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High Speed Marine Vehicles: Structural Loads

1. PURPOSE OF PROCEDURE

To describe model test for prediction structural loads on high speed marine vehicles.

2. TEST TECHNIQUES AND PROCEDURES

2.1 General

The review of HSMV model testing technology conducted by the 16th ITTC was organised in order of HSMV type: SWATH, semi-displacement, planing, hydrofoil, SES and ACV. For each type of craft a summary was given for different areas of technology such as resistance, sea keeping, manoeuvring, performance and propulsor. Upon reviewing this work, the Specialist Committee concluded that the recommended codes of practice would be less repetitive if they were arranged in order of test type rather than HSMV type. The following main test types were identified:

- Resistance (Procedure 7.5-02-05-01)
- Propulsion (Procedure 7.5-02-05-02)
- Sea Keeping (Procedure 7.5-02-05-04)
- Manoeuvring (Procedure 7.5-02-05-05)
- Structural Loads (Procedure 7.5-02-05-06)
- Dynamic Instability (Procedure 7.5-05-02-07)

The test types are listed in order of how often they are carried out according to the questionnaire survey. Resistance tests are the most common by a large margin. Many of the issues that are important for resistance tests of HSMVs are also important for other types of testing. To avoid repetition, these issues are listed only once, under the test heading (recommended procedure) in which they first appear.

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 sensibly 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 will serve as 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, 1998). 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 more correct method is to model a suitable part of the hull plating correctly (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, 1996).

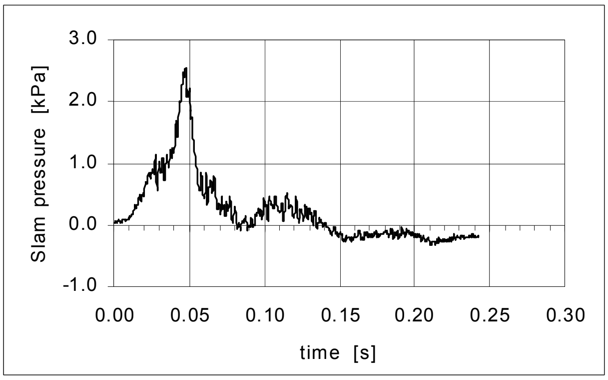

Fig.1 Results of a slamming experiment on the wet deck of a model of a SES, off-cushion mode.

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 100 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.

Figure1 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. Resonance frequency of 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 multi-hulls, 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:

- Continually Elastic model;
- 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 Figure2.

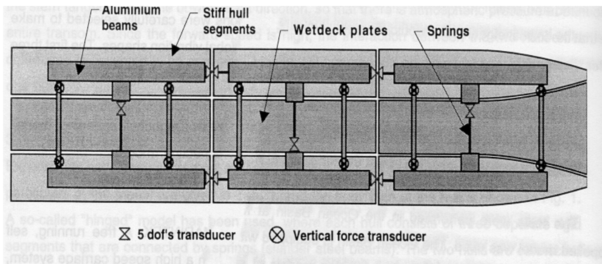

Fig. 2 – Set-up of a hydroelastic catamaran model.

3. PARAMETERS

3.1 Parameters to be Taken into Account

1. Speed
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. Structural properties of full scale ship (stiffness, eigenfrequencies and eigenmodes)
4. Location and number of cuts to be used in a segmented model. Stiffness in connections.
5. Location and eigenfrequency of slamming sensors (local loads)
6. Sample frequency and amplifier rise time for the experiment data collection system
7. Selection of wave spectra and duration of tests

3.2 Recommendations of ITTC for Parameters

1 Location and number of cuts to be used in a segmented model can be determined when the important eigenmodes of the full scale ship are known. Segmentation is made to be able to represent the important eigenmodes. 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 each case.

2 Determination of 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.

3 Sample frequency and amplifier rise time for the experiment data collection system is determined when eigenfrequencies of local and global load measurement arrangements are known.

4 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 extreme slam pressure needs to be determined, a run length sufficient to record 100 slams is required.

4. VALIDATION

4.1 Uncertainty Analysis

None.

4.2 Benchmark Tests

None.