ITTC Quality System Manual
Recommended Procedures and Guidelines

HSMV Model Tests for Prediction of Structural Loads

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Abstract

This document gives guidelines on how to perform tests for assessment of structural loads and load effects for High-Speed Marine Vehicles (HSMV), including model design, instrumentation, data acquisition and test set-up. Special focus is on issues pertinent to HSMV, such as high speed, light weight, rapidly varying forces, hydroelasticity, slamming and multi-hull structures.

HSMV Model Tests for Prediction of Structural Loads

1. PURPOSE OF PROCEDURE

Structural loads developed on HSMV are usually measured as part of a seakeeping model testing program. At high speeds, many of these vehicles are supported by dynamic lift, and many are exposed to external forces that vary rapidly and give rise to dynamic responses. Novel designs, often with multiple hulls, high forward speed and lightweight materials combined with violent impulsive loads make model design and construction more challenging than for conventional ships.

The weight of these hybrid ships is often sustained by a combination of the lift force by displacement, hydrofoil and aircushion. To model these forces properly, similarity between model and real ship of aircushion, flexible skirts, hydrofoils and appendages is important.

The main aim of this procedure is to provide guidance on model tests for prediction of structural loads on high-speed marine vehicles operating in a seaway. The Procedure 7.5-02-07-02.6 already covers load measurements on regular ships. The HSMV Structural Loads procedure highlights issues pertinent to HSMV.

2. MODEL DESIGN AND TEST TECHNIQUES FOR HSMV

2.1 Relevant HSMV procedures

The ITTC recommended procedures pertinent to high-speed craft are given as separate procedures for each test type. The procedures are:

- Resistance (Procedure 7.5-02-05-01);
- Propulsion (Procedure 7.5-02-05-02);
- Seakeeping (Procedure 7.5-02-05-04);
- Manoeuvring (Procedure 7.5-02-05-05);
- Structural Loads (Procedure 7.5-02-05-06);

Issues of importance for different types of high-speed craft are covered in separate sections in each procedure when needed.

2.2 Loads and load effects

The dimensioning of large high-speed vehicles demands a knowledge and methods to determine the limiting environmental loads, operational aspects and structural strength. To achieve good design load predictions, appropriate model test techniques must be applied. Model tests are also required for verification and calibration of theoretical methods and numerical codes.

Structural loads-response problems can be divided into hydro elastic problems and non-hydro elastic problems. The former requires the structural dynamics to be modelled correctly. That means that not only the mass distribution, but also the stiffness must be scaled. The scaling relations are:

- Structural mass: $(M)_S = (M)_M \cdot \lambda^3$
- Bending stiffness: $(EI)_S = (EI)_M \cdot \lambda^5$
- Shear stiffness: $(AG)_S = (AG)_M \cdot \lambda^3$

Structural loads can also be divided into local and global loads.

Due to the rapidly varying loads on HSMV and the use of lightweight and flexible materials, hydro elastic effects are generally more pronounced for these vehicles as compared to conventional ships. This applies both to the local slamming loads and responses, as well as to the global hull girder responses.

2.3 Design of models for measurement of global load effects

The most important global loads are hull girder bending moments (vertical bending moments), and for catamarans and other multihulls, the forces in the bridge deck structure (split moment, pitch connecting moment, vertical shear force) will often be critical. Hydro elastic effects of importance are springing and whipping. There are two principally different ways of constructing the model:

- a continuously elastic model;
- a segmented model.

The continuously elastic model makes it possible to measure the strain in a very large number of positions. Theoretically, this is also the most correct way to model the structural dynamics, since any number of eigenmodes can be represented. However, one is usually interested in forces not in strain, and establishment of a reliable relation between measured strain and global (or local) forces on an elastic model is very difficult. One might need to do a very detailed FEM analysis of the model to establish the relation between strain and global forces. In addition, this relation might be non-linear and have hysteresis, depending on the type of materials that are used. A continuously elastic model is also complicated and expensive to build, and it may be difficult to modify it if the completed model does not have the specified natural frequencies.

