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Committee I.2: Loads

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

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1 Discussion

1.1 Official Discussion by Atilla Incecik

1.1.1 Introduction

The Committee should be congratulated on reviewing 490 papers which cover recent advances in understanding/modelling of wave, current, wind, and ice loads on ships and offshore structures. These loads are critical for safety, structural integrity, and efficient ship and offshore system design. The papers reviewed discuss analytical, numerical, experimental and full-scale measurements, data-driven methods, as well as lessons learnt from the accidents.

Overview of the methods included in the papers reviewed

- Potential Flow Theory (linear, weakly nonlinear, and fully nonlinear) for hydrodynamic load predictions.
- Field Methods solving Navier–Stokes equations (e.g., CFD tools such as OpenFOAM, STAR-CCM+, ANSYS).
- Model Tests using segmented rigid or flexible ship models, fibre optic sensors
- Full-scale measurements/monitoring.
- Data-driven methods including machine learning, physics-informed neural networks, and multi-fidelity models.
- Uncertainty analysis using ITTC, ISO, ASME guidelines and benchmark studies combining experiments and simulations.

1.1.2 Summary of the Remarks

Wave Loads on Ships & Offshore Structures

Potential Theory Methods: Both linear/weakly nonlinear and fully nonlinear approaches are widely used for predicting motions, added resistance, and structural loads. However, validation and comparison with earlier models or experiments are often insufficiently addressed.

Field Methods: Shown to align well with model-scale and full-scale measurements in several studies, offering advantages over potential flow methods, but detailed methodological descriptions are often lacking.

Experimental Model Tests: Essential for capturing nonlinear effects (springing, whipping, slamming, hydro-elastic loads). New sensor technologies (e.g., Fibre Bragg Grating) to enhance accuracy, though uncertainties remain.

Full-Scale Measurements: Valuable in validating numerical techniques, model to full scale extrapolation methods and classification society recommendations, with some studies showing conservative biases.

Slamming and Whipping: Strongly linked to accidents; research highlights lack of consensus on extreme design/operational conditions. Advanced numerical models now integrate two-way fluid–structure interaction.

Sloshing: Both global ship motion and local tank impact pressures are critical; results depend on fill levels, air entrainment, and hydro-elastic effects.

Data-Driven Methods: Machine learning and physics-informed models are increasingly applied for predicting motions, loads, and structural responses, showing promise in accuracy and efficiency.

Current & Wind Loads

Empirical drag-coefficient-based methods remain baseline (API, DNV, OCIMF).

CFD and wind tunnel studies confirm reliability of modern simulations for wind loads on ships/offshore platforms.

Wind-assisted propulsion (Flettner rotors, rigid sails, towing kites) is under active study.

For offshore wind turbines, focus has been on aerodynamic, structural, and mooring behaviour, though second-order wind-induced motions are underexplored.

Ice Loads

Studies combine numerical, model-scale, and full-scale methods.

Ice-induced vibrations (IIV) are a major concern for safety, with recent use of machine learning to improve predictions.

Numerical models combining DEM and CFD are advancing predictive capability.

Uncertainty Quantification

Major focus on slamming, global loads, and mooring systems.

Benchmarks highlight discrepancies between numerical tools and experiments, especially for nonlinear hydro-elastic responses.

Strip theory codes give reasonable results for linear wave loads but underestimate nonlinear effects.

Model experiments require long durations and multiple seeds for statistical reliability.

Numerical investigations show that CFD and SPH analysis can capture impact loads realistically, but assumptions (rigidity, boundary conditions, trapped air) strongly affect results.

Benchmark Study

The benchmark study reported in the report investigated through numerical simulations and experimental measurements the pressures, strains and accelerations due to impact of a rigid and elastic flat plate entering into water. Multiple numerical methods were applied, including CFD (STAR-CCM+), SPH, and LS-DYNA solvers, with rigid and elastic plate assumptions.

1.1.3 Overall Comments on the Report

Strengths

- Very broad coverage (ships + offshore structures, including marine and offshore renewable energy devices + ice).
- Highlights of experimental, numerical, and data-driven approaches.
- Recognition of practical lessons from accidents and full-scale measurements.
- Highlighting the role of uncertainty quantification and benchmark studies.
- Good summary of progress in ML-based approaches, but with realistic caution on data quality.

Limitations

- Many papers reviewed lack clarity on validation methods, especially for new models.
- Several papers reviewed fail to identify the *novel contribution* of recent research compared to existing literature.
- Incomplete or missing details (e.g., exact methods in field approaches, tank filling levels in sloshing studies, offshore structure types in ice load studies, scaling assumptions, error quantification).
- Overreliance on qualitative comparisons—quantitative benchmarking against experiments is often limited.
- Benchmarking across various models/tools used in the papers reviewed are limited and fragmented.
- The marine and offshore industry's use of research results reported in the papers reviewed in this report, for the future design and operation of ships and offshore structures are not highlighted.

