Table of Contents

Updated by	Approved
Load and Responses Committee of 23rd ITTC	23rd ITTC 2002
Date	Date 2002

Analysis Procedure for Model Tests in Regular Waves

1. PURPOSE OF PROCEDURE

To ensure the best possible quality analysis of test results in regular waves and facilitate the comparison with other similar tests.

2. ANALYSIS PROCEDURE FOR REGULAR WAVE TESTS

The 18th 1TTC OE Committee reported an exercise in which a number of institutions performed harmonic and spectral analysis of certain time traces defined by the Committee. Some of the results were quite disappointing in terms of spread in the resulting amplitudes and phase angles.

The present Committee recommends to the ITTC that Fourier analysis of regular wave tests should be performed according to the following procedure:

2.1 Visual Inspection.

The first step in the analysis should always be a visual inspection of the time trace of the lead signal as well as the response to be analysed. Lead signal is here meant to be the signal to which the phase angles and amplitudes of the responses are referred. Normally it will be the wave, or, in the case of forced oscillation tests, the oscillatory motion. If the signals contain an exceptionally high noise level, they may require special treatment. Otherwise, the analysis should be done as described in the subsequent sections.

2.2 Choice of Interval to be Analysed.

In order to have the best possible quality waves, the interval to be analysed should be sufficiently early in the time series, i.e. the time interval before the reflected waves reach the model. On the other hand, in case of large start-up transients, one may have to accept wave reflections so that the analysis will not be disturbed too much by the transients. The final choice may be a compromise.

The choice of interval can be manually done during the visual inspection process.

2.3 Number of Cycles to be Analysed.

For the determination of transfer function just a few wave cycles are in principle sufficient. Generally, the numerical accuracy is improved by increasing the number of cycles. Again there is the compromise between quality of the waves and length of the recording. In practice a number of cycles between 5 and 20 is recommended for the determination of transfer function. For responses with a long natural period and important non-linear effects, such as slowly drifting motions of moored structures, a much larger number of cycles will normally be necessary.

2.4 Determination of Fundamental Period.

The fundamental period should be obtained from the lead signal and this same value should be used for the analysis of all the responses.

There are several methods available for the determination of fundamental period:

a. One is to perform a spectral analysis of the lead signal to obtain a peak frequency. A good resolution by this method implies a relatively long record.

b. Another is to choose start and end points in the time trace and divide the time duration between start and end points by the number of cycles. Most laboratories use this method. The resolution of this method depends again on the record length and can be seriously affected by the presence of noise unless special precautions are taken (e.g. neglecting too short and/or small cycles.

c. Alternatively a non-linear least squares fitting of a multi-harmonic theoretical signal can be carried out. This consists in minimising the error:

$$\varepsilon^2\left(\omega,\mu,A_j,\varphi_j\right)=\frac{1}{N}\sum_{i=1}^{N}\left[x_i-\mu-\sum_{j=1}^{M}A_j\cos\left(j\omega t_i+\varphi_j\right)\right]^2$$

This function is non-linear only in ω for which, normally, a good initial estimate is known (i.e. the expected encounter frequency). This method is very accurate even for short records (3 cycles) and large amounts of noise. It does not need an integer number of cycles.

2.5 Determination of Start and End Points.

These points can be chosen by zero up or down crossing of a certain level (e.g. the mean). The number of cycles for the second method (b.) can be determined in the same way. The selection of start and end points is necessary for the second method (b.) and recommendable for the first one (a.) while for the third one (c.) it is not needed**.** The analysis program can select these end points automatically.

2.6 Filtering, Trend Elimination.

In case of large, low frequency transients high-pass filtering prior to the Fourier analysis should reduce the corresponding errors in the analysis of the responses. A simplified version of the high-pass filtering is 'trend elimination', which consists of subtracting not only the mean value, but also a ramp function, determined by the mean slope of the response signal in the time interval to be analysed.

2.7 Fourier Analysis, Definition of Phase Angle.

After the above points have been considered, the amplitude of the lead signal and the amplitude and phase angle of the responses should be determined by a standard Fourier analysis. The same fundamental frequency should be used for all signals (i.e. that obtained from the lead signal).

When presenting the results the sign of the phase angle is defined by the requirement that the response shall be expressed by

$$x(t) \approx \mu + \sum_{j=1}^{M} A_j \cos\left(j\omega_e t + \varphi_j\right)$$

i.e. response lagging behind lead signal gives negative phase angle.

Many times the wave elevation is measured at a point other than the one to which the phases have to be referred (e.g. the model's centre of gravity). In such cases, the signal or the phases can be corrected by applying the linear dispersion relationship.

