Report of the Ocean Engineering Committee

presented by
Pierre Ferrant, Ecole Centrale de Nantes, France
(Committee Chairman)

September 19, 2008
Fukuoka, Japan

Committee Members

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Dr Rolf Baarholm, Norwegian Marine Technology Research Institute, Norway.

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Meetings

Four Committee meetings were held respectively at:

- MARIN, Wageningen, the Netherlands, June 2006
- MOERI/KORDI, Daejon, Korea, December 2006
- Instituto Superior Técnico, Lisbon, Portugal, June 2007
- Shanghai Jiao Tong University, Shanghai, February 2008

Content of this Presentation

- Tasks assigned by the 24th ITTC
- Structure of the report
- State of the art reviews
- Procedures
- Benchmark study
- Multiple scale model tests
- Wind modelling
- Concluding remarks

Tasks Assigned by the 24^{th} ITTC (1)

State of the Art Reviews

Bottom founded structures, Stationary floating structures including moored and dynamically positioned ships, Modelling of waves, wind and current

- 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

Tasks Assigned by the 24th ITTC (2)

Review Existing Procedures

- 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)
- Hybrid Experiments and Numerical Simulations (7.5-02-07-03.45)

Review 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

Tasks Assigned by the 24th ITTC (3)

Develop New Procedures

- Validation of frequency-domain codes
- Validation of time-domain codes

Review 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.

Review 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.

Structure of the Report

State of the Art Reviews

Section 2: Bottom-Founded Structures
Section 3: Stationary Floating Structures
Section 4: Dynamically Positioned Ships
Section 5: Waves, Wind and Current
Section 6: Hydroelasticity and Impact
Section 7: Renewable Energy Systems
Section 8: New Experimental Techniques
Section 9: Progress in CFD

Existing Procedures

Section 10:

- Multidirectional Irregular Wave Spectra
- Experiments with Offshore Platforms
- Model Testing in Regular Waves
- Turret Tanker Systems
- Hybrid Experiments and Numerical Simulations

New Documentation

Section 11: Benchmark Data for CFD Validation
Section 12: Validation of Software for Predicting Wave Loads and responses of Offshore Structures
Section 13: Multiple Scale Model Testing
Section 14: Wind Modelling

Conclusions and Recommendations

Sections 15 & 16 respectively

Appendix

Section 17: Benchmark Data for validation of CFD codes

State of the Art Reviews

2 - Bottom Founded Structures

- 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 configu-rations.

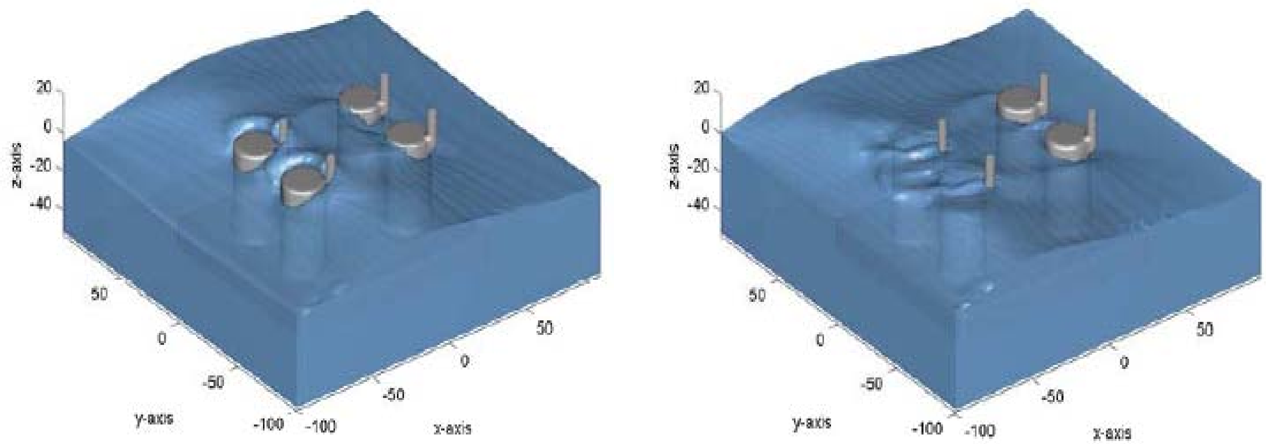
Fig. 6 Model test of a tower yoke mooring system

2 - Bottom Founded Structures

- 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.

Figure 6. Still image showing white water beneath PLATFORM-A. Incident waves are propagating towards the camera.



Numerical wave run up calculations

Wellens et al ISOPE 2007

2 - Bottom Founded Structures

• 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.

Fig.1: Installation of a 5 MW Turbine on Jacket Substructure (Source: REpower Systems AG)

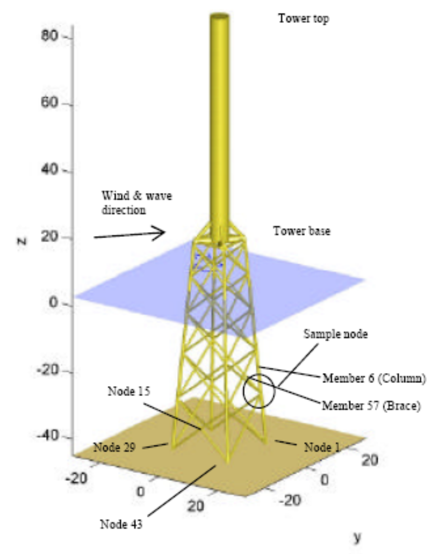


Fig. 2: Support structure model for load analysis

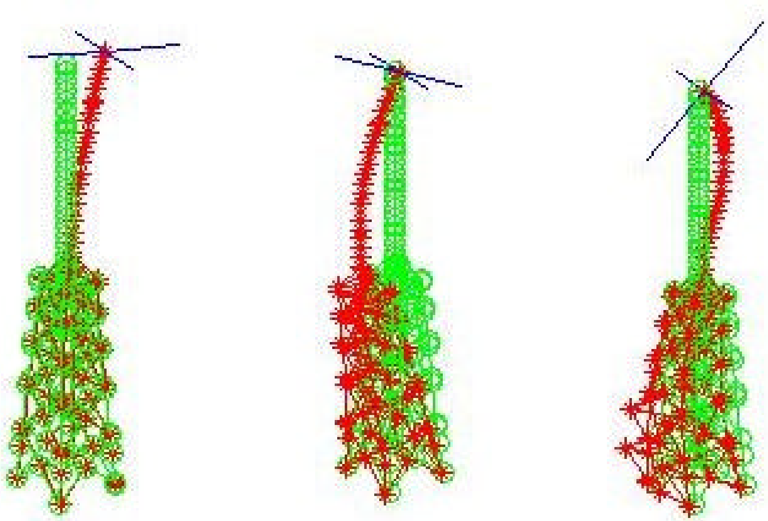


Fig. 3: Suport structure modes 1, 3 and 6

3-Stationary Floating Structures and Ships

Multiple methods in frequency domain and time domain:

- Boundary element method
- Finite element method
- Finite Volumes, Finite Differences
- Meshless methods
- Hybrid schemes

dealing with coupled and non-linear phenomena:

- Second order drift force
- Sloshing
- Green water and air gap
- VIM and VIV
- Multi-body interactions

3-Stationary Floating Structures and Ships

Model experiments with new measuring techniques:

- Particle image velocimetry to measure the velocity field for wave impact, green water,. . .
- Aerial and underwater motion tracking systems
- Optical measurements of water surface motion

Measurements are used to verify the numerical simulations:

- Hydrodynamics, VIM and installation of SPAR platform
- Measurement of green water, air-gap and sloshing
- Hydroelasticity of very large floating structures
- Non-linear behavior of mooring lines and risers

3-Stationary Floating Structures and Ships

Coupled Systems

Floating platform motions → Linear BEM methods

Coupling effects

Mooring lines and risers motions and tensions → finite difference, or finite element methods

