Specialist Committee on Modelling of Environmental Conditions

2017-2021

Chairman : Alessandro Iafrati
Members : Jule Scharnke (Secretary), Marcin Drzewiecki, Toshifumi Fujiwara, Hyun Joe Kim, Pedro C. Mello, Yuxiang Ma, Solomon Yim, Xinshu Zhang

Committee Meetings

- Kick Off Meeting, Wuxi, China, September 22nd 2017
- CNR-INM, Rome, Italy, January 16-17th 2018
- NMRI, Tokio, Japan, 10-12th December 2018
- OMAE, Glasgow, UK, 14th June, 2019
- CTO, Gdansk, Poland, January 2020
- Web Meeting, March, 31st 2021

Outline of the Presentation

- **Modelling of Extreme Environment**
- **Breaking Waves**
- **Wind-Wave interaction and its effect on extreme waves generation**
- **Wave-Current interaction and effects on breaking occurrence**
- **Guideline on Waves**
- **Guideline on Wind**
- **Guideline on Currents**

Modelling of Extreme Environments

Modelling of Extreme Environments

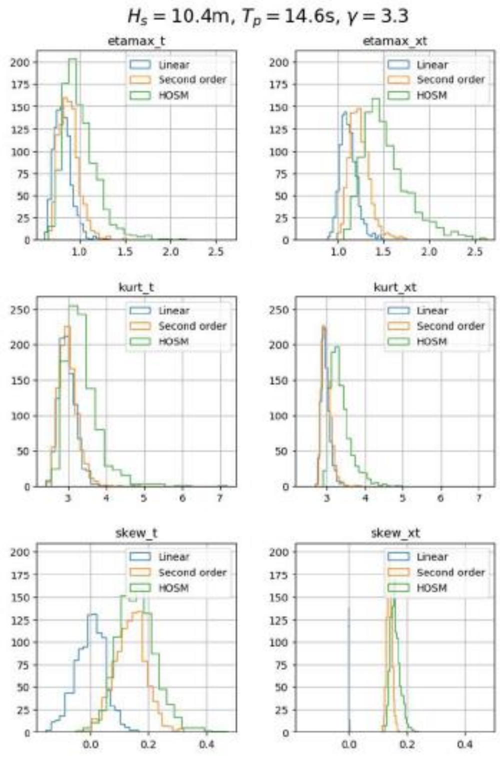
Characterization of the Environment

Sampling variability, limited number of observations, wave record length/domain introduce significant errors

Wave characteristics from space-time data less sensible to sampling variability than single point time series

Dimensions of the selected area relative to wavelength and period more important than sampling step

Higher order NL simulations much broader and more sensitive to sampling variability than second order



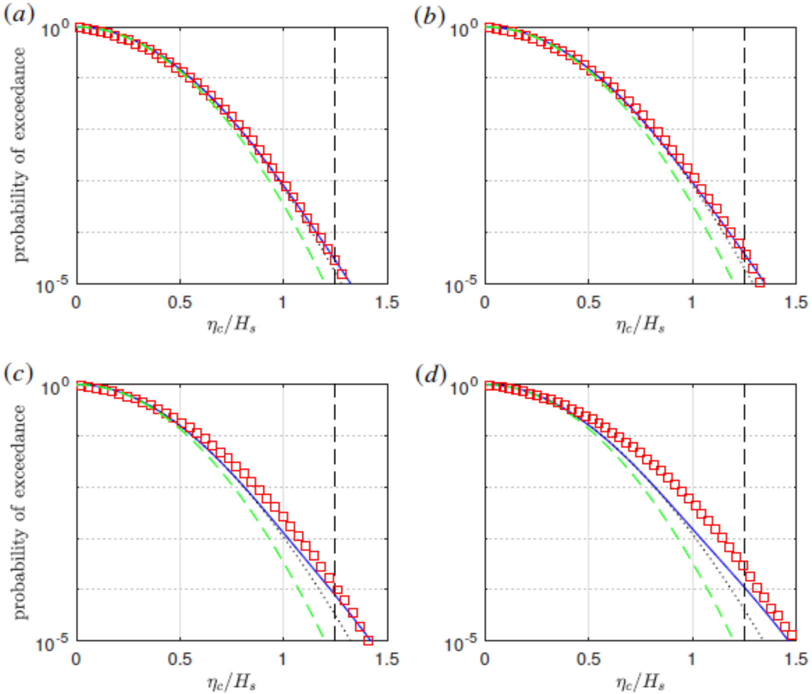
Numerical simulations
Bitner-Gregersen, Gramstad
OMAE 2019-95357

Modelling of Extreme Environments

Crossing seas

Crossing seas may increase the instability growth rates and enlarge the instability region, thus leading to higher probability of exceedence

Numerical studies reveals that second order distributions underestimate the probability of exceedence and even the third-order prediction may be below HOSM simulations



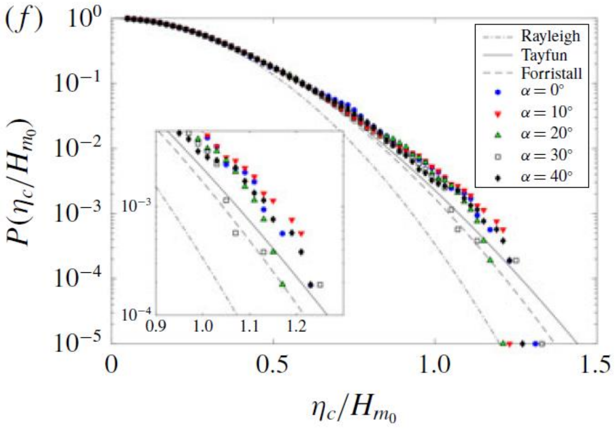
Numerical simulations
Liu, Zhang, Song, Chen
2019-96029

Modelling of Extreme Environments

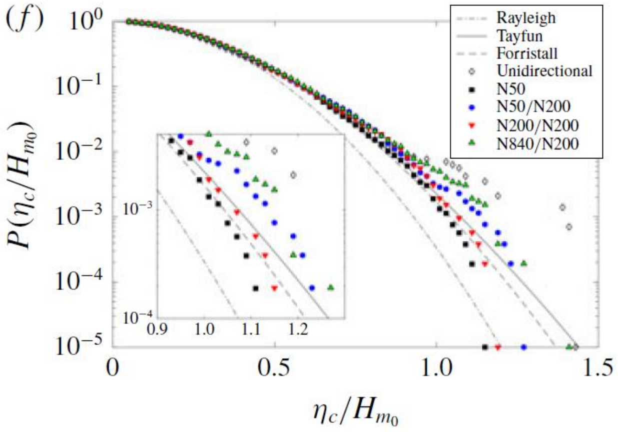
Crossing seas and Directional Spreading

Beside the crossing angle, also the directional spreading has an effect on the exceedence probabiliy. In case of narrower directional spreading of both components, the kurtosis and wave height exceedence probability are much higher than compared to conditions with broader directional spreading at the same crossing angle

Experiments
Luxmoore, Ilic, Mori, JFM 2019



Different crossing angle,
same directional spreading



Same crossing angle,
different directional spreading

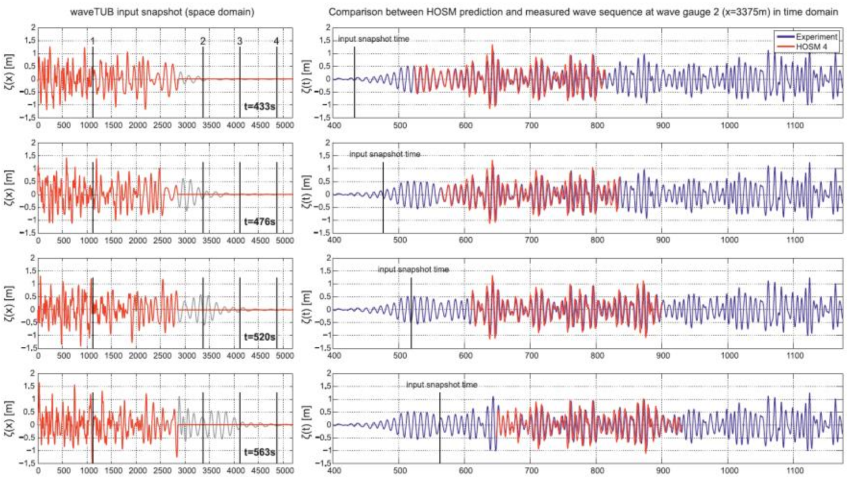
Modelling of Extreme Environments

HOSM validation vs experiments

Numerical and experimental study on the applicability of HOSM as deterministic non-linear wave prediction tool, applied in a semi-empirical procedure.

The fully non-linear numerical wave tank waveTUB is used to reproduce irregular sea states generated in a physical wave tank, and then applied in wave prediction using HOSM and linear transformation.

The results show that the linear method is sufficient for the prediction of irregular sea states with small steepness, resulting in same accuracy as with HOSM. With increasing steepness non-linear effects become more dominant and the accuracy of the linear method decreases. The HOSM simulation results showed good accuracy also for steepest investigated sea states.



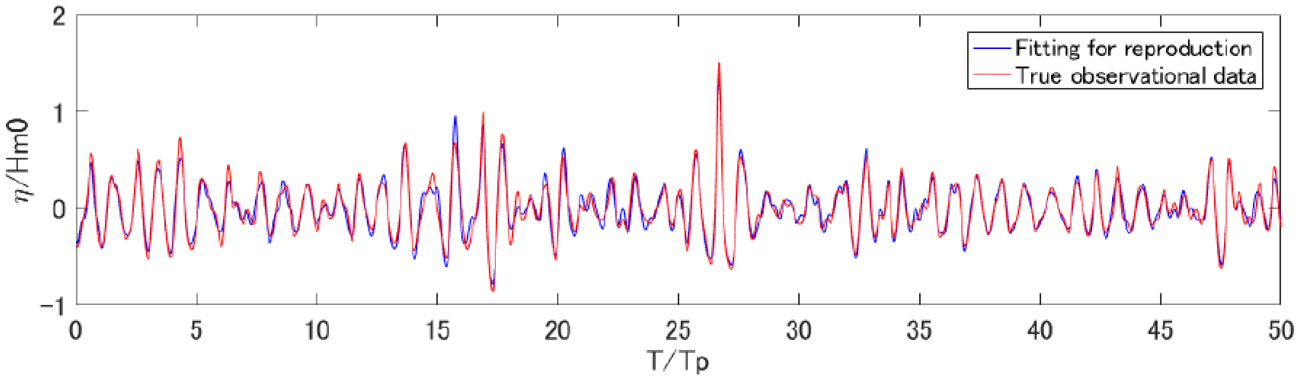
Klein et al, OMAE 2019-95063

Modelling of Extreme Environments

Freak Waves reproduction via Data Assimilation and HOS modelling

Four-dimensional variational (A4DVAR) method to define initial conditions that may minimize the error between observation and model

