SHIP-MOORINGS v5.02

Validation document

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Abstract

Computations have been carried out with SHIP-MOORINGS, Alkyon's computer program for the simulation of moored ship behaviour. Computations have also been carried out with DIFFRAC, the program used to prepare the hydrodynamic coefficients for SHIP-MOORINGS.

The results of these computations have been compared with a set of published computation and scale model test results.

The comparison shows a very good correlation between the SHIP-MOORINGS and DIFFRAC results and the scale model test results.

References

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1 Introduction

Alkyon Hydraulic Consultancy & Research bv has developed the computer program SHIP-MOORINGS that simulates the behaviour of a moored ship or a floating moored object under conditions of wind, waves and current.
The program requires input in the form of hydrodynamic coefficients for the ship, and data for the mooring system and the waves, wind and current acting on the ship (see Figure 1.1). For the preparation of the hydrodynamic coefficients, Alkyon uses the potential theory diffraction program DIFFRAC.

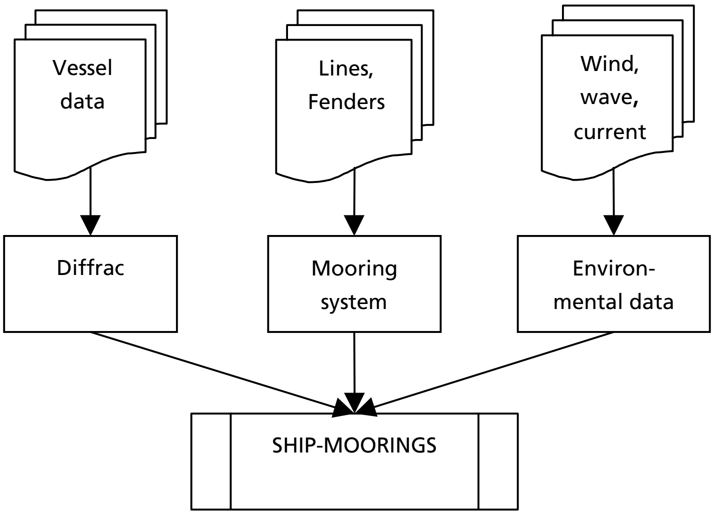


Figure 1.1 Input scheme for SHIP-MOORINGS

For the validation of SHIP-MOORINGS, several tests were carried out.
Firstly, basic theoretical tests were carried out by applying a theoretical force signal to a highly schematised “ship”-like object.
Secondly, tests were carried out with regular waves applied to a free-floating vessel. The resulting response spectrum should be almost identical to a response spectrum obtained directly by applying the DIFFRAC RAO’s (Response Amplitude Operators).
Thirdly, a published case study of a vessel moored to a jetty in irregular waves was reproduced. This case study is described in Van Oortmerssen [I], and gives results of both numerical computations and scale model tests.

In this report, first the input as prepared for SHIP-MOORINGS for the comparison with the published data is presented.
Chapter 2 gives a description of the schematisation of the vessel and the computation of the hydrodynamic coefficients with DIFFRAC and a comparison of those coefficients with the computed and measured coefficients presented in [I].
Then Chapter 3 gives a description of the schematisation of the mooring system and Chapter 4 of the schematisation of the wave spectrum.
Chapter 5 presents the results of the tests carried out with SHIP-MOORINGS and compares them with the mooring simulation results published in [I].
Finally, Chapter 6 presents the conclusions based on that comparison.

In an appendix to this report, some examples of continuing validation cases are presented.

2 Vessel schematisation

2.1 Vessel data

For the validation test with the case study, a 200,000 DWT tanker was schematised. The general data of the vessel are given in the Table below. The table gives the original data as reported in [I] by van Oortmerssen (denoted Van Oortmerssen) as well as the data from the SHIP-MOORINGS schematisation.