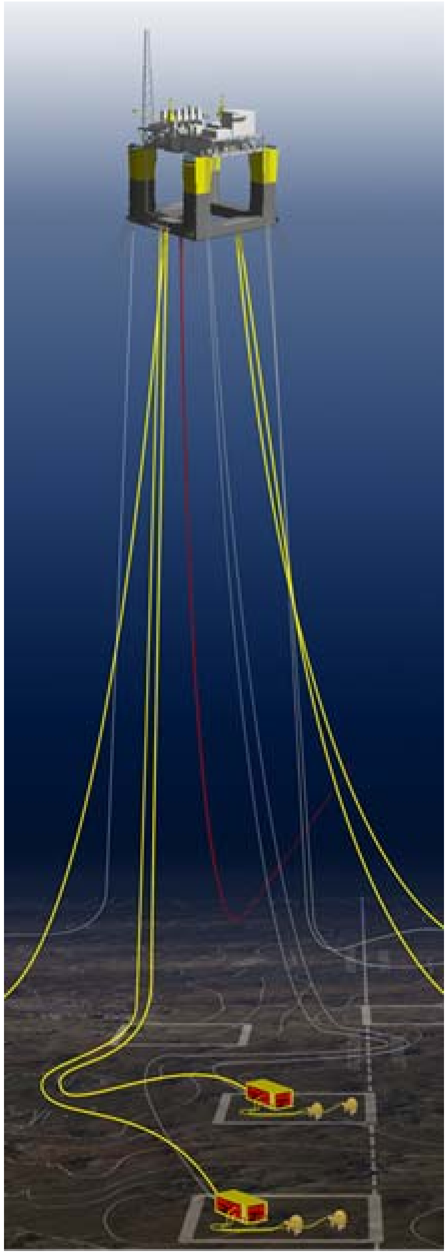
↓

Coupled solution by frequency or time domain methods

Work over the reporting period devoted to:

(a) Development and improvement of fully coupled time domain methods

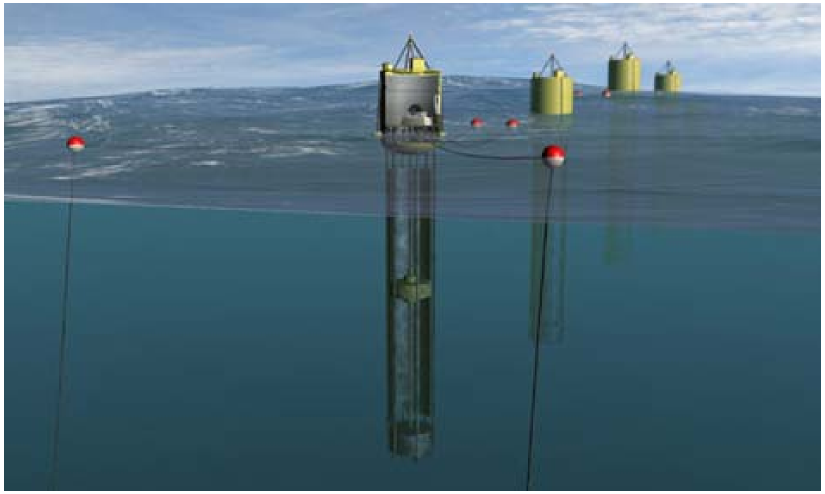
(b) Improvement of frequency domain methods with the aim of reducing computational effort for engineering applications. Consistent stochastically linearization of the mooring forces is essential.



3-Stationary Floating Structures and Ships

Hydrodynamics of Multi-Body Interactions

- Multi-body hydrodynamics in waves is in most cases calculated by linear BEM.
- Motions solved in the time domain to include specific external nonlinear effects.
- Higher Order BEM seems preferable since the computational effort is smaller for the same accuracy.
- As offshore activities expand and diversify, new challenges are posed to the scientific community also in the area of multi-body hydrodynamics (WEC farms)



3-Stationary Floating Structures and Ships

Side by side ships/platforms

- Typical problem: LNG offloading from the floating platform to the shuttle tanker.
- Linear models OK, except at resonant frequencies of the gap between vessels
- Existing semi-empirical methods to reduce the unrealistic high wave elevations between the two bodies have limitations
- Viscous flow models to be validated on such configurations

Courtesy SBM

3-Stationary Floating Structures and Ships

Further research may focus on:

- Complicated nonlinear behavior of stationary floating structures, such as green water, air-gap, multi-body interactions and VIM etc., in time domain
- New experimental techniques, such as particular image velocimetry, fibre optical sensors etc., need further maturing for day-to-day use in the basins.
- Numerical and Experimental Modelling of Floating Renewable Energy Systems to be developed

4-Dynamically Positioned Ships

Trends:

- Increasing complexity of the offshore operations, including: offloading by dynamically positioned shuttle tankers, dynamic tracking, disconnectable FPSOs with DP capabilities, etc.
- Autonomous under water vehicles with DP control

4-Dynamically Positioned Ships

Developments:

- 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

- Model basins have worked on testing dynamic positioned vessels for novel structures or new applications of DP

- The focus in these papers is more on the application of the DP than on the (further development) of the DP control system.

5- Wind, Waves & Current

Extreme waves

- Freak (or Rogue) waves are now intensively studied (see Rogue Wave Symp., 2004, 2008)

- Reproduction of such extreme waves is very important as well as the investigation of their generation mechanism in real sea environments

5- Wind, Waves & Current

Reproduction of extreme waves

- Wave focusing method

  Clauss et al. (2005, 2006a) , Liu et al. (2005)

  Higher-order effects: Buchner et al. (2007), Ducrozet (2006)

- Wave-structure interactions

  Kinoshita et al. (2006), Minami et al. (2006), Johannessen et al. (2006)

- Numerical wave tank

  IVOF: Buchner and Bunnik (2007), FEM vs. VOF: Bunnik and Huijsmans(2005), Spectral: Ducrozet et al (2006)

5- Wind, Waves & Current

Shallow water waves

- Increase of shallow water floating storage facilities such as FSRU
- Increasing importance of low-frequency shallow water characteristics: Stansberg(2006)
  - Wave-group induced low-frequency wave components
  - Bound and free waves, reproduction and correction
  - Set-down effects: Theoretical model & model tests, Voogt et al. (2005)

5- Wind, Waves & Current

Wind & current interactions

- Several commercial wave tests have been conducted combining waves with currents and winds, but few reports have been found for details of combined environments.
  - Koo and Kim (2006) : wave-current interaction by NWT
  - Lee et al. (2006): experimental study on wave-current interaction

