Table of Contents

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Stationary Floating Systems Hybrid Mooring Simulation Model Test Experiments

1. PURPOSE OF PROCEDURE

The purpose of this procedure is to ensure that Hybrid Model Tests are conducted according to the best available techniques and to provide an indication of where improvements in techniques might be made. The procedure also tempts to insure that any compromises, inherent in a particular Hybrid System model test, are identified and their effect on the measured results is understood. In general Hybrid Model Tests are employed when the mooring lines of a deepwater structure are required to be replaced by an active or passive system which provides an approximation of the mooring line response.

It should be noted that as far as we know Hybrid Model Tests with an active system has not yet been used for any real project. Based on some first exploratory studies by some institutes, it is even questionable if an active hybrid mooring representation will ever become feasible. The actuators at the tank bottom would have to deal with the large slow drift motions of the mooring lines and risers at the truncated elevation in x, y and z direction. In addition the faster phenomena such as wave induced motions and line dynamics should be well represented. The required accuracy for the position measurement, control systems and numerical line dynamic models are not yet available.

The recommended procedure for active Hybrid Model Tests presented in this document should therefore be considered as a first attempt to outline the requirements and specifications for conducting such a test, rather than a generally accepted working procedure based on actual experience.

1.1 When hybrid model testing is to be used

Hybrid model test techniques are used when the limitations on the physical size of a testing basin do not allow a full model of a mooring to be accommodated at a reasonable scale within the basin. Requirements for such test techniques depend on the individual basin and may be enforced by considerations of water depth or basin extent. Appropriate scales are frequently a matter of choice with the individual researcher or client. Model tests of offshore structures are usually conducted in the scale range between 1:40 and 1:80 but tests at scales as small as 1:170 have been reported.

2. PARAMETERS TO BE TAKEN INTO ACCOUNT

2.1 Model parameters

The geometry of the model should be built to scale as for normal model tests (Froude). Items such as dimensional tolerances model ballast conditions and other aspects of preparing the model can be found in the ITTC Recommended Procedures for Floating Offshore Platform Experiments (7.5-02-07-03.1).

2.2 Environmental parameters

Parameters related to the simulation of environmental properties such as water depth, basin dimensions, calibrated wave characteristics, calibrated current characteristics, calibrated wind characteristics, combined environment characteristics and relative directions on combined environments can also be found in the ITTC Standard for Floating Offshore Platform Experiments.

2.3 Mooring mass and force characteristics

In the case of a hybrid model test, every effort should be made to correctly model the effects of the mass of the mooring and the elastic effects of the mooring in the characteristics of the truncated mooring and/or actuator. In more sophisticated models it may also be possible to include hydrodynamic effects in the mooring simulation and realize these in the physical mimic.

2.4 Angle of application of mooring forces

Replacing a deep-water mooring with a truncated model may result in some compromise in the geometry of the mooring, at the fairlead, as the vessel is offset. This may be mitigated by providing an actuator that compensates for horizontal offset differences or it may be accepted as a compromise of the truncation. In either event it is generally more important to maintain the horizontal restraint characteristics than the vertical component of the mooring load. Any compromise in geometry should be compensated in the system to maintain the horizontal load characteristic as a first priority.

2.5 Mooring static offset characteristics

As a minimum, any truncated or hybrid mooring should properly represent the static offset characteristics of the deep water mooring. These characteristics may be derived by reference to the mooring designer or through use of a generally accepted software package. With reference to section 2.3, it is desirable that the horizontal component does not deviate by more than 5% and that the vertical component does not deviate by more than 10% in static offset tests.

2.6 Force and position measuring device calibrations

It is expected that devices to measure the mooring forces, the mooring element extensions and the offset position of the vessel will provide feedback to the hybrid model actuator. Since the accuracy of the mooring simulation is dependent, to a large extent, on the accuracy of these feedback measurements, special care should be taken to insure accurate calibration of these devices.

2.7 Test duration

Test duration is dependent on the requirements of the specific model test and should not influence the results of the mooring modeling.

3. PROCEDURE FOR HYBRID MODEL TESTS

This procedure will concentrate on those tests where some sort of computer controlled actuator is used to substitute for a fully modeled mooring system in the physical model test of a floating offshore structure in deep water. In general the procedure involves the following steps:

- A dynamic numerical model of the individual mooring lines and/or risers is developed.
- A physical model of the floating platform is produced at some reasonable scale
- The mooring line or riser model is linked to one or more physical actuators which provide the mooring or riser response for the system.
- A physical simulation is conducted in a model test basin.
- The response of the floating platform is measured including the mooring loads and displacements.
- The response of the floating platform may be used as input to the numerical dynamic mooring line or riser simulation to predict the response of the deepwater elements that were not physically simulated in the model test.