HOSM used to predict the nonlinear evolution by varying the initial conditions



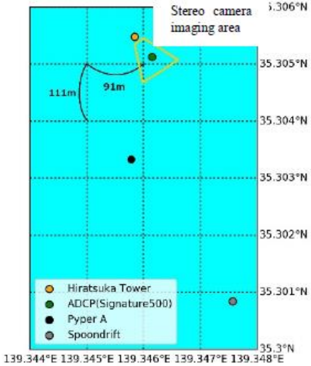
Fujimoto & Waseda,
OMAE 2018-77771

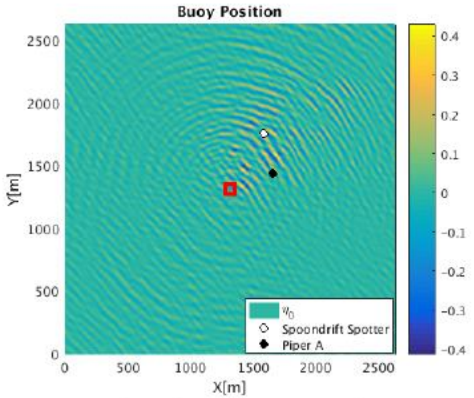
Modelling of Extreme Environments

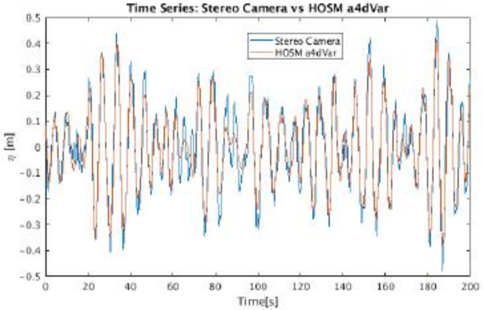
Data Assimilation from Stereo Camera to nonlinear phase-resolved models

Stereo camera systems are becoming a very useful techniques to reconstruct three-dimensional wave fields (*WASS – Waves Acquisition Stereo System*)

By combining data with the A4DVAR and the HOS simulations, a much more accurate prediction of the wave field beyond the field of view can be achieved







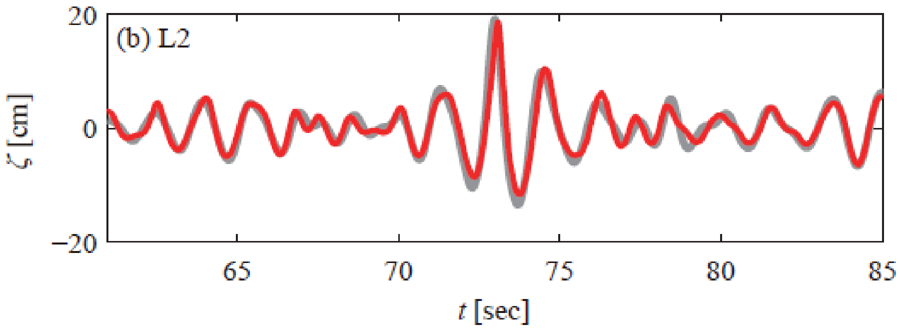
Watanabe, Fujimoto, Nose, Kodaira, Davies, Lechner, Waseda, OMAE 2019-95949

Directional wave fields in basin via HOS simulations

Accurate reproduction of the freak wave occurrence requires that the spectral geometry is correctly reproduced in laboratory

Ship accidents occurred either when frequency bandwidth and directional spreading narrowed (Waseda et al., 2012, 2014) but also in presence of multiple wave systems (Toffoli et al., 2005)

A method, HOSM-WG, to generate spatially periodic wave fields in laboratory has been proposed in Houtani et al. (2019). The method is based on Monte-Carlo HOS simulations until the desired freak wave is found



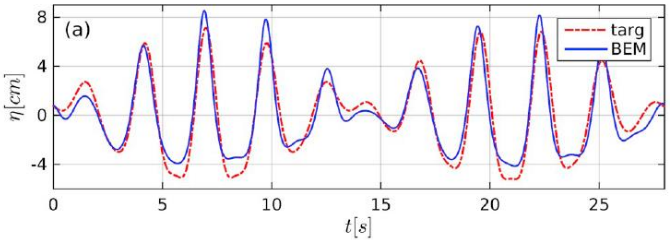
Houtani, Waseda, Fujimoto, Kiyomatsu, Tanizawa
Ocean Eng (2019)

Nonlinear wave generation

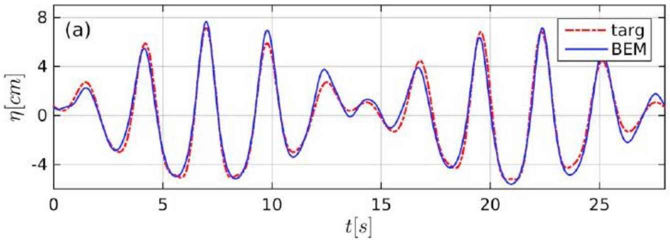
Advanced wave generation techniques that go beyond the second order nonlinearity have been proposed to achieve a more precise reproduction of wave fields in presence of significant higher order effects

Generally, 2nd-order correction are calculated from the spectrum of 1st-order free waves. A significant improvement can be achieved by using nonlinear wave models supplemented with nonlinear boundary conditions at the wavemaker to determine the nonlinear correction to the wavemaker

Linear generation



2nd order – new approach

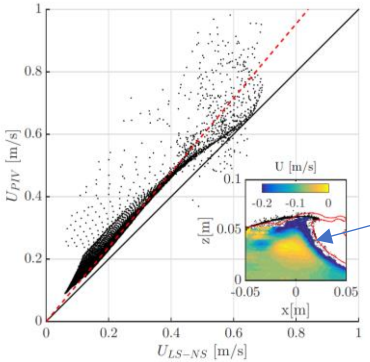


Khait, Shemer
Ocean Eng (2019)

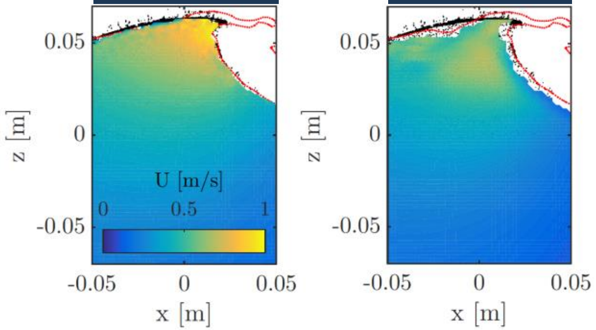
Breaking Waves

Breaking kinematics and typology

Accurate numerical simulations of the complex breaking process remain challenging, and it is still uncertain whether simulations can accurately reproduce the velocity field under breaking waves in experiments. Alberello and Iafrati (2019) performed a numerical and experimental study on breaking waves induced by modulational instability. They found that simulations underpredict the velocity close to the wave crest compared to measurements.



The contour of the velocity difference, i.e. $U_{LS} - U_{PIV}$



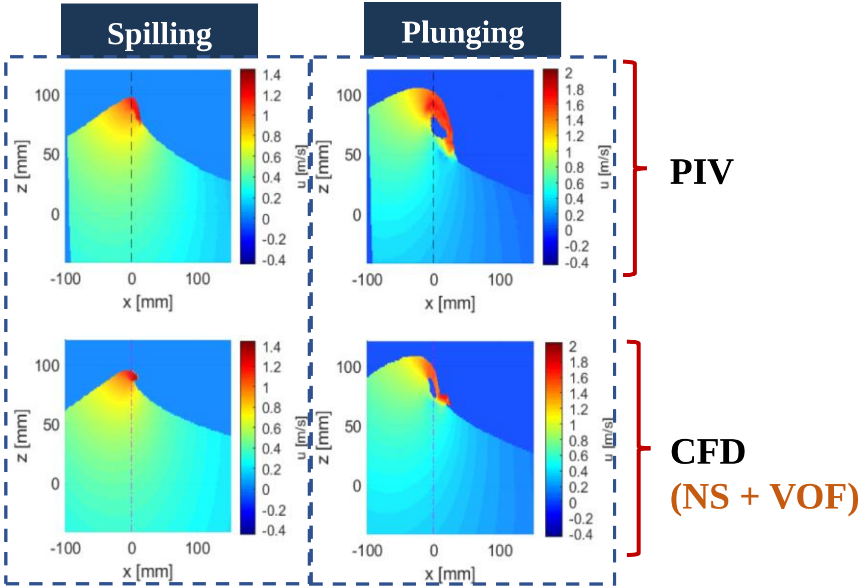
NS + Level-Set

Alberello, Iafrati, 2019, *The Velocity Field Underneath a Breaking Rogue Wave: Laboratory Experiments Versus Numerical Simulations*, Fluids, Vol. 4

Breaking Waves

Breaking kinematics and typology

Duz et al. (2020) also investigated kinematics under spilling and plunging breakers by using both experimental and numerical methods. Their 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.



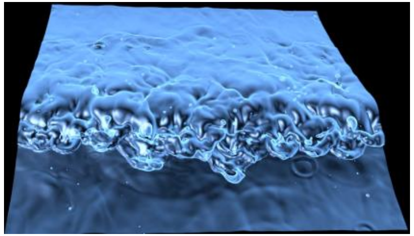
Duz, Scharnke, Hallmann, Tukker, Blanchard, Khurana, 2020, Comparison of the CFD Results to PIV Measurements in Kinematics of Spilling and Plunging Breakers, OMAE2020-19268

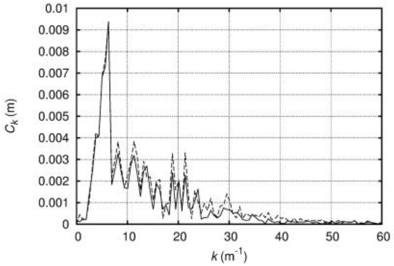
Breaking Waves

Effects of breaking waves on spectral content

Huang and Zhang (2018) developed two semi-empirical wave crest probability distributions for single realization and an ensemble of realizations. A reduction of energy in the high-frequency range of steep measured and simulated wave spectra was also discussed. As this reduction in energy only occurs for steep wave spectra, this may be related to wave breaking.

By comparing the spectra provided by the HOS and two-phase Navier-Stokes results, Iafrati et al. (2015) found that it is possible to distinguish between the changes operated by the time evolution and those associated to the breaking process. And their results clearly indicate that the breaking acts mostly on the higher harmonics.





