# ITTC Quality System Manual

# Recommended Procedures and Guidelines

**Procedure**

# Global Loads Seakeeping Procedure

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| Seakeeping Committee of the 28th ITTC | 28th ITTC 2017 |
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# Seakeeping Model Test Procedure for Global Loads

## 1. PURPOSE OF PROCEDURE

This procedure will outline the measurement of global wave loads through seakeeping experiments. The procedure shall describe the design of the experiment, the set-up of the model and instrumentation, the test, and the analysis. There is already a procedure covering seakeeping experiments which outlines the processes and considerations of those model tests (7.5-02-07-02.1). This procedure will elaborate and outline the additional considerations for measurement of global loads with various types of model and experiment designs.

## 2. GLOBAL LOADS SEAKEEPING EXPERIMENTS

### 2.1 Objectives of experiment

The first step in the experiment design is the determination of the objectives for undertaking an experiment to measure loads and the available methods that are available to meet those objectives. Possible areas of interest that can be addressed by undertaking experiments to measure global loads are to provide data that can help in the understanding of :

- Primary Design Loads
- Slamming, Whipping and Springing Loads
- Validation of Computational Methods
- Frequency Domain Application to Lifetime Designs
- Application to Extreme Loads – Stochastic Analysis
- Fatigue Analysis and Design
- Safe Operating Envelope

The objectives will have to be based upon the operational or design information required, the type and size of vessel, the wave environment, operational variables, and the facility to be used. The experiment design will seek to satisfy the objectives within the constraints of the physical experiment. Global loads seakeeping experiments can be rather complex dependent upon the degree and level to which global loads must be know.

The measurement of primary design loads, requires less complexity than the construction of a model to measure slamming and whipping loads. A model test intent on measuring slamming and whipping will have to be more concerned with scaling issues as a result of local hydrodynamic pressures and hydro-elastic modeling.

Validation of computational methods might require greater fidelity and control. Validation of computational methods will require greater measurement and verification of the force and control variables which affect the resultant global loads, as these will need to be compared against the modeled control forces. The investigators will need to ensure that the variables used in the experiment are adequately modeled and recorded for modeling with the computational methods.

Frequency domain oriented experiments are intent on deriving the frequency response of global loads relative to the seaway of concern. The frequency response can then be used in turn to calculate more thorough load responses across the range of seaway and operational environments expected. The frequency based response functions can also be compared to derived computational solutions.

The stochastic objective requires the production of extreme seaways and components capable of appropriately modeling the extreme seas anticipated in nature. This will require experiment scaling of appropriate nature, based upon the wavemaking capability, and appropriate seaway modeling techniques to ensure proper energy representation and random process modeling.

Testing of the model for the purposes of fatigue analysis requires a test matrix and experiment design which allow suitable verification of distinct seaway and operational sectors. These results will be combined with other numerical and computational methods to populate an anticipated lifetime of exposure and design environments. This, in turn, is then used to determine cumulative lifetime global loading.

## 2.2 Types and selection of global load model type

The global load experiment can be performed with either a "segmented" or an "elastic body" model. For an "elastic body" the prototype is representative of the full scale ship down to the local structural level possible even including hull plating. A whole body structural response is then obtained as function of the hydrodynamic loading. As such the "elastic body" model is referred to as a "hydro-structural" model. For a "segmented model" the global loads will be investigated at discrete points within the hull using a structure independent of the external hull. The model is segmented so that it provides no continuous structural support. The primary strength will be provided by either an "elastic segmentation" or a "rigid segmentation".

Model type is mostly only important for whipping experiments. As the hydro-elasticity is of greater importance there, the model types should either be a "hydro-structural" model or an "elastic segmented" model; a "rigid segmentation" model should be avoided.

### 2.2.1 Segmented models

Global loads and the resultant strains are the cumulative forces applied on a part of the ship due to internal weight and inertial characteristics, control forces, and external hydrostatic and hydrodynamic forces. To quantify these global loads at discrete locations, a model can be divided into several independent segments. Two types of segmented models exist, rigid or elastic, and depend on the type of beam or interface connecting the various segments.

<u>Rigid segmented models</u>

For models segmented on a rigid beam, the beam must have a sufficient rigidity to be considered as infinite compared to the actual rigidity of the ship. The model shape does not change on wave peaks or troughs at studied frequencies and the natural frequency of the structure is much greater than the wave frequencies. Loading measurements are evaluated by either measuring the effort by individual segments or from the direct bending moments of the beam. For the frequencies where the model can be considered as rigid, results for loading can be used as input for a numerical analysis of the structure. The computations can either be 2D (representation of hull girder) or 3D.

<u>Elastic segmented models</u>

Models segmented on a non-rigid beam allow for measurements at multiple locations on the beam, and thus a direct measurement to obtain strain at all sections. Elastic segmented models can also employ internal rigid structure with instrumented joints at each segment which model the rigidity of the ship at each segment.

For all types of segmented models, each segment must have the same inertial properties as the corresponding segment in the real ship and typically the horizontal gap between the segments is around 5 to 10 mm. Ideally, the neutral axis of the backbone for the induced moments under investigation should match or be as close as possible to that of the real ship.

### 2.2.2 Hydro-structural models

Hydro-structural models

Generally speaking, a hydro-structural model can be made to satisfy geometric similarity of the hull form, hydrodynamic similarity and structural similarity with regard to the global vertical bending and shearing forces, and hence it can be used to measure the bending moments at any cross section over the model length. This is a rather complex model which is difficult to manufacture and such experiments have only been performed on a limited basis. Additionally, the types of materials required, polymer products, are not usually stable in the long term and can be subject to structural creep. The design and fabrication of hydro-structural models is costly and time consuming.