3.1 Use of numerical models

Numerical models used to develop mooring line or riser simulations should ideally be fully dynamic three-dimensional models that have been benchmarked or verified against other data. Riser models should be similarly dynamic simulation models that include the effects of bending stiffness in the riser and the effects of fluid flows within the conduit.

3.2 Verification of numerical models

Numerical models of mooring lines or risers should be verified, preferably in publicly available and refereed forums. Verification should include references to, and demonstrations of, simple cases, which can be solved in closed form and compared with the simulation results. In addition the model should be validated against model test data for fully modeled mooring lines at depths which can be achieved in existing model testing basins. If full-scale data for deepwater structures are available they should be used for validation with due attention paid to the higher levels of uncertainty in full-scale data. As a final confirmation, the numerical simulations should be compared to cases developed using other accepted simulation programs.

3.3 Linking the numerical model to the actuator

It is frequently difficult to achieve real-time run speeds with complex simulation models and thus it would be difficult with present technology to link a numerical simulation, particularly for multiple mooring lines, directly to a control system used in a model test. Thus it is necessary to provide an intermediate step to link the output of the numerical model to the input of the mooring actuator. Ideally this link will include dynamic effects including variation in the force response of the mooring line associated with changes in displacement, velocity and acceleration. This may take the form of a multi-dimensional data table or a multi-variate polynomial. Perhaps as computing speed and efficiency increase, it may be possible to link the simulation directly to the actuator.

3.4 Mooring line actuators

Mooring line actuators can take various forms and it is not the intent of this procedure to limit development of methods or prescribe a particular method. A mooring line is effectively a spring that acts to hold the floating platform on location. Risers are not intended to provide restoring force but do act as springs in the system. In both cases mass, geometry and hydrodynamic effects act to dictate the static and dynamic characteristics of the mooring line or riser. The purpose of the actuator is to provide a mimic of the mooring/riser force-displacement characteristic as accurately and reliable as possible without having the full model of the mooring/riser in place. Example systems would be a computer controlled winch that controlled the length of a cable based on a force feedback or an actuator arm that moved a fixed length of cable or rod in response to a force feedback. However, other systems are possible. The primary characteristic of any system is a force or displacement applied to the physical model based on a measured displacement or force in which the relationship between force and displacement (and velocity and acceleration) is dictated by a computer simulation of the full mooring line or riser system.

3.5 Placement of actuators

Hybrid model actuators are intended to mimic mooring lines or risers, and ideally the point of application of the actuator force should be at the point where the mooring line or riser force would be applied to the prototype. This requirement may be modified by the requirement to mimic a number of mooring lines (such as those in a group of lines) or a number of risers with a single actuator, programmed to exhibit the characteristics of the group or bundle. In such cases, the actuator point of application should be at the geometric mean of the group of lines or risers.

In extreme cases, a single actuator may replace the entire mooring and/or riser system. In these cases the point of application of the actuator may be quite different from the mooring line or riser attachment points. In these cases, it should be demonstrated that the hybrid system provides an adequate mimic of the real system and does not involve undue compromises.

The anchoring point or grounding point of an actuator will determine the way the mooring/riser force is applied as the model moves under an environmental load. For example a winch-cable system can be set up with the winch anchored to the tank bottom and the cable attached to the model at the mooring fairlead such that the angle of application is correct for the at-rest position. This arrangement will suffer an increasing mismatch in horizontal and vertical components (assuming the tension is maintained correctly by the control system) as the model is displaced from the mean. This mismatch arises from the geometric distortion due to the fact that the model anchoring point is at a much shallower depth than the prototype anchoring point. For any hybrid model system, the effect of actuator positioning should be assessed and the resulting distortion in geometry or force application should be quantified and demonstrated to not unduly affect the results of the experiment.

3.6 Force and position feedback

The primary characteristic of moorings or risers, in the context of a hybrid model test, is that of the restoring force applied by the mooring or riser element. The main purpose then of the hybrid system is to provide an accurate representation of this restoring force. In the first order, this restoring force/tension is applied as a function of the displacement or extension of the mooring or riser element. In higher order simulations, the force may also be a function of the velocity or acceleration, either of which can be derived from the displacement measured depending on time. As a minimum, in any actuator system employed in a hybrid model test, measurement of the applied force and the extension of the actuator are required. It is also worthwhile (and probably a normal part of any such test) to measure the global position and orientation of the floating platform (model). This global body displacement measurement may be used to provide direct force feedback or may be used to add another dimension to the control system in terms of geometric distortion of the mooring/riser system.

3.7 System verification

The Hybrid Mooring system should be verified for static and dynamic performance against a standard to be agreed with the client/researcher. This verification should take the form of comparison with accepted data based on one or more standardized tests. Such testing could take the form of fixed offsets followed by decay tests or tests with a regular wave input. Data generated in the model test may be compared to numerically generated data or with similar previously generated model test data or full scale data. The level of agreement to be achieved with the reference data should be agreed prior to the start of verification.

