The Ocean Engineering Committee

Final Report and Recommendations to the 25th ITTC

1. GENERAL

1.1 Membership and Meetings

The Members of the Ocean Engineering Committee of the 24th International Towing Tank Conference were as follows:

- Prof. Pierre Ferrant (Chairman), Fluid Mechanics Laboratory, Ecole Centrale de Nantes, France
- Prof. Martin Downie (Secretary), University of Newcastle upon Tyne, United Kingdom.
- Dr Rolf Baarholm, Norwegian Marine Technology Research Institute, Norway.
- Prof. Antonio C. Fernandes, Laboceano, Universidade Federal do Rio de Janeiro, Brasil
- Dr. Nuno Fonseca, Instituto Superior Técnico, Portugal.
- Dr Sa-Young Hong, Maritime and Ocean Engineering Research Institute, Moeri, Korea.
- Prof. Shuichi Nagata, Institute of Ocean Energy, Saga University, Japan.
- Dr Ir Jaap de Wilde, Maritime Research Institute Netherlands, The Netherlands.
- Prof. Jianmin Yang, State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, China

Four Committee meetings were held respectively at:

- Maritime Research Institute Netherlands, the Netherlands, June 2006.
- MOERI/KORDI, Korea, December 2006
- Instituto Superior Técnico, Portugal, June 2007.
- Shanghai Jiao Tong University, Shanghai, February 2008.

1.2 Tasks Based on Recommendations of the 24th ITTC

The original list of tasks recommended by the 24th ITTC was as follows:

State of the Art Reviews Update the state-of-the-art for predicting the behaviour of bottom founded or stationary floating structures including moored and dynamically positioned ships and the modelling of waves, wind and current in emphasizing developments since the 2005 ITTC Conference,

- Comment on the potential impact of new developments on the ITTC.
- Emphasize new experimental techniques and extrapolation methods and the practical applications of computational methods to prediction and scaling.
- Identify the need for R&D for improving methods of model experiments, numerical modelling and full-scale measurements.

Review Existing Procedures

- Review ITTC recommended procedures 7.5-02-07-01.1, 7.5-02-07-03.1, 7.5-02-07-03.2, 7.5-02-07-03.4 and 7.5-02-07-03.45.
- Determine if any changes are needed in the light of current practice.
- Identify the requirements for new procedures.
- Support the Specialist Committee on Uncertainty Analysis in reviewing the procedures handling uncertainty analysis.

Review validation of prediction techniques

Critically review examples of validation of prediction techniques

- Identify and specify requirements for new benchmark data.
- Outline a benchmark study using a simple geometric form for the application of unsteady RANS codes to wave load problems. The study should include validation against experimental data

Develop New Procedures

1. Develop a new procedure for the validation of frequency-domain codes predicting wave loads and responses of offshore structures. The work should be carried out in co-operation with the Seakeeping Committee, and should be based upon the review and update the work done by the 24th ITTC Ocean Engineering and Seakeeping Committees.
2. Develop a new procedure for the validation of time-domain codes predicting wave loads and responses of offshore structures. The work should be carried out in co-operation with the Seakeeping Committee.

Scaling Issues in Multiple-Scale Model Tests Review scaling issues associated with multiple-scale model tests in which, for example, some components become extremely small if proper geometric scaling is used.

Wind Modelling in Model Basins Identify requirements and carry out a review of wind modelling in model basins, including the physical modelling, simplified mathematical models and flow code analysis. The review should include scaling problems; inhomogeneous wind fields, turbulence, coherence, wind spectra, wind-induced motion damping, and waves / wind interaction.

1.3 Structure of Report

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

State of the Art Reviews

- Section 2: Predicting the Behaviour of Bottom-Founded Structures
- Section 3: Predicting the Behaviour of Stationary Floating Structures and Ships
- Section 4: Predicting the Behaviour of Dynamically Positioned Ships
- Section 5: Modelling Waves, Wind and Current
- Section 6: Modelling Hydroelasticity and Impact
- Section 7: Predicting the Behaviour of Renewable Energy Systems
- Section 8: New Experimental Techniques
- Section 9: Progress in Computational Fluid Dynamics

Existing Procedures

- Section 10 reviews existing documentation relating to: the Laboratory Modelling of Multidirectional Irregular Wave Spectra (7.5-02-07-01.1); Experiments with Offshore Platforms (7.5-02-07-03.1); Model Testing in Regular Waves (7.5-02-07-03.2); Turret Tanker Systems (7.5-02-07-03.4) and Hybrid Experiments and Numerical Simulations (7.5-02-07-03.45)

New Documentation

- Section 11 discusses the validation of prediction techniques with particular reference to the necessary attributes of numerical and theoretical data suitable for validating CFD codes applied to wave loading problems.
- Section 12 discusses new procedures for validating frequency domain and time domain codes used for predicting the wave loads and responses for offshore structures.
- Section 13: Multiple-Scale Model Testing
- Section 14: Wind Modelling in Model

Basins.

Conclusions and Recommendations

- Are presented in Sections 15 and 16 respectively.

Appendix

- Benchmark data for validating CFD codes.

2. BOTTOM-FOUNDED STRUCTURES

2.1 Introduction

Bottom founded structures have been traditionally classified in terms of their magnitude in relation to the characteristic wavelength, λ, of their wave environment, and the associated physical phenomena and analytical approaches used to treat them, as discussed by the previous OEC (ITTC, 2005). Small volume structures are typically associated with viscous effects, such as flow separation, and the Morison equation; large volume structures with wave diffraction and potential flow theory. The division between the two, and the beginning of the linear diffraction regime for a vertical circular of diameter D for example, is commonly defined as $D/\lambda = 0.2$ or $ka = 0.2\pi$ where a is the radius and k the wave number. The structures to be discussed here will also be loosely divided into small volume structures, such as jacket and jack up structures, and large volume structures such as gravity based structures (GBSs).

Bottom founded structures are the longest serving offshore, and methods of estimating their fluid loading are well established. Experiments carried out today tend to be looking at unusual structures or operational procedures, investigating fundamental fluid phenomena, and/or for validating newly developed theory and numerical codes. In researching fluid phenomena, bottom founded structures are often idealised as vertical cylinders. These activities encompass a considerable body of work covering a wide range of topics. A comprehensive review of the whole is beyond the scope of the present work, which focusses on a selection of recently published theoretical/numerical, as well as experimental, research reflecting current interests. Relatively new arrivals on the scene of bottom founded structures are those developed as part of the offshore renewable energy infrastructure.

2.2 Small Volume Structures

Common small volume structures, in addition to jacket structures, include such examples as jack up platforms, tower-yoke mooring systems and a variety of compliant structures. Fluid loading on structural elements of such installations is generally computed using the Morison equation. A recurring theme in research on small volume structures is the search for a replacement for, or development of, the Morison equation. One of the methods used in the derivation of the Morison force coefficients is the method of moments. However, the coefficients obtained from this method can show considerable scatter due to large sampling variability. Najafian (2007) has proposed a more efficient form of the method of moments, which reduces the sampling variability. The results using simulated data indicated that the proposed method is superior to the conventional one, particularly for the case for drag-dominated forces.

Vertical Cylinders. An ongoing pre-occupation with small volume structures is the interaction of bodies in close proximity in different flow regimes. Sparboom and Oumeraci (2006) have added to the body of knowledge by carrying out a series of experiments on single vertical and inclined cylinders and arrays of cylinders in non-breaking regular and irregular waves as well as breaking freak waves. They presented maximum wave loads in the context of shelter, interference and amplification effects for closely spaced slender cylinders.

Jacket / Jack-up Structures. The fluid loading of a jack-up drilling platform due to freak waves in the North Sea has been considered by El Moctar et al. (2007) who included highly nonlinear effects, such as wave run-up on platform legs and impact related wave loads on the hull. Their analysis was based on a Reynolds-averaged Navier-Stokes solver using the volume-of fluid approach to describe the physics associated with complex free-surface shapes with breaking waves and air trapping, hydrodynamic phenomena. The wave induced loads were used in a comprehensive finite element structural model of the platform to determine deformations and stresses. The results of base shear and overturning moment of the platform subject to freak waves revealed that predictions based on the use of the Morison formula differed by not more than 25 percent from predictions obtained from CFD techniques.

The probability of the overturning of a jack-up platform was calculated as a function of sea state and operational time by Jensen (2007) using a stochastic procedure, based on the First Order Reliability Method (FORM), for estimating extreme value predictions related to wave induced loads, including second order stochastic waves.

During the demobilization of jack-up rigs, when the hull is 'pulled down' to provide a net upward buoyancy force to extricate the legs, it can attract considerable wave forces. Chakrabarti et al. (2007) have developed a simplified 'pull-down' analysis procedure considering the harmonic wave forces, added mass of the hull in water, boundary condition of the legs in soil, and distributed buoyancy springs under the hull. Using this procedure they predicted the allowable safe wave heights for a range of wave periods for a particular water depth, and draft of the hull. They presented results for one class of jack up rig showing that the leg stresses are strongly dependent on the wave periods, and indicating the importance of including dynamic effects in the pull-down analysis.

The fatigue of jacket structures is an longstanding problem that continues to attract attention. Azimirad et al. (2007) compared the results obtained for fatigue life using frequency spectra with directional spectrum in a deterministic-spectral fatigue analysis of a jacket located in the Persian Gulf. They carried out a dynamic analysis of the jacket under base waves and obtained stress spectra using the transfer functions and multiplying the frequency spectra and directional spectra, separately, and then calculated the fatigue damages for all stress spectra to get the total damage. The ratio of fatigue life obtained in the case of using frequency spectrum to the case of using directional spectrum was 0.775

Another topic of ongoing interest is wave slamming in the splash zone of a variety of bottom founded structures. Ren et al (2007), for example, investigated the characteristics of wave impact on three-dimensional structures and the spatial and temporal distribution of the corresponding impact pressures, and the influence of the wave direction on the wave impact forces on the underside of the structure.

Tower-yoke mooring systems, comprising a tower fixed at the seabed and a mooring yoke assembly connecting a platform with the tower, are used for station-keeping applications in extreme shallow water. Lui (2007) has derived exact solutions for their restoring force characteristics and the motions. He also carried out model tests for the tower-yoke mooring systems and reported excellent agreement between the analytical solutions and the measurements.

Jacket type structures can provide robust support to wind and wave energy devices (eg SEADOG, Serrahn et al., 2006) in challenging offshore environments. An interesting example of a jacket type structure used in the field of renewable energy was given by Argyriadis and

Klose (2007) who presented the results of an integrated time domain analysis of wind turbine behaviour and the structural dynamics of a complex support structure (jacket) under combined wind and wave loads in relatively deep water compared to existing offshore wind farms. The size is comparable to future wind farms in the North Sea that are currently in the design phase. For the OWT configuration investigated, they showed that the wind loads govern the fatigue design while the wave impact is only of minor importance, although the effect could be completely different in the case of smaller turbine and different support structures like a tripod.

Compliant Structures A number of compliant tower designs have been proposed over the last 25 years. A new variant has been presented by Dryne et al (2006) who carried out deepwater wave-basin tests for a series of reduced (1/80) scale model compliant buoyant towers (CBT) based on a conceptual prototype design suited for the Vincent Field situated on the North West Shelf of Western Australia. They varied seabed stiffness, additional buoyancy and platform payload, to investigate how each influenced the performance of the CBT. The dynamic characteristics and responses obtained from the tests were compared with the results from a finite element analysis and were reported to be in accordance with a reasonable degree of accuracy with the numerical predictions.

Renewable energy systems fall into all categories of bottom mounted structures. One that could be classified also as compliant has been presented by Caska and Finnegan (2007) who analysed a wave energy device that consists of a bottom-pivoted array of vertically oriented cylinders. They conducted a limited parametric study to assess the influence of important features of the array on the fluid structure interaction and resulting power output. They concluded that a transverse array of moderately sized cylindrical elements experiences an increase in performance as wave frequency is increased. The entire structure behaved as a grouping of point absorbers rather than a single large body giving an associated reduction in the forcing function due to diffraction.

2.3 Intermediate Structures

There is a class of vertical cylinders that lies outside the linear diffraction regime but in a flow regime where the maximum horizontal wave induced velocity, U_m, and period, T, are such that the Keulegan-Carpenter number, $U_m T/D$, is less than 5. In this regime, viscous drag forces are negligible and potential flow theory is valid, but the Morison inertia term only represents a first approximation to the force and other non-linear terms can become important as the wave steepness increases, particularly as the magnitude of the wave amplitude, A, approaches that of the cylinder diameter (Rainey, 1995 and Faltinsen et al., 1995).

Masterton and Swan (2006) carried out experiments relating to nonlinear wave loads acting on vertical, surface-piercing, columns in just this regime, in regular and irregular waves. They compared measured data, describing the total base shear, and over-turning moment to a second order diffraction solution and a number of higher order potential flow models. They reported a wide range of flow conditions in which the existing potential flow models provided an adequate representation of the applied loading; even in relatively steep waves. Their results also indicated important flow regimes where unexpectedly large nonlinear or high frequency forcing can arise.

In a follow up study Masterton et al. (2007) investigated the implications of their findings for operational problems observed on relatively large volume structures, particularly, the loss of effective air-gap. They considered two larger, practically important, column sizes with the largest lying just outside the linear diffraction regime. The nonlinear scattering mechanisms they had previously observed were again seen across the full range of column size although their significance reduced with increasing column size. Accordingly the second-order prediction was shown to improve for the larger column sizes, and for the largest cases they reported excellent agreement comparison between the calculated and measured data even with relatively steep waves (AK=0.3).

2.4 Large Volume Structures

Much of the work carried out with large volume structures is focussed on investigating fluid phenomena in extreme conditions, and other non-linear phenomena, together with assessing and validating numerical methods for predicting them.

Vertical Cylinders. An interesting use of vertical circular cylinders to investigate problems related to GBSs is provided by Pavone et al. (2006) who analysed diffraction by two bottom mounted cylinders taking the randomness and directional spreading of the waves into account. They proposed a new iterative procedure to estimate the largest forces on the bodies when extreme waves occur using Quasi-Determinism theory (Bocotti, 2000) to predict the force process on each cylinder when an exceptional crest or crest-to-trough height of the incident wave field occurs at a given time and position.

Gravity Based Structures The feasibility of using diffraction solutions to predict extreme green water levels beneath multi-column gravity based structures has been investigated by Walker et al. (2006). They investigated whether diffraction solutions can accurately predict the magnitudes and locations of the most extreme green water levels, and whether reliable green water measurements can be obtained for validating diffraction solutions as possible design tools. They concluded that linear diffraction theory predicts both the magnitude and location of the peak surface magnifications incorrectly whereas a second order diffraction solution provides an improved prediction, although the magnitude of the second order contributions to the overall diffracted wave field are considerable, and discrepancies between estimated and measured results increase with wave steepness and the generation of white water.

In a subsequent study, Walker et al. (2006) incorporated their diffraction analyses into a surface response surface (SRS) method (Tromans and Vanderschuren, 1995) used to compute extreme surface elevation statistics around the platform. They reported excellent agreement with experimental model test data and accurately predicted extreme crest statistics around a realistic concrete gravity-based structure.

Wellens et al (2007) used a combination of diffraction theory and a Navier-Stokes solver with the Volume of Fluid method (VOF) to predict run-up on the columns of a GBS due to the amplified incoming waves. The approach was aimed at accommodating effects such as waves overtopping the columns, and energy dissipation due breaking waves that cannot be treated by conventional diffraction theory. The output from diffraction calculations were used as input on the boundaries of the Navier-Stokes domain. They showed that it is viable to use linear diffraction results, in terms of surface elevations and velocities, to drive a fully non-linear Volume of Fluid simulation. The VOF simulation of the flow in the immediate surroundings of the GBS was in better agreement with the experiment than linear diffraction analysis but it was concluded that when simulations are required in larger domains and for longer periods of time, more accurate boundary conditions would be necessary.

The impact load of a freak wave on a cylindrical tower structure has been computed by Corte and Grilli (2006) using a three-dimensional boundary element method to derive an extreme wave event and initialize computations in a three-dimensional Finite Volume VOF model, which was then used to compute the transient load. The boundary element wave modelling involved discretisation of the fully nonlinear potential flow equations with free surface evolution.

A VOF approach has also been used by Bredmose et al. (2006) to reproduce extreme laboratory wave impacts on a gravity wind turbine foundation associated with slamming onto the under side of a horizontal platform in irregular waves with a current.

3. PREDICTING THE BEHAVIOUR OF STATIONARY FLOATING STRUCTURES AND SHIPS

The important categories in this section include spars, FPSO/FPDSOs, and very large floating structures. They raise such issues as sloshing, green water loading and air gap estimation, and can involve coupled systems and multi-body interactions.

3.1 Spar Platforms

Hydrodynamic Performances of Spar Platforms. Tahar et al. (2006) and Theckumpurath et al. (2006) separately analysed the full scale data of the Horn Mountain Spar collected during hurricanes in both the time and frequency domains. The time domain analysis agreed better with the field data than frequency domain did. Their results also showed that both the slow-drift and the wave frequency surge and sway motions are well predicted in terms of energy spectra. Qi Xu et al. (2007) also analyzed the environmental data and the Horn Mountain Spar responses to the full strength of Hurricane Ivan in 2004. Their findings confirmed both the robustness of the current spar design practice and the accuracy of the spar analysis tools.

The viability of frequency domain coupled analysis has been explored by Low et al. (2006) who performed a systematic comparison of time and frequency domain methods. In their analysis the mooring lines and risers were discretised as lumped masses connected by extending and rotational springs. Coupling between the vessel and the mooring lines was modelled by stiff springs. The vessel was subjected to first and second order wave forces, and the mooring lines to drag and inertia loading. The nonlinear drag forces were stochastically linearised iteratively.

A new simplified but efficient approximate model for the first- and second-order dynamic response analysis of truss spar platforms has been developed by Sadeghi et al. (2006). The results obtained from their model compared well with conventional numerical and experimental data. The solution of the equations of motion are greatly simplified by their approach.

Cell-truss spar platforms have been studied by Zhang et al. (2007) who presented a numerical study on their hydrodynamic behaviour. Features of both truss spars and cell spars were taken into account in this new spar concept. The whole spar system was numerically simulated, and a fully time-domain coupled analysis was conducted to investigate the behaviour of the platform both in operating and survival conditions.

The motion characteristics of a Geometric Spar were analyzed by Fan et al. (2007) for deep water. The hydrodynamic coefficients, first- and second-order wave forces and first-order motion responses were calculated. The hydrodynamic coefficients of the heave plates on the Spar were analyzed using the Morison equation. They found that the low frequency motion component of pitch of the Geometric Spar is important and cannot be ignored. The octagonal hull geometry and heave plates enhanced the drilling capability of the spar in deep water.

Spar Vortex-Induced Motions. Spars are susceptible to vortex-induced motion (VIM). Sirnivas et al. (2006) used a new generation of LES type model to simulate the flow around the Spar geometry. The new method allowed better capture of the back scatter. This approach is well suited for flows where small scales transmit a notable amount of energy to larger ones. The flow simulation was compared with experimental data.

Another approach to predicting realistic spar VIM behavior was taken by Korpus et al. (2007) who presented a modified and validated unsteady Reynolds-averaged Navier-Stokes (URANS) method. It includes the ability to address rough surfaces and high supercritical Reynolds numbers. The resulting algorithms were used to assess the effectiveness of active and passive control strategies for suppressing spar VIM. The active control system involves injecting high-pressure water tangentially into the boundary layer and has been shown to be extremely effective at reducing drag and VIM amplitudes.

Model tests of Spar vortex-induced motions at both sub-and super-critical Reynolds numbers with matching Froude numbers have been conducted by Finnigan et al. (2007). In order to assess the importance of appurtenances (chains, pipes and anodes) and current heading on strake effectiveness, tests were done with several sets of appurtenances, and at various headings and reduced velocities.

Spar Design and Installation. A spar deck float-over feasibility study for West African environmental conditions was carried out by Ji et al. (2006). Their design used two existing barges in a catamaran configuration. They discussed the weather window for spar deck installation and the importance of the synchronized motion of spar, barge and deck during the deck load transfer. The study showed that the float-over and mating operation is feasible in specified West African sea states.

The effect of heave plates on the hydrodynamic performance of a cell spar platforms was investigated experimentally by Zhang et al. (2006) who modelled and tested a variation of the cell spar concept. Experimental results and numerical predictions for the responses of the spar to the wave loading, as well as loads and added mass and damping coefficients on the heave plates have been presented.

3.2 FPDSO

The motion characteristics of an FPDSO and its sheltered riser vessel （SRV） in deep water have been analyzed by Chen et al. (2007) in the frequency domain using a double system coupled potential theory approach. The first order forces and responses were calculated and compared with model test data. The results showed large reductions in, the heave motion of the SRV demonstrating that FPDSOs are well suited for implementation for deep sea drilling operations.

3.3 Green water and air-gap

Green Water. Strongly nonlinear ship-wave interactions have been investigated by Hu et al (2005) with experiments and numerical simulation in which they applied the Constrained Interpolation Profile (CIP) method on a two dimensional box-type floating body. They concluded that for the forced oscillation test, the viscous effect on the damping force can be correctly predicted by the current CFD model. For the wave-body interaction problem, the strongly nonlinear features of the body motion were found to be well simulated in the computation.

Gomez-Gesteira et al. (2005) applied the Smoothed Particle Hydrodynamics (SPH) method to analyze wave overtopping on the decks of offshore platforms and ships. They compared their numerical results to the laboratory results presented by Cox and Ortega (2002). The SPH numerical technique was shown to provide good quantitative predictions of wave motions. It was concluded that the fixed horizontal deck above the mean water level strongly modifies the wave kinematics. The appearance of a jet close to the rear of the deck after overtopping was also observed and analyzed under extreme conditions.

A two-dimensional study of water shipping has been reported by Greco et al (2005). They investigated the main flow features and details of the water shipping, and the impact with the deck structure, using experimental and numerical tools. Their model test was carried out in a wave flume for a fixed barge-shaped structure. The green water loads on the vertical deck structure showed a two-peak behaviour which is typical for wave impacts.

Nonlinear probability density functions for predicting green water loads and volumes have been studied Hanne et al. (2007). Their models were based on the parametric model of Ogawa (2003) combined with the transformation of a second order wave crest height model. Results from the second order models were compared with model tests of a cargo ship with two different kinds of bow flare presented by Ogawa.

Yamasaki et al (2005) have developed a modified marker and cell (MAC) method to predict water impact pressure caused by green water. Also, the density function method was employed in a framework of a refined and overlapping grid system. A fixed rectangular body placed in regular waves, and a second case of a rectangular body with a vertical wall on the deck, were both considered and compared with tank experiments. Satisfactory agreement was shown for wave–body interactions and for the pressure values. The method could be extended to a moving body problem, in which the body was free to undergo heave, pitch, and surge motions.

The problem of LNG sloshing and green water loading has been studied by Wemmenhove et al (2005) who have employed a two-phase flow model based on an improved Volume of Fluid (VOF) method. The two-phase flow has the ability to simulate the effect of gas bubbles in different sizes. They have shown that the physics are more accurately simulated with the incompressible two-phase model.

Another approach was taken by Pham and Varyani (2005) who developed a revised dam-break model with initial velocity to simulate the green water phenomenon using CFD. Loading effects in both horizontal and vertical directions were analyzed and compared with experimental results. It was concluded that the green water flow on the deck of ships with forward speed is well represented by a dam-break model with initial velocity. In a follow up paper, Pham and Varyani (2006) presented an investigation into the designs of V shape and vane type breakwaters. They concluded that for both types of breakwater, the total green water load on the structure behind them is not much affected by changes in the confronting angle, and that both are effective against green water. However, V-shape breakwaters appear to perform better than vane-type breakwaters in terms of reducing the green water load as well as keeping a dry deck.

The velocity field of a plunging wave impacting on a structure has been measured Ryu et al (2005, 2006) in a two dimensional wave flume. A modified particle image velocimetry (PIV) method was introduced to obtain the velocity in the highly aerated region and the splashing water on the deck. It was found that the maximum fluid particle velocity is about 1.5 times the phase speed of the wave, while the maximum horizontal velocity above the deck is less than the phase speed. By applying dimensional analysis to the velocity data, a prediction equation was obtained for the horizontal green water velocity distribution.

