ITTC Quality System Manual

Recommended Procedures and Guidelines

Guideline

Model Construction of Offshore Systems

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Model Construction of Offshore Systems

1. PURPOSE OF GUIDELINE

In the context of the present guideline, an offshore system can be composed of bottom-founded or stationary floating structures, mooring lines/risers and umbilicals, dynamic positioning systems, and/or any other auxiliary structure or equipment involved in offshore operations. Those structures may be subjected to environmental loads such as wind, water waves and current (excluding ice). This guideline may also be applied to subsea and coastal structures such as floating breakwaters and fish farms.

The purpose of this 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). In typical tests of offshore systems, hull platform models are assumed to be rigid bodies, so the focus of this guideline is on this type of structure. However, in some tests, the elasticity of the platform must be modelled. In that case, additional considerations should be done during the design and manufacture of the models.

2. GENERAL DESCRIPTION

2.1 Definition of Variables

Variables used in this guideline are defined below:

L	Characteristic length
B	width of a test tank
Fr	Froude number, $U/\sqrt{gL}$
Re	Reynolds number, UL/ν
St	Strouhal number, $f_s D/U$
KC	Keulegan-Carpenter number, UT/D
U	Flow speed
T	Period
D	Characteristic cross-section dimension
ν	Kinematic viscosity
g	Gravitational acceleration
f_s	Strouhal frequency.

2.2 Components

An offshore system model may include:

- hull(s)
- appendages
- marine growth
- mooring systems
- risers and cables
- thrusters and propellers
- turrets
- superstructures
- dynamic positioning and other control systems
- offloading systems including hoses and fenders
- sloshing tanks
- energy conversion devices, such as wind turbines, current turbines, and wave energy power take-off systems.

3. MODEL DESIGN

The model design depends on the test purposes and specifications, facility dimensions and capacities, materials for model construction, manufacture process and costs, and instrumentations. The design process can be iterative to meet the test requirements.

3.1 Scaling

After the test facility is chosen based on the scope of a test, the similitude law for model scaling can be determined. In general, Froude's scale law is applied for tests in a towing tank or a wave/current basin, while Reynolds number considerations can be used for tests in a wind tunnel. When hydroelastic behavior is to be assessed, Cauchy number should also be included as a similarity parameter.

For tests in a towing tank/wave basin, the model scale can be determined according to Procedure 7.5-02-07-03.1 Floating Offshore Platform Experiments. For tests in a wind tunnel, the model scale is obtained further based on the dimensions and technical specifications of the tunnel. It is particularly important to consider the wind characteristics, such as wind speed profile and turbulence levels.

The model scale will be further adjusted based on the physical phenomenon to be investigated. Dimensional analysis should be carried out to identify the most relevant dimensionless parameters which should be kept similar at model- and at full-scale.

Furthermore, to assist the model design, the model and test set-up should be simulated using numerical tools, for instance, to assess scale effects. For viscous flow effects, since Reynolds similitude cannot be achieved in the model during tests in water, arrangements in the model design should be made to minimize those scale effects, such as distortion of dimensions and surface roughness treatments.

3.2 Coordinate systems

In construction of the model and its components such as appendages, various coordinate systems may be used depending on the manufacturing tools. It is recommended to use the model-fixed system as a reference for coordinate system transformations.

The model-fixed coordinate system should be defined and documented. For example, the origin can be located at the midship section of a ship-like platform model, with positive z upwards, and positive x from the midship to the bow. The vertical origin could be chosen at the hull bottom or on the waterplane at the calm waterline at a specified draft.

3.3 Hull model

The design of the floating offshore structure model should be based on the full-scale design. It is recommended to use 3D solid modelling tools in the design of floating offshore structure models. These tools can automatically calculate the model mass distribution to satisfy the required center of gravity (G) and radii of gyration at a ballasting condition in the model design stage.