Hydro-structural model with backbone

To overcome the difficulties to manufacture the hydro-structural model, backbone can be used to adjust the bending rigidity. In the hydro-structure model with backbone, hull is made of soft material such as polyurethane foam to satisfy geometric similarity of the hull form. The hull surfaces are painted with soft elastic paint to prevent water saturation and crack. The rigidity of the hull itself is low and the structural similarity with regard to the hull-girder response to the hydrodynamic loads is adjusted by backbone. The rigidity and neutral axis of the model ship can be adjusted by designing backbone's longitudinal variation of sectional shape. Using the backbone, design of the model becomes much easier, cost to manufacture can be reduced, influence of property change of polymer product due to ageing can be suppressed and structural creep of model ship can be avoided.

The advantage of the hydro-structural models to the segmented models is its gapless hull surface and continuous elastic deformation. Since there is no disturbance form the sealing of gaps, better hydrodynamic similarity can be expected.

## 2.3 Scaling laws and scale ratio selection

The performance of global loads experiments follow the same Froude scaling laws as used for traditional seakeeping tests. The additional constraints are the scaling of structural similarity as decided upon in the experiment design. All structural similarity must be done within the confines of a geometrically and structurally suitable model. The internal structural components of the model must satisfy weight and volume restrictions, while trying to provide the targeted structural rigidity intended for modeling of the prototype ship.

The test facility capabilities, operational environment, and test objectives are the primary factors which will determine the scale ratio selection. The physical properties will be scaled according to the appropriate scaling factor. These scaling factors are summarized as the first eleven entries of Table 1. Additional scaling factors are required for structural modeling and are presented in the lower portion of Table 1.

The structural rigidity, modulus of elasticity, and section modulus all provide additional challenges with respect to satisfying scaling requirements. In those cases where structural scaling is not possible; corrections to measured strain and associated moments, torsions, and shears might be required.

Other decisions as relates to scale selection are the weight and ballast challenges, and the type of propulsion and maneuvering required for the model. The model weight and ballast conditions must be obtainable on a total model and segment level. Each segment must satisfy its own weight and inertial characteristics. If it is a self propelled model there must be suitable scale to allow for propulsion and powering components.

For a ship beam representation the frequency of resonance is proportional to :

$$\omega = \sqrt{\frac{EI}{\Delta l^3}}$$

with $E$, the Young Modulus of the material, $I$, the moment of inertia of the girder, $\Delta$ the displacement and $l$, the length of the girder.

Usually segmented models on elastic beams use a beam in the same material as full scale. Theoretically the scaling law is then $\lambda^5$. For many reasons (length of the beam, uncertainty on the Young's modulus, "sprung" effect, Achtarides 1983) it is difficult to obtain correctly scaled natural frequencies between the model and the real ship. That means that the model's natural frequency should be adjusted to a value estimated numerically from full scale data.

## 2.4 Model design

Once the type of model is selected a design which integrates the needs within the model package is the most challenging part. Design of an "elastic ship model" is beyond the scope of this procedure. The design involves a detailed knowledge of the ship structure to be modeled, understanding of the detailed modeling and scaling laws, and the ability to design and build a model with thin plastic products and the proper load transference. Examples of an "elastic ship model" test for the SL-7 is provided by Rodd (1976).

Table 1. Ideal and Practical Scaling Ratios (Dinsenbacher, 2010).

| Quantity | Prototype | Ideal Model | Practical Model |
|---|---|---|---|
| Length | L | $L/\lambda$ | $L/\lambda$ |
| Water Density | $\rho$ | $\rho/c$ | $\rho/c$ |
| Time | t | $t/\lambda^{1/2}$ | $t/\lambda^{1/2}$ |
| Mass | m | $m/c\lambda^3$ | $m/c\lambda^3$ |
| Velocity | v | $v/\lambda^{1/2}$ | $v/\lambda^{1/2}$ |
| Acceleration | a | a | a |
| Force | F | $F/c\lambda^3$ | $F/c\lambda^3$ |
| Ship Displacement | $\Delta$ | $\Delta/c\lambda^3$ | $\Delta/c\lambda^3$ |
| Moment | M | $M/c\lambda^4$ | $M/c\lambda^4$ |
| Pressure | p | $p/c\lambda$ | $p/c\lambda$ |
| Frequency (flexural modes and Rigid body motions) | $\omega$ | $\omega\lambda^{1/2}$ | $\omega\lambda^{1/2}$ |
| Bending Rigidity | EI | $EI/c\lambda^5$ | $EI/c\lambda^5$ |
| Shear Rigidity | KAG | $KAG/c\lambda^3$ | $KAG/c\lambda^3$ |
| Modulus of Elasticity | E | $E/c\lambda$ | $E/e$ |
| Section Area | | | |
| Moment of Inertia | I | $I/\lambda^4$ | $Ie/c\lambda^5$ |
| Distance from neutral axis to outermost fiber for hull-girder (prototype) or strength bar (model) | y | $y/\lambda$ | $y/r$ |
| Section Modulus | Z | $Z/\lambda^3$ | $Zer/c\lambda^5$ |
| Flexure Stress | $\sigma$ | $\sigma/c\lambda$ | $\sigma\lambda/er$ |

Note:
$\lambda$ is the ratio of prototype to model length
c is the ratio of prototype to model water density
e is the ratio of prototype to model modulus of elasticity
r is the ratio of distances from neutral axis to outermost fiber

As discussed earlier, the design of a segmented model will have two decidedly different paths based upon whether it is an elastic or rigid segmented model. In either case the ballasting of each segment must satisfy the weight and inertial properties of concern for that section, and the overall hull weight and ballast conditions must be satisfied.

