1 Seakeeping Model Tests

1.1 General considerations on model tests

Sea state model tests are expensive compared to other model tests due to the longer waiting period until the water surface is calm and because of the numerousness of parameters to be varied (wave lenght, wave height, angle of encounter, ship speed, hydrostatics, stability and so on). Therefore such tests are normally only carried out to investigate effects which are not easily accessible to computation. The following questions may be adressed with model tests:

- Determination of roll damping
- Determination of non-linear motion
- Slamming and local loads
- Shipping of green water
- Capsizing of intact ships
- Capsizing of damaged ships

Such tests are mostly carried out with self-propelled models. They are usually free sailing, steered by automatical or hand-operated rudder machines. In some cases captive models are used which are guided by levers or wires. Correspondingly some degrees of freedom are inhibited.
As for any other type of model test like resistance and propulsion tests the scale and effects due to it have to be considered.
Model geometry is easily converted by the scale factor λ. A geometrically similar wave has a phase velocity which scales with $\sqrt{\lambda}$ $\left(\Rightarrow \sqrt{\lambda} = \frac{c_{Full-scale}}{c_{Model}}\right)$ and hence a wave frequency which scales with $\frac{1}{\sqrt{\lambda}}$ $\left(\Rightarrow \frac{1}{\sqrt{\lambda}} = \frac{\omega_{Full-scale}}{\omega_{Model}}\right)$. The gravity forces scale with a factor λ^3 $\left(\Rightarrow \lambda^3 = \frac{F_{Full-scale}}{F_{Model}}\right)$. The accelerations from harmonic motion with the same amplitude are similar for model and ship as the mass scales with $\lambda^3 = \frac{m_{Full-scale}}{m_{Model}}$. The ratio between gravity and inertia force is equal for model and ship. The period of the oscillations as well as the time the ship needs to travel its own lenght are the $\sqrt{\lambda}$ longer for the ship $\left(\sqrt{\lambda} = \frac{t_{Full-scale}}{t_{Model}}\right)$. Thus videos taken during model tests must be shown in slow motion $\left(\frac{1}{\sqrt{\lambda}}\ slower\right)$ to have the same appearance as for the ship.
Finally the different densities of sea water and tank water have to be taken into account in all calculations of course.

1.2 Test facilities

There are mainly two different types of model basins used for seakeeping investigations, represented by the following examples:

- HSVA, Hamburg
  The Hamburg Ship Model Basin (HSVA) tank is a long and relatively narrow tank. Figure 1 shows a sketch of the large HSVA tank with its main dimensions and its devices: The trim tank is the part of the towing tank where the models

are trimmed by adding weights to adjust a certain draft and trim. The main carriage is a moving waggon to tow the model with up to $10.0\frac{m}{s}$ and to carry measuring instruments. The Computerized Planar Motion Carriage (CPMC) is a device for manoeuvring tests. It offers two different operating modes, the captive (model fixed in some degrees of freedom) and the tracking mode (free model).

