

Technical Committee on Ocean Engineering

2017-2021

Chairman : Claudio A. Rodríguez Castillo (LabOceano, Brazil) Members : Longfei Xiao (SJTU, China), Rae Hyoung Yuck (SHI, Korea), Qing Xiao (U. Strathclyde, UK), Viacheslav Magarovskii (KSRC, Russia), Halvor Lie (SINTEF Ocean, Norway), Ayhan Mentes (ITU, Turkey), Yasunori Nihei (OPU, Japan)





Prof. Claudio A. Rodríguez Castillo (Chairman), LabOceano – Federal University of Rio de Janeiro, Brazil

Prof. Longfei Xiao (Secretary), Shanghai Jiao Tong University, China

Dr. Viacheslav Magarovskii, Krylov State Research Center, Russia

Dr. Rae Hyoung Yuck, Samsung Heavy Industries Co. Ltd, Korea

Dr. Halvor Lie, SINTEF Ocean, Norway

Prof. Qing Xiao, University of Strathclyde, United Kingdom

Prof. Ayhan Mentes, Istanbul Technical University, Turkey

Prof. Yasunori Nihei, Osaka Prefecture University, Japan





The Committee meetings were held at:

- University of Strathclyde, Glasgow, United Kingdom, January 24-26, 2018.
- Samsung Heavy Industries, Daejeon, Korea, September 12-14, 2018.

Due to the COVID-19 pandemic, scheduled meetings for 2020 were cancelled and the last stage of coordination of the tasks has been done online.





- 1. Tasks assigned by the 28th ITTC
- 2. Structure of the final report
- 3. State-of-the-art reviews in offshore structures
- 4. Review of existing procedures
- 5. State-of-the-art review in offshore aquaculture systems
- 6. State-of-the-art review in model tests of cable/pipe dynamics close to the sea surface
- 7. State-of-the-art review in hybrid testing software-in-the-loop tests for modelling of wind forces
- 8. Experimental benchmark on wave run-up on cylinders
- 9. CFD benchmark on two-body interactions based on the assigned 27th ITTC experimental benchmark
- 10. State-of-the-art review in large diameter flexible risers for deep water mining
- 11. Procedure/Guideline for Model Construction
- 12. Conclusions and Recommendations





- (1) Update the state-of-the-art for predicting the behaviour of bottom founded or stationary floating structures, including moored and dynamically positioned ships, emphasizing developments since the 2017 ITTC Conference.
- (2) Review ITTC Recommended Procedures relevant to ocean engineering.
- (3) Review the state-of-the-art in offshore aquaculture systems (deeper water, further from shore, not in sheltered waters), including harsher conditions, larger volumes and scaling of whole structure vs scaling forces acting on nets.
- (4) Review the state-of-the-art in model tests of cable/pipe dynamics close to the sea surface
- (5) Review the state-of-the-art in hybrid testing software-in-the-loop tests for modelling wind forces.





- (6) Extend experimental wave run-up benchmark tests (four squared vertical cylinders) to measure wave run-ups and global forces on cylinders and to investigate scale effect.
- (7) Carry out CFD benchmark study on two-body interactions, focusing on the investigation of viscous effects on the gap surface elevation using the benchmark experimental results produced by the 28th ITTC OE committee.
- (8) Review the state-of-the-art for large diameter flexible risers used for deep water mining.
- (9) Re-write Model Construction Procedure with focus on model construction issues (materials, tolerances, production methods, quality control, acceptance testing, etc.).





- Section 2: State-of-the-art reviews
- Section 3: Review of the existing procedures
- Section 4: State-of-the-art in Offshore Aquaculture Systems
- Section 5: State-of-the-art In Model Tests of Cable/Pipe Dynamics Close to the Sea Surface
- Section 6: State-of-the-art In Hybrid Testing Software-in-the-loop Tests for Modelling Wind Forces
- Section 7: Experimental Benchmark on Wave Run-up on Cylinders
- Section 8: CFD Benchmark on Two-Body Interactions
- Section 9: State-of-the-art in Large Diameter Flexible Risers for Deep Water Mining
- Section 10: Procedure/Guideline for Model Construction
- Section 11: Conclusions and Recommendations





3. State-of-the-Art Reviews in Offshore Structures

- Bottom founded structures
- Stationary floating structures
- > Dynamically positioned floating structures
- New technological developments
- New experimental techniques and extrapolation methods
- Practical applications of computational methods to prediction and scaling
- Need for R&D for model experiments, numerical modelling and full-scale measurements



Source: https://www.strukts.com/2012/05/types-of-offshore-platforms_70.html





- Life extension of existing fixed platforms (some have already exceeded their design life): fatigue and vessel impact loads are of concern.
- Earthquake loads for the design of offshore wind turbines (OWT)







Dehghani and Aslani (2019)





 Foundations continue to be a concern for these structures: scour processes, collisions,

geotechnical issues, etc.



