ITTC Quality System Manual

Recommended Procedures and Guidelines

Procedure

HSMV Structural Loads

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Disclaimer

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High Speed Marine Vehicles: 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 extremely dynamic forces. These issues present new challenges for making load measurements in the towing tank and new test procedures are constantly being developed to address them; especially for HSMV like hybrids.

The weights of these hybrid ships are sustained by the combination of the lift force by displacement, hydrofoil and air-cushion. The interaction of these sustain forces should be considered and predicted more precisely. In this sense, similarity between model and real ship of air-cushion, flexible skirts, hydrofoils and appendages will be the important part in case of hybrid type HSMV.

The main aim of this procedure is to provide guidance on seakeeping 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 high-lights issues specifically for HSMV.

2. TEST TECHNIQUES AND PROCEDURES

2.1 General

The ITTC recommended procedures peculiar 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 Structural Loads

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 developed. Model tests are also required for verification and calibration of theoretical methods and numerical codes.

Structural loads can be divided into hydroelastic problems and non-hydroelastic 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. This division implies that each of these cases can be treated individually. In some cases, hydro elasticity is important, in others it can be neglected.

2.2.1 Local Loads

For the local problem the slamming force is the most important load contribution. Firstly, one should not consider point pressures, but rather forces on a carefully chosen area, e.g. a single plating field (Carcaterra & Ciappi, 1998, Carcaterra et al., 1999). The dynamic behaviour of the elastic plate is governed by the structural properties of the plating (including longitudinal stiffeners between two transverse frames).

The global response of the ship serves as an input to the problem defining the relative speed and orientation of the local area of interest during the impact with the waves. For flat-bottom slamming, and wet-deck slamming of multi-hulls, hydro elasticity is crucial for the magnitude of the slamming loads. Testing is done either with the dynamic behaviour correctly modelled, or the results are used solely to document the occurrence of slamming, not the magnitude of the forces.

For bow slamming, and slamming on surfaces with a dead rise angle of more than approximately 15°, hydroelastic 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 hydroelastic effects.

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 loads 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).
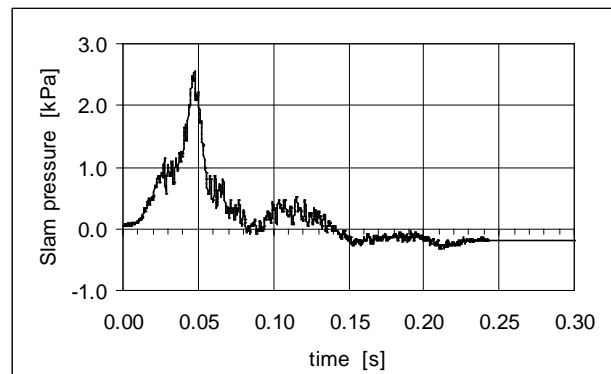

Fig.1 Results of a slamming experiment on the wet deck of a model of a SES, off-cushion mode.

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.

Fig. 1 shows a typical duration of a slam measured with a flexible panel. Values in figure are given on model scale. They are collected with a sampling rate equal to 7 kHz. Pressure is measured on a panel that is connected with a strain gauge to the model. The resonance frequency of the panel was equal to 700 Hz.

2.2.2 Global Loads

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. Hydroelastic effects of importance are springing and whipping. There are two principally different ways of constructing the model:

- a continually elastic model;
- a segmented model.

The continually 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 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 segmented model is built in a number of stiff segments connected with force transducers (usually strain gauge type). If the structural dynamics is to be modelled, springs are added between the stiff sections. The spring stiffness and mass distribution should be selected in order to represent the first few eigenmodes of the hull girder correctly. The segmented model is much easier to calibrate, and the results are much more readily analysed. The drawbacks are problems with the weight of the model, and a limited number of eigenmodes that can be represented (limited by the number of sections). For most practical cases, the segmented model should be preferred.

In the case of a hydroelastic model, the structural properties of the full scale ship must be determined previous to the design of the model, for instance by FEM analysis, regardless of the selected modelling technique.

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. The model set-up is shown in Fig. 2.
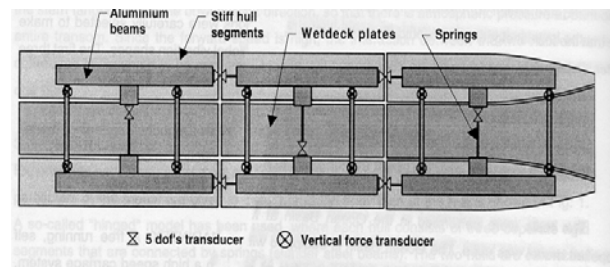
Fig. 2 – Set-up of a hydroelastic catamaran model.

3. PARAMETERS

3.1 Parameters to be Taken into Account

1. Towing method and if applicable towing point;
2. Mass and mass distribution of the model. For a stiff model only mass, centre of gravity and radii of inertia need to be represented;
3. Wave height (fixed or encountered) measurement, selection of wave spectra and duration of tests;
4. Speed;
5. Ship motions in all relevant degrees of freedom;
6. Structural properties of full scale ship (stiffness, eigenfrequencies and eigen-modes);
7. Location and number of cuts to be used in a segmented model. Stiffness in connections;
8. Location and eigenfrequency of slamming sensors (local loads);

9. Sample frequency and amplifier rise time for the experiment data collection system.

3.2 Recommendations of ITTC for Parameters

1. 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 hydroelastic model will be applied. This must be calculated in either case.

10. 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.

11. 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.

12. 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.

4. VALIDATION

4.1 Uncertainty Analysis

Not yet treated.

4.2 Benchmark Tests

Not yet treated.

5. REFERENCES

Carcaterra, A. and Ciappi, E., 1998, "Impact of structures on the water surface: an upper bound analysis of the induced stress," In Proceedings of the 23rd ISMA: International Conference on Noise and Vibration Engineering, Vol. 2, pp. 647-654.

Carcaterra, A., Ciappi, E., Iafrati, A., and Campana, E.F., 1999. "Slamming of elastic structures on the water surface: a shock spectral approach". In Proceedings of the 9th International Offshore and Polar Engineering Conference, Vol. 4, pp. 440-449.

Faltinsen, O.M., 1997. "The effect of hydroelasticity on slamming". Phil Trans R Soc London, Ser. A 355:575–591

Kvålsvold J., 1994, "Hydroelastic Modelling of Wet-Deck Slamming on Multi-Hull Vessels", Mta-report 1994:100, Depart-ment of Marine Hydrodynamics, The Norwegian Institute of Technology, Norway.

Kvålsvold, J. and Faltinsen, O.M., 1995, "Hydroelastic modelling of wetdeck slamming on multihull vessels", Journal of Ship Research, 39, 225-239.