

Workshop on Response Based Design Loads, Impact on Model Testing

Session Chair: Dr. I.J. Fylling

I INTRODUCTION

Overview - "Response based Design" - a step in a developing process

Design of ships, like everything else, started as a trial and error process, Cfr. Table 1

Table 1 Response based design
Steps in a development

1. Trial and error
2. Rules
3. Design wave
4. Design storm
5. Design response
6. Design reliability

With the accumulation of experience, sets of design rules were developed. The next step, involving theoretical response analysis, was development of design wave specification. This is still to a large extent adequate for static and quasi-static responses. However, for large structures where dynamic responses are important, the irregular wave characteristics have to be incorporated in the form of a design storm specification, typically representing a 50 or 100 year return period of waves, combined with "representative" wind and current parameters. This approach is adequate for passive structures where critical responses are governed by wave loads.

For structures where wind- and current loading are important in addition to the wave loads, or where the responses are affected by the operation, such as load condition, speed, etc. it has been suggested to use the 50 or 100 year return period of the response as a basic design parameter, cfr. Table 2.

Table 2 Response based design
Shift of design basis is caused by

1.	Two or more environmental parameters are important w.r. to response magnitude.
2.	The response is a nonlinear function of the environmental parameters.
3.	Different responses depend to a large extent on different sets of environment parameters.
4.	Operation status, such as load condition or speed, is important w.r. to response magnitude.

Figures 1 and 2 show an example of 100 year response as derived from a long-term simulation. The next step in the development is called reliability based design. With this approach the design storm as well as the design response are left out. Instead a design reliability is the target of the design process. In the near future this method will mainly be used for research and calibration of more straightforward design methods, such as design storm approach or response based design methods.

Challenge for hydrodynamic laboratories

In traditional ocean engineering, structures are designed to withstand an extreme wave condition, or a so-called design storm. This case is normally also selected as the condition for experimental design verification.

In design of structures or operations involving combined wind-, wave- and current loading, as well as non-linear responses, it is often impossible to specify a design storm that

is critical for all relevant responses. The interesting responses may range from vessel checking responses from one design storm, typically a 100 year return period storm, it is necessary to check a wide range of wind-, wave- and current parameters.

Leaving the design storm approach is a challenge to the experimental test facilities because the number of environment conditions involved may increase dramatically. We can see a trend in this direction for example for testing of moored floating production systems. The situation may be difficult both for the customer, wanting to check the worst conditions, which may be difficult to identify, and for the laboratory, facing requirements to a large number of tests, that may require unreasonable time and budgets.

- Will there be new requirements to analysis and result presentation?
- Higher requirements to comparison of theory and test results?
- Will testing become more expensive?

These are some of the questions that should be discussed in this session.

Table 3 Response based design - Practical approaches.

•	Test several conditions and select the worst result as design response.
•	Combine environmental parameters to represent 100 year return period value of response.
•	Test several equally probable extreme conditions and average the results
•	Partial testing, to verify theoretical response models. Perform design verification by means of analysis (Long-term simulation)

Table 4 Design storm vs. response based design

•	<p>Design storm</p> <p>100 year waves, wind and current combination</p> <p>Problem: There are infinitely many combinations of environmental parameters with return period 100 years.</p> <p>Different design conditions may be required for the different types of responses.</p>
•	<p>Response based</p> <p>100 year return period of critical responses.</p> <p>Problem: A lot of cases have to be analysed or tested.</p> <p>Efficient analysis and testing methods are required.</p>

3.5 years of long-term simulation, total mooring force and line tension

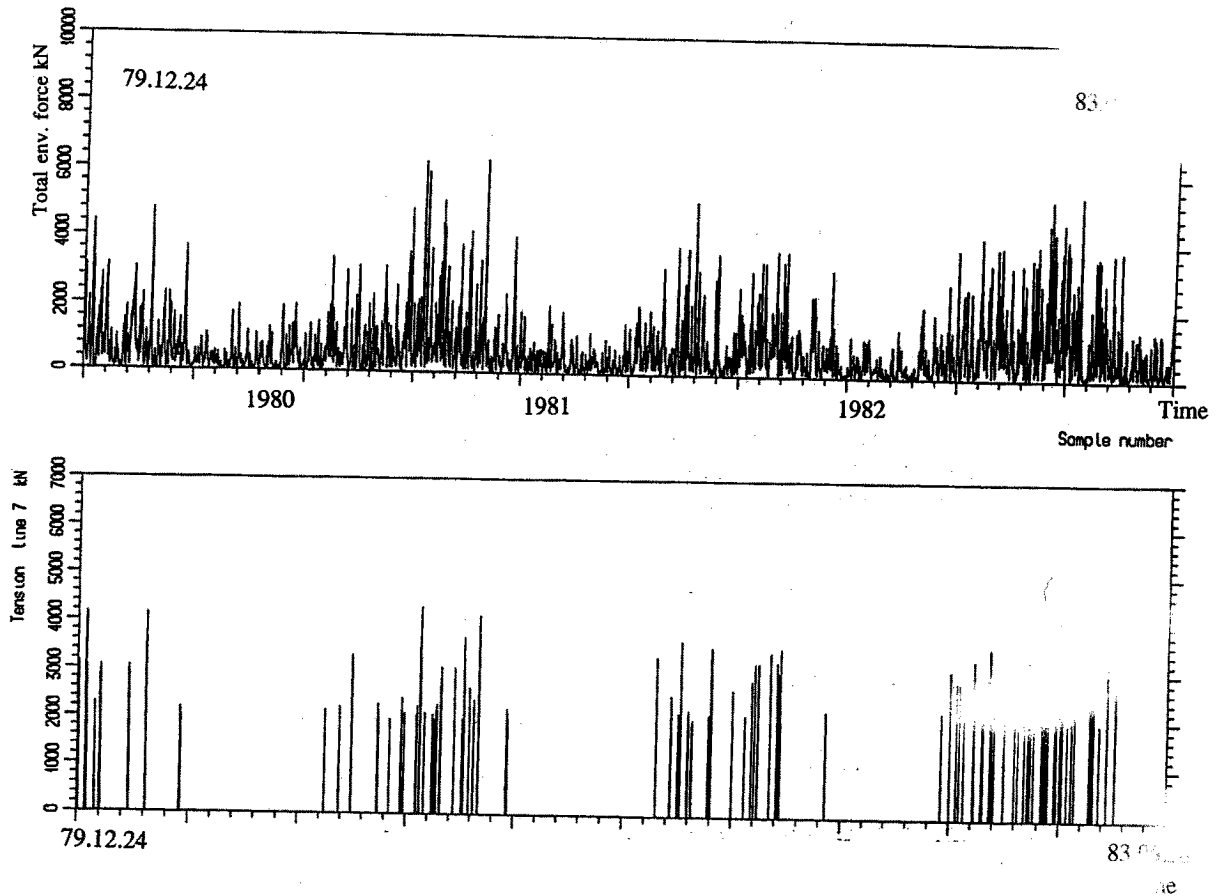


Figure 1. Part of a long-term simulation of mooring line tension. Static force is calculated for 3 hour intervals over 16 years. Dynamic response in all anchor lines are calculated only for cases where static force exceeds a selected level (3000 kN)