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(Moulas et al., 2017)





Reviewed the state-of-the-art of:

- FPSO vessels
- Semi-submersibles
- TLPs
- Spar platforms
- Floating LNG production storage and
 - offloading vessels
- Floating offshore wind turbines (FOWT)



Stationary Floating Structures – FPSOs (2/7)

- Several experimental and numerical studies on with green water and wave impact events under extreme wave conditions: CFD simulations, motions, impact loads, wave elevations on the deck, etc.
- Side-by-side configuration: wave elevation in the gap, shielding effects, horizontal and vertical forces, etc.
- Slow yaw rotations, wind-induced damping, low-frequency drift forces, roll damping.









Stationary Floating Structures – Semi-Submersibles (3/7)

- Several numerical (CFD) studies (few model tests) on Vortex Induced Motions (VIM): effects of column shape, column corner shapes, column-steps, pontoon shapes, use of helical strakes, etc.
- Besides the typical concerns (motion responses, wave impact), several other issues associated to decommision process, float-over installation, loading due to ice conditions, etc.



(Tan et al., 2017)





(M. Liu et al., 2017a)







- Responses under extreme wave conditions: wave in-deck events, maximum and minimum tendon tensions, airgap, etc.
- Interaction effects with other bodies: Tender assisted drilling (TAD) operations, gangway connections, multimodal behaviors, etc.
- Challenges: modelling of tendons, risers, hawsers.







(Abdussamie et al., 2017)





Stationary Floating Structures - Spars (5/7)

- New concept: Spar Drilling Production Storage Offloading Platform (SDPSO) fro ultra-deep water.
- Numerical and experimental studies on typical issues: coupled spar-mooring system responses under wind, waves and currents, slow drift motions, VIV and VIM under harsh environments, parametric roll/pitch resonances, etc.





- Experimental and numerical investigations on the effects of inner-tank sloshing on motions responses
- Side-by-side configuration: loads on connections, large lowfrequency responses, gap wave responses, sloshing effects, mooring lines and fenders responses.





(Kawahashi et al., 2019)



- Model testing and numerical simulations: coupled aero-hydro-servo-elastic models, potential flow, nonlinear hydrodynamic responses, uncertainties.
- Real-time hybrid model (ReaTM): rotor and tower loads, SiL (software-in the loop) approach for aerodynamic forces
- Wind farms: array of semisubmersibles.
- New concept: MWWC (Monopile-WT-WEC Combination)



(Ren et al., 2018)





Dynamically Positioned (DP) Structures

- The application of DP to actual system such as decommissioning & heavy lift operation and DP positioned vessel are the most studied;
- The new algorithm for DP control system including thrust allocation, control logic and the integrated system are actively researched;
- The thrust-thrust & thrust-hull interaction and thrust deduction are still a major research topic;
- The study on DP in ice field is to be a new field of research.











The following guidelines/procedures have been reviewed:

- 7.5-02-07-03.1 Floating Offshore Platform Experiments;
- 7.5-02-07-03.2 Analysis Procedure for Model Tests in Regular Waves;
- 7.5-02-07-03.4 Active Hybrid Model Tests of Floating Offshore Structures with Mooring Lines;
- 7.5-02-07-03.5 Passive Hybrid Model Tests of Floating Offshore Structures with Mooring Lines;
- 7.5-02-07-03.6 Dynamic Positioning System Model Test Experiments;
- 7.5-02-07-03.10 Guideline for VIV Testing;
- 7.5-02-07-03.11 Model Tests of Multibodies in Close Proximity;
- 7.5-02-07-03.13 Guideline for VIM Testing;
- 7.5-02-07-03.14 Analysis Procedure of Model Tests in Irregular Waves;



