Seakeeping Simulations and Seaway Models and Parameters  
Supporting Ship Design and Operation

Heike Cramer¹, Konstanze Reichert², Katrin Hessner², Janou Hennig³, Günther F. Clauss³
¹ Flensburger Schiffbau-Gesellschaft  
Flensburg, Germany  
² OceanWaveS  
Lüneburg, Germany  
³ Technische Universität Berlin  
Berlin, Germany

Abstract

All three ship design, ship approval and ship operation determine the safety of a vessel in rough conditions. Now while designing as much seaworthiness as economically possible into a ship from the start provides the best basis for safe operation, it alone is not enough. Experience from ship operation shows, that the safety of a vessel and its crew relies strongly on the ability of the crew to judge the vessels performance and its limits. This paper summarizes developments within the German BMBF-funded project SinSee where one goal is to more closely link numerical assessments, model tests and real environmental data.

Keywords

Safety, seakeeping, motion simulation, deterministic wave groups, wave radar, decision support

Introduction

In today’s highly competitive environment ship designs change very rapidly. Especially in areas where the design process is supported by advanced design and analysis tools which are available for application worldwide today, e.g. CFD-optimization or FEM-Analysis used either by the yards themselves or being accessed through subsuppliers. Consequently also the seakeeping characteristics of modern vessels change and thus it is increasingly difficult for the crew to identify and judge possibly dangerous environmental conditions correctly. Typical problems are large container ships being susceptible to parametric rolling and/or pure loss of stability, Ferries and Cruise ships suffering from very short roll periods and/or high accelerations and the like. Still, sea keeping assessments and characteristics are usually not included in the building contract and developments to introduce more suitable assessments of ship dynamics in rules and regulations will take some more years.

Available means to investigate the sea keeping performance of vessels are numerical simulations and/or model tests. Many examples show, that today’s tools and procedures in these areas are well suited to investigate accidents [3], [6]. With respect to design optimization it can furthermore be demonstrated that the consequent application of numerical investigations in the early design phase allows to efficiently improved in the design performance with respect to intact safety [2]. But what is lacking are standards with respect to such evaluations.

With respect to ship operation – obviously valuable data is available or can be generated, which can be used as a basis to compile information for decision making in ship operation. But ways need to be developed of how to present these information in the most pragmatic and useful way. And again standards defining minimum requirements with respect to significance and reliability are lacking. Furthermore it is well known that seaway parameters such as the significant wave height and the peak period are difficult to impossible to estimate visually from on board a ship. But especially the peak period is the basic information needed to identify possibly dangerous combinations of ship speed and encounter angle with respect to any roll resonance problems.

Within the project SinSee, funded by the German BMBF, a full-scale measurement system is developed and tested which will allow a simultaneous measurement of ship reactions and the belonging environmental conditions. Basis for the measurement of the seaway is the sea-clutter data from a standard X-band marine radar. The Wave Monitoring System
WAfMoS was developed to determine the directional wave spectrum and all derived sea state parameters in real time from these radar images.

While in SinSee the focus is on the development of a full-scale measurement system, with the data to be used for validation purposes and the system being available for future long-term measurements, components could also be used as a basis for the development of decision support systems.

With respect to the validation of numerical tools – the main basis for the validation are scaled model tests. Within SinSee computer controlled model test techniques are used and further developed to allow for more detailed studies of dangerous phenomena in model testing on the one hand, and the generation of synchronized data for waves and ship motions for validation purposes on the other. Model tests are quite intense with respect to time and costs, thus the test conditions should be well chosen. With respect to dangerous roll angles two conditions are of major interest: 1. The performance of the vessel in resonance conditions (not necessarily extreme), 2. the performance of the vessel in extreme conditions. Based on the tests from the Roll-S project, quite some experience is available for the modelling of extreme conditions, e.g. extreme wave groups embedded in regular or random seaways. When assessing resonance phenomena the testing condition need to be tuned to the individual ship characteristics. For the latest test series numerical simulations were successfully used to pre-select interesting conditions. This new approach will be further developed. Based on these findings further developments are planned to also re-model conditions measured in full scale in numerical or tank environments.

These links between numerical simulations, model tests and full scale measurements are vital for the further development of safer ships and as basis for future decision support systems.

Numerical assessments

Several numerical motion simulation programs exist worldwide ranging from rather simplified linearized tools to sophisticated non-linear tools. All simulation methods use underlying assumptions in their mathematical model, in order to reduce the computing time. Still some of the highly non-linear methods have longer computing times than simulated time, which strongly reduces their practical applicability for safety assessments. For practical applications (i.e. safety assessments, design evaluations, etc.) often specialized tools are in use.

All numerical simulation programs require a thorough validation of their results and have restrictions regarding their applicability depending on the underlying assumptions and models. Unfortunately no common criteria and methods for quality and accuracy control exist.

In SinSee three goals are targeted with respect to numerical simulations:

1. dedicated model tests are carried out in order to produce reliable and suitable data for the validation of numerical methods. For the validations purpose as such different approaches are used to identify different weaknesses (i.e. in the wave or force model respectively).