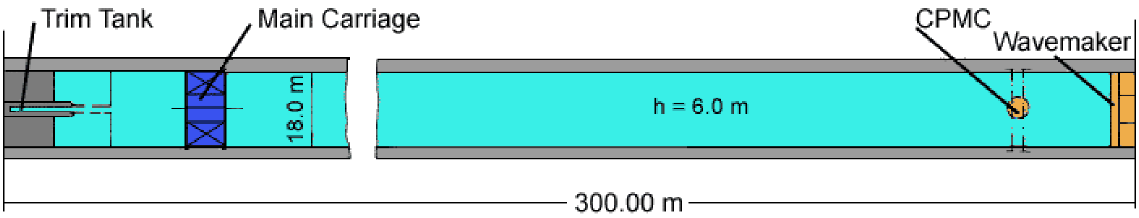

Figure 1: Large HSVA Towing Tank

On the right hand side of the sketch the wavemaker is labelled. It is a double flap wavemaker which means that two flaps of same height are mounted one upon the other. The lower flap is bedded turnably on a basement about two meters below the waterline while the upper is seated on top, connected by a hinge. This configuration allows to approximate the amplitudes of the horizontal component of the orbital velocity as they decrease downward by e^{-kz}. If the chosen wave lenght λ is relatively small (that means: k is large) only the upper flap moves. To generate irregular seaways the motions corresponding to many individual waves are superimposed.
The wave amplitudes are chosen according to the seaway spectrum that is to be reprensented as the square root of the area under the spectrum in a certain frequency interval is a measure for the amplitude (see formula (47), page 36). Further the phases are randomly chosen. Amplitudes and phases together are used to perform an inverse Fourier Transformation. Finally the obtained parameters are transformed by the tranfer function of the wavemaker. The maximum irregular wave height for the HSVA wavemaker is about $H_{\frac{1}{3}} = 0,5m$, limited by the maximum flap angle and the power of the hydraulic system.
In some tanks another type of wavemaker is used. For example in the smaller tank at HSVA a plunger (a corpus which radiates waves by being vertically sub- and emerged, see figure 2) is installed.

Figure 2: Plunger of the small HSVA Towing Tank

All seakeaping test tanks have to have a rectangular cross section as inclined or round shaped sidewalls would influence the waves! On the opposite side of the wavemaker a "beach" is needed to absorb the waves as completely as possible. Otherwise the waiting time mentioned above would increase.

- MARINTEK, Norway
  The tank at MARINTEK has got a more rectangular shape with an aspect ratio of about 1 : 1.5, as shown in picture 3. Waves are generated by a multi flap wavemaker along the longer side and a double flap wave make along the shorter side of the tank. The latter works as described above, whereas "multi flap" means that flaps of about 40 cm width along the wall are activated individually. A phase shift between the actuation of each flap enables different wave propagation directions. There is another tank of this type at MARIN, Netherlands, which is even bigger.