An elastic segmented model will require careful design of a backbone, internal truss, or connecting structure from knowing the strength and rigidity properties of the prototype. If an internal truss or connecting structures are used between segments then the connections should model, as closely as possible, the anticipated ship rigidity and damping at that point. The natural frequencies and achieved modal shapes should also be used to evaluate the correct structural modeling.

The backbone must be designed with variable beam properties, to at a minimum, satisfy the variations at the stations. The variation of the backbone rigidity beyond the segment level allows further strain measurement at intermediate longitudinal locations. Examples of elastic segmented models are provided in Figure 1 and Figure 2.

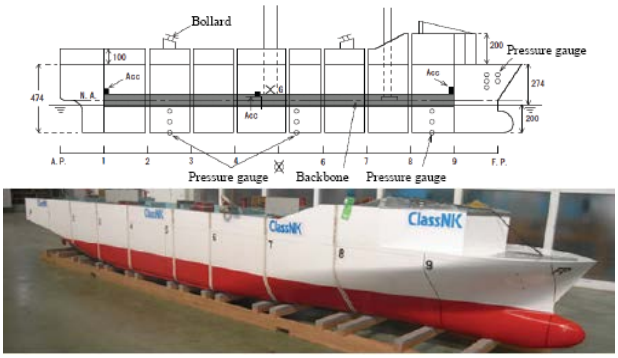


Figure 1. Elastic Segmented Model with Internal Backbone Beam (Miyake, 2009).

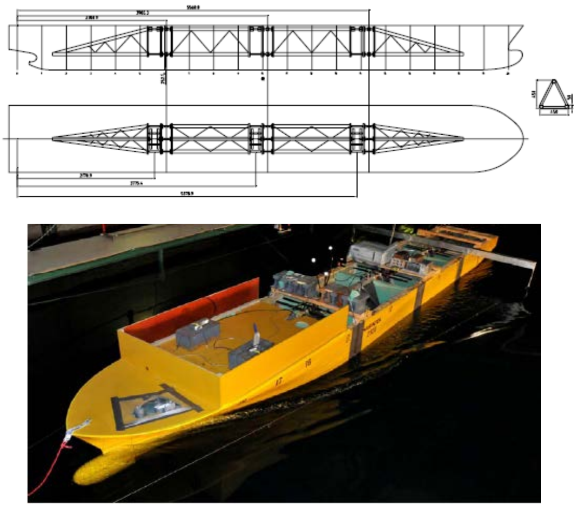

Figure 2. Segmented Elastic Model with Transducers at Segments (Wu, 2010).

A rigid segmented model will also require a design which meets geometrical and physical inertial characteristics. A rigid segmented model can incorporate either a very rigid backbone or internal truss, or instrumented rigid joint connections along the segmented plane.

Design of the hydro-structural model with backbone is similar to that of the segmented model. First, the rigidity of soft hull is calculated based on the section shape of the model hull and Young's Modulus of hull material. If it is not clear, material testing is conducted to measure it.

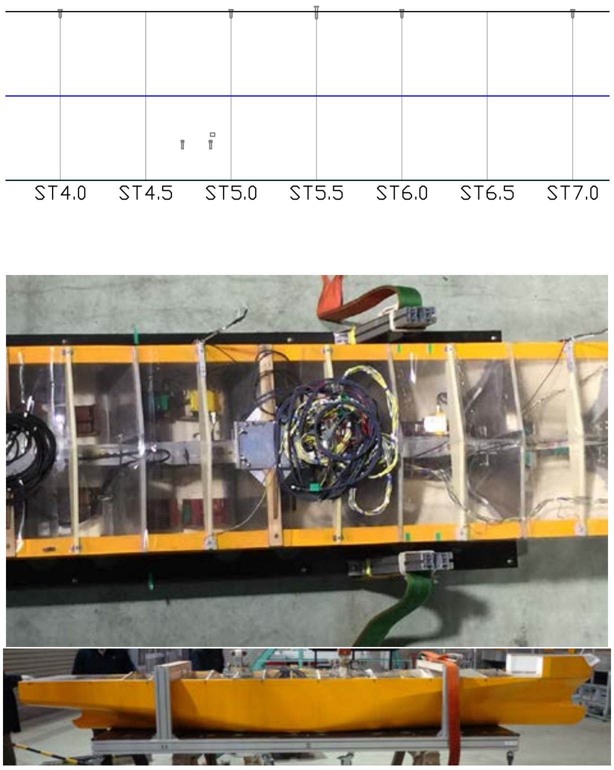


Figure 3. Hydro-structural model with backbone (Houtani, 2016).

Next, the backbone's longitudinal variation of rigidity, location of neutral axis and the installation height from the keel is designed to satisfy structural similarity of entire model. In the soft hull, rigid bulkheads are installed to connect the hull and the backbone tightly to come together as a single beam. Example of hydro-structural model with backbone is provided in Figure 3.

### 2.5 Design, fabrication, and instrumentation of structure for segmented model

For the segmented model there is an instrumented structure which is used to provide the hull structure. This structure can be either "elastic" or "rigid". "Elastic segmented" structure modeling will allow hull rotation and longitudinal and transverse bending relative to the wave environment. Hence the design must try to model the rigidity of the ship hull.