5. State-of-the-art review in offshore aquaculture systems (1/3)

According to C. M. Wang et al. (2019), offshore fish farming:

- (i) unsheltered waters, defined by the seaspace outside a straight line joining two major capes/promontories or within 25 nautical miles from the shoreline for economic feasibility;
- (ii) water depth greater than 3 times the cage height and at least 15 m between the cage bottom and the seabed for better dispersion of fish wastes and
- (iii) current speed ranging from 0.5 m/s to 1 m/s.



https://www.maritimeexecutive.com/article/norwa y-targets-offshore-fish-farminnovation



http://www.takepart.com/article/20 16/01/15/seaworld-fish-farmenvironment



5. State-of-the-art review in offshore aquaculture systems (2/3)

Fish farming worldwide is moving offshore due to:

- lack of available nearshore production sites ** (where conflicts with shipping, fishing, tourism, conservation and recreation are frequent),
- much larger sea space availability and *
- better water quality (essential for the ** production of healthy fishes).

However, going offshore poses many challenges the high environment, due to energy inaccessibility of power supply and supporting services (C. M. Wang et al., 2019).

Open-net cage system



Floating flexible cages



Floating rigid cages



Semi-submersible rigid cages



Submerged cage



Closed fish farm concept "fish farm egg"



Neptun closed containment fish tank



Concrete containment fish tank



5. State-of-the-art review in offshore aquaculture systems (3/3)

- Fluid-structure interactions between environmental loads and aquaculture cages;
- Analytical studies, numerical implementations, field tests and laboratory experiments have been found and reported;
- Mooring and grid systems, drag coefficients of the net panel, hydrodynamic behaviours of cage components, velocity reduction of cage array and volume reduction caused by cage deformation are topics of concern;
- New concepts

Havfarm





Wind-Solar-Aquaculture (WSA) system





6. State-of-the-art review in model tests of cable/pipe dynamics close to the sea surface

Fluid Transfer Lines (FTL) - Pipes

Advantages (compared to the subsea pipelines):

- improved flow assurance due to higher sea-water temperature leading to reduced risk of blockage by formation of wax and hydrates;
- avoidance of seabed constraints: ground instability, irregular sea-bed profile, subsea hardware congestion.



Artist impression of the suspended FTL connected to the Spar and FPSO

Disadvantages:

- Limitation in the sizes (length, diameter, curvatures);
- Strength and fatigue problems;
- Flow-assurance concerns: possible temperature drop, high cost of materials, installation;
- Interactions with platform motions and exposure to waves and/or higher current velocities;





6. State-of-the-art review in model tests of cable/pipe dynamics close to the sea surface

Fluid Transfer Lines (FTL) - Pipes

VIV on offshore risers, offloading lines: effects of current and waves, complex interactions with platforms motions (both line-ends connected), use of helical strakes, effect of platforms' VIM;







6. State-of-the-art review in model tests of cable/pipe dynamics close to the sea surface

Cables



- Few studies, only numerical: power cables for WECs, towing cables, cables for nets;
- Responses of power cables, including dynamic motion, curvature, cross-sectional forces, and accumulated fatigue damage;
- Effects of environmental conditions on the long-term mechanical life spans;





7. State-of-the-art review in hybrid testing – software-in-the-loop tests for modelling of wind forces (1/8)

SIL approach:

Using **realistic force** to represent the aerodynamic force on the turbine in the model testing of floating wind turbine.

- Substituting the wind turbine scaled rotor with ducted fan
- Fan thrust is controlled by the controller (by varying the fan rotational speed)
- Fan thrust depends on a computer real time simulation, considering the platform motions measured in real time in the wave tank test.
- (Müller et al., 2014).



(Azcona et al., 2014)





7. State-of-the-art review in hybrid testing – software-in-the-loop tests for modelling of wind forces (2/8)

Advantages

Compared with traditional model test, with the SIL approach:

- Tests doesn't require a wind generation system
- There is no requirement to construct a scale-model rotor and drive.
- The scale of the tests is dictated only by the hydrodynamics of the floater, which in this case allows a test at relatively large scale.
- The test procedure can replicate turbulent or steady wind in a variety of directions relative to the wave heading.
- The impact of the turbine control system and blade elasticity may be modelled
- Correct simulation of the aerodynamic drag load on the tower and parked turbine in extreme conditions is possible
- Some special cases, such as emergency stop tests can be simulated with correct full-scale behavior.