1.1.4 Wave Loads on Ships

Potential Theory Methods

In this section the recent research outputs on frequency domain methods based on linear or weakly non-linear potential theory as well as fully non-linear solutions to determine excitation forces, transfer functions for motions and structural loads, added-mass were reviewed. In addition, field methods, roll damping of ship ships in waves, green water on ships, and new field methods were discussed.

Linear and Weakly Nonlinear Potential Flow Theory

Recent papers on modified strip theory to determine the added-resistance and ship motions in shallow water were discussed but there was no indication whether the results obtained in these papers were compared with those obtained from earlier numerical studies and/or experiments to show the progress. This section refers to a hybrid three-dimensional linear flow model developed by Dong et al. (2024) to predict motion responses and added-resistance. Whilst it was stated that this new model was verified there was no mention of how this was done.

Fully Nonlinear Potential Flow Theory

This section refers to the papers on fully non-linear potential flow calculations to predict the motions and bending moments, shear forces and torsional forces acting on rigid and a flexible ship advancing in non-linear waves. There was no reference how the methods used in these papers made improvements compared to the fully non-linear potential flow models reported in the following papers:

- R-Q Lin and W Kuan "A fully nonlinear, dynamically consistent numerical model for solid-body ship motion with fixed heading", Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 2011
- M Irannezhad, A Eslamdoost, M Kjellberg, R E Bensow, "Investigation of ship responses in regular head waves through a fully nonlinear potential flow approach", Ocean Engineering, 2022.

Field Methods

This section emphasises the advantages of field methods for ships over potential flow methods and refers to a study where ship motions and added resistance obtained from a field method compared well with those obtained from model-scale and full-scale measurements. No details about the field methods used were given in this section.

Roll Damping of Ships in Waves

This section summarises the studies on roll damping coefficients obtained using field methods for ships and a ship with a moonpool. Parametric roll predictions were also included in this section. The papers referred to in this section include the comparison of the results obtained from field methods with experimental measurements.

Green Water on Ships

First paper (Islam & Soares, 2022) referred to in this section assessed the sea margin and the added-resistance in waves using a field method. The results of predictions compared well with the measurements.

Second paper (Sun et al., 2023) gives the results of simulations to obtain the level of water on deck and water pressure for different wave steepness. The results of the simulations were compared with the experimental measurements. The paper concluded that the steepness significantly affected the level of water on deck. Recommendations for future work were given in this paper. No comments on the second paper as to the level of agreement between the simulations and the measurements were given.

Notable Applications of Field Methods for Wave Loads

In this section the first paper (Jeon et al., 2022) reviewed focused on ship motions due to focused waves. The second paper (Gong et al., 2022) reviewed was a broaching study for a trimaran. The paper showed that the steep waves and a wave phase velocity close to the ship's forward velocity were the necessary conditions for broaching to occur. No detailed information on the method used or the validation of the results in both papers reviewed were given.

New Field Methods for Wave Loads on Ships

The papers reviewed in this section investigated the effect of aeration on impact pressure during slamming. The numerical simulations compared well with the measurements.

Model Tests

Introduction

This section has a good summary of the reasons as to why model tests are required especially as the ship sizes increase and ships operate in extreme weather conditions. The papers reviewed in this section addressed through model tests the non-linearities related to the variation of wave steepness, the impact of forward speed, loading conditions and extreme wave heights.

Model and Experiment Design

The papers reviewed in this section focused on the experiments carried out with segmented and fully elastic ship models to measure hydro-elastic design loads. The importance of correct scaling to predict the non-linear loads due to springing, whipping and antisymmetric vibrations was emphasised. As the design and fabrication of segmented ship models significantly impact wave-induced loads the number of segments to be used need be decided following a convergence calculation of natural modal frequencies based on a finite element analysis. In addition, calibration procedures, precise control of repeated measurements are important to reduce the uncertainties in measurements.

This section also refers to Fibre Bragg Grating sensors (FGD) used to measure strain and pressure distributions on a model ship hull. The care needs to be taken for variations of tank water temperature during measurements.

Finally, this section provides practical guidelines for the selection of the number of test realisations to obtain reliable extreme design loads from tests in irregular waves.

It would have been useful to refer to relevant ITTC guidelines in the areas discussed in this section and how the new papers could guide enhancement of the ITTC guidelines.

Experimental Studies

This section includes a summary of five papers reporting on experimental measurements carried out with segmented models to measure vertical and horizontal bending moments, torsional moments, slamming loads and whipping responses to investigate the effect of non-linearities due to increasing wave steepness. It was not clear what was the new knowledge resulting from the investigations summarised in this section compared to what was published previously in this area.

Full-Scale Measurements

The papers reviewed in this section concern with the estimation of wave and slamming induced loads from the stress measurements, and of wave spectra obtained from on board stress and motion measurements. In addition, long-term stress measurements carried out on board a wave-piercing catamaran ferry operating in the Canary Islands were compared with a classification society-based estimation. The results showed that the classification society-based estimation was rather conservative.

Slamming

In this section lessons learnt from accidents that resulted due to the slamming loads were reviewed.

