Specialist Committee on Modelling of Environmental Conditions

Final Report and Recommendations to the 29th ITTC

1. GENERAL

1.1 Membership and Meetings

The Specialist Committee on Modelling of Environmental Conditions appointed by the 29th International Towing Tank Conference consisted of the following members:

- Alessandro Iafrati, CNR-INM, Italy (Chairman)
- Toshifumi Fujiwara, NMRI, Japan
- Hyun Joe Kim, Samsung Heavy Industries, Korea
- Yuxiang Ma, Dalian University of Technology, China
- Jule Scharnke, MARIN, The Netherlands (Secretary)
- Prof. Solomon C. Yim, Oregan State University, USA
- Pedro Cardozo de Mello, University of Sao Paolo, Brazil
- Xinshu Zhang, Shanghai Jiao Tong University (SJTU)
- Marcin Drzewiecki, Ship Design and Research Centre (CTO S.A.)

Four Committee meetings were held respectively at:

- CNR-INSEAN, Rome, Italy, January 2018
- NMRI, Tokyo, Japan, January 2019
- OMAE, Glasgow, June 2019
- CTO S.A., Gdansk, Poland, January 2020

Additional short meetings were held in the form of web conferences.

1.2 Tasks based on the Recommendations of the 28th ITTC

1. Complete tasks originally assigned to the committee i.e. propose and develop guidelines for generation of waves, wind and current in model scale. Each guideline should address the following problems:

Waves:

- Non-linear effects – analysis, control
- Interactions with current and wind
- Distribution of extremes
- Wave grouping (characterization and reproduction)
- Short-crested wave modelling
- Deterministic generation of extreme waves
    - Confinement
    - Wave frequency and low frequency reflections
- Radiation and reflection from model, beach, etc.
- Measurement and analysis of long- and short-crested waves
- Non-stationary power spectrum (time and space)
- Wave breaking – influence on statistics and kinematics
- Geographical consistency of wave spectrum selection
- Investigate techniques for modelling those aspects of the extreme wave environment that are important in the determination of dynamic instability of intact vessels. Coordinate and exchange information with the Stability in Waves Committee on this task.

Wind:

- Interaction with waves
- Gusting (including squalls)
- Turbulence
- Vertical profiles
- Horizontal variation
- Measurements
- Geographical consistency of wind conditions

Current:

- Interaction with waves
- Turbulence

- Vertical profiles (including current reversal)
- Horizontal variation
- Measurements

2. Continue work of modelling extreme wave environment including design wave groups.
3. Continue work on breaking waves
    a. Breaking kinematics and typology
    b. Effects of breaking waves on spectral content
    c. Statistics of breaking occurrence and spectral shape
    d. Extreme wave generation and statistics
4. Investigate and review state-of-the-art of wind-wave interactions and the effects on wave breaking
5. Investigate and review state-of-the-art of wave-current interactions and the effects on the generation of extreme waves

1.3 Structure of the report

The work carried out by the committee is presented as follows:

Modelling of extreme wave environments

Breaking waves

State-of-the-art review of wind-wave interactions and the effects on the generation of extreme waves

State-of-the-art review of wave-current interactions and the effects on wave breaking

2. MODELLING OF EXTREME ENVIRONMENTS

In Bitner-Gregersen et al. (2019), a comparison of temporal and spatial statistics of non-linear waves is presented. In the past, it was most common to derive wave parameters and their statistics from time series of wave elevation. The duration of the wave records has been usually restricted to 20 or 30 minutes. Recently, increasing attention has started to be given to spatial wave data and wave statistics, particularly due to introduction in oceanography of stereo camera systems for collecting space–time ensemble of sea surface elevation. Using numerical linear, 2nd and 3rd order simulations this study compares temporal and spatial statistics of wave parameters. The 3rd order wave data are simulated by a numerical solver based on the Higher Order Spectral Method (HOSM) which includes the leading order nonlinear dynamical effects, accounting for the effect of modulational instability. The study demonstrates differences between the temporal and spatial statistics of wave parameters based on unidirectional numerical linear, 2nd order and HOSM simulations for the JONSWAP gamma parameter γ=1, 3.3 and 6. The maximum surface elevation, skewness and kurtosis are considered. It is shown that the higher order nonlinear wave field including dynamical effects is more sensitive to sampling variability than the 2nd order and linear ones. The dynamical effects have significant impact on the analysed parameters, particularly on η_{max}/H_s. The discrepancies between the estimators of the wave parameters derived from the HOSM simulations and the linear ones are much larger than the ones obtained from the 2nd order and linear simulations. The shape of a wave spectrum does not affect much skewness, being primarily a second order effect, but impacts kurtosis and the maximum surface elevation. Further, it is shown that, consistent with earlier findings, directionality reduces kurtosis significantly. The HOSM means over all random realizations of the same sea state of the temporal skewness and kurtosis estimators are approximately equal to the spatial ones. In contrast with it, as expected, the mean maximum temporal surface elevation is significantly lower than the spatial one, since the spatial calculation covers many more waves than the single point measurement. There is large spreading around the mean values due to sampling variability, being larger for the temporal data than the spatial data. This should be considered in design work and in forecasting of rogue waves.

