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Truncation of Test Models and Integration with Numerical Simulations

1. PURPOSE OF PROCEDURE

For the model test verification of large floater systems, including moorings and risers, one sometimes encounters systems that are too large for a full-depth (or full-width) model in a given test basin. This may, for example, be the case in the testing of ultra-deepwater systems, or for the testing of very wide systems. Truncated models are then needed. In most cases it means shortening of mooring and riser models. The purpose of this recommended procedure is to ensure that testing with such truncated model test set-ups, and the integration with subsequent numerical simulations, are conducted according to the best available and well-accepted methods.

The techniques described herein (hybrid model testing) are limited to those based on integration with passive (off-line) computer simulations only. An alternative approach includes active (on-line) systems, described in a separate procedure. While the development of the latter method is an interesting challenge for future applications, it may at present be considered immature for the establishment of procedures for common use. Thus the passive procedure reflects the actual practice of today.

The present description is primarily intended for application within ultra deep-water problems (vertical truncation), while basic principles could also be applicable for horizontal truncation.

2. SCOPE

2.1 Model testing for verification of global system analysis

The use of model tests is generally recommended to verify the expected global performance of large moored floating systems:

- Validation of design assumptions and critical design response parameters,
- Validation of the numerical design tools,
- Verifying the expected general sea keeping performance under design, operating conditions, and during the installation to discover unexpected system behaviours.

In particular, model testing of floating systems is helpful in the verification and analysis of extremes, of non-linear effects, and of complex mechanisms and coupling effects

2.2 When to use a truncated set-up

For a given basin size, there is a trade-off between a large model scale and no truncation (or use as little truncation as possible). Traditionally, scales in the range of 1:40 – 1:80 have been applied for ocean engineering purpose. In certain cases, however, scalefactors up? to 150-170 have been applied with reasonable results when compared to larger scale results.

Generally speaking, scalefactors smaller? than 80 - 100 are recommended, and truncation should be considered as an alternative if full-depth tests with smaller scales are discussed. Fig. 2.1 qualitatively illustrates this. However, in certain cases with particular details to be modelled, a lower scale limit may be necessary, and vice versa, smaller scales may be possible in some other cases.

If truncated, models are normally made in "traditional" scales ≈ 1:40 – 1:80.

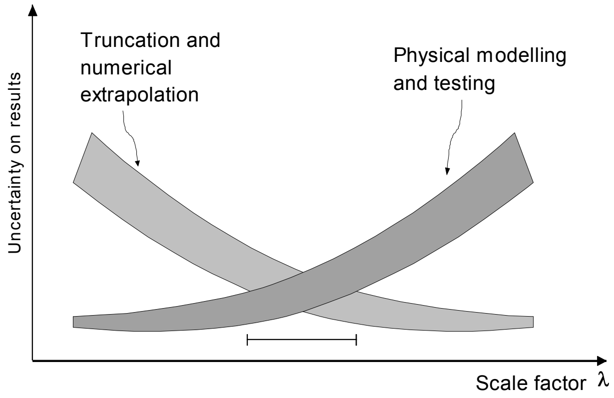

Fig. 2.1. The balance between uncertainties related to truncation and to small scales (i.e. large scale factors).

2.3 Hybrid model testing philosophy

In the place of a full-depth basin experiment for the verification of a global design analysis, there may in principle be several possible alternatives:

1) Ultra-small scale (scale factor bigger than 100)
2) Truncated set-up experiments combined with numerical simulations (hybrid model testing)
3) Fjord or lake testing
4) Alternative numerical models

For general use, alternative 2 – hybrid model testing - is recommended, and is described in the present document. The other three have clear limitations. Alternative 1 will have practical depth limitations, although it may be a realistic alternative in some cases. Alternative 3 may be a valuable alternative for particular research studies, but is difficult for standard use. Alternative 4 is an actual choice if no other method is available.

The principles of the recommended passive (off-line) hybrid procedure are as follows: Experiments are first run with a truncated set-up. Truncations should be made such that the resulting floater motions (the time-varying force vectors on the floater) are similar to those expected for the full-depth case, while dynamic loads on moorings and risers are not expected to be always modelled accurately. The measurements are then used to calibrate a numerical model of the actual experiment. Finally, the calibrated data are applied in full-depth simulations, from which final verification results are obtained. A hybrid verification methodology is described by e.g. Stansberg et al (2000, 2002) and recently a descriptions of the procedure is given by Baarholm et al (2006). A similar approach is addressed by Waals and van Dijk (2004).