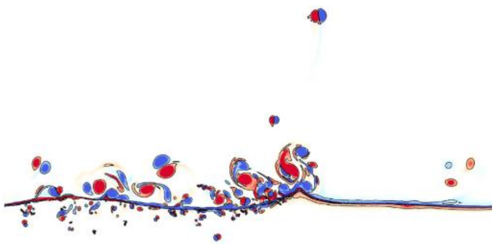
Huang, Zhang, 2018, *Semi-Empirical Single Realization and Ensemble Crest Distributions of Long-Crest Non-Linear Waves*, OMAE2018-78192
Iafrati, De Vita, Alberello, Toffoli, 2015, *Strongly Nonlinear Phenomena in Extreme Waves*, SNAME Transactions, 123

Breaking Waves

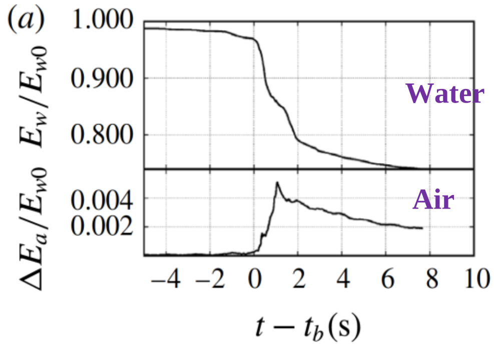
Effects of breaking waves on spectral content

De Vita et al. (2018) conducted a high-resolution CFD simulation of the breaking of modulated wave trains with the open source code Gerris. Vorticity and wave energy variation in air and water were analyzed. And they also found that the down-shifting of the fundamental component to the lower sideband is made irreversible by the breaking, as mentioned in Tulin et al. (1999).

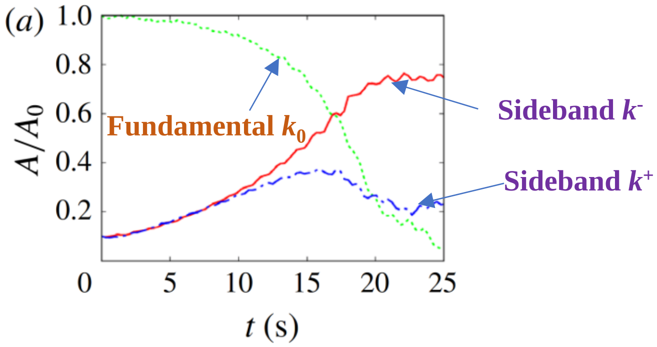
Vorticity in breaking



Energy in water and air



Evolution of spectrum



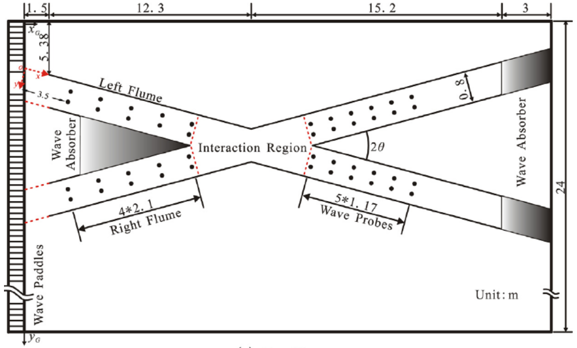
De Vita, Verzicco, Iafrati, 2018, *Breaking of Modulated Wave Groups: Kinematics and Energy Dissipation Processes*, J Fluid Mechanics, 855
Tulin, Waseda, 1999, *Laboratory Observation of Wave Group Evolution, Including Breaking Effects*, J Fluid Mechanics, 378

Breaking Waves

Effects of breaking waves on spectral content

Dong et al. (2019) presented a new experimental study in which large isolated focusing wave groups were generated in a special “X” configuration. They found that the nonlinear energy transfer during wave-wave interactions is particularly sensitive to the directional spread. When breaking occurs, energy loss comes from the high-frequency components of the first harmonic band.

Evans et al. (2019) considered a key practical steps required to correctly estimate the trispectrum and tricoherence, and demonstrated the usefulness of the trispectrum and tricoherence in identifying wave-wave interactions in synthetic and measured wave time-series



(a) Plan View

Dong, Liu, Ma, Perlin, 2019, *Experimental investigation of weakly three-dimensional nonlinear wave interactions*, Europ J Mechanics B/Fluids, 77

Ewans, Christou, Ilic, Jonathan, 2019, *Identifying Higher-Order Interactions in Wave Time-Series*, OMAE2019-95378

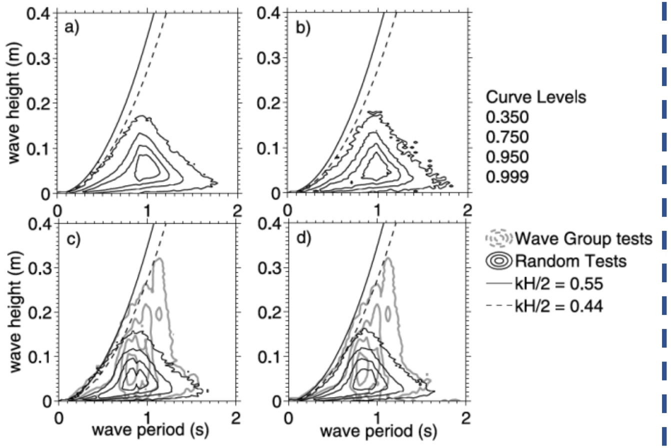
Breaking Waves

Statistics of breaking occurrence and spectral shape

Babanin (2009) made 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.

Toffoli et al. (2010) presented a statistical analysis of a large sample of individual wave steepness. They collected a large amount of data from measurements of the surface elevation in laboratory facilities and the open sea under a variety of sea state conditions. They found that waves are able to reach steeper profiles than the Stokes' limit for stationary waves.

Joint cumulative distribution function of wave height and period.



Babanin, 2009, *Breaking of Ocean Surface Waves*, Acta Phys. Slovaca, 56
Toffoli, Babanin, Onorato, Waseda, 2010, *Maximum Steepness of Oceanic Waves: Field and Laboratory Experiments*, Geophys Res Lett, 37

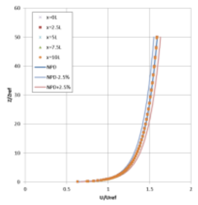
Wind-Wave Interaction and Generation of Extreme Waves

Wind-Wave Interaction and Generation of Extreme Waves

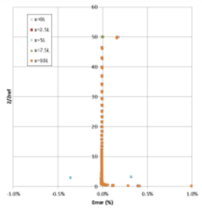
CFD Estimate of Wind Load

In SNAME OC-8 CFD Task Force, a modelling practice was developed and successfully validated for a semi-submersible topside with several independent participants (Kim et al., 2018; and Kim et al., 2019)

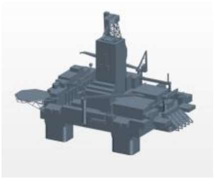
In a Joint Development Project (TESK) by TechnipFMC, EURC, SHI and KRISO, the procedure was further verified for hulls with more complicated topsides (Yeon et al., 2019).



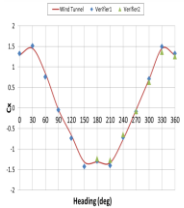
Wind profile with sustainability



Error of wind profile



Semi-submersible



Wind load

Yeon et al. OMAE 2019-96429

Kim, Jang, Xu, Shen, Kara, Yeon, Yan, 2018, *Numerical Modeling of Neutrally-Stable and Sustainable Atmospheric Boundary Layer for the Wind Load Estimation on an Offshore Platform*, OMAE2018-78699

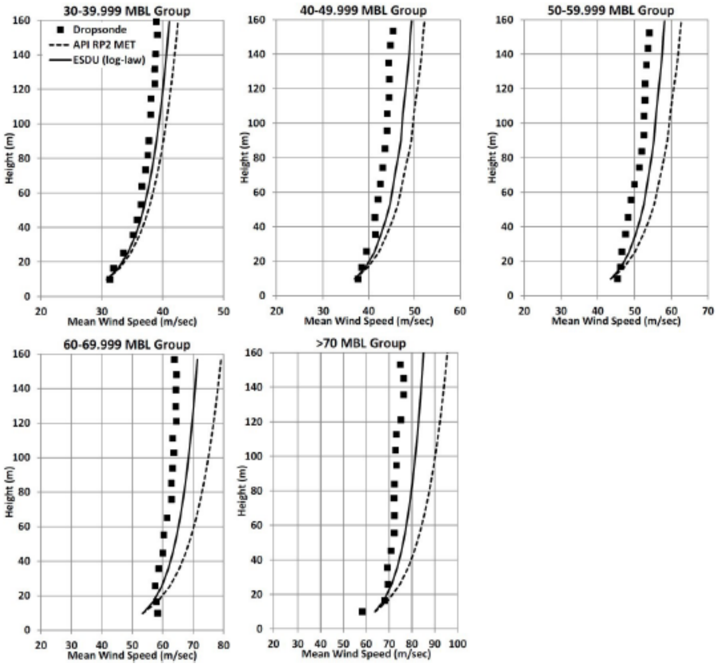
Kim, Jang, Xu, Shen, Yeon, 2019, *Developing Industry Guidelines for the CFD-Based Evaluation of Wind Load on Offshore Floating Facilities*, OTC-29270-MS.

Yeon, Jang, Kim, Kim, Nam, O’Sullivan, Huang, Kim, Hong, 2019, Numerical Modeling Practice and Verification of the Wind Load Estimation for FPSO and Semi-submersible, OMAE2019-96429

Wind-Wave Interaction and Generation of Extreme Waves

Vertical Wind Profiles in a 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



Vickery, 2014, Analysis of Hurricane Winds, OTC-25244-MS.

Figure 1—Comparison of ESDU (log-law) and API RP 2MET mean velocity profiles to velocity profiles derived from dropsonde data for profiles located less than 30 km from the center of the hurricane. Radius independent sea-surface drag coefficient used to define aerodynamic roughness of the sea surface.

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

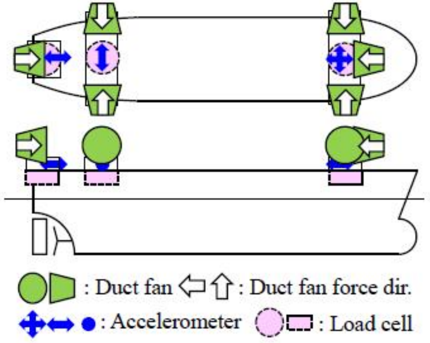


Fig. 1 Configuration of onboard part of the wind loads simulator.

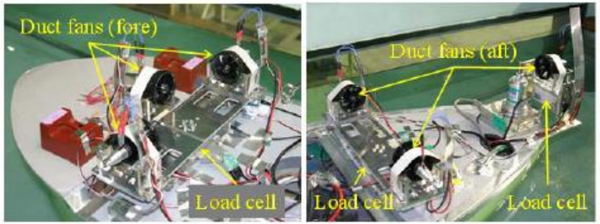


Fig. 2 Wind loads simulator on a model ship.