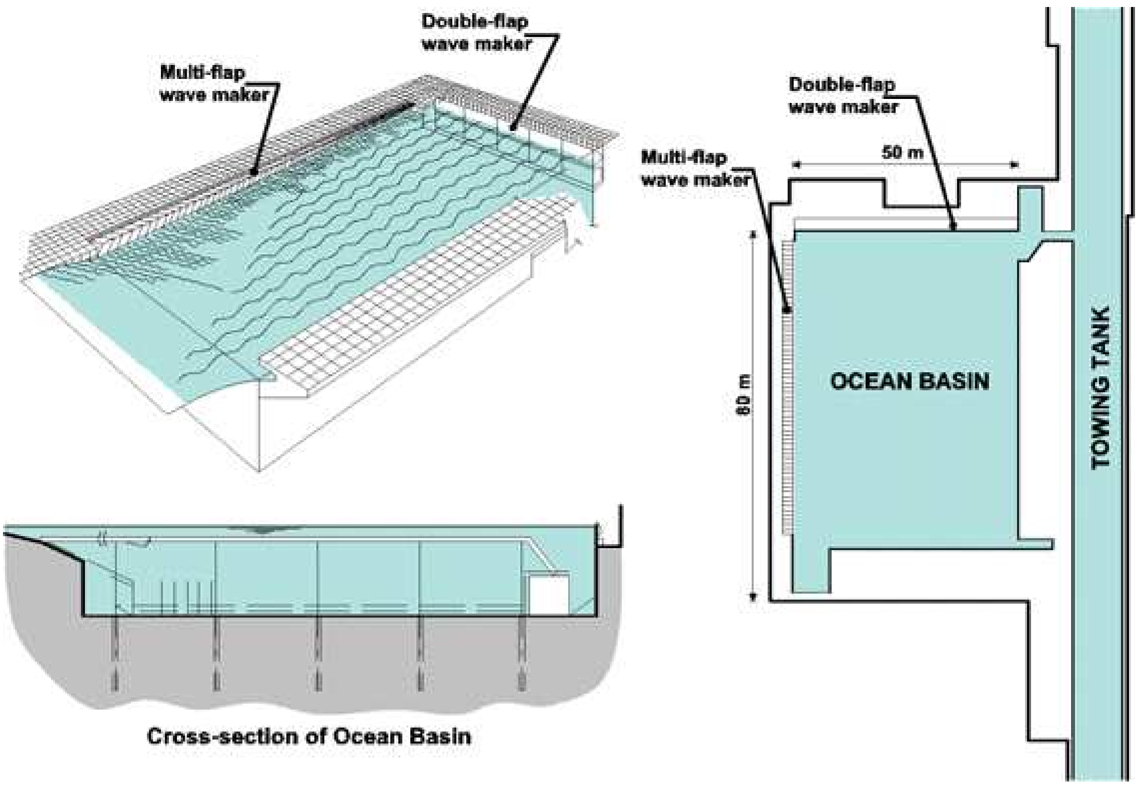

Figure 3: Seakeeping Tank at MARINTEK

Comparing these two concepts of seakeeping test model basins, it has to be pointed out that both concepts have got advantages: The more longish tanks as the one at HSVA allow relatively long measurement times what is especially important for measurements in irregular waves. However only small deviations of the angle of encounter from $\mu = 0°$ or $\mu = 180°$ can be tested for non-zero speed.
The more rectangular type offers the possibility to create short crested waves. The main disadvantage is the relatively short measuring length. To increase measuring time one has to choose smaller models. In this case other disadvantages appear like scale effects or even capillary waves. Also two different models for resistance and propulsion tests and for seakeeping tests become necessary.

1.3 Measuring instruments

As the interaction of waves and ships (models) are a major concern of seakeeping tests both the deflection of the water surface and the ship's (model's) motion have to be measured.

1.3.1 Wave height and relative motion

Wave probes record either the absolute water surface deflection viewed from the carriage or the relative motion viewed from the model. The two common types of wave probes, acoustical and resistive probes (see figure 4), are described in the following. A third type, capacitive wave probes, are mentioned shortly.

- Acoustical wave probes
  Acoustical wave probes work like an echo sounder: Ultrasonic sound is emitted by a transmitter shown on the left hand side of picture 4. The signal reflected from the water surface is received by the same device, the run-time between sending and receiving the signal is recorded. Then the distance D between the probe and the water surface equals to half of the product of sound velocity c and the run-time t: $D = \frac{1}{2} \cdot c \cdot t$
  In this manner the wave height can easily be calculated. However if waves are too steep not the vertical distance between sounder and water surface is measured but the shortest and the echo might become too weak.

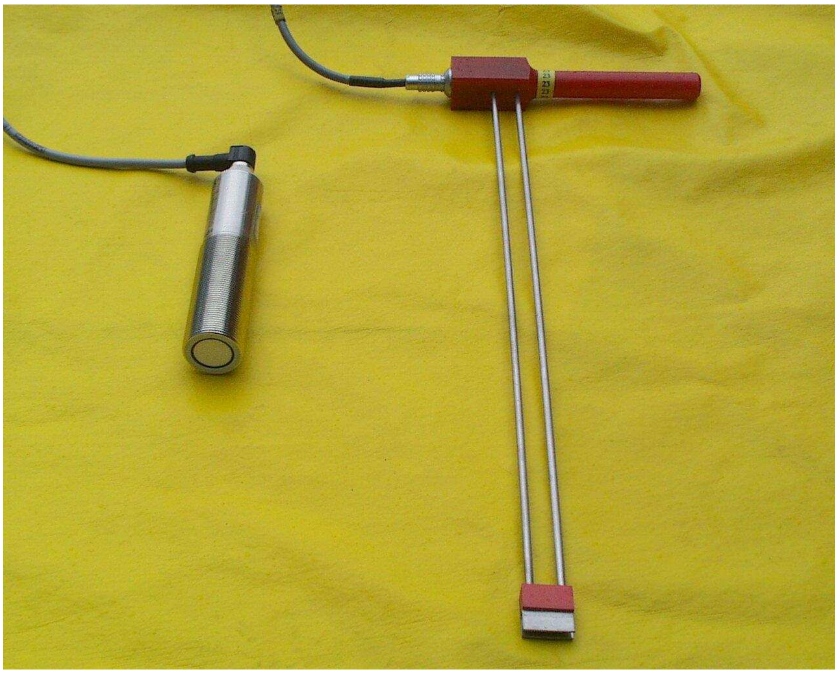

Figure 4: Acoustical (left) and resistive (right) wave probe

- Resistive wave probes
  On the right hand side of picture 4 a resistive wave probe is shown. An AC voltage is impressed on two wires. Depending on the water level the wires are wetted up to a certain height. The resistance measured between the wires changes according to this height. Hence the water level can be calculated from the resistance measured and the known conductivity of the water. If another