This requires some knowledge of the ship rigidity along the length of the ship. If the ship design itself is immature, then structural characteristics typical of the ship class may be used. The backbone is typically constructed from aluminium due to weight and ease of fabrication. However, more rigid metals might be more suitable for more rigid, heavier ships. The backbone is often built with varying cross-section to model the ships varied rigidity with respect to longitudinal location. This can be done by altering the flange thickness of the beam. Other materials can be used, but aluminium typically is easy to work with, is less costly, and provides a larger cross-section for model attachment. Whenever possible the backbone should be designed and located so that the bending neutral axis of the backbone corresponds to the neutral axis of the ship. With respect to torsional vibrations the shear center is important, however very difficult to obtain, since for open sections the shear center might be below the hull.

At the location of the segments the beam is outfitted with strain gages to monitor the primary forces and moments of concern. Examples of possible strain gage instrumentation on an internal elastic H-beam backbone are provided in Figure 4. The relationship between backbone strain and global loads is determined by force and moment calibration prior to testing. If there are cross talk terms this can be resolved with a calibration matrix which takes into account any cross talk components.

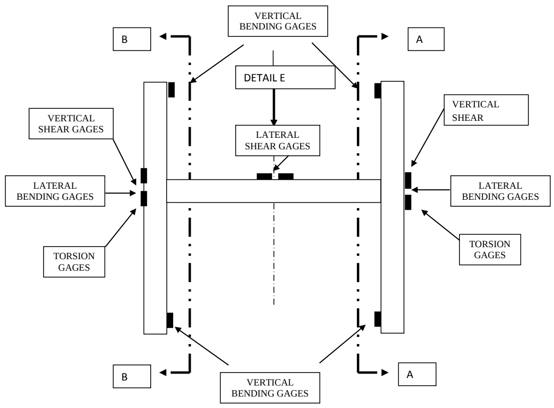


Figure 4. Possible Strain Gage Measurement for Internal Elastic Strength Bar (Dinsenbacher, 2010).

The other type of "elastic segmented" model involves the use of instrumented flexible connections at the segment break as shown in Figure 5. If possible the flexible connections should have the same structural damping as the ship hull at that segment break in the hull. In some cases the damping/rigidity can be adjusted dependent upon the mechanical arrangements. At a minimum, the degree of damping should be at the same order of magnitude as the ship structure. The moment and shear can be measured via force transducer at each connection point between the segments. With the right solution method and number of determinant measurements the global forces at the segment break can be defined.

The other form of a segmented model involves the use of a "rigid" structure. This involves either the use of a rigid instrumented connection between rigid hull segments, or a very rigid beam where load transducers between the segments and the rigid structure define the cumulative force and moment acting from that particular segment.

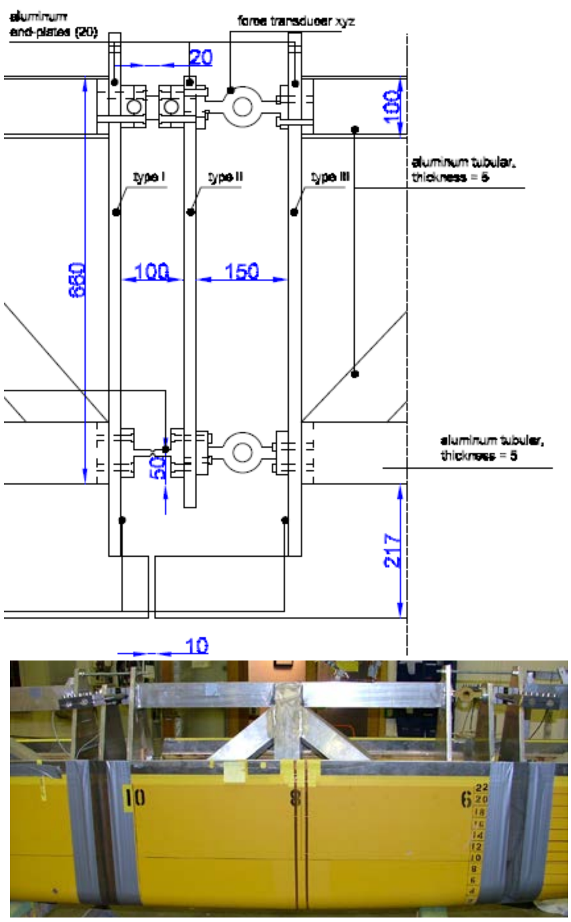


Figure 5. Instrumented Flexible Connections for Non-Backbone Elastic Segmented Model (Drummen, 2007).

In all cases the inertia of the structure will need to be accounted for both as a contributor to the segment inertia as well as the overall hull inertia. This will require a very thorough treatment of weight and locations for the structural components.

In all cases of load instrumentation you are not really measuring the load directly, but rather the reaction to loads. Even if load transducers are calibrated independently, the overall force from a segment should be verified in situ with independent application of force and force couples about the segment locations.

## 2.6 Model Segmentation

For models which are segmented, the segmentation is selected based upon the primary modes of structural deformation to be studied. If only mid-ship bending is required then only one mid-ship cut would be required. If maximum shear were also needed then three cuts/four sections would be required. If a more thorough understanding of the dynamic load flow along the hull is required, then five or more cuts might be required. Thinner cross-sections at the bow, and steering and propulsive needs at the stern will require longer sections for the bow and stern as shown in Figure 1 and Figure 6

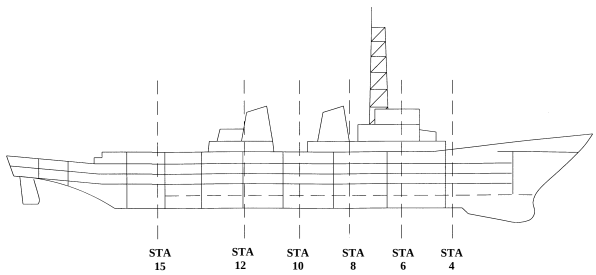


Figure 6. Example Segmentation Spacing (Dinsenbacher, 2010).