Tsukada, Suzuki, Ueno, 2017, *Wind Loads Simulator for Free-Running Model Ship Test*, OMAE2017-61158

Wind-Wave Interaction and Generation of Extreme Waves

Wind-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

Figure 3: PICTURE OF BREAKING WAVE, SIDE VIEW FOR A TEST CASE WITHOUT WIND.

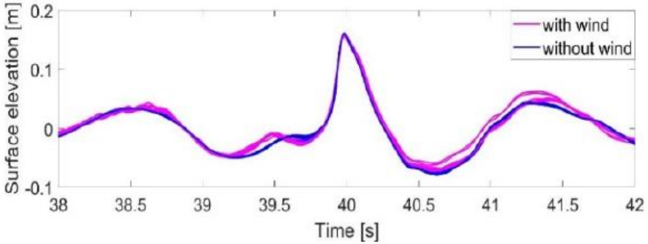


Figure 6: COMPARISON OF MEASURED SURFACE ELEVATION IN TESTS WITH AND WITHOUT WIND FOR WAVE CONFIGURATION II FOR 10 REPETITIONS.

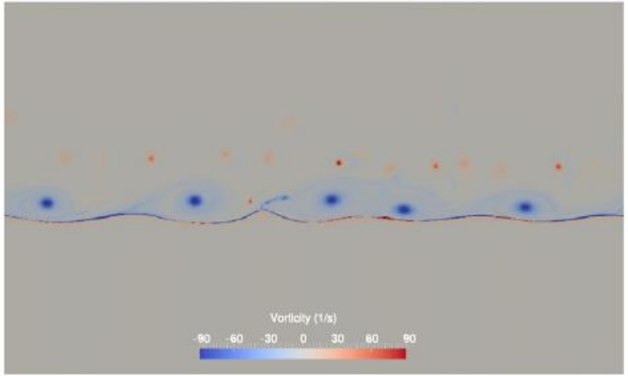
Kristoffersen, Bredmose, Georgakis, Tao, 2019, *Preliminary Experimental Study on the Influence of the Local Wind Field on Forces from Breaking Waves on a Circular Cylinder*, OMAE2019-95179

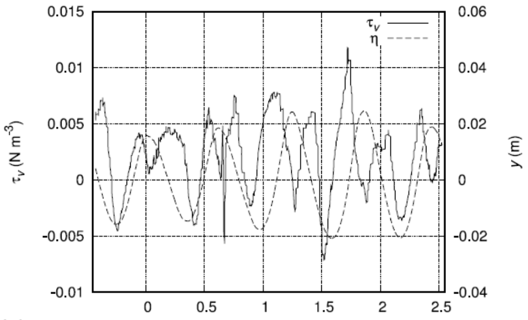
Wind-Wave Interaction and Generation of Extreme Waves

Wind-Wave Interaction effects on breaking waves and induced loading

A numerical investigation of the effects of the wind on the development of modulational instability is provided in Iafrati et al. (2019).

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).





(a)

Iafrati, De Vita, Verzicco, 2019, *Effect of the Wind on the Breaking of Modulated Wave Trains*, European Journal of Mechanics/B-Fluids, 73

Wind-Wave Interaction and Generation of Extreme Waves

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 increases with the duration. The weather system has a significant impact on the wind factor and the turbulence intensity

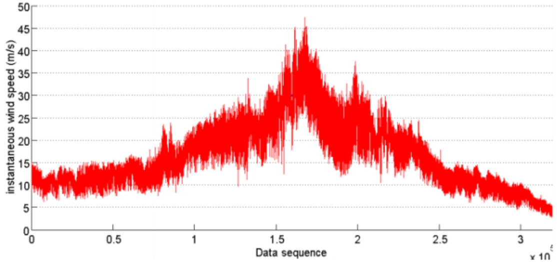


Fig.3 the wind velocity time series of typhoon

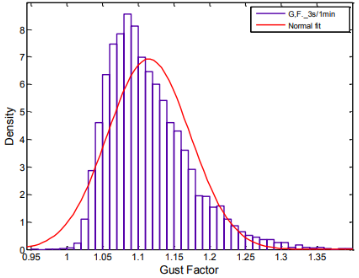


Fig.5 Gust factors relative to 1-min mean wind speed

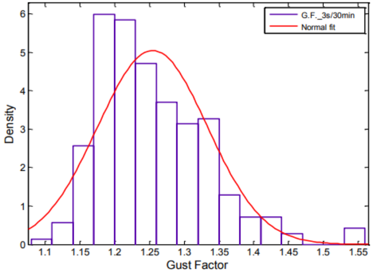


Fig.7 Gust factors relative to 30-min mean wind speed

Xie, Ren, Li, Duan, Wang, Zhao, 2019, *Study on Gust Parameters and Wind Spectrum of South China Sea*, OMAE2019-95779

Wind-Wave Interaction and Generation of Extreme Waves

Modelling of Tropical Cyclones and Climate of Southern Ocean

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).

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.

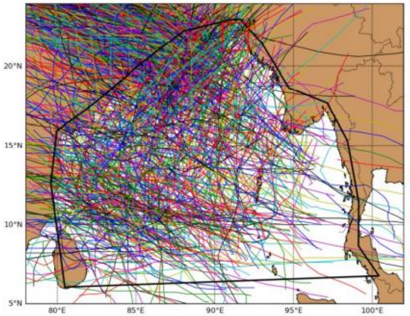


Figure 2 The region of interest (ROI), shown as a thick black polygon, and all tropical cyclone tracks passing through the ROI recorded in the IBTrACS database. The red box indicates the area in Figure 1.

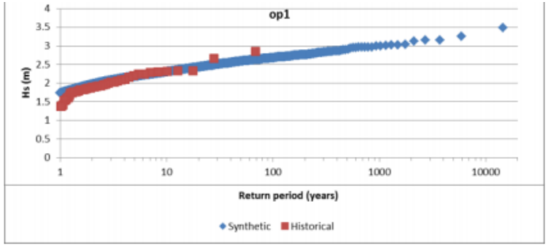


Figure 12 Significant wave height predicted from synthetic cyclones compared to wave height predicted from historic cyclones (1970 to 2016).

Grey, Liu, 2019, *A Probabilistic Approach to Tropical Cyclone Modelling*, OMAE2019-96245

Young, 2019, The Wave Climate of the Southern Ocean, OMAE2019-95168

Wave-Current Interaction

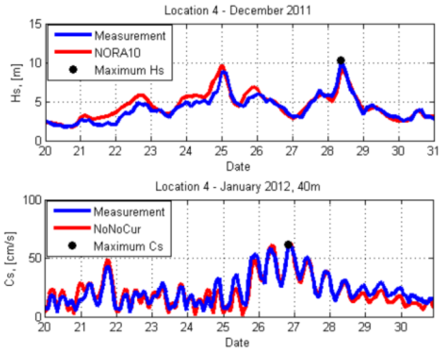
Wave-Current Interaction

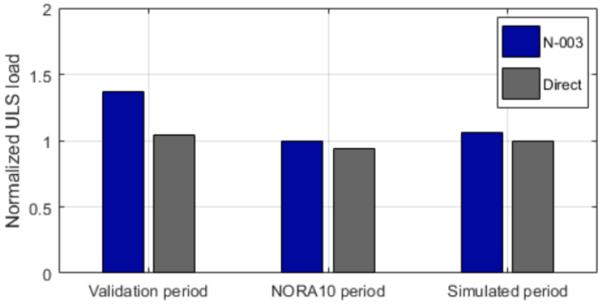
Stochastic models for prediction of design loads

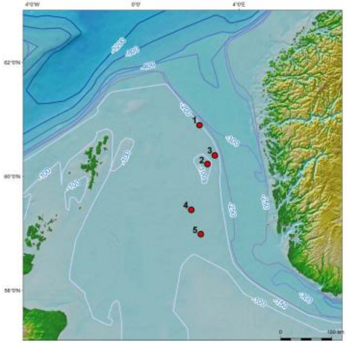
When simultaneous data of wind, waves and currents are available, combinations of meteocean parameters can be used for load estimation (e.g. NORSOK N-003)

Good agreement is achieved both for waves and current hindcast data

By comparing estimates based on different approaches, it is found that the NORSOK N-003 is not necessarily conservative







Measurement sites at Northern north sea

Bruserud, 2018, *Simultaneous Stochastic Model of Waves and Currents for Prediction of Structural Design Loads*, OMAE2018-77219

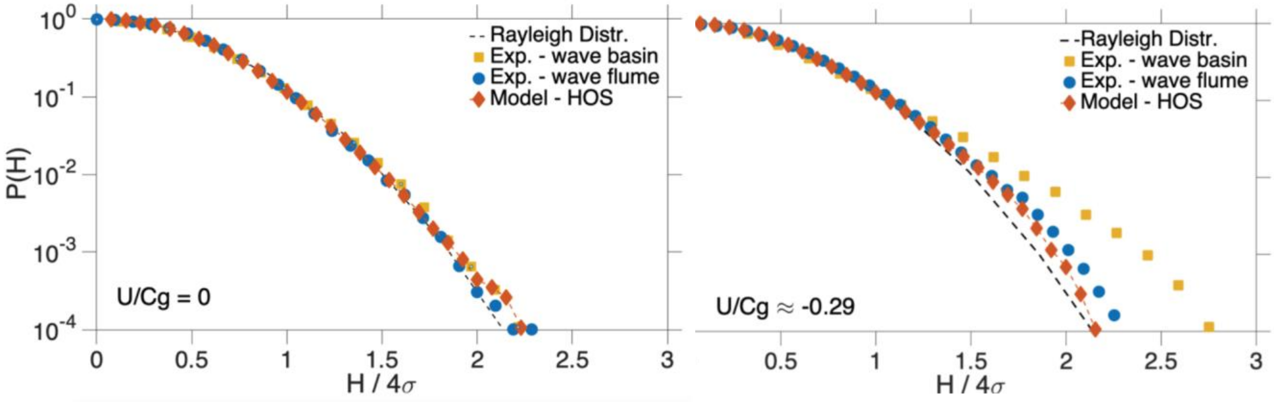
Wave-Current Interaction

Wave current interaction on rogue waves

Currents induce a substantial deviation from the Rayleigh distribution, which clearly under predicts the occurrence of waves with height H/4σ > 1.3

The PoO of extreme and rogue waves (H/4σ>2) increases by one order of magnitude in the flume due to wave-current interaction: from 1×10^{-4} (no current) to 1×10^{-3} (with current). In the wave basin, this enhancement is even more substantial, with probability of occurrence increasing up to 6×10^{-3}.