6- Hydroelasticity & Impact

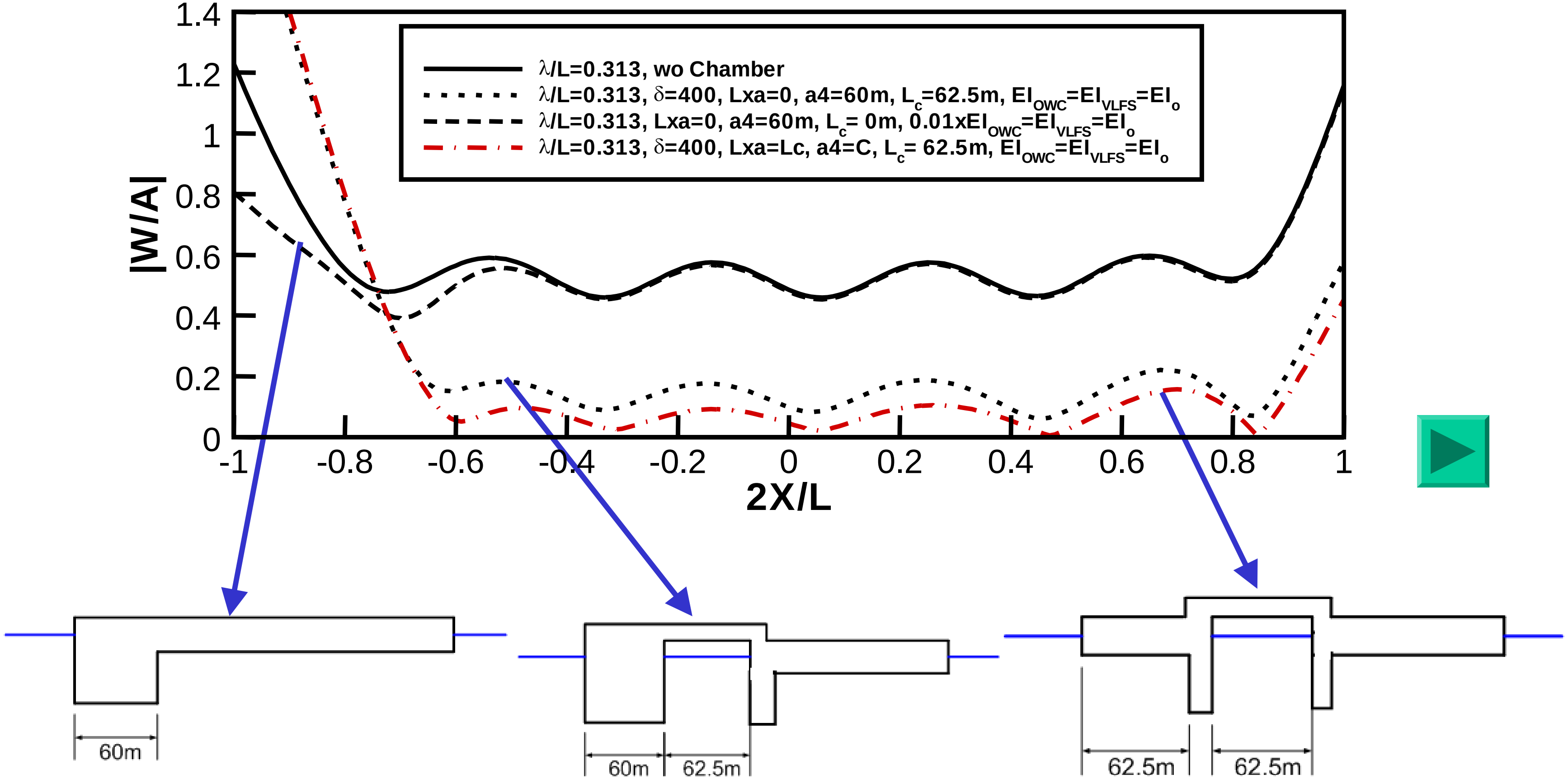
Hydroelasticity of VLFS

- Inherent weakened structural stiffness
- Reduction of wave loads due to hydrostatic balance due to structural deformation
- Response time scale is comparable to wave periods

Research Trends:

- Validation studies
- Combined effects: bottom geometry, air cushion effects
- Fully nonlinear time-domain methods

Shape of fore structure of OWC chamber



6- Hydroelasticity & Impact

Whipping and Sloshing Impact

- Consideration of hydroelasticity in analyzing impact responses
  - Deuff *et al*, 2006, fluid-structure coupling using SPH
- Hydroelasticity related with sloshing
  - Malenica et al.(2006), simplified asymptotic impact theory
  - Rognebakke & Faltinsen (2006), entrapped air effects
  - Wang & Kim(2007), FE analysis considering hydroelastic and visco-elastic effects
- Whipping & Springing
  - Storhaug & Moan(2006), experiments on whipping & springing
  - Malenica *et al*, 2008

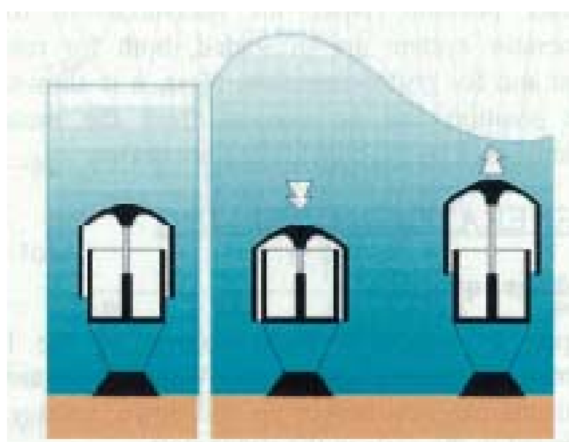
7- Renewable Energy Systems

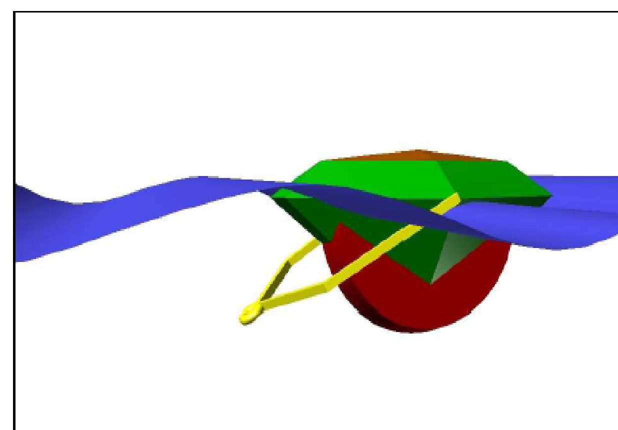
Wave Energy Converters (WEC):

Many different types :

- Oscillating water columns
- Moving or articulated bodies
- Internal pendulum
- Wave overtopping devices, etc…

Mostly systems based on moored bodies





7- Renewable Energy Systems

Wave Energy Converters (WEC):

Numerous difficulties for Design and Modelling:

Modelling of power take-off mechanism

Strong nonlinear effects

Vortex shedding and viscosity affect efficiency

Multiple body interactions

Mooring lines damping

Real time monitoring of wave conditions for optimum control

Robust and cost-effective design is mandatory

A real challenge for EFD, CFD & Optimization !

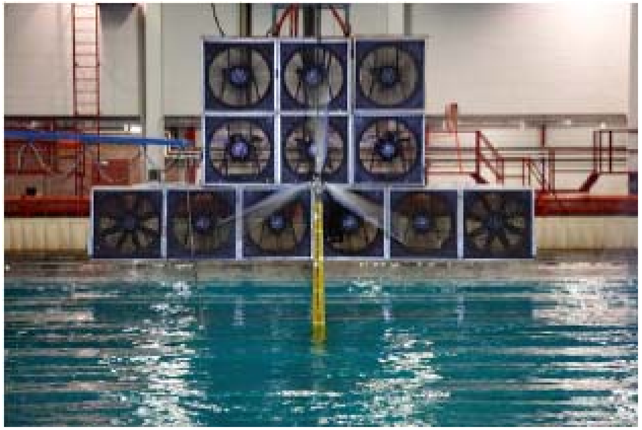
7- Renewable Energy Systems

Wind Energy:

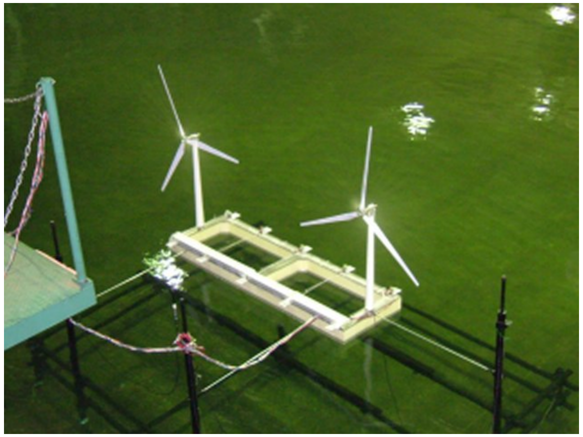
Floating offshore wind farms based on Spars, TLPs, box girders are being studied.

Coupling effects between the support structure and the wind turbine when subjected to combined wind and wave loading must be modelled

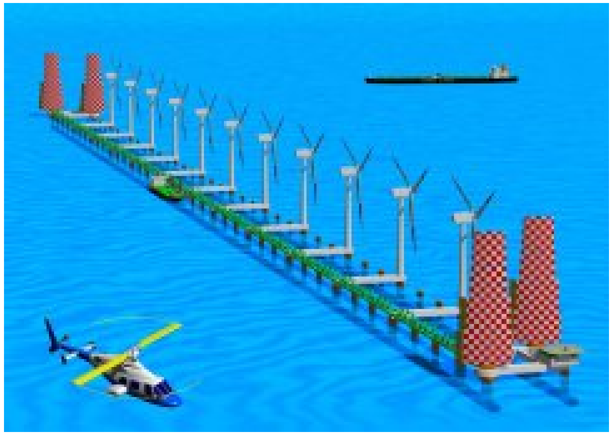
Wind generation in model basins to be improved



