ITTC Quality System Manual

Recommended Procedures and Guidelines

Procedure

Experiments on Rarely Occurring Events

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Experiments on Rarely Occurring Events

1. PURPOSE OF PROCEDURE

Rarely occurring events are usually associated with large amplitude motions of an intact ship in heavy. A wide variety of motion behaviour can be typified as a rarely occurring event. Traditionally, slamming, deck wetness, and propeller emergence, were the mainly considered as rarely occurring events. These events usually are most pronounced in head to bow quartering seas, although for some hull shapes and vessel types also stern slamming at slow speed in following waves can be of importance.

Other events are regarded as rarely occurring events as well. These include course keeping in following and stern quartering waves and broaching, bow diving, extreme roll motions and loss of static and dynamic stability. In extreme cases most of these rarely occurring events can lead to capsize. The recommended procedures and guidelines on Stability (Section 7.5-02-07-04 of the Recommended Procedures and Guidelines) deal with this type of rarely occurring events.

Finally, high speed marine vehicles are particularly sensitive to certain types of rarely occurring events. Besides slamming, this also includes dynamical instabilities in calm water and roll, pitch, and yaw related events in waves, such as broaching. A separate set of procedures and guidelines are being developed in Section 7.5-02-05 of the Recommended Procedures and Guidelines.

The following list provides an overview of the ITTC procedures relevant to rarely occurring events:

- 7.5-02-07-02.1 Seakeeping Experiments: motions and loads of ships in waves;
- 7.5-02-07-02.3 Experiments on Rarely Occurring Events: slamming, green water propeller emergence of ships in waves;
- 7.5-02-05-04 HSMV Seakeeping Tests: motions and loads of high speed marine vehicles in waves;
- 7.5-02-05-06 HSMV Structural Loads: measurement of local and global loads on high speed marine vehicles, including slamming;
- 7.5-02-05-07 HSMV Dynamic Instability Tests: dynamic instability of high speed craft in calm water;
- 7.5-02-07-04.1 Model Tests on Intact Stability: broaching, deck/bow diving, extreme roll, parametric roll, loss of static and dynamic stability of intact vessels.

This procedure provides a means for undertaking, and understanding the results from, an experiment to quantify the frequency and severity of rarely occurring events with respect to slamming, deck wetness, and propeller emergence. In this instance the procedure covers tests on a rigid body model (not a segmented or elastic model) to define extreme motions, extreme motion related phenomena, and local loads but not aimed at quantifying global hull loads.

In extreme sea conditions deck wetness events (or the shipping of green water onto the foredeck) can lead to equipment loss or damage, in some cases it may even lead to capsize: slamming (slamming as a result of forward keel emergence, bow flare immersion and stern emergence) can create significant hull structural responses leading to noise, vibration and structural fatigue issues: propeller emergence degrades the performance of the propeller and leads to excessive cavitation, noise and fluctuating loads on the drive train. Thus, it is necessary to assess the frequency and severity of these rarely occurring events for a particular hull form in a sea condition.

One option to undertake this assessment is to carry out model experiments to the frequency and where possible the severity of the events. The general purpose of model tests is to assess the operational safety of the ship at sea. Thus, recommendations in the form of a test procedure are useful for understanding the test performance in agreement with the specific test objectives.

2. TEST PROCEDURE

2.1 Model Size

The size of a model should be as large as possible but is usually constrained by the capacity of the wave maker to generate the waves required for the tests and speed limitations of the carriage in the basin. Other considerations should be both that the tank wall interference effect as well as the bottom interference effect should be as small as possible.

In the seakeeping test procedure 7.5-02-07-02.1, useful data are provided for the limitation on the relationship between the tank geometry, the model size, and wave parameters with regards to the interference effects.

2.2 Model Completeness

In practice, it is unlikely that there will be a model built solely for testing in extreme wave conditions. It is more likely that the model will be manufactured for a series of tests.

The seakeeping test procedure 7.5-02-07-02.1 provides guidance on how a model should be constructed for the traditional seakeeping tests aimed at deriving linear and weakly non-linear type responses.