Recently, some studies were performed for crossing sea states, for instance by Liu et al. (2019). Numerical simulations for crossing seas were performed and investigated on the occurrence of rogue waves using HOS. A number of non-collinear systems with different total wave steepness were investigated, and for each case, 10 repetitions with different random phases were performed. The temporal evolution of directional and omnidirectional wave spectra, wave crest distribution, as well as the kurtosis and skewness of free surface elevations were obtained and analysed. Their results show that the skewness and kurtosis are found to increases quickly from the initial Gaussian value within a small time scale and then stay rather stationary. The theoretical third-order crest distribution tends to underestimate the probability of extreme crest height for the crossing sea states with large wave steepness.

An experimental study was reported in Luxmoore et al. (2019). Their study shows that the third-order nonlinearity was more affected by varying the directional spreading of the components instead of the crossing angles between components. They also found that the kurtosis, which quantitatively describes the third-order nonlinearity, can be estimated from the directional spreading using an empirical relationship based on the two-dimensional Benjamin-Feir index (BFI2_d), proposed by Mori et al. (2011). More recently, Liu et al. (2020) derived a new coupled two dimensional Benjamin-Feir index (CBFI_2d) for crossing seas to quantify the third-order nonlinearity effects. Their results show very good agreement with experiments for a broad of wave spreading functions.

In Ross et al. (2019), a review of the current practice of the application of environmental contours is discussed. Environmental contours are used in structural reliability analysis of marine and coastal structures as an approximate means to locate the boundary of the distribution of environmental variables, and to identify environmental conditions giving rise to extreme structural loads and responses. There are different approaches to estimate environmental contours, some directly linked to methods of structural reliability. Each contouring approach has its pros and cons. Although procedures for applying contours in design have been reported in articles and standards, there is still ambiguity about detail, and the practitioner has considerable flexibility in applying contours. It is not always clear how to estimate environmental contours well. Over four years, DNV-GL, Shell, the University of Oslo and HR Wallingford worked together to review current practice regarding the use of design contours.

In Huang et al. (2018), a semi-empirical distribution for long-crested non-linear waves is proposed. In comparison with simulations as well as measurement data the proposed distribution function appears to give promising results. However, at this point wave breaking is not yet included in the semi-empirical distribution function, which may result in an over prediction of the highest crests for very steep sea states. Wave breaking can cause a reduction of the amplification of the extreme crest heights with respect to linear or 2nd order theory, as described in Buchner et al. (2011).

Liu et al. (2019) developed a Higher-order Spectral (HOS) model by combing with wave breaking model based on eddy-viscosity to study the extreme wave occurrence for long-crested random waves. They compared the numerical results with the measurements in wave basin and satisfactory agreement was found. In addition, they also developed a semi-empirical distribution based on extensive 3-hour simulations using HOS. The semi-empirical formula may be used to obtain criteria for wave calibration before model tests in a wave basin.

In Klein et al. (2019), the systematic experimental validation of high-order spectral method for deterministic wave prediction is presented. The aim is to identify and evaluate possible areas of application as well as limitations of use. For this purpose, irregular sea states with varying parameters such as wave steepness and underlying wave spectrum are addressed by numerical simulations and model tests in the controlled environment of a seakeeping basin. In addition, the influence of the propagation distance is discussed. For the evaluation of the accuracy of the HOSM prediction, the surface similarity parameter (SSP) is utilized, allowing a quantitative validation of the results. The results obtained are compared to linear wave prediction to discuss the pros and cons of a non-linear deterministic short-term wave prediction. In conclusion, this paper shows that the non-linear deterministic wave prediction based on HOSM leads to a substantial improvement of the prediction quality for moderate and steep irregular wave trains in terms of individual waves and prediction distance.

Fujimoto et al. (2018) developed a four-dimensional variational method (4DVAR) for wave reconstruction to study the generation of freak waves. The 4DVAR methods performs perturbed ensemble simulations to evaluate the gradient of the squared error and is easy to parallelize and implement. They also adopted HOS to predict the nonlinear wave evolution, which is essential for freak wave generation. They found that considering the nonlinearity in HOSM was crucial to estimate the freak wave accurately.

McAllister et al. (2019) performed physical tests in FloWave basin to recreate the Draupner wave with an equivalent surface elevation time series and demonstrate that a wave of the same and greater steepness than the Drauper wave can arise as a results of crossing seas at large angles (between 60 and 120 degrees). They also investigated the role of wave breaking.