3. PARAMETERS

3.1 Parameters to be Taken into Account

The following parameters should be carefully considered:

- Model Dimensions
- Tank Dimensions
- Wave Calibration
- Test Duration
- Measuring Equipment
- Method of Restraint
- Wave Periods and Wave Heights
- Speed and Heading
- Wave Probes Location
- Number of Repeat Runs
- Accuracy of the Different Gauges

3.2 Recommendations of ITTC for Parameters

In order to obtain reliable results from regular wave experiments, the test procedures have to be chosen carefully. The following points are recommended to ensure accuracy in regular wave tests:

3.2.1 Model Dimensions.

The scale of the model should be as large as is practicable.

3.2.2 Tank Dimensions.

A wide test area is needed to avoid interference between a model and tank walls. A scaling of the water depth is important in many cases due to hydrodynamic effects and for correct modelling of load-excursion characteristics of compliant platform motions in the horizontal plane.

3.2.3 Wave Calibration and Test Duration.

For fixed model tests, the wave height has to, be measured at the location of the offshore structure model before it is installed to ensure the accuracy of the generated waves. For moving models, the regularity of the waves along the travel path has to be checked by means of several fixed probes or a moving one. A run length of about 10 cycles is normally sufficient for determining first-order motion transfer functions, while drift force measurements require much longer run length due to transients. For ship models a sufficiently long run is necessary, including acceleration and transient phases. The repeatability of the generated waves should be checked, and documentation on wave calibration should be prepared.

The wave probe should be checked regularly for its proper operability in a running condition.

3.2.4 Measuring Equipment.

Generally all six degrees of motion are recorded as well as mooring forces, accelerations, relative motions and structural loads. Particular care has to be taken when models are tested in their natural frequency range and measurements are made with mechanical connectors. In the case of such measurements the use of non-contact measuring systems is preferable.

Development of systems that reduce or eliminate cable connections between instruments on the model and the recording system is encouraged.

3.2.5 Method of Restraint.

For moored models, soft mooring lines adequately model the restraint conditions in many cases. However, depending on the purpose of the tests, where space and depth permit, it is generally preferred to utilise realistic restraints, which possess the correct non-linear characteristics of the mooring lines.

For running models, self-propelled tests are preferable. If, on the contrary, the model is towed, freedom in surge yields more realistic results. Constant force and moment towing can accomplish this.

3.2.6 Wave Periods and Wave Heights.

In order to obtain a complete representation of the motion response amplitudes in the frequency domain, one may need to carry out as many as 20 tests depending on the purpose of the tests. The behaviour of offshore structures in waves is in general affected by non-linear phenomena. The response of non-linear systems is dependent on the wave height and therefore it is recommended that such systems should be checked for a number of wave heights at selected wave periods, especially around the natural periods.

3.2.7 Wave Probes Location.

The location of wave probes relative to the model has to be reported for the pre-calibration tests as well as during the tests. This will allow the correction of signals or phases to the reference position.

The location of the wave probes used during the tests has to be chosen so as to reduce as much as possible the influence of the model on the measurements.

3.2.8 Number of Repeat Runs.

To demonstrate the repeatability of the testing techniques selected frequencies should be repeated non-sequentially.

3.2.9 Presentation of Results.

When presenting results from measurements the accuracy of the different gauges should be stated and the calibration procedures should be described.

The transfer functions and phase lags should be given as a function of non-dimensional wave frequency or encounter frequency.

Care has to be taken to demonstrate the problems associated with transient phenomena either during the tests or during the analysis.

The phase angle should be calculated as defined in 2.7.

4. VALIDATION

4.1 Uncertainty Analysis

None.

4.2 Benchmark Tests

1) Seagoing Quality of Ships
(7th 1955, pp. 247-293)
A Model of the Todd-Forest Series 60, C_B=0.60:
7 tanks used 5ft. models, 2 tanks used 10 ft. models, and 1 tank used 16 ft. model
Froude Numbers 0,0.18,0.21,0.24,0.27 and 0.30
The Ratio wave height to the Length of the Model: 1/36 1/48 1/60 1/72
for Wave Length 0.75*L* 1.0*L* 1.25*L* 1.5*L*

2) Comparative Tests in Waves at Three Experimental Establishments Using the Same Model (11th 1966, pp. 332-342)
British Towing Tank Panel: A 10 ft. Fibre-Glass Model of the S.S. Cairndhu
A Series of Experiments on a Ship Model in Regular Waves Using Different Test Techniques
Data Obtained in Irregular and Transient Waves and Some Result Predicted by the Theory (Based on Korvin Kroukovsky's Work and Employing the Added Mass and Damping Coefficients Calculated by Grim)