medium than fresh water is choosen, the device has to be adjusted differently due to the different conductivity.
A disadvantage is the calibration required before each use because of the dependency on the temperature. Furthermore especially at high speed the wires of the probe superimpose a small wave system and cause spray which affects the measurement negatively.
Figure 5 shows a resistive wave probe mounted in front of the the bow of a model. Relative motion between model and water surface can be measured that way. The angle of the device has to be considered. In this case the model of a damaged ship is drifting freely so that only little disturbance from the wires is expected.

Figure 5: Resistive wave probe mounted in front of a model's bow

- Capacitive wave probes
  There is a third type of wave probes, the capacitive type. An insulated conductor will be mounted on the carriage. The water is used as the opposite conductor “plate”. Together they work as an capacitor. Any change in the water level would change the dielectric effect between the plates, which is then measured. Disadvantageous is the relatively big distance between conductor and water surface that is required.
  This kind of method is very popular for the determination of the fill level of tanks as an arbitrary liquid can be checked.

1.3.2 Recording of ship motion

Stereo cameras

Ship motions during seakeeping or manoeuvrering tests can be recorded via stereo cameras. For that purpose three linear high resolution cameras are mounted in a box on the carriage (figure 6). "Linear" stands for a filtering technique: One camera traces the vertical, the other two the horizontal position of defined objects which are positioned on a frame on the model. These objects are typically white balls (passive system) or lights (more precisely: light emitting diodes, figure 7; active system).
Two horizontally orientated cameras are necessary to get a three-dimensional view as the vertical camera registrates only signals in one vertical plane. In this manner the viewed points are measured in a spherical coordinate system. Afterwards the positions are converted into a cartesian coordinate system.
In case of the passive system the three defined objects are tracked as long as they do not conceal each other. If this happens the user has to intervene. Using an active system the emitter (diodes) and the receiver (cameras) are coupled by an electronic system: The diodes shine one after the other so that the processor "knows" which diode emittes light even if it is hidden. Therefore the active type is suitable for absolutely free models.