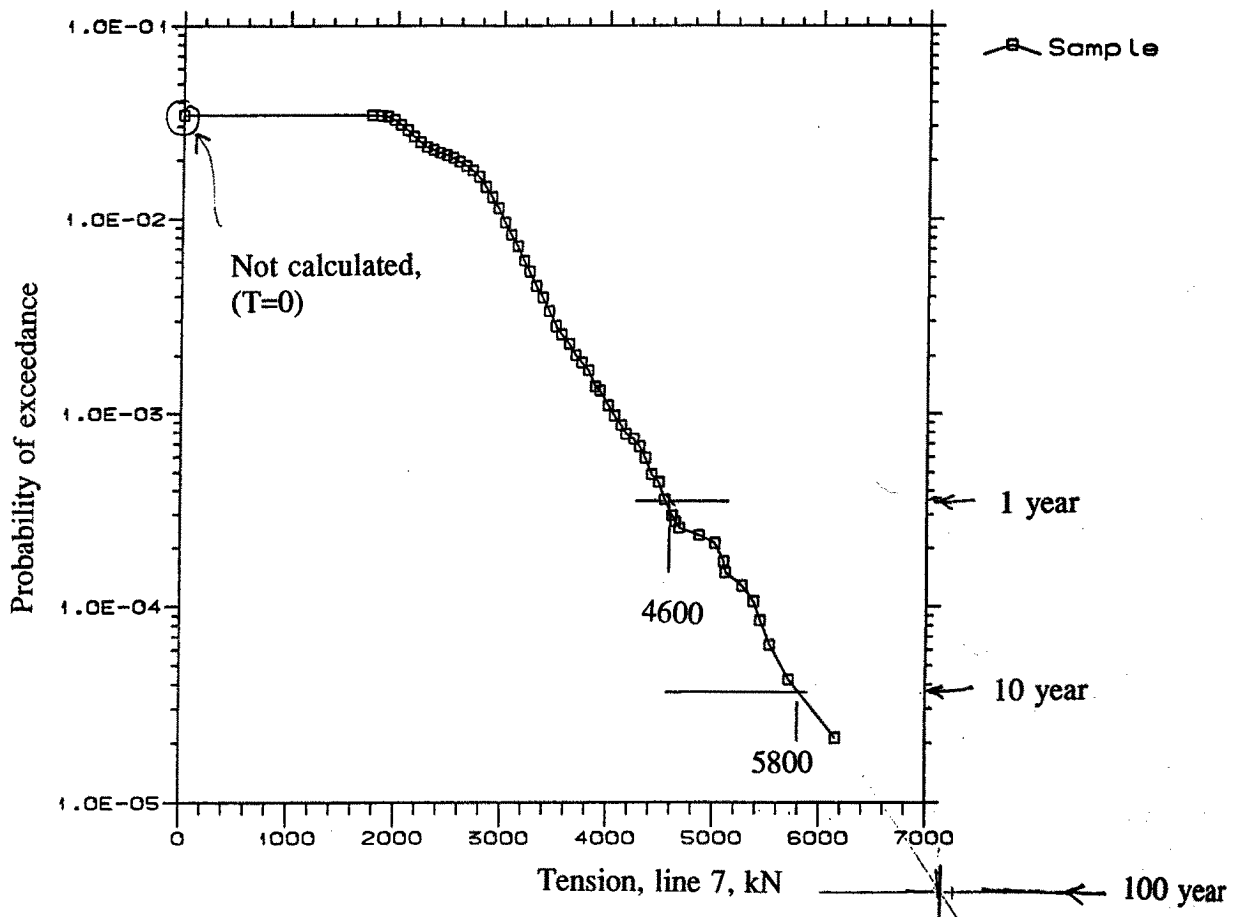


Figure 2 Statistics of 3 hour extreme tension in a selected line. Extrapolation to 100 year return period obviously implies some uncertainty.

II PRESENTATIONS

An overview of the 6 presented contributions for those marked (w). is given below. Written contributions are included.

Dr. J. Wolfram, Heriot-Watt University presented investigations of combining environmental parameters to represent 100 year return period condition. He pointed at the nonstationarity of actual weather conditions, and raised the question of whether the current practice of estimating extremes form 3 or 6 hour duration of waves leads to over-estimation of extremes.

(w) Dr. J.E.W. Wichers, Marin presented an example showing a 2-step approach. First a parameter study is carried out by means of time-domain simulation in order to identify critical responses and corresponding critical

environmental parameters. In the second step these critical environmental conditions form the basis for the model test program.

(w) Professor A. Incecik, University of Newcastle upon Tyne presented a study where environmental force models representing wind-, wave-, and current forces were combined to represent 50- or 100 year return period values of the total environmental load.

(w) Professor H. Maeda, University of Tokyo presented a strategy for combining information from model tests, numerical information and full scale measurements to obtain good estimates of design responses. He also pointed out the importance of incorporating multi-directional waves, multi-peaked wave spectra.

(w) Professor G. Clauss, Berlin University

of Technology described a method to generate wave groups representing extreme wave conditions in a model tank, with the aim of reducing the required testing time.

Dr. E. Comstock, Naval Sea Systems Command, USA, described the development of the design process towards a reliability based design. He pointed out the need to include all operating conditions when estimating the long term distribution of responses, mainly focusing on ship hull loading. He also pointed out the need to follow up the work of the various classification societies in this field, which to some extent is being published through the ISSC.

Simulation of Design Storm Wave Conditions with Tailored Wave Groups

by G.F. Clauss and W.L. Kühnlein
Institute of Naval Architecture and Ocean Engineering, Berlin University of Technology

1. General

Extreme wave conditions in a 100-years design storm arise from the most unfavourable superposition of component waves of the related severe sea spectrum. When generating irregular seas at model scale this crucial condition related to the most critical storm spectra eventually may occur if the random phase shift of all superimposing waves happens to be zero at a certain position - a coincidence which requires a test duration of around 50 hours / $\sqrt{\text{model scale}}$.

As an alternative the component wave of a project oriented design spectrum can be tentatively generated in such a sequence that all waves superimpose without phase shift at a given position. This technique requires

- precise prognosis of the nonlinear hydrodynamics of wave group propagation,
- a sophisticated electro-hydraulic wave generator, and
- sufficient computer capacity for online control and data acquisition.

In addition it may be necessary

- to control the carriage and the track of the self-propelled vessel to ensure model/wave interaction at predefined positions and conditions;
- to provide tank side wall wave absorbers to prevent side wall reflections of diffracting

or radiating wave systems generated by the model.