In Essen (2019), the variability of encountered waves during deterministically repeated seakeeping tests at forward speed is discussed. In this paper a steep wave condition over the longitudinal basin axis (waveA) and a less steep oblique wave condition (waveB) were studied. Overall similarity as well as individual crest height, steepnesses and timing variability are discussed, because ship response is not equally sensitive for every point in the wave time series. It was concluded that the variability of the measured incoming wave crests and their timing increases with distance from the wave generator for waveA. The crest height variability for waveB is lower and more constant over the basin length (because the propagation distance to the model is constant in oblique waves and wave breaking is less likely). It was shown that only a small part of the variability close to the wave generator is caused by ‘input’ uncertainties such as the accuracy of the wave generator flap motions, measurement carriage position, their synchronisation and measurement accuracy. The rest of the variability is caused by wave and basin effects, such as wave breaking instabilities and small residual wave-induced currents from previous tests. The latter depend on previous wave conditions, which requires further study.

Kim et al. (2019) proposed a heuristic approach to develop an optimal grid system for a numerical wave tank by investigating the characteristics of the numerical waves propagating in various CFD-based NWT set-ups. Linear dispersion relations of the waves in a Cartesian grid system are derived analytically. The analytic results lead to an optimal grid aspect ratio for the best dispersion approximation. Extensions of the analytic approach to determine an optimal set up of the grid system of CFD-based NWT are discussed. A roadmap to develop CFD modelling practices based on these heuristic approaches and further numerical verification is proposed for the on-going industry efforts to develop the guidelines for numerical wave tanks, such as the Joint Industry Project on “Reproducible CFD Modeling Practices for Offshore Applications”, Koop et al. (2020).

Baquet et al. (2019) examined the effect of the non-Gaussian distribution in the fully-nonlinear wave on offshore platform responses. In this study, linear wave components with randomly distributed wave phases and fully nonlinear irregular waves using a potential numerical wave tank were used as input to the global performance analysis of two kinds of floating platforms. In the results, the response spectra, the probability distribution and the extreme responses of motions and air gaps are compared, and the way using nonlinear waves could give more realistic motion responses with less uncertainty in the airgap estimation.

Watanabe et al. (2019) developed a stereo camera system to reconstruct three-dimensional wave fields and assimilated into a phased resolved nonlinear wave model to construct a dynamically consistent wave field in a much wider domain. The newly developed scheme named as SWEAD was successfully used to reconstruct wave field. The scheme was tested for different tunable parameter values and model setting to improve the reproducibility of the reconstruction outside of the imaging domain. The SWEAD is not restricted to be used for the stereo imaging system and seems also suitable to analyze surface elevations from ship-borne radars.

Ducrozet et al. (2020) applied the time reversal (TR) methodology to reconstruct real-ocean rogue waves in a laboratory environment conditions. As the purpose to validate the method, three literature real wave recorded were used in experiments conducted in a wave flume. The waves selected for the experiments are known very steep and highly nonlinear, being challenging to be reproduced in controlled environmental conditions in a laboratory. The wave flume characteristics and wave breaking during propagation could be introducing changes to the wave shape. Aspects related to the selected position for the wave reproduction in the flume is also an issue investigated in the paper. It was reported that the TR method presented was robust to reproduce the selected waves with good quality for a unidirectional wave, also in comparison to other methods described in the literature.

Xie et al. (2019) analysed 1-year of wave data measured in the South China Sea at depth from 200m to 1500m. The results showed that JONSWAP spectrum is suitable in the South China Sea and the mean value of peak enhancement factor is about 2.15. The ratio between the maximum wave height and the significant wave height is about 1.7.

In Niu et al., 2020, an improved focusing method named the All Phase Correction Method (APCM) was developed to produce accurate extreme waves at a predefined position in wave flumes. An improved phase estimation algorithm and second-order wavemaker theory was employed to iteratively correct the phases and amplitudes of the generated waves. Compared with the self-correction method which was proposed by Fernández et al. (2014), a faster convergence rate and higher correlation coefficient were obtained utilizing the APCM.

Hidetaka et al. (2018) present a new wave generation method based on the higher order spectral method (HOSM) used to calculate the wave maker control signal. This method was validated for unidirectional spatially-periodic modulated wave trains. Moreover, freak waves were generated in unidirectional irregular waves and in directional irregular waves to obtain time series of the surface elevation, frequency spectra and spatial wave profiles. The measurements generated based on the higher order spectral method compared well with simulations based on the higher order spectral method.