Figure 6: Stereo cameras

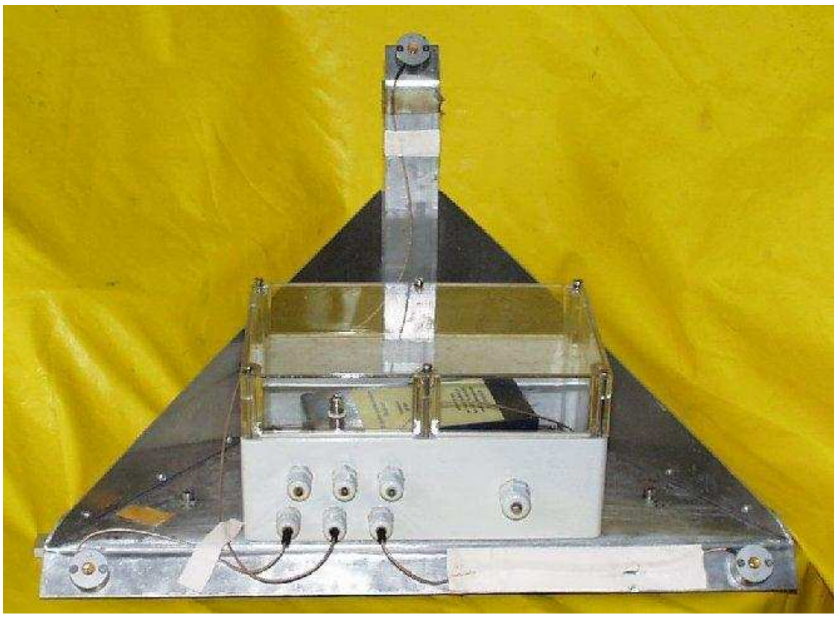

Figure 7: Installation of light emitting diodes

Gyroscopes

Another method to record ship motions is to use a gyroscope. Traditionally mechanical types were deployed, today electronical types are available. Mechanical gyroscopes measure the three angles of motion and additionally contain gyro-stabilised platforms with three orthogonally arranged accelerometers. Because of the stabilised platforms the accelerations are measured in the earth-fixed coodinate system.
The electronic system used for the Laboratory on Naval Architecture ("Schiffbaulabor") at TUHH is called Inertial Vertical Reference Unit (iVRU, see picture 8). It contains three accelerometers for measuring accelerations along the three axis (a_x, a_y, a_z) and three fiber optic gyroscopes (FOG) serving for measuring absolute rotational speeds $(\dot{\varphi}_x,\ \dot{\varphi}_y,\ \dot{\varphi}_z)$, see figure 9. The unit can internally convert the rotational rates into angles of rotation $(\varphi_x,\ \varphi_y,\ \varphi_z)$. As the accelerometers are not connected to stabilised platforms like in the mechanical system the accelerations are measured model-fixed. For further information about the function of the FOG see for example: www.ite.uni-karlsruhe.de → Arbeitsgebiete → Faseroptische Rotationssensoren (FOG).

Figure 8: Inertial Measurement Unit used in Laboratory on Naval Architecture at TUHH

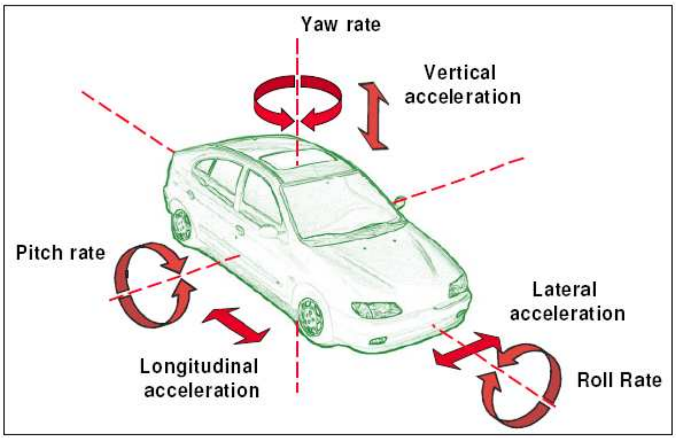

Figure 9: Magnitudes measured by the Inertial Measurement Unit

1.4 Some typical model tests and their intentions

1.4.1 Experimental determination of roll damping

Predicting the intensity of roll motion is important to assure a safe ship operation. Large roll motions can occur due to parametric roll in following or head seas which cannot be calculated by the (linear) methods introduced in this lecture. Instead model tests or time domain simulations are used. For these simulations and also for the linear frequency domain calculations discussed in this lecture the roll damping which is mainly not caused by the radiated waves is difficult to determine. Therefore special model tests using a pair of rotating masses (figure 10) to generate an exciting moment are carried out to determine the damping coefficient at resonance.

Figure 10: Counterrotating masses for roll damping test within a ship model

A further model test concerning roll motion and non-linear effects is the roll decay test: The model is heeled to a certain angle. After releasing the model the amplitudes of roll motion are measured. Then the damping follows from the difference between two successive amplitudes.

1.4.2 Slamming and local loads

As mentioned before, slamming can cause serious damages of the ship structure. To predict the loads due to slamming model tests are carried out. It is possible to use pressure probes installed in small holes. A preparation for the installation of such pressure probes is shown in picture 11.
In this case stern slamming was examined. The oval shaped holes show the locations where the pod drives are about to be mounted whereas the circular holes are for the probes to measure the force (means pressure per area), which scales better. For the analysis of the measured values one has to take into account that the wooden model is more rigid compared to the real ship structure so that the pressures are overestimated.