2. Transient Wave Technique for Seakeeping Tests

The proposed technique is based on a fully automatic, computer controlled procedure which governs

- the generation of a short, specifically tailored, wave train with a "design" spectrum represented by the superposition of thousands of wave frequencies;
- the control of the speed of the carriage and of the model course.

As a result, the model meets the wave train within a predetermined section of the tank which is equipped with vertical side wall wave absorbers for simulating an infinite tank width (Clauss and Kuhlmann, 1995). The duration of a typical seakeeping test is only a few minutes with a relevant time window of 10 - 30 seconds (Clauss and Kühnlein, 1995a). As the wave train is exactly defined in space and time it is easy to transpose the registration to any position along the tank or on the moving vessel. Of course, wave trains are exactly repeatable. Thus, the wave/model interaction of towed or self-propelled vessels can be investigated at different speeds and at different positions in the tank.

As short and high wave groups with strong non-linear characteristics evolve from long and low wave groups, the nonlinear characteristics can be developed from linear principles. During its metamorphosis the total energy of the transient wave is invariant, if breaking phenomena are excluded. Nonlinear surface elevations and particle motions as well as velocities and accelerations are calculated from an expanded velocity potential by solving the mutually dependent particle motion equations in time domain (Clauss and Kühnlein, 1996). Fig. 1 shows the calculated nonlinear water particle motions of a wave packet at different positions ($x = 10 \text{ m}, 25 \text{ m}, 39.1 \text{ m}, \text{ and } 45 \text{ m}$ (concentration point)). If wave spilling or breaking is prevented the nonlinear wave trains converge and - after passing the concentration point without energy dissipation - diverge and fade away as long, low, and linear wave groups. Consequently the extremely high "freak" wave has a linear past and a linear future.

Using this technology, a 3.2 m wave

(probably the highest wave in a tank so far) has been generated in the GWK (Large Wave Tank) in Hannover, Germany. The genesis of this transient wave is predictable, i.e. its kinematics and dynamics can be calculated at any position as a function of time and at any instant as a function of space.

Thus, the transient wave technique which was introduced by Davis and Zarnick (1964), and further improved by Takezawa and Hirayama (1976) has been developed from a battle-axe to a scalpel. It is adaptable to arbitrary model test requirements for investigating marine vessels or coastal engineering projects - in long wave trains or in short "freak" waves.

For seakeeping tests it is recommended to select the location of model/wave interaction shortly before the concentration point. This allows a perfect analysis of the wave-structure interaction within a few seconds and the model starts and stops under still water conditions. The wave steepness of the wave profile can be controlled at any position and time, to ensure that breaking phenomena are excluded. The check of the wave steepness can also be used as an input for modifying the shape of the Fourier spectrum.

3. Analysis of Model Tests

For linear systems, the model response is expressed by transfer functions. If a model is investigated in a transient wave train its response (force, motion, etc.) can be transformed to the complex Fourier transforms. As the wave train and the model response are of limited length, this integration is performed within a selected time window. Thus no statistical scatter occurs, and the integration yields smooth spectra. The time window of the analysis is chosen interactively to avoid errors caused by wave reflections from beach and wave board. The transfer function (RAO) is calculated from the ratio of the respective Fourier transforms of the model response and of the incident wave group. The complex division directly yields the frequency dependent transfer function by magnitude and phase, if both Fourier transforms are related to the same point (Clauss and Bergmann, 1986). As in model tests with self-propelled models it is not possible to measure the wave profile at the model position, therefore the wave train which is measured at the wave probe attached to the carriage has to be transformed from this position to the model position. If the distance

between both points is constant, the above transformation can be performed in the frequency domain. In model tests with self-propelled models, however, a constant distance is not being expected. This requires a transformation procedure in time domain (Clauss and Kühnlein, 1995b).

For nonlinear systems, transfer functions are useless. Therefore new tools for analysing model tests and presenting results are required. Nonlinear loads and response can be thoroughly investigated as any test is exactly repeatable. For investigating structures in a specified design storm the most unfavourable wave train or freak wave can be designed, and the interaction between structure and wave is evaluated under predictable test conditions. Even if the wave train is breaking, it may be the possibly worst condition for a given wave spectrum. The spectrum of this worst case model response is a useful tool to describe the wave/model interaction for a given sea spectra.

4. Conclusions

In summary, the application of the transient wave technique can be adapted to figure out and generate the worst conditions for the investigation of ships and marine structures. This new technique facilitates efficient and reliable investigations of their hydrodynamic characteristics. The transient wave train at the concentration point (breaking or non breaking) is the highest possible wave impulse of a given spectrum (freak wave). For the analysis of experimental tests with nonlinear model response new evaluation techniques are required.

5. References

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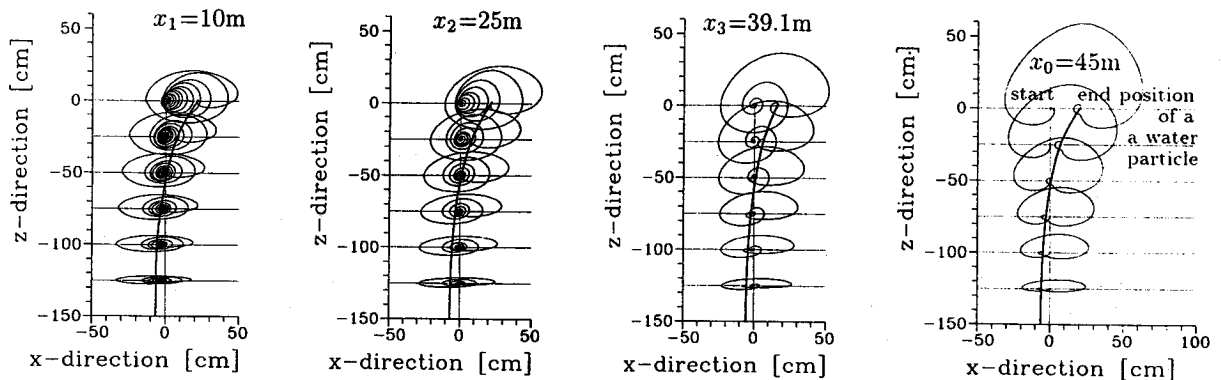


Fig. 1: Calculated water particle motions of a wave packet at $x=10\text{m}$, 25m , 39.1m , and 45m , $d=1.5\text{m}$

Response based design: Fusion of model tank test, numerical tank test and full scale test.

by Hisaaki Maeda, University of Tokyo.

1. 100 year design storm

What is the current 100 year design storm? While a real sea condition which surrounds a moored floating structure consists mainly of short crested waves with multi peak spectrum in frequency and in principal direction, fluctuating wind velocity in time and space, fluctuating current velocity in also time and space, as shown in Fig. 1, the current 100 year design storm is represented as follows;

- Wave: 100 year wave height with uni-direction and mono-peak wave spectrum.
 Wind: 100 year uniform wind velocity
 Current: 100 year uniform current velocity (with wind induced current).