Air-Gap Analysis. The evaluation of the dynamic air gap of a large-volume semi-submersible platform was made by Simos et al. (2006) from towing-tank experiments. The air gap response at different locations of the hull was evaluated under three different sea states, and the results were compared to some semi-analytical models proposed in the literature for preliminary air gap estimation. The role of dynamic coupling provided by a taut-leg mooring system on the air gap results was also studied on the basis of experimental results.

A statistical approach was taken by Forristall (2006) who considered the maximum crest over an area using a combination of analytic theory and numerical simulations. The resulting crest heights of Forristall are significantly higher than those given by point statistics even for relatively small areas. On the other hand, only a small fraction of the deck may be inundated.

Kazemi and Incecik (2007) carried out a comparative study between the theoretical and experimental analysis of air gap response and potential wave on-deck impact forces on floating offshore structures. They introduced a simplified numerical method with sufficient accuracy for the preliminary design stages of a floating offshore platform, and used it to predict the air gap response and to evaluate the vertical wave impact force. The results obtained from the proposed method were compared with those obtained from the experiments.

Low-frequency pitch motions of a moored semi-submersible in irregular sea states have been analyzed by Stansberg (2007) who addressed physical mechanisms and their significance to air-gap problems. He considered primarily excitation from wave drift and from moorings/riser systems, as well as the effects from current and wind. He also discussed the related challenges in deepwater model testing of semis with truncated moorings, and the motion and air-gap data from two previously performed model tests.

3.4 Very large floating structures

Very large floating structures are a subject of continuing interest studied by a number of authors by a variety of methods. Nagai et al. (2006) proposed a new mooring system composed of a combination of an inter-sinker, an interbuoy and an anchor-sinker. Since the motion of VLFS and any forces acting on it are of oscillating nature, the vertical motions of the inter-sinker and the interbuoy could store the swaying energy of the float and release it periodically. In this way, the system prevents the drift of the anchor-sinker or the mooring chain from breaking.

The characteristics of bending moments, shear forces and stresses at the unit connections of VLFS under wave loads has been investigated by Kim et al. (2007). The responses of the VLFS were calculated by solving multi-body equations of motion whilst considering hydroelasticity and connection stiffness. Two types of VLFS units, tandem arranged units and side-by-side arranged units, were considered in the numerical examples. Both rigid body analysis and hydroelastic analysis were carried out in the numerical study and the two approaches compared.

The hydroelastic deformation of a pontoon-type very large floating structure has also been considered by Kyoung et al (2006) who developed a finite element method for the time domain analysis with fully nonlinear free surface conditions. In their computation, with an extreme wave condition, the structural deformation and horizontal forces were obtained by varying structural bending stiffness.

Takagi and Nagayasu (2007) applied ray theory for predicting hydroelastic behavior of a mat-like VLFS. The theory itself is based on the classical ray theory, which allows a fast computational scheme. An experimental technique in a small wave tank with a mini scale model was also developed.

The existence of the upper facilities on VLFSs can influence their hydroelastic deformations. This has been discussed by Murai et al. (2006) who effectively carried out calculations for finding out their optimal arrangement. They chose vertical deformation amplitude and vertical acceleration as the evaluation factor. They concluded that the optimal arrangement of the upper facilities is changed by wave conditions.

The problem of the transient dynamic response of a coupled system consisting of a VLFS and a fluid domain subjected to arbitrary time-dependent external loads was addressed by Qiu and Hua (2007) who developed a time-domain finite element procedure for its solution. They carried out three tests: a weight pull-up test; a weight drop test; and a weight moving test, which idealizes an airoplane landing and taking off, and compared their results with published experimental data.

3.5 Sloshing

A numerical analysis of sloshing in liquid cargo tanks of membrane-type LNG carriers in a rough sea has been undertaken by Arai et al. (2006). They described the influence of three-dimensional effects due to tank motion and tank geometry on the sloshing flow, and demonstrated a strong relationship between the sloshing and the frequency of the ship motion.

The impact pressure due to liquid sloshing in LNG tanks was modelled by Kim et al. (2006) using a three-dimensional finite-element method with the tank motions having six degrees of freedom. The numerical result for an example LNG tank showed good agreement with model test results.

Lee et al. (2007a) carried out a series of parametric sensitivity studies on unmatched dimensionless scale parameters on the LNG tank sloshing loads using a CFD approach. The CFD simulations were also verified against experimental results. In a following paper, Lee et al. (2007b) investigated the coupling and interactions between ship motion and inner-tank sloshing using a time-domain simulation scheme. The liquid sloshing in a tank was simulated in the time domain by a Navier-Stokes solver. The time-domain simulation results showed a similar trend to experimental results. The most pronounced coupling effects found were the shift or split of peak-motion frequencies. It was also found that the pattern of coupling effects appreciably changed with the tank filling level.

A new numerical method for the simulation of violent sloshing flow inside a three-dimensional LNG tank considering wave breaking and liquid-gas interaction was developed Yu et al. (2007). They simulated the sloshing flow inside a membrane-type LNG tank numerically using the Finite-Analytic Navier-Stokes method.

3.6 Coupled Systems

Floating offshore structures are connected to the sea bottom by mooring lines and risers. These lines respond dynamically to the wave frequency motions of the floating structure imposed on them. Due to inertial and drag effects on the lines, they do not achieve their catenary shape instantaneously when excited by the motions of the fairlead, and so the behavior is dynamic in nature. The dynamic effects influence the maximum loads on the lines and they also affect the dynamics of the platform. Therefore, in these cases, it is important to account for the dynamic coupling between the motions of the platform and the motions of the cables. The importance of the dynamic coupling increases with water depth.

There are basically two methods to solve the cable dynamics problem, which is nonlinear; the finite difference method and the finite element method. Regarding the solution of the coupled system, the methods can be divided into frequency domain and time domain methods. The first can only deal with the linearised influence of the mooring on the platform and has the advantage of computational efficiency. Time domain methods are used when it is necessary to account for the nonlinear behavior of the moorings, and different levels of complexity can be considered depending on the characteristics of the problem to be solved. The fully coupled method considers all degrees of freedom of the floater plus the degrees of freedom of all the segments used to represent the mooring and risers simultaneously. The latter is obviously computationally intensive.

Over the past three years some work has been devoted to the development and demonstration of methods for coupled analysis. A great part of this effort has been devoted to the development frequency domain tools with the aim of reducing the computational effort for engineering applications. Garrett (2005) presented frequency domain and time domain methods and compared their results in terms of accuracy and efficiency for a large semi submersible with 16 mooring lines and 20 risers. A moderate sea state and a design storm were used as tests cases. Variances of forces and stresses on the lines were compared and the author concluded that both types of results were similar. However the frequency domain method requires two or three orders of magnitude less computational effort.

Low and Langley (2005) developed a simplified two degrees of freedom frequency domain model to represent the surge motion of the platform and fundamental vibration mode of the lines. Results from the simplified model were compared with fully coupled time domain results for a moored FPSO subjected to a severe storm. The authors concluded that coupled frequency domain calculations provide the accuracy and efficiency necessary for engineering purposes, provided that the nonlinearities of the mooring system are properly stochastically linearised. They presented further comparisons between frequency domain and time domain codes for a FPSO with spread mooring (Low and Langley, 2006), considering a fully coupled analysis with all rigid body modes of the platform. A severe storm was taken as the test case. The comparisons showed that the frequency domain results of the platform motions and mooring line forces were in close agreement with the time domain results.

An experimental investigation of an ultra deep water semi submersible which combines truncation of the mooring lines with calculation from a time domain coupled method has been presented by Baarholm et al. (2006). The truncation design aimed at reproducing the floater motion dynamics of the real deep water system, which was implemented with an optimization procedure. The coupled analysis program was applied to reproduce the measured motions responses and in general the agreement was good.

Following on from their previous work, Low and Langley (2007) discussed analysis methods for efficient coupled analysis in intermediate water depths where the mooring/vessel coupling and the geometric nonlinearity are important. They compared results of motions and line tension from three simplified methods with fully coupled results. Frequency domain results improved when the linearization of geometric nonlinearity is implemented. A hybrid method that combines the low frequency coupled response in the time domain with wave frequency response in the frequency domain compared well with the fully coupled results, using only a fraction of the computational effort.

A fully coupled time domain method, including the hydrodynamic load effects on the lines due to VIV has been presented by Rho et al. (2007) who considered a box shaped FPSO moored with 16 lines in deep water.

3.7 Hydrodynamics of Multi-Body Interactions

The calculation of multi-body-wave interactions is in most cases done by linear frequency domain boundary element methods, or panel methods. If nonlinear mechanical coupling between the bodies needs to be considered, then it is possible to transform the frequency domain results to time domain retardation functions and combine linear hydrodynamics with nonlinear mooring forces (e.g. Naciri et al., 2007).

The recent publications seem to indicate that the higher order boundary element method (HOBEM) is preferable since the numerical solution converges faster and with smaller computational effort. Computational effort becomes a problem when several bodies need to be meshed and it is necessary to calculate second order quantities by the near field method which requires finer meshes. Since these problems are, not only relatively recent, but also very complex, many of the reported studies combine numerical modelling with experimental programs.

A large part of the research effort on the topic of the hydrodynamics of multi-body interactions was motivated by the problem of LNG offloading from a floating platform to a shuttle tanker. In this case an accurate prediction of relative motions and also of wave drift forces is important. Kashiwagi et al. (2005) applied a higher order boundary element method to calculate the first order hydrodynamic coefficients and wave exciting forces on two side by side ships, as well as the mean drift forces. The authors presented a "new" far field method with control surfaces surrounding each of the vessels. They compared numerical results with a comprehensive set of experimental data and concluded that the agreement was good.

Hong et al. (2005) presented further comparisons between first order responses and mean second order forces computed by a HOBEM with experimental data for side by side ship models. Their comparison showed very good agreements both for first and second order quantities except that larger discrepancies occur for a narrow frequency band where resonant motions of the trapped water between the hulls exist.

Unrealistically high wave elevations between two bodies in close proximity predicted by numerical methods is still a concern. Teigen and Niedzwecki (2006) calculated the wave interaction effects on two side-by-side identical rectangular barges. The wave amplifications around them were calculated to second order, and regions of intense amplification were identified. The sensitivity of the results to wave heading and period was particularly strong for the sum frequency.

The problem of the resonant motion of the fluid in the gap between a LNG ship and a gravity based structure was investigated from a more fundamental point of view by Kristiansen and Faltinsen (2007). They simplified the problem by restraining the motion of the ship and assuming two-dimensional flow. Linear and nonlinear time domain boundary element codes were compared with model tests carried out in a wave flume with a two-dimensional midship section. They concluded that the linear calculated free surface elevation in the gap overpredicts the experimental data and the nonlinear results are, in general, between the linear results and the experimental data, still overpredicting the experiments.

The results from a frequency domain panel method were compared with experimental data for side by side moored LNG ships by Pauw et al. (2007). The aim was to assess a new damping lid method, originally proposed by Chen (2005) and tested by Fournier et al. (2006), to reduce the resonant wave elevation between the ships. The method is based on the implementation of a damping force at the free surface gap, represented by a damping parameter. This parameter is tuned by fitting the calculated responses to the measured ones. The authors concluded that no unique value of the parameter is valid for all measured results in the case of the small gap tested (4m). However it is better to tune the damping parameter on the basis of the second order drift force.

Kashiwagi (2007) proposed the use of wave interaction theory to calculate the hydrodynamics of several interacting bodies in waves. The advantage is the less computational effort than the direct panel method. Although the method is theoretically valid for large distance between bodies, some useful results can also be obtained for closely spaced bodies.

Van der Valk and Watson (2005) presented a comprehensive set of model test results for severe multi directional wave climates. Different side by side and tandem arrangements of an LNG and floating production barge were investigated and the authors concluded that the mooring options considered were not ideal for ship to ship transfer of LNG in a severe environment.

Very large floating structures may need to be composed of several connected bodies interacting hydrodynamically. Ikegami et al. (2005) investigated multiple connected floating body systems applying a boundary element method. The connecting forces were represented by a linear dynamic system. Model tests were performed for four connected floating body units and the agreement with numerical results for the motions of the floaters and coupling forces was reasonable. Kim et al. (2007) investigated the loads at the connections between units of a very large floating structure in waves. Multi body analysis was carried out where both the hydroelastic effects and the stiffness at the connections were considered. The HOBEM was applied to solve the body-wave interaction problem, while structural analysis was performed by the finite element method.

The dynamics of tugs when assisting LNG carriers during berthing and offloading operations in an offshore environment has been investigated experimentally by Buchner et al. (2005). They concluded that the motions of the tugs are significant even in small seastates. This work illustrates that new challenges are posed to the scientific community as the offshore activities grow and diversifies.

4. DYNAMICALLY POSITIONED SHIPS, MOBS

4.1 Introduction

Dynamic Positioning (DP) has seen a continuing growth in offshore and ocean engineering applications. Examples are: offshore drilling, supply vessels, tug boats, dredgers, diving support vessels, oil offloading, lifting, pipe- and cable laying, trenching and burial operations, autonomous under water vehicles (AUVs), remotely operated vehicles (ROVs), yachts, cruise vessels and many more. In spite of this, the developments in the model basins seem a bit marginal, at least in terms of what has been published in the open literature. Most referenced papers report on the use of DP model tests as part of a new development or application. Few papers however, present attempts to improve the quality of DP tests in the model basins or attempt to improve the DP capabilities for real applications.

A fairly complete state-of-the-art report on dynamic positioning and dynamic positioning model tests was presented in the 24th ITTC Ocean Engineering Committee report. An update is presented here.

4.2 Trends In DP Development

Dynamic positioning was developed in the late 60’s and has since seen large developments, mainly for offshore drilling operations. Both ship type DP drilling vessels and DP drilling semi-submersibles are nowadays commodities for the offshore oil and gas industry. With the rapid increase of the fuel prices, the drilling companies are rapidly investing in their assets.

Another trend is the increasing complexity of the offshore operations, including the deployment of different vessels and floaters in close proximity, such as: FPSOs which are offloaded by dynamic positioned shuttle tankers in tandem arrangement, supply vessels which use dynamic tracking to follow the motions of a sailing vessel and disconnectable FPSOs which can disconnect from their fixed mooring and switch to free sailing DP mode in the event of heavy weather.

Finally the recent developments of dynamic positioning for autonomous under water vehicles can be mentioned.

4.3 Components of a DP System

The main components of a standard dynamic positioning system (DPS) are:

- Position measuring system
- Low pass filtering algorithm
- Control algorithm
- Allocation algorithm
- A number of propulsors

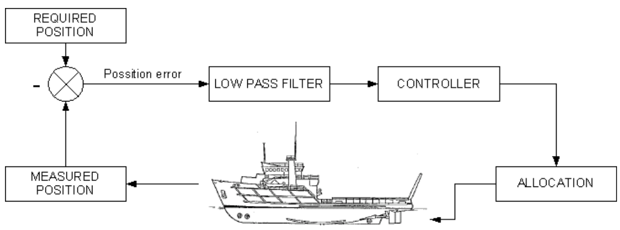

Figure 4.1 Dynamic positioning control system

The components to deliver the actual (propulsive) force may include:

- Azimuthing thrusters
- Main propellers
- Bow tunnel thrusters
- Stern tunnel thrusters
- Rudders

4.4 Control and Filtering Algorithms

A critical analysis of the control and filtering algorithms in real DP systems was conducted by Tannuri et al. (2005). They extended the EKF with three additional state variables presenting the three motions in the horizontal plane, and compared this filter with the existing filtering methods EKF-1 and EKF-RPEM. The Extended Kalman Filters (EKF) are required to remove the position errors in the wave frequency regime from the total measured position error signal.

In 2003, Tannuri et al. investigated the aspects of current force modelling for the assisted dynamic positioning of a moored FPSO. In DP assisted mooring, the mathematical model must attenuate the slow drift oscillations of the moored ship, whereas the static horizontal forces are counteracted by the static mooring system.

Tannuri et al (2005) also investigated an alternative control strategy for dynamic positioning of a shuttle tanker during offloading operations. They claim that conventional DP controllers may see degradation effects in case of large mass variations during the loading operation.

It should be noted that the above studies involved only numerical verification of the algorithms. Model test verification was not carried out.

4.5 Thruster-Thruster Interactions

Brown and Ekstrom (2005) presented results of their recent investigation of the thruster-thruster interactions during azimuthing operations at model scale. This work was an extension of pervious work by Brown and Ekstrom in 2002. Earlier research on this topic has been performed by Lehn (1980) and Nienhuis (1992).

4.6 Thruster-Hull Interactions

Not much progress was found on the thrusters-hull interaction for dynamic positioning of ships. An interesting paper by Chen and Lee (2003) however, reports on the coupling of a Chimera type Reynolds–Averaged Navier-Stokes (RANS) solver with a propeller analysis tool, to study the propeller-ship interactions for ahead, backing, crash-astern and turning conditions. Such developments may in future also be applicable for studying thrusters-hull interaction for dynamic positioning of ships.

4.7 DP Developments and Optimization

Major DP contractors claim important developments in the control strategies of dynamic positioning systems, such as high precision control, DP for calm weather conditions and DP for minimum power consumption. These strategies seem not to have yet been checked in the public domain.

4.8 DP Applications

A fairly large number of model tests have been carried out for testing dynamic positioned vessels for novel structures or new applications of DP. The focus in these papers is more on the application itself than on the actual DP control system. Examples are:

- Dimensioning of a DP system for shuttle tanker operations by Rocha and Portella (2002).
- Development of a dynamically positioned FPSO for ultra deep waters by Cortijo et al. (2003).
- Offshore tanker offloading using a novel floating DP unit by Kaasen and Olsen (2005)
- Floatover deck installation of a Spar by Edelson et al. (2007).

4.9 Autonomous Underwater Vehicles (AUVs)

The development of autonomous under water vehicles with dynamic positioning seems ongoing. The trials of these vehicles are mostly conducted in open water rather than in a laboratory environment. Examples are:

- Parametric identification of the “Olister” under water vehicle by Eteki (2004).
- Developments for the “Urashima” autonomous underwater vehicle by Aoki et al. (2007).

5. WIND, WAVES AND CURRENT

5.1 Extreme Waves

There are two distinct trends in floating structures. The first is for very deep water applications and the second is for shallow water applications. The deep water structures are mainly for production and storage of oil and gas; FPSO, SPAR, TLP and Semis are typical examples. After the existence of freak waves (or rogue waves) in deep water has been verified through remote observations of surface waves and accident reports for exceptional damage of ships and offshore structures, there has been intensive research on the generation mechanism of freak waves (Rogue Waves, 2000, 2004). Recent hurricanes in the Gulf of Mexico (GOM) such as Ivan, Katrina and Rita, even though they are not freak waves in the strict sense, are a reminder of the importance of analysis and simulation of such high waves in the ocean wave basin. van Dijk et al. (2007) reported the significant wave heights in these three hurricanes as observed on board the Marco Polo. The measured extreme wave heights exceeded the expected extreme values. In hurricane Rita a maximum wave height of 26.9 m was observed with an associated crest height of 17.4m. Significant differences in wave spreading have been observed between hurricanes Ivan and Katrina and Rita.

From the observations and interviews of captains, the extreme waves in the ocean can be categorized into long crested waves, and short crested three-dimensional waves. The former type of extreme wave maintains its shape whilst propagating for large distances, whereas the latter seem to exist over a relatively short period. The shape of the short crested wave has a sharper front and shallower trough. It is known that the long crested wave resembles the unstable wave train of the Benjamin-Feir type, whereas the short crested wave resembles the linear dispersive focusing wave (Waseda et al., 2005).

For the reproduction of extreme freak waves in laboratories, studies on generation of high waves have been carried out by controlling wavemaker signals. There are two distinctive methods for generating freak waves in laboratories. The first one is referred to as the wave focusing method which utilizes characteristics of wave dispersion and propagation. The second is to reproduce the so called Benjamin-Feir (BF) instability wave by controlling the initial sideband perturbation. Waseda et al. (2005) showed that the two kinds of extreme waves could be successfully reproduced by controlling wave maker signals in wave basin. In order to improve the accuracy of the reproduction of specific wave records, various studies have been undertaken both numerically and experimentally.

Clauss et al. (2005, 2006a) carried out a series of numerical and experimental attempts to accurately reproduce a predefined record of freak waves in a wave basin and they investigated their effect on wave and structural response (Clauss et al., 2006b).

Three-dimensional wave focusing has been investigated by Liu et al. (2005) who compared waves generated with constant wave amplitude (CWA) to those generated with a constant wave slope (CWS). Buchner et al. (2007) investigated parametric properties of laboratory made waves. They found that linear dispersion is not able to predict the extreme wave crest, and second order theory improves the prediction of the crest amplitude but the highest 10 crests in a 3-hour sea state are underestimated.

Fochesato et al. (2005) investigated the evolution characteristics of three-dimensional focusing waves using a Boundary Element Method (BEM) based numerical wave tank (NWT) in which a fast Multipole technique was adopted. Hague and Swan (2006) adopted a fully nonlinear numerical model in three dimensions based on the BEM for the simulation of free surface fluid flows, including the focusing in space and time of large numbers of wave components. They showed that the approach is capable of simulating highly nonlinear wave groups at or close to their breaking limit.

A High-Order Spectral Tank (HOST) formulation was adopted by Ducrozet et al. (2006) for improvements on the wavemaker modelling. Their HOST-wm2 (2^{nd}-order wavemaker signal) formulation was made to simulate the generation of waves in a wave tank up to second order, and their propagation was performed in a fully-nonlinear manner.

The measured wave elevations were analyzed through statistical, spectral and wavelet approaches by Balaji (2006), theoretically and experimentally. He detected the existence of, and identified, the wave groupiness using each of these methods.

Bunnik and Huijsmans (2005) compared two numerical wave tanks which used a potential flow based FEM and a viscous flow based VOF method respectively. They compared the wave propagation characteristics of each method. They then proposed a hybrid approach which combines the two methods to exploit the merit of each; i.e. no numerical damping in FEM for wave propagation, and the capability of describing violent wave kinematics in the VOF method.

One of the main issues regarding the freak waves is the investigation of their effect on structural response, as well as understanding their generation mechanism. Kinoshita et al. (2006) investigated characteristics of ship wave loads under extreme regular waves and freak waves experimentally. Minami et al. (2006) compared experimental results on whipping and slamming loads in freak waves with numerical simulations. Johannessen et al. (2006) investigated extreme wave effects on wave responses of a TLP through an extensive series of model tests for measurements of the air gap, wave loads and platform response. They also discussed the applicability of numerical simulations based on the VOF method to extreme wave cases. Buchner and Bunnik (2007) investigated the effect of extreme waves on deepwater floating structures, focussing on the numerical prediction of platform response to extreme waves. They also discussed the applicability of an improved Volume of Fluid (iVOF) method in the context of case studies for green water simulation, and for the dynamic response of a TLP.

5.2 Shallow Water Waves, Wave-Current Interactions

The shallow water wave problem has become one of the important issues in offshore hydrodynamics, both in numerical and experimental aspects, as the need for floating LNG terminals increases. The amplitude of the long period resonant motion of moored structures in shallow water is greatly influenced by the low frequency part of the incident waves, which themselves are a result of interactions of the component waves of the incident wave spectrum. Therefore the accurate reproduction of the low-frequency component of the input wave in model basin, and the interpretation of their characteristics, are very important in view of the need for performance evaluation by model tests. Stansberg (2006) has addressed the importance of wave-group induced low-frequency wave components, and he showed that special attention is needed for the reproduction of low-frequency wave component in laboratories. There are two types of low-frequency waves: “bound” waves and “free” waves. The former appear following the wave groups, while the latter propagate with their own speed. Therefore, identification and the possible reduction of the free components is of interest. He demonstrated a way to correct the effect of free wave component through experiments for bi-chromatic waves. Voogt et al. (2005) treated similar topics by investigating bound and free waves considering reflections in wave basins. They proposed an analytical model to calculate setdown in waves. Their model was based on a second order quadratic transfer function and a Lagrangian transformation for the effect of current. Validation of the model was carried out through experiments with a large number of wave probes through the basin. The separated bound wave measured in the basin showed good agreement with the setdown calculated with the numerical model.