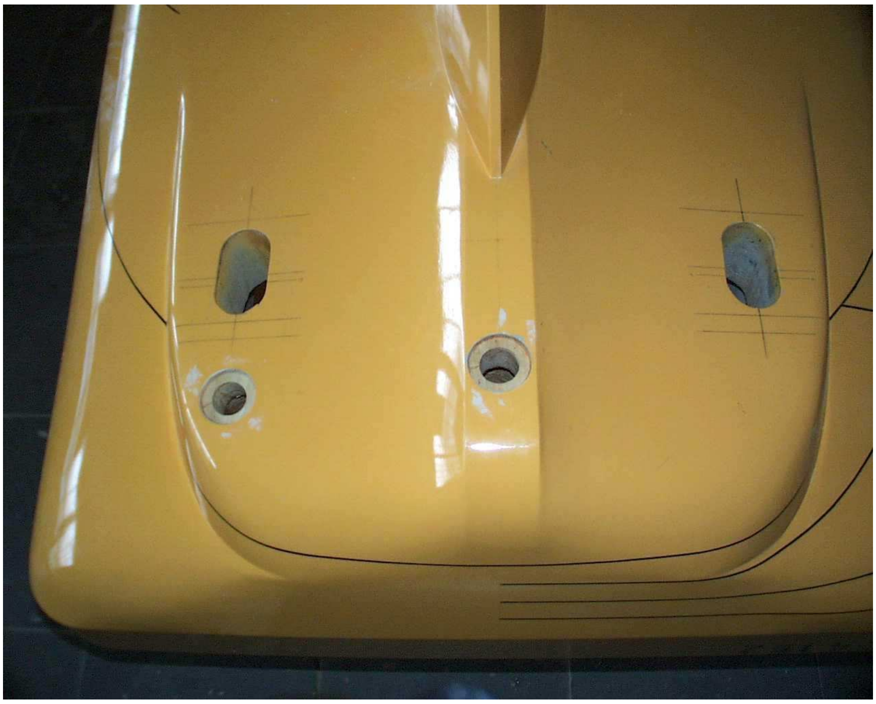

Figure 11: Holes for pressure probes (circular) and pods (oval)

For another test a part of the aftship was fitted with force transducers. Forces measured by this arrangement are shown in the graph in figure 12.

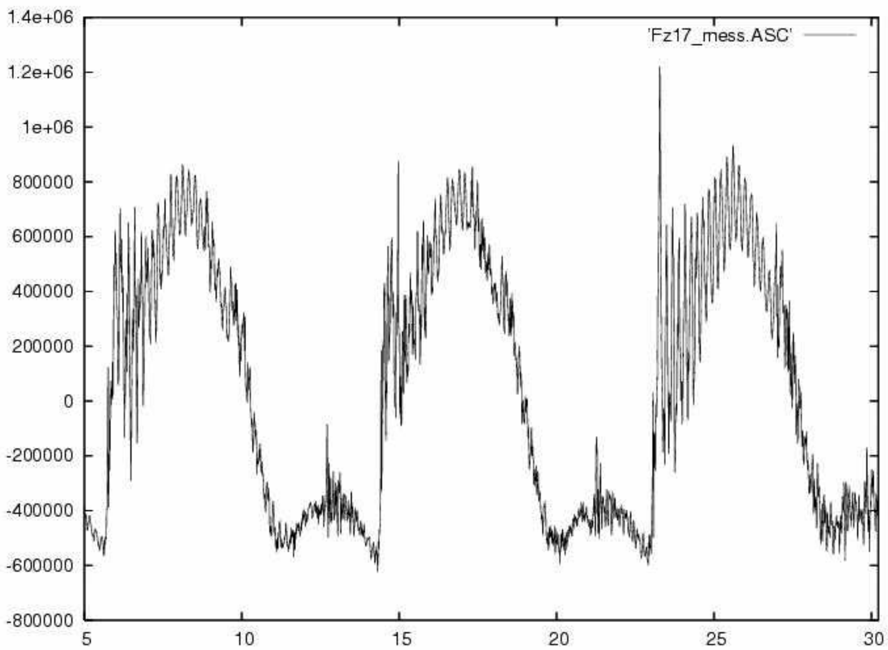

Figure 12: Record of force over time due to three slamming events

The diagram shows the vertical force as a function of time. The force is not linearly depending on the motions or the wave. The peaks ($t = 6, 15, 23, ...$) are aroused by slamming events which cause vibrations of the model and thus oscillating mass forces in the force transducers.