3) Full Scale Destroyer Motion Measurements (11th l966, pp. 342-350)
Full Scale Destroyer Motion Tests in Head Sea
Comparison among Motion Response Obtained from Full Scale Tests, Model Experiments and Computer Calculations
The Destroyer H.M. "Groningen" of the Royal Netherlands Navy
A Scale Ration 40 to 1

4) Comparison of the Computer Calculations of Ship Motions (11th l966, pp. 350-355)
Ship Response Functions for the Series 60 C_B=0.70 Parent Form

5) Computer Program Results for Ship Behaviour in Regular Oblique Waves
(11th l966, pp. 408-411)
Series 60, CB=0.60 and 0.70 Parent Form DTMB Model 421OW and 4212W

6) Experiments in Head Seas

6-1) Comparative Tests of a Series 60 Ship Model in Regular Waves
(11th 1966, pp. 411-415)
Series 60 C_B=0.60

6-2) Experiments on Heaving and Pitching Motions of a Ship Model in Regular Longitudinal Waves (11th 1966 pp.415-418)
Series 60 C_B=0.60

6-3) Experiments on the Series 60, C_B=0.60 and 0.70 Ship Models in Regular Head Waves

(11th 1966, pp. 418-420)
Series 60, C_B=0.60 and 0.70

6-4) Comparison of Measured Ship Motions and Thrust Increase of Series 60 Ship Models in Regular Head Waves (11th 1966, pp. 420-426)
Series 60, C_B=0.60 and 0.70

6-5) Estimation of Ship Behaviour at Sea from Limited Observation (11th 1966, pp. 426-428)

7) Computer Results, Head Seas

7-1) Theoretical Calculations of Ship Motions and Vertical Wave Bending Moments in Regular Head Seas (11th 1966, pp. 428-430)
Series 60, C_B=0.70

7-2) Comparison of Computer Program Results and Experiments for Ship Behaviour in Regular Head Seas (11th 1966, pp. 430-432)
Series 60, C_B=0.60 and 0.70

7-3) Computer Program Results for Ship Behaviour in Regular Head Waves
(11th 1966 pp.433-436) Series 60, C_B=0.60 and 0.70 Parent Form DTMB Model 421OW and 4212W

7-4) Comparison of Calculated and Measured Heaving and Pitching Motions of a Series 60, C_B=0.70 Ship Model in Regular Longitudinal Waves (11th 1966, pp. 436-442)
Series 60, C_B=0.70

7-5) Computer Calculations of Ship Motions (11th 1966, pp. 442)

7-6) Comparison of the Computer Calculations of Ship Motions and Vertical Wave Bending Moment (11th 1966, pp. 442-445)
Series 60, C_B=0.60 and 0.70

8) Comparison of the Computer Calculations for Ship Motions and Seakeeping Qualities by Strip Theory
(14th 1975 Vol.4, pp. 341-350)
A Large-Sized Ore Carrier

9) Comparison on Results Obtained with Computer Programs to Predict Ship Motions in Six Degrees of Freedom
(15th 1978, pp. 79-90)
S-175, C_B = 0. 572

10) Comparison of Results Obtained with Compute Programs to Predict Ship Motions in Six-Degrees-of-Freedom and Associated Responses (16th 1981, pp. 217-224) To Identify the Differences in the Various Strip Theories and Computation Procedures utilised by the Various Computer Programs and Provide Guidance for Improvement if Necessary.
S-175 Container Ship for Fr= 0.275

11) Analysis of the S-175 Comparative Study (17th 1984, pp. 503-511)

12) S-175 Comparative Model Experiments
(18th 1987, pp. 415-427)

13) Rare Events
(19th 1990, pp. 434-442, Seakeeping)

14) Validation Standards of Reporting and Uncertainty Analysis Strip Theory Predictions
(19th 1990, pp. 460-464)

15) ITTC Database of Seakeeping Experiments (20th 1993, pp. 449-451)
Two Dimensional Model, Wigley Hull Form, S-175

16) Validation of Seakeeping Calculations (21st 1996, pp. 41-43)
Basic Theoretical Limitations
Numerical Software Engineering Aspects

17) ITTC Database of Seakeeping Experiments (21st 1996, pp. 43)
S-175, High Speed Marine Vehicle

18) "Experiments and Calculations on 4 Wigley Hull Forms in Head Waves". J.M.J. Journeé, May 1992. DUT-SHL Report 0909. Downloadable from www.shipmotions.nl.