Toffoli, Ducrozet, Waseda, Onorato, Abdolahpour, Nelli, 2019, *Ocean Currents Trigger Rogue Waves*, ISOPE Conf., Hawaii, USA

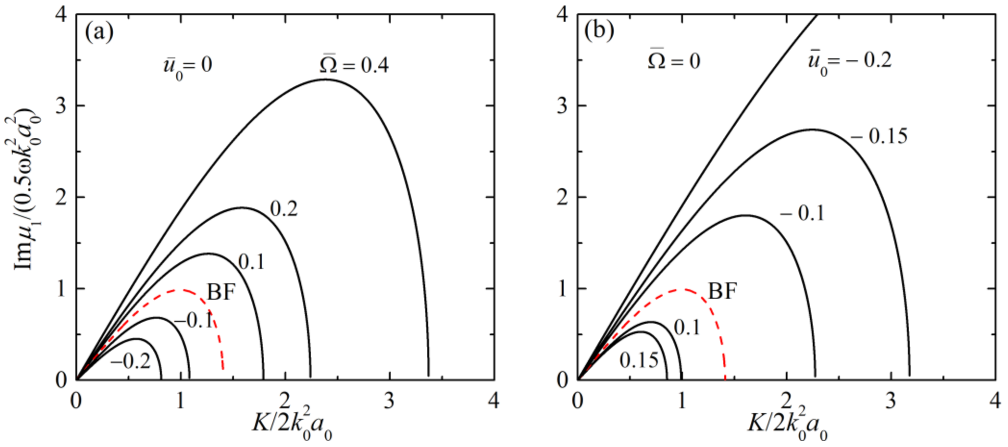


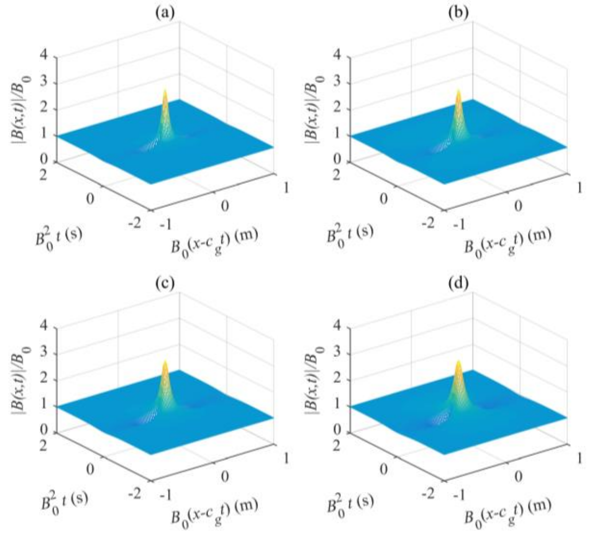
Exceedence probability of the wave height distribution: U/Cg = 0 (left); and U/Cg = -0.29 (right)

Wave-Current Interaction

Wave shear-current interaction on rogue waves

Liao et al. (2017) used a modified Schrodinger equation to investigate separately the role played by the shear and uniform currents on the instability growth rate and on evolution of a Peregrine breather



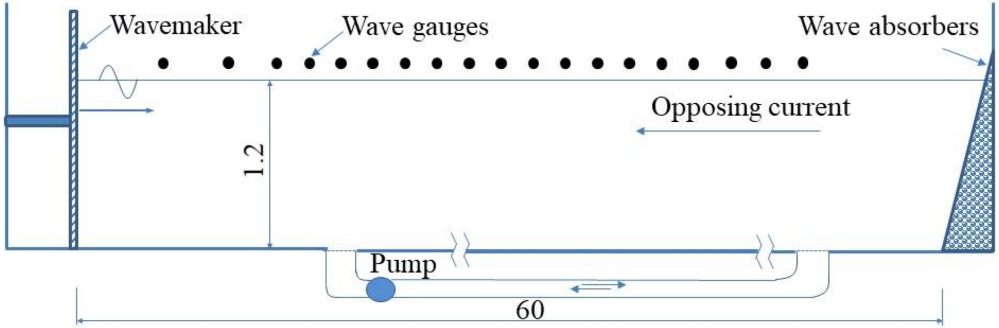


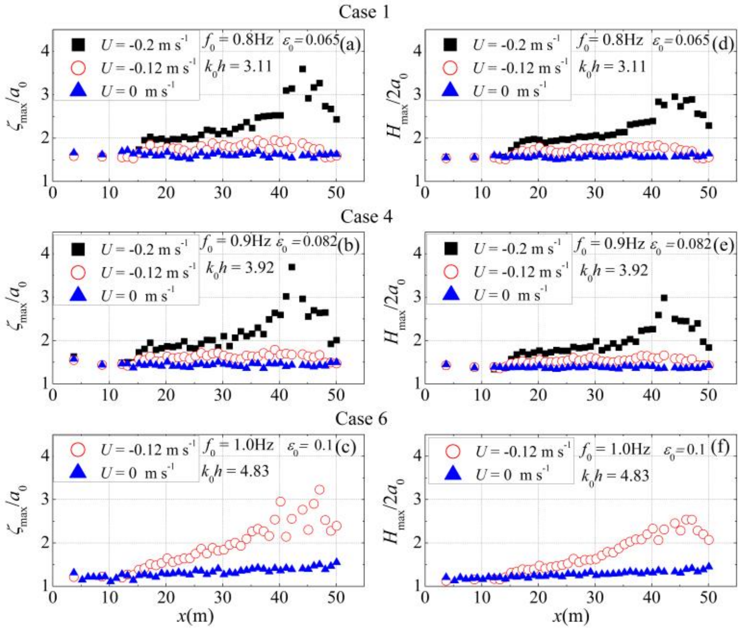
Liao, Dong, Ma, Gao, 2017, *Linear-shear current modified Schrodinger equation for gravity waves in finite water depth*", Physical Review E, 96

Wave-Current Interaction

Wave current interaction on rogue waves

Liao et al. (2018) conducted an experimental study on the evolution of the Peregrine breather in opposite currents and found that the current may trigger the instability





Liao, Ma, Ma, Dong, 2018, *Experimental study on the evolution of Peregrine breather with uniform-depth adverse currents*, Physical Review E, 97

Guideline: Laboratory Modelling of Waves

- Linear Regular Waves
- Non-linear effects, analysis, control
- Confinement
- Wave frequency, low frequency reflections
- Radiation/reflection from model, beaches
- Deviation from ideal conditions
- Irregular Waves: wave spectra
- Irregular waves: non-linear effects, analysis, control
- Irregular waves: bi-modal and multimodal
- Irregular waves: Geographical consistency of wave spectra selection

Guideline: Laboratory Modelling of Waves

Linear Waves

For most regular wave applications, the average wave height H and period T are of main interest.

Properties should be constant throughout time and in space. Time window selection for practical laboratory purposes:

- Based on criteria such as minimum variations
- Minimum transient effects in the model test set-up
- Minimum reflections from the beach or from the side walls
- Normally a minimum of 10 wave cycles are selected

Several analisys method could be used:

- Time domain: zero-crossing, crests, troughs statistics. Root-mean-squared (RMS) of time series
- Frequency domain: FFT or harmonic

Guideline: Laboratory Modelling of Waves

Non-linear effects: analysis, control

Wave steepness ε=kA defines the deviation from linear to non-linear wave: profile asymmetry.

Several works reports different aspects of the non-linearities associated:

- 2nd or higher order approaches: Stokes' expansion, High-Order Spectral Methods (HOSM) and Non-Linear Fourier Analysis (NLFA)
- Instabilities associated to non-linear effect in high steep waves: Toffoli et al. (2005), Tayfun and Fedele (2007)
- Non-Linear generation methods to suppress unintended 2nd order free waves: Schäffer (1993, 1996)
- Non-Linear effects on wave height distributions: Tayfun and Fedele (2007)
- Study on Rogue waves also generated by bounded harmonics: Fedele et al. (2016)
- HOSM to study wave field transformation and wave propagation
- Specific wave modeling methods for shallow, intermediate and deep water by NFLA

Guideline: Laboratory Modelling of Waves

Confinement effects

Wave basin/tank facilities introduce additional effects in the wave field:

- Tank finite depths change the wave dispersion compared to deep water
- Uneven bottom induce refraction and spatial variation (Toffoli et al., 2005)
- Non-linear wave-wave interactions increase with reduced depth (Kennedy and Fenton, 1997)
- Larger set down effects and corresponding return currents;

Side walls and wave generator reflections - > Passive and active wave absorption systems to suppress side walls and wave generator reflections (Chakrabarti, 1994; USACE, 2002)

Wave breaking absorption in porous parabolic beaches could be adapted for a wide range of waves (Straub et al., 2011; Lean, 1967)

Porous surfaces commonly used to damp waves (Chakrabarti, 1994; USACE, 2002)

Discontinuous surface (or singularity) at borders and straight corners induce perturbation to the wave field:

- Wave board smooth fader movements close to corners;
- Wave board movement optimization to suppress spatial perturbation on wave field (Matsumoto & Hanzawa, 2001)
- Wave board with continuous soft curved (circular) geometry

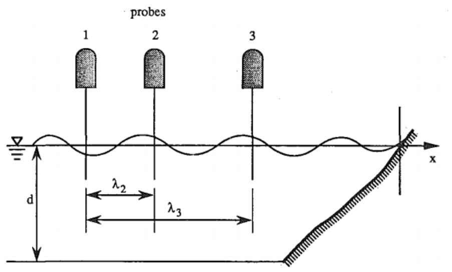
Guideline: Laboratory Modelling of Waves

Wave frequency and low frequency reflections

Wave damping systems to be carefully designed (Straub et al., 2011; Lean, 1967; Chakrabarti, 1994; USACE, 2002)

Several techniques available to measure the reflection coefficients based on one up to three wave probes in order to develop absorbers devices for wave tanks:

- Isaacson (1991) describes technique to separate incoming and reflected waves;
- Drzewiecki and Sulisz (2019) describes a method using Doppler shift in frequency domain from a known velocity of a single measuring probe



Guideline: Laboratory Modelling of Waves

Radiation and reflection from model, beaches, etc

Wave reflection and irradiation by the model interact with side walls and wave generator:

- Transverse and standing waves creation, the phenomenon is noticeable for single board wavemakers
- Passive absorption when applicable (Straub et al., 2011; Lean, 1967; Chakrabarti, 1994; USACE, 2002)
- Interaction of incident and reflected waves changes the wave field by non-linear effects and even breaking
- Active wave absorption by multi-segmented wave maker, e.g. Mello et al. (2013):
  - Supress transverse standing waves
  - Mitigate wave reflection by the model
  - Reduces the interval between experiments

- It is necessary to define a test interval in an appropriate way for the installation
- Solutions to avoid/suppress long standing wave described in Van Essen et al., (2014, 2016)

Guideline: Laboratory Modelling of Waves

Deviations from ideal conditions

In the practice of model tests, deviations from the ideal situation are observed, for various reasons, which are associated with wavemaker, basin and wave absorbing devices

Model testing procedures must take these effects into account, in one or several of the following ways:

- Avoiding them
- Reducing them
- Documenting them and interpreting their effect on vessel and offshore structure responses
- Choosing a proper combination of location and time windows

Another important aspect concerns the model scale:

- When reducing the model scale, and thus the wavelength, the waves are keener to develop natural modulational instability, e.g., Tulin and Waseda (1999)
- The phenomenon is partly reduced by the increased role played by the viscous dissipation (Ma et al., 2012) but a careful check of accuracy and repeatability of the wave quality is needed when using relatively small scales.