The segment gap spacing is usually 5 to 10 mm in width. A dental quality latex is placed along the segment gap completely around any water sealed interface. The latex provides a watertight pliable connection as shown in Figure 7. The latex seal is indented slightly in toward the hull so that the external hull shape is minimally affected.

Usually only the first longitudinal mode is experimentally simulated (sometimes the second). As a matter of scale it is not possible to simulate the response of the structure on local modes or on combinations of modes which are sometimes identified at full scale.

When choosing the segment layout, the representation of the deformed mode shape of a real continuous hull structure by a segmented model composed of a finite number of segments should be considered. This point should be studied numerically, even with simple 2D girder representation. Comparison between segmented mode shape and numerical estimation of the full scale mode shape should be performed in order to check the validity of the model design and segmentation.

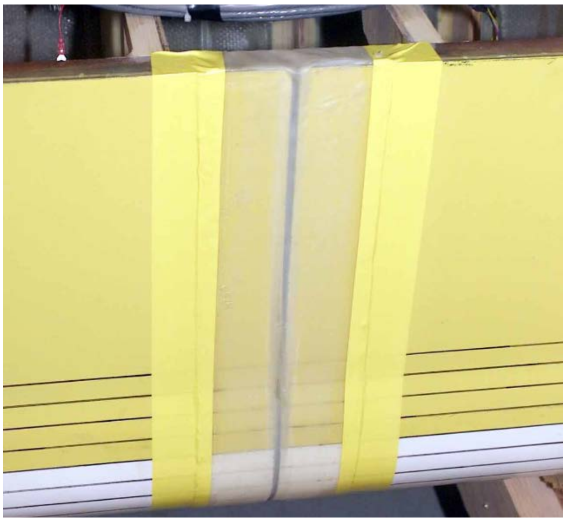

Figure 7. Example of Segment Sealant (Hayden, 2009).

Elastic segmented experiments are performed to determine a response on one or more specific modes, it is thus mandatory to identify the structural damping of the tested structures. Even if the damping at full scale is unknown, experimentally the structural damping should be measured. Kapsenberg (2002) notes that if a succession of impacts are observed, the structural damping is important, especially when a second impact is considered. The response to the second impact can be increased or decreased then by the effect of the first impact which is not totally damped. Damping will have a major effect on the assessment of whipping and springing responses.

## 2.7 Design and fabrication of hydro-structural model with backbone

The hull of the hydro-elastic model with backbone is made of soft materials such as polyurethane foam and smoothly formed to satisfy geometric similarity to the full scale ship. Since the Young's Modulus of polyurethane foam is very small, about 2 x $10^7$ N/$m^2$, the model hull must be thick enough to keep transverse strength to the hydro-static and hydro-dynamic pressure. Number and location of the bulkheads is another important design factor to keep transverse strength. The hull surfaces of both outside and inside are painted with elastic paint to prevent water saturation and crack. Usually, Young's Modulus of the paint is higher than that of base material and rigidity increase due to the paint should be counted to estimate total rigidity of the hull. After the hull is fabricated, its rigidity is roughly measured by three points bending test to check the order of the rigidity.

Even with the thick hull, longitudinal rigidity of the hull itself is still low and the structural similarity with regard to the longitudinal hull-girder response to the hydrodynamic loads is adjusted by backbone. The rigidity and location of the neutral axis of the model ship is adjusted by backbone's longitudinal variation of sectional shape and the installation height from the keel. H section aluminum beam is popularly used for the backbone. The flange of the beam is trimmed to vary the section shape.

The backbone is connected to the rigid bulkheads tightly to transfer hydro-dynamic loads on the hull to the backbone. After the backbone is installed, the model is loaded in the trimming tank, and natural frequencies are measured by hammering test. If the measured frequency of the lowest mode disagrees with the design frequency, backbone is re-trimmed until the design frequency is achieved.

Strain gauges are attached to the backbone to measure the longitudinal hull-girder responses of the model ship to the incident waves. Calibration constants are determined by three points bending test of the hull with backbone. The location of strain gauge is not restricted but just on the bulkhead is not recommended.

### 2.8 Powering and Steering

The powering of the model should be done in such a way as to minimize application of thrust and a moment on any one section of the segmented model. This can be done through appropriate use of gear boxes, flexible joints, timing belts and other mechanical rigging arrangements. The ideal arrangement is to channel the thrust into the longitudinal line of the strength bar or truss. The goal is to ensure that the thrust does not exert a longitudinal moment onto the strength bar. In the case of waterjets this is not possible and at a minimum the waterjets should have the same geometric location as full scale waterjets. Calm water non-zero speed runs can determine the thrust effects on measured loads.

The steering should be performed with an autopilot algorithm if possible so that the algorithm can be transferred across to simulation efforts. If manual steering is required steering should be minimized to just that required to keep the model on heading. The steering from either method should be minimized (or linear) as much as possible during the collection of data. Ultimately the steering forces will introduce a side force to the affected segment and in some cases can introduce some elements of roll and acceleration. The steering motions and forces can be estimated by performing some modified small angle zig-zag maneuvers which might be typical of the rudder and heading variations anticipated during a seakeeping heading run.