Despite the fact that most tests for the performance evaluation of floating structures are conducted under a combined wave, current and wind environments in model basins, few reports are found for describing their interaction effects in detail. Koo and Kim (2006) discussed the effects of wave-current interaction by numerical simulation using a numerical wave tank based on a higher-order boundary element method. They addressed the issue that currents can significantly affect the motions of floating bodies through a Doppler-shift-like phenomenon. They also found that the second-harmonic horizontal force component can be of an order as large as that of the first-harmonic force at certain wave frequencies when the current speed is 10% of the wave celerity. Lee et al. (2006) investigated experimentally the wave-current interaction and its mechanism. They showed that the mean current velocity decreased with the wave-current interaction when the wave direction opposed the current. The wavelength decreases due to the wave-current interaction, and the wave height increases, but the increased wave height decreases gradually as the wave propagates forward.

6. HYDROELASTICITY AND IMPACT

6.1 Very Large Floating Structures

The importance of the consideration of hydroelasticity in the design and analysis of offshore structures has been widely recognized in research into very large floating structures (VLFS) because such huge structures cannot avoid having an inherently weak structural stiffness compared to existing structures based on rigid body design concept. Hydroelasticity in VLFS design and analysis generally contributes to mitigation of wave loads since deformation of the structure induces leading-order hydrostatic counter balancing force components when the time-scale of elastic motion is comparable with the wave period. Regarding hydroelasticity of VLFS in the frequency domain, various solution methods have been developed. These methods can be categorized as eigenfunction methods, mode-superposition methods and direct methods. Each method has its own merits and demerits depending on the application purposes. Riggs et al. (2006) summarized the results of a benchmark study on hydroelastic response on the ISSC VLFS. They concluded that the responses predicted by four different codes gave similar results; the fluid models they considered were potential theory and linear Green Naghdi theory, and the structural models used the three-dimensional grillage, the two-dimensional plate, and the three-dimensional shell approaches. Hong et al. (2005) investigated the numerical accuracy of structural stresses induced by hydroelasticity with three different approaches; the eigenfunction method, mode-superposition method and direct method. The three methods generally gave similar results for bending moments but the mode-superposition method was sensitive to the choice of the mode functions and number of modes included. Park et al. (2006) applied the analysis results of hydroelasticity to the fatigue strength analysis of a pontoon-type VLFS. Greco et al. (2006) presented a two-dimensional composite method for hydroelasticity which combined a linear method for global analysis and a nonlinear time-domain method for local analyses such as slamming.

Other topics associated with the hydroelasticity of VLFS considered so far are: the interaction with bottom topography; time-domain analyses capable of transient response and nonlinear wave condition such as tsunami; and coupled analysis with motion reduction devices such as oscillating water column (OWC) chambers, which are important for performance evaluation and enhancement in th final stage of design.

Non-uniformity of the sea bottom may cause unexpected high motion responses due to local amplification of the waves. Kyoung et al. (2005) and Song et al. (2005) both investigated sea bottom effects. Kyoung et al. (2005) employed the FEM to analyze the local change of sea bottom, and showed that the FEM is very effective and accurate for the estimation of the sea bottom effect in comparison with model test results. Song et al. (2005) used BEM for solving the VLFS hydroelasticity problem considering the sea bottom effect.

Ikoma et al. (2005, 2006, 2007) investigated the characteristics of hydroelastic response and the wave drift force of air-cushioned pontoon-type VLFS. They expanded their previous work (Ikoma et al., 2002, 2003) by adopting a three-dimensional singular point distribution method to consider side wall effect accurately (Ikoma et al., 2005), then characteristics of wave drift force were investigated. They showed a motion reduction effect due to air-cushions both numerically and experimentally. Experimental results showed that there is an additional effect of the air-cushion on the structure, which resulted in the reduction of the wave drift force. Hong and Kyoung (2006) investigated the OWC chamber effect on the motion reduction of VLFS by solving the interaction problem between a VLFS and an OWC chamber. They employed the FEM for fluid motion while the mode-superposition method was adopted for describing the elastic motion of the body. A piecewise constant approach was applied to implementing the mode-superposition technique to consider various conditions of structural stiffness and mass distributions of the structure and OWC chamber. They used a two-dimensional approach for numerical convenience. They found that the frontal shape of the OWC chamber influenced the motion reduction performance behind the OWC chamber under optimized conditions in which an extra ordinarily extended frontal wall of the OWC chamber gave a dramatic decrease of the motion response behind the OWC chamber. Their extended work (Hong and Kyoung, 2007) finally showed that the location of the OWC chamber is one of the very important factors determining motion reduction performance. They showed that the OWC chamber located far from the frontline of the structure by its width gives a better performance than the one located at the front wall. The estimated motion reduction performance was obtained as 70 % for an incident wave of 16 seconds for a 1000m long structure. Their numerical results were compared with model experiments and very good correlations were obtained.

The role of the time-domain method is becoming increasingly important for investigating transient and nonlinear effects on the hydroelastic response of VLFS. In the case of linear transient responses caused by moving cargoes, landing and take-off or falling objects, the linear approach which uses a convolution integral memory function gives good predictions for practical purposes. Under very high and nonlinear wave conditions such as for a tsunami like solitary wave, however, it is important to consider the nonlinearity of incident waves and nonlinear fluid-structure interactions directly.

Kyoung et al. (2006) presented a nonlinear time-domain approach in which the FEM is used both for fluid and structural modelling. A fully nonlinear free surface condition was implemented and the Mindlin plated element was adopted for describing elastic motion. Numerical results were compared with model experiments carried out by Endo and Yago (1996) and good agreement was obtained between the numerical results and experiments. The method was also applied to hydroelastic responses under tsunami like solitary wave conditions. Their time-domain approach was extended so that it could consider horizontal motion effects as well as vertical hydroelastic motions (Kyoung et al., 2007). The effect of the horizontal motion was considered as a normal flux assuming relatively small amplitude motion compared with body length. They found that the resonant motion of a dolphin-fender moored VLFS induced by a tsunami like solitary wave might result in a serious mooring failure since the mooring force was much higher than in the usual cases. They investigated the effect of additional damping mechanisms to the fender system, and that adding a damper to the fender is very effective for reducing resonant motion due to an impact like solitary wave attack.

6.2 WHIPPING AND SLOSHING IMPACT

When the time-scale of elastic motion is much shorter than the wave periods, the contribution from hydroelasticity generally induces higher loads and stresses, which should be included in assessments of wave loads and responses. Whipping due to slamming, and the elastic response of LNG containment due to sloshing, are typical examples of hydroelasticity caused by impact force. Whipping is a resonant elastic response associated with impact loads such as slamming, which leads to very high sharp peaks with rapid decay patterns. Springing is a resonant elastic response induced by higher harmonic wave loads when the exciting frequency coincides with natural mode of hull vibrations.

Malenica et al. (2006) proposed an intuitive approach for the treatment of hydroelastic problems associated with sloshing in which sloshing impact is classified into three main types (steep wave impact, impact with entrapped air and impact with aerated fluid) which are subsequently simplified and solved using the asymptotic impact theories fully coupled with general structural finite element codes. Storhaug and Moan (2006) investigated the whipping and springing responses of a large ocean going vessel experimentally. They compared the results with numerical results considering the steady wave due to forward speed; wave amplification due to reflection; and the bow impact force and higher order effects due to blunt bow reflection. They found that the nonlinear excitation sources affect vibration damage significantly. Deuf et al. (2006) demonstrated the applicability of the SPH method to hydrodynamic impact and fluid-structure coupling analysis. They obtained reasonable correlation between SPH simulation results and analytical results for a falling elastic wedge. Fonseca et al. (2006) presented a time domain method to calculate the ship responses in heavy weather, including the global structural loads due to whipping. Slamming forces were given by the contribution of two components: an initial impact due to bottom slamming and flare slamming due to the variation of momentum of the added mass. The structural dynamic characteristics of the hull were modelled by a finite element representation of a Timoshenko beam accounting for the shear deformation and rotary inertia. Their results for the whipping induced bending moment show a noticeable discrepancy between the simulations and experiments, and they concluded that further study is needed for finding a more reasonable choice of parameters governing nonlinear impact wave loads.

As the capacity of LNG containment increases and partial filling cases are expected more frequently than before, the hydroelastic behaviour of LNG containment due to sloshing impact loads becomes one of the more important design concerns of LNG containment. Rognebakke and Faltinsen (2006) investigated the sloshing pressure of LNG focussing on the effect of the hydroelastic behaviour of partially filled rectangular tank and the entrapment of air. Their numerical method considering both air cavities and hydroelastic effects showed good agreement with model tests. They also presented scale effects of sloshing tests in relation to different ratios of dynamic air cushion pressure and atmospheric pressure, between the model and full scales.

The hydroelasticity effects on sloshing pressure in relation to the geometry of the LNG containment has been investigated by Wang and Kim (2007) who conducted a strength analysis of an LNG tank using numerical analysis. They carried out a nonlinear dynamic FE analysis under sloshing impact pressure using a fluid-structure coupling model. In the FE simulations, the hydro-elastic effect on the structural response was studied considering LNG, foam, plywood and mastic as an acoustic medium; and a visco-elastic material, an orthotropic material, and an isotropic material, respectively. Their numerical model was validated by comparison with analytical values. They defined the hydroelastic and visco-hydroelastic load factors to measure the reduction of hydrodynamic loading when considering the visco-elastic property of materials. Their conclusion was that hydro-visco-elastic effects cannot be neglected, especially in the case of short durations.

7. RENEWABLE ENERGY SYSTEMS

7.1 Wave Energy

Many types of wave energy converter (WEC) have been proposed, but they can be broadly classified into three types: oscillating water columns (OWCs), movable body, and wave overtopping devices. A variety of theoretical and experimental studies have been carried out, e.g. Brooke, 2003 and Cruz, 2008. The basic approach, based on potential theory, for evaluating the performance of WECs is summarized by Mei (1982) and Falnes (2002).

In the experimental study of OWCs with air chambers, there is a difficulty: the hydro-dynamic and pneumatic flows require different model scales and the influence of vortex shedding and viscous effects is difficult to infer from small-scale experiments. Therefore many mathematical and numerical models have been proposed in the frequency and time domains. The effect on water of the air chamber in models based on potential theory is considered as a radiation problem involving the radiation of waves caused by an oscillating dynamic air pressure above the interface. The theory of wave interaction with oscillating water columns based on linear potential theory in the frequency domain has been summarized by Falnes (2002).

The efficiency of the wave power absorption of the floating OWC "Mighty Whale" has been calculated by Osawa et al (2004) using a three dimensional boundary element method. Hong et al. (2005, 2006) also modelled the absorbed wave power of a floating "Backward-bent duct buoy" OWC with an L-shaped duct in the frequency domain using a three-dimensional Higher Order Boundary Element Method. They calculated the drift force acting in the reverse direction of propagation of the incident waves from experimental data. Falcao (2002) considered the control of a wells turbine by employing the rotational speed as the controlling variable on a stochastic model of the fixed OWC performance.

In the time domain, Falcao and Justino (1999) developed a theoretical model based on potential theory to simulate the energy conversion, from wave to turbine shaft, of a fixed OWC plant equipped with a Wells air-turbine and with a valve for air-flow control. They expressed the radiation air-flow rate as a convolution integral involving air pressure in the air chamber. Brito-Melo et al. (2002) also conducted a time domain numerical simulation to investigate the influence of the Wells turbine aerodynamic design on the overall fixed OWC plant performance.

In order to evaluate the performance of the movable body type WECs, time domain models have been developed for predicting motions of the floating devices in waves. The method proposed by Cummins (1962) describing an arbitrary motion of floating devices as a succession of small impulsive displacements is mainly used for calculations based on potential theory in the time domain. The optimum control of the oscillation of floating WECs has been studied by Falnes (2001). Babarit et al. (2005) carried out a multi degree of freedom time domain simulation of the floating WEC 'SEAREV', optimizing the geometry of the device and demonstrating the effectiveness of the latching control. Costa (2005) developed a non-linear time domain model of the 'Archimedes Wave Swing' which is a fully-submerged device consisting mainly of a bottom-fixed air-filled cylindrical chamber and a movable upper cylinder which oscillates vertically with the changes in the wave pressure. The 'McCabe Wave pump' which consists of three barges hinged together for creating fresh water from sea water, has been modelled by Kraemer (2005) who calculated its motions in waves and its power output using a time-domain simulation.

A non-linear numerical model (AMAZIN-SC) based on the Euler equations for two-phase free surface flow, and using the Finite Volume method, has been developed by Mingham (2004, 2005) and applied to the calculation of OWC and 'Pendulor' types of WEC considering their boundary movements.

Many experiments have been carried out in the development of new WEC devices. Retzler (2006) measured the slow drift dynamics of a model of the 'Pelamis', which is a slender semi-submerged articulated horizontal cylinder with a compliant spread mooring system. He showed that the slow drift motion of the 'Pelamis' was a result of the low-frequency damped resonant response of the mooring to the second-order slow drift forces, which are predominantly due to wave power absorption.

A model of the 'Wave Dragon', which is an offshore floating WEC of the overtopping type, equipped with two wave reflectors focusing the incoming waves and a reservoir for collecting the overtopping water, has been tank tested by Soerensen et al. (2005). In their experiments they measured its motions in waves and the discharge rate due to overtopping.

Figure 7.1 A wave farm of WEC 'Pelamis'

7.2 Wind Energy

Various floating offshore wind farms have been proposed and model tests and numerical calculations carried out. In such structures, it is important to understand the coupling between the support structure and the wind turbine when subjected to combined wind and wave loading. Floating offshore wind energy research and development projects world wide have also been discussed by Henderson et al. (2004).

The technical and economical feasibility of five kinds of floating offshore wind farms including SPARs, Box Girders, Hybrid Floaters, and Seabed-seated Floaters, has been studied by Ushiyama et al (2003) under typical environmental conditions for Japan. Blade loading on floating wind turbines has been investigated by Suzuki (2007) who developed two analysis codes, a turbine blade structural analysis code, and a motion analysis code for SPAR type floating platforms. He showed that the increase of maximum load on the blade due to the motion of a floating platform is not serious, but fatigue loads can be significant. Another SPAR offshore wind turbine, the 'Hywind', has been investigated by Nielsen et al. (2006). They carried out experimental studies under coupled wave and wind loads in an ocean basin and showed that conventional rotor blade pitch control for wind velocities above rated wind speed introduces negative damping of the tower motion.

Ohkawa et al (2006) proposed a box girder grid type floating wind power system and carried out the model tests in irregular waves. They conducted a hydro-elastic analysis on the system in waves, as well as the mooring tests in a wave tank, and wind tunnel tests.

Semi-submersibles also offer the possibility of a support structure for offshore wind turbines. Shimada et al. (2007) verified the basic characteristics of the wave-induced motion of a semi-submersible floating structure consisting of a three wind turbine base floater, using numerical analysis in frequency domain and 1/50th scaled rigid model experiments. Zambrano et al. (2006) carried out a numerical calculation in the time domain for motions of a semisubmersible type offshore wind turbine in wind and waves

An unusual concept has been presented by Takagi et al. (2006) who carried out experiments and a numerical analysis of the hydro-elastic behaviour of a very large sailing offshore wind farm, composed of slender beams and demi-hulls. In their calculation, they used a pre-corrected Fast Fourier Transformation (pFFT) technique for the fluid domain and the NASTRAN program for analyzing thin structures.

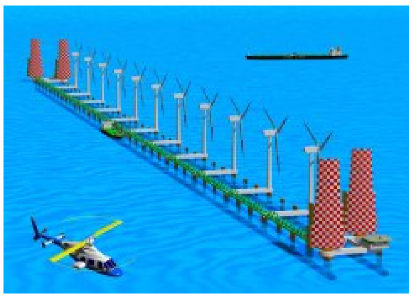

Figure 7.2 Sailing offshore wind farm

7.3 Tidal Energy & Marine Current Energy

Many concepts of tidal and marine current energy converters have been proposed (Fraenkel 2007). In order to evaluate the performance of the turbines or hydroplanes of these converters, a variety of numerical methods, such as RANS CFD, BEM, and vortex methods have been developed, and many experiments carried out.

A tidal power system supported by a bridge pier and exploiting the increase of the current velocity in its vicinity has been proposed by Kyouzuka et al (2006, 2007). They proposed a hybrid turbine, consisting of a Darrieus turbine with a Savonius rotor to improve its starting torque, and conducted the power generation experiments in a towing tank.

A floating tidal power unit, the 'Morild 1', composed of a truss structure supporting four turbines has been proposed by Berstad and Tronatad (2007). They carried out a coupled analysis considering the hydrodynamic loading and the structural response in the time domain under waves, current and wind, as well as performing model tests in a tank. In their analysis, wave loads were calculated using the Morison formula or diffraction theory based on 'strip theory'.

Wind tunnel tests and calculations using vortex methods have been carried out by Kashiwa Bara et al. (2004) on a floating buoy for tidal current power generation. The buoy had a semicircular cross section and vertical through-hole where the turbine was installed. A (three-dimensional) vortex method was also used by Coiro et al. (2005) to predict the dynamic behaviour of a vertical axis tidal current turbine. They showed that the method is capable of evaluating turbine performances for higher solidity values by comparing their results with the experimental measurements. Li and Calisal (2007) also used a vortex method to calculate the performance of a stand-alone vertical axis tidal turbine.

Taking another approach Calcagno et al. (2006) developed an unsteady three-dimensional BEM to predict the performance of a vertical axis marine current turbine. In this method, the vorticity generated on the body is assumed to be shed into a thin layer through the body trailing edge. This thin layer is approximated by a vertical surface. Li et al. (2007) also carried out the calculations and experiments for a vertical axis tidal turbine. They used a commercial RANS code and potential flow solvers such as single and multiple streamtube codes, fixed-wake vortex codes and a free-wake discrete vortex method for their calculations, and compared the relative accuracy of the different methods.

8. NEW EXPERIMENTAL TECHNIQUES

8.1 Introduction

Various types of new experimental measuring techniques are becoming available for ocean engineering model tests, such as:

- Particle Image Velocimetry (PIV)
- Fibre optic sensors
- Rapid prototyping
- Optical motion tracking

A brief description of these techniques with a review of recent developments is given in this chapter.

8.2 PIV, Particle Image Velocimetry

New experimental measuring techniques such as PIV and laser Doppler velocimetry (LDV) are becoming available for detailed investigation of the flow around the hull of a ship model or for instance the flow around models of complex offshore structures. These new techniques are particularly of interest for validation of CFD tools.

PIV is used in model basins for determining the flow field around ship models and offshore constructions, using either an earth-fixed or a carriage-fixed system. The method is relatively fast as a whole measurement plane is measured at once, but several measurements may be needed to get the proper average velocity field in a turbulent flow, or to get the turbulence properties.

The PIV principle is schematically illustrated in Figure 8-1. The three-component or stereo PIV technique uses two digital cameras for recording the displacement of the tracer particles in the flow. The x, y and z components of the velocity vector are measured in the planar measurement area illuminated by the laser sheet.

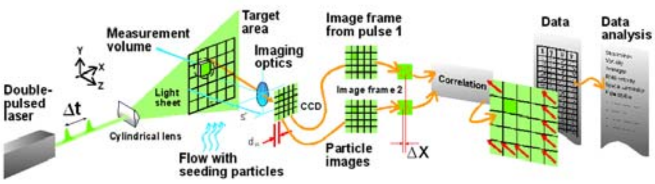

Figure 8.1 PIV principle.

The two synchronised digital cameras record the displacement of the particles between two subsequent illuminations with the laser sheet. The time lapse between the images is short, typically 5 to 20 ms. The displacements and velocities are derived using a cross-correlation technique. The out-of-plane component of the velocity vector is obtained by the stereoscopic images from the two cameras, as shown in Figure 8.2. The projection of the real displacement vector (blue) on the illuminated measuring plane (green) corresponds with the recorded displacement vectors of the two cameras (purple and red).

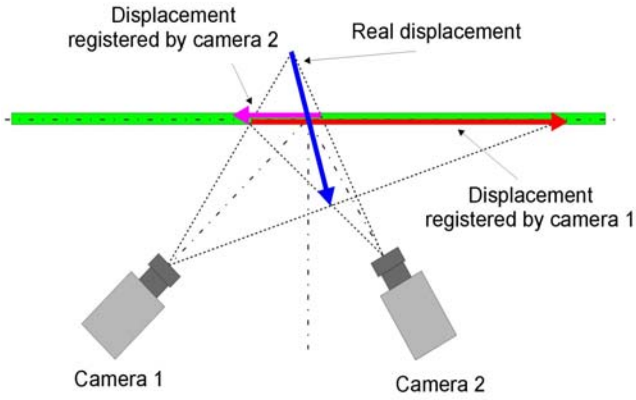

Figure 8.2 3D-PIV principle for x, y, z velocity component measurement.

Capabilities of state-of-the-art digital camera PIV technology for towing tanks and model basins are:

- 1600x1200 pixels
- 10 bits resolution
- 15 Hz sample rate
- x, y and z velocity components measured in plane of laser sheet (3C-2D technology)
- typically 50x50 velocity vectors in measuring area
- typical accuracy of 5%

An increasing use of PIV measurements in towing tanks and model basins has been observed. However the technique needs further maturing for a wider use. The optical accessibility of the measurement plane can be problematic in practice and often requires the use of a streamlined underwater housing. A powerful laser is needed to illuminate the particles in the measuring area. Also the choice of the seeding particles and applied method of introducing the seeding particles into the flow are important aspects for the success of the PIV measurements.

Some examples of successful applications for ship propellers, flow around bilge keels and cylinder flow are briefly discussed below.

The wake of a model ship propeller has been studied experimentally by Felice et al.

(2004) using two-dimensional PIV. By comparison with LDV measurements they concluded that PIV has proved to be a suitable means of investigating the complex flow field in the wake of a propeller.

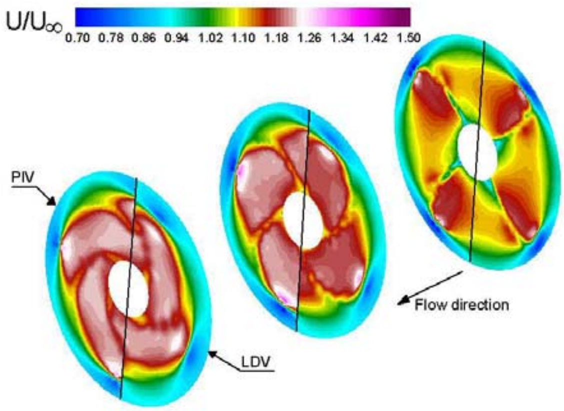

Figure 8.3 PIV and LDV measurements in the wake of a model ship propeller.

As part of the EXPRO-CFD project detailed PIV measurements were conducted on a fixed vertical cylinder in waves and on the bilges of a floating FPSO model in waves. Results were published by Gallagher and Woodburn (2003) and by Huijsmans and Borleteau (2003).

Grant et al. (2007) presented stereo PIV measurements for three-dimensional unsteady flow around the bilges of a sailing ship model in beam waves. The flow maps clearly show the shedding of the tip vortex from the bilge keel.

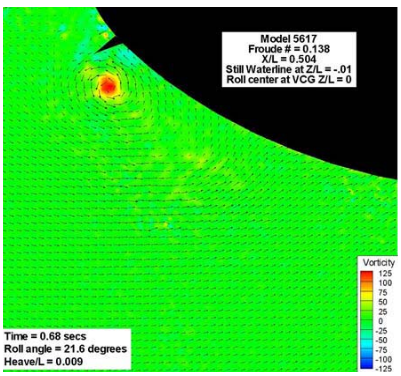

Figure 8.4 PIV measurements around the bilge keels of a sailing ship model in beam waves.