Hull materials, appendages, ballast weights, instrumentation and control systems should be included in the 3D solid model for the mass distribution calculation. The choice of model materials is driven by the following factors:

- a minimum stiffness of the structure for safe handling, ballasting and testing
- required mass distribution within the model
- minimum water absorption (if necessary, surface treatment should be done before painting)

It is important to consider the compatibility of the 3D solid model software used for design with the software used for manufacturing (CAM software).

If the structural dynamics of the model and the prototype is of concern (e.g. hydroelastic behavior), it is advantageous to assess the structural properties using the FEM analysis in 3D modelling tools.

Once the main design of the model has been achieved, the painting and lines descriptions can be improved with render views from the software.

It is also recommended to verify, at the end of this design process, the hydrostatic characteristics of the 'virtual' model with a dedicated ship hydrostatic software program. This verification process is especially helpful when the model includes water ballast, moonpool and buoyancy devices.

3.4 Instrumentation and control systems

A large range of different type of measuring equipment is used for testing floating offshore structures. Usually, instruments are designed to generate an analogue voltage or current signal, which is linearly proportional to the measured parameter. Instruments with digital output are increasingly used, but analogue output is still used to avoid the complexities of dealing with different digital signal protocols. Many tanks seem to prefer digital data and convert from analogue to digital signals as soon as possible for analysis and plotting on computers digital data.

The system required for performing measurements includes the following components: transducers, amplifiers, filters (analogue and/or digital), AD converter, data storage unit, cabling between different components. It is a common practice to use two or more independent computer systems for model tests. One computer is used for real time generation of control signal for the wave maker, and another computer is used for the data acquisition and analysis. Additional computers might be used for control of rudders or other control devices, or for control of the carriage.

The instrumentation may be used for measurement of rigid body motions, air gap, impact pressures or loads, accelerations, mooring line tensions, etc. The instrumentation and control components required to be on-board should be included in the 3D solid model. The on-board instrumentation (including associated batteries, cables, and wires) is considered as part of the ballast. Control systems, such as those for dynamic positioning model tests, should also be included in the model.

3.5 Appendages

Small details, such as anodes, can be neglected, if there is minimal impact on the physical phenomenon to be measured. Appendages, such as bilge keels, mooring lines/risers, thrusters for dynamic positioning and VIM suppression devices, need to be included in the model design. In some cases, distortions of dimensions, bundles or surface treatments may be necessary to minimize viscous flow (scale) effects associated to the appendages.

3.6 Mooring and riser systems

When testing structures with mooring lines, risers, or other submerged lines, modelling of quasi-static and dynamic characteristics is important. The primary requisite is to correctly model the system quasi-static behavior, i.e., forces and moments due to linear and angular offsets of the moored structure.

Full length line models are preferred but shortening or truncation of the lines may be necessary if the chosen model scale exceed the limits of the chosen basin dimension. Shortening of lines are generally done when the full-scale water depth can be modelled in the basin, but the anchor points exceed the basin area dimensions. Truncation is needed when the full-scale water depth exceeds the basin depth. When the truncation of lines is needed, it is difficult to scale the elastic and mass characteristics of prototype lines. Details on truncation for mooring lines/risers are described in Procedure 7.5-02-07-03.5 Passive Hybrid Model Tests of Floating Offshore Structures with Mooring Lines and Procedure 7.5-02-07-03.4 Active Hybrid Model Tests of Floating Offshore Structures with Mooring Lines.

For tests where mooring lines, risers, offloading lines, and fenders are present, the elastic properties of each of these items need to be correctly scaled. For example, both axial and bending stiffness are needed for the case of marine risers, loading hoses and tethers and axial stiffness for mooring lines. It is not easy to correctly scale the axial stiffness for risers, but the designer should try to adjust it as correctly as possible.

To scale the elasticity and mass at the same time, it is often required to change the specified configuration of the segments for each line, or even bundle some very thin lines in groups. This leads to the addition of spring segments, the partial or total substitution of original segments, and sometimes the addition of floaters or clump weights in some segments to correct submerged weight. It should be considered in the model design of mooring lines that in-line instrumentation, including its cables, would change the properties of the line segment where it is located.