Khait and Shemer (2019) suggest an alternative analytic method of determination of nonlinear correction to the wavemaker motion that allows definition of the target wave field in either Fourier or physical space. Rather than starting the derivation from the governing potential flow equations as in the theory by Schäffer, advantage is taken here of the existing nonlinear wave models supplemented by the nonlinear boundary condition at the wavemaker. Since the existing nonlinear water wave theories are accurate to the 3rd and higher orders, the present approach makes possible to circumvent the 2nd-order limitation of the Schäffer theory. This approach allows significant simplification of the procedure needed for determination of the nonlinear correction to the wavemaker driving signal, which is critical in many practical applications. Particular attention was given to significant deviation of the linear wavemaker transfer function obtained in the fully-nonlinear numerical simulations from the theoretical predictions. This deviation was observed in numerous experimental works. The existence of such a deviation in fully nonlinear simulations of potential flow indicates that viscous friction and possible leakages at the wavemaker that were suggested as a possible source for this effect can only play a minor role. The quadratic dependence on the wave steepness of the relative deviation of the transfer function from the linear predictions suggests that the mean current at the 2nd order that results from the nonlinear interaction of the velocity field of the propagating waves with the wavemaker surface oscillations of finite amplitude is a possible reason for this inaccuracy. A more careful investigation is needed to clarify the reasons for this behaviour of the transfer function.

3. BREAKING WAVES

3.1 Breaking kinematics and typology

In Duz et al. (2020) kinematics under spilling and plunging breakers are investigated using both experimental and numerical methods. In a modular laboratory flume, the breakers were generated using dispersive focusing, and the kinematics underneath them were measured utilizing the Particle Image Velocimetry (PIV) technique. Using the state-of-art high-speed video cameras, the kinematics were measured at a high sampling rate without needing phase-locked averaging. Afterwards, computational fluid dynamics (CFD) simulations were carried out for comparison purposes. These simulations were run in single-phase using a finite volume based Navier-Stokes solver with a piecewise-linear interface reconstruction scheme. The spilling and plunging breakers from the measurements were reconstructed in the computational domain using an iterative scheme. As a result a good match with the measured waves was obtained in the simulations. Results indicate that even though measured kinematics are somewhat higher than the simulated ones especially in the spilling and overturning regions, the CFD simulations can accurately capture the relevant details of the flow and produce reasonably accurate kinematics in comparison with the PIV results.

Comparisons between numerical simulation and experimental measurements of wave breaking flows are presented in Alberello et al. (2019). A two-fluid numerical model is used to simulate the multiphase flow. The flow field in the Navier-Stokes solver is initialized by using the HOSM solution computed shortly before the onset of the breaking and the flow is simulated up to the breaking. Experimental measurements are given in terms of the velocity field computed by particle image velocimetry and comparisons with numerical data are established. A rather satisfactory agreement between measurements and numerical data has been found, although some limits still exists very close to the crest where the numerical data seem to underestimate the measurement. This may be due some numerical limits, e.g. grid resolution or thickness of the interface, or to the use of slightly different initial conditions.

3.2 Effects of breaking waves on spectral content

In Huang et al. (2018), a reduction of energy in the high-frequency range of steep measured and simulated wave spectra in with respect to the target wave spectrum is discussed. As this reduction in energy only occurs for steep wave spectra, this may be related to wave breaking.

The changes operated by the occurrence of breaking are discussed in Iafrati et al. (2015) and in De Vita et al. (2018). In Iafrati et al. (2015), a JONSWAP spectrum is initialized and its evolution is followed by using a HOS method. Shortly before the breaking, the HOS solution is used to initialize a two-fluids Navier-Stokes solver which is used to simulate the flow beyond the breaking. By comparing the spectra provided by the HOS and Navier-Stokes results, it is possible to distinguish between the changes operated by the time evolution and those associated to the breaking process. Results clearly indicate that the breaking acts mostly on the higher harmonics.

In De Vita et al. (2018), a careful numerical study on the breaking induced by the modulational instability is presented. As already discussed in Tulin et al. (1999), results shows that the modulational instability causes a downshifting of the energy from the fundamental component to the lower sideband and the occurrence of breaking freezes the energy transfer