Main dimensions 200,000 DWT tanker				
		vOm	*Alkyon*	
Length between perpendiculars	Lpp	310.0	310.0	m
Breadth	B	47.2	47.2	m
Draft	T	18.9	18.9	m
Volume displacement	∇	235.000	231,700	m^3
Block coefficient	CB	0.85	0.84	-
Long centre of gravity	l.o.g.	6.61	5.28	m
Height of centre of gravity	KG	13.32	13.32	m
Metacentric height	MG	5.78	6.25	m
Radius of gyration around x-axis	Kxx	17.0	17.0	m
Radius of gyration around y-axis	Kyy	77.5	77.5	m
Radius of gyration around z-axis	Kzz	77.5	77.5	m

Table 2.1 General ship data

Some small differences are present between the model of [I] and the results of the schematisation for SHIP-MOORINGS. This is a result of uncertainties in the available information (see also Chapter 2.2) as well as due to the limitations of the schematisation. For the schematisation of the vessel in SHIP-MOORINGS, the body plan given in [I] was used. This body plan is shown below.

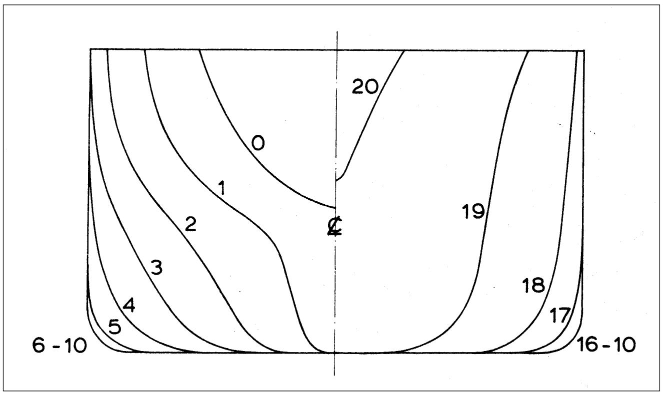


Figure 2.1 Body plan of 200.000 DWT tanker

2.2 Computation of hydrodynamic coefficients

For the computation of the hydrodynamic coefficients for the ship, Alkyon uses the potential theory diffraction program DIFFRAC. For this program, the ship has to be schematised with a large number of panels.
In this Chapter the schematisation prepared by Alkyon is presented and compared with the schematisation used in [I]. Then the hydrodynamic coefficients computed with DIFFRAC based on the Alkyon schematisation are compared with the hydrodynamic coefficients computed in [I] based on the schematisation in [I] as well as with with experimentally determined coefficients also published in [I].

Software package DIFFRAC

For the computation of the frequency-dependent hydrodynamic response characteristics of the ships, Alkyon uses the boundary element 3-D potential theory wave diffraction program DIFFRAC. This program has been developed by MARIN and calculates the wave loads and motion responses of a free-floating or moored structure. The program is applicable to shallow, as well as to deep water.

DIFFRAC is based on a three-dimensional source distribution technique for the solution of the linearised velocity potential problem. For this approach, the fluid is assumed to be inviscid, homogeneous, irrotational and incompressible. The velocity potential is a scalar function of the co-ordinates and of time. Knowledge of the velocity potential around the vessel is sufficient for the computation of fluid pressures and wave loads.

For the computations, the mean wetted part of the hull of the vessel is approximated by a number of plane elements, representing a distribution of source singularities each of which contributes to the velocity potential describing the fluid flow.

Differences in schematisation and uncertainties

The schematisation of the vessel was done with the information given in [I]. However, not all information was available. The uncertainties and the differences in modelling of the vessel are described below:

1. The body plan as shown in Figure 2.1 was used for modelling the vessel, however in [I] the location of the waterline was not indicated. The location of the waterline influences the underwater form and therefore the displacement, location of centre of gravity and the metacentric height.

2. Because of the reduced computing power available when the study in [I] was carried out, the panel schematisation given in [I] is much coarser than the schematisation carried out by Alkyon in this study. The differences are clearly visible when comparing Figure 2.2 (Alkyon schematisation: 2844 panels) and Figure 2.3 (schematisation in [I]: 160 panels).