PIV measurements were carried out by Soni and Larsen (2007) for studying the vortex shedding from forced oscillation tests on a 0.1 m diameter rigid cylinder. The cylinder was forced to follow an oscillatory pattern found from a first set of experiments with a 20 mm flexible pipe model. The PIV measurements show the alternating vortex shedding in the cylinder wake at Reynolds 4,000 to 4,500.

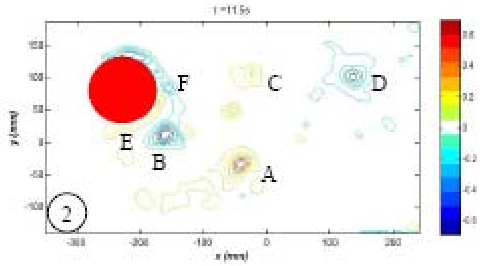

Figure 8.5 PIV measurements in the wake of a 100 mm forced oscillated rigid cylinder.

De Wilde et al. (2006) performed PIV measurements in the wake of a stationary and forced oscillating rigid 200mm cylinder. Reynolds numbers were between 40,000 and 200,000. The PIV measurements showed a strong three-dimensionality in the flow.

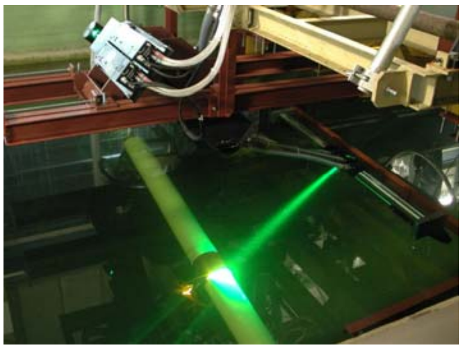

Figure 8.6 PIV set-up for 200 mm rigid cylinder.

The kinematics of the diffracted wave field of a rigid 160mm vertical surface piercing cylinder was studied by Kristiansen et al. (2005) using PIV. The disturbed velocity profiles at 0.1D and 0.5D upstream of the cylinder were presented. The kinematics of a breaking wave over a two dimensional structure at laboratory scale was studied by Ryu et al. (2006). They used a modified PIV method called "bubble image velocimetry" (BIV) for measurements in the highly aerated regions.

8.3 Fibre Optic Sensors

Fibre optics is a particularly new experimental technique which is seeing its first applications in towing tanks and model basins. The technique is based on the same fibre optic technology used in communication which has seen very rapid developments in the last decades. For model tests the technique is attractive when a large number of sensors are required in an area that is small or a difficult to access. Problems with a large number of electrical cables can be avoided with fibre optics. In one single fibre optic line of typically 0.3 mm diameter, literally several hundreds of sensors can be mounted. Optical strain gauges are the most common application, but several other types of sensors are available as well.

There are many different types of optical fibre sensor, working on different principles, such as: intensity modulation (e.g. microbending), interferometry, polarization effects, refractive index changes and reflectometry. One relatively mature type which appears to be particularly attractive in many applications is the Fibre Bragg Grating (FBG). The measured shift in reflected wavelength from the sensor can be interpreted as a measure of the local strain.

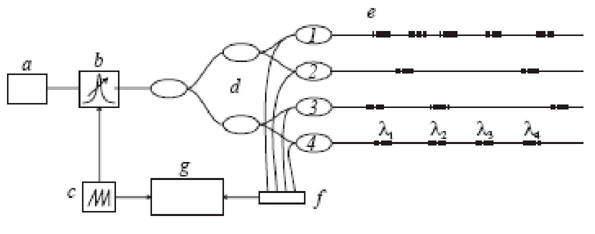

Figure 8.7 schematic representations of 4 fibre optic lines with FBG and wave-division multiplexing.

De Wilde and Huijsmans (2004) used Fibre Bragg Gratings (FBG) type fibre optics for measuring the in-line and cross-flow vibrations of a 12.6 m long 16 mm diameter steel pipe in flow. Lie et al. (2007) measured the vibrations a 20 m long 120 mm diameter full scale umbilical with fibre-optic strain gauges inside at 10 equally spaced stations.

8.4 Rapid Prototyping

Rapid prototyping technology is a group of manufacturing processes that enable the direct physical realization of three-dimensional computer models. This technology converts the three-dimensional computer data provided by a dedicated file format directly to a physical model, layer by layer with a high degree of accuracy. The technology is fast developing and may become very competitive to traditional model building techniques, considering construction time and degree of detail.

Wieneke-Toutaui and Gerber (2003) presented the use of the rapid prototyping technique for a scale 1:11 model for the GEOSTAR project.

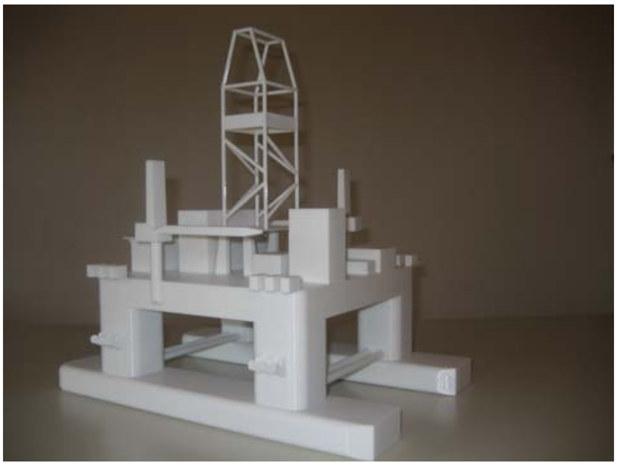

Figure 8.8 Scale 1:300 demonstration model of drilling semi, manufactured with rapid prototyping (courtesy MARIN).

8.5 Optical 6 DoF Motion Measurements

Optical motion measurements of ship models, floater models or rigid bodies have become the standard in most towing tanks and model basins. Two systems seem to be most widely used at this moment:

- The two-dimensional position of retro-reflective markers on the model is determined with high accuracy by the cameras. The three-dimensional position of the markers is calculated by combining two-dimensional data from several cameras. The multiple cameras are often positioned on the sides of the basin.
- A camera with three CCD units is used to measure the position of one or more infrared LED markers on the model. By using multiple markers, the position and orientation of the object can be accurately calculated.

An underwater version of both systems is currently available for use in model basins.

Some examples of recent applications of optical six degree of freedom motion tracking systems in model basins are given below.

Xin et al. (2006) used the system with the retro-reflective markers for measuring the six degree of freedom motions of a scale 1:64 FPSO model. Kim et al. (2004) used the system with active infrared LED markers for measuring the three degree of freedom motions at 47 positions of a scale 1:125 dolphin-fender moored pontoon-type structure.

9. PROGRESS IN CFD

9.1 Introduction

A continuing expansion of the use of CFD in ocean engineering applications can be observed, and this situation is clearly reflected in the other sections of the state of the art review. However, in this section, the most significant recent developments in CFD in the context of ocean engineering will be reviewed in more detail. The review considers first the practical fields of ocean engineering that have been most influenced by recent advances in computational fluid dynamics. Then, some insight into generic developments and concerns in relation to CFD are given.

The main practical application domains concerned with the development of CFD are the following:

- Violent flows, impact, slamming, green water on deck.
- Coupled fluid-structure interaction modelling
- Cylinder flows, risers, VIV
- Wave-structure interactions, including viscous effects and/or extreme waves

Regarding numerical methods themselves, significant recent development have been:

- Hybrid potential/viscous flow coupling schemes
- New methods adapted to massive parallel computing.
- Code verification, uncertainty analysis

9.2 Ocean Engineering Applications Impacted by CFD Developments

Violent Flows. The simulation of violent flows related to impact, slamming, sloshing, and green water on deck, is clearly an area in which CFD has showed very significant progress in recent years.

In Hu et al. (2007), recent developments of the so-called Constrained Interpolation Profile (CIP) method have been shown to improve the capacity of the method to capture impulsive internal impact loading associated with sloshing.

Kim et al. (2007) compare SPH and VOF solvers applied to the simulation of violent sloshing flows.

Oger et al. (2006) apply an improved Smooth Particle Hydrodynamics (SPH) method to two dimensional impact problems. Validations of local and global quantities against experimental results have been presented. Further applications using a parallelised three dimensional version of the code are described in Oger et al (2007).

Souto-Iglesias et al. (2006) use a SPH algorithm to compute sloshing flows and associated loading on ships, while Wemmenhove et al. (2007) and Peric et al. (2007) apply VOF-type solvers to the simulation of sloshing in LNG tanks.

Shibata et al. (2007) present the application of the Moving Particle System (MPS) method to the three dimensional simulation of the coupling between ship motion and water on deck.

Coupled Fluid-Structure Interactions. Both local and global fluid-structure interaction problems fall in this category. In the first case, the interest lies in the simulation of local structural loading and possible failure that may result from slamming or sloshing flows.

In the second case, the objective is to get access to the global hydro-elastic response of a compliant structure in waves. Large container ships in waves represent a typical application of this sort of approach.

State of the art contributions to both local and global fluid structure interaction modelling may be found in Wu and Cui (2006).

Cylinder Flows, Risers, VIV. This topic is of obvious interest for ocean engineering, and related CFD calculations remain challenging. However, we refer to the report of the specialist committee on vortex induced vibration (VIV) for more information, in order to avoid any overlapping.

Wave-Structure Interactions, Including Viscous Effects and/or Extreme Waves. Yang et al. (2007) report on the simulation of extreme ship-wave interactions including green water on deck. The numerical model is based on a Finite Element Method (FEM) for solving Reynolds averaged Navier-Stokes equations, associated with an interface capturing scheme for the free surface. Satisfactory comparisons with experimental data are reported. However, regarding similar developments, the question of the accurate simulation of ship-wave interactions over long periods of time remains open. Wemmenhove et al. (2006) apply the two-phase Volume of Fluid model Comflow to study the effect of breaking waves on offshore structures.

Hybrid Potential/Viscous Flow Coupling Schemes. This type of approach consists of exploiting a potential flow model for the representation of incoming waves, while the interaction with the structure is treated by a CFD approach. Such developments aim at a more efficient use of computing resources. Both functional decomposition techniques (Ferrant et al., 2008) and domain decomposition techniques (Wellens et al., 2007, Kihara et al., 2007) are implemented for this purpose.

New Methods Adapted To Massive Parallel Computing. A recent trend, concerning both naval architecture and ocean engineering domains (amongst others), can be observed towards the development of new strategies for the numerical modelling of free surface flows. The common objective of these developments is to develop numerical schemes able to take advantage of massive parallel computers used nowadays for High Performance Computing (HPC). The explicit character of the SPH method makes it a good candidate for massive parallel computing, despite the lack of data structure which requires a dynamic task allocation procedure (Oger et al., 2007). There is also a clear trend towards the development of innovative methods based on Cartesian grids, see e.g. Dommermuth et al. (2007) and Yang et al. (2007), in which massive parallel computation of ship flows are presented, based on domain decomposition together with an immersed boundary representation for the body geometry.

Code Verification, Uncertainty Analysis. While the use of CFD is growing rapidly, the assessment of the quality of numerical results is becoming an important issue. Besides the classical approach of validating numerical models against experimental and/or analytical results, the approach of code verification through manufactured solutions is worth mentioning (Eca et al., 2006). The numerical estimation of simulation error bars associated with uncertainties of the physical problem and data seems also promising, see e.g. Lucor and Triantafyllou (2007).

10. EXISTING PROCEDURES

10.1 Laboratory Modelling of Multidirectional Irregular Wave Spectra (7.5-02-07-01.1)

The committee reviewed the existing procedure 7.5-02-07-01.1 for the laboratory modelling of multidirectional irregular wave spectra. The structure of the original document was adequate. Some minor changes were made to the text. Two references were added related to the analysis of multidirectional waves.

10.2 Experiments with Offshore Platforms (7.5-02-07-03.1)

The procedure 7.5-02-07-03.1 has been reviewed and consolidated towards the floating platforms analysis. This made it slightly different from the corresponding one from the Seakeeping Committee.

The procedure addresses topics such as the need of a well posed run matrix, the model geometry and inertia adjustments, the instrumentation and its calibration and also the data collection analysis and the presentation of the results. In addition, the test parameters are relating to topics such as the wave heading, the mooring calibration, and the drift forces, are discussed. The procedure concludes with several references where benchmarks may be found.

10.3 Model Testing in Regular Waves (7.5-02-07-03.2)

The committee reviewed the existing procedure 7.5-02-07-03.2 for the analysis of model test results in regular waves. The structure of the original document was adequate, as well as the recommended procedure to analyze the measured signals and the recommendations for several parameters related to the preparation and performing of the model tests.

Regarding the presentation of results, it is recommended that, besides the amplitude and phase angle of the first harmonics, representing the transfer functions, the amplitudes and phase angles of the second and third harmonics of both the leading signal (incident wave) and the responses are also presented. This is useful to characterize properly the harmonic content of the signals since nonlinear signals may include important higher order effects. The mean value of the responses can also be presented, as well as the average values of the positive and negative peaks of the signals.

A small subsection of Uncertainty Analysis was included in the Validation section, which basically refers to other ITTC documents. Recommended procedure 7.5-02-01-01 presents a methodology to estimate the uncertainty in experimental results of fluid dynamics, including experimental data from towing and seakeeping tanks. Recommended procedure 7.5-02-07-02.1 demonstrates the procedure for uncertainty analysis with an example of experimental data of the vertical motions of the S175 containership in regular waves.

The committee recognizes that the present document does not include references with benchmark experimental data specific of ocean engineering problems; however the committee is not aware of any available and complete set of results including uncertainty analysis according to ITTC recommendations.

10.4 Turret Tanker Systems (7.5-02-07-03.3)

As part of its review of the existing ITTC procedure 7.5-02-07-03.3 on Model Tests on Tanker-Turret Systems, the OEC of the 24th ITTC referred back to the ITTC procedure on Floating Offshore Platform Experiments (Procedure 7.5-02-07-03.1). It concluded that there were considerable areas of overlap between the two and that only a few modifications were required to the original procedure to extend its scope to cover Tanker-Turret Systems. It therefore recommended that the procedure on Tanker-Turret Systems should be removed and that the procedure on Floating Offshore Platform Experiments should be appropriately extended. It updated the procedure on Floating Offshore Platform Experiments appropriately. The present committee has also reviewed Procedure 7.5-02-07-03.1 and agrees with the conclusions of the previous committee.

10.5 Hybrid Experiments and Numerical Simulations (7.5-02-07-03.4)

Procedure 7.5-02-07-03.4 on Hybrid Model Testing was introduced by the 23rd ITTC (2002). The purpose was to document a tool or method for carrying out deep-water model tests in a test basin of limited depth, by means of a truncated set-up combined with computer simulations. To the present (25th) ITTC Ocean Engineering Committee's knowledge, the particular testing technique described in this Procedure is not in use as of today. It is recommended that the existing Procedure be reviewed again at a later stage when more experience is gained within active hybrid testing.

10.6 Truncation of Test Models and Integration with Numerical Simulations (7.5-02-07-03.5)

The 24th ITTC Ocean Engineering Committee proposed a new Procedure 7.5-02-07-03.5, on truncated model systems with passive (off-line) integration. This procedure has been reviewed and updated by the present (25th) ITTC Ocean Engineering Committee. This has introduced minor changes in wording, and inclusion of a list of references in the Procedure.

11. BENCHMARK DATA FOR VALIDATION OF CFD CODES

The ITTC Ocean Engineering committee covers moored and dynamically positioned ships and the modelling and simulation of waves, wind and current. Task 3 of the committee's tasks involves a critical review of validation of prediction techniques, including: a) Identifying and specifying requirements for new benchmark data; and b) outlining a benchmark study using a simple geometric form for the application of unsteady RANS codes to wave load problems. The study should include validation against experimental data

In the first OEC meeting (Wageningen, June 2006), the committee generated the following observations:

- Considerable benchmark data for CFD already exists either in the public domain or in the keeping of committee members,
- Existing data is not wholly appropriate for benchmarking ocean/offshore engineering applications,
- Suggested areas for OE benchmarking included: impact problems; multiple body problems; fundamental flow studies on bodies with simple geometries,
- The benchmark data should be relevant to other techniques than just RANS codes, such as SPH,
- The data should allow benchmarking with

respect to viscous effects.

It was decided that ‘unsteady RANS codes’ should be widened to include all CFD codes appropriate to fluid/structure problems in waves. The committee concluded that the benchmarking exercise should focus on a body of simple geometry, that the data should comprise local pressures as well as global wave loads, and that PIV measurements be taken where possible.

In the second ITTC OEC meeting (Korea, December 2006), two candidates were proposed for the CFD benchmark study: a) existing ISSC experiments for wave run-up on a cylinder supplemented with new experiments including force measurements; and b) existing non-oscillating and forced oscillation experiments on a circular cylinder in current

Details of the case studies are presented in the Appendix.

12. VALIDATION OF SOFTWARE FOR PREDICTING WAVE LOADS AND RESPONSES OF OFFSHORE STRUCTURES

One of the tasks based on the recommendations of the 24th OEC was to develop new procedures for validation of frequency domain and time domain codes for predicting loads and responses of offshore structures. The work was to be carried out in cooperation with the Seakeeping Committee.

The Seakeeping Committee (SC) of the 25th ITTC has prepared a new procedure for “Verification and validation of linear seakeeping codes” which covers frequency domain and time domain methods. The OEC reviewed the document and proposes one common procedure for advancing ships and for stationary offshore structures, with the same recommendations regarding documentation, verification and validation of linear seakeeping codes. There are some aspects which are specific to ocean engineering, or offshore, structures and these should be identified as such and added to the former as separate sub-sections in the document.

In the SC document the Verification activities are clearly distinguished from the Validation activities. The recommendations are mostly independent of the method used to solve the problem. On the other hand, one can say that the existing tools to solve the hydrodynamic problem for ships and for stationary floating structures are similar in the sense that they are based on inviscid fluids and boundary element methods (the ones that can be used at present for engineering applications). The differences lie basically in the way the boundary conditions are represented (or simplified). For these reasons a great part of the procedure may be similar for ships and for offshore structures.

Some aspects which are specific to offshore structures include: the effect of water depth, multi-body interactions and second order drift forces. The methods to solve these problems are more a generalization of the methods already covered by the common proposed procedure than new methods. For this reason it is proposed that these specific topics are covered in new sub-sections added to the common document. Nonlinear effects on offshore structures should also be covered by the new procedure, namely the nonlinear geometry effects and nonlinear free surface effects. It is suggested that the former topics specific to offshore structures are considered by the next OEC.

13. MULTIPLE-SCALE MODEL TESTING

13.1 Introduction

Multiple-scale model tests present a series of difficult issues in experimental research. Some important examples will be discussed in the following case addressing aspects relating to both the hull and lines (mooring lines and risers) in model design. Truncation, clashing, interference, oscillatory behaviour, VIV and VSIV are briefly considered to stress the need for a correct consideration of line damping effects. However, at least for the case study, the inertia and restoring forces are taken to be well represented in an ocean basin.

13.2 Case Study

The multiple-scale of model testing can be better understood by considering a well defined and typical case study. The one selected here is an Floating Production Storage and Offloading (FPSO) platform of 300m length, held on location by 20 mooring lines, with 100 risers of different kinds, in over 1500 m water depth, and subjected to random ocean waves, wind and currents. For such systems, it has been natural to resort to all the available engineering resources to assure the success of the project. One of these resources is model testing in a deep ocean basin. Several large and deep ocean basins affiliated to the ITTC have the capability to perform this kind of test.

13.3 Model Test Design

The central issue for model testing is to define the scale of the model, and whenever gravity plays a dominant role, the Froude number equality generally prevails in the scale definition. ITTC community experience has confirmed that wave effects on larger bodies are well represented physically in model testing basins. Hence, based on the ocean basins sizes and wave generators capabilities, typically, the scale factor ranges from 50-90. Smaller scale factors of, say 40-50, would lead to models that are too large to construct and manipulate conveniently. On the other hand, larger scale factors of, say 100-110, would require very sensitive instrumentation that is normally not available.

For the FPSO case study, one feature is that the floating body is not freely floating. The compliant mooring lines are responsible for avoiding horizontal drift and bringing small horizontal restoring properties. If the mass is large (of the order of 300,000 ton) and the restoring properties are small, the horizontal natural frequencies are very small, away from the typical wave period range (5-15 s). The motions at these natural frequencies are excited by random seas due to the presence of wave grouping which produces second order low frequency wave forces with a broadband character. This effect is resonant. Hence, some form of damping is essential to control the response at resonance. Of the possible available mechanisms (within the scope of the present text), the mooring line damping (MLD) contributes most significantly to the final behaviour for the horizontal platform motions. The focus in model design should be the way the energy is dissipated. Is the energy dissipation mechanism well represented in the ocean basin?

In any case, the model test design should consider three aspects that may go beyond geometrical similarity. These are correct representation of the inertia, the damping and the restoring forces. Fortunately, this is well addressed for large bodies. The geometrical similarity alone is enough to take care of the effects corresponding to the added mass, the vertical restoring forces and damping due to radiation. These are the dominant forces for first order wave phenomena. The exception is for roll where viscous forces are important. But for this, also the dominant viscous separation is well represented in the model by geometrical similarity. The full scale mass is also easily represented using internal ballast to assure Froude scaling.

At this point, it is worth to mentioning that several aspects of the MLD have been studied during the FPS2000 JIP in the early 90s. Several comments made here are based on these results. Some of the references are (Huse and Matsumoto, 1989), (Huse and Lian, 1990), (Huse and Oritsland, 1990) and (Huse et al, 1991).

13.4 Line Modelling I

Ideally, the model test design would also have to match all three aspects (inertia, damping and restoring efforts) in relation to the lines. A fortunate point is that, at least for the case study, the inertia of the lines is usually not important for either the horizontal or the vertical floater motion. It is also fortunate that the restoring force representation due to the lines is easily achieved. This is a static aspect and both the global restoring forces and angles at the top connection, now-a-days can be determined from a variety of fast and user friendly multiple lines computer codes. These codes can predict the response on both full and model scale, making it possible to design the model line arrangements. It should be noted particularly that the mooring lines are mainly responsible for the global line restoring forces and may be treated differently to the risers whose top angles are usually much smaller. Of course, the model test design should include truncation (see below). Usually the method is to use an iterative process that is straightforward, because the cited codes are themselves straightforward. On the contrary, the damping caused by the lines is an open question as discussed below.

Of necessity the FPSO model has to be placed in an ocean basin with a limited depth. If the scale is 1:70, the basin should have its depth equal to 21 m. If the mooring system is a catenary type (mooring radius about three times the depth), the mooring diameter would have to be 130 m (for a taut-leg system the diameter is less extreme; approximately 40-45 m). If the geometrical similarity of the mooring lines is to be kept, a 3 inches full scale diameter, line would correspond to a 1 mm diameter line at model scale. Ignoring the risers for the moment, the 1:70 the catenary moored case study model would reach several physical limitations. With respect to the required 21 m depth, there is no such a deep ocean basin (see ITTC member ocean basin descriptions) in the world. For the required 130 m diagonal again, there is no ocean basin with such a large diagonal. The immediate conclusion is that truncation is inevitable for the case study. The required line diameter (1 mm) is possible. However, it is usual to resort to diameter distortion (see below) for damping adjustments, since the diameter is not tightly constrained in relation to representing accurately the global restoring forces and angles at the top connections. Further discussion on this topic is presented by Kendon et al (2008), in which more references may be found.

13.5 Multiple Lines Behaviour

Before discussing line damping adjustment, it is worthwhile to consider the important elements of marine cable behaviour, and select from them the important aspects to be modelled in connection with floating bodies.

The shape and the diameter are important to define the drag forces, which dominate the energy dissipation by the lines. Together with the static global shape the diameter, or more accurately, the equivalent diameter is the important parameter in relation to MLD at model scale. If there is a current, the correct new induced static shape is also important, since the waves would excite an oscillatory mechanism about this new shape. Hence, in principle, to simulate the correct drag effects, the oscillatory behaviour must also be calibrated. For an ideal physical model, Reynolds number will define the drag effect coming from the constant current but one needs another non-dimensional number that will control the oscillatory effect.