Learning from Accidents

The accidents reported in this section included the loss of two container vessels due to lack of adequate strength and to additional hydrodynamic hull girder forces resulting from slamming and whipping. The report concluded that there is a lack consensus on the design or extreme operational conditions, and more in-service data could aid better modelling of fatigue loading due to extreme events.

Local Slamming Loads

This section summarises the research carried out on numerical modelling and experimental measurements to investigate the effect of local slamming loads. The papers reviewed in this section details the estimation of pressure distribution on stiff wedges based on non-linear boundary element method with a jet flow approximation as well as the advanced numerical modelling that considers flow-induced non-linearities and fluid-structure interaction with two-way coupling. In addition, papers presenting slamming impact loads on the bow of an FSPO, under the cross-deck of a catamaran and on the hull of high-speed planning crafts were also reviewed.

Slamming-Induced Whipping Loads

The papers reviewed in this section concern with the hull girder loads due to whipping resulting from bow or stern slamming. The research reported in these papers include investigations based on both numerical simulations as well as experimental measurements. One of the papers (Zou et al., 2024) reviewed investigated bow flare slamming loads and whipping responses through model tests carried out with a segmented model in regular seas. The paper concluded that whipping significantly increases asymmetry of the vertical hull girder bending moment at amidships whilst the shipping at high speed. However, there were no comments on the elastic behaviour of the beam holding the ship model segments and how this compares to the behaviour of a full-scale hull girder.

Sloshing

In this section numerical and experimental studies carried out to investigate the effect of sloshing on global behaviour of the ship and local impact pressures on the tanks containing the liquids were reviewed.

Global Flow

The papers reviewed in this section investigated the effect of global flow in small tanks like swimming pools on board passenger ships and cruise liners, and in large tanks like spherical or prismatic LNG tanks on ship motions. Following the review of the one of the papers it was stated that when a typical LNG vessel equipped with three prismatic tanks when they were equally filled experienced the most conservative roll motions. However, if the filling level was changed in one of the tanks this resulted in significant reduction in roll motions. It would have been useful to indicate the level of filling in the tanks when they were equally filled, and the level of LNG was reduced in one of the tanks.

Another paper reviewed in this section focused on the seakeeping behaviour of ships with anti-rolling tanks. It was concluded that anti-rolling tanks are more effective than U-tanks in stabilising the roll motions.

Local Flow

The papers reviewed in this section focused on the free-surface, local sloshing flow velocities and impact pressures with a view to determining the structural loads on containment tanks due to sloshing. The investigations referred to in this section included both model tests and numerical models which considered water and air mixture. One of the papers (Shen et al., 2024) reviewed concluded that impact due to water with air pocket and wave run up along the tank wall gave rise to significant pressure and resulting stresses. Following the review of another paper it was stated the importance of the hydro-elastic responses of the containment systems but to comparison was given between the rigid and hydro-elastic behaviour.

Data-Driven Methods

Introduction

This section refers to the advancement of data-driven methods based on Machine Learning in optimising ship design and operations for green shipping. The data-driven methods are based on numerical simulations, model tests and full-scale measurements/monitoring.

Structural Responses

The papers reviewed in this section focused on the prediction of vertical bending moments and the total longitudinal hull girder stresses based on multi-fidelity models using artificial neural networks.

Motion Responses

The papers reviewed in this section are based on purely data-driven models, physics-informed models, and calibration models. It was stated that while purely data-driven models provide satisfactory results, physics-informed neural networks offer greater accuracy in many application cases.

Data Processing

This section summarises the importance of data quality and availability on the accuracy of data-driven systems. A paper reviewed in this section focuses on the development and implementation of a data processing system for ship operational data.

1.1.5 Wave Loads on Offshore Structures

Potential Theory Method

Linear and Weakly Non-linear Potential Flow Theory

The papers reviewed in this section include the wave-structure interaction on offshore structures with porous surface, the prediction of wave run-up on a bottom-fixed cylinder, the comparison of the prediction of wave elevation on a cylinder placed near to a vertical wall when the linear- and second-order potential flow solutions were used. Other papers reviewed in this section include a fully coupled aero-hydrodynamic modelling of floating wind turbines, and the linear potential flow modelling to predict the resonance motions of oscillating water column within fixed and floating wave energy converters.

Fully Non-linear Potential Flow Theory

The papers reviewed in this section concern with the development of a 3D, fully non-linear wave tank to predict the motion response of a free-floating cylinder in non-linear waves, a 2D fully-nonlinear model to simulate the free surface oscillations within a fixed oscillation water column device, and a feasibility study to investigate the enhancement of wave energy capture when a multi chamber oscillating water column device is used.

Field Methods

The papers reviewed in this section investigated the non-linear wave-structure interaction by solving Navier-Stokes equations using tools like OpenFOAM, Strat-CCM+, ANSYS/Fluent, and ANSYS/CFX. These tools were applied to investigate the non-linear wave-structure response of various offshore structures including: fixed tandem cylinders; net panels of fish cages and various types of offshore fish farms; barge type moored floating structures and their mooring systems; oscillating water column type wave energy converters; spar-type floating wind turbines; mono-pile and semi-submersible type wind turbines as well as various other types of floating platform and their mooring systems used for wind turbines and sea access roads.