Guideline: Laboratory Modelling of Waves

Irregular waves: spectra

Sea states are generally specified by the short-term variance spectrum S(f) or S(ω)

Many widely-used parametric models for the spectrum of waves measured at a point (without regard to wave direction) are of the Bretschneider (1959) form for typical application:

$$S(f) = \frac{A}{f^5}\exp(-\mathrm{B}/f^4)$$

- Pierson & Moskowitz (one- and two-parameter forms)
- JONSWAP -> Limited fetch
- TMA -> Finite water depth
- Mitsuyasu (1972) -> Well know combination of limited fetch and wind speed

Random simulation of one hour typically for seakeeping and 3 hours for offshore engineering

Irregular waves: Analysis and control

Nonlinear effects increases with increasing wave steepness and affect the measured wave spectrum in the wave basin;

Several works reports different aspects of the non-linearities in wave basin practical uses:

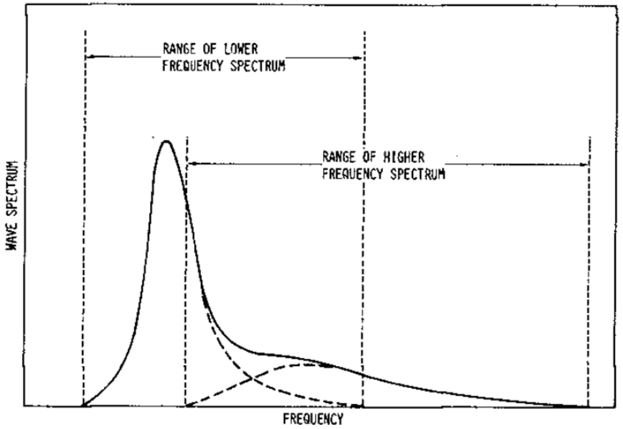
- Drzewiecki (2018): a Black-Box approach on the control signal calibration between the required and realized spectrum
- Schäffer (1993, 1996): a method to suppress unintended and undesirable 2nd order free waves for wave makers
- Sulisz and Hudspeth (1993): a complete second-order solution to wave generation in unidimensional wave flumes
- Ducrozet et al. (2016): HOSM to study wave field transformation and wave propagation
- Osborne (2010): NLFA to model waves in shallow, intermediate and deep water

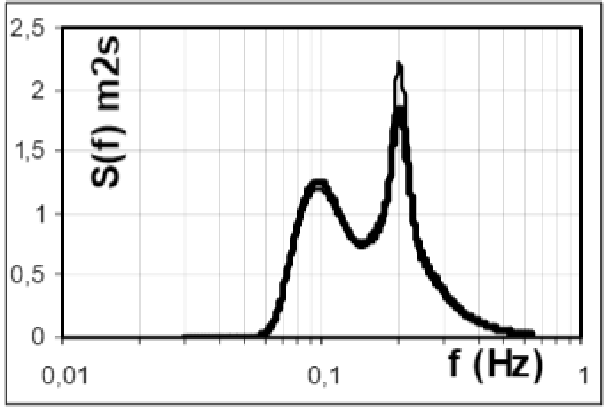
Irregular wave: bi-modal and multimodal

Ocean wave spectra can be characterized by one local wind generated wave system and one or more swells generated remotely. This is the case when a swell generated remotely, combines with a wind sea generated by a local storm close to the observation point

Bi-modal spectra commonly used in laboratories include those by Ochi and Hubble (1976) and Torsethaugen (1993).

More details on Guideline 7.5-02-07-01.1 *Laboratory Modelling of Multidirectional Irregular Wave Spectra*

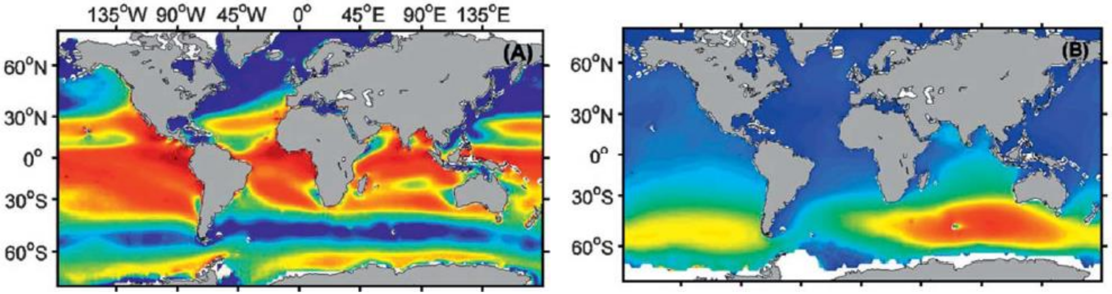


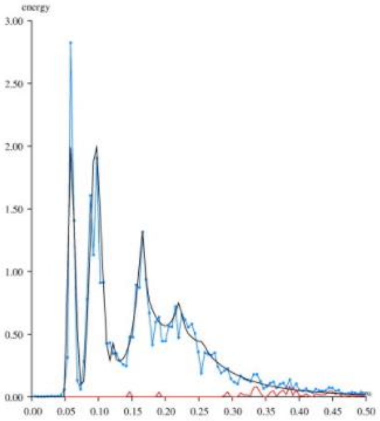


Irregular Waves: Geographical consistency of wave spectrum selection

An accurate prediction of the model response requires accurate reproduction of the wave conditions. Some regions are characterized by specific spectra, often seasonal dependent (Semedo et al., 2011), which need to be properly accounted when performing wave basin experiments.

Several examples exists in different regions. For example, Olagon et al. (2014) presents a sea state dominated by strong narrowness several swells, both in frequency and direction;





(4)

Guidelines: Laboratory Modelling of Wind

- Steady wind
- Spectra
- Turbulence
- Gusting
- Squalls
- Vertical and horizontal variations
- Geographically consistency of wind conditions
- Interaction with waves
- Generation techniques
- Measurements techniques

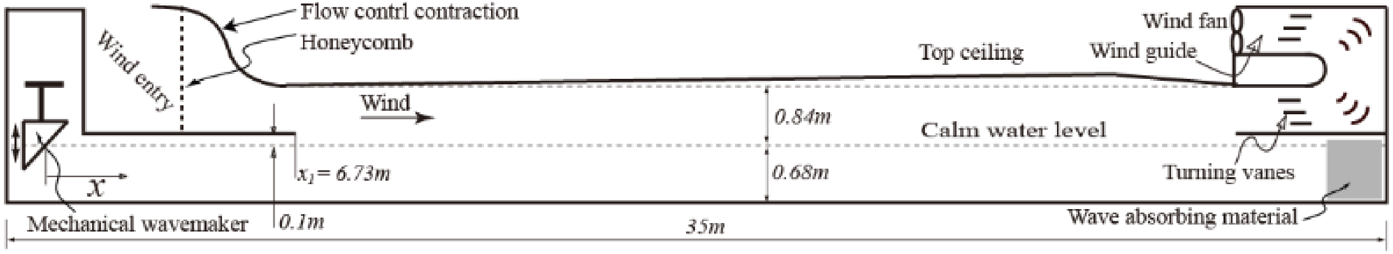
Guidelines: Laboratory Modelling of Wind

Steady Wind

Generally wind fluctuations faster that ship or offshore structure motions → steady wind load relevant to assess floater's responses.

Wind speed taken as average speed over one hour. Typically, the steady speed is the mean wind speed 10 m (full scale) above the mean still water level.

A mean wind speed corresponding to a 100-year return period should be used in the design, based on the marginal distribution of wind speeds at the specific location.



Tian Z, Perlin M, Choi W, 2010, *Observation of the occurrence of air flow separation over water waves,* International Conference on Offshore Mechanics and Arctic Engineering, 49125

Guidelines: Laboratory Modelling of Wind

Wind Spectra

When low frequency excitation is an important design factor, e.g. for station-keeping tests of an offshore platform, a wind spectrum shall be applied.

Wind gusting is commonly assumed to be a Gaussian stochastic process, which can be fully described by a wind spectrum.

Several spectral models exists, such as API (The American Petroleum Institute), NPD (The Norwegian Petroleum Directorate) wind spectrum, etc.

API

$$S_{API}(f) = \frac{\sigma(z)^2}{f_p\left(1+1.5\frac{f}{f_p}\right)^{5/3}}$$

$$\sigma(z) = I(z)U(z) \qquad f_p = \frac{\alpha}{z}U(z)$$

$$I(z) = \begin{cases} 0.15\left(\frac{z}{z_s}\right)^{-0.125} & \text{for } z \le z_s \\ 0.15\left(\frac{z}{z_s}\right)^{-0.275} & \text{for } z > z_s \end{cases}$$

NPD

$$S_{NPD}(f) = \frac{320\left(\frac{U_0}{10}\right)^2\left(\frac{z}{10}\right)^{0.45}}{\left(1+\tilde{f}^{0.468}\right)^{3.561}}$$

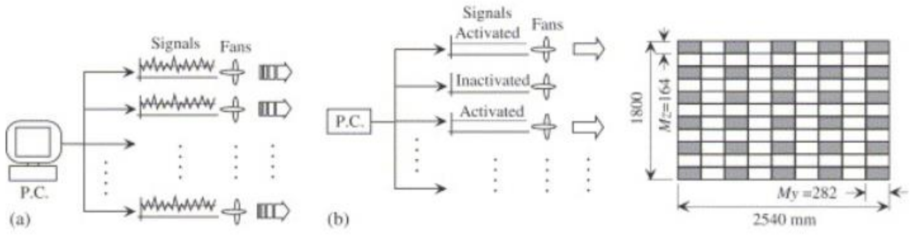
$$\tilde{f} = \frac{172 f\left(\frac{z}{10}\right)^{2/3}}{\left(\frac{U_0}{10}\right)^{3/4}}$$

Turbulence

Turbulence intensity of wind in the boundary layer on sea surface is about 0.1~0.2.