A seminal paper by Keulegan and Carpenter (1958) describes an investigation into oscillatory flow effects by an interesting setup in a sloshing tank used for measuring forces on the cylinders placed on the wave nodes. Later research, using oscillating U-tube tanks, has confirmed and organized the results for drag and inertia coefficients (Sarpkaya and Isaacson, 1981). The non-dimensional parameter that controls the oscillatory effect is denoted the Keulegan-Carpenter (KC) number. For a cylinder residing in a harmonically oscillating current, the KC number is proportional to the ratio the amplitude of the oscillations of the fluid particles to the diameter of the immersed body. For small KC (less than 10) the drag coefficient may be proportional to the KC (Faltinsen, 1990). For large KC, the traditional flat response for two dimensional cylinders under transverse constant directional flow in the usual Reynolds number range (~500 to ~500,000) may completely break down (Sarpkaya and Isaacson, 1981). The reason appears to be that the vortices shed into the flow return to the cylinder on flow reversal and modify the ambient flow. What then is the correct drag coefficient that should be used in numerical codes and in the model test to achieve possibly equivalent lines (but see below)?

The line modelling problem in the present case study is even more complicated. The flow may be oscillatory due the wave field but the lines are not fixed. The KC number based on the amplitude of the wave flow is a valid characterisation of the local flow when investigating fixed jackets but clearly, it is not representative when the lines may move. Due to the large span, the lines are usually compliant. They have infinite modes of vibration. The current easily excites vortex induced vibration (VIV), which increases the drag, which itself affects the MLD. To consider the VIV effect correctly, there are two more relevant non-dimensional parameters. They are the reduced velocity (the transversal current velocity normalised by the excited natural frequency and line diameter) and the mass ratio (it introduces the effect of the cable inertia with respect to the added mass) (Blevins, 1994). It is easy to understand that truncation will affect the reduced velocity and it seems a difficult exercise to correlate the reduced velocity since it involves different spans and compositions. On the other hand, the mass ratio may be made consistent with the plane linear mass necessary for the lines' catenary behaviour affecting the line angles at the top, and consequently the global restoring capability. However, what is the point to have one parameter correlated and the other not?

Another recent study in the context of deep water risers concerns vortex self-induced vibration (VSIV) (Fernandes et al, 2008). The study shows, both in model tests and at full scale, that a steel catenary riser (SCR) may have a VIV response without current excitation (see also Sumer and Fredsoe, 1999 and Le Cuff at al, 2005). The cause is that the line's own motion induced by the platform top connection point motion also generates vortices leading to transverse forces and motions. This phenomenon, in addition to the KC, the reduced velocity and the mass ratio requires also the relative frequency correlation (the lateral response frequency divided by the excitation frequency). However, this parameter would be difficult to correlate in the case of truncation.

Another aspect of the case study is the line quantity, a total of 120 lines. One must also consider the interference effects. In the context of fixed jackets, the bodies are fixed, and the there are several results for the drag of bodies under interference for both tandem and side-by-side relative positions. However, when the lines move, as in the case study, the interference consequences are not very clear yet. Only simple cases have been under investigation (see for instance Assi et al. 2007, Baarholm et al., 2005 and 2007, Blevins et al. 2007 and Fernandes et al. 2008). It is clear, however, that interference will lead to different oscillatory behaviour, leading in turn to different drag coefficients that themselves will change the MLD. This is even more complicated to model if truncation of the lines exists since line truncation cannot accommodate interference effects. How to reintroduce interference effects into the problem is a major issue.

13.6 Line Modelling II

In addition to the aspects discussed above, it is worth mentioning that it has become common practice to use line concentration, which is to use one equivalent line to replace a number of similar lines. This practice introduces more difficulties since most of the aspects discussed above are neglected.

The current procedure is simply to obtain the equivalent line diameter by diameter distortion in such a way as to represent the drag forces of the complete lines in the full scale model by using Froude scaling. This leads to equations like equation (1)

$$D_m C_{Dm} = n_{lines} \frac{D_p C_{Dp}}{\lambda} \qquad (1)$$

where: $(.)_m$ refers to model properties; $(.)_p$ refers to prototype properties; $n_{lines'}$ is the number of lines to be represented; D is the line diameter; C_D is the line drag coefficient; and λ is the linear scale factor

13.7 Conclusions

Due to the overall complexity of such problems, a case by case approach is highly advisable. All the previous knowledge must be collected for each case in order to forecast approximately the loading and responses involved. Based on the ocean basin experience (requiring several model tests of the same system) and based on previous or concomitant numerical simulations, it is possible to predict which effects are the most important for the model test design. Hence, what to do with all the multiple-line effects influencing the damping, even for the case study, is far from reaching a standard.

However, for the case study, the multiple-lines model test design should consider the following:

- the inertial effects are negligible;
- the statics (global restoring force plus the vertical angles at the top connections) maybe designed iteratively with user-friendly computer codes;
- the damping representation, using diameter distortion, lines concentration and truncation should use (1)

Finally, a concluding comment should be made about the hybrid model testing methodology as discussed in ITTC (2005). By this method, the complete reduced model simulation is not required, since advanced computer codes may be used to extrapolate the results. One should be sparing in the use of this method, at least for new systems with multiple lines, and also when the floater may not be considered large as compared with the lines.

14. MODELLING WIND IN MODEL BASINS

14.1 Physical Modelling In Model Basins

Wind loading is an important environmental parameter that influences the design of offshore structures, particularly in harsh environments. Up until now, the following four methods have been used for generating wind forces in model basins: fixed banks of wind fans; wind fans on the model deck; spring-weight systems (or winches); and wave tanks in wind tunnels.

In the method of using a fixed bank of wind fans, the wind load is simulated with the help of blowers placed in front of the model. In the simulation of the actual wind in the model, the Reynolds number for the wind is not reproduced. Sometimes, the calculated mean wind load is scaled using Froude's law, and the mean load rather than the wind speed is reproduced in the model by adjusting the location and speed of the fans as well as the placement of the superstructure (Chakrabarti, 1994). This method seems to be the most popular method and is widely accepted in most of the commercial wave basins. Kaasen et al (2005) used this method to study the positioning behaviour of a DP unit attached to a tanker. Buchner et al (2001) mentioned that modelling the wind velocity using wind fans in the test basin does not automatically result in the correct wind loads. Instead, a method is proposed to calibrate the correct wind loads, rather than generate the correct wind velocity.

The dynamic motions of an elastic floating bridge in waves and wind was studied by Murakoshi et al. (2004) in a wave tank of 12m length, 5.4m width and 0.22m depth, which was able to generate regular waves, installed inside the test section of a wind tunnel. In this experiment, the conditions of the wave and the wind were independently given. The wind velocity was scaled using Froude's law. Shoji et al (2006) investigated the behaviour of ships moored by single anchors in a basin with a wind tunnel. With regard to the interaction problem between the wind and the waves, Mizutani et al. (2003) and Touboul et al. (2006) measured the air-flow field over the waves in a wind/wave flume using a PIV technique and observed air flow separation over a breaking wave.

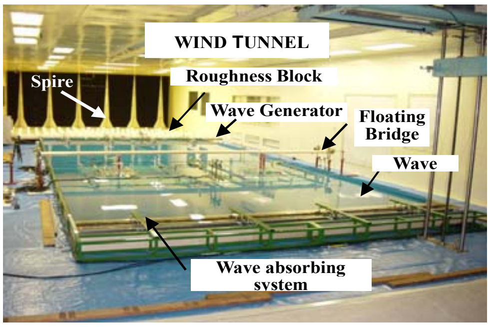

Figure 14.1 Wave Tank in Wind Tunnel

The wind load generation system using wind fans on the model deck has been discussed by Bobillier et al. (2000). The pitch angle of the blades of the wind fan was controlled to generate a time history of the wind load computed from the Morison drag formula using the wind velocity calculated from the wind spectrum and the shape coefficient based on the geometry of the superstructure.

Brown et al (1998) carried out an experimental study investigating the behaviour of a system of springs for yaw motion in order to simulate wind-induced loading effects on turret moored vessels. By comparing the results of this method with results from a fixed bank of wind fans, they showed that the spring system might be used as a mechanism during preliminary model testing to simulate the influence of wind on yawing. Hara et al. (2005) made the wind load work in the model tanker by hanging a weight through the pulley in order to examine the motions of the moored ship in wind and waves. Nagata, et al (1999) applied controlled wind loads in surge, sway, roll and yaw to a floating bridge by using four sets of actuators and wires. Time histories of the wind loads for four modes were computed from the Morison drag formula using the fluctuating wind velocity calculated from the Davenport wind spectrum and shape coefficients obtained by wind tunnel tests. They showed that measured wind load spectrum and time series agreed with input data.

In the above four methods of generating wind forces in model basins, the methods using wind fans on the model deck, and spring-weight systems, cannot represent the shielding effect or wind-induced motion damping. T

Although the method using a wave tank in a wind tunnel is the best, it is difficult to construct large-scale wind tunnels. The method of using a fixed bank of wind fans is the most practical. However, improvements such as modifying the vertical profile of the mean wind velocity to be the same as that of natural wind are necessary.

14.2 Wind Force Simulation By Empirical Models

Most numerical simulations of wind forces use an empirical formula proportional to the square of the wind velocity. This formula includes a shape coefficient such as the drag coefficient.

The shape coefficient has usually been obtained by wind tunnel tests. Simiu and Scanlan (1996) summarized the shape coefficients for offshore structures such as the semisubmersible unit and the guyed tower platform. Tannuri et al. (2002) evaluated the shape coefficient for the static wind forces acting on a pipeline launching barge with the super-structure model turned upside down in the towing tank. Walree et al (1988) developed a method to evaluate the wind loads on offshore structures using a "building block" approach. In this method the offshore structure is represented by a number of standard components with known wind load coefficients. The wind loads on the complete structure are determined by a summation of the individual contributions, taking into account interaction effects, such as wind shielding.

On ships, some methods for estimating the shape coefficients were proposed on the basis of the regression analysis of experimental data (e.g. Ishewood 1972). Fujiwara et al. (2005, 2006) also proposed the method to estimate longitudinal and lateral wind forces and the yaw and heel moments of ships by using regression analysis on a large data set of wind tunnel experimental measurements. Further wind load data on VLCCs based on wind tunnel measurements are available from OCIMF (1994), while OCIMF / SIGGTO published similar data on LNG-carriers (1985).

Wind tunnel tests were also carried out for the shape coefficients for VLFSs. Ohmatsu et al (1997) carried out wind tunnel test for a mat-like VLFS. They measured the pressure drag coefficient and frictional drag coefficient and discussed an estimation method for the wind force. Suzuki et al (2002) carried out wind tunnel tests for a semi-submersible type VLFS. Drag force characteristics and the interaction between the columns in the high Reynolds number region were clarified and a formula was proposed for the estimation of drag forces acting on this type of structure.

The wind velocity in empirical formulae is represented as the sum of the mean and fluctuating components. When the wind spectrum is given, a time series for the fluctuating wind velocity may be generated by superposition of harmonic components with uniformly distributed phases. Various wind spectra have been proposed by Kareem (1985). The wind spectra proposed by Ochi and Shin (1988) and Kato et al. (1990) are spectra representing the wind over the ocean, which contains more energy than the overland spectra at low frequency.

In the case of evaluating the wind load acting on a slender structure, or multiple structures arranged with sufficient separation, the spatial distribution of the fluctuating wind velocity should be considered. The method of using the cross-spectrum of two continuous wind velocity records was proposed to generate the wind velocity considering spatial correlation. Since the cross-spectrum is represented by using spectra at two points and a coherence function, some coherence models for the turbulence component have been proposed (Simiu and Scanlan 1996, Saranyasoontorn et al. 2004). The Davenport exponential model (Davenport 1961) and the IEC exponential model (Thresher et al.1981) are commonly used empirical coherence models based on experimental results. The IEC exponential model expanded the Davenport exponential model by introducing a coherence scale parameter. Theoretical coherence models where local isotropy is not assumed, such as the isotropic von Karman turbulence model (von Karman, 1948) and the Mann uniform shear turbulence models (Mann, 1994) have also been proposed. Saranyasoontorn et al. (2004) compared the isotropic von Karman model, the Mann uniform shear model and the IEC exponential model with the measured coherence for the along-wind, across-wind, and vertical turbulence components, and showed that the Mann model provided the best prediction.

Methods to generate a time series of wind velocity by using a cross-spectrum such as the auto regressive AR method, the auto regressive moving average ARMA method and the Shinozuka method have also been proposed. The AR model can be seen as a particular case of the general ARMA model. The Shinozuka model is based on the introduction of a matrix defined as the Cholesky decomposition of the real part of the cross spectrum, and FFT techniques to improve the efficiency of its generation are used. Rossi et al. (2004) tested the three methods of AR, ARMA and Shinozuka on simple cases and showed that Shinozuka's method appears to give the best results in terms of the overall quality of the signal, while the ARMA technique behaved better than the equivalent AR formulation. Sørensen et al. (2002) presented a wind model based on Shinozuka's method including the spatial variation of the turbulence and the shadows behind wind turbine towers in wind farms. Li et al (2004) carried out a wind simulation using Shinozuka's method for long cable-stayed bridges. Iwatani (1982) presented a time series calculation program for the wind velocity based on the AR method. Fumoto et al (2006) calculated the elastic motion of a floating bridge in waves and wind in the time domain using Iwatani's code. Mo and Reinholdtsen (2003) calculated the time series of wind, current and wave velocity using the ARMA method.

14.3 Wind Simulation By CFD

Most CFD studies have focussed on the prediction of flow around a bluff body, such as a ship, rather than on wind forces acting on offshore structures. Murakami (1997) summarized the CFD techniques used in wind engineering. He compared the relative performance of various turbulence models such as the k-ε model, the Reynolds Stress model and the Dynamic LES for and concluded that the Dynamic LES approach gave the best results for many wind engineering applications. Lübcke et al. (2001) compared the computational results obtained from LES and RANS, using the Boussinesq-viscosity model (BVM) or explicit algebraic stress models (EASM), with experimental results for the turbulent flow around bluff-bodies such as square and circular cylinders over a Reynolds number range of 3900 ~ 140000. They concluded that the EASM offered a reasonable predictive response to unsteady flow conditions, and agreeing closely with LES results. Tominaga et al. (2008) compared CFD results using various revised k-ε models such as the LK model, the MMK model, Durbin's revised k-ε model, and the LES model with experimental results for flow around a high-rise building model within the surface boundary layer. They concluded that Durbin's revised k-ε model and the LES model showed the best agreement with the experiments. Kuroda (2007) compared computational results from an LES model using a dynamic Smagorinsky-type SGS model, with experimental results by PIV measurement for wake flows past a bluff body.

There are some computed results for air flow around a ship. Reddy et al (2000) and Kulkarni et al. (2007) used the FLUENT commercial CFD code with a RANS solver and k-ε turbulence model to calculate the air flow around a ship. El Moctar and Bertram (2003) also carried out the computation of viscous flow around fast ship superstructures using RANS solvers and with k-ε turbulence model. Tai (1997) calculated the ship air wake, including the effect of ship motion, using a RANS scheme.

As mentioned previously, CFD wind load simulations of offshore structures with complicated shapes have hardly ever been carried out. Such calculations are a subject for future study.

15. CONCLUSIONS

15.1 State of the Art

<u>Bottom-Founded Structures</u> Routine experimental and numerical procedures for estimating the fluid loading on bottom founded structures are well established. However, they remain a challenging area of research in extreme environmental conditions. Ongoing

research is required for novel structures of unusual geometry and interaction effects relating to the proximity of components in unexplored configurations. There are still fundamental fluid phenomena to investigate, particularly outside the conventionally defined regimes associated with flow separation and wave diffraction. As numerical/theoretical models become increasingly refined, and the scope of their capabilities widened, experiments and experimental techniques have to be devised for their validation. Relative newcomers to the class of bottom founded structures are the offshore renewable energy converters, which introduce elements to the fluid loading problem not normally encountered in conventional mainstream offshore structures.

Stationary Floating Structures and Ships. Coupled analysis in the time domain and model tests are two of the main research methods in predicting the behavior of stationary floating structures and ships. Numerical methods using potential theory are still widely applied. Many published papers focus on the calculation of slow drift forces. Different numerical models have been presented to deal with complicated non-linear phenomena, such as green water, VIM, VIV and the hydrodynamics of multi-body interactions. However it is difficult to include all the above effects when studying the behavior of stationary floating structures and ships. Problems as complex as a fully coupled time domain method including the hydrodynamic load effects on the mooring lines due to VIV have been presented. However consideration of other complicated behavior of stationary floating structures, such as green water and VIM, modelled in the time domain still need to be studied further.

Dynamically Positioned Ships. The use of dynamically positioned ships has seen a continuing growth. However, there does not appear to be too much on going research activity in the model basins. Most of the recent publications are concerned with the use of dynamic positioning for new applications. A few interesting papers were found however on the analysis of control and filtering algorithms. An area which has not yet been much investigated relates to the claims from major dynamic positioning contractors regarding high precision control and dynamic positioning in relation to calm weather conditions, and for minimum power consumption. Model test verification of these new strategies has not been found in the public domain.

Waves, Wind and Current. Reproduction and identification of extremely high waves in model basins will become very important as requirements for the safety assurance of floating structures become more stringent under severe design conditions. In shallow water, the low-frequency component induced by nonlinear wave interactions is of great importance to the interpretation of the low-frequency resonant motion of moored structures. Consequently the development of standard procedures for the generation and identification of highly nonlinear waves, such as freak waves and setdown waves will enhance the model test input-output relationship.

In spite of its importance to the design and analysis of moored offshore structures, few research results have been found on wind and currents in model basins. More basic and practical model test data on wind and current are needed for constructing reference data.

Coupled Systems. Coupled analysis, representing the dynamic interaction between the floating offshore structure and the mooring and riser lines, becomes important as the number of deep water installations increases. Reliable numerical methods are important for design purposes, operational studies and to support the development of truncated model tests. Over the past three years some work has been devoted to the development and demonstration of methods for coupled analysis, with emphasis on the improvement of frequency domain tools appropriate for engineering applications. Fully coupled time domain codes are accurate; however they require a large computational effort. For frequency domain methods a proper statistical linearization of the mooring nonlinearities is essential.

Hydroelasticity and Impact. Hydroelasticity effects on impact phenomena such as whipping, springing, slamming and sloshing, as well as their influence on design and analysis of very large floating structures, have been recognized as one of the very important issues in the ocean engineering field. Further comparative studies on sloshing or slamming induced impact loads by experiment and numerical prediction will contribute to the future development of reference data and of standard procedures for model tests considering impact and hydroelasticity.

Renewable Energy Systems: State of the art research for wave energy, wind energy, tidal energy and marine current energy has been comprehensively reviewed. It is evident that in relation to the environmental problems of the earth, research in this field will increase in future. Therefore, appropriate experimental techniques and procedures should be developed to cater for this expanding field.

New Experimental Techniques. New experimental measuring techniques, such as particle image velocimetry and fibre optical sensors are becoming more readily available for the towing tanks and the model basins. These new techniques make measurements possible which were previously not feasible at all or practically very difficult. However, these new techniques still need further maturing for day-to-day use in the basins. Most applications so far are for research related projects. However, optical motion measurements in six degrees of freedom can be considered as the standard in most basins nowadays.

Progress in CFD. A continuing expansion of the use of CFD for ocean engineering applications can be observed. Meshless methods have been developed and seem especially suited to the simulation of violent flows associated with impact, sloshing, and wave breaking. Another family of innovative methods exploits Cartesian grids with immersed boundary representation of the body surface, aiming at a better exploitation of massively parallel machines used nowadays for High Performance Computing (HPC). Code verification, uncertainty analysis and validation studies will become more and more important to assess the quality of numerical simulations.

15.2 Procedures

The committee's conclusions on their review of existing procedures are summarized in chapter 10 above.

15.3 New Documentation

15.4 Validation of CFD Codes. The Committee have proposed two case studies for bench-marking CFD codes. Their use for a benchmarking exercise would provide valuable data for the validation of CFD codes.

Validating Frequency and Time Domain Codes. The new procedure prepared by the Seakeeping Committee on 'Verification and validation of linear seakeeping codes' should be reviewed with respect to aspects which are specific to offshore structures, such as: the effect of water depth, multi-body interactions and second order drift forces. Nonlinear effects on offshore structures such as nonlinear geometry and free surface effects should also be considered. It is suggested that such topics are considered by the next OEC with a view to modifying the new procedure to enhance its suitability for offshore applications.

16. RECOMMENDATIONS

The Ocean Engineering Committee has the following recommendations to make to the 25th ITTC:

- Adopt the revised ITTC procedure 7.5-02-07-01.1, "Modelling of Wave Spectra".
- Adopt the revised ITTC procedure 7.5-02-07-03.1, "Experiments with Offshore Platforms".
- Adopt the revised ITTC procedure 7.5-02-07-03.2, "Model Testing in Regular Waves".
- Adopt the revised ITTC procedure 7.5-02-07-03.45, "Hybrid Experiments and Numerical Simulations".

17. APPENDIX: BENCHMARK DATA FOR VALIDATING CFD CODES.

This appendix presents two proposed case studies for providing benchmark data for validating CFD codes. It also discusses the CFD code specification and sources of data for validation.

17.1 Case Study 1: Run Up Around Cylinders

In the design of floating platforms for harsh environments, requirements for calm deck clearance are an important consideration. Sufficient deck clearance must be ensured to avoid damage to the deck due to waves impacting it from below. To design a platform against wave impacts one must be able to accurately estimate the wave scattering around large volume structures. Today's industry standard tools based on frequency domain potential theory solvers have limitations in determining the highly non-linear fluid motions around platform columns.

An objective of the proposed benchmark study is to study how well state-of-the-art RANS codes (and other CFD techniques) can compute the wave scattering around a simple large volume structure due to monochromatic incident waves. The free-surface wave elevation within a column radius distance around fixed vertical columns is to be investigated.

The data to be used in the comparative study is taken from model tests performed at MARINTEK. The data has previously been used in an ISSC benchmark study (see Nielsen, 2003). The model tests and some analysis of the data are also described in e.g. Stansberg and Nielsen (2001), Stansberg and Braaten (2002), Kristiansen el al (2004) and Stansberg and Kristiansen (2005). The ISSC data set does not include force measurements, so additional experiments have been performed by MOERI in 2007. The MOERI experiments were performed with an identical test set-up to the MARINTEK tests, but global and local wave force measurements were also included.

<u>Test Configurations.</u> Run-up around two truncated vertical cylinders with different cross-sectional geometry will be studied: a circular cross-section; and a squared cross-section with rounded corners. The diameter of the circular cylinder is D=16.0m, and the draft of the column is 24.0m. The column extends vertically above the free surface with constant cross-section. The wave elevation is measured at 16 locations in the vicinity of the column. The locations of the measurement probes are given in Table 1. The radial distance is measured from the centre of the column. The positions are illustrated in Figure A1.

The square column with rounded corners has a width of 16.0m, and a draft of 24.0m. The radius of the corners is 4.0m. The width of the plane sections on each side is 8.0m, see Figure A1. The wave elevation is measured at 12 locations in the vicinity of column. The locations of the measurement probes are given in Table 2.

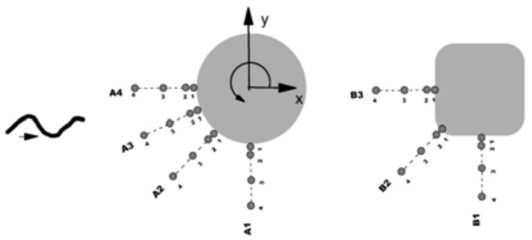

Figure A1 Positions where the wave elevation is measured.