Hywind floating wind turbine tests



Box girder grid type floating wind turbine

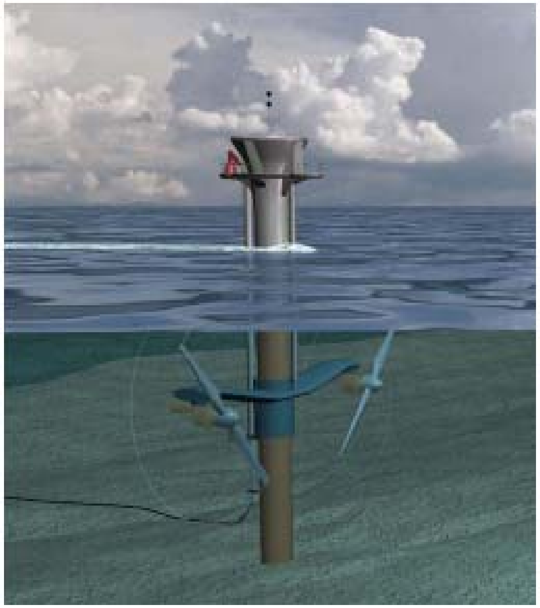


Sailing offshore wind farm

7- Renewable Energy Systems

Tidal & Marine Current Energy

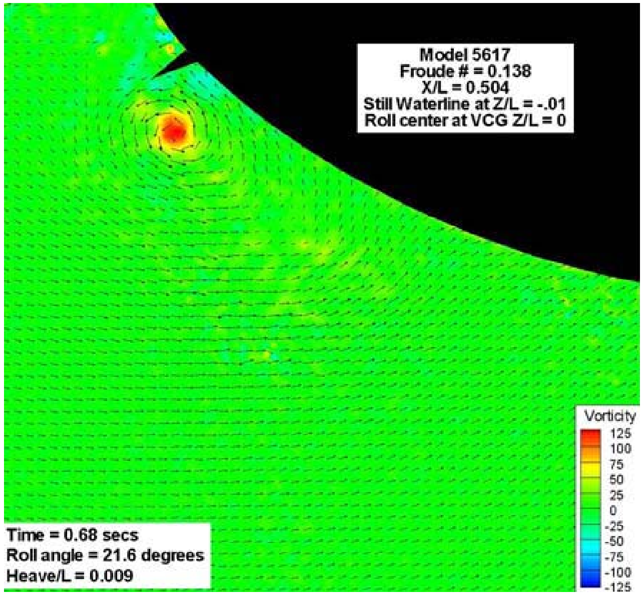
In order to evaluate the performance of the turbines or hydroplanes of these converters, a variety of numerical methods, such as RANS CFD, BEM, and Vortex Methods have been developed, and many experiments carried out.



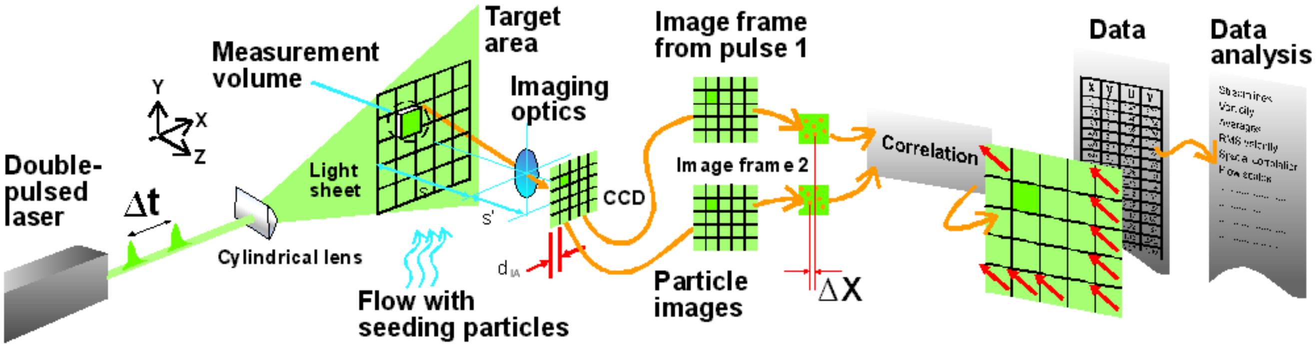
8- New Experimental Techniques

Particle Image Velocimetry

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



PIV measurements around bilge keels



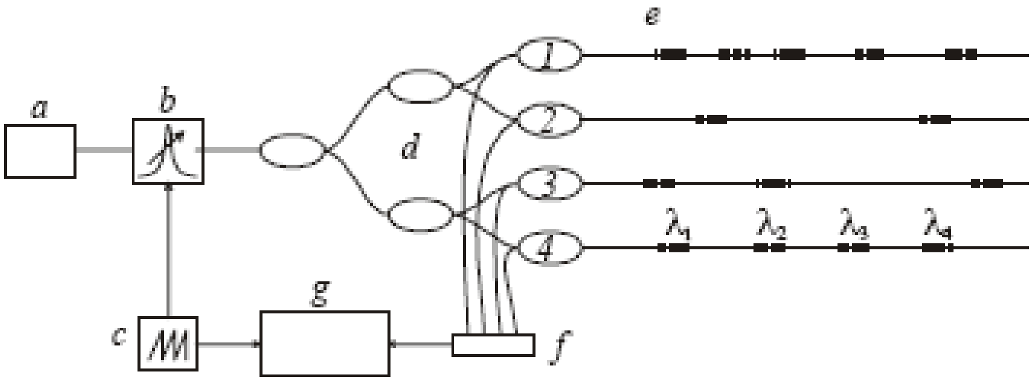
PIV principle

8- New Experimental Techniques

Fiber Optics

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 techniques used in communication.

Attractive when a large number of sensors is required in a small or a difficult to access area.

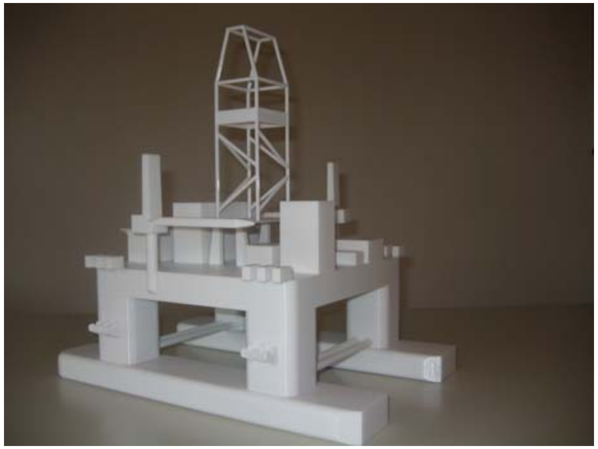


Fibre optic lines with Fibre Bragg Gratings (FBG)

8- New Experimental Techniques

Rapid Prototyping

Rapid prototyping technology is a group of manufacturing processes that enable the direct physical realization of 3D computer models.



Scale 1:300 demonstration model of drilling semi, manufactured with rapid prototyping

Optical Tracking Systems

Optical motion measurements of ship models, floater models or rigid bodies have become the standard in most towing tanks and model basins.

Underwater versions of such systems are now available for use in model basins.

9- Progress in CFD

Main Domains Impacted by CFD:

- Wave Modeling, Extreme Waves
- Violent flows: Impact, Deck slamming, Green water
- Coupled fluid-structure interaction modelling
- Cylinder flows, risers, VIV
- Wave-structure interactions, including viscous effects and/or extreme waves
- . . .