In Ewans et al. (2019) the identification of higher order interactions in wave time-series are described. Reliable design and reanalysis of coastal and offshore structures requires, amongst other things, characterisation of extreme crest elevation corresponding to long return periods, and of the evolution of a wave in space and time conditional on an extreme crest. Extreme crests typically correspond to focussed wave events enhanced by wave-wave interactions of different orders. Higher-order spectral analysis can be used to identify wave-wave interactions in time-series of water surface elevation. The bispectrum and its normalised form (the bicoherence) have been reported by numerous authors as a means to characterise three-wave interactions in laboratory, field and simulation experiments. The bispectrum corresponds to a frequency-domain representation of the third order cumulant of the time-series, and can be thought of as an extension of the power spectrum (itself the frequency-domain representation of the second order cumulant). The power spectrum and bispectrum can both be expressed in terms of the Fourier transforms of the original time-series. The frequency domain analysis therefore provides an efficient means of estimation. However, there are a number of important practical considerations to ensuring reasonable estimation. To detect four-wave interactions, the trispectrum and its normalised form (the tricoherence) needs to be considered. The trispectrum corresponds to a frequency-domain (Fourier) representation of the fourth-order cumulant of the time-series. In the paper it is concluded that the T-tricoherence provides the capability to detect phaselocked four wave interactions of the form $f_4=f_1+f_2+f_3$, that is where three waves interact to force a bound fourth component. However, the estimates of the T-tricoherence on nonlinear wave simulations, and measured laboratory and field (Draupner) records did not indicate significant four wave interactions of this type. While this result is expected for deep-water cases, larger T-tricoherence values for the HOS5 (Table 2) case, for which $k_P\, d \approx 1$ might have been expected. Estimates of V-tricoherence produce high values at frequency triplets that correspond to high harmonics. It is not possible to conclude whether these indicate the occurrence of actual four wave interactions of the type $f_1+f_2=f_3+f_4$, or whether they simply indicate combinations of independent pairs of Fourier components that happen to satisfy the frequency relationship. It is likely though that these four-wave interactions are present, in some of the sea states that were investigated. Alternative tricoherence estimators to differentiate between these two possibilities or to exclude contributions from trivial combinations in the moment estimates are currently being investigated.

In Dong et al. (2019), a new experimental study was presented in which large isolated focusing wave groups were generated in a special “X” configuration. By varying the initial wave steepness, wave groups ranging from near-linear to violent breaking were generated. Essentially, the experimental results suggested that the nonlinear energy transfer during wave-wave interactions is particularly sensitive to the directional spread. Similar to unidirectional laboratory data, nonlinear energy transfers between the first harmonic and second harmonic bands for the non-breaking case, while energy loss comes from the high-frequency components of the first harmonic band when breaking occurs. However, it is the directional interaction that dictates the severity of breaking, i.e. greater breaking occurs when the wave packets propagate with larger approach angle, and hence the energy loss increases generally with an increase of the approach angle.

3.3 Statistics of breaking occurrence and spectral shape

In Babanin (2009) a complete overview of the state-of-the-art knowledge on breaking of ocean surface waves including details regarding the definitions and onset of breaking and wave breaking probability and occurrence are presented. In the paper, variety of definitions related to the wave breaking are discussed and formulated, and methods for breaking detection and measurements are examined. Most of attention is dedicated to the research of wave-breaking probability and severity. Experimental, observational, numerical, analytical and statistical approaches and their outcomes are reviewed. Present state of the wave-breaking research and knowledge is analysed and main outstanding problems are outlined.

In Toffoli et al. (2010) the maximum steepness of oceanic waves is analyzed through filed and laboratory experiments. In this paper it is stated that intuitively, waves break when they become too steep. Unfortunately, a general consensus on the ultimate shape of waves has not been achieved yet due to the complexity of the breaking mechanism which still remains the least understood of all processes affecting waves. To estimate the limiting shape of ocean waves, here we present a statistical analysis of a large sample of individual wave steepness. Data were collected from measurements of the surface elevation in laboratory facilities and the open sea under a variety of sea state conditions. Observations reveal that waves are able to reach steeper profiles than the Stokes' limit for stationary waves. Due to the large number of records this finding is statistically robust.

4. STATE-OF-THE-ART REVIEW OF WIND-WAVE INTERACTIONS AND THE EFFECTS ON THE GENERATION OF EXTREME WAVES

4.1 CFD Modelling Practice for Wind Load Estimation

Wind load is an important parameter to be considered in the design of hull and mooring systems of offshore floating structures. The first step to minimize the uncertainties in wind load is generating an accurate wind profile that satisfies design requirements. Recently, there were some joint-industry effort to implement wind profiles accurately and develop a CFD modelling practice on wind-load estimation. In SNAME OC-8 CFD Task Force, Kim et al. (2018) and Kim et al. (2019), a modelling practice was developed and successfully validated for a semi-submersible topside with several independent participants. In a joint development project, TESK JDP by TechnipFMC, EURC, Samsung Heavy Industries and Korea Research Institute of Ships & Ocean Engineering (KRISO), the procedure was further verified for hulls with more complicated topsides, Yeon et al. (2019). As shown in Figure 1, sustainability, i.e. the capability of a wind profile at the inlet boundary in retaining its shape anywhere in the wind direction, was verified with an NPD (Norwegian Petroleum Directorate) profile in API (2005) and DNV (2014). The sustainable wind profile was applied to a semi-submersible and the calculated wind loads showed good agreement with model test data. Further an exhaustive study was conducted with an FPSO hull in order to determine uncertainties between CFD and model tests in the course of the TESK JDP, Xu et al. (2019). One of the findings was that the gap between FPSO bottom and turntable of the wind tunnel has some impact on the vertical force, roll and pitch moment. In the same study, the effect of the topside modules' porosity on wind loads was explored with several simplified models from original shape, Huang et al. (2020). In another joint development project which was initiated by TechnipFMC, Chevron, and

Samsung Heavy Industries, a sustainable atmospheric boundary layer was implemented and extended to ESDU (Engineering Science Data Unit) (1982,1983) as well as NPD profile. The NPD profile is a neutral atmospheric boundary layer which was proven to be an analytic solution of the Navier-Stokes equations by Richard et al. (1993). Thus, the NPD profile inherently satisfies sustainability conditions. ESDU profile is an unstable atmospheric boundary layer but it was shown that the sustainability could be achieved with modified sustainability conditions as shown in Figure 2.