For model tests with truncated mooring lines/risers, it is important to keep the correct geometrical parameters of the system, i.e., top angles and lines elongation during excursion. This may lead to other distortions on the original specified characteristics of segments. In some cases, a totally different mooring system from the prototype one may be used.

Having assessed the quasi-static issues on the design of scaled submerged lines, the second request is to model the dynamics of the mooring and risers system, such as added mass and damping effects. The drag of the segments may play an important role in the behavior of the floater, especially when the number of mooring lines and risers is large and/or the floater damping is small compared to the damping of the mooring lines/risers. In this case, the truncation will lead to more uncertainties due to geometric differences on segments and great changes of the configuration of the mooring lines. To assess the drag of the modeled lines, an analysis of the Reynolds number for each segment will be necessary and some distortions on diameters may be needed to correct the drag effect.

3.7 Dynamic positioning

When testing structures with dynamic positioning (DP) systems it is important to correctly model the full-scale capacity of the system. This includes thruster design, placement, and control systems.

Due to scaling requirements for offshore structure testing, the thruster model can be determined according to the Froude scale law. However, due to these scaling requirements for offshore structures, sizing may have to be adjusted to correctly model the equivalent full-scale thruster capacity and effect.

Stock thruster/propeller models with similar diameters may be used if the equivalent thruster capacity/effect is correctly modelled. Overall diameter and housing sizing should preferably have a max deviation of no more than 10% from full scale.

The control system should mimic the full-scale system as much as possible with regards to capacity limitations and responses.

Motors and controllers should preferably be mounted on the model and should be considered when designing the model with regards to size and mass distribution. Multi thruster arrangements in full scale can be simplified in the model scale, e.g., 2 tunnel thrusters replaced with 1, if the overall system characteristics of the model are like those of the full-scale system.

The Procedure 7.5-02-07-03.6 Dynamic Positioning System – Model Test Experiments should also be considered when designing such systems.

3.8 Offloading systems

As they are made of elastomeric material, usually fender and hawser systems between multiple floating structures have a nonlinear stiffness. Mooring lines made of composite material (polypropylene, Nylon, etc.) have also a complex behavior under uniaxial tension. For the mooring line and hawser, the nonlinear stiffness can be modelled by using multiple springs/rubber bands and restraining devices such as stoppers. The initial stiffness is matched by the first spring/rubber, which can be stretched to the required elongation when the rest of the springs/rubbers provide no load (i.e. remain slack) but begin to stretch over the next range of stiffness-elongation curve.

A fender can be similarly modelled by using a multiple spring/rubber system, but a lever or pulley is additionally needed to represent compression stiffness of fender. The compression stiffness of fender can be modelled by layered rubber, pneumatic rubber can, and flexible cantilever.

3.9 Moonpool

The Froude scale law is applied to moonpool scaling. The moonpool dimensions should be sufficiently large to reproduce the physical phenomena.

Details such as damping devices and openings should be modeled, while small details like anodes can be neglected.

The whole geometry of the moonpool up to the upper deck should be modeled, since in resonant conditions the oscillations of water inside the moonpool can be more than three times the wave height. Top covers, if any, should be modeled due to their interactions with the free surface inside the moonpool.

Measuring devices such as wave probes located in moonpool should have minimum impact on wave damping.

3.10 Superstructures

The level of details of the superstructure to be modelled depends on the objective of the test and the test facility (ocean basin with/without wind generation facility). For example, if the objective of the test is to measure the effects of greenwater/impact loads on the superstructure, then relevant details need to be considered.

If the model is tested in a wind tunnel facility to derive the aerodynamic coefficients, the model should be scaled according to Reynolds scaling law and should be as detailed as possible. Scale effects such as those associated to roughness height and pressure on the surface of bluff bodies should be given special attention.

3.11 Surface roughness

In certain circumstances, it may be necessary to alter the surface roughness of the model.