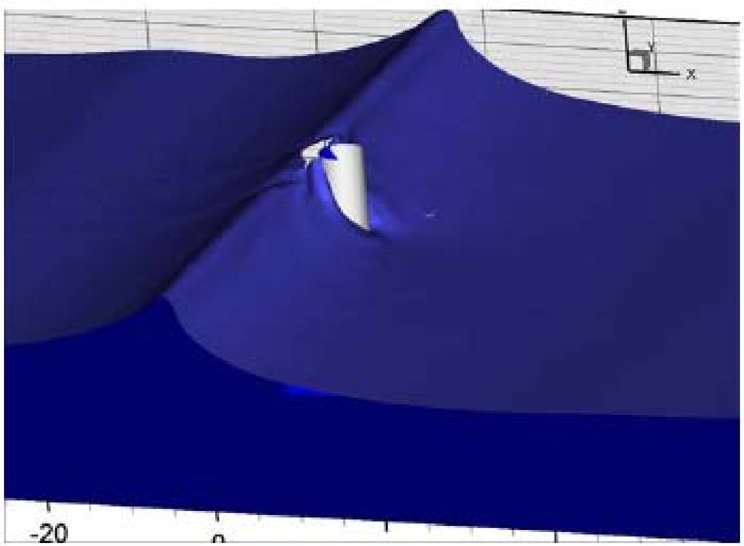
9- Progress in CFD

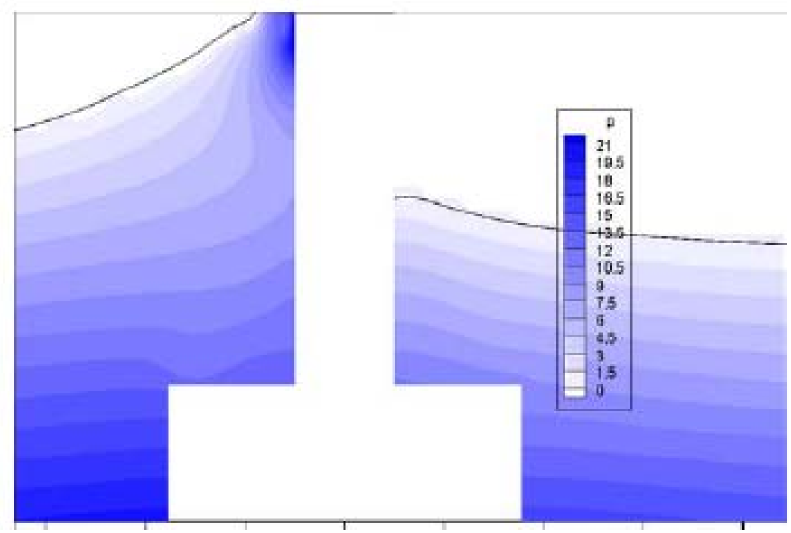
Developments of Numerical Methods

- Finite-Volume methods with interface capturing schemes (‘general-purpose’ tools)
- Hybrid potential/viscous coupling schemes
- Meshless methods show interesting capacities (robustness, complex configurations, multi-physics, adapted to massive parallel computing)
- Efficient cartesian grid-based methods with immersed boundaries technique
- Validation & Verification, Estimation of uncertainties

9- Progress in CFD

- Finite Volumes+Free surface capturing:



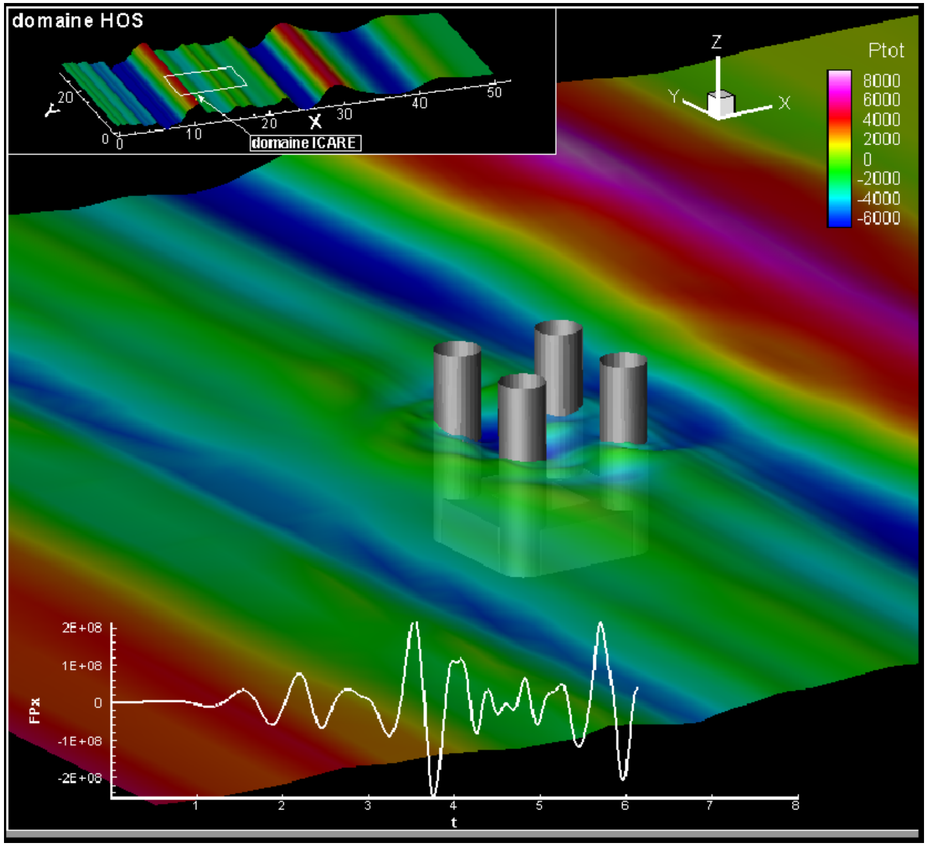


Wave run up and pressure on GBS wind turbine support,
Bredmose et al, OMAE2006

9- Progress in CFD

- Hybrid potential-viscous flow coupling
  - Domain decomposition
  - Functional decomposition

Right: Focused wave on a TLP.
Hybrid HOS/RANSE simulation
(Luquet et al, 2007)



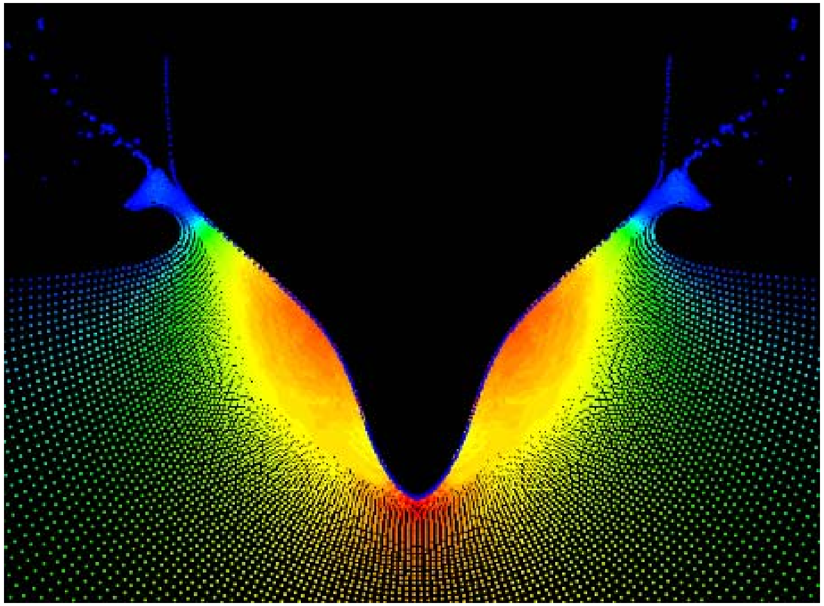
9- Progress in CFD

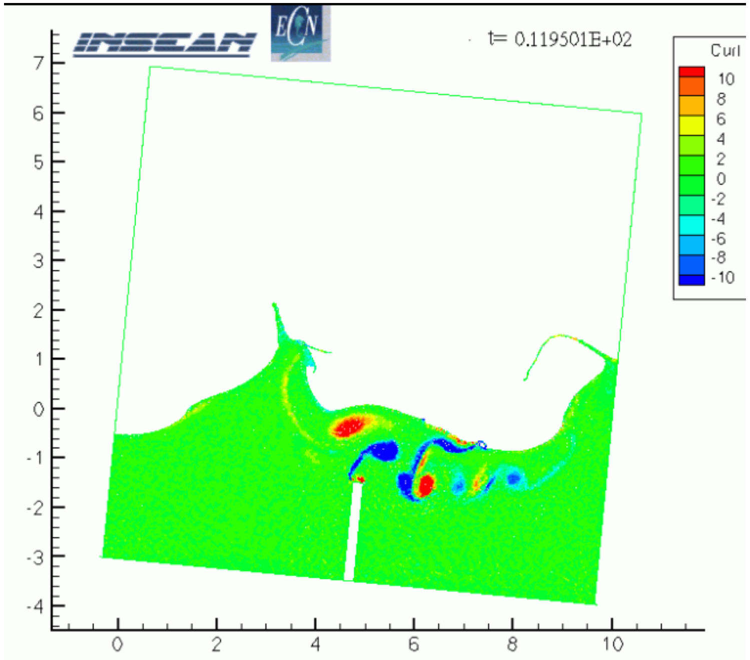
Meshless methods:

Examples : SPH

MPS

(See Violent flow Conference 2006)





9- Progress in CFD

- Cartesian grid methods for massive parallel computations (Domain decomposition, Immersed boundary techniques)

  Dommermuth et al (2007)
  Yang et al (2007)

9- Progress in CFD

- Validation & Verification
- Manufactured solutions for code benchmarking
- Uncertainty analysis, influence of uncertain input data

  Lucor & Tryantafyllou 2007

10- Procedures

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

- Minor changes to the text
- References added

Model Tests in Regular Waves (7.5-02-07-03.2)

- A more complete analysis of the measured signals recommended in order to identify higher harmonic content, asymmetry and mean values,
- Small subsection of Uncertainty Analysis added,
- Lack of references with benchmark experimental data specific of offshore problems, however the committee is not aware of available and complete set of results including UA.