Wave-Current Interaction

This section focuses on the effect of in-line and opposing currents with respect to the direction of wave propagation. The paper reviewed in this section concerns with the resonance motions of twin-cylinder configuration in waves in presence of a uniform current flow. There was no mention of what causes the resonance motions. It would been useful to have some comparisons of motion responses of floating structures with and without current flow presence in waves. There was also no mention of the slowly varying motions of moored offshore platforms due to variations in current flow velocity and direction.

Offshore Wind

This section also refers to the papers published in the area of dynamic loading on fixed and floating offshore wind turbines due to wave-current interaction as well as the loading on a monopile offshore platform due to wave-current-wind.

There was no reference to the second-order motions of moored offshore platforms due to wind gusting which can be more significant than the first-order motions.

Aquaculture

The papers reviewed in this section concern with the forces acting on the mooring lines of fish cages due to waves in the presence of current. The effect of increasing the weight of cages on the mooring line loads was also investigated in one of the papers reviewed.

Tidal Energy

The papers reviewed in this section investigated the coupled behaviour of tidal turbine and a floating structure in terms of fatigue damage and power output.

Submerged Tunnels

The papers reviewed in this section investigated the dynamic motion response of floating under water tunnels due to wave and current loading as well as wave, current and earthquake loading. However, there was no reference to the mooring arrangements of these structures and the loads on their moorings.

Floating Bridges

This section focuses on papers investigated loading on floating bridges due to environmental forces including earthquake induced forces as well as loads due to moving vehicles. The papers reviewed describes both numerical simulations as well as experimental tests carried out in combined wave, wind and current loading conditions.

Mooring Buoys

The paper reviewed in this section investigated the motion responses and mooring forces of a catenary anchor leg buoy subject to wave, current and wind loading.

Airgap and Wave-in-Deck Loads

In this section the importance of managing airgap and wave-in-deck loads properly is emphasised. The level of air gap is critical to prevent wave-in-deck occurrences as the impact due to waves on deck can cause local and global damage.

A complex Phenomenon

This section stresses the importance of using accurate models to predict the airgap and loads on deck structures due to wave-in-deck loads. It was pointed out that the loads predicted using high fidelity tools show significant overestimation of loads (30% – 75%) based on API and DNV recommendations.

Procedural Aspects of Assessment of Wave-in-Deck loads

The papers reviewed in this section include ultimate strength analysis of fixed structures which consider the wave-in-deck loads. Contrary to the conclusions of the papers in the previous section a paper reviewed in this section concluded that the recommended practices underpredict the maximum deck-in-loads.

Application of Non-linear Potential Flow Methods

The papers reviewed in this section detail the air gap and wave-in-deck predictions based on second-order potential flow theory.

Field Methods

The papers reviewed in this section give the results of the investigations on impact forces on deck structures due to waves on deck using the numerical simulations based on Smoothed Particle Hydrodynamics, and experimental measurements. A number of papers reviewed in this section concluded that the predicted or measured wave-in-deck forces are lower than those based on the recommended practices.

Model Tests

In this section the papers reviewed describe experimental investigations carried out with various floating structures to measure wave impact pressures. As the result of the measurements reported in one of the papers (Fonseca et al., 2022) some structural modifications to reduce impact loads to the original design of FPSO balconies were proposed.

Mooring Systems

In this section a large number of papers were reviewed which include the investigation of shared mooring lines of FOWTs to study their technical and economic viability; the study on a mooring system for a semisubmersible type FOWT with varying mooring material and mooring components; and investigation of a constant tension mooring system for shallow water areas. The review also included the papers using different analysis tools based on fully coupled aero-hydro-elastic mooring system modelling. In addition, papers reviewed cover hybrid mooring lines composed of syntenic mooring lines and steel ropes; wave energy devices moored using taut, catenary and TLP systems; moored porous structures such as fish cages; moored floating breakwaters, and the fatigue assessment of mooring systems.

Model Tests

The importance of model tests in validation of theoretical models and understanding of hydrodynamic loads and responses in extreme sea conditions were emphasised in this section.

The papers reviewed include tests carried out with a floating platform subjected to freak waves; an FPSO in oblique waves in the presence of internal solitary waves; and offshore platforms and wind turbines subjected to steep, breaking waves. It would have been useful to define the type of floating platforms that were referred to above. The use of term “empirical” in the following paragraph require clarification: Advanced model testing remains an indispensable approach in studying wave loads on offshore structures. These **empirical** assessments provide crucial insights that directly inform the iterative design and validation of theoretical models and engineering practices. Incorporating these **empirical** results into data-driven methodologies underscores their critical role in the evolving technological landscape of marine engineering.

Other papers reviewed in this section concern with tests carried out with FOWT models of barge, SPAR and TLP type to investigate the effect of second-order hydrodynamic and aerodynamic loads. The importance of tests in combined wave, wind and current was discussed in another paper reviewed in this section.

