Progress in Marine Science and Technology 1

Proceedings of the 20th International Ship and Offshore Structures Congress

Technical Committee Reports

20th International Ship and Offshore Structures Congress
ISSC
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Edited by
Mirek Kaminski and Philippe Rigo

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VOLUME 1

Progress in Marine Science and Technology

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Technical Committee Reports

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Preface

The first volume contains the eight Technical Committee reports presented and discussed at the 20th International Ship and Offshore Structures Congress (ISSC 2018) in Liege (Belgium) and Amsterdam (The Netherlands), 9–14 September 2018, and the second volume contains the reports of the eight Specialist Committees. The Official discusser's reports, all floor discussions together with the replies by the committees, will be published after the Congress in electronic form.

The Standing Committee of the 20th International Ship and Offshore Structures Congress comprises:

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On behalf of the Standing Committee, we would like to thank the sponsors of ISSC 2018.

Mirek Kaminski
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Delft, 1st May 2018

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COMMITTEE II.2

DYNAMIC RESPONSE

COMMITTEE MANDATE

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

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KEYWORDS

Dynamic response, slamming, whipping, springing, hydroelasticity, vibration, sloshing impact, noise, underwater noise, blast, explosion, shock, wind, wave, current, internal flow, propeller, machinery, vortex, model tests, full-scale measurement, monitoring, uncertainty, fatigue, damping, acceptance criteria, countermeasures.

CONTENTS

1. INTRODUCTION

The content of this committee's report is dictated by its mandate and the expertise of its membership. Its structure and content follow along similar lines to that adopted in previous ISSC reports (ISSC 2015). This report examines state of the art methods and techniques in the field of dynamic responses of ships and offshore structures and assesses progress made in this subject area with a critical review of recently published material.

The subject areas undertaken by specialist task committees of ISSC 2018: Experimental Methods (V.2), Offshore Renewable Energy (V.4), Arctic Technology (V.6) and Subsea Technology (V.8), have an impact on the committee's mandate, which affects content of this report. Ice induced vibration have been entirely omitted because that is covered elsewhere (V.6 Arctic Technology). The subject areas of vortex induced vibrations, equipment induced vibrations, subsea and offshore wind turbine monitoring have been reviewed.

This report is subdivided, at the highest level, into two main sections (Sections 2 and 3) concerning the dynamic response of ships and offshore structures, respectively. Section 2 on ship structures is subdivided into sections that range from wave-induced vibration to standards and acceptance criteria. Particular attention is also paid to wave-induced vibration, machinery and propeller induced vibrations, sloshing impact, shock response, noise, damping and countermeasures, monitoring and uncertainties since they are considered as the main topics of this area. The section on offshore structures (Section 3) is further subdivided into eleven subsections. The section treats dynamic response to environmental excitations such as wave, wind, vortex, and operational excitations, such as internal flow and equipment. Specialist offshore topics of monitoring, noise, shock and explosion are also evaluated in Section 3.

Finally, this committee has undertaken a benchmark study regarding whipping responses, with a special focus on nonlinear strip theory and panel methods. The degree of variation in estimates produced by different methods and organizations is revealed, and comparisons with model test measured responses are provided.

2. SHIP STRUCTURES

2.1 Wave-induced vibrations

The influence of hydroelasticity on the global structural response of ships might become very important for some operating conditions. This is particularly true for very large ships for which the structural natural frequencies fall into the range of encounter frequencies, leading to a risk of hydroelastic resonance. This phenomenon is usually referred to as linear springing. Additionally, nonlinear or sum frequency springing may occur in a case where the wave excitation forces act with a higher order of the encounter frequency. On the other hand, the impulsive forces, arising from slamming, green water, underwater explosion, etc., can induce significant hydroelastic responses, regardless of the natural frequencies of hull structure. Indeed, the intensity of hydroelastic response depends mainly on the ratio between the duration of the impulsive force and natural period of hull structure. This phenomenon is usually referred to as whipping, and, contrary to springing, it is transient and usually occurs in heavy sea states. Therefore, its influence on the ship design is important with regard to the fatigue and extreme loading.

Full-scale measurements and model tests have been extensively conducted in recent years. These tests and measurements were mainly focused on unconventional large ships such as Very Large Container Ships (VLCS) and Ultra Large Container Ships (ULCS). These ships have pronounced bow flare and high speeds (over 20 knots). They also have relatively low natural frequencies. Much research has also focused on the effect of hydroelastic responses on fatigue performance of the ship structures.

2.1.1 Full-scale measurements

Results from several full-scale measurement campaigns have been reported. The focus has been on the effect of wave-induced vibrations on fatigue and extreme loading. Some campaigns are old and can be found in previous ISSC reports. However, some of the recent work present the analysis of these data with new and refreshing objectives. A list of recently reported measurements is given below:

- 2800 TEU container ship (Gaidai et al., 2016)
- 2800 and 4440 TEU container ships (Mao et al., 2015b)
- 4400, 8600, 9400 and 14000 TEU container ships (Andersen, 2014)
- 8400 and 8600 TEU container ships (Storhaug & Kahl, 2015)
- 8600 TEU container ship (Barhoumi & Storhaug, 2014)
- Several container ships (Storhaug, 2014a)
- 14000 TEU container ship (Ki et al., 2015)
- 4600 and 14000 TEU container ships (Kahl et al., 2015)
- 8600, 9400 and 14000 TEU container ships (Andersen & Jensen, 2015)
- 4600 and 14000 TEU container ships and a LNG carrier (Kahl et al., 2016)
- 56 m naval high speed light craft (Magoga et al., 2016)
- Several container ships and blunt ships (Storhaug et al., 2017b)
- 210 m Ro-Lo ship (Orlowitz & Brandt, 2014)

Reporting the contribution of wave-induced vibrations to fatigue damage in deck amidships has started to become a standard. Storhaug (2014a) summarized the results from seven container ships ranging from 2800 to 14000 TEU. The vibration damage contribution was in the range of 26 to 57% of the total fatigue damage, with a tendency of larger ships to vibrate more. Storhaug & Kahl (2015), on the other hand, reported a contribution of 36 to 42% on an 8400 TEU vessel on worldwide trade, and 56 and 61% on an 8600 TEU vessel on Asia to Europe and North Pacific trade, respectively. The latter ship had a high bow flare angle, but the results suggest that vibration damage is not sensitive to trade. Barhoumi & Storhaug (2014) studied the wind heading effect on the same 8600 TEU vessel, confirming that head and bow quartering seas dominated the fatigue and vibration damage contributions. They also observed that vibrations contribute significantly to fatigue damage in other headings including stern seas. This was also confirmed for a gas carrier by Storhaug & Kahl (2016). Ki et al. (2015) reported 50% contribution to the fatigue damage on a 14000 TEU vessel on Asia to Europe trade, for which Kahl et al. (2015) reported 57%. On a 4600 TEU vessel in worldwide trade, Kahl et al. (2015) reported 35% contribution to the fatigue damage (at 0.43L). Kahl et al. (2016), on the other hand, reported less vibration damage in the forward and aft regions of the same vessel (26% at 0.35L and 20% at 0.75L). This suggests that vibration damage is highest where the wave bending stress tends to be highest. Storhaug (2014a) also reported model test results of container ships in head seas, suggesting conservative estimates by head sea model tests compared to full scale.

In all cases above, Rainflow counting and Miner's sum have been used. Kahl et al. (2015) carried out fatigue tests based on measured whipping time series. It was confirmed that the contribution of vibrations was well reproduced with the combination of Rainflow counting and Miner's sum. The main contribution to vibration damage came from the low frequency loads, while the additional vibration cycles gave an insignificant contribution. This suggests that an equivalent low frequency wave load can be a useful approach in ship structural design. Kahl et al. (2015, 2016) also showed that most of the fatigue damage comes from the lower frequency part of the stress spectra, despite the fact that the difference between spectra with and without vibration is relatively large at higher stress levels. Storhaug & Kahl (2016) showed that vibration damage and total fatigue damage on a gas carrier mostly came from head seas with 5 meters significant wave height.

Storhaug & Kahl (2015, 2016) and Kahl et al. (2016) refer to approved standard hull monitoring systems and recommend that fatigue rates be displayed onboard for easy understanding. The fatigue rate is defined as the ratio between the measured fatigue damage and the budget damage for a time interval, which is typically half an hour. For instance, if the fatigue rate is 90 over a day, it means that 3 months of fatigue budget is spent. Hull monitoring is used more frequently than full-scale measurements, and a mature bridge display can close the gap between design and operation, including the effect of wave-induced vibration.

Whipping contribution on extreme wave bending at amidships is another reported standard result. Storhaug & Kahl (2015) reported 48 to 59% increase in hogging for the 8600 TEU vessel and 25% for the 8400 TEU vessel with lower bow flare angle. Barhoumi & Storhaug (2014) illustrated that the IACS URS 11 dynamic hogging level was exceeded by 50% at the aft quarter length of the 8600 TEU container ship, due to whipping. That corresponds to a location where MSC Napoli broke in two. Ki et al. (2015) measured only a utilization of 45% in hogging and 76% in sagging on the 14000 TEU vessel during a short measurement period with a maximum significant wave height of 6.5 meters. Horizontal bending and torsion were however more utilized by 95% and 83%, respectively, suggesting that worst sea state was not head seas. Andersen (2014) studied several container vessels: 4400, 8600, 9200 and 14000 TEU container ships. The main conclusions are summarized as follows: Whipping can amplify the wave bending with up to 100% or more; the hogging moment may be as large as the sagging moment; and the governing vibration mode is 2-node vertical bending mode in bow quartering seas. Kahl et al. (2016) illustrated that, on a gas carrier with a hull monitoring system, the crew managed to keep the maximum wave bending moment with whipping below 80% of the rule level (first warning level), except in one half hour during 5 years where it reached 100% of the rule level (second warning level). This suggested that the hull monitoring system worked as intended and probably prevented the loading from exceeding the rule levels.

Torsional response on container ships is regarded as an important design issue. Storhaug & Kahl (2015) confirmed an increase of about 5% in the maximum torsional response due to torsional vibrations measured on a transverse deck strip on two container vessels, i.e. 8400 and 8600 TEU container ships. The vibration damage contribution was about 15-16% and 52-55% on the 8600 TEU and 8400 TEU vessels, respectively. This is the first time that torsional vibration was regarded as significant on a vessel. Ki et al. (2015) investigated the 14000 TEU vessel and estimated the torsional vibration damage as being 13% on the hull girder and up to 25% on the hatch corners. Kahl et al. (2015), however, claimed that, at the inner hatch corners on this 14000 TEU vessel, the torsional vibration was insignificant. Mao et al. (2015b) performed full-scale measurements on 2800 and 4400 TEU ships. Fatigue contributions from vertical bending, horizontal bending and torsion were studied utilizing a finite element model in one sea state, and linear regression analysis was used to obtain relations between wave loads and stresses. It was shown that high frequency warping and horizontal bending account for 10-15% of the vibration damage in the deck area. For structural details in the inner side areas, the vibration damage increases to 30% and 50%, respectively, due to the warping and warping combined with horizontal bending for the 4400 TEU vessel.

Damping affects the vibration levels for fatigue and extreme loading. By analyzing time series of the 8400 and 8600 TEU vessels, Storhaug & Kahl (2015) concluded that the effect of torsional vibration on fatigue was more significant on the 8400 TEU vessel having a structural damping (5% of critical damping) half that of the 8600 TEU vessel (10%). The reason for differences in damping on the similar vessels was not clear. Storhaug & Kahl (2016) estimated the damping for torsional vibration of an ultra-large container ship to be 5.3% of the critical damping at a frequency of 0.28 Hz. Storhaug et al. (2017b) compared six damping estimation methods with artificial data. The methods used time series mainly collected from approved hull monitoring systems of 21 ships, such as slender container ships, blunt oil tankers, ore carriers and gas carriers. For the 2-node vertical mode, the container ships had the highest damping, with an average level of 1.7 %. For the blunt ships, the average damping was estimated as 0.7 %. These values were proposed as target values for numerical analysis. It was also observed that there were no strong effects of vessel size, speed or amplitude dependence (nonlinear effects); however, uncertainties on these parameters were significant. Orlowitz & Brandt (2014) estimated the damping ratios for two node vertical mode of a 210 m long Ro-Lo ship to vary from 0.48 to 1.62% under three different operating conditions (cruising speeds of 0, 10 and 18 knots), showing significant increase in damping at the cruising speed of 18 knots. At the cruising speed of 18 knots, the frequency was also reduced by about 15%.

There are, unfortunately, examples where wave-induced vibration effects are either not estimated or excluded even though measured. Thompson (2016) used full-scale measurements to validate spectral fatigue analysis of a warship. A high sampling rate was used, but whipping was filtered away despite the recommendation of Sheinberg et al. (2011) that it be included. Magoga et al. (2016) compared measured and design stress spectra (load histogram) for fatigue analysis of a 56 m patrol boat. The 2-node vertical vibration mode at 5 Hz was included, and Rainflow counting was used for cycle counting. It was concluded that the stress spectra were well below acceptable levels, only up to about 45% of rule values during 4500 hours of measurements. The shape of the stress spectra was not represented by a Weibull shape parameter of 1.0, i.e. 2-parameter Weibull distribution with Weibull slope of 1.0, and design stress spectra was considered as conservative, possibly due to less severe trade than assumed in design.

Statistical considerations of the measured data are not frequently encountered. However, Gaidai et al. (2016) considered measurements on a 2800 TEU container ship operating in the North Atlantic. A bivariate Average Conditional Exceedance Rate (ACER) function was used to study the joint probability of deck stresses at amidships and aft quarter length. Jensen et al. (2014) carried out extreme value prediction using the Peak Over Threshold method (POT) and individual peak distribution in combination with Gumbel extreme value distribution. The POT method was regarded as the most useful and had the closest agreement with the measurements of a 9400 TEU vessel. Andersen & Jensen (2015) performed extreme value analysis on three container ships with load carrying capacities of 8600, 9400 and 14000 TEU, respectively, adopting the POT method and Gumbel extreme value distribution. The extreme value distributions, compared to URS11 rule values in hogging, suggested that there is a relatively high likelihood of exceeding the URS11 reference value. Clustering effects were also studied using the ACER function. The effect of clustering was confirmed for the 9400 TEU container vessel. Simple theoretical formulas were found suitable for moderate exceedance levels, but they cannot capture clustering effects. Andersen (2014) concluded that, for statistical extrapolation, there is no perfect method that fits all measurements, but the POT is regarded as a necessary starting point while the extreme value distribution needs to be confirmed useful.

2.1.2 Model tests

The effect of wave-induced vibrations in ship hull structures can be quantified by performing model tests, where the flexibility of the ship hull is also modeled. The most common way of doing this is to make a segmented, flexible backbone or hinged model. The main advantages of the former method are that the elastic backbone ensures a continuous stiffness distribution and that the strains are easily measured by strain gauges glued on to the beam. The hinged models consist of segments connected by rotational springs. With this method, it is reasonably straightforward to make a model with adjustable stiffness as, for instance, done by Drummen (2008). Data from Drummen (2008) were also used for the benchmark study that is presented in Chapter 4. A drawback of the segmented models with rotational springs is that the number of locations, where the forces can be measured, is limited.

Fully flexible models are basically a better representation of reality. There have, however, been a number of drawbacks with this modeling technique. The most important ones are cost and difficulties associated with building such models. A thorough review of the early use of fully flexible models was given by Wu et al. (2003). Since then, significant developments have been achieved in rapid prototyping. In order to see whether rapid prototyping could be a powerful tool for making a fully flexible model achievable, Bennett et al. (2015a), investigated the use of three-dimensional (3D) printing technologies for manufacturing structurally accurate flexible models. They discussed several 3D printing methods. All of these methods have constraints with regard to printer bed size. This results in the need to develop a modular approach for the construction of a ship model. For a typical example, the authors obtain a relation between model size and number of modules. For the same example, requirements for global and local scaling were discussed. From their work, the authors concluded that 3D printing is something that will enable fully flexible models to be realized in the future. Currently, however, the technique is not ready yet to be practically used. On the other hand, how fully flexible models perform in terms of modal damping has not been discussed yet.

Some tests with segmented models referenced in the open literature are as follows:

- 321 m long 10000 TEU container ship (Kim et al., 2015a, 2015c; Hong et al., 2015)
- 425 m long 500000 DWT ore carrier (Li et al., 2016b)
- 350 m long 450000 DWT ore carrier (Kim et al., 2015e)
- 112 m long catamaran (Lavroff et al., 2017; Davis et al., 2017).

The 321 m long container ship was tested as part of the WILS (Wave-Induced Loads on Ships) JIP (Joint Industry Project) at KRISO (Korea Research Institute of Ships and Offshore engineering). The model was made of six segments connected with a U-shaped steel backbone. The backbone was instrumented with more than 100 strain gauges to measure structural responses. The bow-flare and stern slamming loads were measured by distributing a number of load cells on the bow-flare and stern areas. The model was tested in regular and irregular waves with various speeds and relative wave headings. Kim et al. (2015c) used the data from the model tests to determine a correlation between slamming impact and whipping vibration. Their results, among others, confirmed that the impact force was proportional to the square of the water entry velocity. It was furthermore observed that, in regular waves and high speed conditions, the vertical bending moment due to the global flexural response was proportional to the slamming force. In irregular waves, it is more difficult to draw conclusions because of the difficulty in distinguishing between springing and whipping. Based on the same data, Kim et al. (2015a) performed an observational study and confirmed the presence of higher order harmonics in both vertical bending and torsional vibrations. Hong et al. (2015) also used the same data and studied the bow slamming loads. They found that it is not only the vertical relative motion but also the instantaneous longitudinal velocity that determines the impact force. This explains the high impact loads due to horizontal relative velocity induced by steep wave and ship forward velocity.

The 425 m long ore carrier was tested at the Harbin Engineering University towing tank. The model consisted of nine segments that were connected to a flexible backbone. The backbone was made up of four different beams. Three backbones with different stiffness values were investigated. The model was tested by Li et al. (2016b) in regular head waves. The periods of the regular waves were chosen such as to excite linear, second and third order springing. Their work confirmed that, as the stiffness and the natural frequency of the flexural vibration modes decrease, the importance of springing becomes more relevant.

Kim et al. (2015e) investigated an ore carrier of 350 m. The model consisted of six segments connected to a backbone. The backbone system is a tripod type truss structure, and a special connection structure was inserted at each connection so that the stiffness of the connection could be adjustable, allowing tuning of the natural frequency of the model. The model was tested in irregular head seas. The measured response was expressed in terms of a quadratic

Volterra series. From this study, it is found that the quadratic part of the global flexural response is comparable to the linear part and that the quadratic part tends to increase with increasing wave height.

Lavroff et al. (2017) tested a model of a 112 m long catamaran in regular head waves in the towing tank at Australian Maritime College, University of Tasmania. The model was made up of six segments; the midsection, two aft sections, two forward demi-hull segments and a separate bow segment. Hollow aluminum beams were rigidly mounted into the segments. Dedicated link elements were designed to connect the hollow beams and thus the natural frequency of the global vibration modes could be tuned. The damping of the model was recorded and turned out to be realistic when compared to full-scale results. During the model tests, a scale slam force equivalent to 2150 tons for the 112 m ship was measured. The contribution of the high frequency response was not mentioned. Davis et al. (2017) tested the same model in irregular head waves. From the tests slam loads, up to 132% of the hull weight were measured. The slam loads had a time scale similar to the period of the lowest global flexural vibration mode, indicating that a hydroelastic representation at model scale is also essential.

Storhaug (2014b) used data from model tests performed for 4400, 8600 and 13000 TEU container ships. The data was used for extrapolation to relevant durations for different sea states. The main question was what the dimensioning sea state is for a container vessel when whipping is included. From this study, it is concluded that it is not the highest sea states that lead to the highest bending moments. Due to the longer time spent in moderate sea states, maximum wave heights are dimensioning in these sea states. By comparing the extrapolations of the three vessels, it was found for whipping that vessel size is not a key factor, but bow flare angle is. There are, on the other hand, uncertainties associated with extrapolation methods. Therefore, Storhaug & Andersen (2015) studied four different extrapolation methods. The differences between the extrapolated values are observed as considerable. This suggests that it is necessary to be careful when selecting an extrapolation method. Due to its simplicity and reasonable accuracy, the method used by Storhaug (2014b) is regarded as useful. The ACER method developed by Naess & Gaidai (2009) is regarded as the most accurate one. The conclusions from Storhaug & Andersen (2015) still support those of Storhaug (2014b) that the moderate sea states from 7 to 9.5 m are dimensioning for the container ships. The model test results for the13000 TEU container ship were used by Zhu & Moan (2015) to investigate the effect of heading. For ships up to 200 m, the largest vertical bending moments typically occur in head waves. As the ship length increases to 300 m or above, vertical bending moments in oblique waves become significant.

Identifying slamming events in a robust manner is not a trivial task. In order to do this from vertical bending moments measured in model or full-scale tests, Dessi (2014) proposed two new approaches. The first approach uses wavelet analysis to derive the vertical bending moment time series at the frequency of 2-node vertical vibration mode. In the second approach, the time series of vertical bending moment is band-pass filtered. Subsequently, the envelope is calculated with a Hilbert transform. It is concluded that both methods can be used to assist determining the occurrence of slamming.

Panciroli & Porfiri (2015) used particle image velocimetry (PIV) during impact tests with a compliant wedge with varying water entry velocities. In this way, the pressure field is indirectly measured. Their investigation showed that the wedge flexibility strongly influences the hydrodynamic loading. The hydroelastic impact is found to be repeatable, both in terms of structural dynamics and hydrodynamic loading, confirming the feasibility of PIV-based pressure reconstruction in water entry problems.

An important recommendation for future model tests is that damping should be added for container vessels. In general, the damping ratio in model tests is found to be too low.

2.1.3 Analysis methods

The numerical modeling of springing and whipping is extremely complex since it requires full coupling of the hydrodynamic and structural solutions at each time step of the simulation. The most common hydroelastic models involve a structural model of the ship, a hydrodynamic model of the fluid and a coupling method ensuring that the interaction effects are properly accounted for. The structural model is usually a 3D Finite Element Model (FEM) or a beam model (Euler-Bernoulli, Timoshenko, Vlasov), and the fluid-structure coupling effects are commonly calculated by using the potential flow theory. Available modeling approaches are summarized in Table 1.

Fluid structure coupling effects are basically calculated by using two distinct approaches, namely strip theory and 3D Boundary Integral Equation (BIE) method. All these methods were established well before the year 2014, and no major improvements have been made since then. Most of the recent work concentrates on using those methods for practical applications. As far as the strip theory is concerned, there exist different variants which are in use for hydroelastic analysis (Bennet et al., 2015b; Cristea et al., 2015; Dhavalikar et al., 2015; Heo et al., 2016; Kawabe et al., 2016; Liu et al., 2017b; Matsui et al., 2016; Rajendran et al., 2016; Wang et al., 2016a; Wu, 2015). Strip theory formulations differ from each other according to the ways of accounting for nonlinear wave effects and forward speed.

Regarding 3D hydrodynamic seakeeping models, there are many variants which are proposed by, for instance, De Lauzon et al. (2015a), Im et al. (2016), Kashiwagi et al. (2015), Kim et al. (2015f), Kim & Kim (2014, 2016), Lee et al. (2015d), Malenica et al. (2015), Ren et al. (2016), Senjanovic et al. (2014), Shan et al. (2017), Southall et al. (2016), Yang et al. (2015b), Zhang et al. (2015, 2016a). These 3D seakeeping models differ in many aspects as indicated in Table 1. The degrees of accuracy and theoretical consistency vary from case to case but there is no clear candidate for the most efficient solution. For ships carrying liquid cargo such as LNG ships and tankers, it is also interesting to mention the work of Malenica et al. (2015), where, in addition to the global hydroelastic interactions, the local interactions within the tanks are also taken into account.

With regard to slamming, the situation is even worse because, within the potential flow theory, there is no consistent numerical model for 3D slamming. Therefore, 2D strip approach is mainly used in combination with strip theory models as well as with 3D seakeeping models. There are basically two 2D models, which are usually employed in analyses. The first one is the so called momentum theory approach, sometimes referred to as von Karman model. Due to its simplicity, this model is used in most of the numerical whipping codes either in combination with strip theory or 3D BIE based seakeeping codes. The second one is the Generalized Wagner Model (GWM). Within this model, the body boundary condition is imposed on the actual position of the entering surface. The GWM slamming model is used, for instance, by De Lauzon et al. (2015b), Kim et al. (2015b, 2015f) and Malenica et al. (2015). Some improvements were, however, proposed recently by De Lauzon et al. (2015b), Khabakhpasheva et al. (2014) and Helmers & Skeie (2015). It is also worth mentioning the method proposed by Lee et al. (2015d) and Southall et al. (2016), where 2D slamming simulations are performed by using CFD (OpenFoam) and coupled with the global hydroelastic model based on 3D potential flow theory. It is, however, not clear if this approach is fully consistent, because the interaction between the potential flow and CFD is not considered at each time step. With respect to slamming, it is also important to mention the determination of input parameters which should be given to slamming modules, i.e. the relative geometry before impact and the relative impact velocity. These modules, therefore, use only incident wave geometry and kinematics for predicting slamming induced forces, and thus, the effect of perturbation waves is ignored. It should also be noted that the relative impact velocity represents the mean velocity of the impacting section, and it does not include the changes in local flow. This is to say that the slamming impact is modeled as an impact on calm water. Finally, it is also important to mention that, most often, the water exit phase is either not modeled or modeled approximately (see, for instance, De Lauzon et al., 2015b). All of these considerations point to the enormous difficulties related to the correct evaluation of slamming loads.

Table 1. Numerical whipping models based on potential flow hydrodynamics.

SEAKEEPING	Basic model	2D strip theory
		Full 3D
	Forward speed approximation	Encounter frequency
		Forward speed
	Linearization procedure	Uniform flow
		Double body flow
		Other
	Time integration	Direct
		Hybrid: Frequency + Time (Cummins approach)
	Numerical method	Rankine singularities
		Kelvin singularities
		Other
	Nonlinearities	Linear
		Weakly nonlinear FK - Incident
		Weakly nonlinear FK - Incident + perturbed
		Other
	Wave modelling	Regular waves
		Irregular waves
	Handling of horizontal motions	Lagrange multipliers
		Springs
		Other

SLAMMING	Theoretical model	Von Karman (or momentum theory)	
		GWM (Generalized Wagner Model)	
		Other (MLM, wedge…)	
	Sections orientation	Vertical	
		Inclined	
	Relative velocity	Wave	Incident wave
			Incident + perturbed wave
		Body	Rigid body
			Rigid + Elastic body

STRUCTURE AND COUPLING	Structural model	3DFEM
		Beam (Timoshenko …)
	Method of solution	Modal
		Direct
	Coupling principles	Weak (one way)
		Strong (two way)

In spite of all the developments on 3D seakeeping models using potential flow theory, it is fair to say that none of the proposed methods can fully and consistently model all the nonlinear aspects of the seakeeping in large waves. In principle, the 3D seakeeping models are more consistent and accurate, at least for springing analysis, but their use for whipping is conditioned by the limitations of 2D slamming models. Having said that, most of the studies report quite good comparisons with experimental results, especially in head waves, where the physical situation is simpler and the approximations, such as weakly nonlinear potential flow and 2D slamming conditions, are more likely to be valid.

Due to the limitations of the potential flow models, there are currently more developments on the seakeeping models that use CFD approaches. The CFD models are based on solving the Navier-Stokes or Euler equations using the so-called field methods (finite volumes, finite differences, particle methods), and they are in principle supposed to model any flow situation, provided that a sufficient number of cells is adopted. Due to the developments in numerical methods and computer power, it is now possible to run very complex seakeeping simulations in large waves in an efficient and theoretically consistent way. The price to pay (CPU time and engineering effort) is still large, but at least something more reasonable and more consistent can be done. This is particularly true for the predictions of slamming forces, which is one of the main drawbacks of the potential flow models. The CFD software, which is used most often for these applications, is the open source CFD code OpenFoam (see, for instance, Craig et al., 2015; el Moctar et al., 2017; Oberhagemann, 2016; Oberhagemann et al., 2015; Seng et al., 2014), but the use of the commercial CFD code StarCCM+ is also reported, for instance, by Kim (2015), Lakshmynarayanana et al. (2015) and Takami et al. (2017). In addition, the in-house code ICARE, which is based on the finite difference method, was used in Robert et al. (2015). The use of the CFD based numerical codes for seakeeping is relatively new, and there is considerable work ongoing in this area. These models will certainly play an increasingly important role in the future regardless of the expense because they seem to be the only possible way to include all the important aspects of whipping.

On structural side, the use of a beam model is reasonably justified due to a limited number of structural modes involved, especially when only bending is of concern. In case of more complex situations, such as the torsional vibrations of ships with open cross sections (container ships), either a 3D FE model (Im et al., 2016) or an improved beam model (Senjanovic et al., 2014) should be adopted. 3D FE models are more robust, not only because the structural behavior is better represented but also because it allows for direct evaluation of the structural stresses at any particular point within the structure (see, for instance, Malenica & Derbanne, 2014; Im et al., 2016).

Finally, concerning the coupling procedures which are usually employed for modeling the hydroelastic interactions, the most common approach is the so-called modal approach because it is cheaper and simpler to put into practice. It seems that all of the numerical codes which are mentioned here use the modal approach either in combination with a beam or 3D FE model. This is true for all the seakeeping solvers that are based on potential flow theory or CFD (Seng et al., 2014). It is important to note that, within the modal approach, special care should be given to proper separation between the dynamic and quasi-static responses (Malenica & Derbanne, 2014). It also has to be said that some numerical codes, especially those based on commercial CFD software, use the so-called weak (or one way) coupling procedures, because the full coupling appears to be more difficult to realize.

2.2 Machinery- and propeller-induced vibrations

It is well-known that there are two major sources within a ship that induce vibrations under normal operating conditions on voyage: namely, main engine and propeller.

As for propeller-induced vibrations, accurate prediction of propeller forces is essential in the assessment of the design of ship structures. For the past three years, there have been several attempts for accurate prediction of propeller-induced hydrodynamic forces in actual operating conditions. Meanwhile, special devices have also been used to reduce the propeller-induced forces in a ship, and some of them have succeeded in validation of their effectiveness in full-scale tests. Furthermore, many researchers have paid attention to the dynamic interaction problem between the ship hull structure and propulsion shafting system.

As for engine-induced vibrations, in the period of this report, no major development has been reported in the open literature on numerical methods for vibration response analysis; most of the attention has been paid to vibration control and vibration reduction techniques. There is rather a small number of references to machinery-induced vibrations compared to other vibration sources as, for instance, wave-induced vibration. However, the topic is expected to come in focus again, primarily due to the introduction of so-called Comfort Class that was first introduced by DNV-GL in January 2011, and later by LR and BV, as other Classification Societies followed the DNV-GL breakthrough. The Comfort Class (requirements for the noise, vibration and indoor climate on board) is applicable to passenger and cargo ships, and it is more restrictive than Safety Class, forcing researchers to pay additional attention to machinery-induced vibrations.