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

- Minor changes and inclusion of a list of references

10- Procedures

Turret Tanker Systems (7.5-02-07-03.3) &
Experiments with Offshore Platforms (7.5-02-07-03.1)

There are considerable areas of overlap between the Turret Tanker Systems procedure and the Experiments with Offshore Platforms procedure.

↓

- ✓ It is recommended that the procedure on Turret Tanker System is removed.
- ✓ The procedure on Experiments with Offshore Platforms was appropriately extended.

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

Procedure to carry out deep-water model tests in a test basin of limited depth using active control of the mooring lines.

Apparently, the technique described in the procedure is still not in use, therefore it is suggested that the procedure is reviewed when more experience is gained within active hybrid testing.

10- Procedures

Validation of Software for Predicting Wave Loads and Responses of Offshore Structures

- The OEC reviewed the procedure proposed by the seakeeping committee (Verification and validation of linear seakeeping codes) and proposes one common procedure for advancing ships and large volume stationary offshore structures.
- It is suggested that topics specific of offshore structures are added to a common procedure, such as: waterdepth effects, multi-body interactions, second order responses.
- Nonlinear effects should also be considered in future updates of the procedure (nonlinear geometric and free surface effects).

11- Benchmark Study

Two candidates are proposed for a CFD benchmark study:

1. **Existing ISSC experiments for wave run-up on a cylinder supplemented with new experiments including force measurements.**

2. **Existing non-oscillating and forced oscillation experiments on a circular cylinder in current**

11- Benchmark Study (1)

Wave Run-up around cylinders

Background

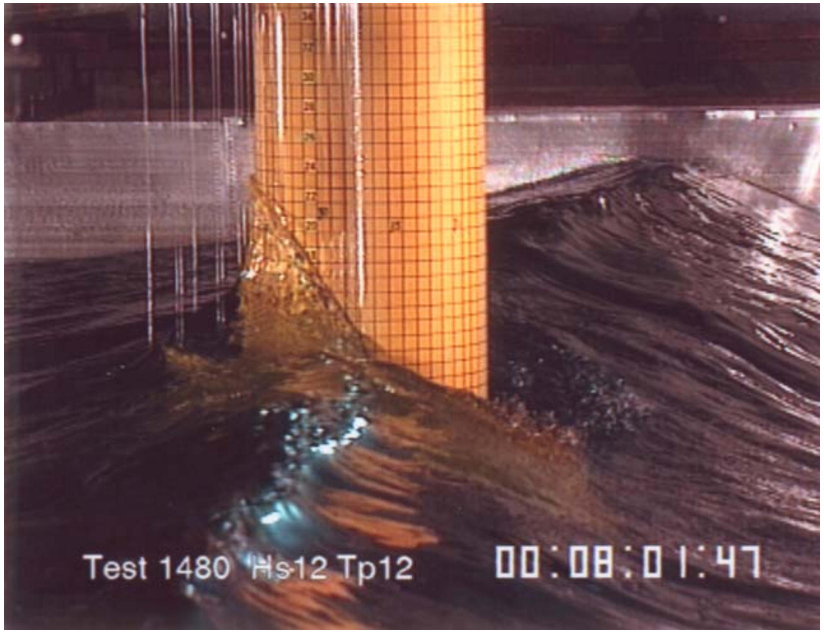
- **Relevant for offshore structures in harsh environment where the air gap is an important parameter in design**
- **Available experimental data exists for wave loads on truncated circular and square cylinders and wave scattering around the cylinders**

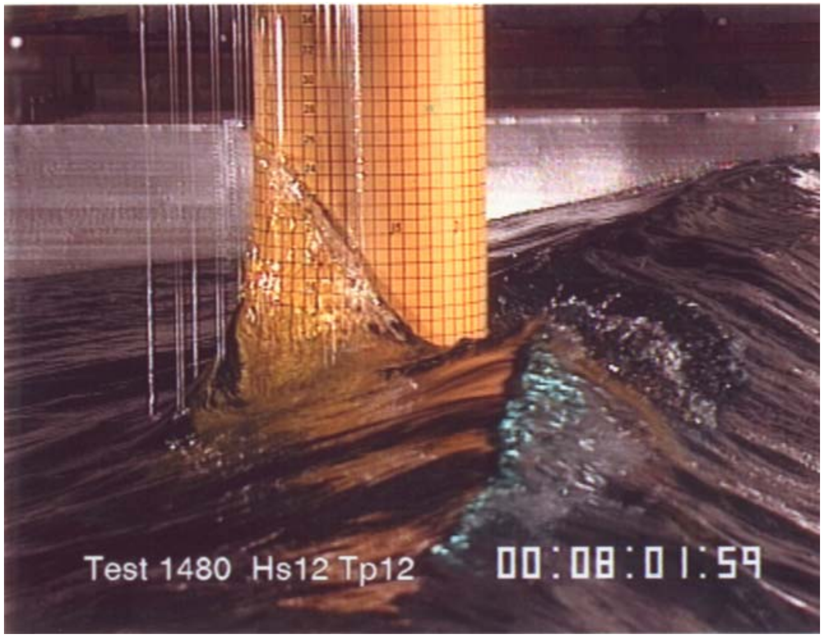
Objective

- **To investigate 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.**
- **Investigation of the free-surface wave elevation within a column radius distance around fixed vertical columns as well as wave loads on the columns**

11- Benchmark Study (1)

Experiments performed at MARINTEK and MOERI



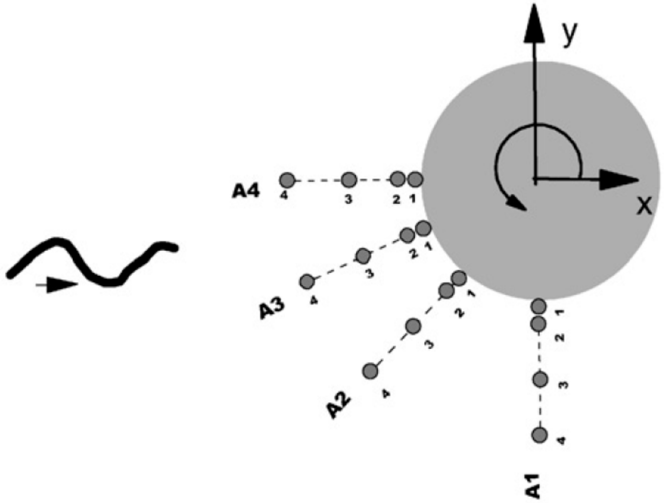


Snapshots from MARINTEK experiments

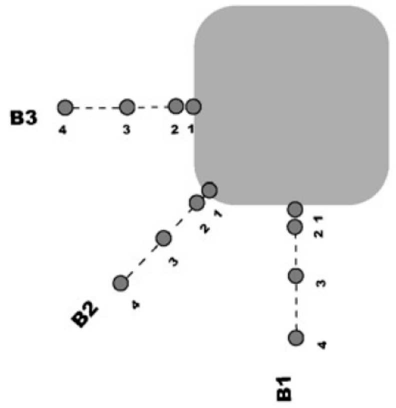
11- Benchmark Study (1)

Available experimental data

- Time traces of calibrated incident waves at the position of the centre of the cylinders
- Time traces of the wave elevation of at the locations given
- Time traces from wave force measurements (local and global).
- Harmonic analysis results for the wave elevation for zeroth, first and second harmonics for wave elevation and wave force.