The tests carried out with oscillation water column type wave converters including those attached to a floating breakwater were highlighted in a number of papers also reviewed in this section These experimental studies were to investigate the performance of the OWCs and to validate the numerical predictions.

The tests carried out in waves with different types of fish cages; floating bridges; semi-submerged cylinders in steady and oscillatory flow conditions; and a very large floating structure are reported in the rest of the papers reviewed in this section.

Data-Driven Methods

The papers reviewed in this section show the progress with the application of data-driven metrologies to marine hydrodynamics and offshore engineering. The studies reported in these papers include applications with semi-submersible vessels; fixed cylinders in shallow water; wave energy converters; flat-plate breakwaters; and barges.

1.1.6 Current Loads and Wind Loads

This section refers to the historical methods of calculating current and wind forces based on experimentally derived drag forces coefficients given by API, DNV and OCIMF. The papers reviewed in this section include wind tunnel tests with a model of a large cruise liner and the buildings at the port in the vicinity of the cruise liner; and CFD modelling of an FPSO and a shuttle tanker moored side by side to determine the wind loading.

Current Loads

The papers reviewed in this section emphasised the importance of accurate current load calculations for safe design of vessels with dynamic positioning. Accurate current load calculations are also important in the estimation of manoeuvring characteristics of marine vessels.

Others papers reviewed in this section concern with the fatigue life of mooring lines and risers due to flow induced vibrations excited by wave and current loads.

The rest of this section included papers on flow induced motions of FOWTs and the selection of devices to reduce vortex induced motions. Following the review of one of the papers it was stated that "Trends and gaps in current research are identified, such as comparative studies and improving the accuracy of numerical engineering tools. The paper also concludes that the traditional modelling approach remains essential for FOWT designs" It would have been helpful to describe what numerical tools were used in the study that require improvement and what is the traditional modelling approach referred to in this paper.

Final paper reviewed discussed the unconventional and cost-effective measurement techniques and therefore it would have been better to include this paper in the Model Tests section.

Wind Loads

Wind Loads on Ships

The papers reviewed in the earlier part of this section focused on numerical and experimental investigations on wind loads on various types of ship including, a large container ship, an LNG carrier, a floating production, storage and offloading vessel, a jack up platform and a navy ship.

The overall conclusion from these papers has confirmed the reliability of CFD simulations in prediction wind loads on marine structures.

The papers reviewed in the last part of the section focused on numerical and experimental studies to investigate the performance of wind-assisted ship propulsion devices, mainly Flettner rotors but there was also reference to rigid sail systems and towing kites.

Wind Loads on Offshore Structures

Whilst the title of this section is Wind Loads on offshore structures the papers reviewed in this section focus on the aerodynamic characteristics, dynamic motion and structural response, structural integrity, mooring design, scouring, remaining life prediction, and cost modelling of different types of floating wind turbines which include mono-pile, spar, semi-submersible and TLP designs.

1.1.7 Ice Loads

Ice Loads on Ships

The papers reviewed in this section concern with global and local ice loads. The investigations reported in these papers are based on various numerical models, model-scale laboratory tests and full-scale trials and measurements.

Full-Scale Measurements and Trials

The investigations referred to in this section focus on different techniques for measuring global and local ice loads during full-scale measurements which include the ice-resistance method; influence coefficient matrix method; far-field identification method; and Green's function method. The last three methods are based on measuring strains on a ship hull and converting the strains to ice loads.

Model-Scale Experiments

The papers reviewed in this section concern with model-scale ice tests to investigate ice resistance of an Arc7 ice-class LNG carrier in different ice and operating conditions;

the escort performance of ships navigating through narrow ice channels created by icebreakers; the effect of initial ice contact shape (cone, dome, wedge, ellipse etc.) on the ice failure modes and resulting ice loads; and ramming performance of an ice-breaking research vessel in artificial thick ice and at different forward speeds.

Modelling and Simulation Effort

Analytical and Semi-empirical Approach

The papers reviewed in this section reported ship resistance formulations based on machine learning algorithms using full-scale data. Some papers reviewed in this section reported the development of an image analysis technique to estimate the circumferential crack size of broken ice; and the effect of waves on ice impact loads in different sea states.

Numerical Approach

The papers reviewed in this section focus on numerical models which combine both the Discrete Element Method and Computational Fluid Dynamics to simulate ice-ship interactions to predict ship resistance, ice impact loads and manoeuvring characteristics in ice.

Statistical Approach

The papers reviewed in this section concern with the prediction of extreme ice loads based on statistical analysis of date obtained from numerical simulations, full-scale measurements, model tests.

Ice Loads on Offshore Structures

General

The papers reviewed in this section concern with analytical approaches, numerical simulations and experimental measurement to predict the structural damage and fatigue failure due to ice impact and continues pulsating loads.

Modelling Effort (Analytical, Numerical and Statistical Approach)

The papers reviewed in the early part of this section focused on ice-structure modelling are based on analytical models or data from full- or model-scale tests.