Turbulence defined as: $\sigma_T(z) = I(z)/U(z)$, where I(z) is the wind velocity variance and U(z) is the mean wind speed at elevation z. The level of turbulence intensity should be measured in the model tests.

Simulation of turbulence characteristics of wind was presented in Ozono et al. (2006), using a multi-fan type wind tunnel. A uniformly active mode (usually employed in tank tests) can reproduce longitudinal fluctuations.



Ozono S, Nishi A, Miyagi H, 2006, *Turbulence generated by a wind tunnel of multi-fan type in uniformly active and quasi-grid modes*, Journal of wind engineering and industrial aerodynamics, 94

Guidelines: Laboratory Modelling of Wind

Gusting

Wind gusting is commonly assumed to be a Gaussian stochastic process, fully described by a wind spectrum.

Gust spectrum may depends on wave age (Myrhaug, 2007). Examples of parameterization provided by Sheridan (2011) but no widely accepted expression for elevation and gust factors suitable for engineering purpose. Available. Available measurements (e.g. Santala et al., 2014; Jeans et al., 2014, 2016) may be useful.

Fluctuating wind velocities can be reproduced with a wind generator. In the region of minimum and maximum wind velocity, it should be confirmed that the Reynolds effect of the wind can be ignored. Whether this is the case depends on the objective of the model tests.

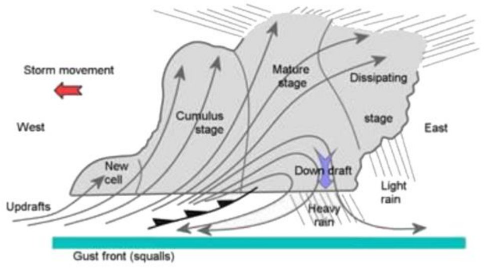
Squalls

A squall is a strong transient wind event generated by a convective storm. There are no widely accepted elevation and gust factors for squalls suitable for engineering purpose at present.

Santala et al. (2014) compared the expressions of the wind gust elevation profile and gust factors for squall winds with that for non-squall winds presently in API and ISO standards. Results may lead to an improved treatment of squall events for offshore engineering applications.

As a squall measurement system in the actual sea, the West Africa Gust (WAG) Joint Industry Project (JIP) present useful information (Jeans et al. 2008).

Santala M J, Calverley M, Taws S, et al., 2014, *Squall Wind Elevation/Gust Factors and Squall Coherence*, Offshore Technology Conference, 2014.



Vertical Profiles

Very limited full-scale data available for the vertical wind profile. It is well known, however, that the vertical profile of the wind is developed by the sea surface roughness.

As conventional treatment, there is the power law model, based on one hour average a height z above sea level given by API

$$U(z) = U_0 \left(\frac{z}{z_R}\right)^{0.125}$$

where $U(z)$ is the average wind speed at elevation z above sea level and U_0 is the 1-hour mean wind speed at reference elevation z_R = 10 m above the water surface

Guidelines: Laboratory Modelling of Wind

Horizontal variations

Generated wind by blowers or fans should cover the entire model, considering the range of wave motions and drift in the facility. In the case of wind farms the area may extend several square kilometers and, correspondingly, in the model test, the modeled wind field is expected to simulate the real situation with respect to velocity and variance in the entire area.

In practice however, it can be difficult, to control a state of the wind in transverse direction. Variance in horizontal wind direction can only be realized in the basin using multiple wind generators.

Guidelines: Laboratory Modelling of Wind

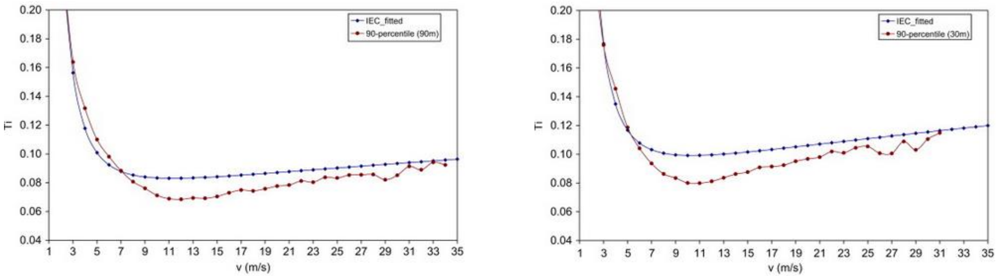
Geographical consistency of wind conditions

It is recommended that the characteristic wind spectrum of the installation area is also employed in the model test. Examples of specific phenomena occurring in some conditions or specific locations can be provided.

For example, in a strong typhoon, turbulence intensity decreases with increasing mean wind speed and remain almost constant when the wind speed becomes high (Cao et al., 2009).

In the German Bight, wind speed turbulence intensity increases with increasing wind speed because of increasing wave height and surface roughness (Tuïrk and Emeis, 2010)

Türk M, Emeis S, 2010, *The dependence of offshore turbulence intensity on wind speed*, Journal of Wind Engineering and Industrial Aerodynamics, 98



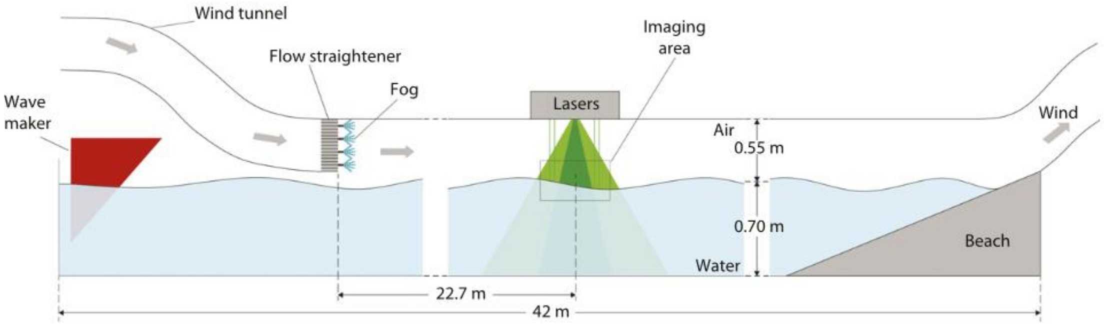
Guidelines: Laboratory Modelling of Wind

Interaction with waves

In heavy sea conditions, wind and wave interaction may not be ignored. Examples of interaction are provided in Tian et al (2010) and Buckley and Veron (2016), Miles (1993), Kharif et al. (2009), Waseda and Turin (1999), and Galchenko et al. (2012).

These publications focus on the wind generation due to the change of wave surface elevation. In this situation, wind condition caused by the rough waves should be represented by the wind profile form developed by the wave condition. Qualitatively and quantitatively analyses of wind interaction effect with waves are expected in model testing.

Buckley M P, Veron F, 2006, *Structure of the airflow above surface waves*, Journal of Physical Oceanography, 2016, 46



Guidelines: Laboratory Modelling of Wind

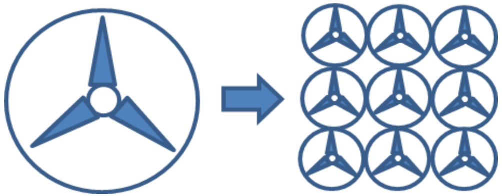
Generation Techniques

Propeller and Sirocco type wind generators are typically used. The wind blowing area should be at least twice the model characteristic length. Numerous small size fans are recommended to simulate wind condition with expected turbulence, profile, horizontal variation as shown in the figure.

Most commonly wind forces are calibrated rather than wind velocities to avoid scale effects of the wind velocities which are generally not reproduced when applying Froude scaling.

Wind fields may not be uniform due to limited number of wind fans and recirculation effects in the basin, (Buchner et al. (1999)). Wind forces can be calibrated with a wind fan setup, by mounting the model in a fixed force frame and deriving a calibration curve of the measured wind loads vs wind fan rpms.

Usually, changes of projection area are required even with well fabricated model topsides due to difference of Reynolds number and uncertainties in the model and wind speeds.



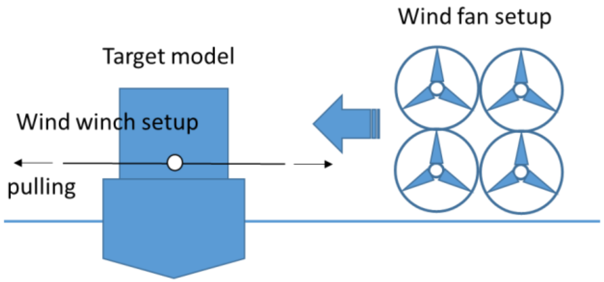
Guidelines: Laboratory Modelling of Wind

Generation Techniques

Alternatively, wind loads can be applied by a wire-winch setup. In both cases target wind loads (mean and fluctuating) can be applied.

Wind fan setup is generally assumed to be most realistic, as it includes dynamic wind effects of floating structure moving in wind and waves, e.g. changes in wind force due to change in heading, lift effects, etc.

Wind winch setup provides a constancy of the applied load with heading changes of the model and is always known (measured) throughout the model test.



Guidelines: Laboratory Modelling of Wind

Measurements

For practical applications, pitot tubes, hot-wire thermos and ultrasonic anemometers etc. are usually employed to measure the wind velocity to verify turbulence and the realized wind profile.

For model testing the same instruments are usually used. Note that for model testing the required accuracy level for Froude-law scaling is much larger. For a 1/100 model scale the required accuracy is 10 times larger.