Circular cylinder



Square cylinder

11- Benchmark Study (1)

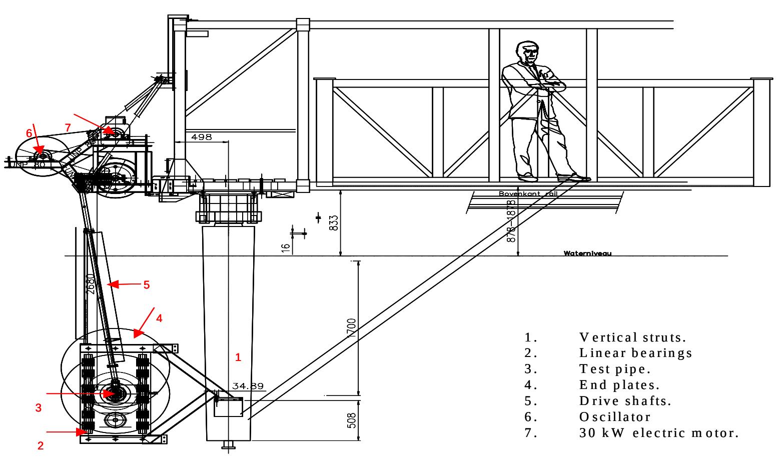
Test Conditions:

- Monochromatic incident waves
- Two wave periods: 9s, 15s
- Three wave steepness (H/ λ): 1:30, 1:16 and 1:10

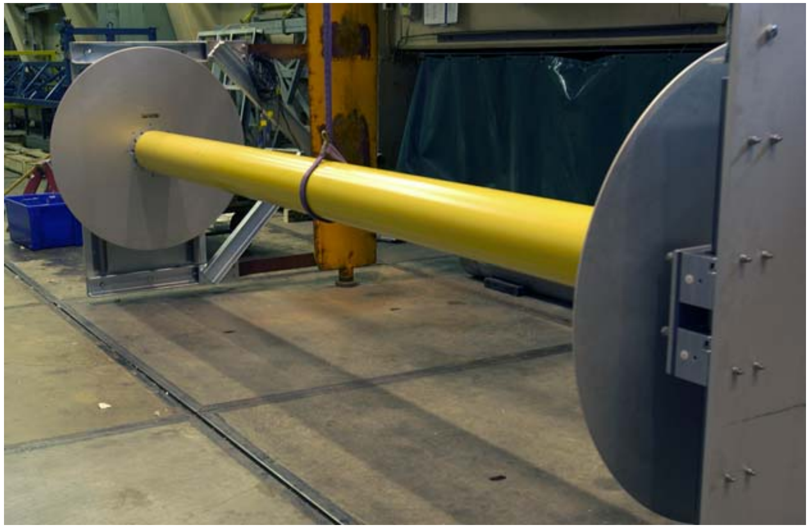
11- Benchmark Study (2)

Forced Oscillations of a Circular Cylinder in a Current

Test set-up and test pipe



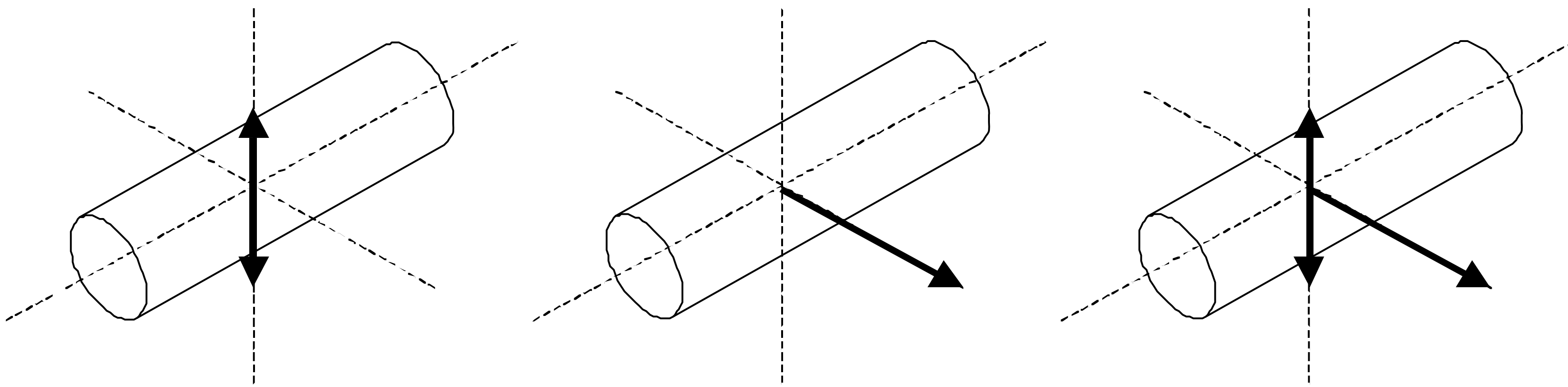
High Reynolds VIV test apparatus



200 mm smooth pipe

11- Benchmark Study (2)

Three types of tests



Test set 1 : Vertical oscillation	**Test set 2 :** Horizontal tow	**Test set 3 :** Vertical oscillation, Horizontal tow

11- Benchmark Study (2)

Test data in ASCII format

- 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

11- Benchmark Study (2)

Stationary Cylinder in a Cross Flow

- 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

11- Benchmark Study (2)

Oscillating Cylinder in a Cross Flow

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

11- Benchmark Study (2)

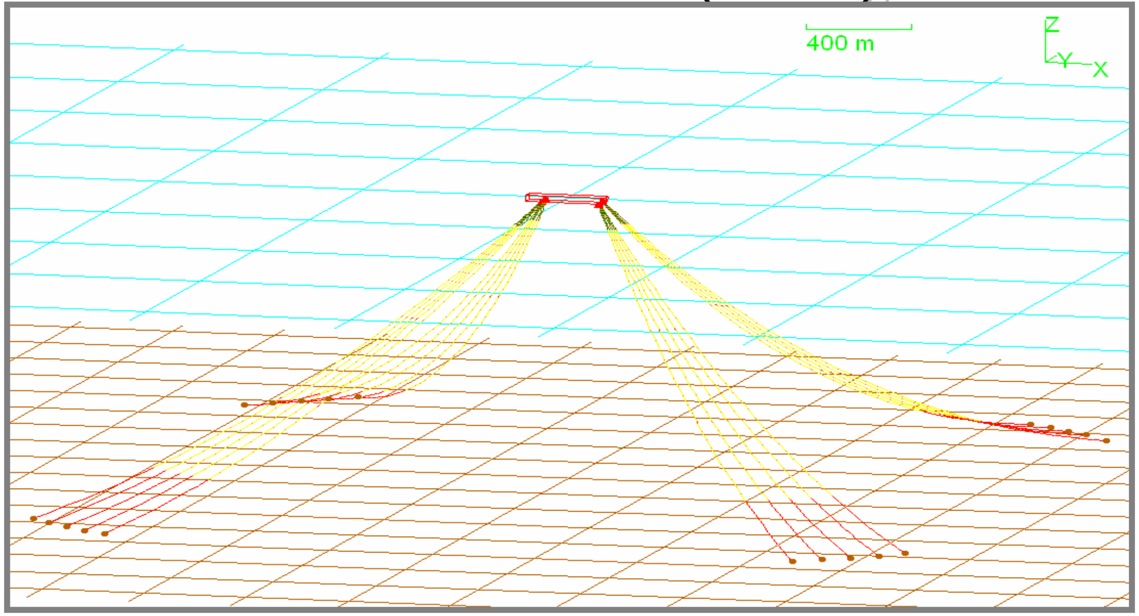
Description of the CFD Metod

- Type of CFD model (RANS, URANS, LES, etc.)
- Discretization method (finite elements, finite volumes, finite differences etc.)
- Turbulence model (e.g. 0-equation, 1-equation, 2-equation, Reynolds-stress model, DES, LES, etc.)
- Wall function (if applicable)
- Grid (e.g. structured, unstructured, etc.)
- Convergence
- CPU time

13- Multiple Scale Model Testing

Choice of a Realistic Case Study:

- FPSO (Floating Production Storage and Offloading)
- L=300 m
- 20 anchoring lines (taut leg mooring lines and polyester)
- 100 different risers
- Water Depth=1500 m
- Submitted to random ocean waves (5-15 s), wind and currents.



13- Multiple Scale Model Testing

Design of the Model Test:

- The central issue: define the scale of the model
- Froude scaling prevails due to the waves and lines responses
- Typically, the scale factor ranges from 50 to 90
- For the FPSO case study, the compliant mooring lines avoid horizontal drift but bring small horizontal restoring properties.
- Second order low frequency resonant horizontal motion.

