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## ITTC Quality System Manual Recommended Procedures and Guidelines

### Procedure

## Analysis Procedure of Model Tests in Irregular Waves


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## Analysis Procedure of Model Tests in Irregular Waves

### 1. PURPOSE OF PROCEDURE

The purpose of this analysis procedure is to ensure the best possible quality and consistent analysis of model test results in irregular waves. Usually model tests in irregular waves are performed to obtain the spectral and statistical characteristics of the responses.

### 2. ANALYSIS PROCEDURE FOR IRREGULAR WAVE TESTS

#### 2.1 Choice of duration to be analysed

The raw time series for analysis should be chosen by excluding the transient signals at the beginning and at the end of tests. The start and end points should be specified and documented. Note that the duration of the measurement should be sufficiently larger than the one for analysis to assist an accurate definition of the initial and end transient periods.

#### 2.2 Filtering and trend elimination

Any high-frequency noise, for example, electrical and mechanical noise, should be filtered from the response time series before the statistical or spectral analysis.

In case of low-frequency trends, high-pass filtering prior to the spectral analysis should reduce the corresponding errors in the analysis of the responses. In shallow water, it is important to consider the natural low-frequency of set-down before applying high-pass filters.

The filtering process should not change the phases of response signals.

#### 2.3 Fourier analysis

The same considerations provided in Section 2.6 of Procedure 7.5-02-03.2 Analysis Procedure for Model Tests in Regular Waves can be adopted.

The measured spectrum is commonly smoothed to reduce undesired fluctuations. This can be achieved by using the weighted averaging method either in the frequency domain or in the time domain.

If the time series contain samples in terms of continuous and singular frequency components, the multi-tapered method can be used for the Fourier analysis (Thomson, 1982).

#### 2.4 Non-Fourier based analysis


The statistical analysis of measured signals, for example, zero-crossing analysis (ITTC, 2014), can also be carried out to obtain statistical distributions and parameters such as significant values, and maximum / minimum values.

Wavelet and Hilbert transforms can be applied to time varying phenomena such as wave grouping (Hudspeth and Medina, 1988).

#### 2.5 Data presentation

The following items should be included in the analysis results:

- Time histories of raw input and response signals
- Chosen analysed intervals with specified start and end points
- Fitting and filtering parameters and methods
- Filtered time histories

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- Wave and response spectra and their parameters
- Results in terms of RAOs, significant values, RMS, mean values, minimum and maximum values, parameters for extreme value distributions, skewness, and kurtosis
- Uncertainty analysis results

### 3. PARAMETERS

To obtain reliable results from irregular wave analysis, the irregular wave tests should be conducted by considering the recommended parameters in Procedure 7.5-02-07-03.1 Floating Offshore Platform Experiments.

In addition, the parameters below should be carefully considered.

#### 3.1 Wave and response spectra

Energy spectra of waves and relevant responses should be produced through spectral analysis using either the indirect method of Fourier transformation of the autocorrelation function, or the direct method of splitting the record into suitable blocks and subjecting these to a Fast Fourier Transform. The obtained wave spectrum based on the time series of measured irregular waves should be compared with the target one to identify resulting platform responses that may be sensitive to particular part of the wave spectrum (ITTC, 2002).

In addition to the spectral analyses, statistical analyses should be performed to produce, at least, the mean, maximum, minimum, and the significant (mean of 1/3 highest) values. In the presentation of the results, the techniques utilized to smoothen spectral shapes, such as block overlapping, should be documented. When reporting statistics, the number of events and number of encounters should also be reported together with the overall statistics.

#### 3.2 Directional waves

Directional wave analysis is preferably performed using the measurements by an array of 5 wave probes. As shown in Figure 1, their locations on a circle of diameter  $R$  depend on the main wave direction ( $x$ ) and the spectrum peak frequency corresponding to a wave length  $\lambda$ . It is necessary to keep the ratio,  $R/\lambda$ , in the range of 0.1 to 0.5, with a recommended value of 0.2 (Benoit, 1993).

Several methods, such as Maximum Likelihood Method (MLM) and Maximum Entropy Method (MEM) (ITTC, 2002), are available for the directional wave analysis. The Bayesian Directional Method (BDM) (Hashimoto and Konbune, 1988) is recommended to ensure robustness and accuracy, despite its computational cost.

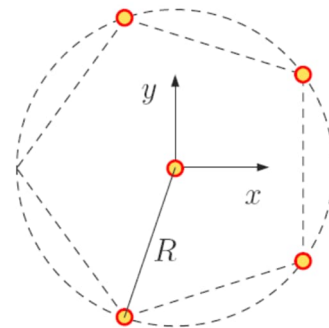



Figure 1. Locations of the five wave probes.

#### 3.3 Nonlinear effects and extremes

Nonlinear effects in irregular wave analysis can be considered in terms of extreme values, which are then used for extrapolation. The histograms derived from measured time series are compared with a known probability distribution, such as Rayleigh distribution and Weibull distribution. The extreme values can then be estimated using the corresponding probability of exceedance.

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### 3.4 Wave grouping

Wave grouping occurs in experiments when wave heights are not present in a uniform way (in time) but in groups of high waves or low waves. It can be quantified by the wave groupiness factor (Mase, 1989). Even though generated from the same wave spectrum, two time signals of wave elevation with different wave groupiness factors may lead to substantially different nonlinear effects and/or drift effects. The wave grouping analysis should therefore be performed and documented for the wave time series. An example of wave grouping analysis is provided in the Coastal Engineering Manual (US Army Corps of Engineers, 2008).

### 3.5 Finite depth

If the water depth of the basin varies along the direction of propagation of the waves, the characteristics of the waves will be changed. For example, if the depth diminishes, the phase speed and the wave length will decrease, while the wave height and the wave steepness will increase (wave period remains constant). This wave transformation effect is known as shoaling.

Provided that the water depth of the basin varies slowly relatively to the wave lengths, i.e., the basin depth changes slowly over the longest wave length considered, the formulae to estimate the changes in wave characteristics presented in DNV (2014) can be used.

### 3.6 Waves in current

The spectrum of irregular waves in current should be checked against the target one.

### 3.7 Deviation from ideal condition

Any deviations from target conditions should be identified and documented. For exam-

ple, the low- and high- frequency wave spectrum tails may not be included in the actual wave spectrum due to the limitation of the wavemaker. Wave breaking at the wavemaker can also dissipate parts of incident energy, leading to lower significant wave height.

Recommended spectrum modification and methods to calculate confidence intervals and tolerance intervals related to generated waves can be found in Kent and Lee, (2016).

### 3.8 Frequency of Encounter

Models may be towed in a towing tank to simulate the current conditions and/or towing conditions. In this case, the response spectra obtained using the measured time series correspond to frequencies of encounter (in terms of speed and heading) rather than wave frequencies. Except for the following seas, the results can then be presented in terms of frequency of encounter for a better understanding of the model behaviour. Notice that when towing is used, current-wave interaction effects should be carefully evaluated.


## 4. UNCERTAINTY ANALYSIS

Uncertainty analysis should be performed in accordance with Procedure 7.5-02-01-01 Guide to the Expression of Uncertainty in Experimental Hydrodynamics.

Details on the sources of uncertainties can be found in the work of Qiu et al. (2014).

## 5. REFERENCES

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