Using test results directly from truncated set-ups, without integration with numerical modelling, is generally not recommended for line tensions and riser responses, nor for final estimates of floater slow-drift damping due to lines and risers. However, for strongly nonlinear responses such as green water, air-gap etc., for which numerical modelling is presently incomplete, measurements may be used directly if the set-up is properly designed according to this procedure

An ideal goal of the hybrid technique should be that the outcome of testing should be as good as if it was made by testing without truncation. In routine use, this is difficult to verify, since there are no full-size results to check against. Moreover, a prototype current profile is difficult to obtain with a truncated set-up. A proper validation of the method itself is therefore essential in order to have confidence in it, and it is recommended that the accuracy of the technique should be regularly documented by adding to the number of benchmark tests for which also full-size results are available.

3. DEFINITIONS

Floater system: Floater, moorings and risers.

Global analysis: Numerical analysis of complete floater system, including floater and riser motions, relative waves as well as mooring forces.

Hybrid verification: Model test verification procedure using a truncated set-up combined with subsequent numerical simulations. Test results are used for validation / calibration by a “Model-The-Model“ approach.

Coupled analysis: Global analysis where forces from moorings and risers form integrated parts of the floater motion simulation, usually made in the time domain.

Ultra-deep water: Usually deeper than 1000 m

4. DESCRIPTION OF PROCEDURE

4.1 Truncation design

4.1.1 Choice of truncated system

Important issues to consider in model testing with a truncated system include:

- when to choose a truncated system
- critical response parameters for the floater system being tested (e.g., static or dynamic responses, horizontal or vertical responses)
- selection of criteria for system truncation
- degree of system truncation in relation to coupling effects of floater and under water systems
- possibility of “equivalent” mooring and riser modelling
- response data needed in verifying the numerical model
- effect on air-gap

The detailed design of the truncated system will depend on the actual floater system. Problem priorities for the tests may be somewhat facility dependent (staff, resources, experience), and will likely be somewhat empirical. Still there is a set of basic recommended criteria to be followed, presented in Section 4.1.2. The truncated system may involve springs, point masses or buoyancy elements in the mooring system, larger (than scale) diameter mooring and/or riser components, drag chains on the basin floor, etc.

Truncated mooring systems with more evenly distributed properties tend to perform better and are easier to analyse.

It is important to check the performance of the truncated model against the properties expected from the design. A complete documentation of the truncated system, as modelled, is critical for the interpretation of model test results and subsequent simulations.

4.1.2 Truncation criteria

Basically, the *motion responses* (low-frequency & wave-frequency) of the floater should be modelled similar to what would result from the full-depth mooring.

Hence, for the modelling of a *vertically truncated deepwater system* the test design should seek to correctly model the following parameters in the given succession of priorities:

1) Total mass of floating system (hull, topside, full-moorings & risers)

2) Total horizontal stiffness

3) Quasi-static coupling between important vessel responses (e.g., between surge and pitch for a Semi-submersible or Spar)

4) Total horizontal & vertical mooring & risers restoring forces

5) “Representative” level of mooring and riser system damping in waves and currents, and current force (e.g. by adjusting the effective mooring line & riser diameters)

6) “Representative” single line tension characteristics for each mooring line and riser (at least quasi-static)

For *horizontally* truncated systems, the same rules may in general be followed, but details must be transformed to the actual problem.

Truncation design principles are described in e.g. Fylling and Stansberg (2005) and in Baarholm et al (2007).

4.1.3 Equivalent modelling by lumped systems

Mooring lines and/or risers may also be “lumped”, that is a number of similar elements may be modelled as one single element. For example, a group of 12 production risers may be represented by one single model riser. Lumped systems are designed to provide appropriately scaled mass, stiffness, and hydrodynamic properties.

The decisions to truncate / lump moorings *and* risers can be made separately, but are obviously interrelated if both are to be used in a model test.