Joint probability between wave, wind, and current:

- 100 year wave, wind, current occur at the same time.
- Direction of 100 year wave, wind, current is the same

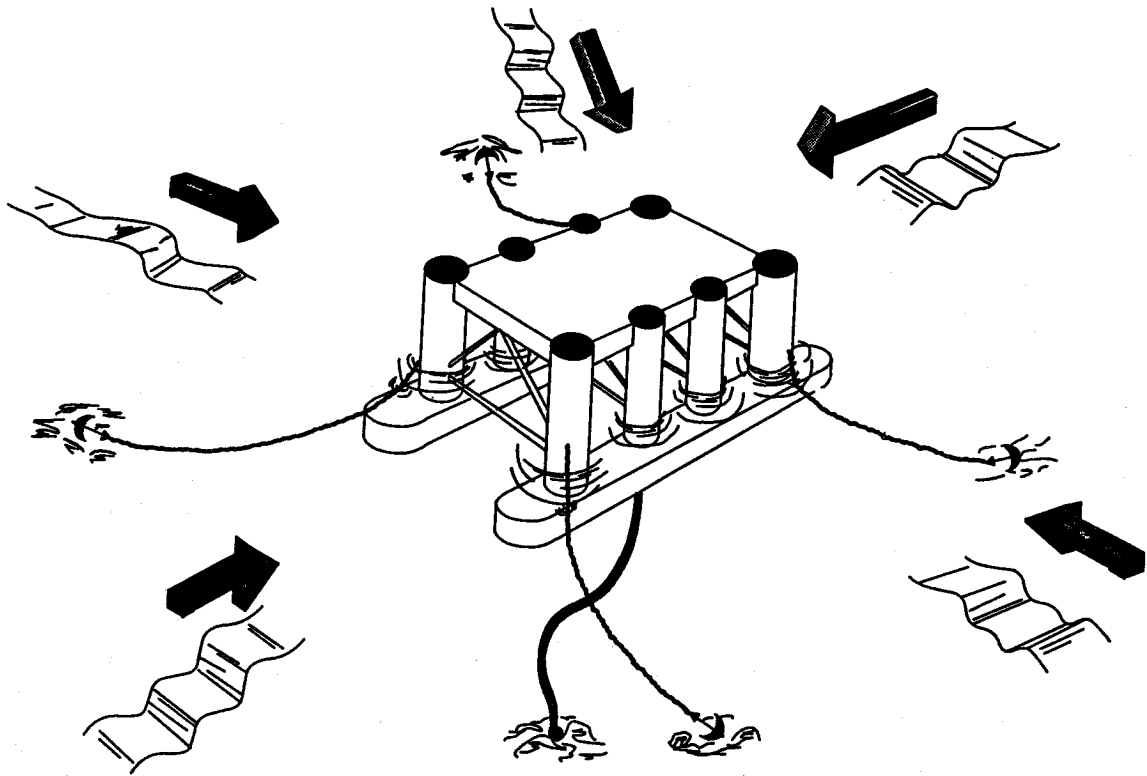


Fig. 1 Moored Floating Structure

Then the current 100 year design storm does not always correspond to the 100 year response, if the response depends on frequency and directionality of wave, wind and current.

second order frequency motion, in which the attention should be paid to the amplitude of sway motion, larger than the surge motion even in head waves.

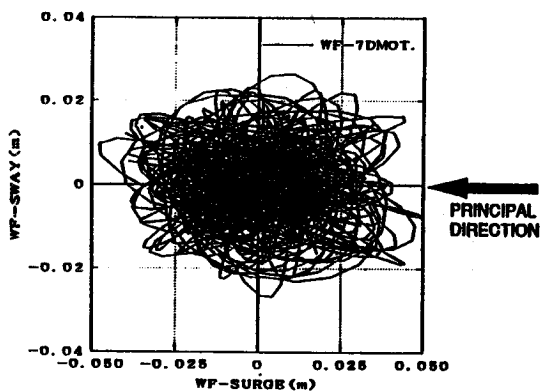


Fig. 2 Trajectory of CG of moored floating Semi-Submersible (1st order motion).

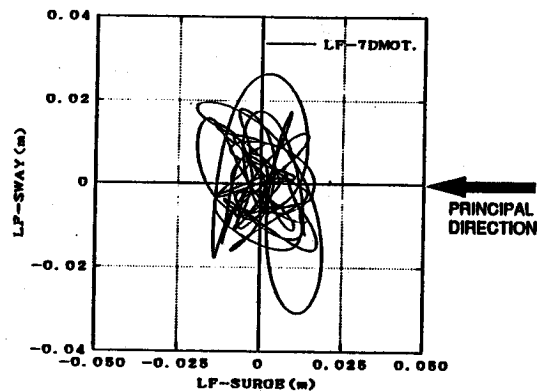


Fig. 3 Trajectory of CG of moored floating Semi-Submersible (2nd order low frequency motion).

Figure 2 and 3 show the trajectory of the center of gravity of a moored floating semi-submersible in the horizontal plane in multi directional waves with longitudinal principal direction. Figure 2 corresponds to the first order low responses, while Fig. 3 shows the

Figure 4 shows twin peak wave spectrum which is often observed in oceans¹⁾. The single peak wave spectrum has the same significant wave height and mean wave period as those of the twin peak wave spectrum. The

corresponding response of a container vessel in this twin peak or single peak wave spectrum is shown schematically in Fig. 5. The response amplitude which corresponds to twin peak wave spectrum is larger than that of single peak wave spectrum because the resonant frequency of the response characteristics is very close to one of the peaks of the wave spectrum.

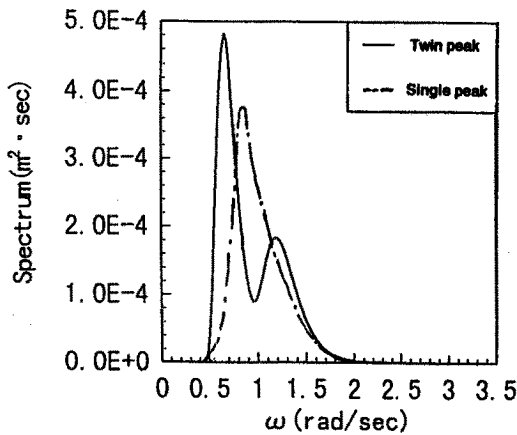


Fig. 4 Wave spectrum

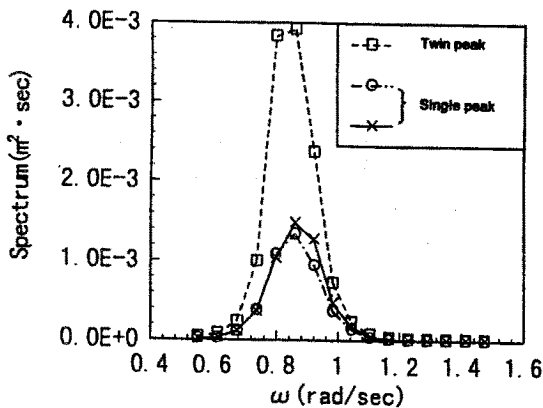


Fig. 5 Heave of a container ship in single and twin peak wave spectrum.