Table 1. Positions where the wave elevation is measured, Circular column

Row	Direction (deg)	Radial distances (m) point no. 1, 2,3 and 4
A1	270	8.05, 9.47, 12.75, 16.0
A2	225	8.05, 9.47, 12.75, 16.0
A3	202.5	8.05, 9.47, 12.75, 16.0
A4	180	8.05, 9.47, 12.75, 16.0

Table 2. Positions where the wave elevation is measured, Square column

Row	Direction (deg)	Radial distances (m) point no. 1, 2,3 and 4
B1	270	8.05, 9.47, 12.75, 16.0
B2	225	9.707, 11.127, 14.407, 17.657
B3	180	8.05, 9.47, 12.75, 16.0

For all cases a water density of $\rho = 1000$ kg/m^3 can be assumed. All incident waves are long-crested and propagating in positive *x*-direction (0deg). The monochromatic waves are specified in terms of wave height and wave periods. The incident wave height, *H* (double amplitude) is specified to avoid the problem of asymmetry in the specification of incident waves. The water depth is 490m.

Wave Conditions. In the original model tests, monochromatic, bi-chromatic as well as irregular wave conditions were studied. The present benchmark study is limited to regular incident wave conditions. The calibrated monochromatic wave conditions had a duration of 17½ minutes full scale time, where approximately 20 oscillations of the wave elevation time series after the transient phase were used to determine the wave height during calibration. The wave conditions to be used in the present benchmark study are given in Table 3.

Available Data. The following data is given for each of the tests cases:

1. Time trace of the calibrated incident wave at the position of the centre of the cylinders
2. Time traces of the wave elevation at the locations given in Tables 1 and 2.
3. Time traces from wave force measurements (local and global).
4. Harmonic analysis results for the wave elevation for zeroth, first and second harmonics for wave elevation and wave force.

Table 3. Wave conditions to be considered in the ITTC benchmark tests.

Monochromatic waves	Wave height, H (m)	Wave period, T (s)	Wave steepness, H/λ (-)
M1	4.22	9.0	1/30
M2	7.90	9.0	1/16
M3	12.65	9.0	1/10
M4	11.71	15.0	1/30
M5	21.96	15.0	1/16
M6	35.13	15.0	1/10

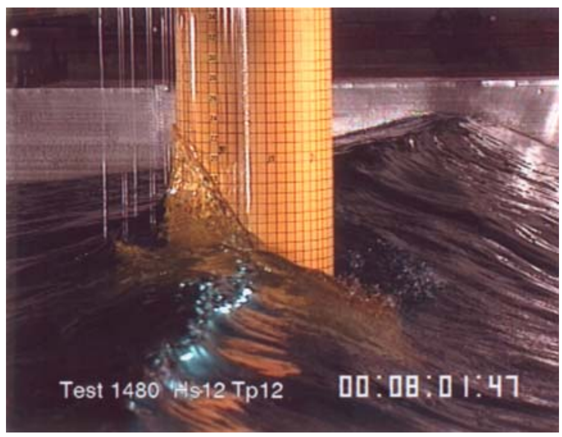

Figure A2 Snapshots from tests.

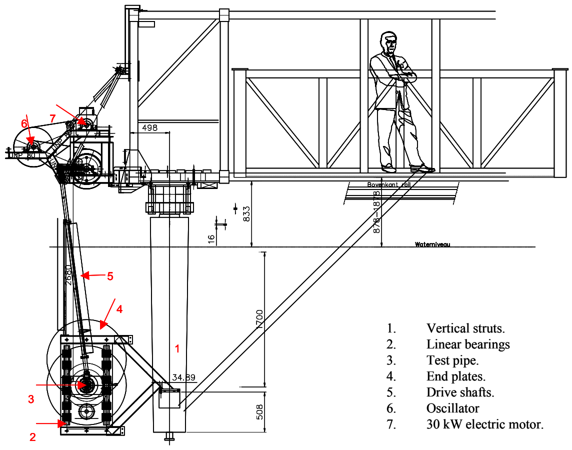

Figure A3 High Reynolds VIV test apparatus.

17.2 Case Study 2: Forced Oscillations of a Circular Cylinder in a Current

A 200 mm circular cylinder with smooth surface was tested at MARIN in the Netherlands (see Figures A3 and A4). The 3.52 m long rigid test cylinder was suspended from the carriage at approximately 1.7 m water depth. The towing tank is 4 m deep, 4 m wide and 210 m long. The cylinder was kept fixed in the flow or could be oscillated in the cross flow direction on linear bearings at both ends of the pipe. The frequency and amplitude of the oscillation could be accurately adjusted.

Three different types of tests can be carried out with the set-up (see Figure A5):

- Oscillation in still water (KC test)
- Non-oscillating tow test (drag test)
- Oscillation while towing (VIV test)

The experimental apparatus and the experiments are described in various publications by de Wilde and Huijsmans (2001) and by de Wilde et al. (2003, 2004 and 2006)

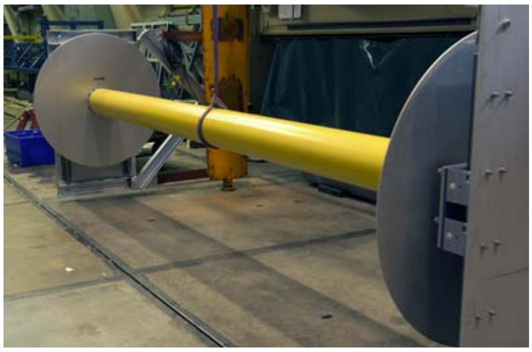

Figure A4 Smooth pipe 200 mm.

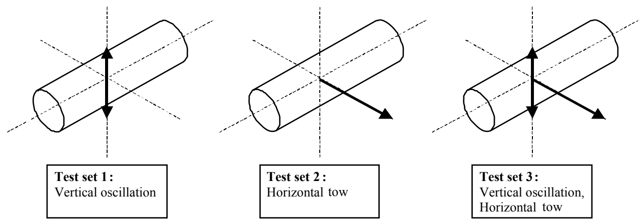

Figure A5 Type of tests carried out.

The measured drag coefficient for the smooth pipe is presented in Figure 6 together with the results from Güven (1975) taken from Sarpkaya (1981).

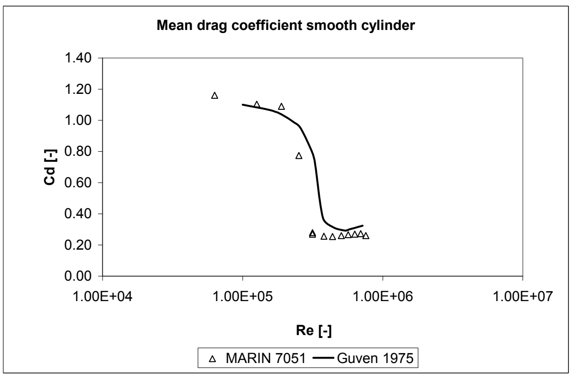

Figure A6 Drag coefficient of smooth pipe.

<u>Stationary Cylinder in a Cross Flow.</u> The following benchmark cases are proposed for the non-oscillating cylinder:

- Re = 9.0E3, 9.0E4 and 5.5E5
- Calculation of minimum of 40 vortex shedding cycles of which 20 will be used for analysis
- Time traces of calculated in-line (Fx) and cross-flow (Fz) forces
- Derivation of mean drag and oscillating lift coefficients Cd and Cl
- Analysis of vortex shedding frequency (St number and spectrum)
- Presentation of flow maps and vorticity plots

Examples of the CFD results by Vaz et al. (2007) are presented in Figures A6 and A7.

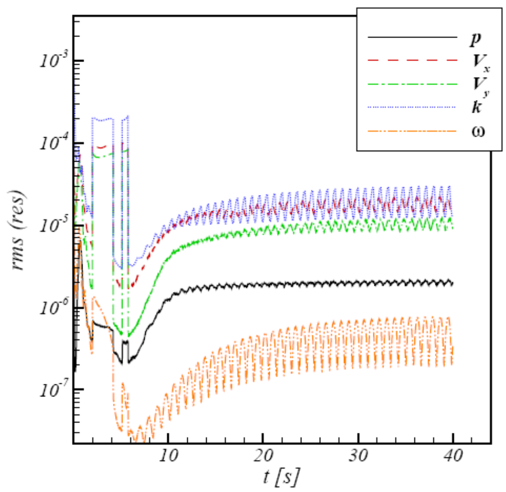

Figure A7 Example of convergence of residuals history (Re 9.3e4)

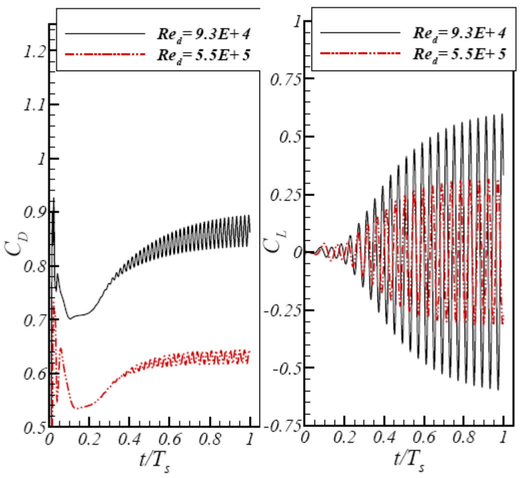

Figure A8 Example of Cd and Cl time history (Re 9.3e4 and Re 5.5e5).

<u>Oscillating Cylinder in a Cross Flow.</u> The following benchmark case is proposed for the forced oscillating cylinder in cross flow:

- Re = 9.0E3
- Reduced velocity of Ur = UT/D = 5
- Amplitude ratio of A/D = 0.3

The added mass and out-of-phase lift coefficients (Cm and Clv) should be derived from the calculated lift forces, as for instance done by Gopalkrishnan (1993).

17.3 Description of CFD method

For the comparison of the different CFD methods, it is important that at least the following is well documented:

- Name of program and main characteristics
- Type of CFD model (RANS, URANS, LES, etc.)
- Two-dimensional or three-dimensional calculation
- Type of discretizeation method (finite elements, finite volumes, finite differences etc.)
- Type of turbulence model (e.g. 0-equation, 1-equation, 2-equation, Reynolds-stress model, DES, LES, etc.)
- Type of wall function (if applicable)
- Type of grid (e.g. structured, unstructured,

etc.)
- Grid and grid size
- Convergence criterion and convergence history.
- CPU time

A grid sensitivity analysis (3 or 4 grids) and time-step sensitivity analysis is proposed.

17.4 Available Data

Available Data. The following experimental data is available for the CFD benchmark cases:
- Time traces of measured in-line (Fx) and cross-flow (Fz) forces on the 3.52m long pipe for tow speed of 0.70 and 3.15m/s
- Cd and Cl coefficients for non-oscillating tests
- Cd, Cm and Clv coefficients for forced oscillating test.
- PIV data for the non-oscillating pipe at 0.5 m/s

18. REFERENCES

Aksu et al., 2007, "Recent Advances on Quasi-Static Response of Ships and Offshore Structures", Proc. 26th OMAE, Paper 29767.

Aoki et al., 2007, "Advanced Technologies for Cruising AUV Urashima", Proc. 17th ISOPE, Lisbon, pp. 750-757.

Arai M., Makiyama H.S., Cheng L-Y., Kumano A., Ando T. and Imakita A. 2006, "Numerical and Experimental Study of 3-D Sloshing in Tanks of LNG Carriers". Proc. 25th OMAE, Hamburg, Germany, Paper 92235.

Argyriadis, K. and Klose, M. 2007, "Analysis of Offshore Wind Turbines with Jacket Structures", Proc. 17th ISOPE, Lisbon, Vol. IV, pp. 3623 – 3629.

Assi, G.R.S., Bearman, P.W. and Meneghini, J.R., 2007, "Unsteady Force Measurements on Responding Circular in the Wake of an Upstream Cylinder", Proc. 26th OMAE, Paper 29040, San Diego, California.

Atluri S., Halkyard J. and Sirnivas S. 2006, "CFD Simulation of Truss Spar Vortex-Induced Motion". Proc. 25th OMAE Hamburg, Germany, Paper 92400.

Azimirad, M., Gharabaghi, A.R.M. and Chenaghlou, M.R. 2007, Deterministic–Spectral Fatigue Analysis Of A Typical Jacket Platform (Spd1), Using Directional Wave Spectrum, Proc. 26th OMAE, San Diego, Paper 29069.

Baarholm R., Kristiansen T. and Lie H., 2007, "Interaction and Clashing between Bare or Straked Risers – Analysis of Experimental Results", Proc. 26th OMAE, Paper 29240, San Diego, California.

Baarholm R., Kristiansen T., Lie H. and Herfjord K., 2005, "Experimental Investigation of Dual Riser Interaction", Proc. 24th OMAE, Paper 67100, Halkidiki, Greece.

Baarholm, R., Fylling, I., Stansberg, C.T., Oritsland, O., 2006, "Model Testing of Ultra-Deepwater Floater Systems: Truncation and Software Verification Methodology", Proc. 25th OMAE 2006, Hamburg, Germany, Paper – 92492.

Babarit,A. and Clement A.H. 2006, "Optimal latching control of a wave energy device in regular and irregular waves", Applied Ocean Research, pp.77-91

Balaji, R., Sannasiraj, S. A. and Sundar, V., 2006, "Laboratory Simulation and Analysis of Wave Groups", Proc. 25th OMAE, OMAE, Paper 92144

Berstad, A.J. and Tronstad, H. 2007, "Development and Design Verification of a Floating Tidal Power Unit", Proc. 26th

OMAE, Paper 29052

Blevins, R.D., 1994, "Flow-Induced Vibration", Krieger Publishing Company, Malabar, Florida.

Blevins, R.D., Jacob, P., Saint-Marcoux, J-F., Wu, M., 2006, "Assessment of Fluid Induced Jumper Interference for Hybrid Riser Tower", Proc. 16th ISOPE, Paper JSC-381, San Francisco, California.

Bobillier, B., Chakrabarti, S. and Christiansen, P. 2000, "Generation and Analysis of Wind Load on a Floating Offshore Structure", Proc. 19th OMAE, pp.317-323

Boccotti, P., 2000, Wave Mechanics for Ocean Engineering, Elsevier Science, Oxford.

Bredmose, H., Skourup, J., Hansen, E.A., Christensen, E.D., Pedersen, L.M. and Mitzlaff, A. 2006, Numerical Reproduction of Extreme Wave Loads on a Gravity Wind Turbine Foundation, Proc. 25th OMAE, Hamburg, Paper 92258.

Brito-Melo A., Gato, L.M.C. and Sarmento, A.J.N.A. 2002, "Analysis of Wells Turbine Design Parameters by Numerical Simulation of the OWC Performance", Ocean Engineering, 29, pp.1463-1477

Brooke, J. 2003,"Wave Energy Conversion", Elsevier Science

Broussard, Louisiana, Pennenergy. Delmar wins contract for Azurite field FPDSO. http://www.pennenergy.com/, Jan 22nd, 2008.

Brown, D.T., and Ekstrom, L., 2005, "Vessel Thruster-Thruster Interactions During Azimuthing Operations", Proc. 24th OMAE, Paper 67500.

Brown, D.T. and Liu, F. 1998, "Use of Springs to Simulate the Wind Induced Moments on Turret Moored Vessels", Applied Ocean Research, Vol.20, pp.213-224

Buchner, B. and Bunnik, T., 2007, "Extreme Wave Effects on Deepwater Floating Structures", Proc. 2007 OTC, Paper 18493

Buchner, B., Cozijn, H., van Dijk, R. and Wichers, J., 2001, "Important Environmental Modelling Aspects for Ultra Deep Water Model Tests", Proc. Deep Offshore Technology Conference (DOT), Rio de Janeiro

Buchner, B., van Dijk, R. and Voogt, A., 2007, "The Spatial Analysis of an Extreme Wave in a Model Basin", Proc. 26th OMAE, Paper 29409

Buchner, B., Dierx, P. and Waals, O., 2005, "The Behaviour of Tugs in Waves Assisting LNG Carriers During Berthing Along Offshore LNG Terminals", Proc 24th OMAE, Halkidiki, Greece, Paper 67219.

Bunnik, T. and Huijsmans, R., 2005, "Validation of Wave Propagation in Numerical Wave Tanks", Proc. 24th OMAE, Paper 67221

Calcagno, G., Salvatore, F., Greco, L., Moroso, A. and Erkisson, H. 2006 "Experimental and Numerical Investigation of an Innovative Technology for Marine Current Exploitation: the Kobold Turbine", Proc. 16th ISOPE, San Francisco, pp. 323-330

Caska, A.J. and Finnigan, T.D. 2007, Transverse Array Structures for Wave Energy Conversion, Proc. 17th ISOPE, Lisbon, Vol. I, pp. 369 - 373.

Chakrabarti, P., Joshi, S. and Maiti, M.K. 2007, Pull-Down Analysis Of Jack-Up Rigs, Proc. 26th OMAE, San Diego, Paper 29083.

Chakrabarti, S.K. 1994, "Offshore Structure Modelling", World Scientific Publishing Co. Pte. Ltd.

Chen C-L., Fan J and You Y-X. 2007, "Analysis of the Motion of a New Type of FPDSO in Deep Sea", Ship and Ocean Engineering, Vol. 36, Part 4, pp. 142-145

Chen, H.C. and Lee S.K., 2003, "Chimera RANS Simulations of Propeller-Ship Interactions Including Crash-Astern Conditions", Proc. 13th ISOPE, Honolulu, Vol. IV, pp. 334-343.

Chen, X.B., 2005, "Hydrodynamic Analysis for Offshore LNG Terminals", Proc. 2nd International Workshop on Applied Offshore Hydrodynamics, LabOceano/ COPPE/UFRJ, April, 14-15, Rio de Janeiro, Brazil.

Clauss, G.F. and Schmittner, C.E., 2005, "Experimental Optimization of Extreme Wave Sequences for the Deterministic Analysis of Wave/Structure Interaction", Proc. 24th OMAE, Paper 67049

Clauss, G.F., Schmittner, C.E., Hennig, J., 2006b, "Systematically Varied Rogue Wave Sequences for the Experimental Investigation of Extreme Structure Behavior", Proc. 25th OMAE, Paper 92273

Clauss, G.F., Schmittner, C.E., Klein, M., 2006a, "Generation of Rogue Waves with Predefined Steepness", Proc. 25th OMAE, Paper 92272

Coiro, D., Nicolosi, F., Marco, A.D., Melone, S. and Montella, F. 2005 "Flow Curvature effects on Dynamic Behaviour of a Novel Vertical Axis Tidal Current Turbine: Numerical and Experimental Analysis", Proc. 24th OMAE, Paper 67193

Corte, C. and Grilli, S.T., 2006, Numerical Modeling of Extreme Wave Slamming on Cylindrical Offshore Support Structures Proc. 16th ISOPE, San Francisco, Vol. III, pp. 394 – 401.

Cortijo, J.L, Duggal, A.S. van Dijk, R.R.T and Matos, S., 2003, "DP FPSO – A Fully Dynamically Positioned FPSO for Ultra Deep Waters", Proc. 13th ISOPE, Honolulu, Vol. I, pp. 194-202.

Cox D.T. and Ortega J. A., 2002, "Laboratory observations of green water overtopping a fixed deck", Ocean Engineering, Vol. 29, No. 14, pp. 1827-1840.

Cruz, J. 2008, "Ocean Wave Energy", Springer

Cummins WE 1962, "The Impulse Response Function and Ship Motions", Schiffstechnik 9 pp.101-109

da Costa, J. S., Sarmento, A and Gardner, F 2005, "Time Domain Model of the AWS Energy Converter", 6th European Wave and Tidal Energy Conference, Glasgow, UK, pp.91-97

Davenport, A.G. 1961, "The Spectrum of Horizontal Gustiness near the Ground in High Winds", Q.J.R. Meteorol. Soc., 87, pp.194-211

Deuff, J.B., Oger, G., Doring, M., Alessandrini, B. and Ferrant, P., 2006, "SPH Analysis of Hydrodynamic Impact, Including Hydrodynamic Fluid-Structure Coupling", Hydroelasticity in Marine Technology, Vol.1, pp. 131-138.

Di Felice F., Di Florio D., Felli M. and Romano G.P., 2004, "Experimental Investigation of the Propeller Wake at Different Loading Conditions by Particle Image Velocimetry", Journal of Ship Research, Vol. 48, No. 2, pp. 168-190.

Dommermuth, D.G., O'Shea, T.T., Wyatt, D.C., Ratcliffe, T., Weymouth, G.D., Hendrikson, K.L., Yue, D.K.P., Sussmann, M., Adams, P., Valenciano, M., 2007, "An Application of Cartesian-Grid and Volume-of-Fluid Methods to Numerical Ship Hydro-dynamics", Proc. 9th Int. Conf. on Numerical Ship Hydrodynamics, Ann Arbor, USA.

Dryne, J., Maeda, K. and Xia, J. 2006, Model Testing Of Dynamic Characteristics Of Compliant Buoyant Towers, Proc. 25th OMAE, Hamburg, Paper 92439.

Ducrozet, G., Bonnefoy, F., Le Touzé D. and Ferrant, P., 2006, "Implementation and Validation of Nonlinear Wave Maker Models in a HOS Numerical Wave Tank" Proc. 16th ISOPE, pp.334-341

Eça, L., Hoekstra, M., 2007, "Code Verification of Unsteady Flow Solvers with the Method of the Manufactured Solutions", Proc. 17th Int. Offshore and Polar Eng. Conference, Lisbon, Portugal

Edelson, D., Halkyard, J., Chen, L. and Chabot, L., 2007,"Floatover Deck Installation on Spars", Proc. 26th OMAE, Paper 29640.

El Moctar, O., Schellin, T. and Peric, M. 2007, Wave Load And Structural Analysis For A Jack-Up Platform In Freak Waves, Proc. 26th OMAE, San Diego, Paper 29434.

El Moctar, O. and Bertram, V. , 2003, "Computation of Viscous Flow around Fast Ship Superstructures", 24th Symposium on Naval Hydrodynamics, pp.940-949

Eteki, R.E., 2004, "A Parametric Identification of the Olister Hydrodynamic Behaviour", Proc. 14th ISOPE, Toulon, Vol. II, pp. 236-243.

Falcao, AF de O. and Justino, P.A.P 1999, "OWC Wave Energy Devices with Air Flow Control", Ocean Engineering, 26, pp.1275-1295

Falcao, AF de O. and Rodrigues, R.J.A. 2002, "Stochastic Modelling of OWC Wave Power Plant Performance", Applied Ocean Research 24, pp.59-71

Falnes, J. 2001, "Optimum Control of Oscillating of Wave-Energy Converters", Proc. 11th ISOPE, Stavanger, pp.567-574

Falnes, J. 2002, "Ocean Waves and Oscillating Systems", Cambridge University Press

Faltinsen, O.M., 1990, "Sea Loads on Ships and Offshore Structures", Cambridge University Press, Cambridge.

Faltinsen, O. M., Newman, J. N., and Vinje, T., 1995, "Non-Linear Wave Loads on a Slender Vertical Cylinder", Journal of Fluid Mechanics, 289, pp. 179–198.

Fan J., Huang X-L. 2007, "Analysis Of The Motion Of A Geometric Spar In Deep Water", Journal of Shanghai Jiao Tong University, Vol. 41, Part 2, pp. 172-176.

Fernandes, A.C., Rocha, S.D, Coelho, F.M., Jacob, B.P., Queiroz, J.V., Capanema, B. and Merino, J.A., 2008 "Riser Clasing Induced by Wake Interference", Proc. 27th OMAE, Paper 57639, Estoril, Portugal.

Fernandes, A.C., Silva, E.M.C., Franciss, R., Coelho, F.M., and Silva Neto, S.F., 2008 "Vortex Self-Induced Vibration Kinematics", Proc. 27th OMAE, Paper 57579, Estoril, Portugal.

Finnigan, T. and Roddier D. 2007, "Spar VIM Model Tests At Supercritical Reynolds Numbers". Proc. 26th OMAE, San Diego, CA, United States, Vol. 3, pp. 731-740.

Fochesato, C., Dias, F. and Grilli, S., 2005, "Wave Energy Focusing in a Three-dimensional Numerical Wave Tank", Proc. 15th ISOPE, pp.24-31

Fonseca, N., Antunes, E. and Guedes Soares, C., 2006, "Whipping Response of Vessels With Large Amplitude Motions", Proc. 25th OMAE, Paper 92412.