2.2.1 Propeller-induced vibration

A group of studies has been reported on the numerical accuracy of propeller induced forces by using enhanced source models and considering actual ship motions in waves. Kim et al. (2014a) studied the hydrodynamic characteristics of non-cavitating propellers. In this study, an advanced source model is proposed based on the lifting surface theory, by considering source strength, its position and axial direction as unknown parameters. The matched-field inversion method is employed to find the unknown parameters. They calculated the pressure fluctuations on the hull based on the proposed model and showed that the results are in good agreement with measurements from model scale experiments. Finally, they concluded that the proposed source model is practically useful in predicting propeller induced forces at the early design stage. Abbas et al. (2015) presented a hybrid URANS (Unsteady Reynolds Averaged Navies Stokes) - LES (Large Eddy Simulations) model for prediction of unsteady forces on marine propellers, caused by the operation of propellers in non-uniform wake flows. From the numerical simulations, strong thrust fluctuations up to 13% of the mean thrust is obtained. They concluded that a hybrid model is necessary to identify peak loading on marine propellers. Taskar et al. (2017) studied the propeller performance in terms of cavitation, pressure pulses and efficiency, not in calm water condition but in actual operating conditions. An 8000 DWT chemical tanker equipped with a twin-podded propulsion system is employed as a case vessel in this study. The effects of various factors affecting propeller performance in waves, such as wake variation, ship motions and speed fluctuation, are investigated using a propeller design software based on the vortex lattice theory. It is found that cavitation and pressure pulses due to wake variation increase substantially and that the effects of other factors are relatively small.

There have been several attempts to reduce pressure fluctuations on hulls or improve hydrodynamic performance of marine propellers by applying practical devices to the stern area of a ship, such as air-balloon or Rim Driven Thruster (RDT). Lee et al. (2015c) presented a design of rubber membrane filled with air near the propeller, which plays a role similar to a dynamic damper at the target frequency. The rubber membrane is fixed to the outer hull surface near the propeller, and its effectiveness is validated by pressure and acceleration measurements in a sea trial. They confirm that the amplitude of hull pressure is reduced and that the resultant vibration response decreases by more than 60%. Chen et al. (2017) calculated the hydrodynamic pressure acting on the blade surface of RDT, using the correlation method based on strip theory. Applying the calculated hydrodynamic pressure to each blade as excitation, the forced vibration response of the RDT is obtained and compared with that of the traditional Shaft Driven Propeller (SDP) with the same blade configuration. It is shown that the resonant amplification of the RDT in the unsteady thrust is still lower than that of the SDP by about 15 - 20 dB.

Conventionally, the shaft forces are mainly responsible from three different modes of shaft vibration in a marine propulsion system: namely, axial, whirling and torsional vibrations. Recently, it has been reported that the hull deformation may seriously change the mounting positions of shafting system, and the ship could not normally be operated under this condition (Leontopoulos, 2006). The shaft forces may also cause unwanted vibrations in the shaft system, owing to the coupled vibration with the hull structure. Zou et al. (2015b) investigated the nonlinear characteristics of a marine propulsion shaft, of which motion is coupled in longitudinal and transverse directions. The nonlinear equation of motion and its solution are obtained by Hamilton's principle and the Galerkin method, respectively. They showed that the bearing support stiffness, propeller mass and slenderness ratio have strong effects on the nonlinearity. Therefore, in whirling vibration analysis of such marine shafts, the nonlinear effects should be considered. Qu et al. (2017) developed a fully coupled vibro-acoustic model between a propeller shaft and a submarine pressure hull for predicting the coupled dynamic response induced by the propeller excitation. The entire structural system consisted of a rigid propeller, a main shaft, bearings and an orthogonally stiffened hull structure. The rings and stringers in the pressure hull are modeled as discrete structural elements. Through the numerical simulations, it is shown that both the axial and vertical stiffness of the bearings have significant effects on the dynamic response of the coupled system. Huang et al. (2017) developed coupled equations of torsional and longitudinal shaft vibrations. Based on this model, the natural frequencies and maximum accelerations in each direction were obtained. It is found that the natural frequencies are not affected significantly by the rotational shaft speed as well as the loading conditions. Meanwhile, the maximum acceleration increased with increasing rotational speed.

2.2.2 Machinery-induced vibration

As mentioned above, in the field of engine induced vibration, compared to other dynamic response issues inherent to ship, there is a relatively small number of publications. Han et al. (2015) estimated the fatigue life of a propulsion shaft from torsional vibration measurements, using the linear damage summation law. The torsional vibrations were measured using strain gauges on the gear input shaft of the engine. The fatigue life of the reduction gear input shaft was estimated by using the Soderberg's safety evaluation method.

Most of other related references are devoted to dynamic response control, as also indicated in a special chapter dedicated to ship vibration and noise control in a book by Bai & Liang (2016). In this respect, Cinquemani & Braghin (2017) presented the design of an active standalone device to suppress vibrations on cruise ship funnels, generated by engines and exhaust stacks. The effectiveness of the device was confirmed by experiments. Guo et al. (2017) developed a model for coupling shaft torsional vibration with a speed control system for an engine, claiming that neglecting the coupling may lead to serious vibrations. The authors also state that, using their model, the speed control parameters can be tuned to predict a stable and safe-running condition for a diesel engine.

As part of recent efforts to reduce emissions and fuel consumption, ultra-long stroke engine (hereafter G-type engines) are now commonly used in eco-ships (Kim et al., 2017d). The best feature of G-type engines is their ability to generate greater power at lower engine speeds. In some recent cases, however, the operators of eco-ships have experienced problems of being unable to pass quickly enough through a critical engine speed. A hybrid (active-passive) isolator consisting of a maglev actuator and air spring is proposed and developed by Li et al. (2017). The dynamic characteristics of this hybrid isolator were analyzed and tested, and its stability and adaptability to shock and swing in the marine environment was improved by a compliant gap protection technique and a suspended structure. Kim et al. (2017d) reviewed the torsional vibration characteristics of a propulsion shafting system equipped with a fuel saving ultra-long stroke engine. The effects of waves on engine-propeller and propulsion performances were analyzed by Taskar et al. (2016).

2.3 Sloshing impact

The violent impact between liquid and structure is an important issue in the ship hydrodynamic community. There are several practical applications where liquid impact loading plays an important role: slamming, sloshing, green water, wave impact on the deck and many others. Extreme impact pressures can affect the integrity of the structure and should be considered with extreme care for the design of floating bodies. The physics of fluid impact phenomenon is extremely challenging both from the numerical and experimental points of view.

Many physical effects in sloshing have to be considered concurrently (gas cushion, liquid compressibility, boiling of liquid cargoes, aeration, thermal exchange, hydroelasticity, etc.). Meanwhile, in parallel with the correct characterization of the hydrodynamic loading, we must always keep the structural response in mind. This implies that the equations for fluid (liquid and gas) and structure must be solved simultaneously unless certain assumptions are made to uncouple them. Furthermore, the modeling of sloshing impact poses difficulties regarding the fact that the structure (Cargo Containment System–CCS) in contact with liquid (e.g. Liquefied Natural Gas - LNG) is extremely complex (combination of plywood, foam, perlite, special steel, triplex, invar, resin rope, etc.). An overview of the difficulties related to the modeling of violent impact situations is given in Malenica et al. (2017) and Dias & Ghidaglia (2018).

During the last three years, the investigation of sloshing impact has been pursued both by experimental and numerical means. Unfortunately, the opinion of this committee is that no significant progress has been made and there is still no efficient solution, neither experimental nor numerical. Most of the investigations concentrate on the evaluation of extreme pressures which occur during the impact, with the idea of simply applying these pressures to the structural model in a second step. However, due to the particular nature of the extreme impact pressures, which are highly localized both in space and time, capturing the pressure extremes correctly appears to be almost impossible both numerically and experimentally. It is thus regrettable that the coupled hydro-structure interaction has not been considered seriously yet. Indeed, even if the pressure distribution is evaluated correctly in time and space, the structural response could not be evaluated by simply applying this pressure distribution on the structural model, because the important dynamic hydro-structure interaction effects will be still missing. This means that the highest pressures will not necessarily cause the highest structural responses.

2.3.1 Experimental approaches

Many model tests at different scales and with different objectives were proposed in the past. In particular, small-scale sloshing model tests became rather classical and many important facilities exist worldwide. The most typical sloshing model testing facilities use hexapods (e.g., see Kim et al., 2017a), which is very efficient in generating arbitrary time histories of the tank motions. The quantities measured are usually the local pressures and the overall forces on the tank. As far as the overall sloshing behaviour is concerned, the small-scale model tests are very useful and give a good qualitative impression of the violent fluid flow. Furthermore, the overall forces on the tank show good repeatability regardless of the model scale. This is because the overall sloshing behaviour is mainly driven by Froude scaling. However, when it comes to the measurements of the pressures, the situation is much more complicated both regarding the repeatability and accuracy of the measurements, especially for extreme events. Even if the impact pressures are measured accurately, it is still very difficult to scale them consistently to full-scale. For instance, the impact pressures generated by a breaking wave will be associated with an appreciable quantity of entrained and/or trapped air, and, as a result of this, Froude scaling leads to erroneous results. This is an extremely important drawback of the small-scale model tests and it is not likely that this problem will be solved in the near future. In the context of the small-scale model tests, it is also important to mention that generally flat surface tanks are used in the sloshing tests. However, two major CCS (MARKIII and NO96) have important geometrical discontinuities such as corrugations and raised edges which can significantly influence the local pressures.

Among the different experimental campaigns reported during the last three years, we can distinguish the classical small-scale model tests either in 2D or 3D and also the model tests dedicated to some specific aspects of the sloshing impact. The air pocket type impact was recently investigated by Firoozkoohi et al. (2017), Yang et al. (2016a), and Neugebauer et al. (2017), and it was shown that, for this particular type of impact, very similar and repeatable results can be obtained in terms of wave shapes and impact pressures. This is due to the facts that the air pockets are large enough and that the pressure measurements are known to be stable for this kind of situations. For other impact types, the pressure measurements differ significantly, and only the free surface geometry can be captured with fair accuracy.

The phase transition effects were investigated by Kim et al (2017c) by using hot water and bubbles, for air-pocket type impact. The conclusion is that the phase transition effects tend to damp both the peak and oscillations of the pressure in air pockets, confirming the numerical conclusions made by other authors (see, for instance, Ancellin et al., 2016; Behruzi et al., 2017). The effect of temperature was also investigated by Grotle et al. (2016) for LNG fuel tanks, and it was concluded that the lower liquid temperatures, relative to the saturation temperature, has a significant influence on the pressure. The scaling of pressures is a critical drawback of the sloshing model tests, and several investigations were carried out in order to quantify more precisely the effects of different scales (Kim et al., 2016, 2017b; Karimi et al., 2015, 2016a, 2016b; Wei et al., 2016; Frihat et al., 2017, 2016). In Karimi et al. (2015, 2016a, 2016b), and Frihat et al. (2017, 2016), the influence of the density ratio between the liquid and gas on impact pressure was also investigated. The conclusions from all these investigations confirm once again that the global flow is almost independent of both scaling and density ratio; however, the local flow and associated pressures are very much dependent on these parameters. Frihat et al. (2017, 2016) studied the influence of surface tension on sloshing impact pressures, through 2D sloshing tests with different density ratios. The preliminary conclusion is that the reduced surface tension leads to reduced pressures. The 3D effects of sloshing flow were investigated by Kim & Kim (2017), and it was shown that there exist significant differences between the 2D and 3D results for pressure measurements (pressure peak and its position, affected area and pressure impulse). A comparative study on pressure sensors for sloshing experiments was performed by Kim et al. (2015d). It was reported that the pressure signals may be quite different, depending on the type of sensor installed on the tank wall. All these uncertainties in the pressure measurements have an important effect on the statistical properties of the measured pressure peaks. Some aspects of these difficulties are discussed in Cetin et al. (2017), where no definite conclusions were made regarding the most appropriate probability distribution to be used for the extrapolation of the measured pressure data.

Large-scale model tests were reported in Kimmoun et al. (2016). In those tests, wave impacts were generated on a horizontal plate, modelling a tank ceiling in a 2D wave flume. Wave impact tests were performed either with a flat ceiling or with a corrugated ceiling obtained by the addition of three solid corrugations representing the corrugations of MarkIII membrane at a scale of one half. The instrumentation consisted of high-speed video cameras synchronized with pressure sensors mounted both on the flat part of the ceiling and, for the first time, directly on the corrugations. Among other things, these experiments allowed for identifying the mechanism leading to high pressures on the corrugations. This may happen due to complex jet impact following the direct impact on ceiling. The authors claim that this phenomenon might be responsible from some deformations of the corrugations.

2.3.2 Numerical modelling

In Computational Fluid Dynamics (CFD), different numerical models proposed before for sloshing have been further investigated during the last three years. CFD tools (either commercial, open-source or user-developed) based on solving the Navier Stokes or Euler equations are most often applied with slightly different numerical strategies. A considerable amount of research work was reported on the use of OpenFoam software (Calderon-Sanchez et al., 2015; Diebold & Baudin, 2016; Firoozkoohi et al. 2017; Grotle & Aesoy, 2017; Lyu et al., 2017; Mai et al., 2015; Wang et al., 2016e). The OpenFoam is an open source software based on the finite volume method, and its capabilities seem to be similar to equivalent commercial codes. The numerical sloshing models using finite volume based commercial tools are reported in Behruzi et al. (2017) (Flow3D), Mokrani & Abadie (2016) (Thetis), Zou et al. (2015a) (Fluent), Yang et al. (2016a) (StarCCM+), Veldman et al. (2015) (Comflow). On the other hand, the numerical models based on the finite difference scheme were adopted by Arai et al. (2016), Liao et al. (2015) and Karuka et al. (2017). Furthermore, the use of meshless or particle methods was also reported in a number of study (Baetan, 2015 and 2017; Buruchenko & Canelas, 2017; Gong et al., 2016; Hwang et al., 2015a; Koh et al., 2015; Lind et al., 2015; Wang et al., 2016e; Zhang et al., 2017d). The main advantage of the particle methods is their ability to easily simulate complicated free surface flows, and their drawbacks are high CPU usage and difficulties related to the consistent treatment of the boundary conditions at the interface with rigid boundaries. Due to the difficulties of modelling the local details of 3D fluid structure interaction problems consistently by CFD methods, some less popular numerical methods were proposed for 2D impact problems. For instance, Scolan & Brosset (2017) proposed a potential flow method based on the desingularization technique, allowing for extremely fast and accurate modelling of the relative geometry between the fluid and structure just before the impact. This method also allows for coupling with more sophisticated purely numerical (Volume Of Fluid (VOF) or meshless) local impact methods, once the impact starts to occur. Hay et al. (2016) proposes a highly precise 2D numerical method based on the finite element technique with adaptive time and space refinements. Furthermore, Janssen et al. (2016) used the Lattice Boltzman model in combination with VOF approach for surface tracking, and they reported encouraging results for the generic 2D cases proposed by Scolan & Brosset (2017). Finally, in addition to the purely numerical methods, a limited number of analytical approaches for simple geometries was also proposed by Korobkin et al. (2017) and Zekri et al. (2015). The advantages of these methods are their extremely high precision and the possibility of taking into account the hydroelastic effects consistently. Therefore, the methods could be used for the validation of numerical methods.

With regard to structural responses (CCS and hull structure), a limited amount of work has been reported in the last three years. Cho et al. (2015) used ABAQUS to model the structure of a recently proposed new insulation system (KC1), with a special emphasis on the thermal behaviour. Hwang et al. (2015b) used the LS-Dyna software to investigate the nonlinear structural response of the CCS under impulsive loading deduced from dry drop tests. Jin et al. (2015) used ABAQUS to study the nonlinear structural response of the KC1 CCS under prescribed triangular impulsive loading. Kayal et al. (2016) employed ABAQUS to define a Triangular Impulse Response Function (TIRF) concept in order to efficiently model the linear structural response of the MARKIII CCS to an arbitrary time history of the prescribed external loading. Lee et al. (2015b) simulate the full-scale wet drop test experiments of the MARKIII CCS using the LS-Dyna, and they emphasize the nonlinear behaviour of polyurethane foam. Ringsberg et al. (2016) used ABAQUS to investigate the dynamic amplification of hull structural response by accounting for the influence of the CCS. The authors conclude that the dynamic amplification might be very important for some temporal load characteristics. In addition to the difficulties related to the modelling of pure structural behaviour, these methods still lack a consistent definition of pressure loading and fully consistent hydroelastic interaction model.

In conclusion, it may be said that, in spite of all the improvements reported on numerical tools and methods, there is still no fully consistent, reliable and efficient method, neither for fluid dynamic modelling nor for fluid structure interactions, which occur during sloshing impact.

2.4 Shock response

The shock and explosion-induced responses of ships are important to naval architects of both military and civilian vessels. The characteristics of the dynamic responses to shock and explosions are of a nonlinear nature on material and geometry, and different than caused by waves and machinery. The work of many researchers is devoted to shock and explosion loading, response and damage of ship structural elements, including composite hull structures.

2.4.1 Air blast

Air blast from both accidental and weapons explosions is an important form of ship structural loading. A key area of concern for blast response is explosion in an interior compartment, and potential damage due to internal explosion is a recent focus area of research. In the field of internal explosion loadings, quasi-static loading was a main concern. Duan et al. (2017) conducted a series of tests with aluminized explosives of different Al/O ratios, and the results showed that the quasi-static pressure gain was maximum at a ratio of Al/O = 0.99 that is almost half the value of the gain of the maximum bubble in an underwater explosion. Salvado et al. (2017) proposed a new method to estimate the peak pressure of an explosion in a compartment. Feldgun et al. (2016) have studied the internal energy of explosion and proposed a simplified approach based on the developed gas pressure, as well as on the Bernoulli equation, which is well-suited for simulation of partially confined explosions and properly describes the pressure relief and gas outflow from a vented compartment.

When a ship is attacked by a missile, the compartment of detonation is subject to shock loads that usually cause serious damage. Many researchers have worked to develop new methods for analysis and experimentation of response and damage of compartments subject to internal explosion. Yao et al. (2016, 2017a) suggested a new dimensionless number for the dynamic response of box-shaped structures subjected to internal blast loading that has clear physical meaning and leads to good correlation between the response of box-shaped structures and the blast energy. They designed three sets of steel box structures using a replica scaling law to investigate their responses under internal blast through experiments, and correction of the traditional scaling law was conducted. Yao et al. (2017b) conducted two series of experiments with different dimensions and different masses of explosive, and six damage modes were observed. Pickerd et al. (2016) conducted internal blast experiments on welded steel containers using digital image correlation to assess the deformation and strain. Weld defects such as porosity and lack of fusion result in highly localized regions of strain that are difficult to account for in simulations. Karagiozova et al. (2015) investigated the response of partially confined hollow stainless steel cylinders to internal air blast loading. A theoretical model was developed for the deformation of a sandwich-walled cylinder configuration, and was used to analyse and interpret the process of the dynamic foam compaction and stress transmission to the outer wall.

2.4.2 Underwater explosion

Underwater explosions are a source of serious damage to ships due to potential loss of hull integrity. Shock loading is the basis for the response analysis and prediction. Recent research has focused on non-ideal explosives and near-field explosions. The underwater explosion loading properties of non-ideal explosives enriched with aluminium was investigated by Komissarov et al. (2015). The shock wave and bubble energy were measured, and it was found that the Al/O ratio is the key parameter that controls the energy output. The specific energy of an explosive charge highly enriched with aluminium can be more than twice that of TNT when the Al/O ratio is 1.85. Wang et al. (2016b) proposed a simple method to determine the mesh size for numerical simulations of near field underwater explosions. The ratio of the radius of the charge to the side length of the element equal to 3 was shown to be an adequate choice. Han et al. (2016) investigated the pressure load of double underwater explosions, including the effect of the detonation time difference and the distance between explosive sources on the resulting damage force. Wang et al. (2016f) combines the Level-Set Modified-Ghost-Fluid Discontinuous-Galerkin (LS/MGF/DG) method and the Boundary Element Method (BEM) to simulate bubble motion and associated pressures near a wall, and the numerical results were compared with experimental data. Zhang et al. (2015a, 2016c) used a Smoothed Particle Hydrodynamics (SPH) method with mesh-free and Lagrangian formulations to simulate the formation process of a shaped-charge jet. Zhang & Jiang (2015) proposed an improved shock factor based on the scattering effect caused by the diameter of smaller submerged cylindrical shells on different wavelength of the incident waves.

Responses of primary structural elements to shock are the basis of understanding and analysing the whole ship structural response. Beam and cylinder idealizations can be used to model the overall structure of surface ships and submarines, respectively. The panel is the typical primary structural member of a surface ship. Chen et al. (2016) investigated the theoretical response of a typical double-bottom structure subjected to underwater blast and established an approximate analytical model which is able to predict the response. Wang et al. (2016d) proposed a dynamic buckling criterion for stiffened plates subjected to an explosive shock wave and discussed the effects of various stiffening configurations on the dynamic and static buckling loads. Furey (2015) evaluated the stress-strain states and the hydrodynamic fields through analysis of stress in two submerged co-axial cylindrical shells and pressure fields in the inter-hull coupling fluid. Changes in behaviour were quantified by varying the relevant parameters of structures and fluid fields. Hsu et al. (2016) numerically investigated the response of three different beam cross-sections (circle, ellipse and streamline shapes) to an underwater explosion and concluded that a circular cross-section is stronger than others. Monteiro et al. (2016) conducted two sets of experiments to investigate the collapse of aluminium tubes to static and underwater explosion loadings, and some collapse phenomena were observed.

The dynamic response of ships to UNDerwater EXplosion (UNDEX) is very important for ship survivability due to the potential for serious damage. Recent research has concentrated on the damage and responses to near-field and contact explosions that are relevant to bubble dynamics and strong nonlinearity, respectively. In near-field UNDEX research, Nie et al. (2015) presented the regimes of underwater explosion for a submerged slender structure excited by pulsating bubble. Near-, middle- and far-fields are identified according to structural global responses. Equivalent dimensionless parameters are obtained by two different dimensional analysis methods, among which a dominant similarity parameter is found. Zhang et al. (2015b) conducted an experiment of a hull girder model subjected to near field underwater explosion at mid-ship. The damage mechanism and mode were discovered by the experiment, and the coupling effect between the whole motion of hull girder and distortion of local structure was discussed. Wang et al. (2016c) developed a new analytical model to predict the damage of a simplified hull girder subjected to an UNDEX shock wave and its bubble pulsation load based on the rigid-plastic material model, the Vernon bubble model, and the modified hydro-plastic analysis method.

In the contact UNDEX research field, Zhang et al. (2015a, 2016c) investigated the damage of double-hulls to contact UNDEX with a simplified SPH method. It was found that either the polyurethane layer or water layer could have a protective effect for the second shell. Zhang et al. (2017b) performed experimental work on the response of multi-layered protective structures subjected to underwater contact explosions. Some important factors in plate damage are analysed, and the role of the compartments with different media on the damage and energy dissipation is discussed.

For stealth, light weight, and other advantages, composite structures are widely used in modern ships. Their response and damage to shock and explosion are areas of recent research. Primary areas of interest are Glass Reinforced Plastic (GRP), Styrene-Butadiene-Styrene (SBS), sandwich plates, and rubber-like material coating structures. Schiffer & Tagarielli (2015) presented a new experimental technique to allow laboratory-scale observation of underwater blast loading on circular quasi-isotropic glass/vinylester composite and woven carbon/epoxy plates. This included dynamic deformation and failure of the plates, as well as the sequence of cavitation events in water and the development of a theoretical model for the response of elastic orthotropic plates to underwater blast. Liu et al. (2017a) investigated the high velocity impact responses of newly designed sandwich panels with aluminum (AL) foam core and Fiber Metal Laminate (FML) skins by experimental methods. Gong & Khoo (2015) used the coupled BEM–FEM to handle the interaction of a composite structure and an underwater explosion bubble, and the mutual effects of relative location and the transient response of a composite submersible hull to an underwater explosive bubble for different charge weights and charge distances were investigated. Jin et al. (2016) investigated the effects of graded foam cores of a sandwich spherical shell subject to underwater explosion from the inner side. It was found that the core arrangement of low/medium/high is best for the case of a relatively strong core condition, and the configuration of high/medium/low has the best performance for the case of intermediate core strengths. Xiao et al. (2015) carried out a comparative study of honeycomb rubber coatings of the same material and total mass subjected to underwater explosion. Three types of cell topologies were considered. Three groups of live underwater explosion tests with different attack angles and stand-off distances were conducted on stiffened metal boxes covered with the coatings. The results show that the protective effects of different coatings are consistent under different attack angles and stand-off distances. Compression performance of the coatings plays a dominant role in underwater shock resistance.

The responses and damage of equipment and on-board systems to shock and explosion are of great concern to naval architects, as protection of their functionality is important to accomplish the ship's mission. Scavuzzo et al. (2015) presented a review of an experimental study and analytical demonstration to explain the effect of dynamic interaction on the shock or response spectrum. A practical example of interaction was studied, with four single mass dynamic systems mounted on a realistic deck and subjected to a high impact shock input. On-board equipment and systems are often comprised of many components, and the anti-shock capability of the components directly affects the anti-shock capability of the equipment. Guzas et al. (2015) used a variety of finite element modelling approaches to represent the behaviour of single solid bolts under static and dynamic tension loading, and simulation results were validated against experimental data from physical testing. Stenard et al. (2017) proposed a new approach for the Universal Adjustable Shock Mount (UASM) to reduce Total Ownership Cost (TOC), by making electronics upgrades on warships as easy as in the commercial sector. Hansen et al. (2016) set up a more precise method for load prediction on piping and small- to medium-sized equipment than the current guidance, which may lead to underestimated explosion loads. Due to the complexity of responses of equipment to shock, reliable validation of anti-shock capability is usually by testing.

2.5 Noise

Noise emissions from shipping activities have been a great concern due to their negative impact on the environment. The ship onboard noise receives close attention due to the increasing awareness of health hazards caused by the long-term exposure of the crew to high noise and vibration levels, and due to the considerations of safety and comfort for crew and passengers. The latest regulatory document on noise levels onboard ship is issued by IMO (2014).

The underwater radiated noise also generates similar effects on the marine fauna, by causing an increase in the background noise of the oceans and modifying the ambient conditions of the fauna. The noise emissions may also interfere with acoustic sensors and underwater monitoring systems.

A proper noise assessment of a ship design is a very complex matter, due to several factors such as:

- The noise is generated by different entities located in different positions on board (machinery, propulsion, ventilation, auxiliaries, etc.);
- There are several mechanisms of transferring noise from one location to another (structural, airborne, waterborne, through ventilation ducts and pipes, etc.);
- There are different targets with different thresholds, or limits (internal, with regard to passenger and crew comfort – external, with regard to airborne noise pollution in coastal areas - underwater, with regard to disturbance to marine environment).

This committee report presents the results of the literature survey with regard to the “receiving environment”. In this respect, it is noted that the general trend of the recent research is to provide a scientific baseline to the standardization of every aspect of the “noise onboard” issue.

Borelli et al. (2016a) presented a comprehensive review. They discuss that while in the field of interior noise there is a coherent set of rules constantly updated for both noise and vibration, in the new fields of application, namely external and underwater radiated noise, the situation is still far from settled. The work started with the concluded European project SILENV (Ship Innovative soLutions to rEduce Noise and Vibrations), for instance, is not complete yet and further investigations are still needed. Three new EU projects are following up the road mapped by the SILENV (2012):

- AQUO (Achieve QUieter Oceans by shipping noise footprint reduction),
- SONIC (Suppression Of underwater Noise Induced by Cavitation),
- MESP (Managing the Environmental Sustainability of Ports for a durable development).

2.5.1 Interior noise

Regarding interior noise, and referring to the above introduction on the adequacy of available norms to the state of the art technology, it is interesting to note that Beltran et al. (2014) commented on the new IMO code, MSC 337(91), as a lost opportunity for making a step ahead in protecting the seafarer’s health and safety. According to the authors, the new code is not so different from the old one, IMO Resolution A.468 (XII), except for those vessels whose tonnage is above 10000 GT. The shipbuilding and noise control technologies are far ahead the new regulation.

Borelli et al. (2016b) also analysed these two regulations, but with regard to annoying tonal noise components in working spaces on board ships. They observed that the application of those norms is difficult in case of tonal components because of the imprecise definition of “tonal component" (referred to as "obvious tonal component" in the MSC Resolution). A measurement campaign was carried out on three different Ro-Pax vessels for 79 different work spaces. The authors adopted another methodology, referred to as Italian Decree D.M. 16/3/98, to assess the presence of tonal components, and they observed significant occurrence of tonal components in different working spaces.

Blanchet & Caillet (2014) presented a methodology of combining different mathematical models into one for obtaining a full frequency coverage in the vibro-acoustic calculation of ship – a luxury yacht in the present case. The approach makes use of several methods and coupling schemes, such as Finite Element Method (FEM), Fast Multipole Method-Boundary Element Method (FMM-BEM), Statistical Energy Analysis (SEA) and FEM/SEA coupling, to represent structure, interior cabins, underwater fluid loading, insulation, etc. This approach may be adopted to describe the complete acoustical behaviour of ship, with regard to internal noise as well as air and underwater radiated noise.

Borelli & Schenone (2014) highlighted the need for an accurate preliminary assessment of internal noise levels on board ship in an early design stage. They developed a "source-patch-receiver" model to evaluate the acoustic performance of the HVAC system of an oceanographic research ship in its preliminary design stage. This simplified approach is proved to be effective in pointing out the weakness of the HVAC system, with respect to its acoustic performance, allowing for adequate countermeasures taken before starting construction.

2.5.2 Air radiated noise

The last committee report summarized the work carried out within the framework of the SILENV project. The ultimate scope of the project was to create an "acoustic green label", including noise targets and guidelines, for the purpose of quantifying the environmental sustainability of a ship in terms of acoustic emissions (internal, external and underwater). However, despite the conclusion of the project, there has been no serious attempt to adopt the outcomes of the project into a norm by classification societies or other normative bodies.

Regarding external airborne noise emissions from ships, Di Bella (2014) addressed the existing regulations. He points out that the assessment of external noise propagation requires more attention due to the fact that the measurement methods do not always fit to the type of vessel, and that the assessment of the noise is more difficult for larger vessels. For moored vessels, the effect of noise produced by the power supply and ventilation system can be significant on the surrounding environment. In case of cruise ships, the ship size does not allow for direct evaluation of the sound power emitted, and the ship therefore has to be considered as a sum of the individual sound sources, measured separately on board the ship. The measurements are then fed into a numerical model in order to calculate the impact on the surrounding environment. A review of available standards to perform this evaluation is provided. It is also noted by the author that there is currently no technical standard that can define unambiguously the methods for determining the sound power emitted from very large sources, such as cruise ships, in a complex environment like a harbour.

One important issue in assessing the level of noise emitted by a ship at berth is measuring the ship itself, without being affected by background noise or noise reflected by surrounding surfaces. An attempt to separate and investigate noise components individually is made by Kamali et al. (2014), by providing a 3D noise model of the port of Tripoli and identifying the different sources such as ship activities, port activities and passengers/visitors. The study emphasized that the noise emitted by a ship is not necessarily the strongest source and that a comprehensive acoustic characterization of the noise in a port area is extremely difficult due to its complex geometry, number of sources, etc. However, single characterization of the various sources is possible and can be inputted into a 3D acoustic model to allow for further scenarios.

A similar conclusion is also reached by Curcuruto et al. (2015) who performed a survey to characterize the noise emitted by ships moored in the Civitavecchia port area in Italy. They measured the radiated noise by a cruise ship and a Ro-Ro vessel, respectively, using the methodology presented in the SILENV. They adopted a simplified methodology which was judged to be more suitable to describe complex areas like a port. The paper describes the difficulty encountered in switching off the external noise sources to characterize correctly the background noise. The authors suggest the characterization of noise sources to make a numerical model for noise mapping of the port area.