With regard to the excitation of the lower bending nodes (see lecture "Schiffsvibrationen") the momentum of the slamming event seems to be the relevant quantity. Figure 13 shows the area that is integrated for one slamming event. From the evaluation of tests in irregular seas probability distributions of momentum can be found and compared for alternative designs.

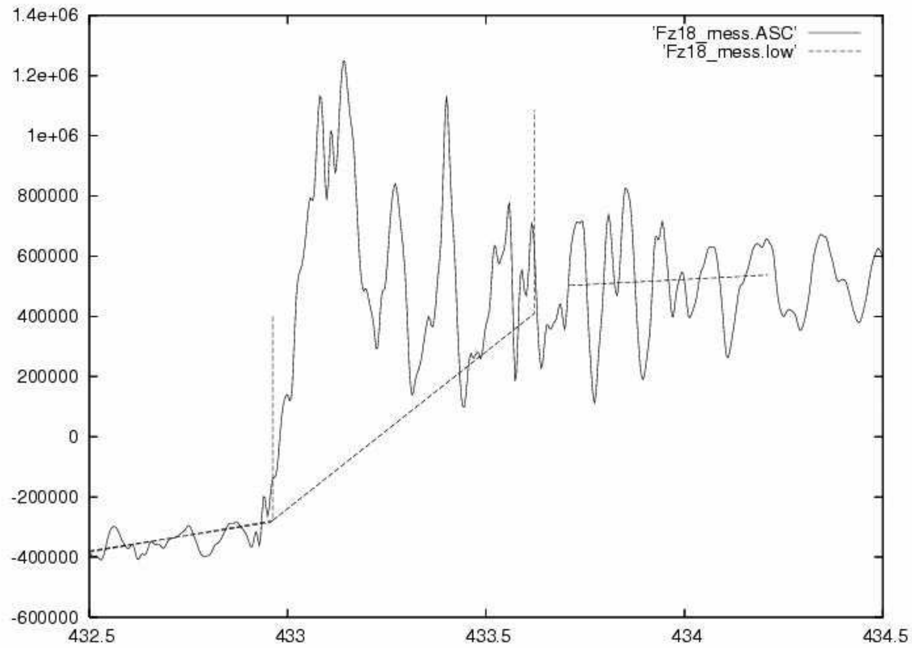

Figure 13: Momentum due to one slamming event (integrated from force)

This type of model test is expensive but on the other hand the only way to compare different hullforms regarding their slamming behaviour.

1.4.3 Shipping of green water

Shipping of green water is uncritical as long as all doors and hatches above freeboard deck are watertight or at least weathertight. The situation is different for an open top design - that means some of the holds have no hatch covers - which is more and more common for container vessels of about 1000 to 2500 TEU. In this case one has to consider the amount of water coming on deck due to seaway as water in the cargo holds has to be avoided because it effects the stability of the ship negatively, the metacentric height will decrease. According to international and classification regulations the capacity of the pumps installed in the holds has to be greater than the water intake. The size of the pumps is generally chosen to be capable of removing heavy tropical rain fall so that the water intake due to waves must not be greater. Measurements are carried out as shown in picture 14 to approve the capacity of the pumps.
If the water intake is too big ship design, freeboard or the shape of the wave breakers have to be changed. Generally head or following sea are the most severe cases, not beam sea.