13- Multiple Scale Model Testing

For the proposed case study:

- 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 is based on **diameter distortion, lines concentration and truncation**
- However, the estimation of line damping remains an open issue

other cases such as CALM buoys would require specific analysis

14- Wind Modelling in Model Basins

14.1 Physical Modelling In Model Basins

14.2 Wind Force Simulation By Empirical Models

14.3 Wind Simulation By CFD

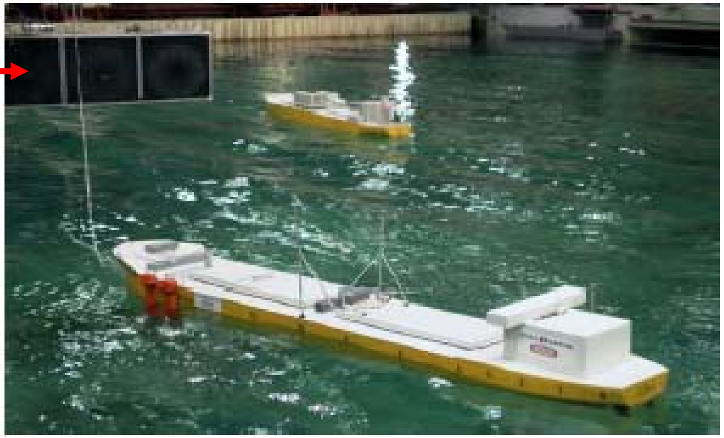
14- Wind Modelling in Model Basins

Physical Modelling:

Four methods to generate wind forces in model basins:

1) Fixed banks of wind fans

A method is proposed to calibrate the correct wind loads, rather than generate the correct wind velocity (Buchner et al. , 2001)

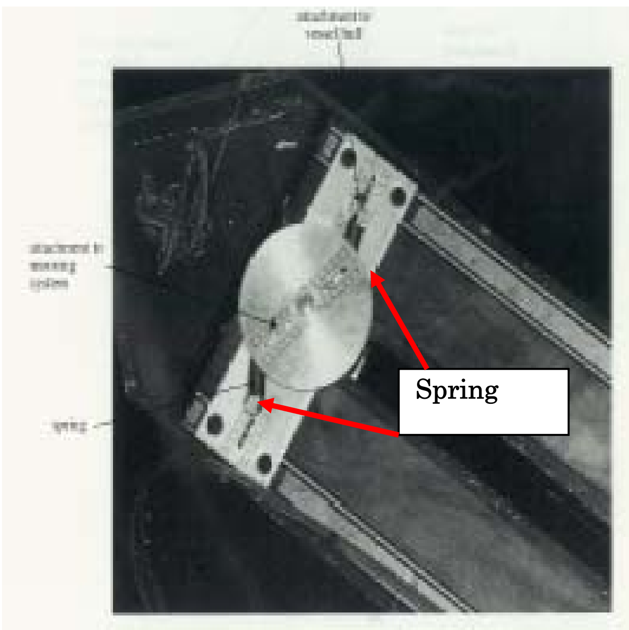


2) Wind fans on model deck (Bobillier et al. 2000)

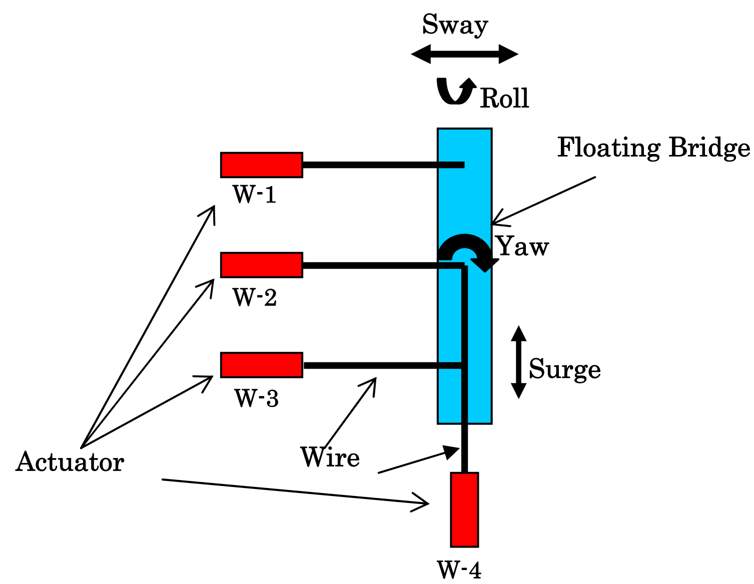
3) Spring-weight systems

a) Applied to wind-induced load in yaw motion on turret moored vessels (Brown et al. 1998)

b) Applied to controlled wind loads in surge, sway, roll and yaw on a floating bridge (Nagata et al. 1999)



Brown et al. 1998

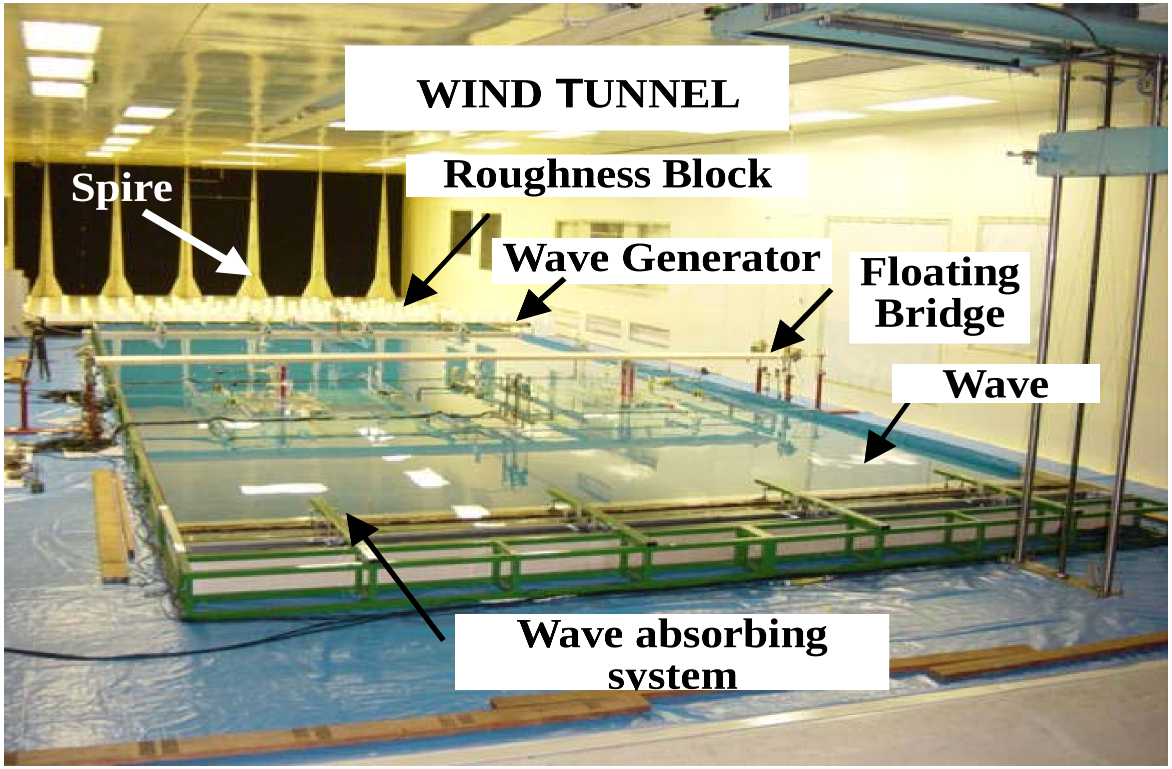


Layout of Actuators

Nagata et al. 1999

4) Wave tanks in wind tunnels

The dynamic motions of an elastic floating bridge in waves and wind was studied by Murakoshi et al. (2004) in a wave tank with 12m length, 5.4m width and 0.22m depth, installed inside the test section of a wind tunnel. Wind velocity scaled using Froude's law.



14.2 Wind Force Simulation By Empirical Models :

Widely accepted method for in-line and transverse forces

Fluctuating wind velocity may be generated by superposition of harmonic components

14.2 Wind Simulation by CFD :

Good agreement, but time consuming

Air flow around a ship

RANS solver + k- ε turbulence model

(Reddy et al 2000, El Moctar et al. 2003)

Turbulent flow around bluff-bodies

RANS solver + various revised k- ε model,or LES

(Murakami 1997 , Lübcke et al. 2001, Kuroda 2003,Tominaga et al. 2008)

Concluding remarks, suggestions

Development of procedures for identification & generation of highly nonlinear waves

Expansion of Marine Renewable Energies requires the development of CFD & EFD for a better design of WECs, Wind & Current turbines

Reference data needed for the validation of fluid-structure numerical models applied in Hydroelasticity & Impact problems

Development of Experimental Techniques: 3D PIV, Optical tracking, Free surface measurement….

New CFD methods are promissing. Their development should be continuously monitored

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THANK YOU