However, there are features required to be included on a model which will be used for an experiment to quantify rarely occurring events, exceeding those for the experiments in the procedure 7.5-02-07-02.1

2.2.1 Model in general

For deck wetness experiments it is essential that the model is completed up to the uppermost weather deck, including forecastle and bulwarks. A more complete modelling of deck fittings, deck houses and freeing ports may be necessary if parameters related to the green water event are to be measured.

For slamming experiments the underwater hull form will be representative of the full scale ship so little additional effort is required on the hull. However, if flare slamming is of interest then the model must be completed up to the upper most weather deck.

It is likely that the propeller will not be representative of the real ship but will be a stock propeller used to “push” the model along. However, if propeller emergence is of interest care should be taken on the choice of the stock propeller - the minimum requirement should be that the propeller diameter be consistent with the full scale equivalent.

2.2.2 Model appendages

The requirement for model appendages is covered in the seakeeping test procedure 7.5-02-07-02.1

2.3 Model Weight Distribution

In cases of a rigid body, the radii of gyration need to be correctly represented. For tests in head or following waves with a model restrained in roll, it is not necessary to simulate transverse weight distribution. Thus, only the pitch radius of gyration is required.

If the longitudinal radii of gyration for pitch or yaw are unknown, a value of 0.25 L_{PP} should be used. If the transverse radius of gyration is unknown, a value between 0.35*B* and 0.40*B*, depending on the ship type, should be used. (These values are representative of the inertia of the body in air).

For experiments in which roll is not restrained, the meta-centric height and roll radius of gyration should be simulated. If the vertical position of the centre of gravity is unknown, it should be established and reported.

When responses of catamarans (or similar multi-hull vessels) cross products of inertia should be taken into account also but it is noted that these cross-inertial terms are difficult to measure.

2.4 Parameters to Be Measured

Clearly, the main objective of the experiment will dictate the extent to which the responses and response phenomena need to be measured.

2.4.1 Generic parameters

The following represents a common set of requirements recommended for the rarely occurring event experiments covered here.

Waves:

Waves should be measured by a wave height sensor mounted next to the model, care should be taken to avoid interference from the ship motion induced waves. The wave height sensor should be fixed to the carriage, if possible to measure the waves encountered by the model. A non-contact measure device is preferable for wave measurement following the model motion, especially at high speeds. It is also recommended to use a more standard resistance type wave probe to measure the waves at a fixed location in the tank.

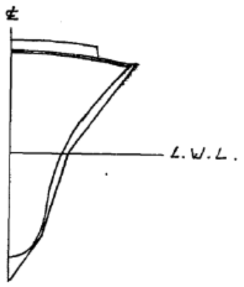
Ship motions:

For head seas tests with the model towed and usually restrained in sway, roll and yaw, it is necessary to measure vertical plane motions (heave and pitch) only. In the case where the towing arrangement allows the model to surge also the surge motion should be measured. For experiments in oblique seas the full six degrees of freedom motions should be recorded.

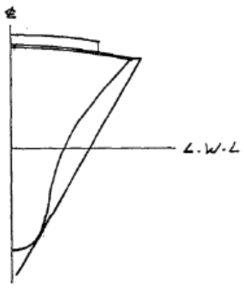
Accelerations:

Accelerations are measured in order to provide corroborating data for computation of accelerations from measured motions and for the analysis of green water and slamming. In addition to the positions where the accelerations are usually measured, accelerations at the positions where deck wetness and slamming events occurred should also be measured. The Care should be taken to ensure that the measured accelerations are in the correct coordinate system. For example, accelerations measured in direction of the body axes should be corrected to earth fixed axes if required.

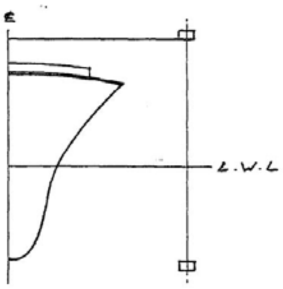
Relative motions:



(a) Probes contouring the hull surface



(b) Straight probe at an angle to the hull surface



(c) Probe vertically alongside the model

Figure 1. Possible Relative motion probe configurations.