Forristall G.Z. 2006, "Maximum wave heights over an area and the air GAP problem". Proc. 25th OMAE, Paper 92022

Fournier, J.B., Maciri, M. and Chen, X.B., 2006, "Hydrodynamics Of Two Side-By-Side Vessels, Experiments And Numerical Simulations", Proc. 16th ISOPE, San Francisco, pp. 158-165.

Fraenkel, P.L. 2007 "Marine Current Turbines: Moving from Experimental Test Rigs to a Commercial Technology", Proc. 26th OMAE, Paper 29642

Fujiwara, T. and Nimura, T. 2005, "New Estimation Method of Wind Forces Acting on Ships on the Basis of Mathematical Model", Proc. 15th ISOPE, pp.82-89

Fujiwara, T., Ueno, M. and Ikeda, Y. 2006, "Cruising Performance of a Large Ship in Heavy Sea", Proc. 16th ISOPE, pp.304-311

Fumoto, K., Utsunomiya, T., Niizato, H., Tanaka, H. and Watanabe, E. 2006," Development of a Program for Dynamic Response Simulation of a Floating Bridge Subjected Both Winds and Waves", Journal of JSCE, pp.1-11

Gallagher, P. and Woodburn, P., 2003, "EXPRO-CFD: An Overview of European Research in CFD-Based Fluid Loading and Fluid Structure Interaction", Proc. 2003 OTC, Paper 15288.

Garret, D.L., 2005, "Coupled Analysis of Floating Production System", Ocean Engineering, Vol. 32, pp. 802-816.

Gomez-Gesteira M., Cerqueiro D., Crespo C. and Dalrymple R. A. 2005, "Green Water Overtopping Analyzed With A SPH Model", Ocean Engineering, Vol. 32, Part 2, pp. 223-238.

Gopalkrishnan, R. 1993, "Vortex Induced Forces On Oscillating Bluff Cylinders", D.Sc. Thesis, Department of Ocean Engineering, MIT.

Grant, D.J., Etebari, A. and Atsavapranee, P., 2007, "Experimental Investigation of Roll and Heave Excitation and Damping in Beam Wave Fields", Proc. 26th OMAE, Paper 29318.

Greco M., Faltinsen O. M. and Landrini M. 2005, "Shipping of Water on A Two-Dimensional Structure", Journal of Fluid Mechanics, Vol. 525, pp. 309-332.

Greco, M., Colicchio, G. and Faltinsen, O.M., 2006, "Local and Global Hydroelastic Analysis of a VLFS", Hydroelasticity in Marine Technology, Vol.1, pp. 225-234.

Hague, C.H. and Swan, C., 2006, "Numerical Simulations of Large Deep Water Waves: The Application of a Boundary Element Method", Proc. 25th OMAE, Paper 92158

Halkyard J., Atluri S. and Sirnivas S. 2006, "Truss Spar Vortex Induced Motions Benchmarking of CFD and Model Tests". Proc. 25th OMAE, Hamburg, Germany, Paper 92673.

Hanne, T., Wist, D. M., Håvard, R. 2007, "Second Order Model for Wave Crests Used in Prediction of Green Water Load and Volume on Ships in Random Waves", Proc. 26th OMAE, Vol. 128, Part, 4, pp. 271-275.

Hara, S., Tanizawa, K., Hoshino, K., Kano, T. and Yamakawa, K. 2005, "On the Mooring Line Tension of the Tanker by Dolphin Mooring in Wind Waves, Proc. 15th ISOPE, Seoul, pp.179-185

Henterson, A.R., Zaaijer, M.B., Bulder, B., Pierik, J., Huijsmas, R., Van Hess, M., Snijders, E., Wiinants, H.G. and Wolf, M.J., 2004, "Floating Wind Farms for Shallow Offshore Sites", Proc. 14th ISOPE, Toulon, pp.23-28

Hong, S. Y., Kyoung, J. H., Kim, B. W. and Cho, S. K., 2005, "On the Numerical Accuracy of Wave Induced Structural Stresses of VLFs for Various Hydroelastic Analysis Methods", Proc. 24th Conf. OMAE, Paper 67101

Hong, S.Y. and Kyoung, J.H., 2006, "Hydroelastic Response of VLFS Coupled with OWC-Type Breakwater", Hydroelasticity in Marine Technology, Vol.1, pp. 245-254.

Hong, S.Y. and Kyoung, J.H., 2007, "Effects of Location and Shape of OWC-Chamber on the Hydroelastic Response of VLFS", Proc. 17th ISOPE, pp.434-438

Hong, S.Y., Kim, J.H., Cho, S.K., Choi, Y.R., Kim, Y.S., 2005, "Numerical and Experimental Study on Hydrodynamic Interaction of Side-By-Side Moored Multiple Vessels", Ocean Engineering, Vol.32, pp. 783-801.

Hong, D.C., Hong, S.Y. and Hong, S.W 2005, "Numerical Study on the Wave Power Absorbed by a Floating BBDB Wave Energy Device", Proc. 15th ISOPE, Seoul, pp.537-541

Hu, C., Kashiwagi, M. and Kitadai, A. 2006, "Numerical simulation of strongly nonlinear wave-body interactions with experimental validation", Proc. 16th ISOPE, San Francisco, USA, pp. 467-472.

Hu, C., Kashiwagi, M., Xiao, F., 2007, 3D Numerical Simulation of Violent Sloshing by Conservative CIP Methods, Proc. Int. Conf. on Violent Flows (VF-2007), Fukuoka, Japan.

Huijsmans, R.H.M. and Borleteau, J.P., 2003, "The Flow around FPSO's in Steep Regular Waves", Proc. 13th ISOPE, Honolulu, Vol. III, pp. 151 - 158

Huse, E. and Matsumoto, K., 1989, "Viscous Surge Damping of Floating Production Vessels Moored at Sea, Proc. 8th OMAE, The Hague, Netherlands.

Huse, E. and Lian, W., 1990, "Parameters Influencing Mooring Line Damping", FPS 2000 – Subproject 1.5 – Mooring Line Damping, Marintek Sintef Group, Trondheim.

Huse, E. and Oritsland, O., 1990, "Measurements of Mooring Line Drag Coefficient in Steady Flow", FPS 2000 – Subproject 1.5 – Mooring Line Damping, Marintek Sintef Group, Trondheim.

Huse, E., Oritsland, O., Reitanand O.E. and Kjeserud, H.K., 1991, "Measurements Of Flow-Induced Beam Vibrations And Drag Coefficients At Low Reynolds Numbers", FPS 2000 – Subproject 1.5 – Mooring Line Damping, Marintek Sintef Group, Trondheim.

Ikegami, K., Matsuura, M., Hayashi, N., Tanigaki, S., Kawazoe, T., Yamauchi, Y., Toshimitsu, K., Nagaosa, S., 2005, "Development of multi-connected floating body system", Proc. 24th OMAE, Halkidiki, Greece, Paper 67365.

Ikoma, T., Masuda, K., Rheem, C.K. and Maeda, H., 2005, "Three-Dimensional Analysis of Hydroelastic Behaviors of an Aircushion Type Large Floating Structure", Proc. 24th OMAE, Paper 67057

Ikoma, T., Masuda, K., Rheem, C.K. and Maeda, H., 2006, "Response Reduction of Motion and Steady Wave Drifting Forces of Floating Bodies Supported by Aircushions in Regular Waves", Proc. 25th OMAE, Paper 92072

Ikoma, T., Masuda, K., Rheem, C.K. and Maeda, H., 2007, "Response Reduction of Motion and Steady Wave Drifting Forces of Floating Bodies Supported by Aircushions in Regular

Waves: The 2nd Report, Response Characteristics in Oblique Waves", Proc. 26th OMAE, Paper29472

Isherwood, R.M. 1972, "Wind resistance of Merchant Ships", Trans the Royal Institution of Naval Architects, Vol.115, pp.327-338

ITTC, 2005 "Report from Ocean Engineering Committee", Proc. 24th ITTC, Edinburg, Scotland.

Iwatani, Y. 1982 "Simulation of Multidimensional Wind Fluctuation Having any Arbitrary Power Spectra and Cross spectra", Journal of Wind Engineering, No11, pp.5-17

Jensen, J.J., 2007, Extreme Response Predictions For Jack-Up Units In Second Order Stochastic Waves By Form, Proc. 26th OMAE, San Diego, Paper 29022.

Ji C., Halkyard J. 2006, "Spar Deck Float-Over Flexibility Study for West Africa Environment Condition", Proc. 25th OMAE Conference, Hamburg, Germany, Paper 92157.

Jin-Ha Kim, Sa-Young Hong, Seok-kyu Cho and Seong-Hwan Park, 2004, "Experimental Study on a Dolphin-Fender Moored Pontoon-Type structure", Proc. 14th ISOPE, Toulon, Vol. I, pp. 551-557.

Johannessen, T.B., Haver, S., Bunnik, T. and Buchner, B., 2006, "Extreme Wave Effects on Deep Water TLPs - Lessons Learned from the Snorre A Model Tests", Proc. DOT, Houston

Kaasen, K.E., and Olsen, C.W., 2005,"Offshore Loading Using Tankers Of Opportunity: Model Testing Of A Weathervaning Dynamic Positioning", Proc. 15th ISOPE, Seoul, Paper 290_JSC_443, pp. 343-349.

Kaasen, E.K., Andersson, F., Lehn, E. and Olsen, C.W. 2005, "Offshore Loading Using Tankers of Opportunity: Model Testing of Weather-vaning Dynamic Positioning", Proc. 15th ISOPE, pp.343-349

Kareem, A. 1985, "Wind-Induced Response Analysis of Tension Leg Platforms", Journal of Structural Engineering, Vol.111, No.1, pp.37-55

Kashiwabara, T., Nakajima, N., Kanemoto, T. and Nakanichi, Y. 2004, "Hydraulic Characteristics of a Floating Buoy for Tidal Current power generation", Proc. 14th ISOPE, Toulon, pp.177-182

Kashiwagi, M., 2007, "3-D Calculation for multiple floating bodies in proximity using wave interaction theory", Proc. 17th ISOPE, pp. 2246-2252.

Kashiwagi, M., Endo, K., Yamaguchi, H., 2005, "Wave drift forces and moments on two ships arranged side by side in waves", Ocean Engineering, Vol.32, pp.529-555.

Kato, S., Ando, S., Sato, H. and Motora, Y. 1990, "At-sea Experiment of a Floating Offshore Structure, Part 1 Wind Characteristic at the Test Field", Journal of the Society of Naval Architects of Japan,Vol.167,pp.125-135

Kazemi, S. and Incecik A. 2007, "Theoretical And Experimental Analysis Of Air Gap Response And Wave-On-Deck Impact Of Floating Offshore Structures", Proc. 26th OMAE, San Diego, CA, United States, Vol. 1, pp. 297-304

Kendon, T.E., Oritsland, O., Baarholm, R. Karlsen, S.I., Stansberg, C-T, Rossi, R.R., Barreira, R.A., Matos, V. and Sales Jr., J.S. 2008 "Ultra-Deepwater Model Testing of a Semisubmersible and Hybrid Verification", Proc. 27th OMAE, Estoril, Paper 57400, Portugal.

Keulegan, G.H. and Carpenter, L.H., 1958, "Forces on Cylinders and Plates in an Oscillating Fluid", J. Res. Nat. Bureau of Standards, Vol. 60, No. 5, pp. 423-440.

Kihara, H, Sueyoshi, M., Kashiwagi, M., 2007, "A Hybrid Computational Method for Nonlinear Free Surface Problems", Proc. Int. Conf. on Violent Flows (VF-2007), Fukuoka, Japan

Kim, J., Kim, Y., Park, I.R., Van, S.H., 2007, "Comparison of Numerical Methods Applied to Violent Sloshing Flows", Proc. 9th Int. Conf. on Numerical Ship Hydrodynamics, Ann Arbor, USA.

Kim J.W., Lee J.M., Bai K.J., Sim I.H. and Lee Y.B. 2006, "A Finite-Element Computation For Three-Dimensional Problems Of Sloshing In LNG Tank", Proc. 25th OMAE, Hamburg, Germany, Paper 92564.

Kim, B.W. Hong, S.Y., Kyoung, J.H. and Cho, S.K. 2007, "Evaluation Of Bending Moments And Shear Forces At Unit Connections Of Very Large Floating Structures Using Hydroelastic And Rigid Body Analyses", Ocean Engineering, Vol. 34, n 11-12, pp. 1668-1679.

Kim, B.W., Hong, S.Y., Kyoung, J., Cho, S., 2007, "Evaluation Of Bending Moments And Shear Forces At Unit Connections Of Very Large Floating Structures Using Hydroelastic And Rigid Body Analysis", Ocean Engineering, Vol. 34, pp. 1668-1679.

Kim, J.H, Lew, J.M., Hong, D.C., Hong, S.Y., Hong, S.W. and Hong ,K.Y. 2006, "An Experimental Study on the Reverse Wave Drift Force of a BBDB Type OWC Wave Energy Device" , Proc. 16th ISOPE Pacific/Asia, Dalian, pp.237-242

Kinoshita, T., Shi, J.S., Nakasumi, S., Kameoka, H., Suzuki, K., Waseda, T., Tanizawa, K. and Yuhara, T., 2006, "Longitudinal Loads on a Container Ship in Extreme Regular Sea and Freak Wave", Hydroelasticity in Marine Technology, Vol.1, pp. 103-110.

Koo, W. and Kim, M.H., 2006, "Numerical Analysis of Current Effect on Nonlinear Wave-body Interactions", Proc. 16th ISOPE, pp.377-383

Korpus, R. A. and Liapis S. 2007, "Active and Passive Control Of Spar Vortex-Induced Motions", Proc. 26th OMAE, Vol. 129, Part 4, pp. 290-299.

Kraemer, D.R. 2005, "Simulation of the Motions of the McCabe Wave Pump System", Proc. 6th European Wave and Tidal Energy Conference, Glasgow, UK, pp.251-258

Kristiansen T., Baarholm R., Rortveit G.J., Hansen E.W. and Stansberg C.T., 2005, "Kinematics in a Diffracted Wave Field: Particle Image Velocimetry (PIV) and Numerical Models", Proc. 24th OMAE, Paper 67176.

Kristiansen, T. and Faltinsen, O.M., 2007, "Resonant Water Motion Between A Ship And A Terminal In Shallow Water", Proc. 26th OMAE, San Diego, Paper 29397.

Kristiansen, T., Baarholm, R., and Stansberg, C.T., 2004, "Validation of Second-Order Analysis in Predicting Diffracted Wave Elevation Around A Vertical Cylinder", Proc. 14th ISOPE, Toulon, Vol. I, pp. 369-373.

Kulkarni, P.R., Singh, S.N. and Seshadri.V. 2007,"Parametric Studies Exhaust Smoke-superstructure Interaction on a Naval Ship using CFD", Computers and Fluids, 36, pp. 794-816

Kuroda, M., Tamura, T. and Suzuki, M. 2007,"Applicability of LES to the Turbulent Wake of a Rectangular Cylinder – Comparison with PIV Data", Journal of Wind Engineering and Industrial Aerodynamics, 95, pp.1242-1258

Kyoung, J.H., Hong, S.Y and Kim, B.W. 2006, "Finite Element Method for Time Domain Analysis on Hydroelastic Response of VLFS with Fully Nonlinear Free Surface Conditions", Proc. 16th ISOPE, San Francisco, California, USA, pp. 130-136.

Kyoung, J.H., Hong, S.Y. and Kim, B.W., 2006, "Time Domain Analysis on Hydroelastic Response of VLFS Using Finite Element Method", Hydroelasticity in Marine Technology, Vol.1, pp. 273-282.

Kyoung, J.H., Hong, S.Y. and Kim, B.W., 2007. "Time Domain Analysis on Hydroelastic Response of VLFS Considering Horizontal Motion", Proc. 17th ISOPE, Vol. 1, pp. 231-236.

Kyoung, J.H., Hong, S.Y., Kim, B.W., Cho, S.K. and Bai, K.J., 2005, "Finite-Element Method for the Hydroelastic Response of Very Large Floating Structure in Water of Variable Depth", Proc. 24th OMAE, Paper 67084

Kyozuka, Y., Akira, H., Nakamura, N. and Urakawa, Y. 2007, "Hydrodynamic Characteristics of a Darrieus-Savonius Water Turbine for Tidal Power Generation, Proc. East Asian Workshop for Marine Environment, National Cheng Kung University, Taiwan,pp.119-129

Kyozuka, Y., Gunji, T. and Wakahama, H. 2006, "Tidal Power Generation by Making Use of a Bridge Pier", Proc. 17th ISOPE, pp.317-322.

Landrini M, Colagrossi A, Greco M, Tulin MP, 2007, "Gridless simulations of splashing processes and near-shore bore propagation", Journal of Fluid Mechanics, 591 pp.183-213.

Le Cunff, C., Biolley, F., and Damy, G., 2005, "Experimental and Numerical Study of Heave-Induced Lateral Motion (HILM)", Proc. 24th OMAE, Paper 67019, Halkidiki, Greece.

Lee D.H, Kim M.H., Kwon S.H., Kim J.W. and Lee Y.B. 2007a, "A Parametric Sensitivity Study on LNG Tank Sloshing Loads By Numerical Simulations", Ocean Engineering, Vol. 34, Part 1, pp. 3-9

Lee S.J., Kim M.H., Lee D.H., Kim J.W. and Kim Y.H. 2007b, "The effects of LNG-tank sloshing on the global motions of LNG carriers", Ocean Engineering, Vol. 34, Part 1, pp. 10-20

Lee, K.H., Mizutani, N., Kamatsu, K. and Hur, D.S., 2006, "Experimental Study on Wave-Current Interaction" Proc. 16th ISOPE, pp.486-492

Lehn, E. 1980, "Thruster interaction effects", NSFI, Marintek report, R102-80.

Li, Y. and Calisai, S.M. 2007, "Preliminary Results of a Vortex Method for Stand-Alone Vertical Axis Marine Current Turbine", Proc. 26th OMAE, Paper 29708

Li, Y., Nabavi, Y., Alidadi, M., Klaptocz, R.K., William, G.W. and Calisal, S.M. 2007, "UBC Numerical Investigation of Vertical Axis Tidal Turbine: RANS CFD and Potential Flow", Proc. 17th ISOPE, Lisbon, pp.314-321

Li, Y., Liao, H. and Qiang, S. 2004, "Simplifying the Simulation of Stochastic Wind Velocity Fields for Long Cable-stayed Bridges", Computers and Structures, 82, pp.1591-1598

Lie, H., Braaten, H., Kristiansen T. and Nielsen, F.G., 2007, "Free Span VIV Testing of Full Scale Umbilical", Proc. 17th ISOPE, Lisbon, Paper 2007_JSC_213, pp. 2764-2771.

Low, Y.M. and Langley, R.S., 2005, "A Simplified Model For The Study Of Dynamic Coupling Effects In Deepwater Floating Structures", Proc. 24th OMAE, Halkidiki, Greece, Paper 67062.

Low, Y.M. and Langley, R.S., 2006, "A Comparison of Time and Frequency Domain Approaches For the Fully Coupled Analysis of Deepwater Floating Systems", Proc. 25th OMAE, Hamburg, Germany, Paper 92172.

Low, Y.M. and Langley, R.S., 2007, "A Comparison Of Methods For The Coupled Analysis Of Floating Structures", Proc. 26th OMAE, San Diego, Paper 29229.

Lübcke. H., Schmidt, S., Rung, T. and Thiele, F 2001,"Comparison of LES and RANS in Bluff-body Flows", Journal of Wind Engineering and Industrial Aerodynamics, 89, pp.1471-1485

Lucor, D., Triantafyllou, M.S., 2007, "Parametric Study of Two Degree-of-Freedom Vortex-Induces Vibrations of a Cylinder in a Two-Dimensional flow", Proc. IUTAM Symp. on Unsteady Separated Flows and their Control, Corfu, Greece

Lui, Y. 2007, "The Exact Solutions of Tower-Yoke Mooring Systems", Proc. 17th ISOPE, Lisbon, Vol. I, pp. 264 -269.

Malenica, S., Korobkin, A.A., Scolan, Y.M., Gueret, R., Delafosse, V. and Gazzola, T., 2006, "Hydroelastic Impacts in the Tanks of LNG Carriers", Hydroelasticity in Marine Technology, Vol.1, pp. 121-130.

Malenica, S., Stumpf, E., Sireta, F.X., Chen, X.B., 2008, "Consistent Hydro-structural Interface for Evaluation of Global Structural Responses in Seakeeping", Proc. 27th Int. Conf. Offshore Mech. and Arctic Engg., OMAE 2008, Estoril, Portugal.

Mann, J. 1994, "The Spatial Structure of Neutral Atmospheric Surface-Layer Turbulence", Journal of Fluid Mechanics, 273, pp.141-168

Masterton, S. and Swan, C. 2006, Wave Forces on a Single Surface-Piercing Column: Comparison Between Theory and Experiment, Proc. 25th OMAE, Hamburg, Paper 92339.

Masterton, S., Swan, C. and van Zutphen, H. 2007, Nonlinear Wave Scattering From A Single Surface-Piercing Column Comparison With Second-Order Theory, Proc. 26th OMAE, San Diego, Paper 29201.

Mei, C.C. 1982, "The Applied Dynamics of Ocean Surface Waves", John Wiley & Sons, Inc.

Minami, M., Sawada, H., Tanizawa, K., 2006, "Study of Ship Responses and Wave Loads in the Freak Wave", Proc. 16th ISOPE, pp. 272-278

Mingham, C.G., Qian, L, Causon, D.M. and Ingram, D.M. 2004,"Non-Linear Simulation of Wave Energy Devices", Proc. 14th ISOPE, Toulon, pp.194-201

Mingham, C.G., Qian, L., Causon, D.M. and Ingram, D.M. 2005,"A Numerical Study Of The OWSC Wave Power Device Using A Two-Fluid Free Surface Code", 6th European Wave and Tidal Energy Conference ,Glasgow, UK, pp.313-319

Mizutani, N. and Hashimoto, N. 2003, "Air Flow Characteristics over Wind Waves form Measurements by the PIV Technique", Proc. 13th ISOPE, pp.253-257

Mo, K. and Reinholdtsen, S.R. 2003 "Method for Generating Non-stationary Current, Wind and Wave Time Series in the Time Domain", Proc. 13th ISOPE, pp.277-285.

Murai, M., Inoue, Y. and Mori, K., 2006, "A Study On An Optimal Arrangement Of Upper Facilities On A Very Large Floating Structure Considering With The Hydroelastic Response In Waves", Proc. 16th ISOPE, San Francisco, California, USA, pp. 108-115.

Murakami, S. 1997,"Current Status and Future Trends in Computational Wind Engineering", 67&68, pp.3-34

Murakoshi, J., Fumoto, K., Nagata, S, Niizato, H., Tanaka, H., Watanabe, E. and Utsunomiya, T. 2004, "Experimental Study on Motions of Elastic Floating Bridge in Waves and Winds", The 3rd Int. Conf. Advances in Structural Engineering and Mechanics, Seoul, pp.572-583.

Nagai, B.M., Ameku, K. and Nagai, Y. 2006, "Mooring Method of Very Large Floating Structure" Proc.16th ISOPE, San Francisco, California, USA, pp. 116-121.

Nagata, S., Miyake, S., Fujita, T., Yoshida, H., Tanaka, H., Maruyama, T. and Ueda, S. 1999, "Motions of a Movable Floating Bridge in Waves", Proc. VLFS'99, Honolulu, pp.358-366

Najafian, G.., 2007, A More Efficient Form Of The Method Of Moments For Derivation Of Morison's Force Coefficients, Proc. 26th OMAE, San Diego, Paper 29605.

Nielsen, F.G., 2003, "Comparative Study On Airgap Under Floating Platforms And Run-Up Along Platform Columns", Journal of Marine Structures, 16, pp. 97-134.