2. existing numerical tools are being further developed based on the findings. These models are developed to support the ship design process, therefore it is necessary that the numerical tools are fast and robust at sufficient reliability.

3. methodologies are being developed to assess the safety of ship’s with respect to intact stability. Results from this part of the project are also presented at this conference by Krüger et al.

Design evaluation and optimization based on numerical simulations

In order to improve the sea keeping characteristics of a design it is important to identify, evaluate and understand the deficiencies a design might have. Fig. 1 shows a plot of the roll angle and the wave elevation versus time, of a situation where a container ship encounters extreme angles of roll due to parametric excitation.

![Figure 1: Roll angle and wave elevation versus time for a containership encountering parametric excitation](image)

Such detailed simulations are used to study the phenomena endangering the respective vessel in detail and develop possible design alternatives. While for design comparisons and the evaluation of the ship’s seakeeping performance usually the results from numerous simulations are summarized in polar plots.
Here the focus is not necessarily only on capsizing or the occurrence of extreme angles of roll, but (depending on the transport task of the vessel) also on accelerations, the efficiency of roll stabilizing systems, etc. Fig. 4 shows examples for such diagrams with respect to the danger of sliding of unlashed cars.

**Deterministic wave sequences for model testing**

While numerical investigations are very useful to evaluate a design’s performance, further developments especially with respect to the validation of the prediction of combined failures (e.g. combinations of stability loss, surf-riding and broaching to) and some basic assumptions (e.g. with respect to roll damping) are necessary. The most efficient way to investigate these gaps are model tests. Additionally in discussions with authorities today, usually only model tests are accepted.

Thus it is necessary to adequately model the environmental conditions in the tank. For achieving this a computer controlled test procedure in combination with the deterministic generation of arbitrary (dangerous) wave sequences has been developed.

As a first step, a target wave sequence is chosen as time series at a target position in time and space — i.e. the position where the ship encounters the wave train at a given time. This can either be a wave sequence from the numerical simulation of a rolling/capsizing scenario or an arbitrary rogue wave sequence.

This wave train is transformed upstream to the position of the wave maker wherefore different approaches for modelling non-linear wave propagation are applied [1]. The corresponding control signals for driving the wave maker are calculated using adequate transfer functions. The resulting wave train is generated and measured at the selected positions in the tank. The ship model arrives at the target position by the corresponding target time (measured from the beginning of wave generation). This is achieved by the fully automated test procedure at the Hamburg Ship Model Basin [4]:

The ship moves in parallel with the tank side wall at a required minimum distance. Registration starts by setting the desired course. The ship’s course is controlled by the master computer by telemetry which commands a Z-manoeuvre at given constant course angle and model velocity. Ship motions in six degrees of freedom are registered precisely by computer controlled guidance of both, the towing and the horizontal carriage: During the entire test run, the ship model stays in the field of vision of the optical system line cameras. Additionally, the wave train is measured at several fixed positions of the wave tank. When the model reaches the critical safety limit at the wave maker or the absorbers at the opposite side of the tank, the ship and the carriage stops automatically.

Thus, the test is realized by a deterministic course of test events which allows a reproducible correlation of wave excitation and ship motion - both as time series in the moving reference frame of the ship. As an example, Fig. 2 shows a test with a multipurpose vessel. A wave packet within a regular wave is measured at a stationary wave probe close to the wave board ($x = 297.8$ m, model scale 1:34). It is transformed to the ship position shown in the second picture i.e. in the moving reference frame wave train. The resulting wave sequence is quite regular and contains the target rogue wave at the location of interaction with the cruising ship. As a result, the ship behaves inconspicuously until it encounters the high transient wave. For obtaining such an apparently simple wave train in the moving frame (compare wave registration close to the main board), the described wave generation technique and test procedure are applied. Thus, the ship behaviour can be clearly related to the wave sequence.

![Figure 2: Roll motion of a multipurpose vessel](image-url)

**Figure 2**: Roll motion of a multipurpose vessel ($GM = 0.44$ m, $v = 14.8$ kn und $\mu = \pm 20^\circ$) in a regular wave from astern ($\lambda = 159.5$ m, $\zeta_{crest} = 5.8$ m) with proceeding high transient wave packet.
Model tests are rather expensive and time consuming. Thus, especially when testing in irregular seas, the test conditions should be well chosen. Within SinSee numerical investigations were used to identify interesting conditions with respect to resonance phenomena for the latest series of tests. Numerous simulations in following and head seas were run and evaluated. Some of the most interesting or typical examples with respect to parametric excitation as well as pure loss of stability were chosen as test cases. Corresponding model seaways were generated and the test conditions (especially with respect to timing between waves and vessel) designed.

This set-up is regarded as rather promising in order to investigate dangerous resonance problems in rough but not necessarily extreme conditions. Further tests were run in extreme conditions to extent the test conditions and identify possible gaps in the numerical pre-investigation.