For the range of experiments considered here the rarely occurring event is usually related in some way to the motion of the body in relation to the waves. Thus, measurements of the relative motions between the model and the water surface at pertinent points around the model can be very valuable in understanding and correlating freeboard exceedance and deck wetness events, for example, keel emergence and slamming, or stern emergence and propeller racing. Measurement of relative motion should cover as many locations as is practicable but at least should correspond to the positions where the rarely occurring events are concerned. Relative motion is usually measured with resistance, capacitance, or sonic probes. The probes can be mounted down the side of the hull or at some distance away from the hull.

Figure 1 illustrates this concept; for deck wetness and keel slamming. Figure 1(a) shows an example of a relative motion probe contouring the hull surface, Figure 1(b) shows the same relative motion probe mounted at a constant angle to the side of the hull, Figure 1(c) shows the same probe but this time mounted vertically alongside the model.

Capacitance probes tend to be in the form of a strip mounted flush to the hull. However, care should be guarded against water adhesion to the hull causing erroneous measurements. It is also difficult to extend capacitance probes beyond the extent of the hull.

Resistance probes can be mounted contouring (but not flush with) the hull, mounted by two points on the hull (as a straight line) or mounted away from the hull as a vertical wave probe. In the event of the probe contouring the hull, it should be recognised that depth of immersion of the local freeboard may not be a linear function of the amount of immersion of the relative wave probe, thus, resulting in a non-linear calibration.

For deck wetness and slamming experiments, to ensure non-truncated time histories, it is recommended to ensure the relative motions probes extend beyond the local freeboard and the local keel. For propeller emergence extending the probes beyond the hull may not be practicable.

In the event of the signals from the relative motion probes becoming saturated due to the water surface exceeding the extremes of the measurement range then additional analysis will be required to address this problem. Otherwise erroneous values for the RMS relative motion to be measured.

Sonic wave probes can be considered as a useful alternative to capacitance or resistance wave probes. The probe is none invasive and can be mounted in a way that it can record freeboard exceedances and keel emergences without any additional modifications to the hull or without time consuming post experiment analysis.

However, sonic wave probes can not easily measure the near hull swell up very easily, any steep waves may not be measured and sonic probes are known to have short comings in areas where the waves are breaking and so care should be taken.

Rudder angle:

In cases where the model tests are in oblique waves, an active rudder control is to be employed; the rudder angle should be continuously monitored. It is not usually necessary to employ an active rudder in head and following seas tests especially if the model is restrained only to move in heave, pitch and surge. In oblique sea tests, it is usual to control the rudder with a linear autopilot. In most cases the autopilot would be a linear function of the heading error and yaw rate. It is prudent to control the overall gain of the autopilot to ensure that the rudder is neither angle limited nor rate limited too often.

Encounter angle:

The angle between the mean model heading and the wave direction.

Still water resistance and added resistance:

If required, when running captive tests.

Propeller rate of revolutions:

Whenever a self-propelled model is used, rate of revolutions of the shaft should be recorded.

2.4.2 Deck wetness

Green Water on Deck and Fluid Velocities

Green water events (water depth and incident wave profile shape) can be quantified by an array of small wave probes mounted (inverted) on the forecastle, as shown in Figure 2.

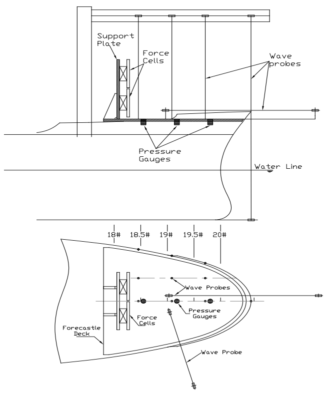


Figure 2. Possible wave probe layout for wave depth and incident wave-profile shape.

The number of probes should be chosen according to needs of the specific experiment. Fewer probes cannot catch the real profile of green water; more will increase signal disturbance between probes, especially for capacitance probes. If possible, the number (and distribution) of probes, shown in Figure 2, can be used to test horizontal velocity of water entry on the deck. The velocity is determined from the derivative of the immersion height measured from the deck probes. There should be sufficient gap between probes and deck to minimize erroneous measurements.

For head sea model tests, the probes can be mounted on half of the deck for to minimize the number of signals.

These capacitance or resistance type probes have the advantage of measuring the depth of water on the deck or wave profile shape at the location of the probe. An alternative is to use contacting electrodes that only determine the incidence and duration of deck wetness and not the extent. However, with either of these technologies, it is possible that small pools of water can collect around a deck wetness probe and provide errors in the readings.

