT. Other important aspects quoted by the OD in the "Outfitting" chapter are the Superyacht Builder Association (SyBass) and the "environmental challenge", better known as "green technologies", by which the owner and the shipyards aim at ensuring their yachts achieve the highest levels of efficiency and the lowest possible environmental impact.

2.1.7 Sailing Yachts

This chapter, particularly loved by all members of the Committee, doesn't have the space it deserves. Owing to space limitation in the Report, it has been assessed only from the point of view of an updating of the previous V.8 ISSC 2009 edition. Nevertheless the authors have been able to include as much new information as possible, integrated by Mr. Moretti observations.

2.1.8 Conclusions and Final Remarks

The Official Discusser concludes his review with some final considerations, the Committee fully agrees with, especially in the following two cases:

- harmonization of yacht rules and regulations relative to structural scantlings (because a large part of the design is based on them);
- better understanding between designers and naval architects (often in contrast each other).

Moreover the Committee finds very important a larger participation of yacht shipyards and technical offices in research and dissemination programs (including ISSC) not finalised only to commercial purposes.

2.2 Reply to the Floor and Written Discussions

2.2.1 Simon Benson

In some sections of our Report we assimilate super-yachts to "conventional ships", and not to "commercial ships", given that by this term we consider a large category of vessel in which both merchant and military ships are included. This statement finds its main justification if we refer to the previous V.8 ISSC Committee on "Sailing Yacht Design", where the described design and construction procedures are specifically developed for and applied to sailing yachts, however not excluding that, also in this case, many common aspects exist with conventional ships.

The common aspects between super-yachts and ships ranges from their characteristics in terms of dimensions, speed and construction materials, up to the design approach ("first principle" approach and/or Classification Societies Rules approach), loads (both typologies and calculation procedures), and instruments utilised for structural and seakeeping analysis (FEM and CFD). Other super-yacht issues are assessed with the same philosophy of ships, such as fatigue and reliability, even if they have not critical aspects like in case of ships.

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The Committee agrees with Dr. Benson about the importance of the research on naval vessels and its relationship with yacht industry; many characteristics of some yacht typologies derive from military vessels: an example above all is represented by the planing, hard chine hulls, lent by fast patrol vessels to all kinds of fast motor yachts. Many other elements coming from naval vessels have been adopted on motor yachts such as high resistance materials, low noise propellers, silenced electric generators and, as ultimate application, security instruments.

2.2.2 Andrea Vivaldi

First of all we acknowledge Mr. Vivaldi for his comment to maintain this Committee also for the next ISSC edition but, unfortunately, this does not depend on the Committee members. About his question, Classification Societies behave differently about super-yachts; some of them have specific rules, others prefer to apply conventional ship rules. In any case it is to be highlighted the good work done by MCA which adapted the most important International Conventions developed for ships to yachts, allowing the latter to maintain their particular identity.

2.2.3 Jerolim Andrić

The reference quoted in the Report is relative to a naval vessel with higher performances and the capability to face rougher sea conditions with respect a motor yacht of similar dimensions. In addition superstructures on naval vessels are particularly extended in length and width. The insertion of expansion joints is the only solution in this case to avoid critical stresses in the higher superstructure decks. In case of motor yachts superstructures have a reduced length with respect to the hull. In addition the lower speed and wider breadth of the hull makes superstructures from one side less stressed and, from the other one, stronger. This does not exclude the utilisation of expansion joints also on yachts, even though of very large dimensions.

Given the complex hull structure of modern super-yachts, the FEM approach remains the best tool to perform preliminary vibration calculation. Anyway other theoretical or analytical methods can be used in a preliminary assessment of natural frequencies of a deck with a regular geometry. One of these is the Raileigh method, an application of which is reported by A. Laakso *et al.* in a paper presented at MarStruct 2013 Congress in Aalto (Finland), entitled "An Analytical Method for Cabin Deck Fundamental Frequency".