Typically, as Froude scaling is used for testing, there is a compromise in terms of Reynolds scaling with regards to flow characteristics. In most cases, in order to achieve the high Re numbers of full scale, it is possible to modify the surface of the model augmenting its roughness to simulate the effects of high Reynolds flows without interfering with Froude scaling with regards to size and flow speed.

The effect of appendages on large offshore structures can be modelled as surface roughness elements to capture the turbulent flow effects present in full scale. Similarly, boundary layer trips can be used to ensure that the flow around the structure is turbulent, thus mimicking the high Reynolds number effects. It should be considered that at model scale small appendages usually result inside the boundary layer of the main hull, while at full scale, these appendages can protrude into the free stream (due to the thinner boundary layer). Thus, separation and form drag may not be properly modelled.

In addition to turbulent flows, the presence of marine growth on models in full scale can also be modelled by altering the surface roughness. Depending on the model scale, the influence of marine growth on slender structures may have to be considered. The presence of marine growth influences the full-scale model by altering the equivalent diameter, thus altering the response of the structure when compared to the 'clean' configuration. This is particularly noticeable in VIV/VIM behavior of structures where marine growth can affect strake performance or alter the surface roughness. Further details on the influence of marine growth on offshore systems can be found in Heaf (1979), Wolfram et al. (1993), Shoefs and Boukinda (2004), Farmakis et al. (2014).

4. MODEL MANUFACTURE

The offshore platform models can be of large dimensions and weights. From the design stage to the manufacturing process, these characteristics should be considered to allow safe and efficient handling and storage. The lifting means should be identified and adapted to the model and the facility.

4.1 Hull manufacture

Differently from ship models, a floating offshore model can consist of many elements, and require assembly at a later stage. The elements can be manufactured in different materials and by using different processes.

For ship-shaped hulls and other complex geometries typical materials may include wood, high-density closed cell foam and fiber reinforced plastics (FRP). For simple shaped hulls such as semisubmersibles, barges, spars and buoys, metal models can also be used.

The choice of the processes strongly depends on the material of the hull, and may include milling, forming, welding, additive manufacturing using resins, plastic-like materials, and metal. The following aspects should be considered:

- the available machines and abilities of the personnel;
- the cost of the manufacturing (cost of material, time to manufacture, etc.);
- the delay of the availability for the remaining assembly.

The main dimensions of the hull should be carefully checked. The recommendations given in Procedure 7.5-01-01-01 Ship Models may be adopted as typical tolerance requirements for hulls.

The final process of the manufacturing is painting and is generally the same as the hull model section of Procedure 7.5-01-01-01 Ship Models.

4.2 Mooring lines, risers, offloading lines, fenders

For risers or tethers, a frequently used method is to apply a steel or aluminum core with dimensions determined to give correct bending stiffness. Around the core is fitted buoyancy material to obtain the correct outer geometry and weight. In using this method, it is important to avoid motions and resulting friction between the core and the buoyancy material to avoid introducing artificial structural damping. The axial elasticity of mooring lines can be modelled by introducing axial springs in one or more positions along the lines. Nonhomogeneous models of risers and mooring lines are typical and may consist of thin rope (fishing line), wire, chain, springs, discrete lead weights, floats, etc. To check the static load versus displacement curve as well as the geometry of the mooring and risers lines, pull-out tests may be performed.

4.3 Thruster systems

As an alternative to the stock propellers mentioned in Section 3.7, a 3D printer can be used to manufacture the scaled model of the propeller and housing.

4.4 Marine growth

Different manufacturing techniques can be employed to alter the model. For example, gravel/rocks can be attached to models to simulate barnacle growth, or nylon/plastic material to simulate seaweed growth (Baarholm, 2008). For VIV and VIM tests, details can be found in Guideline 7.5-02-07-03.11 VIM Testing and in Guideline 7.5-02-07-03.10 VIV Testing.

4.5 Verification and model assembly

Quality control of dimensions, watertightness and weights should be performed along the manufacturing process of each element of the offshore system model, as well as at the model assembly stage considering the acceptance criteria. Eventual deviations should be documented and discussed with the Client.