<u>Local loads due to deck wetness</u>

Local loads due to deck wetness are usually used for the assessment of local structure strength usually for equipment mounted on the foredeck of the foredeck itself. There are two types of measuring devices; pressure gauges and force cells. The pressure gauge can pick up pressure peaks, while the force cell measures average pressure over a limit area. The measuring device should be selected with consideration to the kind of green water impact and the structure detail for the strength analysis. An array of pressure gauges is also an alternative, which has the advantage providing information in detail about the propagation of the hydrodynamic pressure in time and in space.

In addition to the deck probes, Figure 2 shows 3 pressure gauges on the deck and 4 force cells on a vertical rigid support plate. A typical profile of green water impact pressures at model scale is shown in Figure 3.

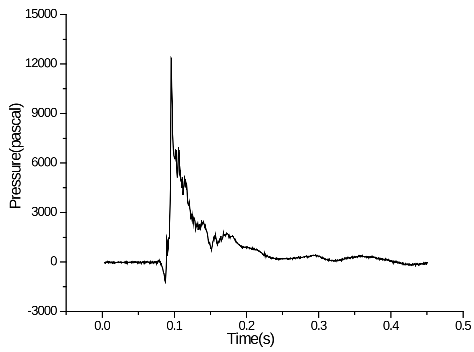


Figure 3 Typical profile of green water impact pressure (model scale)

Because of high frequency characteristic (Generally, the rise time of impact pressure is between 0.10s and 0.35s for full scale) of impact loads due to green water, the sampling rate should not be less than 2kHz to capture the peak loads.

Froude scaling can be used to extrapolate the model pressures and forces to full scale. The scaling factor of pressure and force are 1.025λ and $1.025\lambda^3$ respectively, the coefficient 1.025 represents the ratio between specific seawater density and fresh water density.

For the analysis of local structure vibration, pressure gauge matrix is preferred for the hydrodynamic pressure measurement

<u>Visual records:</u>

Video recording of deck wetness events is still regarded as important in such experiments. Tests should be recorded visually, either by film or video, preferably in a way allowing synchronised in time with the measurement of other parameters. Analysis of video is an effective means of quantifying deck wetness events in terms of their occurrence and their severity.

PIV technology and/or high resolution video recorder may be used to give more accurate wave field and profile measurement.

The sample rate in the data acquisition needs to be fast enough in order that a sufficient resolution is achieved. A sampling rate corresponding to about 4 Hz at full scale is enough for most measurements but much higher rates (of the order of kHz) are necessary to detect pressure peaks from green seas events.

2.4.3 Slamming

Slamming is defined as an impact between the hull of a vessel and the water surface.

For a monohull, a slam occurs when there is the combination of a sufficiently large relative motion (between the water surface and the hull) and a relative vertical velocity (between the water surface and the hull) above a critical value. Such a slam impact can occur on the keel of the vessel, usually at the bow but also it is possible for vessels to experience stern slamming. If a vessel has significant bow flare then slam impacts can occur on this flare region.

Catamarans generally do not experience keel or flare slamming due to the slender shape of their demihulls. However when the water surface impacts the cross deck structure with sufficient relative vertical velocity then a slam may occur. This type of impact is known as a wetdeck slam.

Keel, stern, flare or wet deck slamming can impart significant global and local structural loads onto vessels. The impacts can also induce vibration within the ship (known as whipping) and can ultimately lead to an increase in structural fatigue.

Slamming pressure:

The key issue related to slamming tests on a rigid model is the slamming pressure

For a rigid body measurements of slamming loads are made by discrete pressure cells mounted around the area of the model where the slamming events are expected. A typical profile of a keel slam is shown in Figure 4. There is a rapid increase in pressure within 10-20μs as the keel re-enters the water. This is followed by a slower decrease in pressure until the buoyancy forces start to overcome the force of entry of the model. To capture this profile correctly, in order to define the peak impact pressures there is a requirement to sample at high frequencies.