Fotini et al. (2016) mapped the noise emissions at the port area of Piraeus in Greece by taking into account the emissions from various sources such as moored vessels, passing vessels and other human activities. A digital model was created for the purpose of noise mapping, and each noise source was set as a point source (mooring places) or linear source (typical path of moving vessel). An interesting outcome of this study is that the noise disturbance from the vessel activities is almost insignificant. The noise from the road network adjacent to the port area or caused by mooring activities, etc. causes a bigger annoyance than the passage of a vessel.

Curletto et al. (2015) presents design solutions for the new FREMM frigates of the Italian Navy in order to reduce the external radiated noise emitted by the ships. A prediction study was performed to estimate the noise levels around the ships. It is noted that the measured noise levels confirm that the external noise levels generated by the ships are lower than the limits defined by the national rules and regulations.

Di Bella et al. (2016) presents a comparative study of methods for measuring large vessels during both navigation and mooring. Their conclusion, aligned with other studies, is that 3D acoustic mapping can be a useful tool to explore different noise scenarios, where the ship is not the only source contributing to the noise pollution in the surrounding area of a port. However, its characterization is difficult, and no unified and unambiguous method is available for the time being.

It may be argued that the characterization of the noise impact of a ship moored in a port environment is a very difficult task, because of a number of reasons:

- The ship is a “big” object and there has been no available standard or procedure yet to measure the emitted sound. Several efforts have been made, but those have not been transferred into a standard or a “class green label”;
- The measurements are generally affected by the background noise from the surrounding environment, which is not always easy to isolate. However, especially for the areas located in heavy trafficked commercial harbours, the ship is not always the strongest noise source, but other port activities such as loading/unloading, railways, etc. can be;
- The environmental background noise is also partially made by the ship itself, due to the reflections that are normally present in harbour, marina or shipyard areas.

The noise footprint of port activities may be evaluated using a digital model, in which the noise sources could be modelled individually. By using such a model tuned to real measurements, different scenarios could be explored, and, therefore, the expected “acoustic green label” or, more properly, the acoustic characterization of ships could be achieved. The development of a measurement procedure, free from reflection and other disturbances, is required, and, hence, newly built ships could be measured as part of normal sea trial or commissioning process.

2.5.3 Underwater radiated noise

Underwater radiated noise mainly comes from mechanical vibration (ship hull, engine, etc.) and marine propeller, either with or without the presence of cavitation. In the preceding committee report, the important issues such as noise mapping of seas and establishing limits on received underwater noise were discussed. In the present report, the focus of the research is still the same with small differences. More achievements have been made in the field of noise mapping of the oceans in this period of the committee report.

In this regard, Kaplan & Solomon (2016) examined the growth in emitted noise from three major segments in commercial shipping (container ships, oil tankers and bulk carriers) and argued that the maximum noise capacity of the global ship fleet could increase by 87%-102% on average by 2030 due to the combined effect of increased shipping, larger and noisier vessels, and longer cruising distances.

Audoly et al. (2016) summarized the results of the European research project AQUO. The project was created according to the Marine Strategy Framework Directive (MSFD), the European Union (EU), which requires from its member states to develop strategies that should lead to measures that achieve or maintain Good Environmental Status (GES) in European marine waters, by the year 2020. The AQUO Project demonstrated the feasibility of real time monitoring of the underwater noise footprint regarding shipping in a maritime area, using a predictive tool adopting Automatic Identification System (AIS) data and environmental information. Moreover, a number of recommendations was made for design, construction and management of ships and their routes in order to help yards and ship owners to improve the future fleet with respect to underwater noise emissions.

According to the requirements of the MSFD, some steps were also made in the direction of setting up a territorial noise monitoring plan, as indicated in Borsani et al. (2015). The authors describe how to establish an underwater noise monitoring system for the Italian seas. They used the shipping traffic data gathered by AIS applications to establish proper sensor positions and measuring methodology. The study is based on the adaptation of the MSFD, which considers the underwater noise as a descriptor for the environmental status of the European seas. The target is to provide a unified method to measure and quantify the underwater noise pollution in a way that enables comparisons among different countries.

A similar approach to comply with the requirements of the MSFD was also followed by Tegowski et al. (2016), who presented a methodology for correlating underwater ambient noise to shipping traffic by means of a noise prediction method. The project, called BIAS (Baltic Sea Information on the Acoustic Soundscape), has the main goal to monitor the shipping noise in the Baltic sea and to use it as input to a prediction model. The final goal of the project is to give the maritime authorities an effective tool to monitor the intensity of underwater noise caused by marine vessels without undertaking costly and difficult hydro-acoustic measurements.

In the framework of the European project AQUO, Dambra & Firenze (2015) performed an underwater acoustic assessment of a small vessel (less than 19 m) highlighting that the available standards are often calibrated on big ships and that they are not suitable for measuring small vessels. This requires further research and standards which consider vessel size.

As a noise abatement measure, Wochner et al. (2015) presented an underwater resonator system as a passive countermeasure for underwater radiated noise from different sources, including ships. The system uses Helmholtz resonators – already well known and widely used in airborne noise problems – in a completely new environment, namely in water. The system was tested at two offshore wind farm construction sites in the North Sea in 2014, and 20 to 40 dB sound level reduction was achieved in the frequency band of 20 Hz to 20 kHz.

Tiancheng et al. (2017) investigated the noise characteristics of a submerged exhaust by an experimental study. Through a series of experiments, the main sources of underwater exhaust noise were investigated. The results showed that the low frequency noise was dominant and mainly produced by the downstream two-phase flow. The intermediate frequency noise had a strong correlation with the gas velocity. The high frequency noise was mainly due to aerodynamic noise generated in the upstream pipeline.

2.6 Damping and countermeasures

Damping is an important factor in all dynamic response analyses, since resonance vibration levels are inversely proportional to the damping level, and the vibration cycles decay exponentially in time due to the damping after an impulsive loading. The level of damping therefore affects all forced responses, hence fatigue and extreme loading as well as vibration and acoustic levels. Modelling the damping is difficult due to the limited knowledge about the amount of damping in various materials, joints, etc. Therefore, accurate damping estimates, at least for the damping in structures, are usually found based on the measurement data.

Although the damping comes from several different sources, linear as well as nonlinear, it is usually modelled as equivalent viscous damping in structural response computations. There are several sources of damping affecting ship vibrations, and the most important ones are:

- material damping in the welded and un-welded structure;
- friction occurring in, e.g., joints, hatch covers and cargo;
- water friction;
- vortex shedding from sharp edges such as bilge keels, rudder, appendices;
- pressure wave generation;
- surface wave generation;
- artificially added damping.

Hydrodynamic damping is plausibly easier to compute numerically, compared with damping from material or friction, but it requires a very fine computational mesh. The models for hydrodynamic damping are, however, not well developed. el Moctar et al. (2016, 2017) reports a comprehensive study of numerical modelling methods for the hydrodynamic damping in extreme seas. They report that the hydrodynamic effects contribute significantly to the life cycle load spectra of wave-induced hull girder stresses. In the study, the model test measurements were used to validate the numerical simulations. The study also states that the damping has significant effects on both whipping and springing events, and it was also found that the hydrodynamic damping contributes substantially to the overall damping. Unfortunately, a direct comparison of the computed and measured hydrodynamic damping was not found possible.

Full-scale measurements are necessary to obtain data for actual operating conditions. Thus, Takahashi & Yasuzawa (2014) reports an Experimental Modal Analysis (EMA) test on a 310000 DWT VLCC (Very Large Crude Carrier), which was drifting without the engines on, in deep waters. The wind conditions, depth etc. are, however, not reported. The authors used stepped sine excitation in both vertical and lateral directions to obtain frequency response functions. The modal parameters, such as natural frequencies, damping factors and mode shapes, were then extracted using a commercial EMA software. The damping was found to be in the range of 0.1 – 1% of critical damping, which was reported to be significantly lower than those recommended by classification societies for container ships.

Orlowitz & Brandt (2014) applied Operational Modal Analysis (OMA) to a 19200 DWT and 210 m long RO-LO ship during sea trial (i.e. unloaded ship). The ship was equipped with 45 accelerometers, and the measurements were performed under three different operating conditions: anchored, and cruising with 10 knots and 18 knots, respectively. The cruising speed of 18 knots is the design speed of the ship. For the anchored and 10 knot cruising speed conditions, the damping ratios of the first three vertical bending modes were found to be between 0.2 and 0.6%. At the cruising speed of 18 knots, the damping ratios of the same modes increased significantly to 1.1 – 1.4%. The first two torsional modes had approximately stable damping ratios around 1%, and the first horizontal bending mode had 0.6 – 0.9% damping ratios at different speed conditions.

Particular attention has been paid to large container ships, as these ships are regarded as highly flexible with low natural frequencies, with high speed potential and significant bow flare. They are thus vulnerable to extreme and fatigue loadings from whipping and springing. Storhaug (2014a) used model and full-scale measurements to study whipping and springing and concluded that the damping needs to be studied in more detail. Andersen (2014) reported results on four container ships ranging from 4400 to 14000 TEU, equipped with strain gauges. Using the OMA analysis, the damping ratios of the 2- and 3-node vertical bending modes were found to be between 1.3 – 2.5%, with container load. No correlation of damping with ship size was found.

Storhaug et al. (2017b) investigated 14 container ships between 1700 and 19000 TEU, two LNG ships of 85000 DWT, two ore carriers of 210000 DWT, one ore carrier of 220000 DWT and two oil tankers of 18000 and 268000 DWT, respectively. In the study, several techniques for damping estimates were compared. It was concluded that half power and log decrement techniques should not be used due to their inaccuracy. Instead, it was found that random decrements, spectral method, enhanced frequency domain decomposition and stochastic subspace identification were found reliable. The damping ratio of the 2-node vertical bending was found to be approximately 1.7%, on average, for the container ships, with no systematic differences between ships of various size or speed. Ore carriers, LNG, and oil tankers were found to have approximately 0.7% damping ratio on average, i.e. substantially lower than those for the container ships.

It is usually assumed that the 2-node vertical bending mode is more easily excited and gives the largest vibration bending moment amidships, dominating the vibration effect on fatigue. Shi et al. (2016) developed a model based on stochastic distribution of stresses caused by combined loads considering the slamming effects. They found that a 1% damping ratio yielded about 250 times greater up-crossing rate than a 10% damping ratio, and it is thus concluded that the damping has a greater effect on the fatigue reliability. Furthermore, Storhaug & Kahl (2015) investigated the effect of torsional vibration on fatigue for two container ships of 8400 TEU and 8600 TEU, respectively. On the 8600 TEU ship, the effect was found insignificant; however, it was expected to be significant for the 8400 TEU container ship. It is also interesting to note that the damping ratio of the first torsional mode was 9.7% and 5.2%, respectively, for the 8600 TEU and 8400 TEU container ships.

Recently, Pais et al. (2017) investigate vibration levels for a 60 m superyacht, both experimentally and numerically. The global damping ratio was calculated using a procedure based on dynamic finite element analysis. The propeller-induced pressures were applied to the finite element model of the ship structure, and the forced response spectrum was calculated. The spectrum was compared to the measured spectrum at the propeller blade frequency, and the damping was then iteratively altered until the computed forced response spectrum coincides with the measured one. It should be noted that this approach depends on the correctness of the applied pressure level. The damping was found to be 9-10% relative to critical damping.

Lavroff et al. (2017) reported the full-scale tests of two INCAT catamarans, one being 86 m long and other 96 m. They identified the damping ratios as 1.8% and 3.5% for the 96 m and 86 m ships, respectively. On the model tests of another ship, they found no frequency change with speed, but damping increased by 65% over the speed range 0 to 2.89 m/s, corresponding to full-scale speed of 20.6 m/s (40 knots). This increase in damping with increasing speed is in line with the full-scale measurements by Orlowitz and Brandt (2014) reported above.

Despite all the efforts made, the damping mechanisms and actual damping values, for ships in different operating conditions, are not fully understood. This is particularly true for modern large container ships as well as other ship types, for which whipping and springing responses are important. For the numerical investigation of springing and whipping in the design phase, according to guidelines produced by classification societies, a target damping is needed. There is thus a need for more full-scale data, together with the information on wind and wave conditions, ship speed as well as cargo condition and draft, which may affect the damping values. A step in the right direction is the revised hull monitoring rules by DNV-GL (2017a) which requires damping estimates to be automatically produced onboard when the hull vibrates.

As far as countermeasures are concerned, not much work seems to have been reported in the period of this report. On cruise ships and superyachts, where excessive vibrations cause discomfort for passengers, the damping materials such as rubber and elastomers are often added for vibration mitigation and insulation purposes. Additionally, tuned dampers may be used for adding damping to the 2-node ship vertical bending mode.

2.7 Monitoring

The following topics are addressed here: definitions, hull monitoring rules, hull monitoring suppliers and digitalization. Monitoring with full-scale measurements of wave-induced vibrations is covered by Section 2.1.1.

2.7.1 Definitions

An attempt is made to standardize different terminology and technology in relation to monitoring. Condition Monitoring (CM) is often about collecting and observing data. The system used to collect data is referred to as a Condition Monitoring System (CMS), which is a system used for machinery, components and equipment within different industries. CMSs may be certified (DNV-GL, 2016f). On the other hand, Condition Based Maintenance (CBM) is more about using these data in maintenance strategies to define appropriate inspection intervals or CM program (DNV-GL, 2015). CMS is based on sensors, but manual readings may also be collected on board ships.

There is also a distinction between full-scale measurement and hull monitoring system. Both systems are based on sensor measurements, but the former is more for research and troubleshooting, while the latter represents more standard systems approved by the classification societies, according to their hull monitoring rules with associated class notations (Kahl et al., 2016). This means that the full-scale measurements may be done by non-approved equipment, which even may not be allowed to connect to other systems, and the systems are not necessarily intended to be permanent. For ships, hull monitoring is essentially related to the hull structure, but the hull monitoring rules from ABS, CCS and DNV-GL are more about sensor monitoring and not necessarily all about strain sensors (ABS, 2016a; CCS, 2015; DNV-GL, 2017a).

In the offshore industry, owners and operators generally have a larger group of technical staff, compared to those in the shipping industry. As a result, the operators are more involved with monitoring programs and rely less on the classification regulations. A hull monitoring system may be categorized as a Decision Support System (DSS) (Storhaug & Kahl, 2016), which is meant to provide input to onboard personnel to support their decision making activities. However, the DSSs normally contain more information about what-if scenarios, i.e. that the effects of changed conditions can be evaluated before they are executed. A hull monitoring system displays the consequences of a change after it has been done, so it is not fully a DSS.

The control and monitoring systems are also an important part of the rules (DNV-GL, 2017c) and they deal with machinery, systems and components, but not hull and structural response. In the changes to these rules, it was emphasized that the rules are also applicable to safety systems by using the terminology “control, monitoring and safety”.

2.7.2 Hull monitoring rules

Hull monitoring rules are covered here instead of in Section 2.9. There have been several revisions of the hull monitoring rules by the classification societies recently. This does not necessarily mean that significant changes have been made.

DNV-GL has a major revision of the rules associated with the class notation HMON (DNV-GL, 2017a). Time series from all sensors should be down-sampled and stored continuously. A 10 Hz sampling frequency is required for strain sensors. Statistics for all connected sensors should also be stored. The qualifier for vibration dose value has also been introduced and specified based on 3-axial accelerometers. Weighting is required separately for vertical and horizontal vibrations in the range from 0.4 to 10 Hz (ISO, 1997), basically covering the main global vibration modes. This is a subject for passenger ships. The qualifiers are also introduced for parametric roll and ice response monitoring, where the latter includes dynamic vibratory response. The ice response requirements are more in functional nature rather than descriptive, compared to rules from other classification societies. That has been based on the experience collected from full-scale measurements of ice-going vessels in various research and joint industry projects (Nyseth, 2016). The HMON rules also have 18 different types of qualifiers referring to different types of sensors and features. It also gives clear requirements to reveal the effect of vibratory response, and the damping is required to be estimated for the governing vibration modes. Calibration of sensors is a topic which may be taken for granted. This is also emphasized more in the revised rules and includes the effect of static hydroelasticity. As stated by Storhaug et al. (2016), the strain based on the loading computer may be several percent off the target for calibration due to the hydroelastic effect. This uncertainty may increase significantly if cargo is on board during calibration, as stated by Storhaug et al. (2017a) who compared laser measurements with loading computer results.

The hull monitoring rules from NK (2017a) do not appear to have been revised significantly. They are associated with the class notation HMS*R when continuous recording is required. Fatigue or vibration are not even mentioned, but strain sensors are required to measure up to 5 Hz and accelerometers from 0 to 100 Hz so that at least the most important vibratory responses for the hull should be recorded.

BV's HULL-MON notation and associated rules (BV, 2017) do not appear to have been updated recently, with a frequency band up to 1 Hz on strain sensors and accelerometers. Whipping, springing and fatigue are not mentioned. A separate notation MON-Shaft is however included for shaft monitoring.

LR has a class notation SEA (HSS-n) added to their ShipRight notation, which involves the fitting of a hull stress monitoring system. VDR, N, M and L are additional notations related to voyage data recorder, navigation, motions and loading computer (LR, 2017a). The rules do not appear to have been revised recently, and they are very top level and do not contain detailed requirements. There is, however, a guide to these rules, describing more details (LR, 2008). It is stated in the rules that the fatigue should be estimated and that strain sensors and accelerometers should measure frequencies up to 5 Hz.

ABS have made a significant revision to their hull monitoring rules (ABS, 2016a). Some additional notations can be assigned following the main class notation HMn (n being 1 to 3); for instance, "Sea State", "LC" for loading computer connection, "Navigation", "Wind", "Shaft monitoring" and "SL" for shore link. Each sensor has an additional notation and number. It approaches to the flexibility in DNV-GL (2017a) rules, with the intention of supporting a digitized future. HM2+R is most relevant for the hull girder response, with R+ meaning that the data is recorded for later use. Whipping and springing are also mentioned in the context of both fatigue and extreme loading.

CCS (2015) hull monitoring rules support the class notation HMS for global strain sensors and HMS(), where the parenthesis contain a list of other sensors types. This is almost identical to the DNV-GL hull monitoring rules, with the class notation HMON (DNV-GL, 2017a), where the list also includes a number of sensors of different types. The CCS (2015) does not include a letter "N" requiring that the data should be stored by the class society. The CCS (2015) rules are almost identical to the DNV (2005) rules in content and include~~s~~ the same requirements for the filtering and handling of the measured signals. The systems designed according to these rules will then involve fatigue and extreme loading and reveal the importance of whipping and springing.

Overall, the hull monitoring rules of several classification societies appear to lag behind the design requirements related to wave-induced vibrations (whipping), in particular for large container ships.

2.7.3 Hull monitoring suppliers

A list of suppliers of hull monitoring equipment for ships is given by Storhaug and Kahl (2016). About 19 suppliers are mentioned, but only four can be regarded as leading. Out of these four, only three are currently delivering new systems: Light Structures (Norway), Strainstall (UK) and SST (Korea). The fourth significant supplier, BMT Seatech (UK), is only maintaining old systems. Strainstall has delivered the most systems, but Light Structures is leading on a number of optical systems. Light Structures delivered many systems in recent years, e.g. on large container ships, naval/coast guard ships and offshore assets. These systems may contain more advanced instrumentations, while SST and Strainstall have more standardized systems with global strain sensors in the deck only. The smaller suppliers may also provide complicated instrumentation, which can be required in research projects.

Since 2006, the offshore industry has been developing their own standard for hull monitoring systems by joint industry projects like MONITAS. Hull monitoring software helps the operator with an approval of possible field lifetime extension and with an assessment of fatigue loading for relocation purposes. It explains reasons for potential deviation of the actual lifetime consumption from design predictions and translates the monitoring data into operational guidance and advice in an easily understandable format.

2.7.4 Digitalization

Digitalization is a global trend. There are several classification societies with hull monitoring rules which have optional requirements to store data, and they can potentially support this development. Another challenge, however, is to get this data to shore.

DNV-GL (2017a) and ABS (2016a) are supporting this, by having mandatory requirements to process and store data. The former has requirements to store statistical data for five years and time series for one year. The latter has a requirement of one year on statistical data. DNVGL (2017a) has a qualifier “D” for an online link to shore. ABS (2016a) has the notation “SL” for shore link, which can reduce the need for a one-year storage requirement on board. Further, DNV-GL (2017a) also has a qualifier “B” for backup to be annually sent to the class society. These two rule sets are also quite flexible on the content of data.

It is however not enough to have systems that measure, process, store and send data to shore. It is also necessary to have a system at shore to retrieve data, i.e. a database or platform. No significant information has been found on this, related to dynamic response, although it is a common practice in fields such as powering performance or machinery maintenance, where periodic transfer of data, storage and remote access have been addressed successfully. There is, however, a press release suggesting that NK (2015) decided to establish a data center and that the data center ShipDC was launched in May 2016 (NK, 2016). Another platform is Veracity (2016). This platform established a recommended practice (DNV-GL, 2017b) for a data quality assessment framework, which includes organizational maturity and data risk assessment. Knutsen et al. (2017) outlines the application of the recommended practice for the assessment of the data quality of sensor systems and time-series data. Many ISO references are utilized. Guan et al. (2016) defines a sensor system and gives an overview of sensor system reliability as a main challenge in daily use.

The aggregation of large amounts of monitoring data on a data platform can reveal new knowledge, for instance in relation to benchmarking of various dynamic responses. Articles related to these data platforms are yet to be seen. Manual comparison of smaller data sets has been done. A study into six years of full-scale measurement data, in combination with model tests and numerical tools, for a frigate type hull has been conducted by Hageman et al. (2014a, 2014b). This research showed a sensitivity between the performance of hydrodynamic tools and operating parameters, such as vessel speed and incoming wave direction. Storhaug (2014a) showed the importance of whipping and springing for a few ships from the model tests and full-scale measurements. From the model tests, the vibration damage contributions for four container ship designs varied between 37 to 87% of the total damage in different trades for deck amidships. Similarly, the vibration damage contributions in the full-scale tests were estimated between 26 to 57% for seven container ship designs in deck amidships, suggesting a smaller contribution in full scale. However, the results from a frigate type hull (Drummen et al., 2014) suggest a contribution of only 7% in fatigue damage. This type of structure is much more rigid compared to a container vessel, which also operates in more severe sea states. The publications of similar findings on other ship types would be very welcome. Storhaug et al. (2017b) also collected and compared damping data for the governing vibration mode shapes of 21 ships, with an average damping of about 1.7% of the critical damping for container ships and about 0.7% for blunt ships like oil tankers, LNG vessels and ore carriers. Hageman & Drummen (2017) identified a damping ratio of around 0.7% for a frigate, but also showed large variability of this ratio and its sensitivity to vessel speed. The results from bigger data sets would be appreciated, and it is expected to be realized in the future through digitalization. A real starting point on digitalization was presented by Eisinger et al. (2016), who matched ship positions and wave data for many ships from huge databases, e.g. all the container ships in the North Atlantic over a period of three years, etc. The main result was that they encountered less severe conditions than expected due to their capabilities of avoiding storms. This information can be used in subsequent assessments of dynamic response.

2.8 Uncertainties

Uncertainty is in general an interval that contains exact solution with a certain degree of confidence. According to ISO (2008), it is a parameter, associated with the result of a measurement, which characterizes the dispersion of the values that could reasonably be attributed to the measurement. Uncertainty in measurement is used in almost all subject areas (ASME, 2014). It is an important index to estimate the quality of data from a measurement. The International Towing Tank Conference (ITTC) has recommended an alternative approach to experimental uncertainty (ITTC, 2014a; ITTC, 2014b).

There are different procedures for uncertainty assessment in Computational Fluid Dynamics (CFD) (Diez et al., 2017) as well as in Experimental Fluid Dynamics (EFD) (ITTC, 2014a; ITTC, 2014b).

In general, it is assumed that the uncertainties in the modeling of hydrodynamic loads are larger than those related to the structural responses. However, according to linear theory, the uncertainties in hydrodynamic loads are also valid for the structural responses.

Qiu et al. (2014) presented studies on uncertainties related to the prediction of loads and responses for ocean and offshore structures in accordance with the findings by the Ocean Engineering Committee of the International Towing Tank Conference (ITTC). The parameters that may cause uncertainties in ocean engineering model tests and full-scale tests were presented in terms of physical properties of the fluid, initial conditions, model definition, environment, scaling, instrumentation and human factors. A methodology for uncertainty analysis was described according to ISO (2008). This document reported about challenges related to the extrapolation of model test results to full scale.

Tenzer et al. (2015) presented the results of experimental investigations on impact loads. Uncertainties related to the measured impact loads and deformations of wedge-shaped structures were described. To investigate impact-induced hydroelastic effects on slamming pressures, four test bodies were examined. Two bodies were fitted with stiffened, rigid bottom plating and two bodies with thin elastic bottom plating, each case with 5° and 10° dead rise angles. The results were comprised of impact-induced pressures, accelerations, forces, and structural strains. Measurement repeatability, sampling rate effects and hydroelastic effects were investigated. The measured pressures and forces were compared with published experimental data. Additionally, this paper documents body geometries and test rig set-ups including instrumentation and experimental procedures.

Papanikolaou et al. (2014) highlights the importance of understanding and integrating uncertainties in the context of useful prediction tools for the assessment of ship wave-induced design loads. This is elaborated by presenting some recent advances in (a) modelling the combined hydrodynamic responses of ship structures using cross-spectral combination methods and in (b) implementing uncertainty models used for the development of modern decision support systems as guidance to ship master.

el Moctar et al. (2017) presented computational methods to assess slamming-induced hull whipping on sectional loads of ships in regular and irregular waves. The numerical methods solved the Reynolds-Averaged Navier-Stokes (RANS) equations coupled with the nonlinear rigid body motion equations of the elastic ship hull. Uncertainties related to discretization errors were investigated. The authors numerically investigated three container ships in regular waves, in random irregular long crested waves, and in deterministic wave sequences. Comparisons to experimental measurements agreed favorably. They relied on different wave models, including second order Stokes waves and nonlinear wave fields obtained from the solution of NonLinear Schrodinger (NLS) equations. Simulations in random irregular waves provided short-term ship response probability distributions under sea state conditions relevant for design loads.

Diez et al. (2017) presented a high fidelity Uncertainty Quantification (UQ) of a high-speed catamaran, with focus on (a) the validation methods for ship response in irregular waves and (b) the validation methods for a stochastic regular wave UQ method. The approach includes *a priori* CFD simulations by Unsteady Reynolds-Averaged Navier-Stokes (URANS), followed by *a posteriori* EFD campaign. The validation variables are the wave elevation, force, heave and pitch motions, vertical acceleration of the bridge and vertical velocity of the flight deck.

Earlier research by the researchers in UQ for ship hydrodynamics addressed URANS simulations of the Delft catamaran (100 m long with a displacement of 3225 t) in calm water with stochastic speed (Diez et al., 2014) and in stochastic regular and irregular waves (He et al., 2014). A rigorous statistical validation of ship response in irregular waves has been presented by Diez et al. (2015, 2016) and Sadat-Hosseini et al. (2015). The former presented a validation study of the Delft Catamaran in head waves free to heave and pitch (captive), comparing URANS CFD to EFD, and a regular wave UQ method was also formulated and validated against irregular wave benchmarks for both EFD and CFD. The latter presented a study of the fully-appended free-running model of a surface combatant for multiple headings, comparing URANS and potential flow CFD to EFD. The validation addressed time series values (referred to as primary variables) and mean-crossing wave amplitude, height and period (referred to as secondary variables) of wave elevation, forces/moments and motions/velocities/accelerations.

Eca & Hoekstra (2014) attempted to generalize the concept of Richardson extrapolation and propose uncertainty estimators based on truncated power series expansion formulations and least squares fitting to allow for large flexibility and data scatter in grid refinement studies.

2.9 Standards and acceptance criteria

Classification societies make rules for design of ships, and these rules specify requirements, scope, extent and acceptance criteria. The methods and procedures to be used may, however, be explained in class guidelines and recommended practices. Ships designed to these methods and procedures and satisfying the rule requirements may be assigned a class notation.

Classification societies take into consideration the requirements of IMO conventions and recommendations and set out or update their rules. International Association of Classification Societies (IACS), on the other hand, provide unified requirements and interpretations.

2.9.1 Wave-induced vibrations

A major milestone has been reached in the maritime industry within the topic of wave-induced vibrations. IACS issued unified requirements for longitudinal strength of container ships, URS11A (IACS, 2015). This reference document provides functional requirements to account for whipping in the ultimate capacity check (hull girder collapse) in the design of Post Panamax container ships with a breadth greater than 32.26 meters. Unless the classification societies make reservations against this document, it implies that all classification societies must adopt these requirements into their rules. IACS is thereby recognizing the contribution of whipping to the risk of breaking a vessel in two. It is, however, up to the class society to define how this should be accounted for. Derbanne et al. (2016) and Peschmann et al. (2016) explain the background leading up to this fundamental change. This development came as a result of the report from Marine Accident Investigation Branch (MAIB, 2008) based on the MSC Napoli accident, where the classification societies BV and DNV stated that whipping could have contributed to the accident. The report on the MOL Comfort accident (JAPAN, 2015) was also considered in this development.

There are, in principle, three types of changes in rules, related to whipping and springing:

- Rules for design of container ships have been changed to account for whipping and springing;
- Class notations associated with rule text have been developed;
- Class guidelines have been issued either as independent or supporting documents.

DNV (2010) had a high partial safety factor of 1.5 for the wave bending in the ultimate capacity check. Although it is not explicitly stated, this factor accounts for a significant amount of whipping contribution. Many of the classification societies have URS11A formulations included in their rules since 2016. DNV-GL (2016b) has a rule formula for whipping for container ships and for the ships with a breadth greater than 32.26 m. For long (length greater than 290 m), wide (beam greater than 47 m) or fast (maximum speed greater than 25 knots) ships, or for container ships with large bow flare (greater than 55 degrees), direct calculations are recommended. For fatigue strength assessment (DNV-GL, 2017d), vibration damage contributions from whipping and springing are also accounted for in the wave bending moment for all types of ships. This increases the wave bending moment between 10 and 20% depending on the ship beam. LR (2017b) has mandatory requirements in its rules through class notations WDA1 and WDA2 for container ships, with a beam above 32 m and a length above 350 m, respectively. The notations WDA1 and WDA2 both are based on direct calculation analysis. NK (2017b) uses a partial safety factor of 1.5 to account for whipping in the ultimate capacity check for Post Panamax container ships (beam gerater than 32.26 m) with a rule length exceeding 300 m. ABS (2016b) has an ultimate capacity formulation for container ships, where a whipping factor depending on the beam and ship length is included for ships above 130 m. For ships above 350 m, the guidance note (ABS, 2014a) must be followed.

BV, DNV-GL and LR have class notations for whipping and springing referred to as WhiSpn (n being a number from 1 to 3) (BV, 2017a; 2017b), WIV (DNV-GL, 2015a), ShipRight (WDAn, FDA SPR) (n being 1 or 2) (LR, 2017b), respectively. It should be noted that DNV-GL's WIV notation is not limited to container ships and includes both ultimate capacity and fatigue checks with whipping and springing. The rule requirements for container ships with formulas or factors are referred to as Level 1, while direct calculations are referred to as Level 2. Strictly speaking, BV's WhiSpn notation is not limited to a particular ship type, but it has been mainly applied to ultra large container ships. WhiSp1 notation covers the effect of linear springing in the fatigue damage assessment for ships between 300 m and 350 m. WhiSp2 corresponds to WhiSp1 notation with additional whipping computation for ultimate strength assessment, for ships above 350 m. WhiSp3 notation, on the other hand, corresponds to WhiSp2 notation with additional whipping computation for fatigue assessment. LR's WDA1 and WDA2 notations refer to Level 1 or Level 2 whipping design assessment procedures, while FDA SPR refers to springing fatigue analysis. The latter notation is for ships with a length above 350 m, but the length is reduced to 250 m in case of fast ships, based on an encounter frequency versus natural frequency criterion.