### 2.9 Instrumentation

The instrumentation should be sufficient and appropriate to measure all components of concern for a global loads experiment. Due to the nature of a global load elastic model, there can be a greater variation in accelerations, angular displacements, and angular rates between the ~~segments of~~ locations on the model being tested as compared to a rigid model. Due to model flex, it is possible to have varying angles of absolute roll and pitch for the ship. In an ideal world with unlimited funds a high precision 6-axis measurement device would be placed in each ~~segment~~ location. Then the relative pitch and roll between sections could serve as a check on angular hull rotation as noted from the structure. In most cases the accuracy and cost required for such a comparison is not reasonable or obtainable.

Instruments can be attached to the rigid strength beam or rigid hull points. Accelerometers should be located at pre-determined points of interest. However the instruments should be mounted away from any flexure points that might affect movement of the beam.

In addition to the regular seakeeping motions any parameters which effect loading on the hull should be collected. If reasonable the loads from the propulsion and steerage should be documented. If there are sidehulls the loads induced from the side hull acting on the main hull should be instrumented and collected. A more detailed summary of the parameters to be collected are provided in Section 3.1.

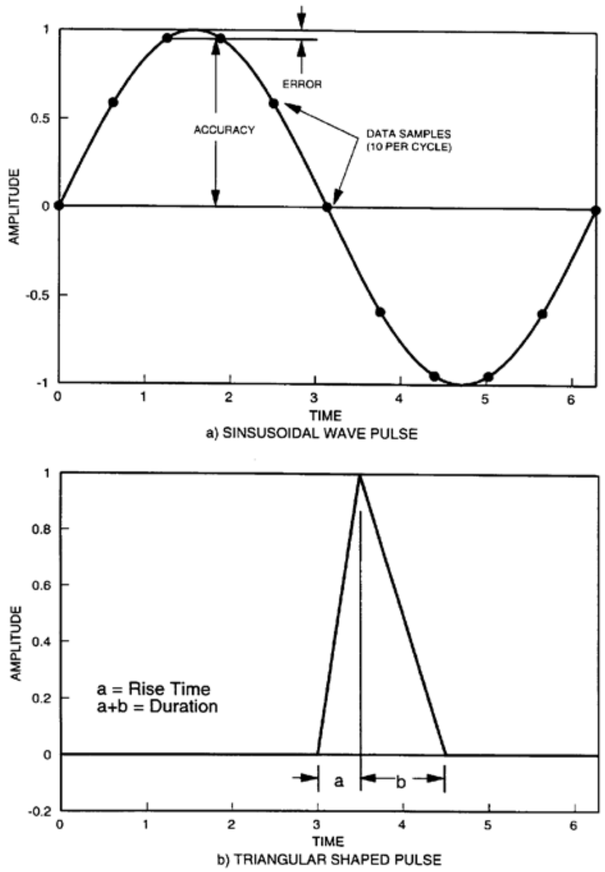


Figure 8. Examples of Loading Time Histories as Relates to Required Sample Rates (Dinsenbacher, 2010).

Part of the experiment design will be to ensure that data are collected at a sufficient rate to fully evaluate frequency content and measure maximum values. This concept is demonstrated by Figure 8. For global loads the loading will typically be cyclical in nature. Hence if the natural frequency of the "elastic" structure is known, then a sample rate adequate to minimize the error when collecting load cycles should be appropriate. A sample rate which provides a minimum of ten data points per cycle is recommended as shown in Figure 8-a.

For impulse loads, as might occur during slamming events, the collection rate should be sufficient to capture rise time and impulse maxima as approximated by the triangular loading of Figure 8-b. The collection rate should be selected to minimize the error when the data is not collected exactly at the loading peak. Dinsenbacher (2010) provides guidance for collection rates in order to collect slam events at both model and full scale.

The sample rates can be pre-calculate knowing frequencies of excitation, but in many cases the collection rates are set based upon prior knowledge and system capabilities. Given the high acquisition capabilities of modern collection systems, many collections are performed at much higher rates than needed and then parsed or filtered to create a lower effective sample rate.

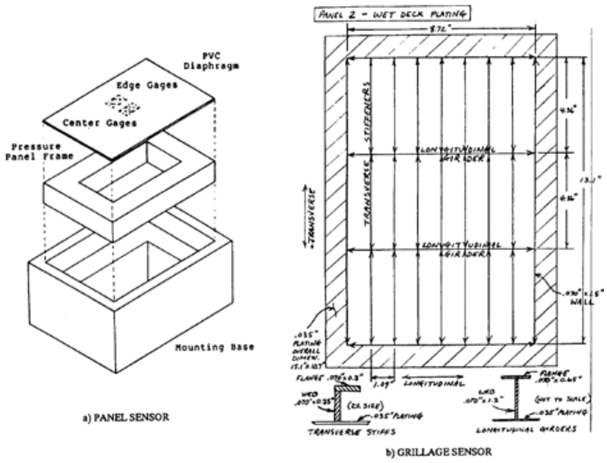


Figure 9. Example of Panel and Grillage Sensors (Dinsenbacher, 2010).

Often times when measuring global loads it is informative and in some cases necessary to also measure secondary loads to aid in the interpretation of the global loads. In some cases the secondary loads are measured with pressure sensor grids. However this method of secondary load measurement requires a rather large number of transducers and interpolation techniques to derive the pressure distribution. The preferred method for secondary load measurement uses slam panels and grillages as shown in Figure 9. The panels and grillages are normally designed to represent hull plate and stringer geometries present on the hull. The panel and grillage sensors provide a better method for getting a more accurate secondary design load. Dinsenbacher (2010) provides some rather detailed information for panel and grillage design.