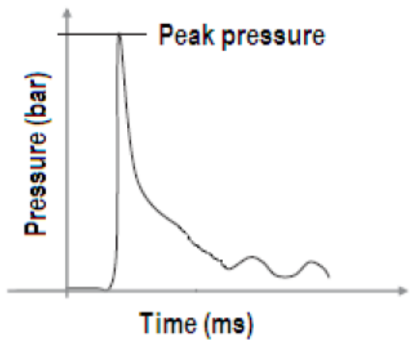


Figure 4. Typical profile of a keel slam.

The most common choice for measuring pressure is using a diaphragm construction with strain gauges either bonded to, or diffused into it, acting as resistive elements. Under the pressure-induced strain, the resistive values change. In most cases this diaphragm technology can have resonant frequencies that are unsuitable for the measurement of slamming pressures and so care should be taken in choosing the pertinent pressure transducer.

Piezoresistive (silicon based) pressure sensors can be used with a nominal pressure range of up to 1 bar (for a typical 1:22 model scale). Typical resonant frequencies for these types of transducers are around 130 kHz.

Sensitive electronic pressure devices, such as the quartz crystal gauge, have improved pressure-transient testing. A quartz pressure gauge is a popular choice for pressure-transient testing because of its high degree of accuracy and sensitivity.

The sample rate in the data acquisition needs to be fast enough in order that a sufficient resolution of the pressure profile. For these tests a sampling rate corresponding to around 20 kHz at full scale is enough for most pressure measurements.

Visual records:

Video recording of slamming events is still considered as important in understanding peak pressure correlation with relative motion.

2.4.4 Propeller emergence

When the relative motion at the stern becomes sufficiently high the propeller may break the surface. These propeller emergence events degrade the performance of the propeller, leads to excessive cavitation, noise and can induce fluctuating loads on the drive train.

Propeller cavitation (a major contributor to ship self-generated noise) is influenced by the depth of immersion of the propeller, and so propeller vertical motion with respect to the sea surface has an important influence. Since models for predicting the effects of ship motion on cavitation do not exist, propeller emergence can only be used as a qualitative criterion. Similarly, propeller emergence can also be used as a qualitative criterion for propulsion system loading problems (i.e. propeller racing).

It is generally agreed that a propeller emergence event is defined when a portion of the propeller diameter is exposed. In some cases this could be a quarter or a third of the propeller diameter but depends on the requirements from the client.

In a similar fashion to deck wetness and slamming, it is preferred that the relative motion at the stern is measured. However, typical relative wave probes may be too intrusive.

Additional measurements should include:

- propeller thrust and torque;
- propeller rotational speed;
- photographic and video records.

2.5 Run duration

Care must be taken for the duration of the data acquisition so that enough data are recorded for the objective of the test. The test duration is represented by total number of waves (encounters) N. The N=100 should be taken as a lower limit. Larger values are to be preferred and it is more usual to take N=200 as the standard; N=400 or above is considered excellent practice. N=100 corresponds to one hour of full scale equivalent run duration, which is considered to be good practice.

If there are no target design wave condition, for comparative tests (e.g. to establish the relative merits of different designs), the wave conditions should be chosen so that a substantial number of events occur. It should be pointed out that this refers only to conventional ships at normal speeds.

An alternative technique is to select the more severe portions of a wave time history to induce rare events in order to study the severity of extreme conditions.

The assumption is that for any given wave conditions the number of rarely occurring events would have a Gaussian distribution. However, if the number of events is too low or too high the distribution would become skewed at zero or the number of waves encountered respectively. The wave conditions should be sufficient to ensure that during the experiment the model would experience a reasonable frequency (wets per ship model length) of between 0.4 and 0.6

In the absence of specific wave spectrum data the ITTC spectrum for open ocean or JONSWAP for limited fetch, should be used. In generating irregular waves in a tank, the input signal to the wave maker should be produced in such a way that the generated waves encountered by the ship should be non-repeatable.

Energy spectra of waves and responses of interest 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 Fast Fourier Transform.

In addition to the spectral analysis, statistical analysis should be performed to produce at least the mean, maximum, minimum, and the average of the 1/3-highest amplitudes. Techniques utilised to smooth spectral shapes, such as block overlapping, should be documented in the presentation of the results. When reporting statistics, the number of events and number of encounters should also be reported together with the overall statistics.