3.8 Calibration of actuators

Actuators should be bench-calibrated to demonstrate that the feedback system is developing the desired force-displacement (velocity, acceleration, angular) characteristics. This may require development of a calibration apparatus (particularly for dynamic calibrations) and the bench calibrations should be presented as single variate plots in which all the variables are exercised in matrix form to adequately cover the expected range required for the model test. For systems that are built up and maintained as a unit it may only be necessary to demonstrate that the system maintains its previous calibration by demonstrating a smaller number of points.

An in-situ calibration of the entire system should be performed prior to commencement of testing. This would be the form of tests normally employed to validate a model test of a moored system. Such tests would, as a minimum, include offset tests for each mooring line or group along the axis of the mooring line or group and a global x and y offset for the system as a whole with force displacement measurements conducted on all hybrid actuators.

Dynamic calibration of the global system may consist of natural frequency oscillation tests in whatever modes are most appropriate to the model test.

3.9 Environmental calibrations

Environmental calibrations of waves, currents and/or wind should take the form normally employed in conventional tests of offshore structures as defined by the ITTC Recommended Procedures or the conventions of the particular test basin. It is not suggested that any attempt of corrections be made in the current loading to account for that part of the water column that is truncated during the model test.

3.10 Model testing program

The model testing program to be conducted after the verification tests are carried out is a function of the requirements of the particular test or research program and should be dictated by the requirements of that program.

3.11 Data collection

In addition to any other data required as part of the model test, the following quantities should be measured as part of a Hybrid Model Test.

1. Actuator force at the point (or points) of application to the model
2. Actuator extension or offset or displacement (depending on the type of actuator)
3. Six Degree of Freedom motions of the floating platform using a system that allows measurement of low frequency motions (non-inertial) and offset. Data should be collected at a sufficiently high rate that dynamic effects in the mooring line response are captured.

3.12 Data analysis

In addition to any other data analysis requirements laid out by the model test program, the following data analysis should be performed as a requirement of the hybrid model test.

Generate time series plots of all mooring line tensions, mooring line extensions and 6 degree-of-freedom motions of the floating platform. In addition the mooring line tension time series should be plotted against the mooring line extension time series.

3.13 Post test verification

Ideally the hybrid model test will be verified by post-test analysis. As a minimum, this analysis should feed the measured floating platform displacements back into the numerical model of the mooring system. The purpose of this check is to verify that the global restoring force from the numerical simulation of the mooring system provides a good match with the global restoring force provided by the actuator system in the hybrid model test.

3.14 Presentation of results

The quantities of interest for the system are the mooring load response and the motions of the vessel. These results should be presented as a complete matched time series on a common time base. This is primarily to allow subsequent use in numerical simulations or checking against time series generated in numerical simulations. Because the time series are expected to be long, statistical or spectral information derived by data processing may be some aid in any comparisons.

4. VALIDATION

A hybrid model testing scheme represents a relatively complicated apparatus and support system which has a major bearing on the outcome of the experiment.

Validation of the mooring simulation and the applied forces is important in establishing the validity of the tests. The following sections identify means of confirming the accuracy of the simulation and of identifying areas where full representation is compromised by the truncation scheme.

4.1 Uncertainty analysis

Uncertainty analysis should be conducted on the mooring system as per ITTC recommended Procedure (7.5-02-01-01 (Uncertainty Analysis in EFD) in addition to any uncertainty analysis performed on the model test as a whole. The purpose of the mooring uncertainty analysis is to determine the degree to which the target mooring characteristics have been achieved and to allow this effect to be included in an analysis of the overall model test.

4.2 Validation of numerical models

Numerical models used to generate data for use in or comparison with Hybrid Model Tests should be validated by direct comparison of generated data with results derived from:

- Known solutions for simplified cases.
- Generally accepted model tests or experiments specifically for verification,
- Full scale data available from installations.

It is recognized that data from full-scale installations is rare.
See also section 3.2

4.3 Validation of moorings

The model moorings should be validated using static offset tests in the direction of interest and possibly by forced dynamic response tests where the dynamic response of the deep water mooring is expected to play a significant role in the overall response of the vessel-mooring system. In cases where the mooring dynamics are not expected to have a major influence on the vessel response, the mooring dynamics may be adequately verified by subsequent analysis. Care should be taken that the truncated mooring or hybrid model actuator does not introduce unwanted dynamic effects that are functions purely of the modeling.

See also Sections 3.7 and 3.8.

4.4 Benchmark tests

Benchmark tests may be used as a means of demonstrating the general validity of the Hybrid model testing apparatus and software. In this case a generic set of tests would be conducted and compared to alternative means of analysis with an emphasis on identifying areas where the hybrid modeling differs from, or offers improvements over, alternate means of performing the same analysis.