(Azcona et al., 2014)



7. State-of-the-art review in hybrid testing – software-in-the-loop tests for modelling of wind forces (3/8)

Review of SIL approach

- Wind tunnel testing is used to model behavior of a floating wind turbine
- The impact of the platform motions on the turbine performance is simulated by 6-Degrees-of-Freedom PKM-Hexaglide robot
- A 5-MW spar buoy floating turbine were analyzed to verify the reliability of the robot to reproduce the dynamics of nominal operating conditions, in terms of slider displacements, forces and power within the design ranges.



(Bayati et al., 2014)





7. State-of-the-art review in hybrid testing – software-in-the-loop tests for modelling of wind forces (4/8)

- Thys et al. (2018) presents Real-Time Hybrid Model (ReaTHM) tests that are performed on a 10-MW semisubmersible floating wind turbine in the Ocean Basin
- The wind turbine tower and rotor were modelled by NREAL FAST and used to compute the aerodynamic loads on the tower, which were then applied on the model by use of a cable-driven parallel robot
- Test results show that the wind turbulence played an important role for the surge and pitch responses at low frequency



(Thys et al., 2018)





7. State-of-the-art review in hybrid testing – software-in-the-loop tests for modelling of wind forces (5/8)

- Hybrid wind tunnel and ocean basin model tests with a FOWT were performed
- In the wind tunnel, a physical wind turbine connected to a 6DOF parallel kinematic robot controlled by real-time simulations of the floater subject to hydrodynamic loads.
- In the ocean basin, a physical model of the FOWT, without the rotor geometry, was placed in the basin and coupled to a **force actuator** controlled by the simulated aerodynamic loads.
- Results indicates that the linear response to small to moderate wave excitation is accurately modelled, but calibration of the numerical model is needed for accurate modelling of the low frequency response





7. State-of-the-art review in hybrid testing – software-in-the-loop tests for modelling of wind forces (6/8)

- The first validation of the SIL approach coupling in real time of rotor simulation that controls the fan with the measured motions of a 6MW semi-submersible scaled floating wind turbine.
- The platform design and the assessment of the performance of the SIL system is verified
- The effect of wind over the pitch motion is very accurately captured, which is important to calculate the correct rotor loads





(Azcona et al., 2014)





7. State-of-the-art review in hybrid testing – software-in-the-loop tests for modelling of wind forces (7/8)

- The Iberdrola TLPWT platform consists of a central cylindrical column with four square section is studied, aimed at supporting a 5MW generator. Wave and current environment are modelled physically in the Ocean Basin, while the wind environment is modelled numerically
- The fan produces thrust action only in the x direction
- A maximum motion RAO of 5 in surge in a period range between 20-25s is found, which decays quadratic for lower periods leading to operational sea states RAOs that is lower than one.
- Sauder et al. (2016) then identify and apply all aerodynamic load components for the on the physical model







(Zamora-Rodriguez et al., 2014)



7. State-of-the-art review in hybrid testing – software-in-the-loop tests for modelling of wind forces (8/8)

- The SIL approach was used by Day et al. (2017) and Oguz et al., (2018) to control a ducted fan to simulate the aerodynamic thrust load on a TLP floating wind
- Sauder et al. (2016) then identify and apply all aerodynamic load components for the on the physical model
- The 6DOF rigid-body motions of the platform are computed from the measurements and output in real time to the control PC. The control PC runs FAST aero-hydro-servo-elastic code to calculates the aerodynamic thrust expected with the instantaneous platform location and dynamics in the wind field and outputs the thrust demand to the fan controller.

Mooring Line

Properties

and Dynamics

Platform

Properties

WAMIT V HydroDyn Hydrodyn amie

Dynamics

FAST

Wind Turbine Properties

Wind



(Oguz et al., 2018)

(Oguz et al., 2018)

8. Experimental benchmark on wave run-up on cylinders (1/7)

- Objectives
 - The study focuses on the interaction between waves and fixed column array with four rounded-square columns, and mainly seeks to investigate the influence of wave parameters, including wave steepness and wave period.
 - The tests performed as a part of the test campaign of 29th ITTC Ocean Engineering Committee(OEC)
- Corporative Study
 - State key laboratory of Ocean Engineering, Shanghai Jiao Tong University, China





8. Experimental benchmark on wave run-up on cylinders (2/7)

The experiment target:

Regular waves parameters:

Fixed column array with four rounded-square columns

3 wave steepness and 4 wave periods

The experiment site:

SJTU Multiple Function Towing Tank



Regular wave parameters			
Wave No.	Η/λ	<i>T</i> (s)	<i>A</i> (m)
1	0.03	0.99	0.03
2		1.27	0.04
3		1.70	0.07
4		2.12	0.12
5	0.06	0.99	0.05
6		1.27	0.08
7		1.70	0.14
8		2.12	0.22
9	0.07	0.99	0.05
10		1.27	0.09
11		1.70	0.16
12		2.12	0.25



8. Experimental benchmark on wave run-up on cylinders (3/7)



Wave incident angle: 0 deg







8. Experimental benchmark on wave run-up on cylinders (4/7)







Heading=0 deg

1. The wave run-up ratio increases with wave steepness. For long waves, the steepness effect is even more pronounced.

2. For 0 deg cases, the wave run-up ratio around rear column is smaller than that around the front. While for 45 deg cases, the results are opposite. Heading=45 deg



8. Experimental benchmark on wave run-up on cylinders (6/7)

1. The force in X direction at 45 deg wave incident direction is greater than that at 0 deg cases under the same wave parameters.

2. As the wave steepness increases, the force difference between 0 deg and 45 deg wave incident angles becomes obvious.



Comparison of wave induced force on columns with 0deg and 45deg incident angle



8. Experimental benchmark on wave run-up on cylinders (7/7) Discussion

- The model test results show the effect on wave run-ups on fixed column array of different wave steepness and periods.
- The wave run-up ratio increases with wave steepness, and this is even more pronounced for long waves.
- For 0 deg cases, the wave run-up ratio around rear column is smaller than that around the front. While for 45 deg cases, the results are opposite.
- The incident direction has a great effect on wave run-ups and the force on columns.
- The further CFD study is needed by the various participants to establish the CFD procedure for fixed column array interaction problem.





9. CFD Benchmark Study on Two-Body Interaction (1/7)

- Objective
 - To carry out the benchmark studies on the multiple-body interactions in regular waves, model test of two identical floaters in close proximity
 - The tests performed as a part of the test campaign of 27th and 28th ITTC Ocean Engineering Committee(OEC)
 - The benchmark studies can use the various CFD software and methodologies to produce the best solution for the two-body interactions
- Corporative Study
 - SHI (Samsung Heavy Industries)
 - KRISO (Korea Research Institute of Ships and Offshore Engineering
 - PNU (Pusan National University)



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9. CFD Benchmark Study on Two-Body Interaction (2/7)

<Bench Mark Test Case>

*Completed in 28th OEC

- Target : box-like models
- Calculation Items
 - 6 DoF motion
 - Gap wave elevation
 - Mean wave drift force
- Gap Distance
 - 0.4, 0.45 and 0.55 m
- Regular Waves at Head Sea











9. CFD Benchmark Study on Two-Body Interaction (3/7)

< CFD Methodology Setup >

- To sum up the methodology from each facilities
 - General Numerical Method (Software, Discretization scheme, Density definition, Pressure and velocity field, Treatment for unsteady characteristics)
 - Grid System (Software, Coordinate, Dimension and type, Handling method for body motion, Number of grids, Non-dimensional length of first grid size)
 - Numerical Scheme (Convection term, Order of accuracy of convection term, Temporal term, Order of accuracy of temporal term, Conserved quantities, Linearization scheme, Iterative scheme, Pre-conditioning or acceleration techniques)
 - Boundary Condition (Boundary type, Wave generation, Wave absorption)
 - Turbulence Modelling (Viscous Regime, Type of turbulence model, Transition treatment, Wall treatment)
 - Free-surface treatment (Treat method)
 - Computation (Computer performance in simulation, Computer system, Parallel computing, Computation time / finest grid)





9. CFD Benchmark Study on Two-Body Interaction (4/7)

< Setup of CFD Analysis (by SHI) >

- Software : STAR-CCM+
- Numerical Modeling
- Boundary Conditions

13 - 18 June 2021

Туре	Surface, Region
Velocity inlet	Inlet/Outlet/Side(far from the model)/Bottom boundary
Symmetry	Side boundary
Pressure outlet	Top boundary
Forcing zone (Relaxation zone)	Forward, Backward, Side region

• Computational Domain (No. of mesh: 1.5~2.4milli.)