## 2.10 Test Program

The test program is designed based upon the program objectives. The wave environment and the type of runs will be based on the needs developed by the test objectives. At a minimum there is a need for calm water runs at zero speed and at the speeds to be used for testing. Calm water data can be used to note hog and sag of the model at constant speed. Roll decay and maneuvers required for testing will help to quantify the measured loads from the model operating without waves. These runs can be used when interpreting the loads measured when operating in waves. With respect to regular wave and irregular wave testing, the guidance provided by the Seakeeping Experiments ITTC Procedure 7.5-02-07-02.1 is also applicable to global loads testing when defining the environment for testing.

If the test program is designed to support numerical simulations, then particular care should be taken to provide 6-DOF motions or accelerations. External propulsive and steering forces should also be characterized. Initial test conditions should be controlled and documented for best correlation.

Regular waves provide the easiest comparison to simulations and to aid in the development of transfer functions. With proper wave elevation measurements relative to the model the phase angle of the loading relative to the wave can be determined. Wavelength ($\lambda$) to ship length ($L$) ratios of 0.5 to 2.0 should be investigated. A wave steepness ratio of 1/50 ($H/\lambda$) is recommended for good linear results, however steeper waves should be considered for specific resonant and critical loading frequencies. Various headings from head to following should be considered, and speeds chosen should be based upon heading and operational scenarios.

Irregular wave tests should be performed to determine unknown resonance, obtain response amplitude operators, and provide time series data suitable for deriving long term statistics. The sea state and spectral shape to be modeled for testing is dependent upon anticipated operability requirements and load concerns. As with regular waves a range of speeds and heading should be investigated to identify response and operability concerns. Head, beam, and following headings should be performed at a minimum to provide motions which might be singularly based upon a co-linear versus orthogonal motions input. However oblique (bow) headings tend to provide a more realistic operational heading, and in some cases can provide the greatest loading, particularly with respect to torsion.

Other tests to consider are short crested seas where the water surface profile can sometimes provide a more severe loading on the hull. If short crested seas are to be considered than there will need to be sufficient definition of the target seaway and measurement of the generated seaway to verify proper modeling. This is normally defined and documented by specifying the spreading distribution of the short crested seaway.

Other testing to be considered is the collection of long total run times to verify long term estimated maxima of global loads. This is accomplished by testing for extended periods of time. For most basins this means the assimilation of individual basin passes. It is important to ensure that wavemaker repeat sequences of irregular waves are not of concern for random stochastic testing. In the event that design extreme wave conditions are known, then the design of a deterministic extreme seaway for testing might be more suitable if this can be obtained in the test facility.

## 2.11 Data Analysis

Data analysis for global loads testing centers about the effort to discern global loads information from measured strains, loads, and moments measured with the various instrumented structure. In many cases post acquisition calculations must be performed to calculate forces and moments. In some cases calibration matrices must be applied to address cross-talk and interrelation amongst measured structural response. Additionally there is also the need to separate structurally measured responses into lower frequency global hull responses as compared to higher frequency whipping and structural responses which might be present. These types of analysis and filtering are typically performed in the time domain at each time step of collected data. The low and high frequency responses can typically be separated with digital filtering, or if planned appropriately the recording of the analog channels at various stages of filtering. An example of the results of this approach is presented in Figure 10. All of these methods assume data collection has been performed at sufficiently high rates to collect all phenomena of interest.

Once the measured responses are divided into the frequencies of concern, the analysis will deviate for the two type of responses. Primary statistics, histograms, spectral analysis, and response amplitude operators can be calculate for the low frequency global components.

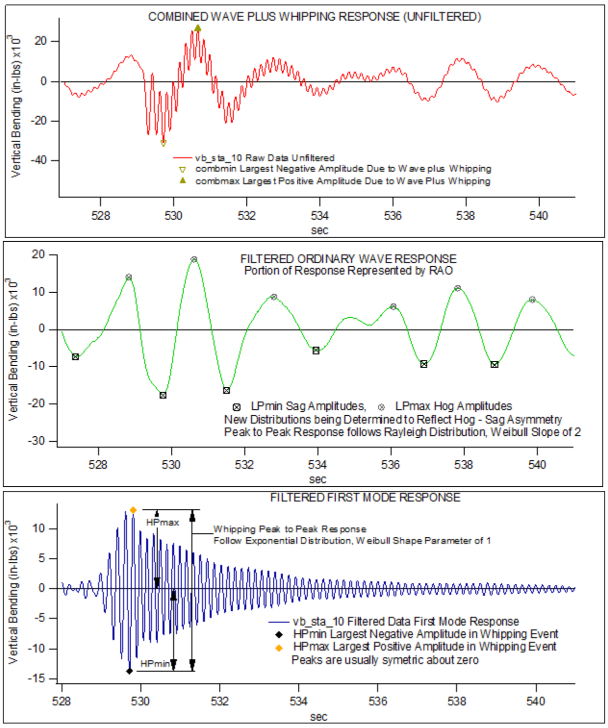


Figure 10. Example of Analysis to Filter and Arrive at First Mode and Whipping Responses (Dinsenbacher, 2010).

The short duration slamming responses will need to be analyzed with temporal analysis to determine rise time and duration of slam events. The whipping and springing motions will need to be analyzed to determine resonance and damping. Weibull and extreme value analysis can be performed on measured response event distributions and response time histories to calculate future probability and magnitudes of extremes.

## 2.12 Data Presentation

The structural data can be presented either as full scale values required for design, or as dimensionless values more suitable for comparison to other designs and computational approaches. Model scale values can be used as a way of visualizing and interpreting the results early on in the experiment, but ultimately most global loads results are needed at a level beyond this early analysis. The global loads data must be taken from the measurement level of strain and transducers values to overall hull loads such as shear, moment, and torsion which are required in the hull design. These overall design loads can then be made non-dimensional using the representation provided by Dinsenbacher (2010) in Table 2.