4.2 Model test program

In brief, the test program should be designed to provide data to meet the following objectives:

- Validate that the test environment is repeatable, stationary, and homogeneous throughout the test area and is accurately calibrated to represent the desired metocean test conditions

- Validate that the actual test model has the desired scaled properties during model design

- Assure to measure the critical vessel responses in metocean environmental conditions which are likely to be experienced during the design life. Extreme and operating conditions are normally of interest. The range of metocean environments tested should be broad enough to cover unexpected floater behaviours in conditions that are likely to be encountered.

- Validate the numerical model of the floater responses (at model scale) that will ultimately be used to analyse the prototype responses. This validation is done at model scale, termed “Model-The-Model” (see Section 4.3).

4.3 Calibration for off-line numerical simulation: “Model-The-Model”

A numerical model of the actual model test is made and compared to the measurements, using the same software tool as for the final full-depth simulations. This is used as a basis for calibration of the final model.

4.3.1 Numerical model of truncated set-up

A complete numerical model of the actual set-up should be established, that describes the dynamic responses to winds, waves, and currents of a moored system with risers. Time domain numerical models are more commonly used than frequency domain models because they can describe non-linear terms with less simplifications and assumptions. Thus time domain models are generally regarded as a more robust tool for calibrating at model scale and applying at prototype scale. However, frequency domain models can be calibrated with test data, and have been successfully used to analyze the responses of platform systems in deep water.

A coupled numerical model is recommended, i.e. it should simultaneously solve the dynamics of the floater and its moorings and risers. The forces on the hull should include first-order wave forces and hydrodynamic reaction forces, second-order wave drift forces, second-order wave drift damping, and wind and current forces. The hydrodynamic forces on the moorings and risers should be included in a relative motion formulation. The numerical model should include terms that describe the viscous contributions to roll damping and the low frequency horizontal motions of the hull.

4.3.2 Validation of numerical model

The numerical model of the truncated system is validated by comparing predicted responses (normally from simulated time series, statistics and spectral values) with measured model test data. Typically, this means that hydrodynamic parameters of the vessel and for the (truncated) slender bodies are checked and calibrated if needed. In addition, the reconstruction provides a valuable check of the whole numerical tool. Actually measured wave records and wind/current conditions are normally used as an input.

4.4 Full-depth numerical simulation

A numerical model of the full-depth (prototype) floater system is established by use of the same numerical tool as for the truncated system, i.e. a coupled analysis tool is recommended. Parameters obtained from the validated or calibrated truncated numerical model are used in the final prototype simulations. (In using this approach, it is preferred that the truncated system is as "similar" as possible to the real system, following the criteria from 4.1.2 above). Comparisons between resulting predicted responses for the prototype floater system and the responses originally expected for the system design will then provide a basis for verifying the performance and adequacy of the design. The verified model must be adjusted to incorporate the prototype geometry, prototype scale properties and coefficients for drag and damping, and actual (non-truncated and non-simplified) moorings and risers.

5. KEY PARAMETERS

- Model scale
- Physical floater parameters:
  mass,
  geometry;
  hydrostatic parameters
- Numerical panel model parameters of floater
- Total horizontal restoring force stiffness
- Total vertical stiffness from moorings and risers
- Drift forces and moments; Quadratic transfer functions; Viscous excitation
- Low-frequency damping:
  wave-drift damping,
  viscous hull drag,
  damping due to drag on mooring lines and risers
- Mooring lines:
  axial stiffness;
  underwater weight;
  diameter;
  pre-tension;
  drag coefficients;
  truncation;
  finite element model parameters.
  lumped model parameters, if any.
- Risers: As for mooring lines.
- Environmental conditions:
  waves,
  current and wind.

6. VALIDATION

In each test: The technique in itself includes a validation or calibration of the numerical model in use (as an integrated part of the methodology).

Validation of methodology: A two-step procedure will always introduce additional uncertainties. In order to reduce these, and thereby increase the general reliability of the method, new particular validation cases - where truncated test cases (with numerical model integration) are benchmarked against full-depth tests - are always of great value. A related option is to carry out two-scale experiments. Model test data for more simplified cases also enhance the reliability of validation such as regular wave tests, free decay tests, etc.

In addition, sub-tools such as specific numerical codes used for the floater hydrodynamics and for the moorings / risers should be validated independently

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