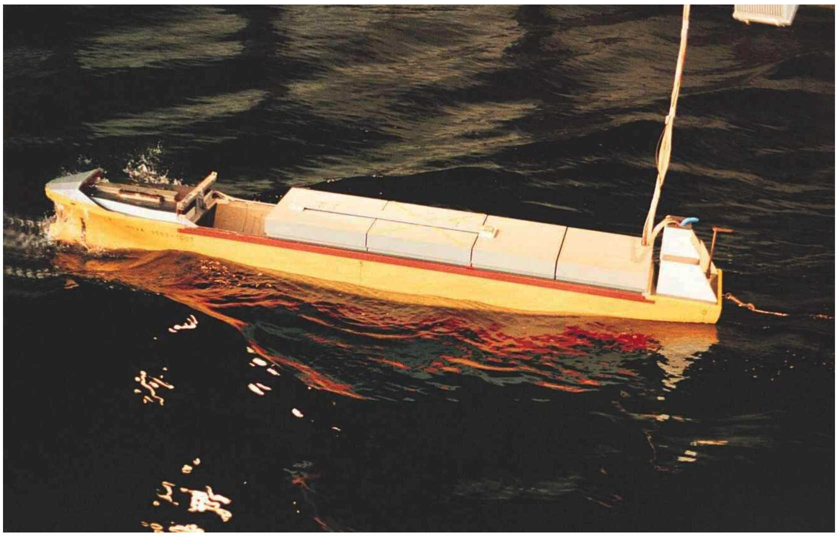

Figure 14: Open top container vessel with shipping of green water

1.4.4 Capsizing of intact ships

Not only damaged but even intact ships capsize due to waves coming from certain directions. Waves need not necessarily to be extremely high to cause capsizing if we consider for example parametric roll as mentioned above. Model tests help to research which combinations of wave lenghts, heights and periods and which angles of encounter might be critical.
Picture 15 illustrates a RoRo-vessel capsizing in following sea. On the deck a frame with light emitting diodes mentioned above (motion recording via stereo cameras, active system) can be spotted.

Figure 15: Capsizing of an intact RoRo vessel

1.4.5 Capsizing of damaged ships

The stability of damaged ships can be researched by appropriate model tests for example for a damaged RoRo ship corresponding to the Stockholm Agreement, see figure 16.

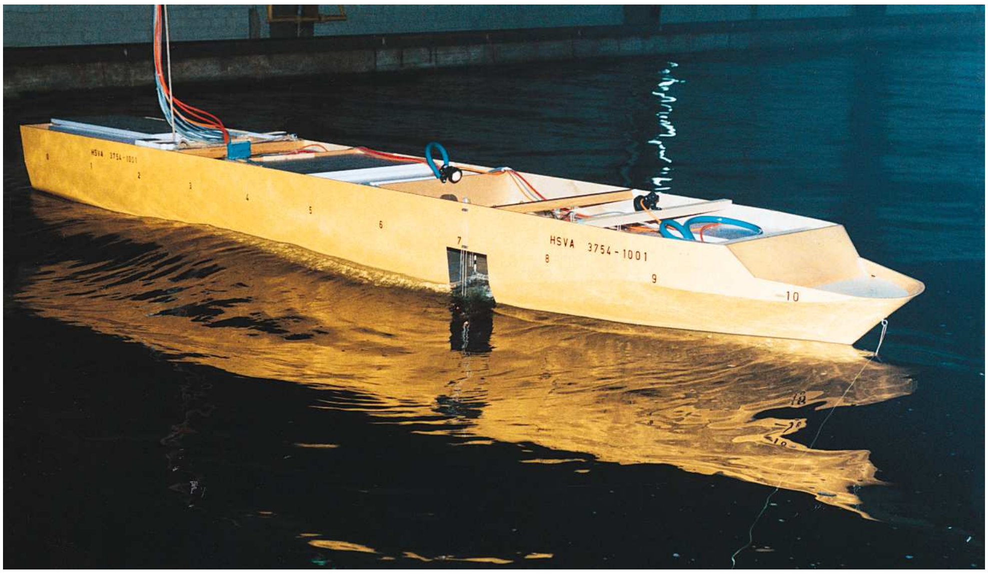

Figure 16: Damaged RoRo vessel

The dimensions of the leak and the ratio between width and penetration depth are prescribed. The test objective is to find a configuration of bulkheads and compartments so that stability is ensured for certain leaks. On closer inspection a capacitive wave probe as mentioned above can be recognised at the entrance of the leak.