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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

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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

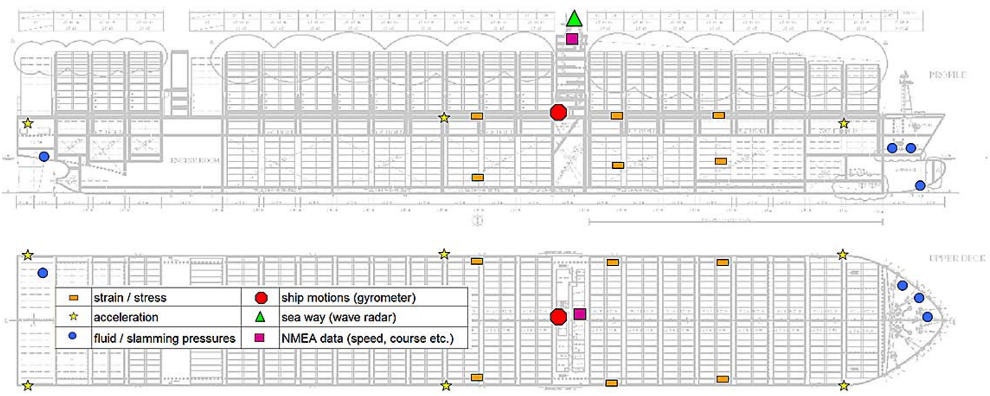

Figure 1: Whipping & Springing Monitoring System onboard 14000 TEU CV (courtesy DSME and Germanischer Lloyd SE)

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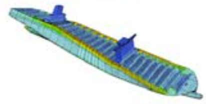
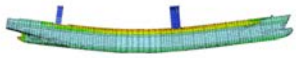
Natural Vibration Mode Shape		Ballast	Design	Full
1-node torsion		0,45 Hz	0,32 Hz	0,26 Hz
		2,2 s	3,1 s	3,8 s
2-node vertical bending		0,68 Hz	0,48 Hz	0,43 Hz
		1,5 s	2,1 s	2,3 s
2-node horizontal bending/torsion		0,75 Hz	0,47Hz	0,38 Hz
		1,3 s	2,1 s	2,6 s

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

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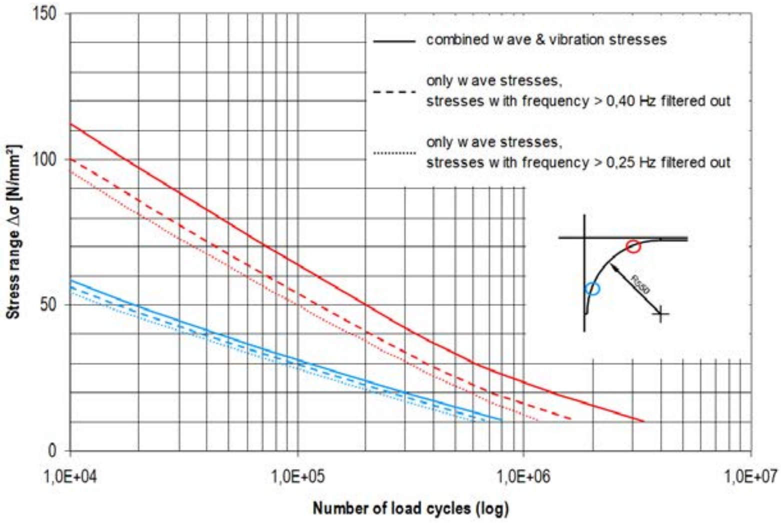

Figure 3: Measured Stress Spectra at Hatch Corner of 14000 TEU CV after 1.3 years of Ship Operation (courtesy Germanischer Lloyd SE)

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 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 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 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.

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.*

Morooka, C.K., Tsukada, R.I., da Silva, S., Franciss, R., Matt, C.G.C. (2009). Model test of a steel catenary in towing tank. *International Conference on Ocean, Offshore and Arctic Engineering, 2009, 79499.*

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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http://www.stg-online.org

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 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, 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.

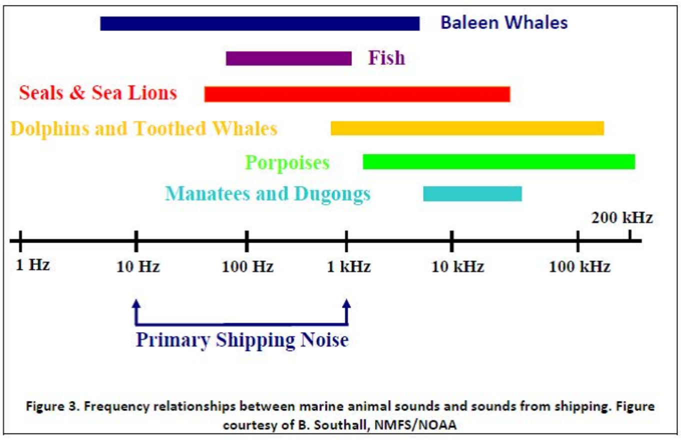

Figure 4: Figure taken from Okeanos (2008)

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http://www.stg-online.org

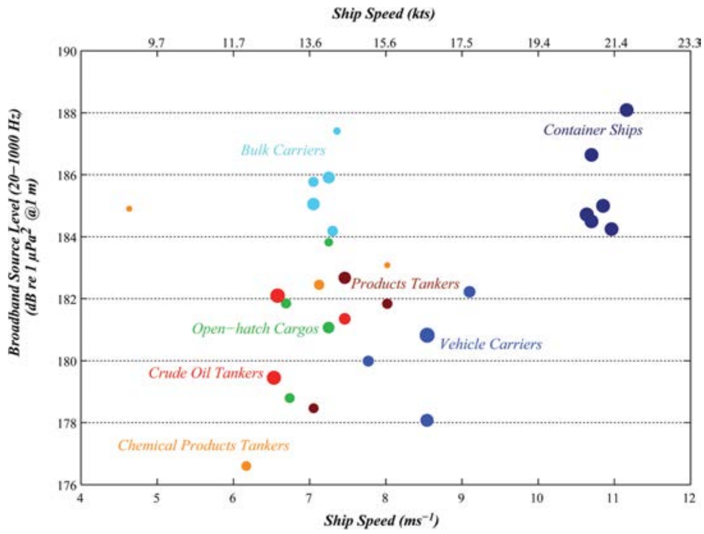

Figure 5: Figure taken from McKenna *et al.* (2012)

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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Okeanos (2008). Shipping Noise and Marine Mammals, *International Workshop on Shipping Noise and Marine Mammals*, Ed. Wright, A.J. , Okeanos - Foundation for the Sea, Hamburg, Germany.