Nielsen, F.G., Hanson, T.D. and Skaare, B. 2006, "Integrated Dynamic of Floating Offshore Wind Turbines, Proc. 15th OMAE, Paper 92291

Nienhuis, U., 1992, "Analysis For Thrusters Effectivity For Dynamic Positioning And Low Speed Manoeuvring", PhD thesis, TUD.

Ochi, M.K. and Shin, Y.S. 1988, "Wind Turbulent Spectra for design Consideration of Offshore Structures", Proc. 1988 OTC, Paper 5736, pp.461-467

OCIMF Publication, "Prediction of Wind and Current Loads on VLCCs", 2nd Edition, 1994.

OCIMF / SIGGTO Publication, "Prediction of Wind Loads on Large Liquefied Gas Carriers", 1985.

Ogawa Y., 2003, "Long-term prediction method for the green water load and volume for an assessment of the load line" Journal of Marine Science Technology, Vol.7, No. 3, pp. 137-144.

Oger, G., Doring, M., Alessandrini, B., Ferrant, P., 2006, "Two-Dimensional SPH Simulations of Wedge Water Entries, Journal of Computational Physics, Vol. 213, pp 803-822.

Oger, G., Le Touzé, D., Alessandrini, B., Ferrant, P., 2007, "3D Impact Flows Using an Enhanced Parallelized SPH Model", Proc. Int. Conf. on Violent Flows (VF-2007), Fukuoka, Japan.

Ohkawa, Y., Yago, K., Miyajima, S., Chujo, T., Suzuki, H., Sekita, K., Hineno, M. and Takano, O. 2006, "A Basic Study Of Floating Wind Power System For Purpose Of Alternative Fuel Production", Proc. Japan Society of Naval Architects and Ocean Engineers, Vol.3, pp.213-216

Ohmatsu, S., Takai, R. and Sato, H. 1997, "On the Wind and Current Forces Acting on a Very Large Floating Structure", Journal of OMAE, Vol.119, pp.8-13

Osawa, H., Miyazaki, T., and Miyajima, S. 2004, "Characteristics Of Hydrodynamics And Generating Output Of Offshore Floating Wave Energy Device "Mighty Whale". Proc. 23rd OMAE, Paper 51349

Park, S.W., Han, J.W., Han, S.H., Ha, T.B., Lee, H.G., Hong, S.Y., Kim, B.W. and Kyoung, J.H., 2006. "Fatigue Strength Analysis of Pontoon Type VLFS Using Spectral

Method", Proc. 16th ISOPE, Vol. 1, pp. 137-143.

Pauw, W., Huijsmans, R.H.M. and Voogt, A., 2007, "Advances in the hydrodynamics of side-by-side moored vessels", Proc. 26th OMAE, San Diego, Paper 29374.

Pavone, D., Snamprogetti, S. da Costa, J. S., Sarmento, A and Gardner, F 2005, "Time Domain Model of the AWS Energy Converter", 6th European Wave and Tidal Energy Conference, Glasgow, UK, pp.91-97

Pavone, D., Snamprogetti, S. and Arena, F. 2006, "Forces Of Random Wave Groups, On Vertical Cylinders", Proc. 25th OMAE, Hamburg, Paper 92484.

Peric, M., Zorn, T., El Moctar, O., Schellin, T.N Kim, Y.S., 2007, "Simulation of Sloshing in LNG-Tanks", Proc. 26th Int. Conf. Offshore Mech. and Arctic Engg., OMAE 2007, San Diego, USA.

Pham, X.P. and Varyani, K.S. 2005, "Evaluation Of Green Water Loads On High-Speed Containership Using CFD", Ocean Engineering, Vol. 32, Part (5-6), pp. 571-585.

Pham, X.P., and Varyani, K.S. 2006, "Generic Design Of V-Shape And Vane-Type Breakwaters To Reduce Green Water Load Effects On Deck Structures And Containers Of Ships: Case Study", Journal Of Waterway, Port, Coastal, And Ocean Engineering, Vol.132, Part 1, pp. 57-65.

Qi, X., Perryman, S., and Prislin, I., 2007, "Assessment of the Horn Mountain Spar In Hurricane Ivans", Proc. 26th OMAE, San Diego, USA, Paper 29354.

Qiu, L. and Hua, L. 2007, "Three-Dimensional Time-Domain Analysis of Very Large Floating Structures Subjected to Unsteady External Loading", Proc. 26th OMAE, Vol. 129, n 1, pp. 21-28.

Rainey, R.C.T., 1995. "Slender Body Expressions For The Wave Load On Offshore Structures". Proc. Royal Society, London. A, 450, pp. 391–416.

Reddy, K.R., Toffoletto, R. and Jones, K.R.W. 2000, "Numerical Simulation of Ship Airwake", Computers and Fluids, 29, pp.451-465

Remy, F., Molin, B. and Ledoux, A., 2006, "Experimental and Numerical Study of the Wave Response of a Flexible Barge", Hydroelasticity in Marine Technology, Vol.1, pp. 255-264.

Ren, B., Ding, Z., Wang, Y. and Ren, X. 2007 Experimental Study of Regular Wave Impact on the Three-dimensional Structure in the Splash Zone, Proc. 17th ISOPE, Lisbon,Vol. IV, pp. 3623 – 3629.

Retzler, C., 2006, "Measurements of the Slow Drift Dynamics of a Model Pelamis Wave Energy Converter", Renewable Energy, 31, pp.257-269

Rho, J-B., Korobkin, A.A., Jung, J-J, Shin, H-S, Lee, W-S, 2007, "Coupled analysis of deepwater floating system including VIV in time domain", Proc. 26th OMAE 2007, San Diego, Paper 29523.

Riggs, H.R., Suzuki, H., Yasuzawa, Y., Kim, J.W. and Ertekin, R.C., 2006, "Hydroelastic Response of the ISSC VLFS Benchmark", Hydroelasticity in Marine Technology, Vol.1 , pp. 207-214.

Rocha, S.D. and Portella R.B., 2002, "Dimensioning of a dynamic positioning system for a shuttle tanker", Proc. 21st OMAE Paper 28232.

Rognebakke, O. and Faltinsen, O.M., 2006, "Hydroelastic Sloshing Induced Impact with Entrapped Air", Hydroelasticity in

Marine Technology, Vol.1, pp. 169-180.

Rogue Waves, 2000, Brest, France 29-30 Nov. 2000, http://www.ifremer.fr/metocean/conferences/wk.htm.

Rogue Waves, 2004, Brest, France 20-22 Oct. 2004,http://www.ifremer.fr/web-com/stw2004/rw/.

Rossi, R., Lazzari, M. and Vitaliani, R. 2004 "Wind Field Simulation for Structural Engineering Purposes", Int. Journal Numerical Methods in Engineering, 64, pp.738-763

Ryu, Y., Chang K-A. and Lim, H-J. 2005, "Use Of Bubble Image Velocimetry For Measurement Of Plunging Wave Impinging On Structure And Associated Green Water", Measurement Science and Technology, Vol. 16, Part 10, pp. 1945-1953.

Ryu, Y., Chang, K-A and Mercier, R. 2006, "A Laboratory Study on Green Water Velocity Measurement and Prediction", Proc.16th ISOPE, San Francisco, USA, pp. 260-264.

Sadeghi K. and Incecik A., 2006, "A Comparison of Time Domain and Frequency Domain Approaches for the Fully Coupled Analysis of Deepwater Floating System." Proc. 25th OMAE, Hamburg, Germany, Paper 92405.

Saranyasoontorn, K., Manuel, L. and Veers, P.S. 2004, "A Comparison of Standard Coherence Models for Inflow Turbulence with Estimates from Field Measurements", Journal of Solar Energy Engineering, Vol.126,pp.1069-1082

Sarpykaya, T. and Isaacson, M., 1981, "Mechanics of Waves Forces on Offshore Structures", Van Nostrand Reinhold Company, New York.

Serrahn, C.S., McHaney, S.X and Thomas, M., 2006, Design of the SEADOG Offshore Wave Energy Generator Support Structure Proc. 16th ISOPE, San Francisco, Vol. I, pp. 488 – 494.

Shibata, K., Tanizawa, K., Koshizuka, S., 2007, "Numerical Analysis of Coupling between Ship Motion and Green Water on Deck Using MPS Method", Proc. Int. Conf. on Violent Flows (VF-2007), Fukuoka, Japan.

Shimada, K., Ohyama, T. Miyakawa, M., Ishihara, T., Phuc, P.V. and Sukegawa, H. 2007, "A Study on a Semi-Submersible Floating Offshore Wind Energy Conversion System", Proc. 17th ISOPE, Lisbon, pp.348-355

Shoji, K. Minami, K., Kimura, A., Mita, S. and Inoue, M. 2006, "Experimental Study on Behavior of Ship Moored by Anchor, Proc. 16th ISOPE, pp.160-165

Shuxue, L., S., Li, J., Hong, K. and Meza, E., 2005, "Experimental Study on Multi-directional Wave Focusing and Breaking in Shallow Water", Proc. 15th ISOPE, pp.486-492

Simiu, E. and Scanlan, R.H. 1996, "Wind Effects on Structures", 3rd Ed., Wiley

Simos, A.N., Fujarra, A.L.C., Sparano, J.V., Umeda, C.M. and Rossi, R.R. 2006, "Experimental Evaluation of the Dynamic Air Gap of a Large-Volume Semi-Submersible Platform", Proc. 25th OMAE, Hamburg, Germany, Paper 92352

Sirnivas, S., Allain O., Wornom S., and Dervieux A. 2006, "A Study of LES Models for the Simulation of a Turbulent Flow Around a Truss Spar Geometry", Proc. 25th OMAE Conference, Hamburg, Germany, Paper 92355.

Soerensen, H.C., Madsen, E.F. and Christensen, L. 2005 "The Results of Two Years Testing in Real Sea of Wave Dragon", Proc. 6th European Wave and Tidal Energy

Conference, Glasgow, UK, pp.481-487

Song, H., Tao, L., Cui, W. and Liu, Y., 2005, "Hydroelastic Response of VLFS on Uneven Sea Bottom", Proc. 24th OMAE, Paper 67557

Soni, P.K. and Larsen, C.M., 2007, "Vortex Induced Vibration of a Rigid Cylinder Oscillating with a given Trajectory Profile", Proc. 26th OMAE, Paper 29193.

Sørensen, P., Hansen, A.D., Andre, P. and Rosas, C. 2002, "Wind Models for Simulation of Power Fluctuations from Wind Farms", Journal of Wind Engineering and Industrial Aerodynamics, 90,pp.1381-1402 .

Souto-Iglesias, A., Delorme, L., Perez Rojas, L., Abril-Perez, S., 2006, "Liquid Moment Amplitude Assessment in Sloshing Type Problems with Smooth Particle Hydrodynamics", Ocean Engineering, 33, pp1462-1484.

Sparboom, U. and Oumeraci, H. 2006, Wave Loads Of Slender Marine Cylinders Depending On Interaction Effects Of Adjacent Cylinders, Proc. 25th OMAE, Hamburg, Paper 92626.

Stansberg C-T. 2007, "Slow-Drift Pitch Motions And Air-Gap Observed From Model Testing With Moored Semi-Submersibles", Proc. 26th OMAE, San Diego, CA, United States, Vol. 1, pp. 659-668

Stansberg, C.T. and Kristiansen, T., 2005, "Non-Linear Scattering of Steep Surface Waves Around Vertical Columns", Applied Ocean Research, 27, pp. 65-80.

Stansberg, C.T., 2006, "Laboratory Wave Modelling for Floating Structures in Shallow Water", Proc. 25th OMAE, Paper 92496

Stansberg, C.T., and Braaten, H., 2002, "Nonlinear Wave Disturbance Around A Vertical Circular Column", Proc. 21st OMAE, Oslo, Paper 28620.

Stansberg, C.T., and Nielsen, F.G., 2001, "Nonlinear Wave-Structure Interaction On Floating Production Systems", Proc. 11th ISOPE, Stavanger, Vol. IV, pp. 363-372.

Storhaug, G. and Moan, T., 2006, "Springing/Whipping Response of a Large Ocean-going Vessel-Investigated by an Experimental Method", Hydroelasticity in Marine Technology, Vol.1, pp. 89-102.

Sumer, B.M., Griffin, and Fredsøe, J., 1999, "Hydrodynamics around Cylindrical Structures", World Scientific, Singapore.

Suzuki, H. and Sato, A. 2007, "Load Turbine Blade In Induced By Motion of Floating Platform and Design Requirement For The Platform", Proc. 26th OMAE, Paper 29500

Suzuki, H., Sawai, T., Oka, N., Masanobu, S. and Kobayashi, K. 2002, "Wind Loads on Columns of Semi-Submersible-Type-MegaFloat", Proc. 12th ISOPE, Kitakyushu, pp.267-274

Taghipour, R., Perez, T. and Moan, T., 2007. "Time Domain Hydroelastic Analysis of a Flexible Marine Structure Using State-Space Models", Proc. 26th OMAE, Paper 29272.

Tahar A., Halkyard J. and Irani M., 2006, "Comparison of Time and Frequency Domain Analysis with Full Scale Data for the Horn Mountain Spar during Hurricane Isidore", Proc. 25th OMAE, Hamburg, Germany, Paper 92137.

Tai. T. 1997, "Effect of Ship Motion on DD-963 Ship Airwake Simulated by Multizone Navier-Stokes Solution", Twenty-First Symposium on Naval Hydrodynamics, pp.1007-1017

Takagi, K. and Nagayasu, M. 2007, "Ray Theory For Predicting Hydroelastic Behavior Of A Very Large Floating Structure In Waves", Ocean Engineering, Vol. 34, n3-4, pp. 362-370.

Takagi, K., Noguchi, J. and Kinoshita, T. 2005, “Hydro-elastic Motions and Drift Forces of Very Large Mobile Offshore Structure in Waves”, Proc. 15th ISOPE, Seoul, pp.196-202

Tannuri, E.A., Simos, A.N., Pesce, C.P. and Donha, D.C., 2003, “Assisted Dynamic Positioning of a Moored FPSO: Robustness Aspects Regarding Current Forces Modeling”, Proc. 22nd OMAE, Paper 37066.

Tannuri, E.A., Morishita, H.M., Veras, V.L.M. and Lago, G.A., 2005, “Critical Analysis Of Control And Filtering Algorithms Used In Real Dynamic Positioning Systems”, Proc. 24th OMAE, Paper 67137.

Tannuri, E.A., Kubota, L.K. and Pesce, C.P., 2005, “An Adaptive, Robust, Model-Referenced Control Strategy for the Dynamic Positioning of a Shuttle Tanker during Offloading Operations”, Proc. 24th OMAE, Paper 67131.

Tannuri, A.E., Pesce, P.C., Alves, S.G, Masetti, I., Ferreira, R.P.P. and Umeda, H.C. 2002, “Dynamic Positioning of a Pipeline Launching Barge”, Proc. 12th ISOPE, pp.108-114

Teigen, P. and Niedzwecki, J.M., 2006, “A Computational Study Of Wave Effects Related To Side-By-Side LNG Offloading”, Proc. 16th ISOPE, San Francisco, Vol. I, pp. 238-247.

Theckumpurath B., Ding Y. and Zhang J, 2006, “Numerical Simulation of the Truss Spar Horn Mountain", Proc. 16th ISOPE conference, California, USA, 2006: 203-209.

Thresher, R.W., Holley, W.E., Smith, C.E., Jafarey, N. and Lin, S.R. 1981, “Modeling the Response of Wind Turbines to Atmospheric Turbulence”, Report No.RL0/2227-81/2, Department of Mechanical Engineering, Oregon State University

Tominaga, Y., Mochida, A., Murakami, A. and Sawaki, S. 2008, “Comparison of Various Revised k-ε Models and LES Applied to Flow around a High-rise Building Model with 1:1:2 Shape Placed within the Surface Boundary Layer”, Journal of Wind Engineering and Industrial Aerodynamics, 96, pp.389-411

Touboul, J., Giovanangeli, J.P., Kharif, C. and Pelinovsky, E. 2006, “Freak Waves under the Action of Wind: Experiments and Simulations”, European Journal of Mechanics of Fluids, 25, pp.662-676

Tromans, P.S., and Vanderschuren, L. (1995). “Response based design conditions in the North Sea,” Proc. Offshore Tech. Conf. 7683, Houston, USA, pp.387-397.

Ushiyama, I., Seki, K. and Miura. H. 2003,”A Feasibility Study on Floating Offshore Wind Farms in Japanese Waters”, Proc Int. Sym. Ocean Space Utilization Technology, Tokyo Japan, pp.390-397

van der Valk, C.A.C. and Watson, A., 2005, “Mooring Of LNG Carriers To A Weathervaning Floater – Side-By-Side Or Stern-By-Bow”, Proc. 2005 OTC, Houston, Paper 17154.

van Dijk, R. and van den Boom, H., 2007, “Full Scale Monitoring Marco Polo Tension Leg Platform”, Proc. 26th OMAE, Paper 29409

van Walree, F. and Willemsen E., 1988, "Wind Loads on Offshore Structures", Proc. BOSS Conference, Trondheim.

Vaz. et al, 2007, "Viscous Flow Computations On Smooth Cylinders – A Detailed Numerical Study With Validation", Proc. 26th OMAE, Paper 29275.

Vestbostad, T.M., Faltinsen, O.M., Kristiansen, D., 2007, "Validation Methods and Benchmark Tests for 2D CIP Method Applied to Marine Hydrodynamics", Proc. 17th Int. Offshore and Polar Engg. Conference, Lisbon, Portugal.

Von Karman, T. 1948,"Progress in the Statistical Theory of Turbulence", Proc. Natl. Acad. Sci., U.S.A., 34, pp.530-539

Voogt, A., Bunnik, T. and Huijsmans, R., 2005, "Validation of an Analytical Method to Calculate Wave Setdown on Current", Proc. 24th OMAE, Paper 67436

Walker D.A.G., Taylor P.H., Eatock Taylor R, Tromans P.S. and Zang J. 2007, "Water Wave Diffraction and the Spectral Response Surface Method", Proc. 17th ISOPE, Vol. 17, Part 4, pp. 254-258

Walker, D.A.G, Taylor, P.H., Eatock Taylor, R. and Zang, J, 2006, Diffraction Theory as a Tool for Predicting Airgap beneath a Multi-column Gravity Based Structure, Proc. 16th ISOPE, San Francisco, Vol. III, pp. 165 - 172

Walker, D.A.G., Taylor, P.H., Eatock Taylor, R, Tromans, P.S. and Zang, J, 2007, Water wave diffraction and the spectral response surface method, Proc. 17th ISOPE, Lisbon, Vol. IV, pp. 3623 – 3629.

Wang, B. and Kim, J.W., 2006, "Strength Evaluation of LNG Containment System Considering Fluid-Structure Interaction under Sloshing Impact Pressure", Proc. 26th OMAE, Paper 29425

Waseda, T., Rheem, C.-K., Sawamura, J., Yuhara, T., Kinoshita, T., Tanizawa, K. and Tomita, H., 2005, "Extreme Wave Generation in Laboratory Wave Tank", Proc. 15th ISOPE, pp.1-9

Wellens, P.R., Pinkster, J.A., Veldman, A.E.P. and Huijsmans, R. 2007, Numerical Wave Run Up Calculation on GBS Columns, Proc. 17th ISOPE, Lisbon, Vol. III, pp. 2200 - 2206.

Wellens, P.A., Pinkster, J.A, Veldman, A.E.P., Huijsmans, R.H.M., 2007, "3D Diffraction Based Boundary Conditions", Proc. 9th Int. Conf. on Numerical Ship Hydrodynamics, Ann Arbor, USA.

Wemmenhove R., Luppes R., Loots E. and Veldman A.E.P. 2005, "Modeling two-phase flow with offshore applications", Proc. 24th OMAE, Halkidiki, Greece, Paper 67460.

Wemmenhove, R., Loots, E., Veldman, A.E.P., 2006, "Hydrodynamic wave loading on offshore structures simulated by a two-phase flow model". Proc. 25th Int. Conf. Offshore Mech. and Arctic Engg., OMAE 2006, Hamburg, Germany.

Wemmenhove, R., Luppes, R., A.E, Veldman, A.E.P., Bunnik, T., 2007, "Numerical simulation and model experiments of sloshing in LNG tanks". Proc. Int. Conf. Comp. Meth. Marine Eng., Marine 2007, Barcelona.

Wieneke-Toutaui, B. and Gerber H.W., 2003, "Rapid Prototyping Technology – New Potentials for Offshore and Abyssal Engineering", Proc. 13th ISOPE, Honolulu, Vol. I, pp. 27-32.

Wilde, J.J and Huijsmans, R.H.M, 2001, "Experiments for High Reynolds Numbers VIV on Risers", Proc. 11th ISOPE, Stavanger, Vol. III, pp. 400-405

Wilde, J.J, Huijsmans, R.H.M, and Triantafyllou, M.S., 2003, "Experimental Investigation of the Sensitivity to In-line Motions and Magnus-like Lift Production on Vortex-Induced Vibrations", Proc. 13th ISOPE, Hawaii, Vo. III, pp. 593-598.

Wilde, J.J, Sworn, A., Cook, H., Willis N., and Bridge, C., 2004, "Cross section VIV Model Test for Novel Riser Geometries", Proc. Deep Offshore Technology Conference (DOT), New Orleans, Paper 12-3-Jaap de Wilde.

Wilde, J.J. de and Huijsmans, R.H.M., 2004, "Laboratory Investigation of Long Riser VIV Response", Proc. 14th ISOPE, Toulon, Vol. III, pp. 511-516.

Wilde, J.J. de, Huijsmans, R.H.M. and Tukker, J., 2006, "Experimental Investigation into the Vortex Formation in the Wake of an Oscillating Cylinder using Particle Image Velocimetry", Proc. 16th ISOPE, San Francisco, Paper 2006-JSC-434, pp. 798-805.

Wu, Y.S., Cui, W.C. (Editors), 2006, Proc. 4th International Conference on Hydroelasticity in Marine Technology, CSSRS, Wuxi, China.

Xin L., Yang, J. and Xiao, L., 2006, "Research on Motion Response of Soft Yoke Mooring FPSO System", Proc. 16th ISOPE, San Francisco, Paper JMY_02, pp. 181-186.

Yamasaki, J., Miyata, H. and Kanai, H. 2005, "Finite-Difference Simulation of Green Water Impact on Fixed and Moving Bodies", Journal of Marine Science and Technology, Vol.10, Part 1, pp.1-10.

Yang, C., Lu, H., Löhner, R, Liang, X, Yang, J., 2007, "An Unstructured-Grid based VOF Method for Ship Motions Induced by Extreme Waves", Proc. 9th Int. Conf. on Numerical Ship Hydrodynamics, Ann Arbor, USA.

Yang, J., Sakamoto, N., Wang, Z., Carrica, P., Stern, F., 2007, "Two Phase Level-Set/Immersed-Boundary Cartesian Grid Method for Ship Hydrodynamics", Proc. 9th Int. Conf. on Numerical Ship Hydrodynamics, Ann Arbor, USA.

Yu, K., Chen, H-C., Kim, J.W. and Lee, Y-B. 2007, "Numerical Simulation Of Two-Phase Sloshing Flow In LNG Tank Using Finite-Analytic Level-Set Method", Proc. 26th OMAE, San Diego, CA, United States, Vol. 4, pp. 851-860

Zambrano, T., MacCready, T., Kiceniuk, T., Roddier, D.G. and Cermelli, C.A. 2006, "Dynamic Modeling Deepwater Offshore Wind Turbine Structures In Gulf Of Mexico Storm Condition", Proc 25th OMAE, Paper 92029

Zhang F., Yang J. M., Li R. P. and Hu Z. Q., 2006, "Effects of Heave Plate on the Hydrodynamic Behavior so Cell Spar Platform". Proc. 25th OMAE, Hamburg, Germany, Paper 92199.

Zhang F., Yang J., Li R. and Chen G. 2007, "Numerical Study on the Hydrodynamic Behavior of a New Cell-Truss Spar Platform", Proc. 26th OMAE, San Diego, CA, United States, Vol. 2, pp. 93-102.

.