3. PARAMETERS FOR REPORTING

3.1 Parameters

The following parameters defining the tests should be included in the report, together with the measured data:

- Scale;
- Model dimensions;
- Ratios of model to tank dimensions;
- Hull configuration (lines, appendages, superstructures, ...);
- Loading conditions (displacement and drafts);
- Mass distribution (COG, inertias, ...);
- Towing and/or restraining device characteristics (specially DOF);
- Speeds and headings;
- Wave characteristics (heights, periods, spectra, dispersions, ...);
- Autopilot control law;
- Speed control characteristics;
- Run duration;
- Number of runs per test condition;
- Positions of sensors (accelerometers, relative motion, pressure sensors, encountered wave, ...);
- Sampling frequency;
- Sensor calibrations and accuracy.

3.2 Data Presentation

The coordinate system in which the measured data are presented should be defined as well as for the motion components.

The hydrodynamic pressure should be made non-dimensional by ρg. It is recommended to use the non-dimensional forms suggested in procedure of seakeeping test procedure 7.5-02-07-02.1 for presentation of the other measured data.

The following is recommended as a way of presenting the data:

For tank, model and wave data the following parameters should presented:

- Model length;
- Tank length;
- Number of tank runs;
- Rms wave amplitude;
- Significant wave height;
- Modal period.

The wave data should be presented as graphs of probability of exceedance. These graphs are derived from histograms containing the maxima (wave crests) and minima (wave troughs) between zero crossings. It is usual to compare these data with the Rayleigh distribution. In cases of extreme waves, it is expected that the Rayleigh distribution curves tend to underestimate the probability of wave crests and over estimates the probability of wave troughs. This is probably due to the non-linear nature of such high waves in a severe wave spectrum.

For absolute and relative motions the following should be presented for each area of interest:

Mean absolute motion displacement

- Rms absolute motion displacement;
- Mean relative motion displacement;
- Rms relative motion displacement.

Again, these motion data can also be presented as graphs of probability of exceedance and compared with their respective Rayleigh distribution.

3.2.1 Deck Wetness

The deck wetness frequency data can be presented in a few different ways but are usually presented as a mean wetness values from an amalgamation of the runs making up the 200 model lengths.

The data can be presented as;

- Full scale equivalent of number of deck wettings per hour
- Probability of deck wetness
- Non dimensional deck wetness frequency given as $N_W^{'} = N_W \dfrac{N_R L_T}{L_{PP}}$ where N_W is the number of mean number of deck wettings per run, N_R is the number of runs, L_T is the averaged length of the test run.

3.2.2 Slamming

The data can be presented as;

- Full scale equivalent of slamming events per hour;
- Probability of a slam;
- Maximum slamming pressure;
- Mean peak slamming pressure;
- Slam duration.

3.2.3 Propeller emergence

The data can be presented as;

- Full scale equivalent of emergences per hour;
- Probability of an emergence;
- Rms/Peak torque;
- Rms thrust**.**

4. VALIDATION

4.1 Uncertainty Analysis

At moment there are no available data as an example of uncertainty analysis of experiments on rarely occurring events. However, the sample analysis of S-175 ship in the procedure of seakeeping test **7.5-02-07-02.1** gives an uncertainty analysis which might be taken as an example.

4.2 Benchmark Tests

1) Rare Events

(19th ITTC 1990 pp.434-442, Seakeeping)

2) K. Garme.

Time domain simulations and Measurement of Loads and Motions of Planning High Speed Craft in Waves, PRADS 2001 pp.579-585

3) Ogawa, Y. H. Taguch, I. Watanabe, S. Ishido. Long Term Prediction Method of Shipping Water Load for Assessment of the Bow Height. PRADS 2001 pp.603-609

4) B. Hamoudi and K.S. Varyami, Significant Load and Green Water on Deck of Offshore Units/Vessels, Ocean Engineering. Vol.25 No.8 pp715-731, 1998, S-175 Model Tests in Head Sea Waves for Deck Wetness Measurement

C.T. Stansberg and S.I. Karlsen,..Green Sea and Water Impact on FPSO in Steep Random Waves, PRADS 2001, pp593-60

5) B. Peseux_, L. Gornet, B. Donguy Hydrodynamic impact: Numerical and experimental investigations, Journal of Fluids and Structures 21 (2005) 277–303