The remaining papers reviewed concern with the development of numerical simulations based on fully coupled CFD/SPM and FEM/DEM methods to predict the impact loads, ice-induced vibrations on offshore wind turbines. In addition, there was a paper (Zhang et al., 2022) reviewed in this section focused on the development of a fully coupled time-domain simulation of a semi-submersible type oil and gas platform to predict ice loading as well as dynamic motions and mooring forces in waves and ice conditions. Another paper reviewed in this section highlighted the relationship between the ice thickness and the mean and maximin motion of a moored platform and its mooring forces.

This section in some parts refers to investigation with 'offshore structures' it would have been good to specify the type of an offshore structure.

Model-Scale Experiments

In this section a number of papers reporting on the model-scale tests were reviewed to highlight the ice-structure interaction with various structures. However, there was no information on the types of structure.

Full-Scale Measurements and Trails

This section highlights the difficulty and costs with full-scale tests in ice whilst the value of full-scale test data in new designs and validating new prediction methods.

The paper reviewed in this section reported the full-scale vibration measurements on a mooring dolphin platform with an isolation cone. The paper concluded that the cone significantly reduced the ice-induced vibrations.

Ice-Induced Vibrations

This section highlights the importance of ice-induced vibrations as they affect the structural safety and safety of the equipment on board the structures. Ice-induced vibrations (IIV) occur when the interaction between ice and a structure causes the structure to vibrate. The vibrations arise from a complex interplay of ice failure mechanisms (like crushing, buckling, or shear), the structure's dynamic response characteristics, and the characteristics of the ice-structure interaction.

The papers reviewed in this section concern with various numerical model development and experimental studies to investigate ice-induced vibration problems of jacket platforms with and without ice breaking cones, vertically-sided offshore structures, offshore wind turbines and moored structures. The last two papers reviewed detailed the application of machine learning methods to predict structural response due to ice induced vibrations. One of these papers described a prediction method based on the field monitoring data.

1.1.8 Uncertainty

This section discusses the evaluation of uncertainties in loads on ships and offshore structures, focusing on numerical methods, experiments, and standards used for quantification which include ISO, ITTC, ISSC, and ASME are used to quantify and express uncertainties.

Slamming Loads

This section highlights that slamming loads are challenging to measure at full scale, so model-scale tests and numerical simulations are commonly used.

A paper (Yan et al., 2023) reviewed in this section compared experimental measurements and simulations for flat plate water entry, focusing on hydroelasticity, air trapping, and modelling assumptions. Experiments used a platform with sensors and strain gauges, while simulations were based on the two-way fluid-flexible structure coupling scheme using STAR CCM+/ABAQUS interface. Uncertainty was estimated for sensors, repeated experimental measurements, and numerical discretization using the Grid Convergence Index (GCI) method. The paper concluded that higher impact speeds reduced validation uncertainty for pressure, while force-related uncertainty was velocity-independent.

Regarding purely numerical simulations the second paper (Wang et al., 2021) reviewed in this section analysed numerical uncertainty in water-slamming loads using two ITTC-recommended methods. It was concluded that the Courant-Friedrichs-Lewy (CFL) method showed better accuracy than the independent grid and time-based discretisation method.

Global Loads

This section discusses **global loads on ships**, which can result from waves, grounding, or collisions. These loads can be studied through numerical simulations which can treat the hull as rigid or flexible and account for both linear and nonlinear effect, or through model-scale experiments. Regarding **the linear models t**he main uncertainty lies in evaluating transfer functions. The results of a benchmark study organised by the ISSC-ITTC Joint Committee on global linear wave loads on a contained ship with forward and reported in a paper (Parunov et al., 2022) reviewed in this section describe testing of 15 seakeeping codes based on strip theory, 3D frequency-domain, and 3D time-domain methods to assess their influence on predicting extreme vertical wave bending moments. Uncertainties in the seakeeping codes were evaluated for the heave, pitch, and vertical wave bending moment at midship for three heading angles. The paper concluded that strip theory codes showed small deviation from the average of the other codes and the experimental values.

Another paper (Kim & Kim, 2016) in this section assessed the uncertainties using the **Frequency Independent Model Error (FIME)**. The paper concluded that the FIME was the most promising method. Both strip theory and 3D methods gave reasonably good results for linear wave load predictions. Considerable uncertainties were found in the non-linear response predictions, including the hydro-elastic responses.

The uncertainties in non-linear responses investigated in a paper (Hirdaris et al., 2023) reviewed in this section emphasised the importance of uncertainties in hull girder loads influenced by flexible fluid-structure interactions. The paper concluded that despite 40 years of research, a clear understanding of Hydro-elastic uncertainties in wave-induced loads remained elusive.

Another paper (Kim et al., 2022) reviewed in this section compared explicit nonlinear FEA and a semi-numerical super-element method for passenger ship collision and grounding, finding generally similar maximum responses except in oblique collisions and sharp-rock groundings, with key uncertainties tied to model size, fracture strain, and mesh resolution.