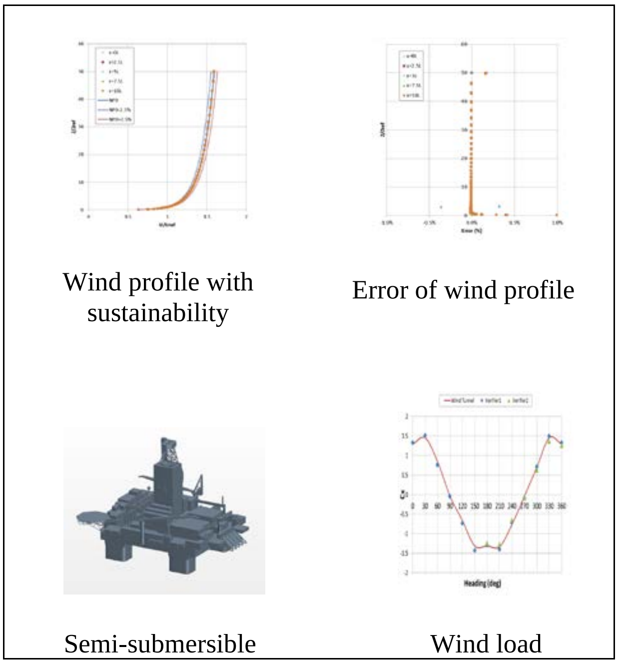

Figure 1. sustainable NPD profile and its wind load on semi-submersible, Yeon et al. (2019)

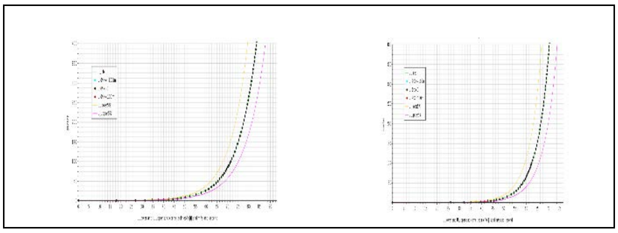

Figure 2. sustainable wind profile implementation: NPD (*left*), ESDU (*right*)), ESDU (1982, 1983)

4.2 Vertical Wind Profiles in strong wind conditions

Vickery (2014) presents the examination of the suitability of the models for atmospheric turbulence used in the draft of API RP 2MET, (2013), for describing the characteristics of hurricane winds offshore, using data collected in Gulf of Mexico from recent (post-2000) hurricanes. The investigation found that the API RP 2MET model yields an underestimate of the true gust factors for the height range examined, and it exhibits a trend for the gust factor to increase as wind speed increases which is not seen in in the data because the model is based on North Sea data. The ESDU (1982, and 1983) models give the gust factors more consistent with the measured field data.

4.3 Wind Load Simulation in Model Test

Tsukada et al. (2017) developed a wind load simulator (WiLS), which simulates forces and moments directly using three pairs of light and small duct fans, not generating environmental wind loads. The wind load simulator can be used to the free-running model tests for evaluating ship performance at actual seas. A feedback control was adopted to take into account the supposed true wind speed and direction, and instantaneous model ship speed, drift and heading angle. Fan inertial forces measured from the accelerometers were corrected in the fan control.

4.4 Wind and Wave Interaction effects on breaking waves and induced loading

Kristoffersen et al. (2019) presented a series of experimental studies on the spatially localized influence of wind on wave induced load on a flexible circular cylinder, which were conducted in a wave-wind-current flume at Newcastle University. These tests were motivated from other experimental and numerical investigations showing air flow separation on the leeward side of steep waves that can lead to added wind energy transfer resulting in an increase of impulsive wave loading. In the tests, the maxima of the force acting on the body are compared for the tests with and without wind. For low wave amplitudes, there was a decrease in force response when wind was introduced. For the largest wave amplitude, the maximum of the force response was increased by 6.5 % when wind was introduced. Some differences in the time series of the free surface elevation were observed when wind was present, but the maximum of the surface elevation did not change notably, and the slope was only minimally changed, meaning that this should not give basis for the differences in the loads.