Item	scheme
Governing equation	RANS(Reynolds-averaged Navier–Stokes equations)
Multiphase model	Implicit VOF(Volume of Fluid method)
Temporal discretization	2nd-order implicit unsteady
Turbulence model	k-Omega SST with all y+ wall treatment
Body-Environment coupling	Linear spring
Body motion	Overset mesh w/ 3-DOFs(surge, heave, pitch)





9. CFD Benchmark Study on Two-Body Interaction (5/7)

< Results of CFD Analysis >

• Motion: Viscosity effect on motions due two body interaction is small







9. CFD Benchmark Study on Two-Body Interaction (6/7)

< Results of CFD Analysis >

• Mean Drift Force



• Gap Wave Elevation



- CFD compares well with model test
- Potential calculation deviates from model test and CFD results.
 → Viscosity affects the drift force and gap wave elevation.





9. CFD Benchmark Study on Two-Body Interaction (7/7)

< Discussion >

- The model test and CFD results show the viscous effect on the motion and drift force on bodies and the gap wave elevation when comparing the potential calculation.
- The viscous effect on body motion is the smallest and it shows larger influence on the gap wave elevation.
- The viscous effect is more pronounced at the higher wave frequency region.
- The smallest gap distance of 0.4m shows the largest viscous effect and the distance of 0.55m shows negligible viscous effect on the body motion, drift force and gap wave elevation
- The further CFD study is needed by the various participants to establish the CFD procedure for 2 body interaction problem and to update the two-body model test procedure based on this bench mark CFD study.





State-of-the-art review in Large Diameter Flexible Risers for Deep Water Mining (1/4)

Background



- (a) Rigid pipe transporting system (Vercruijsse et al. 2011)
- (b) Flexible riser transporting system (Deepak et al. 2007)
- (c) Flexible hoses with buoyancy materials (Yoon et al. 2011)

Flexible risers/hoses are commonly used to cater the varying water depth, the seabed topography, and the movement of the mining vehicle.

Major Challenges

- Pressure loss of the mixture
- dynamic responses and spatial configurations of the riser

Flow assurance issues





10.

State-of-the-art review in Large Diameter Flexible Risers for Deep Water Mining (2/4)

- **Research 1: Pressure drop inside flexible riser**
- Problem Definition: The pressure drop of the mixture determines the pump head and energy consumption and is affected by many factors such as *particle size, particle density, solid volume fraction, flow rate* and *spatial configuration* of the flexible risers.
- Main research methods: Experiments & Numerical simulations Relative references (2001–2017) are discussed.



- (a) Flow experiment system for flexible riser
 (Yoon et al. 2009)
- (b) An example of CFD-DEM simulation of ore particles (Parenteau 2010)



(c) Subsea Mining small-scale flow loop test description (Parenteau et al. 2011)



(d) Spooled riser applied on a vessel (Heeren et al. 2013)



(e) Experimental system (Yao et al. 2017)





10.

State-of-the-art review in Large Diameter Flexible Risers for Deep Water Mining (3/4)

Research 2: Dynamic responses and spatial configurations

- Problem Definition: Reliable experimental and numerical methods are required to predict the nonlinear geometric deformation and tension of the flexible risers under complicated sea states and operating conditions of the mining vehicle.
- Main research methods: Experiments & Numerical simulations

Relative references (2005–2020) are discussed.



(a) Shape of flexible hose due to movement of mining vehicle (Wang et al. 2007)



(b) Photograph and schematic diagram of the experiment by Chen et al. (2014)





State-of-the-art review in Large Diameter Flexible Risers for Deep Water Mining (4/4)

Research 3: Flow assurance issues

10.

- Research points:
- (1) Dynamic performance of minerals in the risers
- (2) Flow correlation validation and abrasion test
- (3) Pipe wear under hydraulic transportation (variables: pipe materials and pipe inclination)
- (4) Comparison of CFD results with test results for predicting erosion rate
- Relative references (1978 2019) are discussed.



(a) Large-scale rig test overview (Rongau et al. 2017)





(b) Design for flexible cross-section containing (c) anti-abrasion layer (Rongau et al. 2017)



13/04/2021





11. Procedure/Guideline for Model Construction (1/3)

- The 28th OEC developed a preliminary version of a procedure for the construction of offshore models.
- After the comments from the 28th ITTC-AC and the recommendations of the 29th ITTC-AC, the Committee developed the Guideline 7.5-02-07-03.15 Model Construction of Offshore Systems.