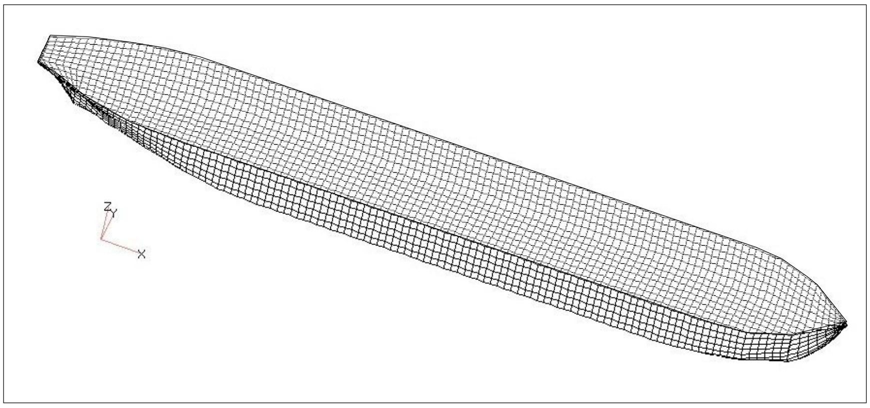


Figure 2.2 Panel schematisation of the vessel in DIFFRAC for the validation of SHIP-MOORINGS

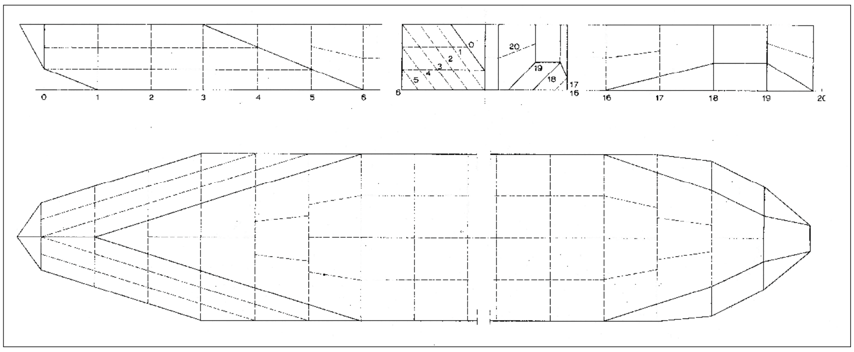


Figure 2.3 Old schematisation

The schematisation as presented in Figure 2.2 was used for input in the model DIFFRAC. The results from DIFFRAC of the added-mass, damping and wave forces and moments are discussed in the following section.

2.3 DIFFRAC results

The add mass and damping curves are presented in Figures 2.5 – 2.10. The computed transfer curves of the wave forces and moments are presented in Figures 2.11 - 2.13. In these figures, also the values of numerical computations and experiments from [I] are presented. The numerical results from [I] are denoted “vOm”.

The system of axes used is shown in Figure 2.4.