When the 100 year design storm is defined as the combination of 100 year wave height, 100 year wind velocity and 100 year current velocity, the 100 year design storm seems to be one million year phenomenon and the response must be larger than the 100 year response.

The above mentioned examples indicate us that the current 100 year design storm does not always give the 100 year response.

Then what is the rational definition of the 100 year design storm? Important is not 100 year design storm, but 100 year response in order to design floating structures. Therefore 100 year design storm should be defined as the

one which correspond to 100 year response.

2. 100 year response

Once 100 year design storm is defined rationally, how can we realize the corresponding 100 year response which is necessary for designing rationally ocean structures?

Consider first dynamics of 6000 m drilling pipes for a deep ocean drilling vessel which will be built in Japan near future, or 300 m deep water flexible risers under given 100 year design storm. It is quite difficult to realise the corresponding model test in a common model basin because a water depth of a model basin is relatively so shallow that the similarity law is not satisfied.

Consider, secondly behaviour of a very large floating structure such as 5 km x 1 km floating airport. It is impossible to simulate the perfect model test in a model basin because a size of a model basin is relatively too small and the capacity of wave maker is limited relatively to lower frequency and could not simulate the corresponding real sea condition

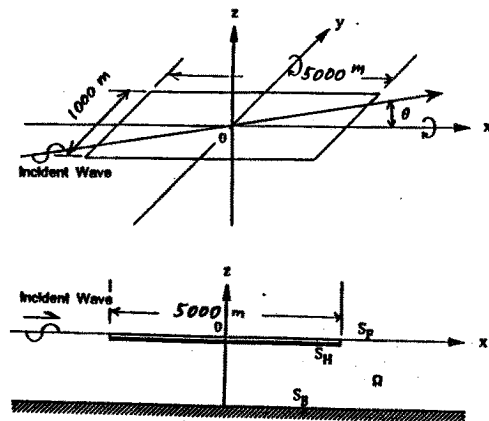


Fig. 6 Floating airport

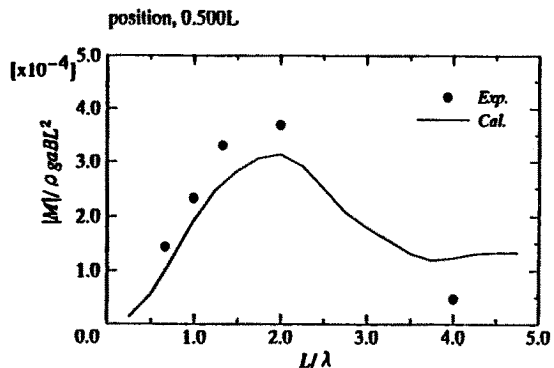


Fig. 7 Bending moment of flexible floating airport in head seas

Figure 7 shows the agreement between model test results and numerical results for bending moment at midship is not bad, however, the range of L/λ is limited within the range of 5.0. The length of a floating airport L is 5000 m and the length of incident waves is around 100 m or 50 m, then the parameter L/λ is between 50 and 100. It is very difficult to carry out a model tank test for a very large floating airport. The model tank test has some limitation to simulate actual 100 year response in some cases. The model tank test is not perfect.

Then how can we obtain 100 year response results? The availability is remained in a numerical tank test which has been developed by the improvement of computer and CFD algorithm. However CFD is not perfect.

Figure 8 indicates the trajectory of a bottom end of a flexible hanging riser which oscillates in in-line. Reynolds number is 5000 and Keulegan-Carpenter number KC varies from 6 to 12. In a certain case the bottom end of the flexible riser behaves chaotically. The

corresponding CFD results are given in Fig. 9 which seems not to agree well with the experimental results. The CFD results are done only for laminar flow, while the turbulent flow may occur at this Reynolds number. It is not easy to introduce practical turbulent model for the vortex shedding problem.

CFD results always require verification and validation. This can be done by model tests or full scale tests or sometimes prototype model tests. If 100 year response include fully non-linear phenomena, the corresponding mathematical model to these phenomena may not exist, and the CFD approach, that is, numerical tank test may not work at all.

While the full scale test is free from size problem, it is quite difficult to encounter 100 year storm at a real sea during a certain limited period. Even though we meet 100 year storm, there are a lot of uncertainties on monitoring systems at a real sea for wave, wind and current during a 100 year storm.