- An offshore system can be composed of bottomfounded or stationary floating structures, mooring lines/risers and umbilicals, dynamic positioning systems, and/or any other auxiliary structure or equipment involved in offshore operations.
- The purpose of the guideline is to ensure the correct design and manufacture of the model of the offshore system for its testing in towing tanks, wave/current basins, and/or wind tunnels (excluding field tests).
- Key elements of the procedures include the model design, the manufacture and the preparation of the model tests, the uncertainty analysis and the documentation.





(Huang et al., 2018)





11. Guideline for Model Construction (3/3)

- An offshore system model may include:
 - hull(s) and buoys,
 - appendages,
 - surface roughness and/or marine growth,
 - mooring systems,
 - risers and cables,
 - offloading systems including hoses and fenders,
 - dynamic positioning and other control systems,
 - thrusters and propellers,
 - turrets,
 - superstructures,
 - sloshing tanks, and
 - energy conversion systems such as wind turbines, current turbines and WECs.





- State-of-the-art review in offshore structures
 - Bottom Founded Structures. For bottom-founded structures, life extension of existing fixed platforms has attracted attention. Fatigue and vessel impact loads are of concern. For (fixed) offshore wind turbines, besides waves, wind and current loads, earthquake loads have become an item of concern. There is a need of full-scale tests for validation studies.
 - Stationary Floating Structures. Several experimental and numerical studies have been devoted to green water and water impacts associated to extreme waves. Side-by-side configurations and viscous damping are issues that have attracted much attention for FPSOs and FLNGs. In the case of TLPs, semisubmersibles and FOWTS, several works have been devoted to VIM. Operations under ice conditions have also attracted attention and deserve further experimental and numerical research.





12. Conclusions and Recommendations (2/7)

- State-of-the-art review in offshore structures
 - New technological developments.
 - The hybrid foundation proposed by Cheng et al. (2019) for bottomfounded OWTs.
 - The topology optimization design method for jackets and other fixed structures proposed by Tian et al. (2019).
 - W. Liu et al. (2017) have described the new concept of a Spar Drilling Production Storage Offloading Platform (SDPSO) for ultra-deep waters.
 - Ren et al. (2018) have presented a new concept, the 'MWWC' (Monopile-WT-WEC- Combination)
 - Fu et al. (2020) have proposed a new concept to remove large and heavy structures with a single lift, utilizing three semi-submerged DP vessels.





- State-of-the-art review in offshore structures
 - New experimental techniques and extrapolation methods
 - A creative method for the equivalent design of an oil offloading line for model tests was proposed by Kang et al. (2017).
 - Park et al. (2021) have proposed a new experimental method for the assessment of towingand course-stability of a FPSO towed by a tug-boat.
 - Practical applications of computational methods for prediction and scaling
 - Lyu et al. (2019) have developed a novel multi-body dynamic mathematical modeling for the Soft Yoke Mooring System (SYMS) of FPSOs.
 - Koop (2020) have used CFD simulations to address Reynolds scale effects and shielding effects on current loads of offshore vessels in side-by-side configuration.
 - Wang and Zhou (2020) carried out numerical simulations and experiments about the scale effect of internal solitary wave loads on spar platforms.





- Offshore aquaculture
 - Offshore aquaculture systems have been concentrated on the development of larger floating structures. Close containment tank systems have been proposed to avoid the effects of sea lice on fish.
 - Hydrodynamic interaction among the main floating structure, mooring system, and the fishing nets continues to be a concern, especially under harsh environmental conditions.
 - More physical model tests and numerical simulations are required to study the effects of swimming of fish on the selection of farming sites and on designs of offshore aquaculture cage systems.
 - Fluid-ice-aquaculture structure interactions must be studied for aquaculture cages deployed in regions where drift ice could damage the cage structures.
 - Integration of offshore aquaculture farming and ocean renewable energy system should be further developed and studied.