Several classification societies have issued guidelines for the calculation of whipping and springing effects. BV (2015) NR 583 is dedicated to whipping and springing assessment and it supports WhiSpn class notations. It also describes the methods and tools to be used for direct analysis of fatigue and extreme loading, including whipping and springing. DNV-GL (2015b) is totally revised to support the new class notation on Wave Induced Vibration (WIV), including whipping and springing. It also includes a semi-direct analysis for Level 1, where the wave bending moment for fatigue is directly calculated. It is also stated that model tests can be an alternative for Level 2, instead of a direct hydro-elastic analysis. However, the Level 2 analysis methodology is not described in detail, but presented by Oberhagemann et al. (2015). For blunt ships, ship specific Level 1 factors for fatigue are included in DNV-GL (2016c) class guideline. These can replace the beam dependent rule factors. ABS (2014a) has a guideline on whipping assessment for container ships, including a close-form method along with a numerical method. In the numerical method, the vessel speed is described as a function of significant wave height. Both extreme and fatigue loadings are included, but different North Atlantic wave scatter diagrams are employed for strength and fatigue assessments. ABS (2014b) also has a guideline for linear numerical springing analysis for fatigue assessments. KR (2017) has a guideline for whipping assessment of container ships by direct analysis methods associated with the class notation WHIP. This document refers to ultimate strength capacity and uses a design wave or sea state method. The wave environment is not clearly specified but the speed is defined to be 5 knots.

The methodologies from different classification societies used to calculate extreme whipping loads differ. Most of the classification societies ends up with a dimensioning sea state that is similar as in linear analysis at 5 knots or zero speed. However, for DNV-GL, the maximum achievable speed is calculated for each sea state, and the sea state with zero or negative speed is removed, where it is assumed that the ship is not able to maintain the heading. This results in much lower sea states becoming dimensioning with higher speeds (Oberhagemann et al. 2015). DNV-GL also uses CFD calculations with most likely extreme waves, while the other classification societies use boundary element methods in regular or irregular waves with 2D slamming. It, however, remains to be seen how the results compare when deriving adequate design values. The differences and consequences should be studied in more detail.

Regarding the rules or standards for wave-induced vibrations on fatigue and particularly for container ships, it is interesting to notice the criticism of Storhaug (2015). He combined the newly developed linear wave bending moment formulations from Derbanne et al. (2016) and pointed out that something should have been wrong with the wave loading level based on direct analysis from the IACS scatter diagram of North Atlantic (IACS, 2001). It was further commented that there should have been much more damage than the fleet experience suggested. Eisinger et al. (2016) matched ship positions from AIS with wave data from a wave model (ERA-Interim), and this suggested that the encountered wave conditions in the North Atlantic is less severe than IACS North Atlantic (IACS, 2001). This thereby basically supports the conclusions by Storhaug (2015). This overestimation of the wave loads was also recognized by Derbanne et al. (2016), who reduced the wave bending moment from direct calculations by 15% in URS11A (IACS, 2015). Achieving an improved wave environment for design of ships must be important for the industry, especially when wave-induced vibrations become explicitly accounted for.

2.9.2 Noise

IMO (2014) published a guideline for the noise levels on board ships for both passengers and crew members based on the A-weighted equivalent continuous sound level during time interval of at least 15 sec. Various noise levels were set for different spaces of ships with 1600 to 10000 GT and those greater than 10000 GT.

As for environmental noise resulting from traffic noise, WHO (2011) suggested that L_{night} (annual average night time road traffic noise level) of 40 dB should be implemented to avoid possible health risk; this is also true for shipping noise, as was discussed in Murphy (2014).

2.9.3 Sloshing impacts

Not much progress regarding the rules and guidelines for sloshing impact assessment has been introduced in the period of this report. This means that a direct calculation procedure for sloshing assessment is not yet possible, and the socalled comparative approach is still in use (ABS, 2014; BV, 2011; DNV-GL, 2016a). The philosophy of this approach is relatively simple and consists of comparing the loading and capacity of the new design with the reference ship which has never sustained damage due to sloshing impact. Small variants from one classification society to another exist, but they are not very significant.

3. OFFSHORE STRUCTURES

3.1 Wave-induced vibration

Wave-induced vibrations of offshore platforms, referred to as springing, ringing, or whipping, are challenging factors for offshore designers. In addition, ringing can not only cause a total breakdown even in moderate storms, but also can hamper daily operations and lead to fatigue failure. The variations in dynamic response with respect to water depth and tether tension are presented by showing their influence on springing and ringing response. Offshore platforms may be exposed to wave impacts and slamming in extreme wave conditions. Vertical wave loads on decks due to insufficient air-gap are a major concern for many in-service platforms. A numerical method, based on a fixed regular Cartesian grid system, for investigating wave impact loads on semi-submersible platforms in extreme sea states were described in Liao et al. (2017).

For preliminary design of risers and mooring lines, dynamic analyses of wave and floater-induced responses are frequently based on the application of regular waves with given amplitude and period. For a more comprehensive verification concept, a stochastic model of the ocean surface and wave kinematics is typically applied. The corresponding dynamic response will hence also be of a stochastic nature, which implies that suitable probability distributions of local maxima and extreme values need to be identified. As the response processes in general are of a non-Gaussian nature, this may frequently become a challenging task. Such response analyses, in general, need to be repeated for multiple sea states. This implies that considerable computational efforts are required, unless some kind of selection of important sea states is performed.

Ortega et al. (2017) identified and quantified the interaction of internal slug flow and wave loads on flexible riser dynamics by using two coupled in-house codes. One code carries out a global dynamic analysis of the slender structure using a finite element formulation. The other program simulates the behaviour of the internal slug flow using a finite volume method. By means of distributed simulation, these two programs run synchronously and exchange information during the time integration process. A test case using hydrodynamic forces, according to the linear Airy wave theory coupled with an internal unstable slug flow, was analysed, and the results showed amplification of the dynamic responses due to the interaction between the two load types.

Grytøyr et al. (2017) studied four sets of measurement data for accurate assessment of the fatigue loads imposed on the subsea wellheads from Statoil, with the intention to quantify the degree of conservatism to be expected from drilling riser analysis. They found that the global drilling riser analyses accurately predict the cyclic loads on the subsea wellheads, provided that the input data are known with a high degree of detail, including riser tension setting, drill pipe tension variation over time and hydrodynamic loads. It is found that scatter in the results is due to the uncertainty inherent to several of the input parameters. It is also shown that the accumulated fatigue damage from a full drilling campaign can be established with a sufficient degree of accuracy. Directionality and spreading of the wave field can be handled by use of factors on the damage rate.

Vibration reduction can be achieved in many different ways, depending on the problem; the most common ones are stiffening, damping and insulation. Stiffening involves a sort of shifting the resonance frequency of the structure beyond the frequency band of excitation. Damping consists of reducing the resonance peaks by dissipating the vibration energy. Isolation is a method that can be used to prevent the propagation of disturbances to sensitive parts of the systems. Vibration control on marine offshore structures is challenging with self-excited nonlinear hydrodynamic forces, large deformations and highly nonlinear responses.

A study comparing the different schemes of controlling steel jacket offshore structures subjected to hydrodynamic wave forces is presented by Nourisola et al. (2015). The performances are evaluated in terms of control force and amplitude reduction.

Reducing the vertical motion is of practical importance when accounting for marine operations like drilling and oil production, making it desirable to minimize the heave motion to reduce its down time to weather. An increase in the hydrodynamic mass and damping, for instance, can be achieved by increasing the draft of the platforms. A good example of this is the turning point of the classical spar to a truss spar. Heave plates are also used for the purpose of generating huge added mass and reducing the steel weight and consequently the cost of the hull (truss spar). The resemblance with the Tuned Mass Damper (TMD) concept is discussed for a semi-submersible platform with heave plates by Liu et al. (2016b).

Kandasamy et al. (2016) gave a review of vibration control methods for marine offshore structures, which categories the general approaches as passive, active, semi-active and hybrid, respectively. This is then followed by a review of the specific marine offshore vibration control methods and a comparison of the approaches. The marine offshore structures considered in this review include jacket structures, Tension Leg Platforms (TLPs), spar structures, Floating Production Storage and Offloading vessels (FPSOs) and riser structures. It can be found that the general trend is progressing towards semi-active and hybrid vibration control from passive or active control, as they provide more practical approaches for implementation, possessing the advantages of passive and active control systems.

3.2 Wind-induced vibration

Wind-induced vibration is one of the important factors to the structural safety of offshore structures. In recent years, several papers have been published on wind-induced vibration, where the offshore structures as well as Offshore Wind Turbines (OWT) are investigated. These papers can be categorized into following two groups:

- Estimation of structural response due to wind loads,
- Control and reduction of wind-induced vibration using passive/active dampers.

Jia (2014) calculated the wind-induced fatigue damage of offshore structures using nonlinear time domain dynamic analysis. The author showed the effects of time step, time duration and flare boom connection stiffness on the response. The results for the static and dynamic analyses were compared, and it was concluded that it is important to consider the contribution of secondary structures such as flare and vent lines when assessing the wind-induced fatigue damage. In addition, the effects of gravity on the structure's fatigue damage were also studied, and non-Gaussian responses are discussed through the statistical investigation of the local responses. Finally, it is noted that the fatigue methodology presented can be extended to other offshore tubular structures exposed to wind excitation.

Liu et al. (2016a) investigated the wind-induced vibration of a large towering offshore oil platform using the results of a 1/100 scaled model test as well as finite element analysis. In order to obtain the lengthwise and crosswise fluctuating wind loads acting on the platform, a high frequency force balance experiment under various wind directions was carried out. Using the load distribution obtained by the experiment, a nonlinear finite element analysis, considering pile-soil interaction, was carried out. The acceleration and displacement of the large oil platform as response to wind load are estimated by using the finite element analysis. It is found that the RMS (Root Mean Square) of the fluctuating cross-wind load is about 10% of that lengthwise wind load. It is found that the wind-induced vibration mainly concentrates in the towering and hollowed-out structures and that RMS of the cross-wind acceleration is about 55-61% of the lenthwise-wind acceleration. It is therefore concluded that, for large towering platforms, special attention should be paid to the wind-induced response on the top and bottom of towering structures (derrick, crane, etc.) in wind-resistant designs.

Dezvareh et al. (2016) investigated the reduction of wind/wave-induced vibrations for JOWTs (Jacket-type Offshore Wind Turbines) using a passive vibration absorber called TLCGD (Tuned Liquid Column Gas Damper). Assuming various combinations of wind/wave loading conditions, a series of analysis were carried out for three different JOWTs using a nonlinear model in the time domain. The main parameters of the TLCGD are optimized to reach the minimum standard deviation of turbine nacelle displacements. The results indicate that, depending on the wind/wave combinations, the TLCGD can result in reductions up to 45% and 51% in turbine nacelle displacement standard deviation and maximum acceleration, respectively. It is pointed out that the TLCGD is well suited for fatigue critical JOWTs as it leads to more reduction in the standard deviation of the displacements compared with the maximum displacement.

Utsunomiya et al. (2015) presented a design methodology for a hybrid spar type floating wind-turbine installed in Japan. Moreover, the environmental design conditions such as Design Load Cases (DLCs), dynamic analysis and fatigue analysis are also presented briefly. A full-scale measurement and numerical analysis are carried out. Essentially, a design wind speed is obtained by a comparison between the annual maximum wind speed obtained by a Monte Carlo simulation of typhoons and the observation data at the site (estimated from the database of the past typhoons). From the load analysis results, it is concluded that, for the hybrid spar structure, a simple one-dimensional structural model can be used. Utsunomiya et al. (2017) presented an additional analysis and validation of the numerical analysis model. Application of wind loading to the tower structure is carried out based on the model of Utsunomiya et al. (2015). The modified simulation results are compared with the field data (experiment) in terms of natural periods of each Degree Of Freedom (DOF). The simulation results were in good agreement with the measured values, such as the power and mean value of the pitch response during power production.

Zuo et al. (2017) investigated a method using MTMDs (Multiple Tuned Mass Dampers) to control the tower vibration of OWTs. A finite elemental analysis of the offshore wind turbine tower vibrations induced by wind, sea wave and earthquake loading was presented. The tower responses of the original wind turbine (without control devices) are compared with those controlled by STMD (Single Tuned Mass Dampers) and MTMDs, and the robustness of the proposed method is also discussed. The dynamic responses of the tower to the combined wind, sea wave and earthquake loads are calculated. It is observed that the fundamental vibration modes and higher vibration modes can be controlled effectively by the MTMDs. Furthermore, using smaller MTMDs can significantly improve the robustness of the control system.

Zhang et al. (2017a) presented different types of active control schemes, such as delayed feedback control, sliding model control, sampled-data control and network-based control, to suppress the vibration of offshore platforms. They also presented other control schemes, such as passive control schemes and semi-active control schemes.

3.3 Vortex-induced vibration

Vortex-Induced Vibration (VIV) is a phenomenon that cylindrical structures may experience due to interactions between the structure and ambient currents. These vibrations occur as a result of the oscillating forces caused by flow separation and vortex shedding. When VIV occurs, the structure is subjected to cyclic bending stresses, causing fatigue crack growth over time, which may eventually lead to fracture. In addition, the vibrations lead to an increase in the mean drag forces, referred to as drag amplification, causing enlarged static displacements and tensile forces. The vortex shedding triggers vibration, while the cylinder motion alters the flow, thus affecting the fluid forces. On the other hand, if the vortex shedding frequency is close to the natural frequency of the cylinder, large body motions are observed and this phenomenon is referred to as “lock-in”.

3.3.1 Experimental studies

A survey of the published papers in recent years shows that the majority of the reported work is concerned with model tests. The typical scaling factors are within the range of 1:40-1:75. In the field of ocean engineering, simultaneously satisfying Reynolds and Froude scaling for the model and prototype conditions is impossible in practice. Full-scale testing is therefore necessary.

2D tests

In 2D tests, rigid cylinders with various geometric shapes are elastically mounted or forced to oscillate. The cylinder can either be towed in a towing tank (normally in calm water) or tested in a tank with current. This type of test can be used to study VIV characteristics of one short section of an elastic structure such as a riser.

Assi et al. (2014) investigated the effects of free-to-rotate splitter plates and a short-tail fairing on a rigid circular cylinder. The study shows that the rotational friction between the fairing and the cylinder reduces the VIV when the rotational friction is above a critical limit. The effect of the fairing is similar to that of a free-to-rotate splitter plate solution. A non-rotating fairing and splitter plates were found to develop severe galloping instabilities in 1-DOF experiments. The galloping phenomenon was the focus of a subsequent study by Assi & Bearman (2015), where the effect of a slotted splitter plate was examined. Hydrodynamic force decompositions and PIV measurements of the flow field around the plates confirmed that a transverse galloping mechanism drives the cylinder with splitter plates into high-amplitude vibrations.

Allen et al. (2015a) performed experiments on a cylinder with a combination of helical strakes and fairings at high Reynolds numbers. Tests were also conducted in a circulating water tunnel on an array of cylinders. The study shows that it is possible to mix helical strakes and fairings on one cylinder, but care must be taken as to the length and coverage. In the case of tandem cylinders, the responses are highly sensitive to the coverage on the upstream and downstream cylinders. Allen et al. (2015b) continued the studies by using the same experimental configuration where marine growth was simulated in the models. It was found that the presence of marine growth can affect the performance of the VIV suppression devices by reducing their effectiveness, and this may be amplified in the case of an array of cylinders. The paper also states that the study has not yet been complete, and there is still a substantial amount of research to be done to fully understand this phenomenon.

Cicolin & Assi (2015) presents a study investigating the influence of permeable meshes attached to a rigid cylinder on the VIV responses. Three different types of mesh geometries were investigated, and the results show that VIV responses are reduced by about 50-60% depending on the type of mesh used, but the effect on the drag varies.

3D tests

3D tests of long flexible pipes were carried out with varying geometries and boundary conditions. The test arrangements made it possible to create various flow conditions and current profiles. This type of test is typically used to study the VIV of risers, umbilical, free span pipelines and cables. It can also include realistic boundary conditions, for example, seabed for a Steel Catenary Riser (SCR).

Huera-Huarte (2014) studied VIV suppression by using splitter plates on a flexible circular cylinder. The coverage of elastically mounted splitter plates was varied along the length of the cylinder. The splitter plates were prohibited from rotation but allowed to hinge about the attachment point. The study shows that the VIV response can be reduced by up to 90% if splitter plates cover less than half length of the model. However, it was found that the performance of the splitter plate is dependent on the alignment of the incoming current. Thus, it is only applicable to known or easily controlled current headings.

The effect of surface roughness was studied by Gao et al. (2015) using a flexible circular cylinder. The roughness was altered by gluing sand to the surface of the cylinder, which in turn affected the flow over it. It was observed that in-line responses were increased with a rough cylinder, with lock-in occurring earlier compared to a smooth cylinder.

Wu et al. (2016a) presented a VIV model test study of a large aspect ratio flexible cylinder with staggered buoyancy elements. The test simulated a steel lazy wave riser, where the buoyancy section is a critical element of the design. The diameter ratio between the bare cylinder and buoyancy elements is a key factor in the response, where the response of the bare cylinder would lead to more fatigue damage even if the buoyancy element may have larger displacements.

More recently, Yin et al. (2017) carried out VIV tests on a full-scale riser model at prototype Reynolds numbers. This reduced the uncertainties that may be present when testing at Reynolds numbers smaller than full-scale or prototype Reynolds numbers. Forced oscillation tests were also performed along with tests on surface roughness, which is a critical parameter at prototype Reynolds numbers. The study concluded that the drag coefficient is dependent on the Reynolds number and surface roughness ratio. Also, at critical and supercritical flow regimes, the responses are not sensitive to Reynolds number. At subcritical flow regimes, however, the responses are distinctively larger.

Fan et al. (2015) and Yin et al. (2016) performed VIV tests on flexible cylinders, where both the top and bottom attachment points were examined, to model the full-scale effects and boundary conditions. In Fan et al. (2015), the bottom of the cylinder was connected to a setup modelling the seabed floor. Yin et al. (2016) investigated a drilling riser setup with different boundary conditions at the top and bottom for simulating the vessel, the well head or other aspects. In these studies, the characteristics of the top and/or bottom attachment points were found to influence the VIV responses.

The above studies have been mainly focused on VIV responses due to the presence of a current or an incoming flow field. Wang et al. (2014, 2015) and Fernandes et al. (2014) presented studies considering VIV of steel catenary risers induced by vessel motions. This is similar to oscillatory type flows. The results of these studies indicate that this type of vessel-induced vibrations plays a significant role in the fatigue damage to SCRs.

Full-scale tests

Extensive experimental research has been conducted to study VIV in the past several decades. However, most of the experimental work uses small-scale models and relatively low Reynolds numbers (Re) - “subcritical” or even lower Reynolds number regime. There is a lack of understanding of the VIV in prototype Re flow regime. In addition, the surface roughness of the structure is also an important parameter, especially in the critical Re regime.

Yin et al. (2017) studied two full-scale rigid riser models with different surface roughness ratios in the towing tank of MARINTEK in 2014. Stationary tests, pure CrossFlow (CF) free oscillation tests, and forced/controlled motion tests were carried out. The conclusions were drawn that the drag coefficient depends on the Re number and surface roughness ratio. At critical and supercritical flow regimes, the displacement amplitude ratio is less sensitive to Re than to lower Re. The displacement amplitude ratio in the subcritical flow regime is significantly larger than in critical and supercritical flow regimes.

3.3.2 Semi-empirical methods

For the semi-empirical models, the work recently done is focused on the enhancement of existing codes to overcome some of the shortcomings of previous methods, on the benchmarking of different tools and on their validation with comparisons with model and full-scale experimental data.

A semi-empirical model for time domain simulation of cross-flow, vortex-induced vibrations of slender circular cylindrical structures is developed by Thorsen et al. (2014). A model for the synchronization between the lift force and structural motion is derived from already established data for the cross-flow excitation coefficient. The proposed model is tested by numerical simulations, and the results are compared to experimental observations. Comparison with experiments shows that the model is capable of reproducing important quantities, such as frequency, mode and amplitude, although some discrepancies were seen. In the studies by Thorsen et al. (2015, 2016), realistic estimates of the structural response through simulation of several experiments of flexible pipes in uniform, sheared and oscillatory flow were presented. The heave-induced VIV of an SCR with non-linear bottom contact was simulated. The response was in good agreement with measurements (Thorsen et al., 2017).

Ulveseter et al. (2017) modified the original semi-empirical, deterministic time-domain model, which was developed by Thorsen et al. (2014), into a new stochastic model. The stochastic feature is to make the mid-point of the synchronization range a slowly time-varying Gaussian process. The stochastic process introduces two new empirical coefficients, i.e. the standard deviation and the upper limit of spectral frequencies included in the process. Sheared flow experiments with a bare riser from the Norwegian Deepwater Programme (NDP) tests are used to verify the new stochastic approach against the measurements. Response sensitivity of the two new empirical coefficients is performed, trying to realistically capture both amplitude modulation and frequency variations in the riser experiments.

3.3.3 Numerical methods

Most of the work done in recent years concerning the VIV responses of isolated rigid and flexible cylinders was devoted mainly to improving the prediction capabilities of wake oscillator models rather than to the development of new CFD or semi-empirical models. In fact, a significant number of the published papers describe very sophisticated wake oscillator models able to capture the nonlinear multi-mode dynamics and interactions of flexible curved or straight structures undergoing VIV and to overcome the limitation of previous models in predicting the amplitude of oscillations. All of the traditional computational approaches have been adopted for the flow description including Direct Numerical Simulations (DNS), RANS methods, LES model and Detached Eddy Simulation (DES) using finite difference, finite volume and finite element scheme. In particular, several authors proposed space-time finite element as a valid tool to solve fluid-structure interaction problems with moving boundaries such as VIV of an elastic cylinder and to improve the convergence rate in iterative solution of the large scale non-linear equation system.

For instance, Postnikov et al. (2017) presented a new two degree-of-freedom wake oscillator model to describe vortex-induced vibrations of elastically supported cylinders capable of moving in cross-flow and in-line directions. The total hydrodynamic force acting on the cylinder is obtained here as a sum of lift and drag forces, which are defined as being proportional to the square of the magnitude of the relative flow velocity around the cylinder. Two van der Pol type oscillators are then used to model fluctuating drag and lift coefficients. As the relative velocity around the cylinder depends both on the fluid flow velocity and the velocity of the cylinder, the equations of motions of the cylinder in cross-flow and in-line directions become coupled through the fluid forces. Existing experimental data and CFD results are used to calibrate the proposed model and to verify the predictions of complex fluid-structure interactions for different mass ratios. The "super upper" branch phenomenon, exclusive for a two degree-of-freedom motion at low mass ratios, has been observed. The influences of the empirical parameters of the wake oscillators and fluid force coefficients on the dynamic responses are also discussed.

3.4 Internal flow-induced vibration

Despite the rapid development of offshore oil exploitation which involves a large number of pipelines to process oil and gas, a limited number of publications have been found on internal flow-induced vibration in the period of this report.

Eftekhari & Hosseini (2015) studied the thermomechanical stability of a cantilevered pipe spinning around its longitudinal axis and carrying an internal axial flow. The pipe is subjected to an axial force at the free end operating in a high temperature environment. The Extended Galerkin's Method (EGM), in conjunction with a proper representation of the displacements of the pipe, was used to solve the eigenvalue problem. The authors investigated the effects of spin rate and velocity of fluid flow on the stability, and they concluded that the system generally does not lose its stability by divergence, even with the existence of a compressive axial load.

Lu et al. (2016) proposed a multi-physics approach for characterizing Flow-Induced Vibrations (FIVs) in a subsea jumper (an M-shaped pipe providing a connection between manifold and tree) subject to internal fluid flow, downstream slug movemnt and ocean current. The authors successfully addressed the coupled vibration response problems of the subsea jumper; VIV due to the ocean current; FIV due to the internal flow and slug-induced vibration (SIV) due to the downstream slug. It is also mentioned that, compared to the VIV and FIV responses, the pressure fluctuation due to the downstream slug plays a dominant role in generating excessive vibrational response and potential fatigue failure in the subsea jumper.

Li et al. (2016a) investigated the fluid flow vibration of a subsea spanning pipeline conveying gas-water two-phase flow with two ends fixed. The dynamic behaviour of the pipeline was analysed at different flow velocities and volume fractions. The natural frequencies of the pipeline were compared with the structural system vibration frequencies, and the stress range was consequently obtained.

Alizadeh et al. (2016) used the Monte Carlo simulation method in conjunction with FEM for probabilistic self-excited vibration and stability analyses of pipes conveying fluid flow. For the fluid-structure interaction, the Euler-Bernoulli beam model was used for analysing pipe structure and plug flow model for representing internal fluid flow in the pipe. After comparing the randomness effects of fluid parameters on the system with those of structural parameters, it was concluded that the uncertainties in fluid parameters had much stronger effects, and the uncertainties in structural parameters could be ignored.

Meng et al. (2017) investigated the Internal Flow Effect (IFE) on the cross-flow VIV of a cantilever pipe discharging fluid. The study showed that when the internal flow velocity is small, the pipe loses energy to the inner flow and the VIVs can be depressed significantly. On the other hand, the pipe would lose its stability when the internal flow exceeds a critical value, which depends on the current velocity and dominant VIV mode.

3.5 Equipment-induced vibration

Many types of equipment are installed in offshore facilities for production, storage and unloading of oil and gas, and it is almost impossible to consider all of the equipment as excitation sources at a design stage. Therefore, it is necessary to determine the major equipment that degrade habitability in accommodation areas and structural integrity. According to a common practice of shipyards, the major equipment includes rotating machinery operated below 4800 rpm and reciprocating engines exceeding an output power of 30 kW. Some interesting papers related to this subject and published in the period of this report are reviewed.

Seawater hydraulic Axial Piston Motor (SAPM) is an important component in underwater tool systems of offshore facilities. The underwater tool system driven by seawater hydraulics has many advantages, including non-flammability, low operating cost, and low pollution potential to marine environment. One of the most important issues for the SAPMs is low vibration and noise behaviour. For instance, Yang et al. (2015a) proposed an integrated torque model of the hydraulic axial piston motor, which consists of a torque sub-model and a dynamic pressure sub-model, in order to design a seawater motor having a small torque fluctuation. They considered the effects of the dynamic pressure inside of the piston chamber, pre-compression angle and relief-groove obliquity in the integrated torque model. As a result, they showed that an adequate pre-compression could help diminish the pressure shock and that a large relief-groove obliquity decreases the output-torque fluctuation.

Gjinolli et al. (2016) presented analytical processes and design methods to develop a complex exhaust system for a reciprocating engine, which is a power source in offshore facilitipres. In their study, the acoustical and aerodynamic analyses were carried out for a muffler design considering the acoustic performance. Furthermore, the structural analysis was also conducted for evaluating the performance of the exhaust silencer and stack systems, in order to avoid a resonance with the main excitation of the engine.

Twin-screw multiphase pumps have been a good alternative to substitute the conventional pump used for fluid separation, liquid pumping and gas compression facilities, since they can pump mixtures of liquid and gas at very different gas volume fractions in a wide range of pressures. Ramos et al. (2016) proposed an analytical procedure to obtain the forced response of the rotors of twin-screw multiphase pumps. In a case study, only the self-weight of the rotor with a constant speed was considered in the forced vibration analysis in order to evaluate the maximum transverse displacements of the rotors.

Fluid flows downward inside the drill pipe and upward in the annulus between the riser and the drill pipe during the drilling operations. Therefore, significant riser oscillations are observed during deep water drilling operations. Blevins et al. (2016) investigated the riser drilling-induced vibrations. They proposed an analytical model for predicting riser vibrations during drilling operations. As a result, they showed that the fluid forces could cause riser vibrations with a rotating drill pipe and that the magnitude of the fluid force increases with increasing rotational speed of the drill pipe.

Decommissioning is quickly becoming an important field of activity and research for offshore structures for oil and gas production. The North Sea is one such area, with many installations approaching or exceeding their design life. Davidson et al. (2017) experimentally investigated the feasibility of a vibro-extraction method to extract a pile that was submerged in sand. In their study, the force required to extract the model pile was investigated under three different conditions for both loose and dense sand. A model-scale vibration source was designed to provide balanced, vertical sinusoidal vibration, and it was installed at the top of the pile. As a result, they showed that the pull-out load of the pile was reduced by 36% in dense sand and to the self-weight of the pile in loose sand.

3.6 Shock and explosion

An offshore structure may be subject to several types of shock loading, including internal explosion of oil, gas and other chemical matter, external explosion due to weapons attack, and seismic loading from foundation attachments to the sea floor. Many offshore structural engineers work to predict and control the risks caused by internal explosion of petrochemical products. Bang et al. (2016) proposed a method to predict the effect of hydrogen gas tank explosions on nearby pipelines and provided a conservative estimate of the worst-case accident scenario involving an instantaneous explosion of a large hydrogen mass leading to the formation of a shock wave. Darvishzadeh & Sari (2015) used CFD coupled with finite element methods (FEM) for analysis of the shock wave interaction with the structure and large pipe, including impact damage. CFD was also used for analysis of the air temperature increase in a modular structure subject to explosion. Salvado et al. (2017) proposed a thorough validation process of the numerical model and new methods to estimate the peak pressure in the compartment. Shi et al. (2017) presents a numerical procedure to derive analytical formulae to easily generate a Pressure-Impulse (P–I) diagram for corrugations with the Non-Linear Finite Element Analysis (NLFEA) method. Based on the numerical results, analytical formulae to predict the P–I diagram are derived. Gharib & Karkoub (2015) presented an experimental study on the effectiveness of the Linear Particle Chain Impact Damper (LPC ID) in reducing the vibrations of a single DOF frame structure under different shock excitations. Sohn et al. (2016) examined the effect of adding stiffeners to corrugated blast walls aboard offshore structures. Corrugated blast walls tend to buckle at the web-flange interface, and it was shown through FEA that adding flat plate stiffeners at this location improved blast resistance.

Reinforced material usage is a growing area for offshore structures. Recent research has focused on investigation of the blast resistance of reinforced concrete materials. Critical offshore infrastructure such as bridge abutments, petrochemical docking components, ports, and flood control devices often contain concrete structures, and their vulnerability to both accidental and intentional explosive loading makes the response of these structures to such loadings important to researchers. Li et al. (2016c) examined the effect of adding polyethylene, micro-steel, and hybrid steel-polyethylene fibre reinforcements to concrete slabs to improve blast response performance. Samples were cast and field blast-tested and, along with static material laboratory tests, show the performance improvements of using such fibres to reinforce concrete slab structures. Olmati et al. (2015) investigated the blast resistance of precast concrete panels not originally designed for such loads using a probabilistic numerical approach. The probability of a pre-cast concrete panel exceeding its limit state is generated, and fragility curves are computed using Monte Carlo simulations.

Response to seismic shock loading is also of interest to the offshore community. Wu et al. (2016b) validated the favourable response performance of a TMD under earthquake loading by numerical analysis and 1:200 scale model testing. The results indicated a reduction in the displacement and acceleration response of the structure with a TMD over one without, and that a properly tuned TMD would activate within the first 3 seconds of seismic excitation.

3.7 Noise

Exploration, construction, transport, drilling and production are important offshore activities. However, these activities may cause high levels of noise to be emitted into the surrounding environment. The activity of pile driving for the construction of foundations of wind turbines and other offshore structures may be the most important noise source, and therefore, much research has been published on this topic. These research activities may be divided into two major groups: those involving numerical and experimental methods for analysing the noise emitted due to pile driving and those involving noise mitigation measures.

