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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.

## CONTRIBUTORS

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Giorgo Bacicchi
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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

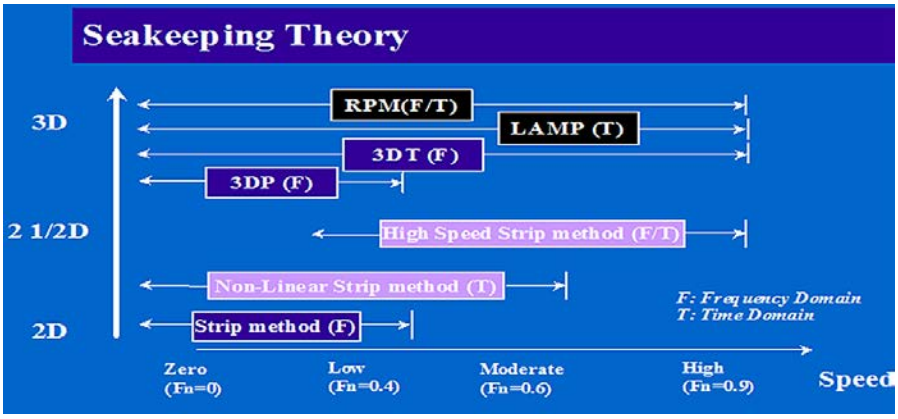


Figure 1: Seakeeping theories and their ranges of application

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:

- 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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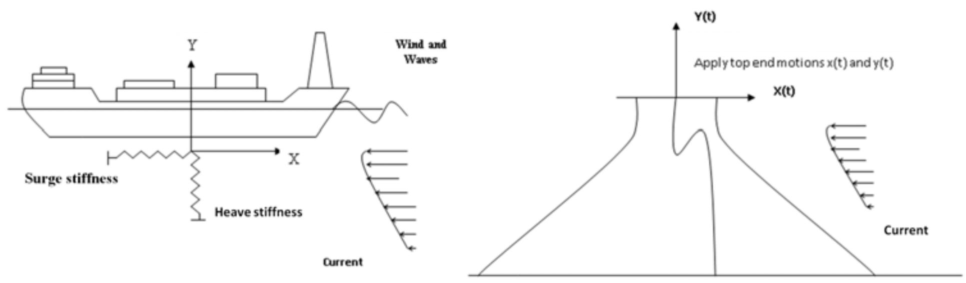


Figure 2: Uncoupled System analysis

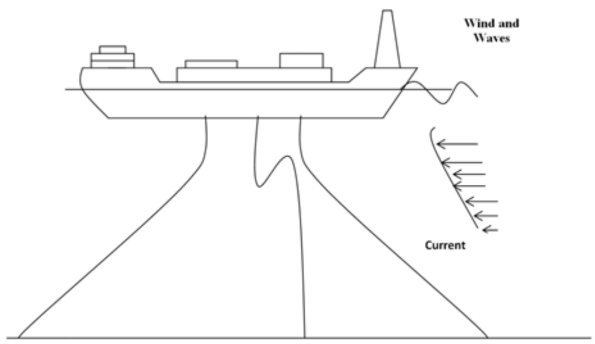


Figure 3: Coupled System Analysis

*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

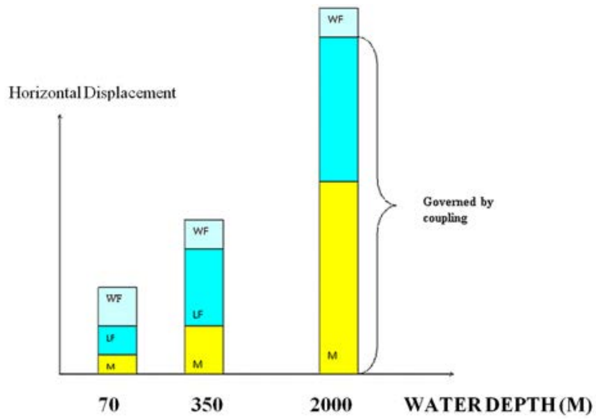


Figure 4: Horizontal motions of a moored platform

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*

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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.

Wnek, A.D. and Guedes Soares, C. (2011). Numerical analysis of the shadow effect of LNG floating platform on a LNG carrier under wind condition, The Proceedings of IMAM 2011 Conference, Genoa, Italy.