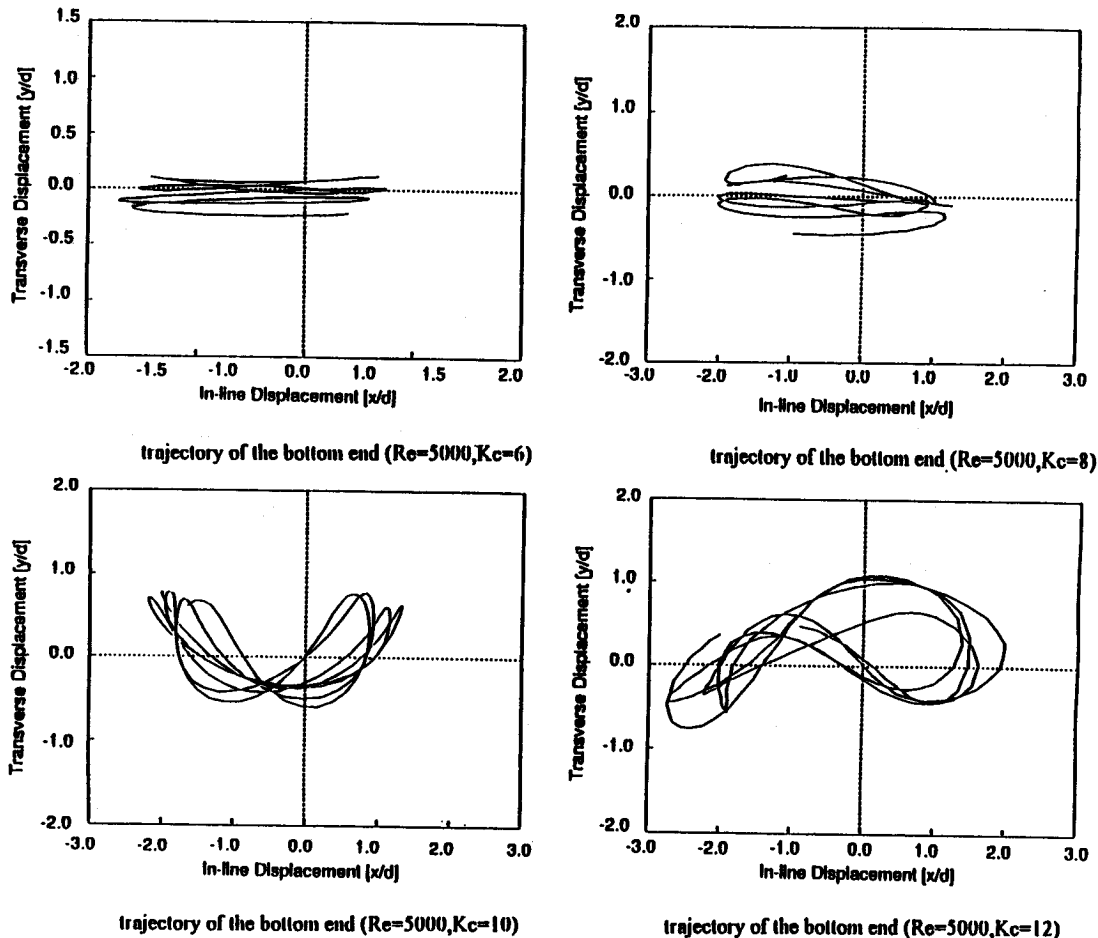
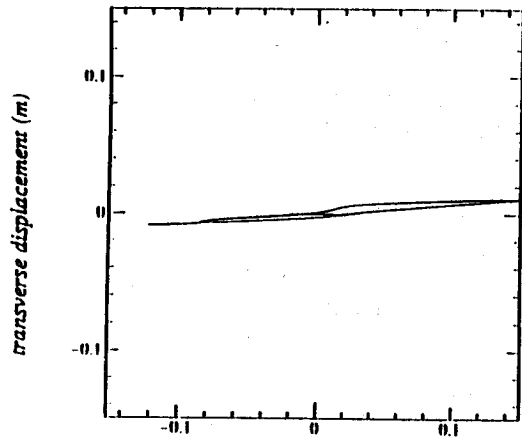
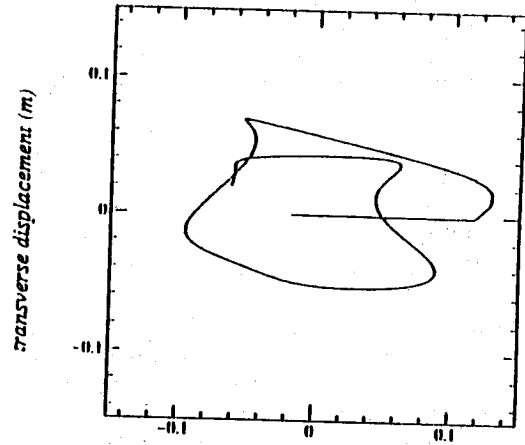


Fig. 8 Trajectory of bottom end of flexible riser (experiment)



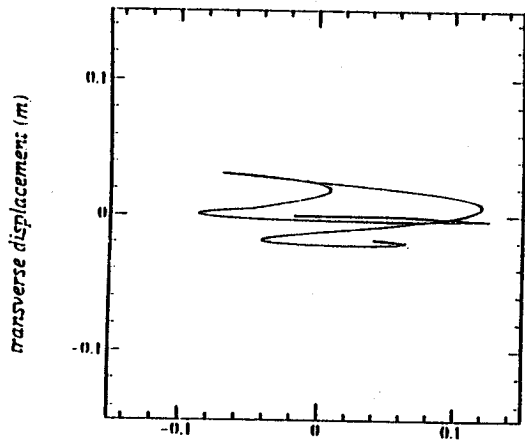
in-line displacement (m)

trajectory of the bottom end (Re=5000, Kc=6)



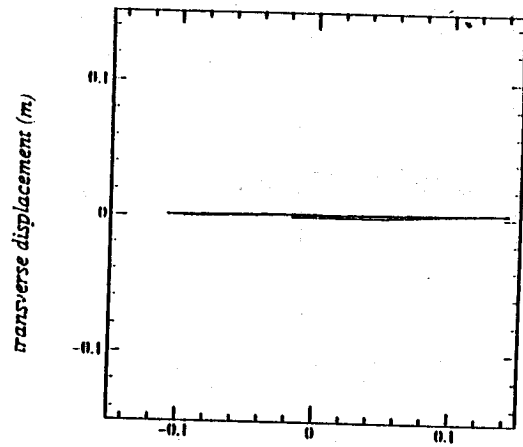
in-line displacement (m)

trajectory of the bottom end (Re=5000, Kc=8)



in-line displacement (m)

trajectory of the bottom end (Re=5000, Kc=10)



in-line displacement (m)

trajectory of the bottom end (Re=5000, Kc=12)

Fig. 9 Trajectory of bottom end of flexible riser (CFD calculation)