Depending on the application and on the calibration type, i.e. wind velocity or loads, one or more sensors may be required in the testing area (De Ridder et al., 2014)

ultrasonic anemometer

hot wire

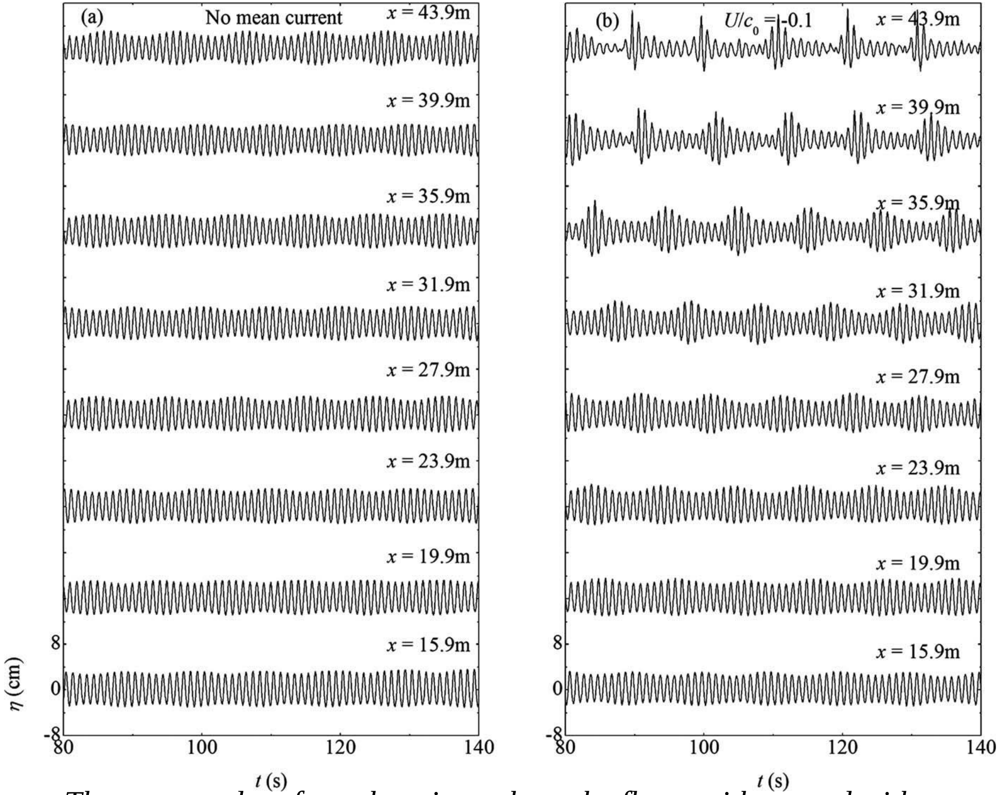
Guidelines: Laboratory Modelling of Currents

- Interaction with waves
- Generation
- Vertical and Horizontal variation
- Turbulence and oscillatory currents
- Measurement techniques

Guidelines: Laboratory Modelling of Currents

Interaction with waves

Currents may influence the development of modulational instability. Opposite currents can speed up the growth of the instability (Ma et al. 2013).



The measured surface elevations along the flume without and with an opposing current.

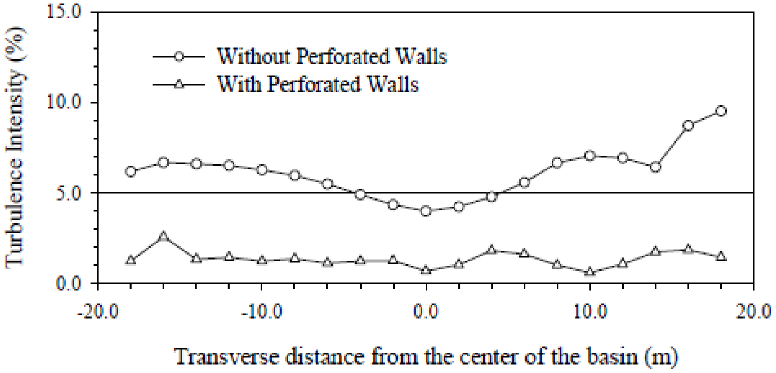
Ma, Y., Ma, X., Perlin, M., 2013, *Extreme Waves Generated by Modulational Instability on Adverse Currents*, Physics of Fluids, Vol. 25.

Guidelines: Laboratory Modelling of Currents

Current Generation

Current is generated by re-circulating the water, either in the basin or outside the basin.

In general, the turbulence intensity in the measuring area should be below 5%. In order to achieve low turbulence intensity, specific structures such as perforated walls, flow guiding vanes, mixing chambers and turbulence grids etc. need to be set in the inflow and outflow culvert (e.g. Lu et al., 2006).



Lu, H. N., Yang, J. M., Peng, T., 2006, *Characteristics of Current Generation in the New Deepwater Offshore Basin*, OMAE2006-92140, Hamburg, Germany.

Guidelines: Laboratory Modelling of Currents

Vertical Profiles

Many previous studies indicated that the vertical velocity profiles of an open channel flow and long shore currents are well described by the logarithmic law

In wave basins or flumes, current velocity profiles can be reproduced by different layers of pumps or specific devices such as perforated walls (Buchner et al., 2008).

Fine mesh turbulence grids

Pumps

Pump room

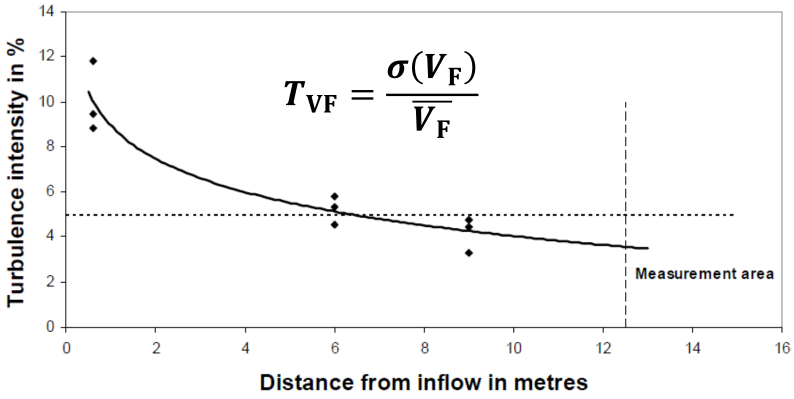
Buchner, B, de Wilde, J., 2008, *Current Modeling Experience in an Offshore Basin*, OMAE2008-57597, Estoril, Portugal.

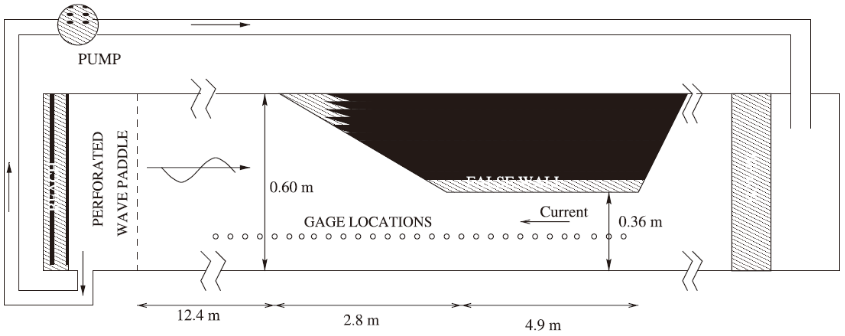
Guidelines: Laboratory Modelling of Currents

Horizontal Variations

Horizontal variations can be induced via gradually reduced depths (Chawla and Kirby, 2002)

Variations in the turbulence intensity with the distance have to be accounted for (Buchner and de Wilde, 2008)



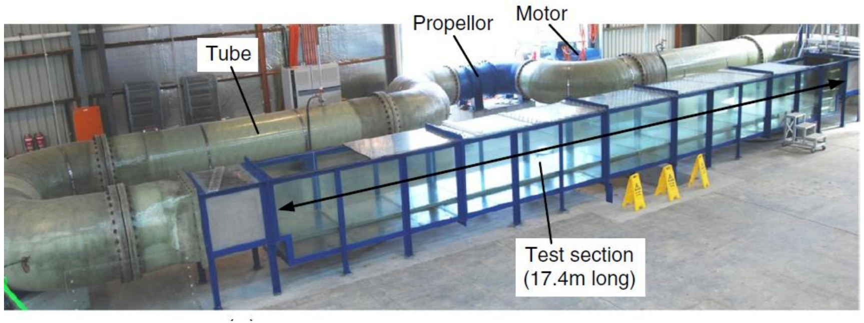


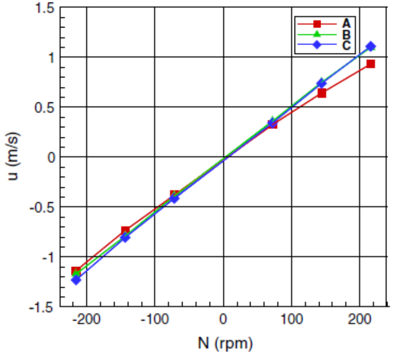
Buchner, B, de Wilde, J., 2008, *Current Modeling Experience in an Offshore Basin*, OMAE2008-57597, Estoril, Portugal.

Chawla, A., Kirby, J.T., 2002, *Monochromatic and Random Wave Breaking at Blocking Points*, Journal of Geophysical Research, 107

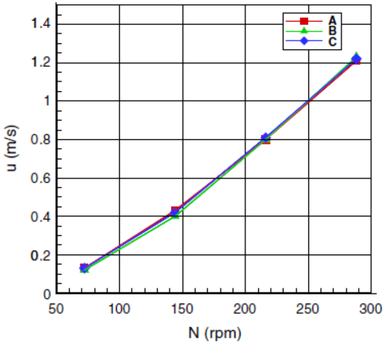
Oscillatory Flow

Oscillatory flows may be generated in order to reproduce typical prototype of tropical storm conditions (e.g. An et al., 2013)





(b) Steady current condition



(c) Oscillatory flow condition

An, H., Luo, C., Cheng, L., White, D., 2013, *A New Facility for Studying Ocean-Structure - Seabed Interactions: The O-Tube*, Coastal Engineering, 82

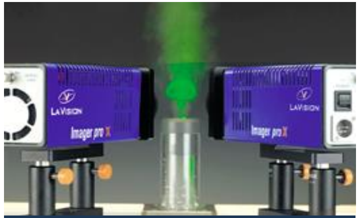
Guidelines: Laboratory Modelling of Currents

Measurements

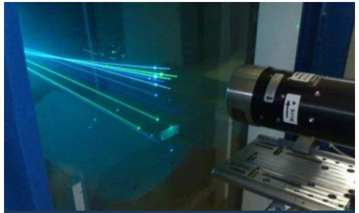
Particle Image Velocimetry (PIV), stereoscopic PIV (SPIV), Laser Doppler Velocimetry (LDV), Particle Tracking Velocimetry (PTV), holography, and other emergent methods are described in detail in ITTC (2014).

The acoustic Doppler velocimetry (ADV) and the ADV profiler (ADVP) were applied widely in velocity and turbulence structure measurements for non-uniform flows (Song et al., 1994).

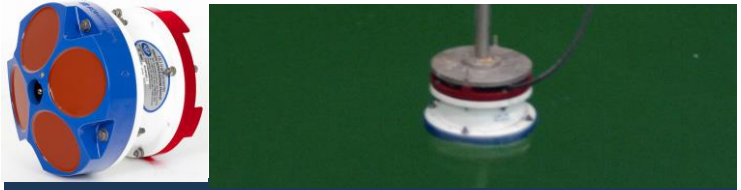
PIV system



SPIV system


LDV system


ADV


ADVP system

Song, T., Graf, W. H., Lemmin, U., 1994, *Uniform Flow in Open Channels with Movable Gravel Bed*, Journal of Hydraulic Research, 32

Conclusions/Recommendations

Guideline Recommendation

It is recommended to adopt the revised Guideline on **Laboratory Modelling of Waves** (7.5-02-07-01.2) and the new Guidelines on **Laboratory Modelling of Wind** and **Laboratory Modelling of Currents**