A paper (Scharnke et al., 2023) on experimental approaches analysed experimental convergence for extreme-value wave and impact loads, showing that long exposure durations and many test seeds are needed for reliable estimates, Weibull fitting has little effect, and the high time/cost demands suggest exploring more efficient methods. The authors recommended exploring alternative methods to improve efficiency.

Mooring

The paper (Abdelwahab & Soares, 2023) reviewed in this section focused on the uncertainty modelling of experimental results for a scaled tanker model moored to a terminal inside a port. The paper concluded that Type B uncertainties (wave measurements, model geometry, mass distribution) dominated over However, Type A uncertainties were not defined. It was also concluded that nonlinear wave forces, ship response and mooring forces significantly impacted uncertainty. Systematic uncertainty analysis is essential for improving the quality of measurements, despite long analysis time and cost.

Others

First paper (Gaidai et al., 2022) reviewed in this section proposed a new method for assessing structural reliability of multidimensional structural responses with limited data.

The method was successfully applied to container ship deck panel stresses and extreme roll angles. The method was benchmarked with onboard measured time histories.

Another paper (Miratsu et al., 2022) reviewed in this section investigated the effect of ship operations on sea loads experienced by a ship hull using a statistical storm avoidance model.

Offshore Structures

A paper (Islam & Guedes Soares, 2021) reviewed in this section highlighted the assessment of different uncertainty analysis method commonly used for uncertainty quantification in Computational Fluid Dynamics (CFD) Courant–Friedrichs–Lewy (CFL) number-based approach for uncertainty estimation was compared with the ITTC recommended grid and time-independent procedures.

Another paper (Hallak et al., 2022) reviewed in this section concerned with the air gap estimation for semi-submersibles. The study focused on epistemic model uncertainties in determining operational and survival air gaps.

Wave Description

The papers reviewed in this section focused on the uncertainty evaluation of wave data and models used for the design and testing of marine structures by highlighting the differences in uncertainty definitions between ISSC and ITTC; initial uncertainties in maximum wave prediction in short term sea states; and the review of the latest findings regarding the statistical modelling of the ocean environment.

1.1.9 Benchmark Study

The benchmark study reported in this section investigated through numerical simulations and experimental measurements the pressures, strains and accelerations due to impact of a rigid and elastic flat plate entering into water. Multiple numerical methods were applied, including CFD (STAR-CCM+), SPH, and LS-DYNA solvers, with rigid and elastic plate assumptions.

The study concluded that CFD and SPH methods can replicate key features of water impact loads, but accuracy depends heavily on the modelling assumptions (rigidity, air effects, boundary conditions). The simulations with hydro-elastic modelling improves agreement with experiments compared to simulations with purely rigid modelling. Simulated void fractions (air cavities) match experimental observations well. Future work on uncertainty modelling should follow ASME Verification and Validation guidelines, with closer collaboration between scientists carrying out experiments and numerical simulations.

1.2 Floor and Written Discussions

1.2.1 Ekaterina Kim

- Did the committee members use AI-Copilots to support the literature review and analysis, consensus of the trend etc. If yes, please elaborate how.
- Should the review of the data driven method/approaches also include a critical review of the data underlying those methods?

- Suggestions: Large language models (AI copilots) can be effectively used to support the work of committee members. One such tool is Connected Papers (connectedpapers.com), and another is Research Rabbit (researchrabbit.ai). These tools can save hours during literature reviews, allowing the committee to focus on more important tasks that require human expertise—for example, validating existing methods and approaches, performing cross-comparisons based on common test cases, and conducting benchmarking.

1.2.2 Ling Zhu

- My compliments on the well-written report. It is interesting to note that both this committee and Committee V.I have chosen plate slamming as the subject for their benchmarking studies. In the present study, a rigid plate and a plate with elastic response were adopted, whereas Committee V.I focused on plates with plastic deformation, which are often found in plate structures subjected to severe slamming impacts
- Suggestion: It is recommended that readers review both benchmark studies in Committees I.2 and V.1 to gain a more comprehensive understanding of the subject.

1.2.3 Krzysztof Wołoszyk

In the report of benchmark study, the direct FSI methods available in LSDyna Software were incorporated. However, some things need further clarification:

- Please provide the exact name of first method which is referred as NMRI LSDYNA method. Actually, this is not correct name in my opinion, since it does not reflect numerical approach which is considered. From my knowledge, the ALE (Arbitrary Lagrange Euler) and its extension S-ALE methods are available for direct coupling of solid and fluid domains. This need further explanation.
- Why in SPH method, the plate was considered rigid? The LS-Dyna software allows for modelling elastic bodies to be coupled with SPH method.

2 Reply by committee

2.1 Reply to the Official Discusser Atilla Incecik

The committee wishes to express its appreciation to Dr. Incecik for his valuable comments and contributions.

2.1.1 Lessons Learned from the Current Committee Work

As part of the answering of the OD's questions, there are several questions/comments across the various chapters. The questions and responses are:

- Validation clarity (various chapters): We recognise that during the review process, we should have prioritized papers with clear and effective validation. However, the level of validation can sometimes be hard to judge.