3.7.1 Pile-driving-induced underwater noise

To predict the noise emission caused by pile-driving under offshore conditions, a numerical model was presented and validated by Göttsche et al. (2015). The model combines a finite element method with a Parabolic Equation (PE) technique to compute the pressure spectrum, sound exposure and peak level in a certain distance of the pile. The results are compared to measurements performed during two full-scale offshore tests. Furthermore, a procedure is presented to compute the acoustic properties of the sediment as a function of frequency, depth and density.

Fricke & Rolfes (2015) presented an approach for the prediction of underwater noise caused by pile driving, and it is validated based on *in situ* measurements. It can be concluded from their results that the overall approach and underlying assumptions are appropriate for the frequency range considered. The authors also concluded that it is a reasonable simplification to formulate the soil-structure interaction in terms of a perfect contact condition, without tangential slip between the pile and soil.

Schecklman et al. (2015) presented a hybrid modelling approach, that uses the PE technique with an empirical source model, to predict the underwater noise due to pile driving in shallow, inhomogeneous environments over long propagation ranges. The empirical source model uses a phased point source array to simulate the time-dependent pile source. The pile source is coupled with a broadband application of a PE wave propagation model that includes range-dependent geo-acoustic properties and bathymetry. The simulation results are in good agreement with acoustic observations of pile driving in the Columbia River. The authors found that the absolute depth of the bathymetry is the only factor that significantly affects long-range sound levels, while bathymetry variations create localized effects. The top sediment layer was shown to affect sound levels greatly.

Deng et al. (2016) developed a three-dimensional semi-analytical method, in which the pile is modelled as an elastic thin cylindrical shell governed by a variational equation, to predict vibration and underwater acoustic radiation caused by a hammer impact. The cylindrical shell is decomposed uniformly into shell segments whose motion is governed by the variational equation. The soil is modelled as uncoupled springs and dashpots distributed in three directions. The case study of a model subject to a non-axisymmetric force demonstrates that the radiated sound pressure has dependence on the circumferential angle. Furthermore, another case study including an anvil shows that the presence of the anvil tends to lower the frequencies and the peaks of sound pressure spectrum.

In many cases, the construction work takes place in shallow water environments, where the soil has a major impact on the resulting wave field. This is mainly due to the occurrence of multiple reflections, the excitation of head waves, and the possibility of energy tunnelling sound mitigation systems through the soil. Measuring these seismic arrivals enables further information to be gained about the local soil characteristics. Ruhnau et al. (2016) investigates the characteristics of direct as well as seismic arrivals within the frame of offshore pile driving based on measurement data collected at the wind farm Borkum Riffgrund located in the German Bight.

Farcas et al. (2016) reviewed the process of underwater noise modelling for environmental impact assessment and explored the factors affecting predictions of noise exposure. The consequences of errors and uncertainties in noise modelling can lead to significant pitfalls in the environmental impact assessment process. The authors therefore discussed the future research needs to reduce uncertainty in noise assessments.

3.7.2 Mitigation of pile-driving-induced underwater noise

Numerical studies considering a sound mitigation system was carried out by Heitmann et al. (2015) and Tsouvalas & Metrikine (2016). In the study of Heitmann et al. (2015), an accurate description of the impact hammer and the layered soil were used. The influences of several mitigation systems on the underwater sound pressure level are evaluated with a numerical method. The construction guidelines were provided to define an optimal position for such a system. It was shown that the radius for the system should be as large as possible when only one system is used.

Tsouvalas and Metrikine (2016) performed a parametric study based on a semi-analytical model to analyse the principal mechanisms for the noise reduction due to the application of the air-bubble curtain placed around the pile. The results show that the noise reduction depends strongly on the frequency content of the radiated sound and on the characteristics of the bubbly medium. The distinction was made between the piles of large and small diameters due to the considerable difference in spectrum of noise generated. In the case of practical applications related to the installation of large foundation piles, only the lower end of the frequency spectrum is usually of interest.

Dardis et al. (2015) developed a new double-walled pile design with an air gap to decrease the noise transmitted into the sediment and water. The mechanisms of the noise generation in both single- and double-walled piles were described, and a full-scale field test was performed in the Puget Sound, Washington. The results showed that the use of double-walled piles reduced the peak sound pressure by more than 20 dB relative to single-walled piles, while only a 3 to 6 dB reduction was obtained using a bubble curtain.

3.8 Damping and countermeasures

Vibrations in offshore structures may be caused, for example, by

- engines and process equipment,
- wind excitation,
- wave excitation, or
- vortex induced excitation.

Excessive vibrations can cause problems of several kinds, such as

- safety issues, for example, fatigue,
- limited serviceability, for example, due to excessive noise levels,
- reduced platform productivity due to abrupt disasters.

Vibration mitigation is therefore an important area of study. Despite this, not much effort is devoted to research in this field. The main focus area in controlling vibrations in offshore structures is vibration absorbers. The vibration absorbers can be divided into three main categories: (i) passive devices, (ii) semi-active devices (mainly actively tuned passive devices), and (iii) active devices. Of these categories, the passive devices are the dominating category in operations today, due to their reliability and lack of requirement for an energy source. It can likely be expected, however, that the semi-active and active devices will be introduced more frequently in near future. There are therefore currently some research efforts spent on the development of such devices.

Kandasamy et al. (2016) contains an overview of techniques for vibration control in offshore structures. The most commonly used passive devices are TMDs and Tuned Liquid Dampers (TLDs), although the damping materials, such as rubber and synthetic elastomers, are also frequently used in the vibration control. Of these, the TMDs and TLDs are typically used to add damping to the first mode or first few modes of the structure to mitigate the total response to wave and wind loads, which cause fatigue. The damping materials are rather used for vibration isolation of machines and for reducing noise.

Lotfollahi-Yaghin et al. (2016) studied the efficiency of TLDs for the reduction of dynamic responses due to earthquakes on offshore jacket platforms. The results showed that the efficiency varies by earthquake, which is attributed to the frequency content of the earthquake energy. A new development of TMDs, the so-called Pounding TMD or PTMD, is reported by Li et al. (2015). The laboratory tests and numerical studies found the PTMD to be more robust to off-tuning in comparison with the traditional TMDs. Xue et al. (2016) performs a robustness and control performance study of the PTMD. In this study, a model of an offshore platform is used, and the PTMD is found to suppress vibrations over a larger bandwidth than the traditional TMDs.

Damping is important for mitigating vibrations, and an accurate knowledge about damping is a necessity in forced response computations in order to obtain correct response levels, for example for fatigue estimations. Since analytical models for damping are missing, the damping levels normally need to be obtained by experiments. Gres et al. (2016) reports an assessment of damping for an offshore mono bucket foundation, using Operational Modal Analysis (OMA). They found the first mode of vibration to have approximately 1.1% relative damping. Yang et al. (2016b), on the other hand, present the OMA results of a jacket platform excited by ice loading. The first four modes of the jacket platform were found to have approximately 2 to 3.8% damping ratios. In an experimental study of a 1/10 model of an offshore jacket platform standing on soil in water, Mao et al. (2015a) found the damping ratio of the first mode of vibration to be between 3.6 and 4.4%. They also found that the contribution of the foundation degradation to the damping was small.

Zhang et al. (2017c) made a theoretical study of a Pall-type Frictional Damping (PFD), with shape memory alloy installed on the isolation layer of a jacket platform. They showed that the system is successful in reducing earthquake-induced vibrations. The damping ratios were obtained experimentally as approximately 4 to 5%.

Another area of interest is noise and comfort for personnel on board offshore platforms. Lee et al. (2015a) thus presents a design process for anti-vibration mounts for offshore structures accommodations. The design method allows mount type, allowable displacements and design loads to be selected. The method was verified on a scaled structure. Zhu et al. (2015) studied magnetorheological elastomers with alloys, adjusting stiffness and damping by varying a magnetic field around the material. The material was reported to be promising for adaptive vibration mitigation.

3.9 Monitoring

This section covers developments in the monitoring of offshore structures. In general, measurement campaigns cover a broad range of goals. Since structural dynamics are of lesser concern in the offshore industry, the monitoring campaigns, mainly focus on the assessments of maintenance needs, extreme responses and reliability of local structural details and components. Views on goals and scope of monitoring programs within offshore projects are discussed in Section 3.9.1. The monitoring programs aim to investigate the critical areas within the offshore structures. However, there are technical challenges associated with structural monitoring in such hostile environments.

Firstly, the development of fatigue cracks as a result of structural response is one of the major concerns in the offshore industry. This is often related to maintenance, but within the offshore industry, the fatigue can also be a safety issue, equivalent to structural overloading scenarios such as buckling, yielding and dents (collisions). Fatigue crack monitoring methods are discussed in Section 3.9.2.

Secondly, the dynamic response of subsea components is often challenging to monitor. Therefore, subsea monitoring systems may be enhanced with the analysis tools that enable derivation of system properties, which can otherwise not be obtained reliably. These are discussed in Section 3.9.3. Floating offshore wind applications feature different monitoring challenges compared to the oil and gas offshore industry. Monitoring solutions for the response of offshore wind plants are discussed in Section 3.9.4.

3.9.1 Goal and scope

Condition monitoring or integrity management is an important driver to perform offshore monitoring. Identification of physical damage remains a challenging item. An extensive review of damage identification methods, using the dynamic structural response, is provided by Sun et al. (2016). The authors discuss, among other things, sensor selection and placement, the performance of time domain and frequency domain identification methods and artificial intelligence, such as Genetic Algorithms. Next to the technical aspects of integrity management, organizational challenges also need to be addressed. Wisch & Spong (2016) discuss the playing field between operators, classification societies and authorities.

Monitoring programs can be used to achieve maintenance efficiency. May et al. (2015) show a cost-benefit analysis for two different monitoring approaches on an offshore wind turbine. They identify replacement costs, loss of production and logistics costs, resulting in an overall cost reduction of 6% when using a response monitoring system. The main challenge in cost-benefit analyses is to quantify the costs involved in a useful format.

Another goal of in-service monitoring is to gain an understanding of the real-life physics by setting up relationships between the measurements. This information can be used for the improvement of future projects. An example thereof, considering a 5 MW wind turbine using 2 years of in-service measurements, is discussed by Hu et al. (2015). An array of four bi-axial accelerometers was used for this purpose. This research shows the dependency between vibration characteristics and environmental conditions such as temperature, wind speed and operational conditions.

3.9.2 Fatigue crack monitoring

The development of fatigue cracks as a result of continuous wave loading and structural vibrations is receiving much attention from the offshore industry. Makaya et al. (2016) shows a theoretical study on fatigue crack detection using Guided Wave technology, wherein Lamb waves and Shear Horizontal waves are monitored during crack growth. The relations between different wave types can be used to locate the crack. Once the crack is discovered, monitoring of the crack may be necessary. Horst & Kaminski (2017) discussed the theoretical analysis and laboratory test of a fatigue crack monitoring device using magnetic flux leakage. The methodology does not require continuous monitoring, allowing for low power consumption. Bernasconi et al. (2015) showed in field testing that vibro-acoustic sensor systems can be used to monitor a 155 km long (subsea) gas pipeline over a prolonged period of time. One test described by the authors focussed on the detection of damage events and spilling, using a decommissioned pipeline. The authors detected impacts at a distance of 6 km and spilling events at 30 km.

3.9.3 Subsea monitoring

Subsea monitoring projects have been and still are challenging. Wang & Lu (2016) presents an overview of different technologies for monitoring the response of subsea lines and their maturity for ensuring integrity of mooring systems. The authors present solutions using load cells, inclinometers and GPS-based systems, discussing both technical and economic feasibility of these systems. An example of the latter system is presented and discussed by Minnebo et al. (2014). They discuss the setup and requirements for such a system. The observed motions of the floater can be used to identify failures of the mooring system.

Grytøyr et al. (2015) discuss the measurement of structural response of a wellhead using direct stain gauge and indirect accelerometer measurements. Their solution uses only subsea compatible equipment, all located on the drilling riser above the BlowOut Preventer (BOP). The estimates based on accelerometer measurements show good correspondence with the structural stresses measured on the BOP. Hørte et al. (2013) used a similar setup to examine the structural reliability of a wellhead. Their analysis shows that the uncertainty in the assessment is mainly related to the fatigue capacity, location measurements, Palmgren-Miner hypothesis and FE analysis. Uncertainties in soil characteristics, cement level and stiffness of the BOP are of lesser importance. The analysis also shows a relation between the applied design fatigue factor and probability of failure.

Besides integrity management, the process control of subsea wells also offers considerable challenges. Letton et al. (2015) discusses the results of a joint industry effort to improve on various subsea well control topics, such as fluid sampling and flow meter verification.

3.9.4 Monitoring of offshore wind turbines

In the case of the monitoring of OWTs, direct monitoring may not be economically attractive or technically viable. OWTs are slender structures which can be monitored using a simple sensor setup in combination with powerful post-processing tools. Because of its different topology, the monitoring strategies in offshore wind differ from those in offshore oil and gas. Male & Lourens (2015) show a promising theoretical study into the development of a monitoring system which is able to identify load characteristics and, from there, determine the dynamic response consisting of accelerations and strains at various locations within the structure. Antoniadou et al. (2017) present an identification method to discover damage from response measurements. The method is successfully applied on wind turbine blades and gearboxes, which are the critical elements of an OWT.

3.10 Uncertainties

Floating offshore structures such as wind turbines often include many DOFs, variables, and excitation from both wind and waves, making the assessment of uncertainty in a test campaign challenging. In addition, it is important to consider many different conditions, requiring a large number of experiments to be run, including numerous repetitions. The variables can be strongly or weakly coupled, meaning that error sources can strongly influence each other. On the hydrodynamic side, offshore wind tests are similar to those done for seakeeping of offshore structures. Uncertainty quantification in the seakeeping field is also not well developed, and it is only recently getting attention (Kim & Hermansky, 2014; Hirdairs, 2014). Uncertainty quantification, however, is essential and needs to be pursued.

Qiu et al. (2014) identified parameters that may cause uncertainties in ocean engineering model tests, full-scale tests and numerical simulations, in terms of the physical properties of fluid, initial conditions, model environment, scaling, instrumentation and human factors. As an example, the uncertainty analysis method (ISO, 2008) was applied to the tests of a moored semi-submersible platform model. The combined and expanded uncertainties were quantified in experimental results including motion responses, air gap and mooring line tensions.

Junior et al. (2014) qualitatively addressed the consequences on uncertainty for the execution of an inclining test of a semi-submergible platform with a mooring system and risers at the production site and compared the results to the ones taken from typical inclining test procedures at sheltered waters, as defined by ASTM F1321. The authors applied uncertainty analysis by evaluating the propagation of uncertainties from the measurements to the final calculations.

Robertson (2017) examined the sources of uncertainty associated with the measured loads for a scaled, floating offshore wind test performed in a wave basin within the OC5 project (which is focused on validating offshore wind modelling tools by comparing simulated responses of selected offshore wind systems to physical test data). The research qualitatively examined the sources of uncertainty associated with the test to start a discussion of how to assess uncertainty for these types of experiments and to summarize what should be done during future testing to acquire the information needed for a proper uncertainty assessment.

3.11 Standards and acceptance criteria

3.11.1 Wave-induced vibrations

The offshore industry has not recognized wave-induced vibrations to the same extent as in maritime industry. However, offshore ships like FPSOs can utilize the same standards as in maritime, for instance, rules for hull monitoring systems, e.g. HMON (DNVGL, 2017a) and voluntary class notations, e.g. WIV (DNV-GL, 2015a). NORSOK (2017) also includes local and global vibrations from slamming, dynamic analysis for fatigue, ultimate and accidental limit states. Hull monitoring systems have become more popular for such offshore ships, since a more flexible inspection regime, risk based inspection, is accepted. For some of these offshore ships, the classification society may also accept using maritime rules, which include the effect of wave-induced vibrations (DNV-GL, 2017d). It should, however, be emphasized that the offshore structures are related to low (current) to zero speed, which tend to reduce the effect of wave-induced vibrations, but on the other hand, such vessels operating in harsh environments may maintain head seas in more extreme weather conditions, which tends to increase the relative importance of whipping. The Monitas JIP is an example where this effect was briefly considered for fatigue (but not published).

For other offshore structures, class may lack rules and standards for wave-induced vibrations, but they may still request assessment of consequences and suggest that the resonance periods may be kept as low as possible. This could be related to innovative structures, such as ocean farms and other flexible offshore structures. For jack-ups, specific assessment of dynamic amplification is required for fatigue and ultimate limit state. For TLP, ringing and springing are well known phenomena that can contribute to fatigue damage of the tension loaded tethers.

3.11.2 Vortex-induced vibrations

VIV due to current and waves are well known within slender structures like free span pipelines and risers, but the vortex shedding can also cause low frequency dynamic response of mooring systems without any elastic response of the platform itself. These vibrations can then be dominated by low and high frequency responses, compared to wave frequency response, which makes Rainflow counting and time domain analysis a natural choice for fatigue assessment. For riser fatigue, this is covered by a recommended practice (DNV-GL, 2017e) which also includes a simplified method for this additional vibration effect. For free span pipelines, the VIV are both relevant in fatigue and in extreme loading, and even sensor monitoring is now included as an approach (DNV-GL, 2017f). For free spanning subsea power cables, VIV can also be part of the fatigue limit state requirements (DNV-GL, 2016d).

NORSOK (2017) includes VIV in general terms based on water flow and wind. NORSOK basically mentions vibration and dynamic response for all types of offshore structures and suggests that if the natural period is less than two seconds, a simplified method for estimating the dynamic amplification factor (DAF) can be used for a single DOF system, based on Baarholm et al. (2013).

Classification societies may also request the assessment of VIV caused by wind for slender topside equipment without having specific requirements in the rules. In certain cases, it is a question of reducing the natural periods to reduce the dynamic response levels.

3.11.3 Noise and vibration

While the comfort class notation COMF is mainly used within the maritime domain for passenger ships, the class guideline gives more general criteria, which can also be used within offshore accommodation units (DNV-GL, 2016e).

3.11.4 Underwater noise

Within the last couple of years, underwater noise generated by the installation of offshore windfarms has gained wide-spread concern. The guidelines for measuring underwater noise generated by windfarm constructions are given by ISO (2017), Dekeling et al. (2014a, 2014b and 2014c), BSH (2013) and Robinson et al. (2014) for ISO, EU, Germany and UK, respectively. According to BSH (2011), the sound exposure should not exceed 160 dB (re 1μPa) outside of a circle of 750 m radius.

4. BENCHMARK STUDY

4.1 Introduction

Throughout the maritime world, considerable effort is being spent on predicting loads associated with slamming (see, for instance, Kapsenberg & Thornhill, 2010). The ISSC 2012 Dynamic Response committee performed a benchmark study on the accuracy of the translation from these loads to the structural responses. Six participants entered the benchmark study. The goal of this benchmark was twofold. On the one hand, the degree of variation in estimates produced by different methods and organizations was revealed. On the other hand, the absolute error made in the analyses was investigated by reproducing model test responses. From the benchmark, it was concluded that the shapes and frequencies of the two and three node, dry and wet, horizontal and vertical flexural vibration modes determined by the participants were well in line with experimental results for four of the six participants. When participants applied different realistic but analytical pulses to their model, significant differences up to a factor of five were found. On the time series level, two of the six participants have results that correlate well. Details on the benchmark and the results were discussed by Drummen & Holtmann (2014). The benchmark considered a range of methods varying form empirical methods to determine the added mass to a coupled structural and RANS solver. Results for an intermediate one-way coupling were presented by Dhavalikar et al. (2015). The ISSC 2012 Dynamic Response committee benchmark study provided insight into the accuracy of the range of methods that is available for predicting the dynamic response of ships.

For performing long-term design calculations for ships, any kind of CFD calculation will generally be time consuming and thus may not be realistic, although it may be practical in future. Two- and three-dimensional panel methods will remain the primary approach for some years to come. In order to further investigate the accuracy of the predicted dynamic response, the ISSC 2018 Dynamic Response committee chose to also perform a whipping benchmark study. But this time, the focus was on nonlinear strip theory and panel methods.

4.2 Benchmark setup

Four participants entered the benchmark. Two research organizations (SINTEF Ocean and National Maritime Research Institute, NMRI) and two classification societies (BV and NK). The benchmark consisted of two parts. The first part is a comparison of the shape and natural frequencies of the first two global flexural modes. In the second part, a comparison is made between standard deviations of the total stresses and high frequency stresses at the three cross sections for 16 sea states. Participants were provided with the following data:

- Geometry consisting of points on a large number of cross sections,
- mass distribution along the length of the model,
- natural frequencies, shapes and damping ratios of the first three dry global vertical flexural vibration modes,
- time series (30min – 45min) of the wave at the Center of Gravity (COG) of the model for each of the 16 sea states.

Given this input data, participants were asked to provide the shapes and natural frequencies used in their method and to determine the vertical bending moments at the quarter lengths and amidships.

The experimental results that are used as a benchmark are presented in Section 4.3. Methods used by the participants are described in Section 4.4. Participants are referred to as A, B, C and D. Sections 4.5 and 4.6 respectively describe the results of the benchmark and its conclusions.

4.3 Experimental results

The model tests used as reference were performed in the towing tank at the Marine Technology Centre in Trondheim. The tank is 260 m long, 10.5 m wide and from 5.6 to 10 m deep. The double flap wave maker is able to produce both regular and irregular waves. The model tested was based on a container ship with a length between perpendiculars of 281 m. It has a large, flat, overhanging stern, a pronounced bow flare and a large bulb. The model was built to a scale of 1:45. More detailed information about the experimental setup was given by Drummen (2008). With reference to Section 2.1.2 a segmented hinged model was used. Figure 1 shows a picture of the model. As can be seen from the figure, the model consisted of four segments and three rotational springs. The stiffnesses of the springs were tuned to achieve the desired scale natural frequencies of the ship.

Figure 1. Picture of the segmented model

The model was tested in irregular head waves, as this condition is usually the most severe with respect to the vertical response. The chosen sea states are given in Table 2. The JONSWAP spectrum was used as the target wave spectrum. The peakedness parameter is also shown in Table 2. The forward speed was chosen to be constant in sea states with the same significant wave height and was based on full-scale measurements reported by Moe et al. (2005). The full-scale forward speeds of the model in the investigated sea states are also given in Table 2. For each sea state, three runs were conducted in waves that were realisations of the same spectrum. The realization periods were short enough to avoid repeating wave trains. The combination of the three runs resulted in a record length between 30 and 45 min full scale, depending on the chosen speed.

4.4 Methods

Table 3 summarizes the different approaches used by the participants. Participant A used a nonlinear strip theory approach where the radiation/diffraction forces were calculated with a BEM in frequency domain. The hydrodynamic radiation/diffraction force coefficients were represented in values of zero-cross wave frequency. The nonlinearities of the Froude-Krylov forces and hydrostatic restoring forces were taken into account. The nonlinearities of radiation and diffraction forces were also considered by using the “hydrodynamic coefficient table,” which is prepared before time series calculations for various ship drafts and roll angles for each section, in frequency domain. All degrees of freedom except surge are considered in the computations. The slamming impact was calculated using the momentum theory. The structural model was an Euler-Bernoulli beam based on modal decomposition, and the first three global vertical flexural vibration modes were taken into consideration.

Table 2. Overview of irregular waves. H_s, T_p, γ and U denote significant wave height, peak period, peakedness parameter and vessel speed, respectively.

Run	H_s [m]	T_p [s]	γ [-]	U [kn]
1	3	10.6	1	22
2	3	13.4	1	22
3	3	16.3	1	22
4	3	19.1	1	22
5	5	10.4	1.5	20
6	5	13.4	1	20
7	5	16.3	1	20
8	5	19.1	1	20
9	7	9.5	5	16
10	7	13.4	1	16
11	7	16.3	1	16
12	7	19.2	1	16
13	9	9.5	5	12
14	9	12.8	2.3	12
15	9	16.3	1	12
16	9	19.1	1	12

Participant B used a strip theory approach in which the radiation forces were calculated with a boundary element method. Only heave and pitch were considered. Nonlinearities of the Froude-Krylov forces and hydrostatic restoring forces were considered, as well as slamming. The slamming impact was calculated using the momentum theory. Participant C used a hydro-elastic approach, based on a potential flow solver and a modal decomposition of the elastic motions on the first 2 natural vibration modes (vertical bending). The hydrodynamic radiation/diffraction is first solved in the frequency domain using a 3D BEM solver; in time-domain, the radiation forces are computed using a convolution integral and infinite frequency added mass values. The diffraction forces are recomposed from the frequency domain results, and the hydrostatic and incident wave loads are recomputed at each time step using the exact position of the ship and the incident wave profile. The slamming loads are computed using a

Table 3. Overview of methods used by participants in the study.

	Structural model	Added mass	Nonlinearities
A	Euler-Bernoulli beam	2D BEM	Froude-Krylov, hydrostatic restoring, radiation and diffraction (table), slamming (momentum theory)
B	Euler-Bernoulli beam	2D BEM	Froude-Krylov, hydrostatic restoring, slamming (momentum theory)
C	3D finite element model	3D BEM	Froude-Krylov, hydrostatic restoring, radiation and diffraction, slamming (Generalized Wagner Model)
D	Vlasov beam	2D BEM	Froude-Krylov, hydrostatic restoring, slamming (momentum theory)

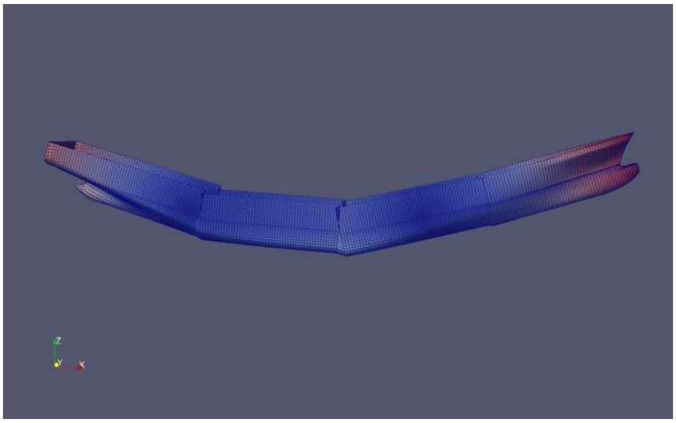

Figure 2. Illustration of two node vertical flexural vibration mode by Participant C.

2D-strip approach; on each 2D section, the GWM is adopted to compute the slamming pressures, which are then mapped onto the 3D mesh. For these particular head wave computations, the sway, roll and yaw motion are fixed to zero, and the surge motion is imposed to be equal to the re-composition of the frequency results. Figure 2 shows an illustration of the two-node vertical flexural vibration mode by Participant C.

Participant D used a nonlinear hydroelastic strip theory method for the predictions of wave-induced vertical motions, considering load effects in the ship with large amplitude motions and small hull deformations. The global hull deformation is approximated by an aggregate of flexible modes, and the wave-induced ship responses are obtained by modal superposition. The nonlinear effects in the vertical motions and cross-sectional load effects are introduced in the form of a nonlinear vertical excitation force. In this way, the relationship between the ship motions or the load effects and the excitation force can remain linear, while the excitation force is no longer linear with respect to the incident wave. The total nonlinear excitation force consists of a linear part as well as a nonlinear modification part. The nonlinear modification part is obtained as the convolution of the linear impulse response function and the nonlinear modification force. The considered nonlinearities are due to the slamming impact force, incident wave force and hydrostatic restoring force. The slamming impact force is determined from the momentum considerations and is neglected during water exit. Only the first global vertical flexural vibration mode was adopted.

4.5 Results

Figures 3 and 4 show the shapes of the first two global vertical flexural modes, respectively. In general, the calculated modes are well in line with the ones from the model tests. The model tests results are provided with a 95% confidence interval that is based on the results from several measurements. The mode shapes used by Participant C deviate most from the others. This is related to the fact that a 3D finite element model was used and that the mode shapes do not regard the neutral axis. The corresponding wet natural frequencies are presented in Table 4. Results from the participants are well in line with the experimental results.

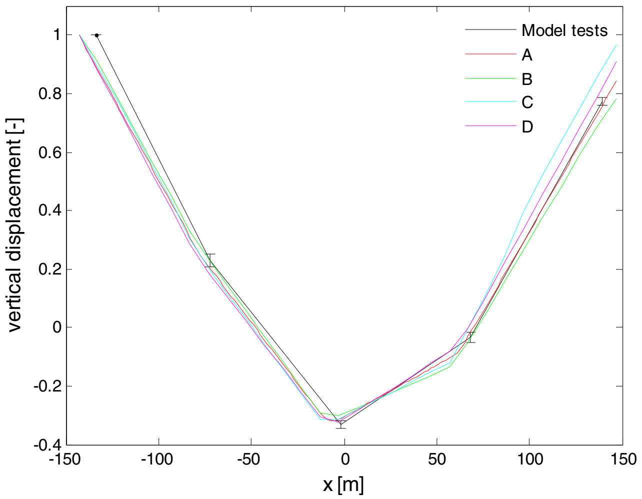

Figure 3. Shape of the first global vertical flexural vibration mode.

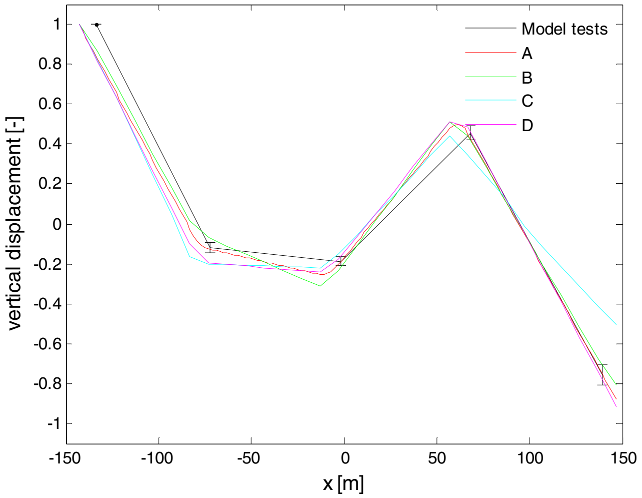

Figure 4. Shape of the second global vertical flexural vibration mode.

Table 4. Wet natural frequencies of the two- and three- node vertical flexural vibration modes.

	Two node mode [Hz]	Three node mode [Hz]
EXP	0.56	1.30
A	0.57	1.42
B	0.57	1.41
C	0.55	1.31
D	0.56	-

Figures 5, 6 and 7 show the unbiased standard deviations of the measured and predicted bending stresses at the three measurement sections. Participants were asked to provide vertical bending moments for these sections. These bending moments were transformed to stresses using 27.4 m^3, 30 m^3 and 30 m^3 as section modules for the forward, amidships and aft sections, respectively. This was combined with a stress concentration factor of two. The standard deviation of the stress was used as an important parameter in predicting the fatigue damage. The predicted number of cycles is also important. Due to page limitations, this was, however, omitted from the comparisons presented here. Each figure is built up of four subplots showing the stresses per wave height and speed, as a function of peak period. From Figure 5, it may be concluded that Participant A over-predicts the stresses on average by 30%, and Participant B slightly more than this, approximately 35%, on average. Participant C under-predicts by approximately 25%. Predictions in higher wave~~s~~ heights are better than in the lower wave heights. The stresses obtained by Participant D agree well with the experimental results and are within 5% on average. The stresses in the amidships section, shown in Figure 6, are predicted by Participant A and agree well with the experimental results. The predictions by Participant C under-predicts the experiments and are approximately 10% low, on average. Participant B under-predicts the stresses by approximately 20%. Participant C, on the other hand, over-predicts by 10%, on average. At the aft section, as seen in Figure 7, Participant C obtained very close agreement with the experimental measurements. On average, a difference of 4% is seen. Participants A and B slightly under-predict the stresses by about 10%. The predictions of Participant D show about 15% over-prediction, on average.