Vice versa - when focussing on validation - regular waves are frequently used for validation purposes, mainly because the comparison is relatively straightforward, especially if the ship’s response reaches a steady state (as far as amplitude and phase shift are concerned) also. In irregular waves a comparison is more complicated. Traditionally statistical quantities are compared, but this of course does not deliver a detailed analysis of possible weaknesses in the numerical tool.

Based on the new test set-up where the wave elevation is known at all positions of the tank and at all times during the test it is now possible to extent the validation of tools to more details. At the same time the already mentioned pre-calculation of tests is possible, and might also prove to be a very trust-enhancing set-up, as here the motions are predicted before the actual test run.

Fig. 3 shows a first preliminary qualitative comparison of a capsize in a wave group.

**First steps towards decision support for operation**

The given examples show that a lot of interesting information regarding the vessel’s behaviour in rough conditions is in principle available or could be generated. At the same time there is an increasing demand for operational guidance to support crews in their decision making while sailing in rough conditions. Especially as international guidelines such as the MSC Circ. 707 are found to be insufficient for modern designs.
Yet again, no standards exist with respect to functionality, scope and reliability of such systems. Based on the results from the numerical design evaluation carried out at FSG a so called "operational performance" booklet was developed to summarize the findings and communicate these to the ship’s crew. Fig. 4 shows an example extracted from such a manual. In these polar plots the danger of the occurrence of sliding of unlashed cars is presented for two different load cases and different wave length.

While this information enables the crew to better understand their vessels behaviour in rough conditions and more appropriately plan their voyages and the corresponding necessity for cargo securing, it is not suitable for real time decision support in dangerous situations for three reasons: 1. only some standard loading conditions are covered in the booklet in order to avoid an information overflow. 2. It is a booklet, this means the user would have to be extremely familiar with the content to find the correct answers fast and reliable while being in the potentially critical situation. 3. It is well known that it is extremely difficult to impossible for the crew to visually identify the basic characteristics of the seaway with sufficient reliability (especially in confused seas and at night).

**On board wave monitoring – WaMoS II – Wave Monitoring System**

For surveying the ocean wave field WaMoS II, an operational wave monitoring system based on a common marine X-Band can be used. Mounted on a ship, oil rig or onshore it is a proven instrument that measures the wave energy its directions and heights as well as the surface currents. The system consists of conventional navigational X-band radar, a high speed video digitizing and storage device and a standard PC. The analogue radar video signal is read out and transferred to the PC for storage and
further real time processing. The data can be accessed either directly, via removable media, or on-line via modem/telephone or Internet. The measurement is based on the backscatter of microwaves from the ocean surface that is visible as 'sea clutter' on the nautical radar. One measurement consists of a 32 consecutive radar images. This allows to describe the sea surface in space and time. From that observable sea clutter an analysis is carried through to deduce the unambiguous directional wave spectrum and the surface currents in real time. Sea state parameters such as wave heights, periods, wave lengths, wave directions and the surface currents are estimated by a straightforward analysis. Based on a standard marine X-Band radar the wave monitoring system WaMoS II has been proven to be a powerful tool to monitor spectral sea state parameters from fixed platforms as well as from moving vessels [5].

One radar image consists of about 700 000 pixels. The spatial distance of each pixel is 7.5m. One radar revolution corresponds to 2 seconds. A complete measurement consists of 32 images, containing the spatial and temporal information of the individual waves. The position of the buoy is marked in the upper part of the radar image. The position of the buoy is covering 1 pixel in the radar image that is shown in figure [6]. As the radar measurement consists of a time series of radar images, each pixel theoretically can be looked at as an independent buoy.

The spectrum of the above radar time series is shown in figure [7]. The sea state at that time was rather strong, with a significant wave height ($H_s$) of 4.4 m, a peak wave period ($T_p$) of 9.4 s, and a peak wave direction ($p_{dir}$) of 352 °. The surface current ($U$) was 0.3 m/s with a direction of 347 °.
In order to investigate single waves the nautical radar image sequence obtained by WaMoS II was inverted to a sea surface elevation map [7]. The advantage of this method is the possibility to investigate individual waves in time and space and hence the identification of extreme wave events. As an example the radar raw image from above was inverted into a sea surface elevation map (fig. 8).

During SinSee, six months of WaMoS II data was collected on board the RoRo vessel Tor Magnolia simultaneously with motion data in all six degrees of freedom. The above presented method will be applied to that data and compared and correlated with the other on board measurements.

Conclusions and Perspective

In SinSee developments focus on ship’s safety in severe seas. This paper summarizes some of the developments in numerical analysis and validation, model tests especially addressing the modelling of the seaways and means for the on board measurement of the environment. Such joint efforts are important, as it is necessary to provide links/connections between the real world, the model world, and simulation to investigate ship’s safety, understand phenomena and really support ship design and operation.

Next steps in the project will target the precise correlation of time and place of ship and waves between model tests and numerics, thus more detailed quantitative comparisons are possible. The principles for modelling wave propagation outlined here can be applied to transform wave registrations from space to time domain. Thus, the data from the full scale measurement campaign will be thoroughly analyzed and
interesting situations will be chosen for a future re-modelling in the test tank and in simulations.

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References