A segmented model is built with a number of stiff segments connected with force transducers (usually strain gauge type). If the structural dynamics is to be modelled, flexible connections are added between the stiff sections. The inertia properties of each section should represent that of the real vessel, and the flexibility of the connections should be so that the relevant global eigenmodes of the vessel are modelled with correct frequencies (and damping, if values are specified). Hence, the flexible connections should be designed for easy adjustment of the stiffness. Compared to the continuously elastic model, the segmented model is much easier to calibrate, and the results are much more readily analysed.

Instead of using rigid segments with flexible connections, one may use a segmented model where each segment is connected to an elastic backbone, which is instrumented with strain gauges at the relevant cross sections.

More information about different model types can be found in the ITTC Global Loads Seakeeping procedure (7.5-02-07-02.6). That procedure also includes a section on self-propelled/steered models and towed models.

Regardless of model type, calibration of the force/moment instrumentation with the application of known forces and moments is essential.

For catamarans and other multi-hulls, both demi-hulls and the connection between the demi-hulls (bridging structure) should be segmented and joined with force transducers, in the same manner as for the hull girder. An example of a catamaran model is shown in Figure 1. Here, the wet-deck plating is supported by vertical force transducers to measure the vertical loads on each of the three wet-deck segments.

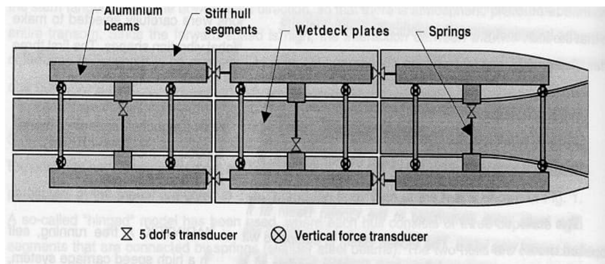

Figure 1 – Set-up of a hydro elastic catamaran model.

2.4 Local loads and load effects

For local loads on the hull structure the slamming force is the most important load contribution. The global response of the vessel defines the relative speed and orientation of the local area of interest during the impact with the waves.

For conventional ships, the hull plating is relatively stiff and the rise-time of the loads due to slamming is relatively long compared to the structure's natural period. Hence, hydro elastic effects can be neglected in most cases.

For HSMV on the other hand, the local structure is usually more flexible, and - especially for horizontal areas such as wet-decks - the rise-time of the slamming load is very short. Hydro elastic local response is therefore more pronounced for these vehicles. For hull bottoms and for vehicles with wet decks, one should therefore consider the structural dynamics when measuring the slamming loads.

For bow slamming and slamming on surfaces with a dead rise angle of more than approximately 15°, hydro elastic effects are less important and testing can be performed without modelling the local structural dynamics (Faltinsen, 1997). Forces can be measured by means of a suitably sized panel mounted on a strain-gauge arrangement. The panel should be stiffly mounted in order to avoid artificial hydro elastic effects. Since the peak of the slamming pressure is very localized one should not use point measurements, but rather use panels of a certain area. The measured slamming loads will then be more representative of the loading on the hull structure. A diameter of around 5 cm is often used.

If conventional slamming panels are used in wet-decks or other places where the response is hydro elastic, one should only use the results to document the occurrence of slamming and not focus too much on the magnitude of the measured loads.

The simplest method for measurement of slamming with modelled structural dynamics is with a strain-gauge mounted stiff panel where stiffness and mass are correctly scaled to yield the correct frequency of the first eigenmode. A better method is to correctly model a suitable part of the hull plating (mass and stiffness). An even more complete, but elaborate, way is to model for instance a wet deck completely with stiffeners and plating. An alternative to modelling the structural dynamics, at least for wet deck slamming, is to calculate the magnitude of the local responses numerically and only measure relative motions and/or the number of slamming events. A practical method is described by Kvålsvold (1994) and Kvålsvold et al. (1995).