## ***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?

#### 1.2.5 References

Bourguet, R., Karniadakis, G.E., Triantafyllou, M.S. (2011). Vortex-induced vibrations of a long flexible cylinder in shear flow. *Journal of Fluid Mechanics 677*, 342 – 382.

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## 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

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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

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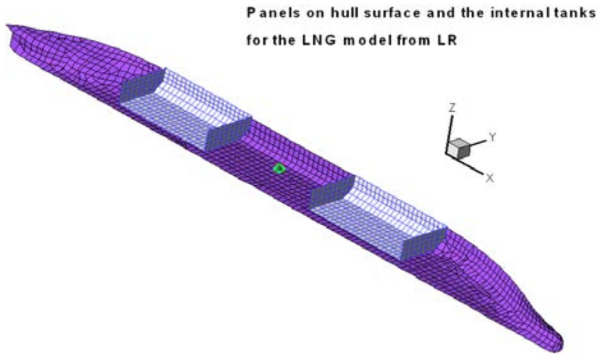


Figure 5: Hirdaris *et al.* (2011) hydrodynamic mesh for LNG carrier using Lloyd's Register FDWAVELOAD (tanks 2 and 4 are partially filled)

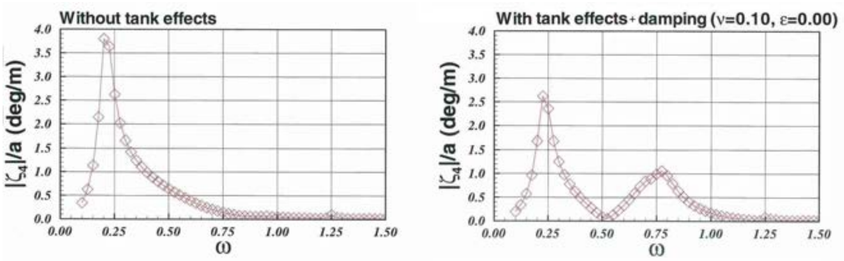


Figure 6: Roll motions of LNG carrier with and without tank effects - Hirdaris *et al.* (2011)

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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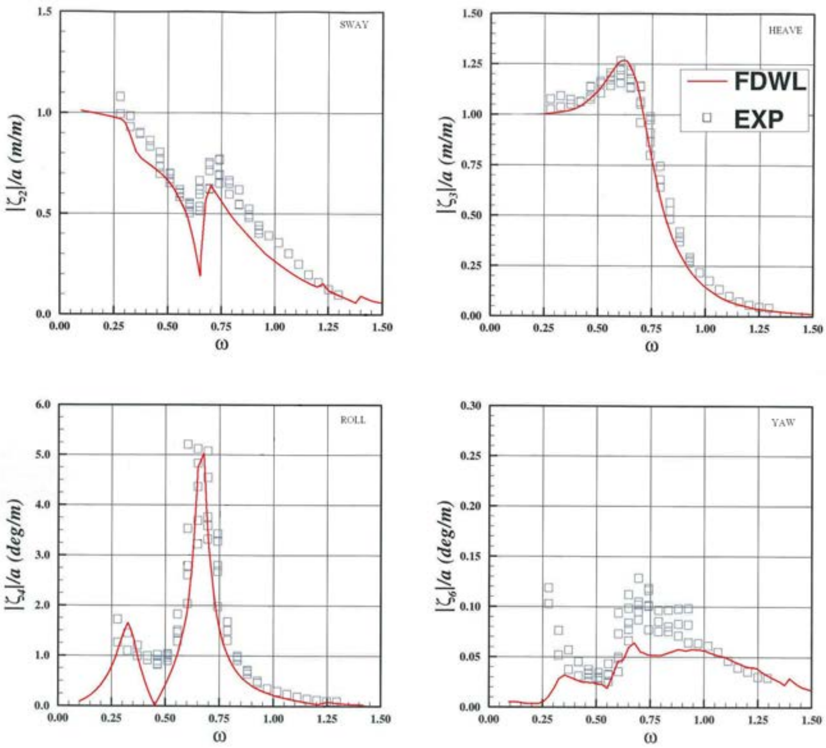


Figure 7: Comparison with model test results - Motions of LNG carrier at 0 knots, beam Seas (different loading condition compared with Fig 2) – Hirdaris *et al.* (2011)

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.

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