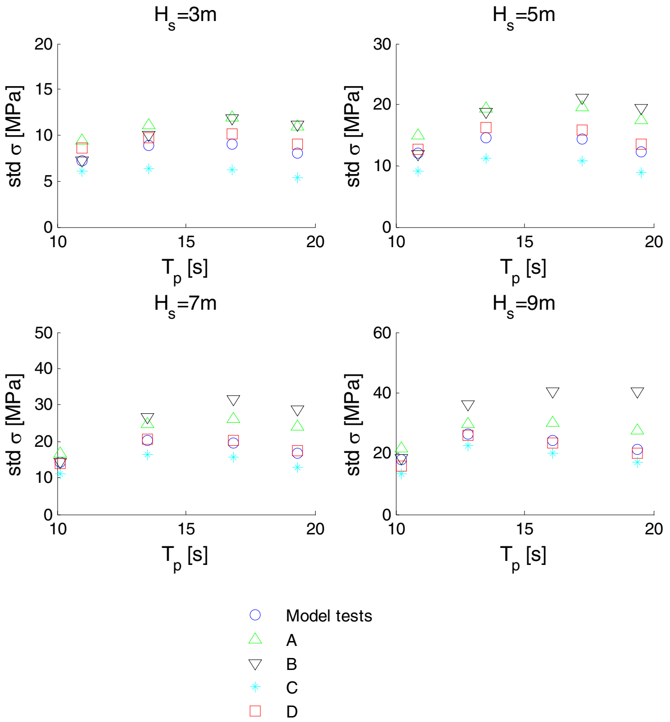

Figure 5. Standard deviation of the total stress at the forward section.

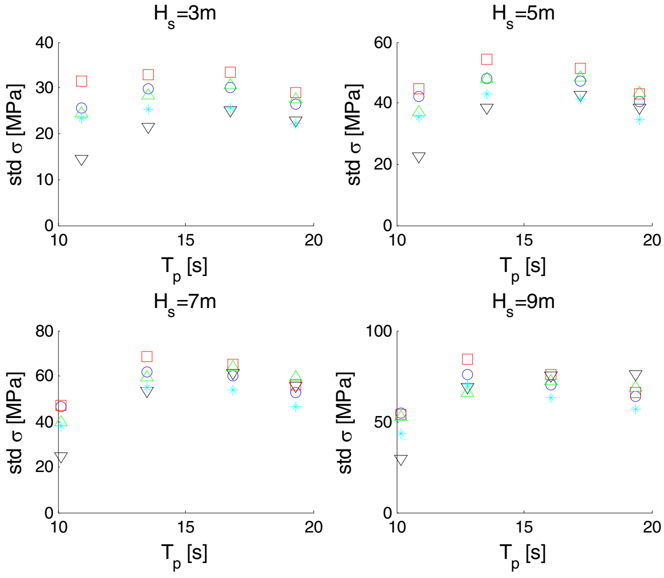

Figure 6. Standard deviation of the total stress at the amidships section.

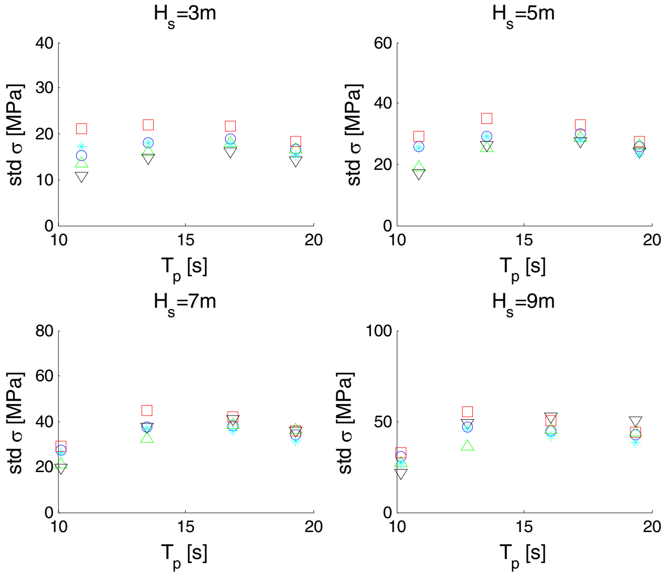

Figure 7. Standard deviation of the total stress at the aft section.

Figures 8, 9 and 10 present the unbiased standard deviations of the high frequency bending stresses at the three measurement sections. These were obtained by high-pass filtering the original stress signals using a cutoff frequency of 0.4 Hz. This excludes the stresses directly induced by the waves and only contains bending stresses as a result of vertical flexural vibrations of the global hull girder. The high frequency stresses are mainly induced by slamming. Participants A, B and D used the momentum theory to obtain the slamming force. Participant D adopted the GWM.

From Figure 8, it can be seen that stresses at the forward section predicted by Participants A, C and D agree quite well with experimental results except for the lowest wave height, where results are conservative. On average, the conservatism is about 20%, 15% and 50%, respectively. The results from Participant B are generally conservative by a factor 2.5. At the amidships, as shown in Figure 9, Participant C is well in line with the experimental results. On average, the results are 15% lower in comparison with the experimental measurements. On the other hand, Participant A estimated substantially high stresses for low wave heights and low stresses for high wave heights. The trend for Participant B is also similar, but it starts off with a reasonable estimate in the lower wave heights and a conservative prediction in the higher waves. The predictions by Participant D are on average about 60% conservative. At the aft section, as shown in Figure 10, Participant D over-predicts experimental results by 70%. Participant A is close to experiment results for low wave heights but under-predicts by about 20% for high wave heights. The trend for Participant B is again similar but starts off with a reasonable estimate in the lower wave heights and a conservative prediction in the higher waves. The results obtained by Participant C are close to experimental results, with a 2% difference on average.

4.6 Conclusions

In order to investigate the accuracy of the predicted dynamic responses, the ISSC 2018 Dynamic Response committee also chose to perform a whipping benchmark study. The focus of the study was on nonlinear strip theory and panel methods.

All of the computational codes involved in the benchmark calculations gave acceptable results. Higher and/or lower stresses are observed, depending on the stress location. The predicted high frequency stress components are scattered more than the total stresses. This may be caused by the differences in the methods for slamming impact computations. It should be noted that the differences between the methods using momentum theory are sometimes larger than those observed between the methods adopting momentum theory and GWM, respectively.

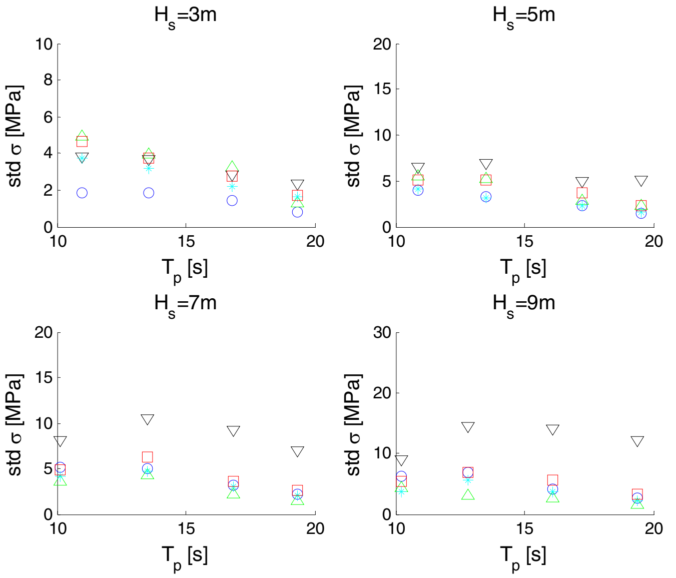

Figure 8. Standard deviation of the high frequency stress at the forward section.

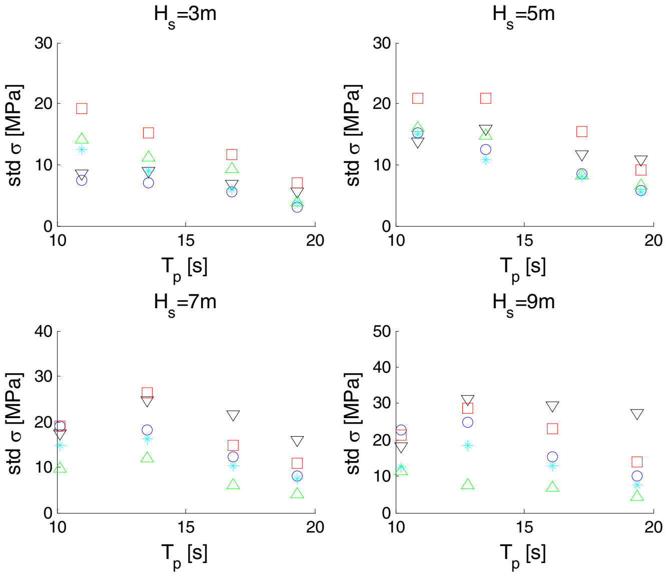

Figure 9. Standard deviation of the high frequency stress at the amidships section.

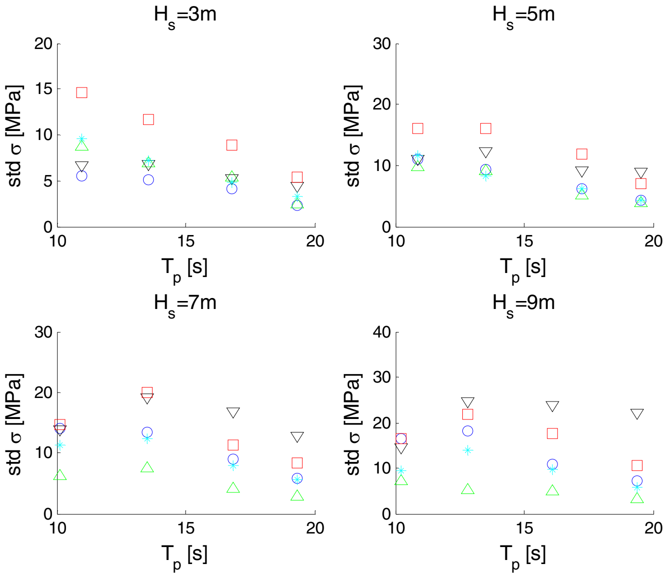

Figure 10. Standard deviation of the high frequency stress at the aft section.

In the present benchmark study, one participant used a 3D panel method, and the rest of participants 2D nonlinear strip theory methods. 3D methods need more computation time than 2D methods. However, according to the present results, 3D methods and 2D strip methods give comparable predictions, and clear differences between these two methods cannot be observed as far as the present benchmark study are concerned.

It is strongly pointed out that the present benchmark study is carried out for a specific experiment ship type for limited irregular sea states. Therefore, in order to derive generalized conclusions, more studies are needed.

5. CONCLUSIONS

Full-scale measurements and model tests in recent years have been focused on unconventional ships such as VLCS and ULCS. They also have relatively low natural frequencies. Most papers are related to only seven different container ships. Based on the attention around MSC Napoli and MOL Comfort, this is understandable, but wave-induced vibrations are not limited to container ships, and future studies should include other ship types as well. Also, the effects of sea state, heading, speed, size, loading condition, trade and structural location are well understood and addressed. There is also a rising trend that data is assessed based on standard hull monitoring systems rather than full-scale measurements from research projects. This trend should be supported and could accelerate the knowledge on a large number of ships and ship types. Only some papers have compared the measured or extrapolated values to design values, which is of particular interest for container ships in relation to IACS URS11A (IACS, 2015). It is recommended that statistical extrapolation of results for comparison with design values are used more frequently. Most studies are also related to vertical vibration, and it is recommended that more attention is given to torsional vibrations and other topics, such as vibration dose values and acceleration levels for cargo securing. Damping is a special challenge for numerical predictions, and better target values are needed. Mature hull monitoring systems can, however, close the gap between design and operational wave-induced vibrations.

Fully consistent modelling of whipping is still a challenge, and only approximate solutions exists. The future developments on the hydrodynamic side are likely to be based on CFD, because the potential flow models seem to reach their limits for the applications in large waves. Having said that, the potential flow models appear to be good enough for some operation conditions, such as head waves at low speed, and they can be used with confidence for the identification of the worst operating conditions from a whipping point of view. Since CFD cannot be practically used for long-duration simulations, the most efficient methodology for whipping assessment will combine the potential flow models (long-term simulations, identification of critical events) and CFD methods (short-term simulations for critical operating conditions).

Propeller-induced vibrations are still considered important in hull structure and shafting systems. In the period of this report, there have been some advances in numerical simulation of propeller excitation forces by considering dynamic interaction effects in shafting system under actual operation conditions. Many researchers have tried to make their numerical models to be practically useful in the prediction of propeller performance in terms of cavitation, pressure pulses and efficiency at early design stage. Also, application of CFD methods is reported. It is expected that there will be further attempts to improve the numerical accuracy of CFD methods for the prediction of propeller excitation forces. Meanwhile, practical devices are applied to ships for reducing the propeller forces, and some of them have succeeded in validation of their effectiveness through full-scale tests.

It is evident from the open literature that there has been no major development reported on the methods of analysis for engine-induced vibrations. Most attention has been paid to vibration control and vibration-reducing techniques. Also, there has been a rather small number of references on machinery-induced vibrations, compared to other sources. However, the topic is expected to come into focus again, due to the introduction of the so-called Comfort Class. Furthermore, some problems have been reported for ultra-long stroke engines with low engine speeds.

Sloshing-induced impacts are very important in the design of a ship tank and the CCS. In the reporting period, the investigation of sloshing impacts has been pursued by experimental and numerical means. Unfortunately, no significant progress has been made, and there is still no efficient solution, neither experimental nor numerical. It is also common practice in tank design to do model experiments for sloshing-induced impact effects. However, it is still very difficult to scale the measured pressures consistently to full-scale. On numerical side, it is regrettable that the correct numerical modelling of coupled hydro-elastic interactions has not been considered seriously yet. CFD tools based on solving the Navier Stokes or Euler equations are most often applied with slightly different numerical strategies. A considerable amount of work has been reported on the use of OpenFoam software.

The shock- and explosion-induced responses of ships are important to military and civilian vessels. A key area of concern for blast response is explosion in an interior comportment. In the field of internal explosion loadings, quasi-static loading has been the main concern. In the reporting period, many researchers have proposed new methods for analysis and experimentation of response and damage of compartments subjected internal explosion. On the other hand, the dynamic response of ships to UNDerwater EXplosion (UNDEX) is very important for ship survivability due to the potential for serious damage. Recent research has concentrated on the damage and responses to near-field and contact explosions that are relevant to bubble dynamics and strong nonlinearity, respectively. Shock resistance performance of composite structures, such as GRP, SBS, sandwich plates and rubber-like material coating structures have been the area of recent research.

Regarding interior noise regulations, the new IMO code, MSC 337(91) is regarded as a lost opportunity for making a step ahead in protecting seafarer's health and safety. The new code is not so different from the previous one, IMO Resolution A.468 (XII), except for those vessels whose tonnage above 10000 GT. It has also been noted that the shipbuilding and noise control technologies are far ahead the new regulation. Furthermore, the application of these norms is found difficult in the case of tonal noise components because of their imprecise definition. Within the air radiated noise, the assessment of external noise propagation requires the measurement of sound power emitted from ship. However, there is no available technical standard for determining the sound power of very large sources, such as cruise ships in a complex environment like a harbor. 3D acoustic mapping can be a useful tool to explore different noise scenarios where the ship is not the only source contributing to the noise pollution of an area surrounding a harbor. With regard to underwater radiated noise, most research has focused on the fields of noise mapping of seas and establishing limits on received underwater noise, in this reporting period. Within the EU project AQUA, a number of recommendations are made for design, construction and management of ships and their routes to improve the future fleet on underwater noise emissions. A concluded project called BIAS had a main goal to monitor the intensity of underwater noise caused by shipping without undertaking costly and difficult hydro-acoustic measurements.

Despite all the efforts made, the damping mechanisms and actual damping values, for ships in different operating conditions, are not fully understood. In the forced vibration analysis of ship structures, damping is still accounted for in a simplified way, i.e. by lumping all of its components together through a constant damping coefficient specified as a percentage of critical damping. There is thus a need for more full-scale data, together with the information on wind, wave conditions and ship speed, as well as cargo condition and draft, which may affect the damping values. A step in the right direction is the revised hull monitoring rules by DNVGL (2017a) which requires damping estimates to be automatically produced onboard when the ship vibrates.

In this report, an attempt is made to standardize different terminology and technology in relation to monitoring, such as condition monitoring, condition monitoring system, condition based maintenance, etc. Also, a distinction is made between full-scale measurements and hull monitoring systems. The control and monitoring systems are also an important part of the rules, and they deal with machinery, systems and components. Recently, there have been several revisions of the hull monitoring rules by the classification societies. However, this does not necessarily mean that significant changes have been made. On the other hand, digitalization is a global trend, and some classification societies encourage storage and processing measurement data and sending it to shore. It is also necessary to have a system at shore to retrieve data. Unfortunately, not much has been found on this, with regards to dynamic response.

IACS issued unified requirements for the longitudinal strength of container ships, URS11A (IACS, 2015), and classification societies changed their rules for container ships to account for whipping and springing. These changes arise because of the accidents of MSC Napoli and MOL Comfort. Criticism of the newly developed rules and standards has been made for wave-induced vibrations, especially for container ships, and overestimation of wave loads has been recognized. On the other hand, IMO (2014) published a guideline for the noise level on board ships for both passengers and crew members, and various noise levels were set for different spaces onboard ship. With regard to sloshing, not much progress has been made in the period of this report. This means that a direct calculation procedure for sloshing assessment is not yet possible, and the so-called comparative approach is still in useVibration in offshore structures due to environmental and operational loads continues to be a major concern for design. The dynamic analysis of wave-induced response is usually based on a stochastic model of the ocean surface and wave kinematics. The corresponding dynamic response is then obtained as a probability distribution of local maxima and extreme values. Vibration control is also an important topic for offshore structures. The methods employed are generally categorized as passive, active, semi-active and hybrid.

Wind-induced vibration is one of the important factors for the structural safety of offshore structures. Several investigations have been reported in the period of this report, targeting offshore platforms as well as offshore wind turbines. The recent literature generally involves the estimation of structural response due to wind loads and control and reduction of wind induced vibrations.

With regard to Vortex Induced Vibration (VIV), a survey of recent publications is mainly concern with model tests. The typical scaling factors are within the range of 1:40-1:75. It is impossible to simultaneously satisfy Reynolds and Froude scaling for model and prototype conditions, and this implies that full-scale testing is necessary. On the other side, most of the work done in recent years is devoted mainly to improving the prediction capabilities of wake oscillator models rather than to the development of new CFD or semi-empirical models. A significant number of papers describe very sophisticated wake oscillator models which are able to capture the nonlinear multi-mode dynamics and interactions of flexible curved or straight structures undergoing VIV.

Despite the rapid development of offshore oil exploitation which involves a large number of pipelines to process oil and gas, a limited number of publications have been found on internal flow-induced vibration in the period of this report.

Many types of equipment are installed in offshore facilities for production, storage and unloading of oil and gas. However, it is almost impossible to consider all the equipment as excitation sources at a design stage. According to the common practice of shipyards, the major equipment includes rotating machinery operated below 4800 rpm and reciprocating engines exceeding an output power of 30 kW. Some interesting papers have been published in the period of this report.

Offshore structures may be subjected to several types of shock loading, including internal explosion of oil, gas and other chemical matter, external explosions due to weapons attack, and seismic loading from foundation attachments to the sea floor. CFD has been generally employed coupled with finite element methods for analysis of the shock wave interaction with structures. On the other side, reinforced material usage is a growing area for offshore structures, and recent research has focused on the investigation of the blast resistance of reinforced concrete materials. Critical offshore infrastructure, such as bridge abutments, petrochemical docking components, ports, and flood control devices, often contain concrete structures, and their vulnerability to both accidental and intentional explosive loading makes the response of these structures to such loading important to researchers and designers.

The activity of pile driving for the foundation construction of wind turbines and other offshore structures may be the most important noise source, so much research work, therefore, has been published on this topic. These studies may be categorized as those involving numerical and experimental methods for analyzing the noise emitted due to pile driving, and those involving noise mitigation measures.

Regarding monitoring of offshore structures, the monitoring campaigns, mainly, focus on the assessments of maintenance needs, extreme responses and reliability of local structural details and components. Monitoring of fatigue cracks, subsea equipment and offshore wind turbines are important research topics in this field.

Floating offshore structures, such as wind turbines, include many degrees of freedom, variables, and excitation from both wind and waves, making the assessment of uncertainty in a test campaign challenging. In addition, it is important to consider many different conditions, requiring a large number of experiments to be run, including numerous repetitions. The variables can be strongly or weakly coupled, meaning that error sources can strongly influence each other.

The offshore industry has not recognized wave-induced vibrations to the same extent as in the shipbuilding industry. However, offshore ships like FPSOs can utilize the same rules and standards as in shipbuilding. For other offshore structures, class may lack rules and standards for wave-induced vibrations, but they may still request assessment of consequences and suggest that the resonance periods may be kept as low as possible. On the other side, for free-spanning subsea power cables, VIV can be part of the fatigue limit state requirements. NORSOK (2017) includes VIV in general terms based on water flow and wind. Furthermore, the comfort class notation COMF is mainly used for passenger ships, but the class guideline gives more general criteria which can also be used within offshore accommodation units.

Finally, this committee has undertaken a benchmark study regarding whipping responses, with a special focus on nonlinear strip theory and panel methods. The degree of variation in estimates produced by different methods and organizations is revealed, and comparisons with model test measured responses are provided.

REFERENCES

Abbas, N., Kornev, N., Shevchuk, I. & Anschau, P. 2015. CFD prediction of unsteady forces on marine propellers caused by the wake nonuniformity and nonstationarity. *Ocean Engineering* 104, 659-672.

ABS 2016a. *Guide for hull condition monitoring systems*. 15 December 2015 (updated March 2016). American Bureau of Shipping.

ABS 2016b. *Rules for building and classing steel vessels*. American Bureau Shipping.

ABS 2014. *Guidance notes on strength assessment of membrane-type LNG containment systems under sloshing*. American Bureau of Shipping.

ABS 2014a. *Guidance note on whipping assessment for container carriers*. American Bureau of shipping.

ABS 2014b. *Guidance note on springing assessment for container carriers*. American Bureau of Shipping.

Alizadeh, A.A., Mirdamadi, H.R. & Pishevar, A. 2016. Reliability analysis of pipe conveying fluid with stochastic structural and fluid parameters. *Engineering Structures* 122, 24-32.

Allen, D.W., Lee, L., Henning, D. & Liapis, S. 2015a. The effects of mixing helical strakes and fairings on marine tubulars and arrays. In *Proc. 34th International Conference on Ocean, Offshore and Arctic Engineering OMAE, St. John's, Newfoundland, Canada.*

Allen, D.W., Lee, L., Henning, D. & Liapis, S. 2015b. Practical design considerations for managing marine growth on VIV suppression devices. In *Proc. 34th International Conference on Ocean, Offshore and Arctic Engineering OMAE, St. John's, Newfoundland, Canada.*

Ancellin, M., Brosset, L. & Ghidaglia, J.-M. 2016. Preliminary numerical results on the influence of phase change on wave impact loads. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Andersen, I.M.V. 2014. *Full scale measurements of the hydro-elastic response of large container ships for decision support*. PhD thesis, Technical University of Denmark, Denmark.

Andersen, I.M.V. & Jensen, J.J. 2015. Extreme value prediction of the wave-induced vertical bending moment in large container ships. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Antoniadou, I., Dervilis, N., Papatheou, E., Maguire, A.E. & Worden, K. 2017. Aspects of structural health and condition monitoring of offshore wind turbines. *Philosophical Transactions A* 373.

Arai, M., Cheng, L.-Y., Wang, X., Okamoto, N., Hata, R. & Karuka, G. 2016. Sloshing and swirling behavior of liquid in a spherical LNG tank. In *Proc. 13th Int. Symp. on Practical Design of Ships and Other Floating Structures PRADS, Copenhagen, Denmark*.

ASME 2014. *Test uncertainty, performance test codes*. ASME PTC 19.1-2013.

Assi, G.R.S. & Bearman, P.W. 2015. Transverse galloping of circular cylinders fitted with solid and slotted splitter plates. *Journal of Fluids and Structures* 54, 263-280.

Assi, G.R.S, Bearman, P.W. & Tognarelli, M.A. 2014. On the stability of free-to-rotate short-tail fairing and a splitter plate as suppressors of vortex-induced vibration. *Ocean Engineering* 92, 234-244.

Audoly, C., Rousset, C., Baudin, E. & Folegot, T. 2016. AQUO Project - Research on solutions for mitigation of shipping noise and its impact on marine fauna - Synthesis of guidelines. In *Proc. 23rd International Congress on Sound and Vibration ICSV, Athens, Greece.*

Baarholm, G.S., Johansen, A., Birknes, J. & Haver, S. 2013. Estimation of equivalent dynamic amplification factor (EDAF) on a jacket structure. In *Proc. 32nd International Conference on Ocean, Offshore and Arctic Engineering OMAE, Nantes, France.*

Baeten, A. 2017. Fluid structure interaction analysis of composite structures exposed to sloshing. In *Proc. 27th Int. Offshore and Polar Engineering Conference ISOPE, San Francisco, USA.*

Baeten, A. 2015. Numerical analysis of liquid impact energy dissipation. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

Bai, Y. & Liang, J.W. 2016. *Marine structural design*, Second Edition, Butterworth-Heinemann.

Bang, B., Park, H.-S., Kim, J.-H., Al-Deyab, S.S., Yarin, A.L. & Yoon, S.S. 2016. Simplified method for estimating the effect of a hydrogen explosion on a nearby pipeline. *Journal of Loss Prevention in the Process Industries* 40, 112-116.

Barhoumi, B. & Storhaug, G. 2014. Assessment of whipping and springing on a large container vessel. *International Journal of Naval Architecture and Ocean Engineering* 6(2), 442-458.

Behruzi, P., Gaulke, D., Haacke, D. & Brosset, L. 2017. Modeling of impact waves in LNG ship tanks. *International Journal of Offshore and Polar Engineering* 27(1).

Beltrán, P., Salinas, R. & Moreno, A. 2014. The new IMO noise code: A lost technical opportunity. Irreversible and high cost consequences for fishermen and other seamen that will continue being deaf. In *Proc. 21st International Congress on Sound and Vibration ICSV, Beijing, China.*

Bennett, S.S., Downes, J., Dickson, T., Phillips, A.B. & Turnock, S.R. 2015a. Rapid prototyping of flexible models – a new method for model testing? In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Bennett, S.S., Hudson, D.A. & Temarel, P. 2015b. The effect of abnormal wave sequences on 2D hydroelastic predictions of global loads. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Bernasconi, G., Giunta, G. & Chiappa, F. 2015. Gas filled pipelines monitoring using multipoint vibroacoustic sensing. In *Proc. 34th International Conference on Ocean, Offshore and Arctic Engineering OMAE, St. John's, Newfoundland, Canada.*

Blanchet, D. & Caillet, A. 2014. Full frequency noise and vibration control onboard ships. In *Proc. 21st International Congress on Sound and Vibration ICSV, Beijing, China.*

Blevins, R.D., Coughran, C.S., Utt., M.E. & Raghavan, K. 2016. Drilling-induced riser vibration. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Borelli, D., Gaggero, T., Rizzuto, E. & Schenone, C. 2016a. Holistic control of ship noise emissions. *Noise Mapping* 3, 107–119.

Borelli, D. & Schenone, C. 2014. Application of a simplified "source-path-receiver" model for HVAC noise to the preliminary design of a ship: A case study. In *Proc. 21st International Congress on Sound and Vibration ICSV, Beijing, China.*

Borelli, D., Schenone, C., Gaggero, M., Gaggero, T. & Rizzuto, E. 2016b. Seafarer's work exposure to tonal noise components. In *Proc. 23rd International Congress on Sound and Vibration ICSV, Athens, Greece.*

Borsani, J.F., Curcuruto, S. & Farchi, C. 2015. Setting up an underwater noise monitoring plan for Italian territorial waters. In *Proc. 22nd International Congress on Sound and Vibration ICSV, Florence, Italy.*

BSH 2013. *Standard: Investigation of the impacts of offshore wind turbines on the marine environment (StUK4)*. Bundesamt für Seeschifffahrt und Hydrographie, Federal Maritime and Hydrographic Agency.

BSH 2011. *Offshore wind farms: Measuring instruction for underwater sound monitoring, Current approach with annotations*. Bundesamt für Seeschifffahrt und Hydrographie, Federal Maritime and Hydrographic Agency.

Buruchenko, S.K. & Canelas, R.B. 2017. Validation of open-source SPH code DualSPHysics for numerical simulations of water entry and exit of a rigid body. In *Proc. International Conference on Ocean, Offshore and Arctic Engineering OMAE, Trondheim, Norway.*

BV 2017. *Rules for the classification of steel ships*. NR 467, July 2017, Part F, Chapter 5 Monitoring equipment. Bureau Veritas.

BV 2017a. *Rules for classification of steel ships*. Bureau Veritas.

BV 2017b. *Structural rules for container ships*. Rule note NR 625, Bureau Veritas.

BV 2015. *Whipping and springing assessment*. Rule note NR 583 DT R01 E. Bureau Veritas.

BV 2011. *BV guidance note NI 554, Design sloshing loads for LNG membrane tanks*. Bureau Veritas.

Calderon-Sanchez, J., Duque, D. & Gomez-Goni, J. 2015. Modeling the impact pressure of a free falling liquid block with OpenFoam. *Ocean Engineering* 103, 144-152.

CCS 2015. *Rules for classification of sea-going steel ships*. Part 8 Chapter 21 Hull monitoring systems. China Classification Society.

Cetin, E.C., Kim, S. & Kim, Y. 2017. Analysis of sloshing impact pressures using different extreme statistical theories. In *Proc. 27th Int. Offshore and Polar Engineering Conference ISOPE, San Francisco, USA.*

Chen, Y., Wang, L. & Hua, H.X. 2017. Longitudinal vibration and unsteady thrust transmission of the rim driven thruster induced by ingested turbulence. *Ocean Engineering* 131, 149-161.

Chen, Y., Yao, X. & Xiao, W. 2016. Analytical models for the response of the double-bottom structure to underwater explosion based on the wave motion theory. *Shock and Vibration* 2016.

Cho, Y.-B., Jin, K.-K., Yoon, I.-S., Yang, Y.-C. & Kim, Y.-G. 2015. A study of cryogenic-temperature structural behavior for KC-1 corner insulation system. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

Cicolin, M.M. & Assi, G.R.S. 2015. VIV response and drag measurements of circular cylinders fitted with permeable meshes. In *Proc. 34th International Conference on Ocean, Offshore and Arctic Engineering OMAE, St. John's, Newfoundland, Canada.*

Cinquemani, S. & Braghin, F. 2017. Decentralized active vibration control in cruise ships funnels. *Ocean Engineering* 140, 361-368.

Craig, M., Piro, D., Schambach, L., Mesa, J., Kring, D. & Maki, K. 2015. A comparison of fully-coupled hydroelastic simulation methods to predict slam-induced whipping. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Cristea, B., Mocanu, C.I. & Domnisoru, L. 2015. Non-linear hydroelastic and fatigue analyses for a very large bulk carrier. In: Soares, C.G. & Shenoi, R.S. (eds) *Advances in Marine Structures*. London, UK: Taylor & Francis Group.