A numerical investigation of the effects of the wind on the development of modulational instability is provided in Iafrati et al. (2019). Therein, the evolution of a modulated wave train under a uniform wind profile is simulated and comparisons with the corresponding evolution in no-wind solution are established. The occurrence of flow separation at the crest similar to that found experimentally in Buckley et al. (2019), is observed. Results indicate that the presence of wind have a stabilizing effect on the steep waves that delays the onset of the breaking and the allows the waves to reach larger steepnesses. Such results are in general agreement with what found in Touboul et al. (2006) and Kharif et al. (2008).

4.5 Tropical cyclones: modelling and characterization

Grey et al. (2019) proposed a new probabilistic method to increase the sample of tropical cyclones by producing 10,000 years of synthetic cyclone tracks with a range of paths, intensities and sizes based on Hall et al. (2007) and Casson et al. (2000)]. From this set of synthetic tracks, the tropical cyclones that most likely affect the site of interest are modelled using time varying wind fields based on the Holland model in Holland (1980) with surge, current and waves then simulated by the hydrodynamic model TELEMAC-2D coupled to the SWAN wave model. As it is impractical to model 10,000 years of tropical cyclones, a Gaussian process emulator is employed to relate the resultant conditions to parameters defining the cyclones, such as track position, heading, intensity and radius to maximum wind. The result is a synthesized 10,000 years of cyclone events from which design conditions for a range of return periods can be predicted with a greater degree of certainty than by extrapolating from historical events.

Tao et al. (2019) performed a statistical study on the duration of each tropical cyclone that attacked Hong Kong, the time interval between every two continuous tropical cyclones during the year, and the time interval between the last cyclone of each year and the first cyclone of the following year.

4.6 Gust parameters and wind spectrum

Xie et al. (2019) studied the parameters of the gust factor and wind spectra during typhoon and monsoon period by using the observational data of long-term wind on a platform in South China Sea. It has been found that there was no significant positive correlation between the gust factor and turbulence with the wind speed. The gust factor decreased with increase of the gust duration, and the turbulence intensity increased with the duration. The weather system has a significant impact on the wind factor and the turbulence intensity. A seasonal trend of gust turbulence has been observed: the turbulence changes greatly in summer and the gust factors are relatively stable with high wind speed in winter and typhoon processes. After comparison, the NPD spectrum was recommended in SCS according to the observed data.

4.7 The wave climate of the southern ocean

Young (2019) presented an analysis of field measurements of wind and waves in the Southern Ocean based on a combination of more than 30-years of satellite altimeter data plus insitu buoy measurements at 5 locations. The analysis shows that the Southern Ocean is a unique environment where there are strong winds year-round with only a relatively small variation with season which blow over exceptionally long distances, in contrast to the Northern Hemisphere, which is relatively calm at high latitudes in Summer, The strong persistent winds of the Southern Ocean generate swell which propagates across the South Pacific, South Atlantic and Indian Oceans. Therefore, the wave climate of the Southern Ocean impacts half the oceans of the world. As a result, the fact that wind speed and wave heights, particularly the extremes, are changing, is of importance for wave setup and coastal erosion around these oceanic basins. The unique environment is a continuous “race track” of winds generating waves which give rise to spectral forms seen in no other ocean at these latitudes. The spectra are unimodal, with spectral parameters very similar to actively wind generated seas. This is despite the fact that the energetic waves are almost always propagating faster than the local wind. The spectra are a clear indication of the important role of nonlinear interactions in wind.

5. STATE-OF-THE-ART REVIEW OF WAVE-CURRENT INTERACTIONS AND THE EFFECTS ON WAVE BREAKING

5.1 Current Load Estimation using CFD

Current load is an important parameter to be considered in the design of hull and mooring systems of offshore floating structures. To accurately predict the motions of moored vessels, current load should be determined with confidence in the results. To improve the confidence level, there were several joint studies performed recently. One of the working group in Xu et al. (2019) developed a modelling practice and verified the practice. the developed modelling practice was further tested with more participants and various CFD solvers in a blind manner. The compared result following the modelling practice gave good match with model test data within 10% tolerance, Koop et al. (2020).

5.2 Stochastic models of waves and current for prediction of structural design loads

In Bruserud (2018) a simultaneous stochastic model of waves and currents for prediction of structural design loads is presented. In the paper it is discussed that Simultaneous data of metocean parameters, such as wind, waves and current, of sufficient quality and duration are necessary to establish reliable, joint models of metocean loads and load effects on marine structures. In lack of such joint models, the Norwegian design standard, NORSOK N-003, recommends combinations of metocean parameters for load estimations assumed to be conservative. However, the degree of conservatism is rather uncertain. The possible conservatism in NORSOK N-003 for combinations of wave and current conditions in the northern North Sea has been assessed. To perform such an assessment, precise knowledge about the wave and current conditions is required, as well as simultaneous wave and current data of high quality and long duration.