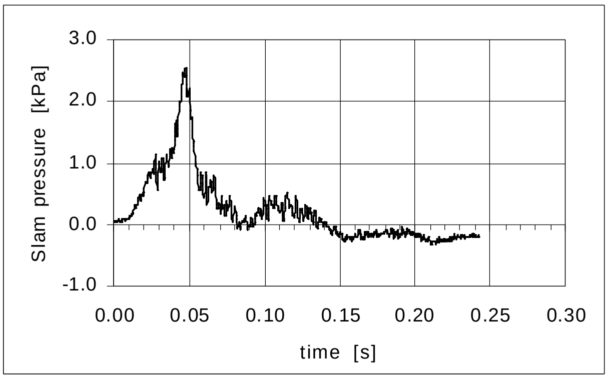

Figure 2: Results of a slamming experiment on the wet deck of a model of a SES, off-cushion mode.

Measurement of slamming is demanding with respect to instrumentation. Compared with conventional model testing, a much higher sampling frequency of the digital recording of the different measurements is required. The sampling frequency should be in the order of 10 to 20 kHz in most cases. Further, the amplifiers have to satisfy requirements to a large linear frequency range. For the different transducers, sufficiently low-rise time and high resonance frequency of the transducers are required to match the time scale of an impact.

Figure 2 shows a typical duration of a slam measured with a flexible panel. Values in the figure are given in model scale. They are collected with a sampling rate equal to 7 kHz. Pressure is measured on a panel that is connected to a strain gauge to the model. The resonance frequency of the panel was 700 Hz.

3. VALIDATION

3.1 Uncertainty Analysis

Not yet treated.

3.2 Benchmark Tests

Not yet treated.

4. PARAMETERS

4.1 Parameters to be Taken into Account

- Scale ratio (λ)
- Model dimensions (Lpp, B, T etc.)
- Ratios of model to tank dimensions
- Hull configuration (lines, appendages, superstructures, ...)
- Loading conditions (displacement ∇ and draft T)
- Towing method and if applicable towing point;
- Mass and mass distribution of the model. Mass, centre of gravity and radii of inertia for each segment need to be represented;
- Speeds (V) and headings (ψ)
- Wave characteristics (heights, periods, spectra, dispersions, ...)
- Run duration (TR)
- Sampling frequency (fs).
- Ship motions in all relevant degrees of freedom;
- Accelerometers. One on each segment is recommended.
- Structural properties of full-scale ship (stiffness, eigenfrequencies and eigenmodes);
- Location and number of cuts to be used in a segmented model. Stiffness in connections;
- Location and eigenfrequency of slamming sensors (local loads);
- Sample frequency and amplifier rise time for the experiment data collection system.

4.2 Recommendations of ITTC for Parameters

- The location and number of cuts to be used in a segmented model can be determined when the eigenmodes of interest of the full-scale ship are known. Segmentation is made to be able to represent the important eigenmodes. The stiffness in connections must either be enough to ensure no effect of flexibility or to give correct eigenfrequencies depending on whether a stiff or hydro elastic model will be applied. This must be calculated in either case.
- The determination of the location of slamming sensors is done by experience, specified by the client, determined from numerical simulations of seakeeping, or from initial seakeeping tests. The eigenfrequency should match that of the structure of the full-scale ship if hydro elastic effects are important.
- The sample frequency and amplifier rise time for the data acquisition system is determined when eigenfrequencies of local and global load measurement arrangements are known and should be sufficient to capture the rise time of the measurements with sufficient accuracy.

- The duration of the tests must be sufficiently long to get reliable statistical estimates of the quantities of interest. Since structural loads tests often are carried out to determine maximum values, long time series are often required. For instance, if an extreme slam pressure needs to be determined, a run length sufficient to record at least 100 slams is required.

5. REFERENCES

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6. KEYWORDS

HSMV, Catamaran, Hydroelasticity, Global load effects, Slamming, Segmented model