The model must be properly assembled from the different parts: hull, appendages, thrusters, on-board instrumentation, etc.

The on-board sensors should be calibrated before their installation in the model and verified after the final assembly. Calibration methods are described in Procedure 7.5-01-03-01 Uncertainty Analysis, Instrument Calibration.

The additional ballast must be secured and accurately positioned according to the model design. It is recommended to include mechanical displacement devices to allow a fine tuning of the weight location during dry tests.

Weight may be distributed in the hull model as determined at the design stage. All parts such as superstructures, thrusters for dynamic position, targets for optical measurements and instrumentation should be attached to the specified locations in the hull model before measurement of mass, center of gravity and radius of gyration. All parts should be checked to be attached to the hull model by using a check list.

Weight distribution needs to be adjusted if the measured values of mass, center of gravity and radius of gyration are beyond the specified tolerance. All measured values should be recorded and documented.

If necessary, the structural natural frequencies should be checked against the target ones.

Length and weight of mooring lines or risers should be prepared within the specified tolerances. The measured values also should be recorded and documented.

5. PRE-TESTS IN WATER

The objectives of the pre-tests in water are to finely tune the properties to the target ones (from design stage) and to obtain their experimental values for data processing.

The first task with the free-floating model in water (without mooring and risers) is to verify its water tightness and equilibrium, i.e., if model draught, trim and heel are to be achieved as the required (target) values within the specified tolerances. If any modification is to be made on the model weight distribution, these changes should be recorded and documented. The measured/computed model inertial properties should be updated according to these changes and the final values should be documented. Water density and temperature of the basin should be also measured and documented for extrapolation purposes.

Once the free-floating model equilibrium has been verified, the initial hydrostatic stability may be assessed through inclining tests. Decay tests may be also conducted to verify the natural frequencies and/or measure some hydrostatic and hydrodynamic parameters of the model, e.g., hydrodynamic damping.

After the free-floating tests, mooring and risers can be attached to the model. Equilibrium and stability of the model with mooring and risers should be checked. The stiffness introduced by mooring and risers system should be measured by pull-out tests. Any modification regarding the design values of the model and its mooring and risers system should be recorded and documented.

In the case of models equipped with a dynamic position system, preliminary specific tests may be necessary to verify the system's performance.

All the instrumentation, including data acquisition system, should be tested. Verification should attempt the check of calibration gains, zeroes, and other initial values. Signs of forces, reference frames and directions should be verified. The tests should also be performed to check the synchronization between different acquisition systems.

6. UNCERTAINTY ANALYSIS

Many of these aspects of the design and model manufacture contribute to type-B uncertainties. Details of these aspects and sources of uncertainties can be found in Qiu et al. (2014).

Additional references can be found in the Procedure 7.5-02-01-01 Guide to the Expression of Uncertainty in Experimental Hydrodynamics.

7. DOCUMENTATION

All the aspects of the model design, manufacturing and verification stages should be documented as much as possible, including texts, pictures, CAD files etc. It should include the uncertainty levels for each item.

The following aspects should be provided:

Hull Model (as built) and appendages

- Identification (model number or similar)
- scale
- materials of construction
- principal dimensions
- general arrangement
- mass and inertia properties (in air)

- hydrostatic properties (displacement, GM and GZ curves)
- turbulence stimulation techniques
- deviation from the full-scale target (where applicable)

Instrumentation and control systems

- Layout
- range and calibration
- sensors' electrical specifications
- Mooring, risers, off-loading systems
- Layout
- components of each line, including a complete description of cross-section, material, bending and axial stiffness, damping characteristics
- anchors and fairleads locations
- total restoring forces.

Dynamic positioning and thruster systems

- Thruster capacity
- calibration curves (RPM vs. output)
- layout
- geometric characteristics of the thrusters / propellers
- control systems particulars.

Superstructures

- geometry (if applicable)
- CFD simulations and/or wind tunnel tests results (if applicable).

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