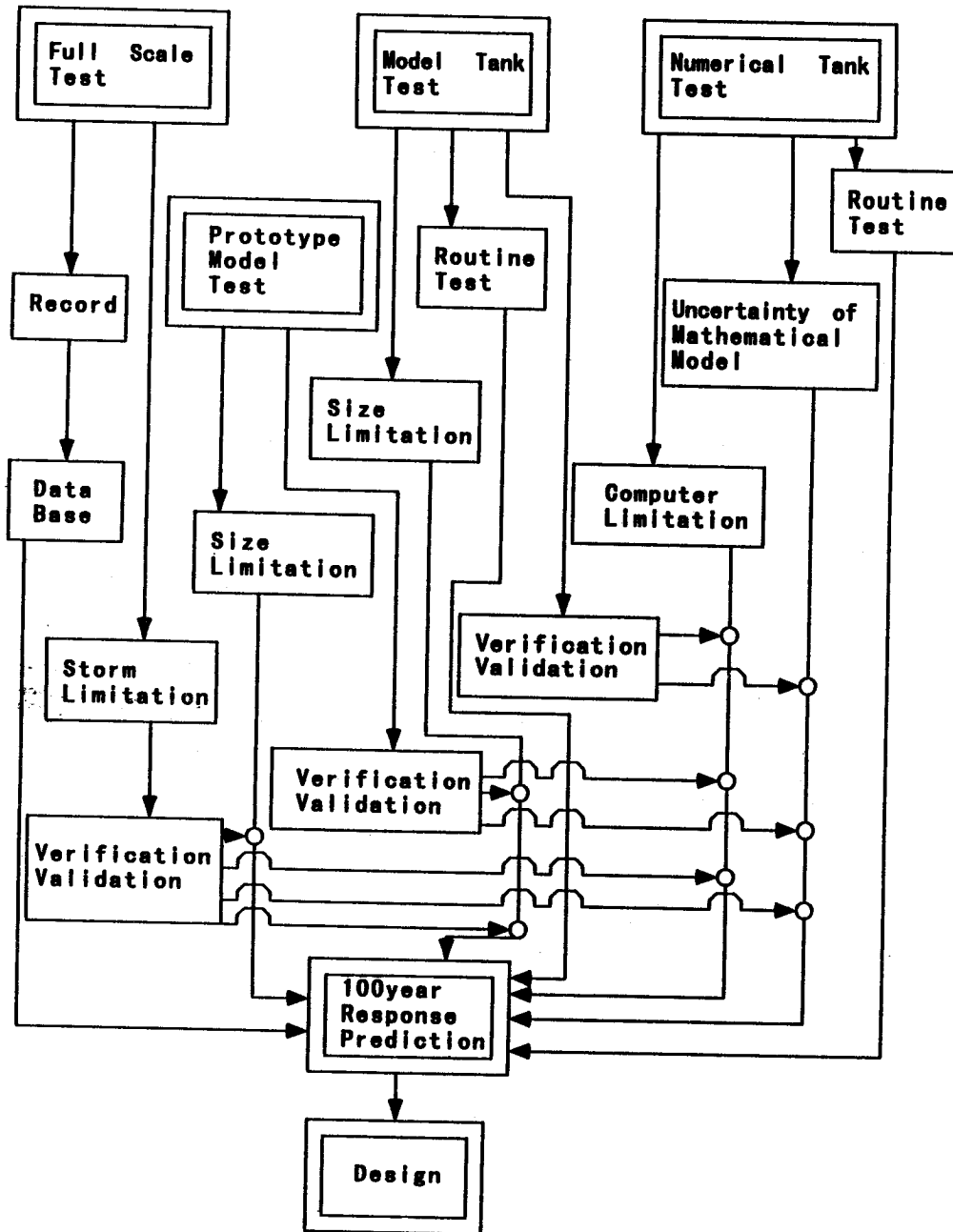


Fig. 10 Fusion of model tank test, numerical tank test and full scale test for 100 year response

3. Fusion of model tank test, numerical tank test and full scale test²⁾

In the previous section, the author pointed that any one of a model tank test, a numerical tank test and a full scale test is not perfect. There is no only way to predict 100 year responses by itself. They have not only merits but also limitation or uncertainties. The only way left is the integrity of these three tests, that is, the fusion of a model tank test, a numerical tank test and a full scale test. Moreover a prototype model test can be added in some case. The fusion diagram is shown in Fig. 10.

There is an example for the fusion of these tests. In Japan there is the Megafloat Project started in 1995, the objective of which is the feasibility study of a very large floating ocean structure such as a floating airport, an electric power plant, a garbage plant etc. The length may be very large such as 5000 m. We are carrying out model tank tests with 4 m, 15 m length models in a seakeeping basin, or wind and circulating water tunnel, or 50 m length 2D model in a narrow towing tank which covers the parameter L/λ , structure length over wave length ratio 50. A prototype model test is also being carried out at a real sea, the dimension of which is 300 m length, 60 m breadth, 2 m depth and 0.7 m draft, very flexible elastic plate which consists of nine units. We are also developing the corresponding mathematical model for numerical tank test. There are still many problems left which should be solved before long. We are now on the way to the final conclusion in which we can realize 100 year responses by using the fusion of these tests. The discussion in this workshop is very helpful for us.

There is one more big problem left. How can we identify 100 year design storm which corresponds to 100 year response, the worst condition for an ocean floating structure. The fusion of a model tank test, a numerical tank test and a full scale test is also available to identify 100 year design storm. At first a numerical approach can be used to estimate roughly 100 year design storm which may correspond to the worst condition and then a model tank test can be used to check it and make uncertainties clearer. Then try to do the numerical tank test again in order to get more reliable information for 100 year design storm.

This kind of design spiral for 100 year design storm is shown in fig. 11.

Numerical tank test \Rightarrow Model tank test \Rightarrow (Full scale test) \Rightarrow Numerical tank test \Rightarrow Model tank test \Rightarrow (Full scale test) \Rightarrow Numerical tank test \Rightarrow . . .

Fig. 11 Fusion of model tank test, numerical tank test and full scale test for 100 year design storm (Design spiral for 100 year design storm)

The author pointed out two issues in this workshop. The first one is how can we define or derive 100 year design storm which includes 100 year response. The second issue is once 100 year design storm is given how can we predict 100 year response under the 100 year design storm which is used to design ocean structures.

In order to make the "Response based design" more rational and reliable, we have to investigate multi-directional waves, multi-peak wave spectrum, wind spectrum, current spectrum, joint probability between wave, wind and current, missions of various kinds of ocean structures, development of new model basins which can be used for 100 year design storm, development of new opto-electronic measurement systems, new computer aided experimental systems, development of practical turbulent model for CFD algorithm, development of new computer machine with many parallel processors, development of remote sensing for monitoring 100 year storm in situ, completion of data base of global ocean climate which are useful for deriving 100 year design storm, and other subjects which have to be taken account to define 100 year design storm and to predict 100 year response under the given 100 year design storm.

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Combining Metocean Parameters to Identify Critical Responses for SPM Moored Tankers

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MARIN

Introduction

For the design of SPM systems the environmental parameters are of prime importance. In operational condition both the magnitude of the characteristics of wave spectra and the wind and current velocities and their mutual directions can vary.

By combining operational metocean parameters in a systematic way, critical responses of for instance a SPM moored tanker can be found. In this contribution time-domain computer simulations were carried out for a systematic number of combinations of wave spectra, wind and current and applied to a loaded and ballasted tanker moored to a CALM buoy. The results of the computations of the non-linear system will lead to weather combinations resulting in the most critical responses. With the identification of the critical responses an optimum experimental test program can be established.

Metocean parameters

For the combinations of metocean parameters two basic cases were considered. For one case the weather condition was combined by varying the internal angle between the parallel directed waves and wind and the direction of the current. In all cases the characteristics of the wave spectrum and the

velocity of the wind and current were kept constant.

For another case the weather condition consists of waves and wind directions which are directed perpendicular to the current speed. While the characteristics of the wave spectrum and wind velocity were kept constant, the current speed was varied. Both weather cases as applied to the SPM system are given in Figure 1.

Results of computations in combined weather conditions

For the crude carrier a loaded and ballasted 140 kDWT tanker moored in 23.7 m water depth was chosen. The tanker is moored by means of a 50 m long Nylon double-braided type hawser. For the buoy a 6-chain leg conventional CALM was used.

The computations were carried out with the MARIN time-domain computer program TERMSIM. For each weather condition the time-domain computations were carried out for a period of 3 hours full scale to ensure a sufficient length for statistical analysis purposes. The results of the computations in terms of hawser forces and relative tanker heading are given in the Figures 2 and 3. Definitions are given in Figure 4.