Curcuruto, S., Marsico, G., Atzori, D., Mazzocchi, E. & Betti, R. 2015. Environmental impact of noise sources in port areas: A case study. In *Proc. 22nd International Congress on Sound and Vibration ICSV, Florence, Italy.*

Curletto, S., Pinto, O. & Dorsaneo, M. 2015. On the characterization of ship external noise. In *Proc. 22nd International Congress on Sound and Vibration ICSV, Florence, Italy.*

Dambra, R. & Firenze, E. 2015. Underwater radiated noise of a small vessel. In *Proc. 22nd International Congress on Sound and Vibration ICSV, Florence, Italy.*

Dardis, I.I., John, T., & Reinhall, Per G. 2015. New offshore pile for reduced acoustic emissions – results from full scale testing. In *Proc. 22nd International Congress on Sound and Vibration ICSV, Florence, Italy.*

Darvishzadeh, T. & Sari, A. 2015. CFD applications in offshore engineering. *Offshore Technology Conference, Houston OTC, Texas, USA.*

Davidson, C., Brown, M., Brennan, A. & Knappett, J. 2017. Decommissioning of offshore piles using vibration. In *Proc. 27th Int. Offshore and Polar Engineering Conference ISOPE, San Francisco, USA.*

Davis, M.R., French, B.J. & Thomas, B.J. 2017. Wave slam on wave piercing catamarans in random head seas. *Ocean Engineering* 135, 84-97.

De Lauzon, J., Benhamou, A. & Malenica, S. 2015a. Numerical simulations of WILS experiments. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

De Lauzon, J., Grgic, M., Derbanne, Q. & Malenica, S. 2015b. Improved generalized Wagner model for slamming. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Dekeling, R.P.A., Tasker, M.L., Van der Graaf, A.J., Ainslie, M.A, Andersson, M.H., André, M., Borsani, J.F., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S.P., Sigray, P., Sutton, G.,Thomsen, F., Werner, S., Wittekind, D. & Young, J. 2014a. *Monitoring guidance for underwater noise in European seas, Part I: Executive summary*. JRC Scientific and Policy Report EUR 26557 EN, Publications Office of the European Union, Luxembourg, 2014, doi: 10.2788/29293.

Dekeling, R.P.A., Tasker, M.L., Van der Graaf, A.J., Ainslie, M.A, Andersson, M.H., André, M., Borsani, J.F., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S.P., Sigray, P., Sutton, G.,Thomsen, F., Werner, S., Wittekind, D. & Young, J. 2014b. *Monitoring guidance for underwater noise in European seas, Part II: Monitoring guidance specifications*. JRC Scientific and Policy Report EUR 26555 EN, Publications Office of the European Union, Luxembourg, doi: 10.2788/27158.

Dekeling, R.P.A., Tasker, M.L., Van der Graaf, A.J., Ainslie, M.A, Andersson, M.H., André, M., Borsani, J.F., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S.P., Sigray, P., Sutton, G.,Thomsen, F., Werner, S., Wittekind, D., Young, J. 2014c. *Monitoring guidance for underwater noise in European seas, Part III: Background information and annexes*. JRC Scientific and

Policy Report EUR 26556 EN, Publications Office of the European Union, Luxembourg, doi: 10.2788/2808.

Deng, Q., Jiang, W., Tan, M. & Xing, J.T. 2016. Modelling of offshore pile driving noise using a semi-analytical variational formulation. *Applied Acoustics* 104, 85-100.

Derbanne, Q., Storhaug, G., Shigunov, V., Xie, G. & Zheng, G. 2016. Rule formulation of vertical hull girder wave loads based on direct computations. In *Proc. 13th Int. Symp. on Practical Design of Ships and Other Floating Structures PRADS, Copenhagen, Denmark*.

Dessi, D. 2014. Whipping-based criterion for the identification of slamming. *International Journal of Naval Architecture and Ocean Engineering* 6, 1082-1095.

Dezvareh, R., Batgi, K., & Mousavi, S.A. 2016. Control of wind/wave-induced vibrations of jacket-type offshore wind turbines through tuned liquid column gas dampers. *Structure and Infrastructure Engineering* 12(3), 312-326.

Dhavalikar, S., Awasare, S., Joga, R. & Kar, A.R. 2015. Whipping response analysis by one way fluid structure interaction – A case study. *Ocean Engineering* 103, 10-20.

Di Bella, A. 2014. Evaluation methods of external airborne noise emissions of moored cruise ships: An overview. In *Proc. 21st International Congress on Sound and Vibration ICSV, Beijing, China.*

Di Bella, A., Remigi, F., Fausti, P. & Tombolato, A. 2016. Measurement method for the assessment of noise impact of large vessels. In *Proc. 23rd International Congress on Sound and Vibration ICSV, Athens, Greece.*

Dias, F. & Ghidaglia, J.-M. 2018. Slamming: Recent progress in the evaluation of impact pressures. *Annual Review of Fluid Mechanics* 50.

Diebold, L. & Baudin, E. 2016. Sloshing analysis of single impact wave & irregular motions in a 2D tank – Experiments & numerics. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Diez, M., Broglia, R., Durante, D., Olivieri, A., Campana, E.F. & Stern, F. 2017. Validation of uncertainty quantification methods for high-fidelity CFD of ship response in irregular waves. In *Proc. 55th AIAA Aerospace Sciences Meeting, Grapevine, Texas, USA.*

Diez, M., Broglia, R., Durante, D., Olivieri, D., Campana, E.F. & Stern, F. 2016. Statistical validation of a high-speed catamaran in irregular waves. In *Proc. 31st Symposium on Naval Hydrodynamics, September 11-16, 2016, Monterey CA, USA.*

Diez, M., Broglia, R., Durante, D., Campana, E.F. & Stern, F. 2015. Validation of high-fidelity uncertainty quantification of a high-speed catamaran in irregular waves. In *Proc. 13th International Conference on Fast Sea Transportation, Washington DC, USA.*

Diez, M., He, W., Campana, E.F. & Stern, F. 2014. Uncertainty quantification of Delft catamaran resistance, sinkage and trim for variable Froude number and geometry using meta models, quadrature and Karhunen–Loève expansion. *Journal of Marine Science and Technology* 19(2), 143-169.

DNV 2010. *Rules for classification of ships*. Det Norske Veritas.

DNV 2005. Rules for classification of ships/high speed, light craft and naval surface craft. Part 6 Chapter 11 Hull monitoring systems. Det Norske Veritas.

DNV-GL 2017a. *Rules for classification of ships*. Part 6 Chapter 9 Section 4. Hull monitoring systems – HMON. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2017b. Recommended practise. Data quality assessment framework, edition January 2017. DNVGL-RP-0497.

DNV-GL 2017c. *Rules for classification of ships.* Part 4 Chapter 9. Control and monitoring systems, edition January 2017. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2017d. *Rules for classification of ships: Hull girder loads*. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2017e. *Riser fatigue. Recommended practise*. DNVGL-RP-F204, October 2017. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2017f. *Free spanning pipelines. Recommended Practise*. DNVGL-RP-F105, June 2017. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2016a. *Class Guideline: Sloshing analysis of LNG membrane tanks*. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2016b. *Rules for classification of ships: Container ships - Hull girder strength*. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2016c. *Fatigue assessment of ship structures*. DNVGL-CG-0129, Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2016d. *Subsea power cables in shallow water*. Recommended practise, DNVGL-RP-0360, March 2016. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2016e. *Criteria for handling of excessive noise and vibration levels*. Class guideline, DNVGL-CG-0493, May 2016. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2016f. *Certification of condition monitoring. Service specification*. DNVGL-SE-0439, edition June 2016. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2015. *Survey arrangement for machinery condition monitoring*. Class guideline DNVGL-CG-0052, edition December 2015. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2015a. *Rules for classification of ships*: *Wave induced hull girder vibration – WIV*. Det Norske Veritas - Germanischer Lloyd's.

DNV-GL 2015b. *Fatigue and ultimate strength assessment of container ships including whipping and springing*. DNVGL-CG-0153, Det Norske Veritas - Germanischer Lloyd's.

Drummen, I. 2008. *Experimental and numerical investigation of nonlinear wave induced load effects in containerships considering hydroelasticity*. PhD thesis, Norwegian University of Science and Technology, Trondheim, Norway.

Drummen, I. & Holtmann, M. 2014. Benchmark study of slamming and whipping. *Ocean Engineering* 86, 3-10.

Drummen, I., Schiere, M., Dallinga, R. & Stambaugh, K. 2014. *Full and model scale testing of a new class of US coast guard cutter.* Ship Structure Committee 2014, 18-20th May 2017, Linthicum Heights, USA.

Duan, X.-Y., Guo, X.-Y., Jiao, Q.-J., Zhang, J.-Y. & Zhang, Q.-M. 2017. Effects of Al/O on pressure properties of confined explosion from aluminized explosives. *Defense Technology* 13(6), 428-433.

Eca, L. & Hoekstra, M. 2014. A procedure for the estimation of the numerical uncertainty of CFD calculations based on grid refinement studies. *Journal of Computational Physics* 262, 104-130.

Eftekhari, M. & Hosseini, M. 2015. On the stability of spinning functionally graded cantilevered pipes subjected to fluid-thermomechanical loading. *International Journal of Structural Stability & Dynamics* 16(9).

Eisinger, E., Helmers, J.B. & Storhaug, G. 2016. A method for describing ocean environments for ship assessment. In *Proc. 6th International conference on Design for Safety, 28-30 November 2016, Hamburg, Germany*.

el Moctar, O., Ley, J., Oberhagemann, J. & Schellin, T.E. 2017. Nonlinear computational methods for hydroelastic effects of ships in extreme seas. *Ocean Engineering* 130, 659-673.

el Moctar, O., Ley, J., Oberhagemann, J. & Schellin, T.E. 2016. Advanced computational methods for hydroelastic effects of ships in extreme seas. *Ocean Engineering* 130, 659-673.

Fan, Y., Mao, H., Guo, H., Liu, Q. & Li, X. 2015. Experimental investigation on vortex-induced vibration of steel catenary riser. *China Ocean Engineering* 29(5), 691-704.

Farcas, A., Thompson, P.M. & Merchant, N.D. 2016. Underwater noise modelling for environmental impact assessment. *Environmental Impact Assessment Review* 57, 114-122.

Feldgun, V.R., Karinski, Y.S., Edri, I. & Yankelevsky, D.Z. 2016. Prediction of the quasi-static pressure in confined and partially confined explosions and its application to blast response simulation of flexible structures. *International Journal of Impact Engineering* 90, 46–60.

Fernandes, A.C., Mirzaeisefat, S. & Cascao, L.V. 2014. Fundamental behaviour of vortex self induced vibration (VSIV). *Applied Ocean Research* 47, 183-191.

Firoozkoohi, R., Abrahamsen, B.C. & Faltinsen, O.M. 2017. Study of an entrapped air pocket due to sloshing using experiments and numerical simulations. In *Proc. International Conference on Ocean, Offshore and Arctic Engineering OMAE, Trondheim, Norway.*

Fotini, C., Dalamagas, V., Dalamaga, D. & Sarantopoulos, G. 2016. Determination of ships as noise sources & noise mapping at passenger & cruise port of Piraeus. In *Proc. 23rd International Congress on Noise & Vibration ICSV, Athens, Greece.*

Fricke, M.B. & Rolfes, R. 2015. Towards a complete physically based forecast model for underwater noise related to impact pile driving. *Journal of the Acoustical Society of America* 137(3), 1564-1575.

Frihat, M., Brosset, L. & Ghidaglia, J.-M. 2017. Experimental study of surface tension effects on sloshing impact loads. *IWWWFB 32, Dalian, China.*

Frihat, M., Karimi, M.R., Brosset, L. & Ghidaglia, J.-M. 2016. Variability of impact pressures induced by sloshing investigated through the concept of 'singularization'. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Furey, C. 2015. *Parametric analysis of the shock response of a system of two submerged co-axial cylindrical shells coupled by the inter-shell fluid*. MSc. Thesis, Dalhousie University Halifax, Nova Scotia.

Gaidai, O., Storhaug, G. & Naess, A. 2016. Extreme large cargo ship panel stresses by bivariate ACER method. *Ocean Engineering* 123, 432-439.

Gao, Y., Fu, S., Wang, J., Song, L. & Chen, Y. 2015. Experimental study of the effects of surface roughness on the vortex-induced vibration response of a flexible cylinder. *Ocean Engineering* 103, 40-54.

Gharib, M. & Karkoub, M. 2015. Shock-based experimental investigation of the linear particle chain impact damper. *Journal of Vibration and Acoustics* 137 (6).

Gjinolli, A.E., Bremigan, C.D. & Morgan, J.S. 2016. Aero-acoustical and dynamic analysis of complex reciprocating engine exhaust systems. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Gong, K., Shao, S., Liu, H., Wang, B. & Tan, S.K. 2016. Two phase SPH simulations of fluid-structure interactions. *Journal of Fluid and Structures* 65, 155-179.

Gong, S.W. & Khoo, B.C. 2015. Transient response of stiffened composite submersible hull to underwater explosion bubble. *Composite Structures* 122, 229–238.

Göttsche, K.M., Steinhagen, U. & Juhl, P.M. 2015. Numerical evaluation of pile vibration and noise emission during offshore pile driving. *Applied Acoustics* 99, 51-59.

Gres, S., Fejerskov, M., Ibsen, L.B. & Damkilde, L. 2016. Experimental damping assessment of a full scale offshore Mono Bucket foundation. In *Proc. 27th International Conference on Noise and Vibration Engineering ISMA, Leuven, Belgium.*

Grotle, E. L. & Æsøy, V. 2017. Experimental and numerical investigation of sloshing in marine LNG fuel tanks. In *Proc. International Conference on Ocean, Offshore and Arctic Engineering OMAE, Trondheim, Norway.*

Grotle, E.L., Æsøy, V., Halse, K.H., Pedersen, E. & Li, Y. 2016. Non-isothermal sloshing in marine liquefied natural gas fuel tanks. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Grytøyr, G., Coral, F., Lindstad, H.B. & Russo, M. 2015. Wellhead fatigue damage based on indirect measurements. In *Proc. 34th International Conference on Ocean, Offshore and Arctic Engineering OMAE, St. John's, Newfoundland, Canada.*

Grytøyr, G., Hørte, T., Russo, M., Gregersen, K. & Aronsen, K.H. 2017. Comparison of global riser analysis to full scale measurements on the NCS. In *Proc. 36th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Trondheim, Norway.*

Guan, S., Taylor, C., Agarwal, A. & Sridhar, N. 2016. Understanding sensor system reliability. Position paper 2-2016. *DNVGL strategic research & innovation.*

Guo, Y., Li, W., Yu, S., Han, X., Yuan, Y., Wang, Z. & Ma, X. 2017. Diesel engine torsional vibration control coupling with speed control system. *Mechanical Systems and Signal Processing* 94, 1-13.

Guzas, E., Behan, K. & Davis, J. 2015. 3D finite element modeling of single bolt connections under static and dynamic tension loading. *Shock and Vibration* 2015.

Hageman, R., Aalberts, P., Shaik, M. & van den Boom, H. 2014a. Development of an advisory hull fatigue monitoring system. *The Transactions of Society of Naval Architects and Marine Engineers SNAME.*

Hageman, R. & Drummen, I. 2017. Modal analysis for the global flexural response of ships. *Marine Structures*, under review

Hageman, R., Drummen, I., Stambaugh, K., Dupeau, T., Herel, N., Derbanne, Q., Schiere, M., Shin, Y. & Kim, P. 2014b. *Structural fatigue loading predictions and comparisons with test data for a new class of US coast guard cutter*. Ship Structure Committee 2014, 18-20th May 2017, Linthicum Heights, USA.

Han, H.S., Lee, K.H. & Park, S.H. 2015. Estimate of the fatigue life of the propulsion shaft from torsional vibration measurements and the linear damage summation law in ships. *Ocean Engineering* 107, 212-221.

Han, R., Zhang, A. & Wang, S. 2016. Pressure load on rigid structure induced by double underwater explosions. In *Proc. 35th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Busan, Korea.*

Hansen, O.R., Kjellander, M., Martini, R. & Pappas, J.A. 2016. Estimation of explosion loading on small and medium sized equipment from CFD simulations. *Journal of Loss Prevention in the Process Industries* 41, 382-398.

Hay, A., Etienne, S., Pelletier, D. & Brosset, L. 2016. Accurate prediction of sloshing waves in tanks by an adaptive two-fluid incompressible front-tracking approach. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

He, W., Diez, M., Zou, Z., Campana, E.F. & Stern, F. 2014. URANS study of Delft catamaran total/added resistance, motions and slamming loads in head sea including irregular wave and uncertainty quantification for variable regular wave and geometry. *Ocean Engineering* 74, 189-217.

Heitmann, K., Ruhnau, M., Lippert, T., Lippert, S. & von Estorff, O. 2015. Numerical investigation of the influence of different sound mitigation systems on the underwater sound pressure level due to offshore pile driving. In *Proc. 22nd International Congress on Sound and Vibration ICSV, Florence, Italy.*

Helmers, J.B. & Skeie, G. 2015. A Meshless boundary element method for simulating slamming in context of Generalized Wagner. *Journal of Offshore Mechanics and Arctic Engineering* 137.

Heo, K., Koo, W., Park, I.K. & Rye, J. 2016. Quadratic strip theory of higher order dynamic behavior of a large containership with 3D flow effects. *International Journal of Naval Architecture and Ocean Engineering* 8(2), 127-136.

Hirdaris, S. 2014. Special issue on uncertainty modelling for ships and offshore structures. *Ocean Engineering* 86(1) 1–2.

Hong, S.Y., Kim, K.W. & Kim, B.W. 2015. An experimental investigation on bow slamming loads on an ultra-large containership. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Horst, M.P. van der & Kaminski, M.L. 2017. Slit induced self magnetic flux leakage in a square steel plate. *To be published.*

Hørte, T., Russo, M., Macke, M. & Reinås, L. 2013. Benefit of measurements and structural reliability analysis for wellhead fatigue. In *Proc. 32nd International Conference on Ocean, Offshore and Arctic Engineering OMAE, Nantes, France.*

Hsu, C.-Y., Liang, C.-C., Teng, T.-L. & Nguyen, H.-A. 2016. The dynamic responses of the submersible vehicle mast with different cross-sectional shapes subjected to underwater explosion. *MATEC Web of Conferences* 54.

Hu, W.-H., Thöns, S., Rohrmann, R.G., Said, S. & Rücker, W. 2015. Vibration-based structural health monitoring of a wind turbine system Part II: Environmental/operational effects on dynamic properties. *Engineering Structures* 89, 260-272.

Huang, Q., Yan, X., Wang, Y., Zhang, C. & Wang, Z. 2017. Numerical modelling and experimental analysis on coupled torsional-longitudinal vibrations of a ship's propeller shaft. *Ocean Engineering* 136, 272-282.

Huera-Huarte, F.J. 2014. On splitter plate coverage for suppression of vortex-induced vibrations of flexible cylinders. *Applied Ocean Research* 48, 244-249.

Hwang, J.-O., Song, G.-D., Chun, S.-E., Bang, C.-S. & Joh, K.-H. 2015a. Direct assessment of LNG cargo containment system under sloshing loads. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

Hwang, S., Khayyer, A., Gotoh, H. & Park, J.-C. 2015b. Simulations of incompressible fluid flow-elastic structure interactions by a coupled fully Lagrangian solver. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

IACS 2015. *Unified requirements S11A (URS11A): Longitudinal strength standard for container ships.* International Association of Classification Societies.

IACS 2001. *Standard wave data*. International Association of Classification Societies.

Im, H.-I., Vladimir, N., Malenica, S. & Cho, D.-S. 2016. Hydroelastic response of 19,000 TEU class ultra large container ship with novel mobile deckhouse for maximizing cargo capacity. *International Journal of Naval Architecture and Ocean Engineering* 9(3), 339-349.

IMO 2014. I817E *Code on noise level on board ships*. International Maritime Organization.

ISO 2017. *ISO 18406:2017 - Underwater acoustics - Measurement of radiated underwater sound from percussive pile driving*. International Organization for Standardization.

ISO 2008. *ISO/IEC Guide 98-3:2008(E) Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995).* International Organization for Standardization.

ISO 1997. *ISO 2631-1:1997-Mechanic vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements.* International Organization for Standardization.

ITTC 2014a. *General guidelines for uncertainty analysis in resistance test.* ITTC Procedure 7.5-02-02-02.

ITTC 2014b. *Example for uncertainty analysis of resistance tests in towing tank*. ITTC Procedure 7.5-02-02-02.1.

Janssen, C.F., Ueberrueck, M., Rung, T. & Behruzi, P. 2016. Real-time simulation of impact waves in LNG ship tanks with Lattice Boltzmann single-phase models. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

JAPAN 2015. *Final report of committee on large container ship safety*. Committee on large container ship safety, The Maritime Bureau of Japan's Ministry of Land, Infrastructure, Transport and Tourism, Japan.

Jensen, J.J., Andersen, I.M.V. & Seng, S. 2014. Stochastic procedures for extreme wave induced responses in flexible ships. *International Journal of Naval Architecture and Ocean Engineering* 6, 1148-1159.

Jia, J. 2014. Investigations of a practical wind-induced fatigue calculation based on nonlinear time domain dynamic analysis and a full wind-directional scatter diagram. *Ships and Offshore Structures* 9(3), 272-296.

Jin, K.-K., Yoon, I.-S. & Yang, Y.-C. 2015. An effect of fluid-structure interaction for KC-1 cargo containment system under sloshing loads. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

Jin, Z., Yin, C., Chen, Y. & Hua, H. 2016. Graded effects of metallic foam cores for spherical sandwich shells subjected to close-in underwater explosion. *International Journal of Impact Engineering* 94, 23–35.

Junior, S.J., Esperanca, T.T.P., Sphaier, H.S. & Machado, C. 2014. Uncertainty analysis for inclining tests. In *Proc. 33rd International Conference on Ocean, Offshore and Arctic Engineering, San Francisco, California, USA.*

Kahl, A., von Selle, H. & Storhaug, G. 2016. *Full-scale measurement and hull monitoring on ships*. International Institute of Welding, Commission V, V-1675-15 (XV-1494-15).

Kahl, A., Fricke, W., Paetzold, H. & von Selle, H. 2015. Whipping investigations based on large-scale measurements and experimental fatigue testing. *International Journal of Offshore and Polar Engineering* 25(4), 247-254.

Kamali, W., Wahab, A.A., El Moghrabi, Y. & Kabbara, H. 2014. Survey on environmental noise in the port of Tripoli. In Proc. *21st International Congress on Sound and Vibration ICSV, Beijing, China.*

Kandasamy, R., Cui, F., Townsend, N., Foo, C.C., Guo, J., Shenoi, A. & Xiong, Y. 2016. A review of vibration control methods for marine offshore structures. *Ocean Engineering* 127, 279-297.

Kaplan, M.B. & Solomon, S. 2016. A coming boom in commercial shipping? The potential for rapid growth of noise from commercial ships by 2030. *Marine Policy* 73, 119-121.

Kapsenberg, G.K. & Thornhill, E.T. 2010. A practical approach to ship slamming in waves. In *Proc. 8th Symp. on Naval Hydrodynamics, Pasadena, California.*

Karagiozova, D., Langdon, G.S., Nurick, G.N. & Niven, T. 2015. The influence of a low density foam sandwich core on the response of a partially confined steel cylinder to internal air-blast. *International Journal of Impact Engineering* 92, 32-49.

Karimi, M.R., Brosset, L., Ghidaglia, J.-M. & Kaminski, M.L. 2016a. Effect of ullage gas on sloshing – Part II: Local effects of gas-liquid density ratio. *European Journal of Mechanics B/Fluids* 57, 82-100.

Karimi, M.R., Brosset, L., Ghidaglia, J.-M. & Kaminski, M.L. 2015. Effect of ullage gas on sloshing – Part I: Global effects of gas-liquid density ratio. *European Journal of Mechanics B/Fluids* 53, 213-228.

Karimi, M.R., Brosset, L., Kaminski, M.L. & Ghidaglia, J.-M. 2016b. Effects of ullage gas and scale on sloshing loads. *European Journal of Mechanics - B/Fluids* 62, 59-85.

Karuka, G.M., Arai, M. & Ando, H. 2017. Sloshing and swirling in partially loaded prismatic chamfered tanks. In *Proc. International Conference on Ocean, Offshore and Arctic Engineering OMAE, Trondheim, Norway.*

Kashiwagi, M., Kuga, S. & Chimoto, S. 2015. Time- and frequency-domain calculation methods for ship hydroelasticity with forward speed. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Kawabe, H., Shigemi, T., Matsumoto, I.K. & Toyoda, K. 2016. Estimation of quantitative influence of whipping on wave induced vertical bending moment for large containership. *NK Technical bulletin*.

Kayal, B., Benoit, A., Frihat, M. & Loysel, T. 2016. Introduction to a structural-based sloshing assessment for membrane containment system. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Khabakhpasheva, T.I., Kim, Y. & Korobkin, A.A. 2014. Generalised Wagner model of water impact by numerical conformal mapping. *Applied Ocean Research* 44, 29-38.

Ki, H.G., Park, S.G. & Jang, I.H. 2015. Full scale measurement of 14k TEU containership. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Kim, B.W., Hong, S.Y. & Kim, K.H. 2015a. Resonant and non-resonant whipping responses of a container model ship in regular and irregular waves. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Kim, D.H., Lee, K.H. & Seong, W.J. 2014a. Non-cavitating propeller noise modelling and inversion. *Journal of Sound and Vibration* 333, 424-437.

Kim, J., Kim, S.-Y., Kim, Y., Lee, K.-M. & Sung, Y.-J. 2017a. Experimental study of slosh-induced loads on LNG fuel tank of container ship. In *Proc. 27th Int. Offshore and Polar Engineering Conference ISOPE, San Francisco, USA.*

Kim, J.H. & Kim, Y. 2014. Numerical analysis on springing and whipping using fully-coupled FSI models. *Ocean Engineering* 91, 28–50.

Kim, J.H., Kim, Y., Yuck, R.H. & Lee, D.Y. 2015b. Comparison of slamming and whipping loads by fully coupled hydroelastic analysis and experimental measurement. *Journal of Fluids and Structures* 52, 145–165.

Kim, K.H., Kim, B.W. & Hong, S.Y. 2015c. Experimental study on correlation between slamming impact and whipping vibration for an ultra-large containership. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Kim, S.P. 2015. Nonlinear time domain simulations of slamming, whipping and springing loads on a containership. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Kim, S.-Y., Kim, K.-H. & Kim, Y. 2015d. Comparative study on pressure sensors for sloshing experiment. *Ocean Engineering* 94, 199-212.

Kim, S.-Y. & Kim, Y. 2017. Comparison of impact pressure on 2D and 3D tanks under harmonic excitation. In *Proc. 27th Int. Offshore and Polar Engineering Conference ISOPE, San Francisco, USA.*

Kim, S.-Y., Kim, Y. & Lee, J. 2017b. Comparison of sloshing-induced pressure in different scale tank. *Ships and Offshore Structures* 12(2), 244-261.

Kim, S.-Y., Lee, J. & Kim, Y. 2016. Study on scale effects on 3D sloshing flows. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Kim, Y. & Hermansky, G. 2014. Uncertainties in seakeeping analysis and related loads and response procedures. *Ocean Engineering* 86, 68-81.

Kim, Y., Lee, J.K. & Kim, J. 2017c. Experimental observation on the effects of liquid temperature and bubbles on impact pressure inside gas pocket. *International Journal of Offshore and Polar Engineering* 27(1).

Kim, Y., Ahn, I.G. & Park, S.G. 2015e. On the second order effect of the springing response of large blunt ship. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Kim, Y., Kim, J. & Kim, Y. 2015f. Development of a high-fidelity procedure for the numerical analysis of ship structural hydroelasticity. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Kim, Y. & Kim, J.H. 2016. Benchmark study on motions and loads of a 6750-TEU containership. *Ocean Engineering* 119, 262–273.

Kim, Y.G., Hwang, S.J., Cho, K.H. & Kim, U.K. 2017d. Characteristics of propulsion shafting system in ships with engine acceleration problems in the barred speed range. *Ocean Engineering* 145, 479-491.

Kimmoun, O., Brosset, L. & Dupont, G. 2016. Experimental study of wave impacts on a corrugated ceiling. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Knutsen, K.E., Lag, S., Brathhagen, S., Stang, J. & Myrseth, P. 2017. *Data quality assessment for sensor systems and time-series data*. DNVGL report no. 2017-0058, rev. 101, dated 9th February 2017.

Koh, C.-G., Luo, M., Bai, W. & Gao, M. 2015. Simulation of wave impact with compressible air entertainment based on consistent particle method. In *Proc. 34th International Conference on Ocean, Offshore and Arctic Engineering OMAE, St John's, Canada.*

Komissarov, P.V., Borisov, A.A., Sokolov, G.N. & Lavrov, V.V. 2015. Experimental comparison of shock and bubble heave energies from underwater explosion of ideal HE and explosive composite mixtures highly enriched with aluminum. *Physics Procedia* 72, 333 – 337.

Korobkin, A.A., Khabakhpasheva, T.I. & Malenica, S. 2017. Maximum stress of stiff elastic plate in uniform flow and due to jet impact (Jet impact onto a clamped elastic plate). *Physics of Fluids* 29(7).

KR 2017. *Guidance on strength assessment of containerships considering the whipping effect*. GC-19-E. 2017. Korean Register of Shipping.

Lakshmynarayanana, P., Temarel, P. & Chen, Z.-M. 2015. Coupled fluid structure interaction to model three-dimensional dynamic behaviour of ship in waves. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Lavroff, J., Davis, M.R., Holloway, D.S., Thomas, G.A. & McVicar, J.J. 2017. Wave impact loads on wave-piercing catamarans. *Ocean Engineering* 131, 263-271.

Lee, C.-H., Kim, S.-H. & Jeon, J.-H. 2015a. A study on structure-borne noise isolation by using AVM for offshore accommodation. In *Proc. 44th International Congress and Exposition on Noise Control Engineering INTER-NOISE, San Francisco, USA.*

Lee, D.-J., Shin, S.-B. & Suhr, J. 2015b. Effect of material behavior of PUF on dynamic response induced by fluid structure interaction in membrane type LNG cargo containment system. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

Lee, J.H., Lee, K.J., Kim, J.H. & Kim, B.K. 2015c. Sea-trial verification of air-filled rubber membrane for mitigation of propeller cavitation induced hull excitation. *Ocean Engineering* 110, 314-324.

Lee, Y., White, N., Southall, N. & Johnson, M.C. 2015d. Impact loads and whipping responses on a large container ship. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

Leontopoulos, C. 2006. *Shaft alignment and powertrain vibration*. American Bureau of Shipping.

Letton, W., Pappas, J.M. & Shen, J. 2015. More improvements to deepwater subsea measurement - Overview. In *Proc. Offshore Technology Conference OTC, Houston, USA.*

Li, F., Cao, J., Duan, M., An, C. & Su, J. 2016a. Two-phase flow induced vibration of subsea span pipeline. In *Proc. 26th International Ocean and Polar Engineering Conference, Rhodes, Greece.*

Li, H., Wang, D., Zhou, C.M., Zhang, K. & Ren, H. 2016b. Springing responses analysis and segmented model testing on a 500,000 DWT ore carrier. In *Proc. 35th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Busan, Korea.*

Li, H., Zhang, P., Song, G., Patil, D. & Mo, Y. 2015. Robustness study of the pounding tuned mass damper for vibration control of subsea jumpers. *Smart Materials and Structures* 24(9).