These results can then be presented as operational cyclical loads (i.e. for fatigue analysis) or anticipated maximum values anticipated based upon seaway conditions, heading, and speed. Extreme value theory and other lifetime design statistics can also be applied to establish the maximum load which should be used in the ship design.

### 2.13 Comparison to Predictions and Numerical Simulation

When comparing predictions to numerical simulations, this can be performed by looking at the magnitude of the interested parameters, or by looking at the loads and motions in either the frequency or the time domain. The mode of comparison is dependent upon the nature and output type of the numerical simulation. If the results of the simulation are output in the frequency domain then the comparison should most likely be performed in non-dimensional frequency coordinates. If specific time domain seaways are modeled, than either the time domain responses and loads in the time domain can be compared or statistical evaluation of the time domain results may be compared. In all instances the measured wave should be used as input to the simulation to ensure better comparison for irregular waves. When comparing the experimental and computed results the uncertainties associated with each should be defined to allow proper comparison.

Table 2. Dimensionless Representation of Key Parameters (Dinsenbacher, 2010).

| QUANTITY | DIMENSIONLESS COEFFICIENT |
|---|---|
| Bending Moment ( $M$ ) | $C_M = \frac{M}{h_W \rho g L_S^2 B} = \frac{\sqrt{RAO_M}}{\rho g L_S^2 B}$ |
| Shear Force ( $V$ ) | $C_V = \frac{V}{h_W \rho g L_S B} = \frac{\sqrt{RAO_V}}{\rho g L_S B}$ |
| Torsion Moment ( $T$ ) | $C_T = \frac{T}{h_W \rho g L_S^2 B} = \frac{\sqrt{RAO_T}}{\rho g L_S^2 B}$ |
| Pressure ( $p$ ) | $C_P = \frac{p}{h_W \rho g} = \frac{\sqrt{RAO_p}}{\rho g}$ |
| Pitch Angle ( $\theta$ ) | $C_\theta = \frac{\theta}{\left(2h_W \pi / L_W\right)} = \frac{\sqrt{RAO_\theta}}{2\pi / L_W} = \frac{\sqrt{RAO_\theta}}{k}$ |
| Heave Displacement ( $z$ ) | $C_Z = \frac{z}{h_W} = \sqrt{RAO_z}$ |
| Roll Angle ( $\phi$ ) | $C_\phi = \frac{\phi}{\left(2h_W \pi / L_W\right)} = \frac{\sqrt{RAO_\phi}}{2\pi / L_W} = \frac{\sqrt{RAO_\phi}}{k}$ |
| Sway Displacement ( $y$ ) | $C_y = \frac{y}{h_W} = \sqrt{RAO_y}$ |
| Surge Displacement ( $x$ ) | $C_x = \frac{x}{h_W} = \sqrt{RAO_x}$ |
| Yaw Angle ( $\psi$ ) | $C_\psi = \frac{\Psi}{\left(2h_W \pi / L_W\right)} = \frac{\sqrt{RAO_\psi}}{2\pi / L_W} = \frac{\sqrt{RAO_\psi}}{k}$ |
| Acceleration ( $a$ ) | $C_a = \frac{a}{\left(h_W g / L_S\right)} = \frac{\sqrt{RAO_a}}{g / L_S}$ |
| Deflection ( $\delta$ ) | $C_\delta = \frac{\delta}{h_W} = \sqrt{RAO_\delta}$ |

Note that in the table the dimensional response is in all cases assumed to be peak to peak. In addition to symbols already defined, $k$ is the wave number, $2\pi / L_W$ .

## 3. PARAMETER

### 3.1 Parameters to be Taken into Account

The following parameters defining the tests are to be taken into account and documented (as applicable):

- Scale
- Model dimensions
- Ratios of model to tank dimensions
- Hull configuration (lines, appendages, superstructures, ...)
- Loading conditions
- Mass distribution (COG, inertias, ...)
- Speeds and headings
- Towing and/or restraining device characteristics (specially DOF)

- 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, encountered wave, ...)
- Natural frequencies and damping characteristics of the elastic model
- Sampling frequency
- Sensor calibrations and accuracy
- Rigidity distribution and height of neutral axis of the elastic model
- Rigidity and damping characteristics of strength bar, or connections used for segmented models

### 3.2 Recommendation of ITTC for Parameters

In addition to the above listed parameters, a sufficient definition of the model design should be provided. The type of global loads testing, and assumptions made during the experiment design should be documented. The experiment documentation should provide any background relative to the experiment and model design which will aid in the future interpretation and correlation to the experimentally collected data.

## 4. VALIDATION

The global loads seakeeping test can become rather complex. The best way to maintain validity across the whole of the experiment is to verify the validity of the intermediate steps. This is accomplished by maintaining accuracies and controls across the experiment design, model and instrument design and fabrication, ballasting and geometric definitions, wave environment, experimental performance, and data collection and analysis techniques. These intermediate steps have been briefly described in the procedure. To maintain and verify validity of the test, the experimenter must maintain, define, and document validity at the intermediate steps.

### 4.1 Uncertainty Analysis

Uncertainty analysis for the experiment should be performed per the recommendations of ITTC Procedure 7.5-02 07-02.1 (Appendix A), following the ISO-GUM 1995 guidelines. Most of the examples and techniques apply equally well to global loads experiments with variations as required to accommodate structural calibrations and measurements.

### 4.2 References

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## 4.3 Benchmark Tests

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