Available measured wave and current data during nearly five years, at selected locations in the northern North Sea, are described. A thorough assessment of the current conditions at these locations is given, with the following important findings;

(1) the quality of measured current data is poorer than anticipated

(2) the dominating current conditions at some locations is wind-generated inertial oscillations

(3) the seasonality of current conditions at these locations is very distinct due to the inertial oscillations and

(4) significant interannual variations in current conditions is found.

For waves in the northern North Sea, both measured and hindcast data are found to be of appropriate quality and duration for joint considerations, but neither current measurements nor hindcast have the required quality or duration. To generate adequate current data, a simple model for wind-generated inertial oscillations is applied and validated at one location in the northern North Sea. With that, simultaneous wave and current data of sufficient quality and duration for joint modelling are available and a joint conditional model for waves and currents is proposed. The anticipated conservatism in NORSOK N-003 for load estimations is assessed by a case study. A simplified model for a generic static load on a jacket, caused by waves and currents, is assumed. For the northern North Sea, metocean loads are estimated first according to the NORSOK N-003 recommendation, and then directly from a load times series. Comparison of the two different approaches gives a clear indication that the NORSOK recommendation is not necessarily conservative in the northern North Sea. Due to several simplifications in the steps leading up to the load estimations, this result is intended to be illustrative.

5.3 Wave current interaction on rogue waves

In the ocean, negative horizontal velocity gradients (i.e. an accelerating opposing current or a decelerating following current) make waves shorten and heighten which enhances wave steepness. As a result, a nonlinear mechanism known as modulational instability develops, leading to the formation of large amplitude waves (the so-called rogue waves), even if they would otherwise be unexpected. In Toffoli et al. (2019), laboratory experiments and numerical simulations with a current-modified version of the Euler equations are presented to assess the role of an opposing current in changing the statistical properties of unidirectional random wave fields. Results demonstrate in a consistent and robust manner that an opposing current induces a sharp and rapid transition from weakly to strongly non-Gaussian properties with a consequent increase of the probability of occurrence of rogue waves. The tests were conducted with irregular unidirectional waves in a wave flume and a directional wave basin at Plymouth University. The initial conditions at the wave maker were given in the form of an input JONSWAP-like wave spectrum to model waves in the frequency domain. As the wave field entered into a region of opposing current, the wave height was observed to increase. Evident breaking dissipation was observed for very strong current fields for U/Cg > 0.3 (breaking appeared with even less strong currents in the wave basin). The presence of the current also accelerated the downshift of the spectral peak, with energy migrating from high to low frequencies bands within scales of tens of wavelengths, in agreement with modulational instability effects, Onorato et al. (2009). The analysis of the statistical properties of extreme (rogue) waves with an aid of kurtosis, the fourth-order moment of the probability density function of the surface elevation. The kurtosis expresses the probability of extreme events in a record (this assumes the value of 3 for Gaussian sea states). The sea state rapidly transitioned from a weakly to a strongly non-Gaussian condition as current speed increased; maximum values of kurtosis were detected to reach 3.5 or higher, which are remarkably high for water waves. These features were evident in both facilities. However, the wave basin exhibited much higher kurtosis (> 4) than the wave flume. Agreement with numerical simulations confirms that this transformation can be attributed to quasi-resonant nonlinear interactions triggered by the background current.

Liao et al. (2017) derived a nonlinear Schrödinger equation for the propagation of two-dimensional surface gravity waves on linear shear currents in finite water depth. Using the equation, the properties of the modulational instability of gravity waves on linear shear currents were investigated. It is showed that shear currents modify significantly the modulational instability properties of weakly nonlinear waves. Furthermore, the influence of linear shear currents on the Peregrine breather which can be seen as a prototype of freak waves was also studied. In intermediate water depth, both currents and the corresponding vorticity have significant influence on the structure of a Peregrine breather. It was demonstrated that depth-uniform opposing currents can reduce the breather extension in both time and spatial domain, but following currents has the adverse impact, indicating that a wave packets with freak waves formed on following currents contains more hazardous waves in finite water depth. However, the corresponding and coexisting vorticity can counteract the influence of currents. Additionally, if the water depth is deep enough, shear currents have negligible effect on the characteristics of Peregrine breather.

Liao et al. (2018) conducted a series of laboratory experiments on the Peregrine breather (which is often considered as prototypes of oceanic freak waves) evolution in a wave flume with a background opposite current. In the experiment, the cases were selected with the relative water depths k_0h (k_0 is the wave number and h is the water depth) varying from 3.11 through 8.17 and the initial wave steepness k_0a (a is the background wave amplitude) ranges between 0.065 and 0.120. The experimental results showed that the persistence of the breather evolution dynamics even in the presence of strong current. The spectrum of the PB persisted at the current, thus making it a viable characteristic for prediction of freak waves. It was also found that the opposing currents tend to shift the focusing point upstream compared to the cases without currents. Furthermore, it was found that depth-uniform opposing currents can reduce the breather extension in time domain.

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