- Cable/pipe dynamics close to sea-surface
 - o Few experimental studies on this topic.
 - Most published works are concerned with fluid transfer lines (FTL) such as risers or offloading hoses.
 - Model tests are needed for cables (ex. power cables) used with ocean renewable energy conversion devices;
 - Behavior of offloading hoses in the gap of side-by-side configurations should be further investigated.
- SiL tests
 - SiL approach offers a number of advantages over conventional full-coupled modelling: ability to deploy in a wide range of facilities, reduced cost, greater flexibility of scale, and ability to simulate control systems.
 - The system is still under development and there are some issues with respect to repeatability and experiment methodology which require further refinement.





- Experimental benchmark on wave run-up on cylinders
 - Benchmark tests were conducted to measure the wave run-ups and global wave loads on fixed four squared cylinders under regular and irregular waves.
 - o Local wave impact loads on the columns are critical and deserve further in-depth studies.
- CFD benchmark on two-body interactions
 - Viscous effect on body motion is the smallest but shows larger influence on the gap wave elevation.
 - Viscous effect is more pronounced at the higher wave frequency region. The smallest gap distance (0.40 m – equal to the beam of the models) showed the largest viscous effect while the largest distance (0.55 m) showed negligible viscous effect on the body motion, drift force and gap wave elevation.





- Large diameter flexible risers for deep water mining
 - o Technologies for the design of flexible risers are not firmly established yet.
 - Owing to the complicated interaction of the flexible riser, the inner flow and the environmental loads, the coupled analysis of the inner flow regime and the external loads are rare.
 - Aggregation and clogging of the ores in the flexible riser should be investigated in detail due to the complex flow regimes and particle motion when the mixture flow is passing the crest and trough of the curved risers.





- Adopt the updated procedure: 7.5-02-07-03.1 Floating Offshore Platform Experiments;
- Adopt the updated procedure: 7.5-02-07-03.2 Analysis Procedure for Model Tests in Regular Waves;
- Adopt the updated procedure: 7.5-02-07-03.4 Active Hybrid Model Tests of Floating Offshore Structures with Mooring Lines;
- Adopt the updated procedure: 7.5-02-07-03.5 Passive Hybrid Model Tests of Floating Offshore Structures with Mooring Lines;
- Adopt the updated procedure: 7.5-02-07-03.6 Dynamic Positioning System Model Test Experiments;
- Adopt the updated guideline: 7.5-02-07-03.10 Guideline for VIV Testing;
- Adopt the updated guideline: 7.5-02-07-03.11 Model Tests of Multibodies in Close Proximity;
- Adopt the updated guideline: 7.5-02-07-03.10 Guideline for VIM Testing;
- Adopt the updated procedure: 7.5-02-07-03.10 Analysis Procedure of Model Tests in Irregular Waves;





- Since in the recent years a number of numerical and experimental works have been reported on side-by-side configuration and on VIM and, the following procedures should be reviewed and updated accordingly:
 - 7.5-02-07-03.11 Model Tests of Multibodies in Close Proximity;
 - 7.5-02-07-03.13 Guideline for VIM Testing;
- Follow the development on offshore aquaculture systems, especially on model testing and numerical modelling. Hydrodynamic modelling of loads on the nets due to fish swimming, wave and/or current should be further investigated. Sloshing in close-containment tank systems should be also of concern;
- Continue the experimental wave run-up benchmark tests (four squared vertical cylinders) to measure wave run-ups and global forces on cylinders and to investigate scale effects. The participation for more institutions should be encouraged. Results should be further analyzed and compared with new data;
- Extend the experimental benchmark on two-body interactions to consider smaller gaps (less than the beam of the models).





- Continue the CFD benchmark on two body interactions to gather results from more participants and extend the CFD study to investigate configurations with smaller gaps (less than the beam of the models). CFD results should be further analyzed and compared with experimental results.
- Carry out CFD benchmark studies on wave run-up (four squared vertical cylinders) focusing on wave run-ups and global forces on cylinders and on scale effects using the benchmark experimental data of the 29th ITTC-OE committee.
- Owing to the complicated wave-column interactions, more experimental and CFD studies on wave run-up (four squared vertical cylinders) should be carried out for different configurations of the four-columns. More extreme waves such as focused waves should be also considered.





Thanks for your kind attention!



Prof. Dr. Claudio Rodríguez (chairman): <u>claudiorc@laboceano.coppe.ufrj.br</u> Prof. Dr. Longfei Xiao (secretary): <u>xiaolf@sjtu.edu.cn</u>