- Lack of details explanation (various chapters): During the review process, we should have selected less papers and add more details. Balancing the content with the page limit was challenging.
- Lack of description of numerical tools and improvement (current loads) – Papers often omit the details, and we should have selected papers with completeness of the work.

2.1.2 Wave Loads on Ships

- ITTC relevance (model and experimental design).- We accept that insights from the papers that are referred to in this section could be used to update ITTC RP 7.5-02-07-02.6 Global Loads Seakeeping Procedure. In particular, with respect to the impact of the number of segments, backbone type (material, dimensions, scale etc.) and new sensor technologies (FBG).
- Novelty (experiments): The purpose of this section is to highlight the current trends and demands in experimental testing of commercial merchant ship designs. From an application point of view, clearly large container ships are in the focus. It is important to look at methods from the application perspective to identify gaps in available methods and tools.

2.1.3 Wave Loads on Structures

- Lack of explanation on the resonance motion/slow varying motion (wave-current interaction) - We agree that the underlying mechanisms leading to the resonant motions, and in particular, how the presence of current influences these, should have been clarified. We also agree that the slowly varying motions induced by changes in current velocity and direction could have been a valuable addition. In this work, however, the focus was placed on shorter time-scale effects, and therefore such longer-term variations were not addressed.
- No reference to second order motion due to wind (Offshore wind) - We agree gust induced excitations may lead to amplification of second-order loads/motions.
- Contradictory results from previous studies (wave in deck load) - Ma & Swan (2023) concluded that wave-in-deck (WID) loads involve complex dynamic phenomena, including slamming and quasi-static contributions, which are not adequately captured by such simplified approaches. This limitation persists even when high-fidelity CFD is applied, for instance by modelling the problem as a dam-break scenario. Furthermore, even physical model tests may be constrained by the range of wave conditions examined, thereby limiting their ability to fully represent extreme WID events.

Clarification for the word “empirical” (model tests) – In Naval Architecture and Ocean Engineering, model tests refer to tank experiments with scaled physical models. Empirical studies are defined as investigations grounded in direct observation, measurement, and experimentation rather than abstract reasoning or theory.

2.1.4 Current/Wind Loads and Benchmark Study

- Suggestion to move one article (Otter et al., 2022) to model tests – Agreed.
- Uncertainty modeling should follow ASME V&V procedure - Agreed

2.2 Reply to the Floor/Written Questions

2.2.1 Ekaterina Kim

Thank you for your comments. Most of us use AI tools as a way to refine our writing, outline sections, or generate initial ideas—essentially as a way to "think with ourselves." In the past, a recent review paper would often serve as the starting point, but now AI tools are increasingly taking on that role.

While large language models (LLMs) can indeed save time, we would caution against relying on them to define the direction or conclusions of a literature review. This is done for two main reasons:

1. As specialists, it is our role to decide what narrative or perspective we want to develop, based on our expertise. LLMs, by contrast, tend to produce broadly accepted or consensus views.
2. LLMs are probabilistic tools that can generate plausible but false information ("hallucinations"), and they often reinforce dominant narratives. This can create self-reinforcing loops that go against the purpose of expert committees like ours.

Regarding the future use of AI in ISSC work, we believe AI can be a helpful starting point that saves time and assists in structuring thoughts or organizing the review process. However, literature review goes beyond summarizing existing work; it requires the critical judgment of subject matter experts (SMEs) to evaluate the strengths, weaknesses, and relevance of the literature. AI can support this process, but it cannot replace human expertise and critical thinking.

2.2.2 Ling Zhu

Thank you for your comments. We recognize the similarities of the benchmark run under the ISSC committee V.I, and we believe it would be beneficial to combine the methods and publish a joint paper. Discussions on this are currently in progress.

2.2.3 Krzysztof Wołoszyk

Thank you for your questions.

- You may find a more detailed description of the NMRI LSDYNA model in Subsection A.4 of the report (and also in Table 4). In our simulations, we used the ICFD (Incompressible Computational Fluid Dynamics) solver instead of the Arbitrary Langrangean Eulerian (ALE) method. As we understand, ICFD can provide a more rigorous fluid simulation, showing performance comparable to other CFD solvers. However, during the benchmark tests, 3D air–water multiphase FSI simulations using ICFD in LS-DYNA were not yet available. We plan to update our results once this feature becomes supported. As you pointed out, we are also planning to perform additional simulations using the ALE approach for comparison.
- We did not use the Smoothed Particle Hydrodynamics (SPH) method in LS-DYNA. Instread the open-source code DualSPHysics (https://dual.sphysics.org/) was enhanced with more advanced self-developed boundary conditions. Further details about the SPH model are also included in Subsection A.4 of the report. DualSPHysics

provides a more time-efficient simulation framework through GPU acceleration. However, at present, performing 3D simulations of elastic plates under fluid impact remains a challenge for this open-source platform.

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