Li, J., Wu, C., Hao, H., Su, Y. & Liu, Z. 2016c. Blast resistance of concrete slab reinforced with high performance fiber material. *Journal of Structural Integrity and Maintenance* 1(2), 51-59.

Li, Y., He, L., Shuai, C.G. & Wang, C.Y. 2017. Improved hybrid isolator with maglev actuator integrated in air spring for active-passive isolation of ship machinery vibrations. *Journal of Sound and Vibration* 407, 226-239.

Liao, K., Duan, W., Ma, Q.-W., Ma, S., Zhao, B. & Hu, C. 2017. Numerical analysis of wave impact loads on semi-submersible platform. In *Proc. 36th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Trondheim, Norway.*

Liao, K., Hu, C. & Sueyoshi, M. 2015. Free surface flow impacting on an elastic structure: Experiment versus numerical simulation. *Applied Ocean Research* 50, 192-208.

Lind, S.J., Stansby, P.K., Rogers, B.D. & Lloyd, P.M. 2015. Numerical predictions of water air wave slam using incompressible-compressible smoothed particle hydrodynamics. *Applied Ocean research* 49, 57-71.

Liu, C., Zhang, Y.X. & Ye, L. 2017a. High velocity impact responses of sandwich panels with metal fibre laminate skins and aluminium foam core. *International Journal of Impact Engineering* 100, 139-153.

Liu, H., Chen, G., Lyu, T., Lin, H., Zhu, B. & Huang, A. 2016a. Wind-induced response of large offshore oil platform. *Petroleum Exploration and Development* 43(4), 708-716.

Liu, K., Liang, H. & Ou, J. 2016b. Numerical investigation of a tuned heave plate energy-harvesting system of a semi-submersible platform. *Energies* 9 (82), 1–22.

Liu, Y., Li, H., Zhang, K., Deng, B. & Peng, Y. 2017b. Analysis of the coupled horizontal and torsional loads of an ultra large containership. In *Proc. 27th Int. Offshore and Polar Engineering Conference ISOPE, San Francisco, USA.*

Lotfollahi-Yaghin, M.A., Ahmadi, H. & Tafakhor, H. 2016. Seismic responses of an offshore jacket-type platform incorporated with tuned liquid dampers. *Advances in Structural Engineering* 19(2), 227–38.

LR 2017a. *Rules and regulations for classification of ships*. Part 3 Chapter 16 Section 6 Ship event analysis. Lloyd's Register.

LR 2017b. *Rules and regulations for classification of ships: Container ships*. Lloyd's Register.

LR 2008. *Provisional rules, classification of ship event analysis systems. A guide to the rules and published requirements*. Lloyd's Register.

Lu, Y.J., Liang, C., Manzano-Ruiz, J.J., Janardhanan, K. & Perng, Y.-Y. 2016. Flow-induced vibration in subsea jumper subject to downstream slug and ocean current. *Journal of Offshore Mechanics and Arctic Engineering* 138, Article Number: 021302.

Lyu, W., el Moctar, O., Potthoff, R. & Neugebauer, J. 2017. Experimental and numerical investigation of sloshing using different free surface capturing methods. *Applied Ocean research* 68, 307-324.

MAIB 2008. *Report on the investigation of the structural failure of MSC Napoli English Channel on 18 January 2007*. Report No. 9/2008 A, Marine Accident Investigation Branch, Carlton House, Carlton Place, Southampton, UK.

Magoga, T., Aksu, S., Cannon, S., Ojeda, R. & Thomas, G. 2016. Comparison between fatigue life values calculated using standardised and measured stress spectra of a naval high speed light craft. In *Proc. 13th Int. Symp. on Practical Design of Ships and Other Floating Structures PRADS, Copenhagen, Denmark.*

Mai, T., Hu, Z.Z., Greaves, D.M. & Raby, A. 2015. Investigation of hydroelasticity: Wave impact on a truncated vertical wall. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

Makaya, K.R., Varelis, G.E. & Roff, A.G. 2016. Condition health monitoring of monopile and transition piece using guided wave testing. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Male, P. van der & Lourens, E. 2015. Operational vibration-based response estimation for offshore wind lattice structures. *Structural Health Monitoring and Damage Detection 7*.

Malenica, S. & Derbanne, Q. 2014. Hydro-structural issues in the design of ultra large container ships. *International Journal of Naval Architecture and Ocean Engineering* 6(4), 983-999.

Malenica, S., Diebold, L., Kwon, S.H. & Cho, D.-S. 2017. Sloshing assessment of the LNG floating units with membrane type containment system. Where we are? *Marine Structures* 56, 99-116.

Malenica, S., Vladimir, N., Choi, Y.M., Senjanovic, I. & Kwon, S.H. 2015. Global hydroelastic model for liquid cargo ships. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Mao, D., Zhong, C., Zhang, L. & Chu, G. 2015a. Dynamic response of offshore jacket platform including foundation degradation under cyclic loadings. *Ocean Engineering* 100, 35–45.

Mao, W., Li, Z., Ogeman, V. & Ringsberg, J.W. 2015b. A regression and beam theory based approach for fatigue assessment of containership structures including bending and torsion contributions. *Marine Structures* 41, 244-266.

Matsui, S., Murakami, C., Hanaoka, A. & Oka, M. 2016. Some considerations on the computational code for longitudinal strength design of a ship taking account of slamming and whipping loads. In *Proc. 31st Technical Exchange and Advisory Meeting on Marine Structures TEAM, Osaka, Japan.*

May, A., McMillan, D. & Thöns, S. 2015. Integrating structural health and condition monitoring: a cost benefit analysis for offshore wind energy. In *Proc. 34th International Conference on Ocean, Offshore and Arctic Engineering OMAE, St. John's, Newfoundland, Canada.*

Meng, S., Kajiwara, H. & Zhang, W. 2017. Internal flow effect on the cross-flow vortex-induced vibration of a cantilevered pipe discharging fluid. *Ocean Engineering*, 137, 120-128.

Minnebo, J., Aalberts, P.J. & Duggal, A. 2014. Deepwater mooring system monitoring with DGPS. In *Proc. 33rd Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, San Francisco, California, USA.*

Moe, E., Holtsmark, G. & Storhaug, G. 2005. Full scale measurements of the wave induced hull girder vibrations of an ore carrier trading in the North Atlantic. In: *Transactions of Royal Institution of Naval Architects, conference on design and operation of bulk carriers, London, UK.*

Mokrani, C. & Abadie, S. 2016. Conditions for peak pressure stability in VOF simulations of dam break flow impact. *Journal of Fluid and Structures* 62, 86-103.

Monteiro, L.L.S., Netto, T.A. & Monteiro, P.C.C. 2016. On the dynamic collapse of cylindrical shells under impulsive pressure loadings. *Journal of Offshore Mechanics and Arctic Engineering* 138(4).

Murphy, E. 2014. An assessment of residential exposure to environmental noise at a shipping port. *Environmental International* 63, 207-215.

Naess, A. & Gaidai, O. 2009. Estimation of extreme values from sampled time series. *Structural Safety* 31, 325-334.

Neugebauer, J., Liu, S., Potthoff, R. & el Moctar, O. 2017. Investigation of the motion accuracy influence on sloshing model test results. In *Proc. 27th Int. Offshore and Polar Engineering Conference ISOPE, San Francisco, USA.*

Nie, B.-C., Li, J.-C. & Zhang, H.-Q. 2015. On the regimes of underwater explosion for a submerged slender structure by pulsating bubble. *Marine Structures* 44, 85-100.

NK 2017a. *Rules for hull monitoring systems*. Nippon Kaiji Kyokai.

NK 2017b. *Rules for the survey and construction of steel ships*. Nippon Kaiji Kyokai.

NK 2016. Press release 6th May 2016. ShipDC launches with new leader at the helm. https://www.classnk.or.jp/hp/en/hp_news.aspx?id=1906&type=press_release&layout=3

NK 2015. Press release 7th December 2015. ClassNK establishes Ship Data Center to accelerate Big Date use in the maritime industry.
https://www.classnk.or.jp/hp/en/hp_news.aspx?id=1759&type=press_release&layout=1.

NORSOK 2017. *Actions and action effects.* NORSOK standard N-003:2017, ICS 75.180.10, www.standard.no.

Nourisola, H., Ahmadi, B. & Tavakoli, S. 2015. Delayed adaptive output feedback sliding mode control for offshore platforms subject to nonlinear wave-induced force. *Ocean Engineering* 104, 1–9.

Nyseth, H. 2016. *Full scale measurements of ice-going vessels. Review of best practice for structural monitoring of ice-going vessels.* DNVGL report no. 2016-1197.

Oberhagemann, J. 2016. *On prediction of wave-induced loads and vibration of ship structures with finite volume fluid dynamic methods*. PhD Thesis, University of Duisburg-Essen, Germany.

Oberhagemann, J., Shigunov, V., Radon, M., Mumm, H. & Won, S.-I. 2015. Hydrodynamic load analysis and ultimate strength check of an 18000 TEU containership. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Olmati, P., Trasborg, P., Naito, C. & Bontempi, F. 2015. Blast resistant design of precast reinforced concrete walls for strategic infrastructures under uncertainty. *International Journal of Critical Infrastructures* 11(3), 197-212.

Orlowitz, E. & Brandt, A. 2014. Operational modal analysis for dynamic characterization of a Ro-Lo ship. *Journal of Ship Research* 58(4), 1-9.

Ortega, A., Rivera, A. & Larsen, C.M. 2017. Slug flow and waves induced motions in flexible riser. *J. Offshore Mech. Arct. Eng 140(1).*

Pais, T., Moro, L., Boote, D. & Biot, M. 2017. Vibration analysis for the comfort assessment of superyachts. *Journal of Marine Science and Application, 16, 323–333.*

Panciroli, R. & Porfiri, M. 2015. Analysis of hydroelastic slamming through particle image velocimetry. *Journal of Sound and Vibration* 347, 63-78.

Papanikolaou, A., Mohammed, E.A. & Hirdaris, S.E. 2014. Stochastic uncertainty modelling for ship design loads and operational guidance. *Ocean Engineering* 86, 47–57.

Peschmann, J., Storhaug, G., Derbanne, Q., Xie, G., Zheng, G., Ishibashi, K. & Kim, J. 2016. Impact study on the new IACS longitudinal strength standard for containerships (URS11A). In *Proc. 13th Int. Symp. on Practical Design of Ships and Other Floating Structures PRADS, Copenhagen, Denmark.*

Pickerd, V., Bornstein, H., McCarthy, P. & Buckland, M. 2016. Analysis of the structural response and failure of containers subjected to internal blast loading. *International Journal of Impact Engineering* 95, 40-53.

Postnikov, A., Pavlovskaia, E. & Wiercigroch, M. 2017. 2DOF CFD calibrated wake oscillator model to investigate vortex-induced vibrations. *International Journal of Mechanical Sciences*, 127, 176–190.

Qiu, W., Junior, J.S., Lee, D., Lie, H., Magarovskii, V., Mikami, T., Rousset, J.-M., Sphaier, S., Tao, L. & Wang, X. 2014. Uncertainties related to predictions of loads and responses for ocean and offshore structures. *Ocean Engineering* 86, 58-67.

Qu, Y., Su, J., Hua, H. & Meng, G. 2017. Structural vibration and acoustic radiation of coupled propeller-shafting and submarine hull system due to propeller forces. *Journal of Sound and Vibration* 401, 76-93.

Rajendran, S., Fonseca, N. & Soares, C.G. 2016. A numerical investigation of the flexible vertical response of an ultra large containership in high seas compared with experiments. *Ocean Engineering* 122, 293-310.

Ramos Jr., R., Oliveira Jr., S., Filho, E.C. & Silva, L.C.T. 2016. Evaluation of transversal displacement of the rotor of a twin-screw multiphase pump. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Ren, H., Zhang, K., Li, H. & Wang, D. 2016. Large containerships fatigue analysis due to springing and whipping. In *Proc. 35th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Busan,* Korea.

Ringsberg, J.W., Liljegren, A. & Lindhal, O. 2016. Sloshing impact response in LNG membrane carriers: a response analysis of the hull structure supporting the membrane tanks. In *Proc. 35th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Busan, Korea.*

Robert, M., Monroy, C., Reliquet, G., Ducoin, A., Guillerm, P. & Ferrant, P. 2015. Hydroelastic response of a flexible barge investigated with a viscous flow solver. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Robertson, A. 2017. Uncertainty analysis of OC5-DeepCwind floating semisubmersible offshore wind test campaign. In *Proc. 27th Int. Offshore and Polar Engineering Conference ISOPE, San Francisco, USA.*

Robinson, S., Lepper, P. & Hazelwood, R. 2014. *Good practice guide for underwater noise measurement*. National Measurement Office, Marine Scotland, The Crown Estate, Robinson, NPL Good Practice Guide No. 133, ISSN: 1368-6550.

Ruhnau, M., Heitmann, K., Lippert, T., Lippert, S. & von Estorff, O. 2016. Understanding soil transmission paths of offshore pile driving noise - Seismic waves and their implications. In *Proc. INTER-NOISE and NOISE-CON Congress and Conference, Hamburg, Germany.*

Sadat-Hosseini, H., Kim, D.H., Toxopeus, S., Diez, M. & Stern, F. 2015. CFD and potential flow simulations of fully appended free running 5415M in irregular waves, In *Proc. 15th World Maritime Technology Conference, Providence, Rhode Island, USA.*

Salvado, F.C., Tavares, A.J., Teixeira-Dias, F. & Cardoso, J.B. 2017. Confined explosions: The effect of compartment geometry. *Journal of Loss Prevention in the Process Industries* 48, 126-144.

Scavuzzo, R.J., Hill, G.D. & Saxe, P. 2015. The “spectrum dip”: Dynamic interaction of system components. *J. Pressure Vessel Technol.* 137(4).

Schecklman, S., Laws, N., Zurk, L.M. & Siderius, M. 2015. A computational method to predict and study underwater noise due to pile driving. *Journal of the Acoustical Society of America* 138(1), 258-266.

Schiffer, A. & Tagarielli, V.L. 2015. The response of circular composite plates to underwater blast: Experiments and modeling. *Journal of Fluids and Structures* 52, 130–144.

Scolan, Y.-M. & Brosset, L. 2017. Numerical simulation of highly nonlinear sloshing in a tank due to forced motion. *International Journal of Offshore and Polar Engineering* 27(1).

Scolan, Y.-M., Hay, A. & Brosset L. 2016. Some aspects of high kinematics in breaking waves due to sloshing. *IWWWFB, Plymouth, USA.*

Seng, S., Jensen, J.J. & Malenica, S. 2014. Global hydroelastic model for springing and whipping based on a free-surface CFD code (OpenFOAM). *International Journal of Naval Architecture and Ocean Engineering* 6(4), 1024-1040.

Senjanovic, I., Vladimir, N., Tomic, M., Hadzic, N. & Malenica, S. 2014. Global hydroelastic analysis of ultra large container ships by improved beam structural model. *International Journal of Naval Architecture and Ocean Engineering* 6(4), 1041-1063.

Shan, P., Wu, J. & Cai, S. 2017. Study of 18000 TEU container vessel's fatigue strength under influences of springing phenomenon. In *Proc. 27th Int. Offshore and Polar Engineering Conference ISOPE, San Francisco, USA.*

Sheinberg, R., Cleary, C., Stambaugh, K. & Storhaug, G. 2011. Investigation of wave impact and whipping response on the fatigue life and ultimate strength of a semi-displacement patrol boat. In *Proc. 11th Int. Conf. on Fast Sea Transportation FAST, Honolulu, Hawaii, USA*.

Shi, J., Zhu, Y., Chen, G., Zhang, R. & Guo, Z. 2017. Assessment on blast loading resistance capacity of corrugations on offshore cabins based on the P–I model. *Process Safety and Environmental Protection* 105, 237–249.

Shi, X.H., Teixeira, A.P., Zhang, J. & Soares, C.G. 2016. Reliability analysis of a ship hull structure under combined loads including slamming loading. *Ships and Offshore Structures, 11, 300–15.*

SILENV 2012. Deliverable 5.2 noise and vibration label proposal. *SILENV - Ships oriented Innovative soLutions to rEduce Noise and Vibrations (N&V), Collaborative project funded by the European Commission under the 7th Framework Program, Theme Transport - Grant Agreement N° 234182, available: http://www.silenv.eu/.*

Sohn, J., Kim, S., Seo, J., Kim, B. & Paik, J. 2016. Strength assessment of stiffened blast walls in offshore installations under explosions. *Ships and Offshore Structures* 11(5), 551-560.

Southall, N., Lee, Y., Johnson, M.C., Lin, F. & White, N. 2016. Coupling CFD with a time-domain ship motions method for prediction of slamming. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Stenard, J.K., Hlavaty, M. & Paulic, A. 2017. The case for a universal adjustable shock mount (UASM). *Naval Engineers Journal* 129(2), 123-126.

Storhaug, G. 2015. The consequence of whipping and springing in fatigue loading of container ships. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Storhaug, G. 2014a. The measured contribution of whipping and springing on the fatigue and extreme loading of container vessels. *International Journal of Naval Architecture and Ocean Engineering* 6(4), 1096-1110.

Storhaug, G. 2014b. Which sea states are dimensioning for container vessels when whipping is included? In *Proc. 33rd Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, San Francisco, California, USA.*

Storhaug, G., Aagaard, O. & Fredriksen, O. 2016. Calibration of hull monitoring strain sensors in deck including the effect of hydroelasticity. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Storhaug, G. & Andersen, I.M.V. 2015. Extrapolation of model tests measurements of whipping to identify the dimensioning sea states for container ships. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

Storhaug, G., Fredriksen, O., Greening, D. & Robinson, D. 2017a. Practical verification of loading computer by laser measurements. In *Proc. 6th International conference on marine structures MARSTRUCT, Lisbon, Portugal.*

Storhaug, G. & Kahl, A. 2016. Hull monitoring closing the gap between the design and operation. In *Proc. 6th Int. Maritime Conference on Design for Safety*, *Hamburg, Germany.*

Storhaug, G. & Kahl, A. 2015. Full scale measurements of torsional vibrations on Post-Panamax container ships. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Storhaug, G., Laanemets, K., Ringsberg, J. & Edin, I. 2017b. Estimation of damping from wave induced vibrations in ships. In *Proc. 6th Int. Conf. on Marine Structures MARSTRUCT, Lisbon, Portugal.*

Sun, L., Lu, Y. & Zhang, X. 2016. A review on damage identification and structural health monitoring for offshore platform. In *Proc. 35th International Conference on Ocean, Offshore and Arctic Engineering, OMAE, Busan, South Korea.*

Takahashi, H. & Yasuzawa, Y. 2014. Investigation on damping model for vibration response analysis using whole ship model. In *Proc. 24th International Ocean and Polar Engineering Conference ISOPE, Busan, Korea.*

Takami, T., Oka, M. & Iijima, K. 2017. Study on application of CFD and FEM coupling method to evaluate dynamic response of ship under severe wave condition. In *Proc. 36th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Trondheim, Norway.*

Taskar, B., Steen, S. & Eriksson, J. 2017. Effect of waves on cavitation and pressure pulses of a tanker with twin podded propulsion. *Applied Ocean Research* 65, 206-218.

Taskar, B., Yum, K.K., Steen, S. & Pedersen, E. 2016. The effect of waves on engine-propeller dynamics and propulsion performances of ships. *Ocean Engineering* 65, 262-277.

Tegowski, J., Koza, R., Pawliczka, I., Skóra, K., Trzcińska, K. & Zdroik, J. 2016. Statistical, spectral and wavelet features of the ambient noise detected in the southern Baltic sea. In *Proc. 23rd International Congress on Sound and Vibration ICSV, Athens, Greece.*

Tenzer, M., el Moctar, O. & Schellin, T.E. 2015. Experimental investigation of impact loads during water entry. *Ship Technology Research* 62, 47-59.

Thompson, I. 2016. Validation of naval vessel spectral fatigue analysis using full scale measurements. *Marine Structures* 49, 256-268.

Thorsen, M., Sævik, S. & Larsen, C. 2017. Non-linear time domain analysis of cross-flow vortex-induced vibrations. *Marine Structures* 51, 134–151.

Thorsen, M., Sævik, S. & Larsen, C. 2016. Time domain simulation of vortex-induced vibrations in stationary and oscillating flows. *Journal of Fluids and Structures* 61, 1–19.

Thorsen, M.J., Sævik, S. & Larsen, C.M. 2015. Fatigue damage from time domain simulation of combined in-line and cross-flow vortex-induced vibrations. *Marine Structures* 41, 200–222.

Thorsen, M., Sævik, S. & Larsen, C. 2014. A simplified method for time domain simulation of cross-flow vortex-induced vibrations. *Journal of Fluids and Structures* 49, 135–148.

Tiancheng, M., Wang, H., Zhou, J. & Wu, D. 2017. Noise analysis and control scheme of underwater exhaust process. In *Proc. 24th International Congress on Sound and Vibration ICSV, London, UK.*

Tsouvalas, A. & Metrikine, A.V. 2016. Parametric study of noise reduction by an air-bubble curtain in offshore pile driving. In *Proc. 23rd International Congress on Sound and Vibration ICSV, Athens, Greece.*

Ulveseter, J.V., Thorsen, M.J., Sævik, S. & Larsen, C.M. 2017. Stochastic modelling of cross-flow vortex-induced vibrations. *Marine Structures* 56, 260-280.

Utsunomiya, T., Sato, I., Kobayashi, O., Shiraishi, T. & Harada, T. 2017. Numerical modelling and analysis of a hybrid-spar floating wind turbine. In *Proc. 36th Conference on Ocean, Offshore and Arctic Engineering OMAE, Trondheim, Norway.*

Utsunomiya, T., Sato, I., Kobayashi, O., Shiraishi, T. & Harada, T. 2015. Design and installation of a hybrid-spar floating wind turbine platform. In *Proc. 34th Conference on Ocean, Offshore and Arctic Engineering OMAE,* Newfoundland, Canada.

Veldman, A.E.P., Luppes, R., van der Heiden, H.J.L., van der Plas, P., Helder, J. & Bunnik, T. 2015. Turbulence modeling for locally-refined free-surface flow simulations in offshore applications. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

Veracity 2016. https://www.dnvgl.com/data-platform.

Wang, X., Temarel, P., Hu, J. & Gu, X. 2016a. Hydroelastic analysis of an ULOC in waves. In *Proc. 13th Int. Symp. on Practical Design of Ships and Other Floating Structures PRADS, Copenhagen, Denmark.*

Wang, G., Wang, Y., Lu, W., Zhou, W., Chen, M. & Yan, P. 2016b. On the determination of the mesh size for numerical simulations of shock wave propagation in near field underwater explosion. *Applied Ocean Research* 59, 1–9.

Wang, H., Cheng, Y.S., Liu, J. & Gan, L. 2016c. Damage evaluation of a simplified hull girder subjected to underwater explosion load: A semi-analytical model. *Marine Structures* 45, 43-62.

Wang, J., Guo, J., Yao, X.L. & Zhang, A.M. 2016d. Dynamic buckling of stiffened plates subjected to explosion impact loads. *Shock Waves* 27(1), 37-52.

Wang, J., Fu, S., Baarholm, R., Wu, J. & Larsen, C.M. 2015. Out-of-plane vortex induced vibration of a steel catenary riser caused by vessel motions. *Ocean Engineering* 109, 389-400.

Wang, J., Fu, S., Baarholm, R., Wu, J. & Larsen, C.M. 2014. Fatigue damage of a steel catenary riser from vortex-induced vibration caused by vessel motions. *Marine Structures* 39, 131-156.

Wang, J., Wan, D., Chen, G. & Huang, W. 2016e. Comparative studies of 3-D LNG tank sloshing based on the VOF and IMPS methods. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Wang, L.-K., Zhang, Z.-F. & Wang, S.-P. 2016f. Pressure characteristics of bubble collapse near a rigid wall incompressible fluid. *Applied Ocean Research* 59, 183–192.

Wang, S. & Lu, P. 2016. On the monitoring of mooring system performance. In *Proc.* 21*st SNAME Offshore Symposium, Houston, USA.*

Wei, Z.-J., Wu, C.-J. & Guan, H. 2016. Experimental investigation of kinematic flow field in the geometric similar GTT tanks. In *Proc. 35th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Busan, Korea.*

WHO 2011. *Burden of disease from environmental noise*. World Health Organization.

Wisch, D. & Spong, R. 2016. Recommended practice for structural integrity management of floating offshore structures – A DeepStar 12401 product. In *Proc. Offshore Technology Conference, Houston OTC, Houston, USA.*

Wochner, M.S., Lee, K.M., McNeese, A.R. & Wilson, P.S. 2015. Underwater noise mitigation using a system of tuneable resonators. In *Proc. 22nd International Congress on Sound and Vibration ICSV, Florence, Italy.*

Wu, M.K. 2015. Fatigue analysis for a high-speed vessel with hydroelastic effects. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Wu, J., Lie, H., Constantinides, Y. & Baarholm, R.J. 2016a. NDP riser VIV model test with staggered buoyancy elements. In *Proc. 35th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Busan, Korea.*

Wu, Q., Zhao, X., Zheng, R. & Minagawa, K. 2016b. High response performance of a tuned-mass damper for vibration suppression of offshore platform under earthquake loads. *Shock and Vibration* 2016, Article ID 7383679.

Wu, Y.S., Chen, R.Z. & Lin, J.R. 2003. Experimental technique of hydroelastic ship model. In *Proc. 3rd Int. Conf. on Hydroelasticity in Marine Technology, Oxford, UK.*

Xiao, F., Chen, Y., Hua, H. & Zhu, D. 2015. Experimental and numerical investigation on the shock resistance of honeycomb rubber coatings subjected to underwater explosion. *Proceedings of the Institution of Mechanical Engineers, Part M: J. Engineering for the Maritime Environment* 229(1), 77–94.

Xue, Q., Zhang, J., He, J. & Zhang, C. 2016. Control performance and robustness of pounding tuned mass damper for vibration reduction in SDOF structure. *Shock and Vibration* 2016.

Yang, K.K., Kim, J., Kim, Y., Kim, S.Y. & Zhu, Z. 2016a. PIV measurement of violent sloshing flows and comparison with CFD computations. *International Journal of Offshore and Polar Engineering* 26(3).

Yang, L., Nie, S., Yin, S., Zhao, J. & Yin, F. 2015a. Numerical and experimental investigation on torque characteristics of seawater hydraulic axial piston motor for underwater tool system. *Ocean Engineering* 104, 168-184.

Yang, P., Gu, X., Tian, C., & Ding, J. 2015b. 3D hydroelastic response of a large bulk carrier in time domain. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Yang, W., Li, L., Fu, Q., Teng, Y., Wang, S. & Liu, F. 2016b. Identify modal parameters of a real offshore platform from the response excited by natural ice loading. In *Proc. 35th International Conference on Ocean, Offshore and Arctic Engineering OMAE, Busan, Korea.*

Yao, S., Zhang, D., Lu, F., Chen, X. & Zhao, P. 2017a. A combined experimental and numerical investigation on the scaling laws for steel box structures subjected to internal blast loading. *International Journal of Impact Engineering* 102, 36-46.

Yao, S., Zhang, D., Lu, F. & Li, X. 2017b. Experimental and numerical studies on the failure modes of steel cabin structure subjected to internal blast loading. *International Journal of Impact Engineering* 110, 279-287.

Yao, S., Zhang, D. & Lu, F. 2016. Dimensionless number for dynamic response analysis of box-shaped structures under internal blast loading. *International Journal of Impact Engineering* 98, 13-18.

Yin, D., Lie, H. & Baarholm, R.J. 2017. Prototype Reynolds number VIV tests on a full-scale rigid riser. In *Proc. 36th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Trondheim, Norway.*

Yin, D., Lie, H., Russo, M. & Grytøyr, G. 2016. Drilling riser model tests for software verification. In *Proc. 35th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE, Busan, Korea.*

Zekri, H.J., Korobkin, A.A. & Cooker, M.J. 2015. Liquid sloshing and impact in a closed container with high filling. *IWWWFB, Bristol, UK.*

Zhang, B.L., Han, Q.L. & Zhang, X.M. 2017a. Recent advances in vibration control of offshore platforms. *Nonlinear Dynamics* 89, 755-771.

Zhang, C., Yue, J., Liu, Z. & He, Z. 2015. A VBM research based on segmented model tests and numerical simulations for a river-to-sea ship. In *Proc. 25th Int. Offshore and Polar Engineering Conference ISOPE, Hawaii, USA.*

Zhang, J., Shi, X.H. & Soares, C.G. 2017b. Experimental study on the response of multi-layered protective structure subjected to underwater contact explosions. *International Journal of Impact Engineering* 100, 23-34.

Zhang, J., Zhehao, M., Liu, F., Zhang, C., Sharafi, P. & Rashidi, M. 2017c. Seismic performance and ice-induced vibration control of offshore platform structures based on the ISO-PFD-SMA brace system. *Advances in Materials Science and Engineering* 2017.

Zhang, K., Ren, H., Li, H. & Yan, L. 2016a. Nonlinear hydroelasticity of large container ship. In *Proc. 26th Int. Offshore and Polar Engineering Conference ISOPE, Rhodes, Greece.*

Zhang, W. & Jiang, W. 2015. An improved shock factor to evaluate the shock environment of small-sized structures subjected to underwater explosion. *Shock and Vibration* 2015.

Zhang, Y., Chen, X. & Wan, D. 2017d. Sloshing flows in an elastic tank with high filling liquid by MPS-FEM coupled method. In *Proc. 27th Int. Offshore and Polar Engineering Conference ISOPE, San Francisco, USA.*

Zhang, Z., Sun, L., Yao, X. & Cao, X. 2015a Smoothed particle hydrodynamics simulation of the submarine structure subjected to a contact underwater explosion. *Combustion, Explosion, and Shock Waves* 51(4), 502–510.

Zhang, Z., Wang, L., Silberschmidt, V.V. & Wang, S. 2016c. SPH-FEM simulation of shaped-charge jet penetration into double hull: A comparison study for steel and SPS. *Composite Structures* 155, 135–144.

Zhang, Z., Wang, Y., Zhao, H., Qian, H. & Mou, J. 2015b. An experimental study on the dynamic response of a hull girder subjected to near field underwater explosion. *Marine Structures* 44, 43-60.

Zhu, G., Xiong, Y.P., Daley, S. & Shenoi, R.A. 2015. Magnetorheological elastomer materials and structures with vibration energy control for marine application. In *Proc. 5th International Conference on Marine Structures MARSTRUCT, Southampton, UK.*

Zhu, S. & Moan, T. 2015. Effect of heading angle on wave-induced vibrations and extreme vertical bending moments in a ultra large container ship model. In *Proc. 7th Int. Conf. on Hydroelasticity in Marine Technology, Split, Croatia.*

Zou, C.-F., Wang, D.-Y. & Cai, Z.-H. 2015a. Effects of boundary layer and liquid viscosity and compressible air on sloshing characteristics. *International Journal of Naval Architecture and Ocean Engineering* 7(4), 670-690.

Zou, D., Rao, Z. & Ta, N. 2015b. Coupled longitudinal-transverse dynamics of a marine propulsion shafting under super harmonic resonances. *Journal of Sound and Vibration* 346, 248-264.

Zuo, H., Bi, K. & Hao, H. 2017. Using multiple tuned mass dampers to control offshore wind turbine vibrations under multiple hazards. *Engineering Structures* 141, 303-315.