For more details reference is made to:
Wichers, J.E.W.: "Combining extreme metocean parameters on SPM moored tankers",
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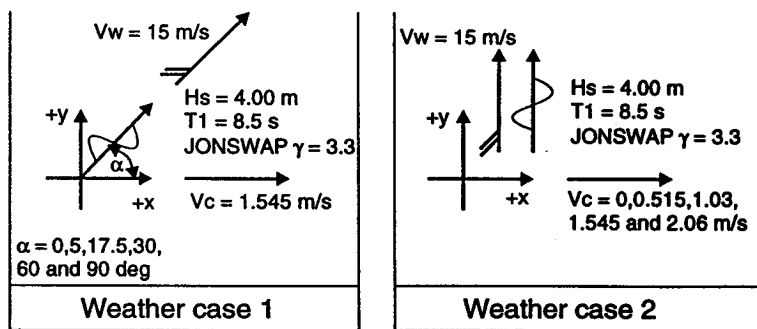


Fig. 1. Review of weather cases applied to the 140 kDWT tanker

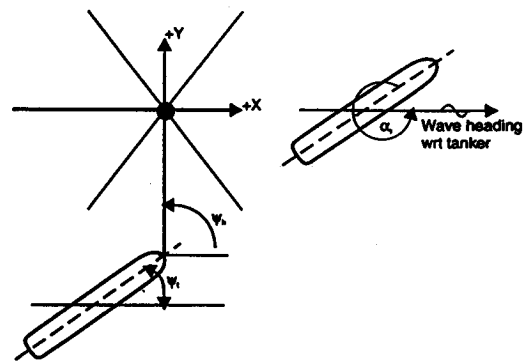


Fig. 4. Definitions of the measured signals

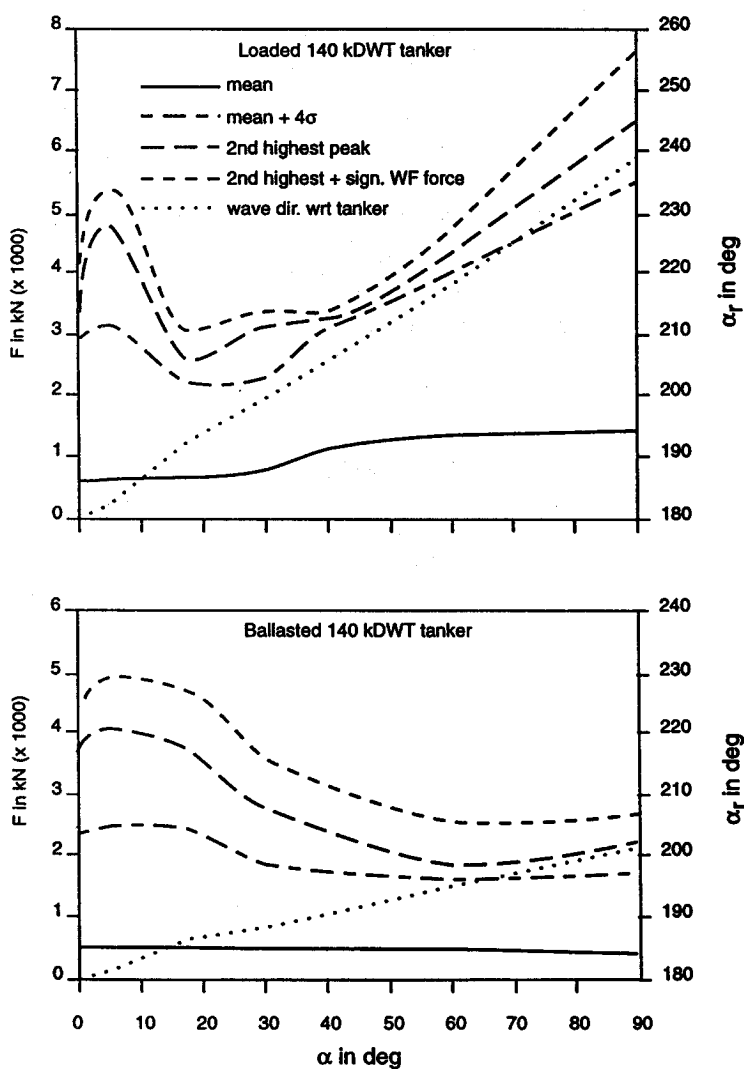


Fig. 2. Hawser force as function of wave/wind direction (weather case 1)

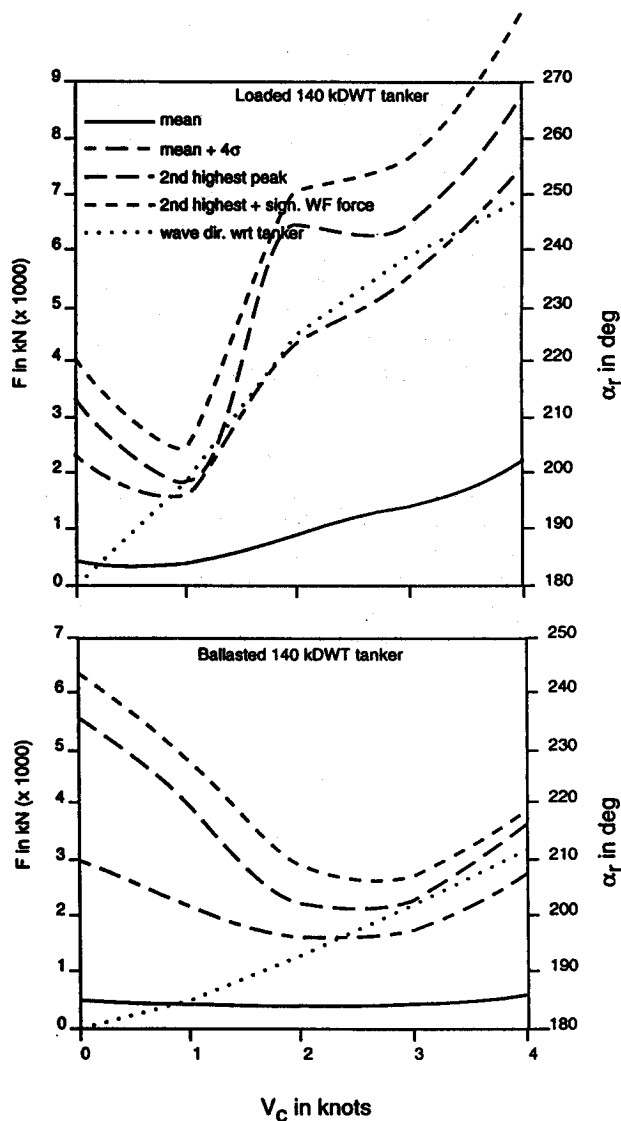


Fig. 3. Hawser force as function of current velocity (weather case 2)