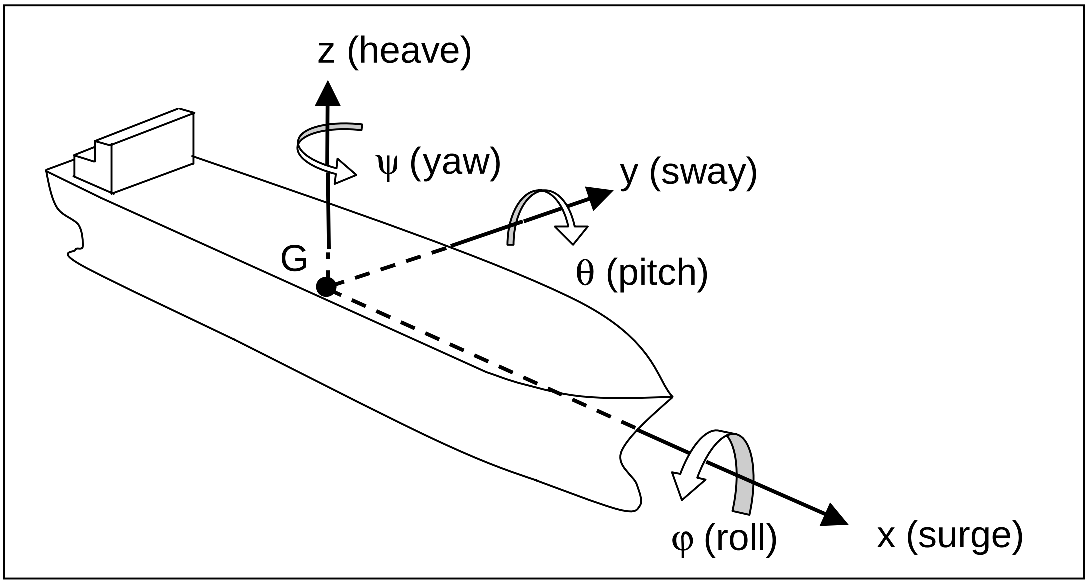


Figure 2.4 Definition of ship motion components

In the figures the added mass and damping coefficients are given with indices 1 –6, in which 1 denotes surge, 2 sway, 3 heave, 4 roll, 5 pitch and 6 yaw.
The x-axe presents the non-dimensional period as

follows: $\omega\sqrt{\frac{L}{g}}$

The added mass and hydrodynamic damping coefficients are presented in non-dimensional form as defined in Table 2.2 below.

Added mass	Damping	Mode
$a'_{jj} = \frac{a_{jj}}{\rho\nabla}$	$b'_{jj} = \frac{b_{jj}}{\rho\nabla\sqrt{g/L}}$	j = 1,2,3
$a'_{jj} = \frac{a_{jj}}{\rho\nabla k_{jj}^{2}}$	$b'_{jj} = \frac{b_{jj}}{\rho\nabla L^{2}\sqrt{g/L}}$	j = 4,5,6

Table 2.2 Definition of non-dimensional added mass and damping coefficients

Added mass and damping

In general, the results compare very well. The overall results of the Alkyon schematisation (especially damping) fit better with the scale model in compared to the Van Oortmerssen schematisation. This can be attributed due to the more detailed new schematisation. However, the discrepancy for the added mass for roll and pitch and the damping for surge are not solved with a more detailed schematisation. As described in [I], these differences could partly be a result of measurement inaccuracies.

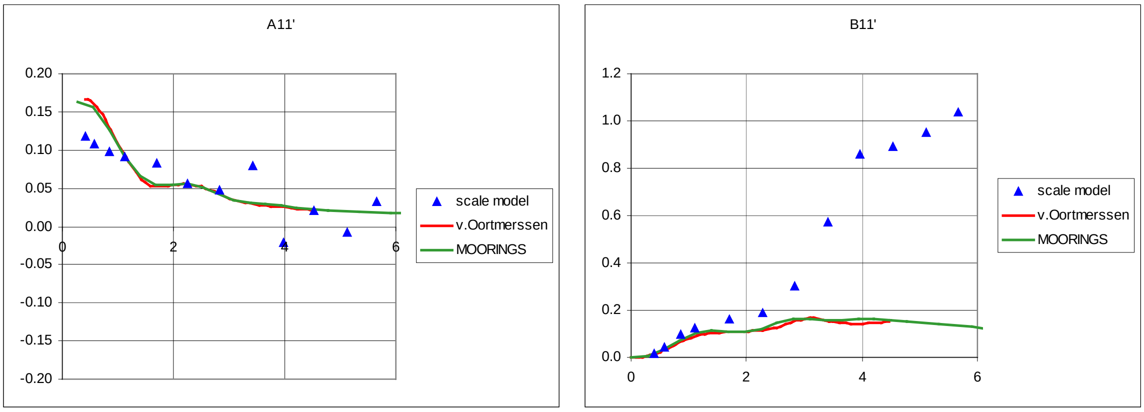


Figure 2.5 Added mass and damping for surge

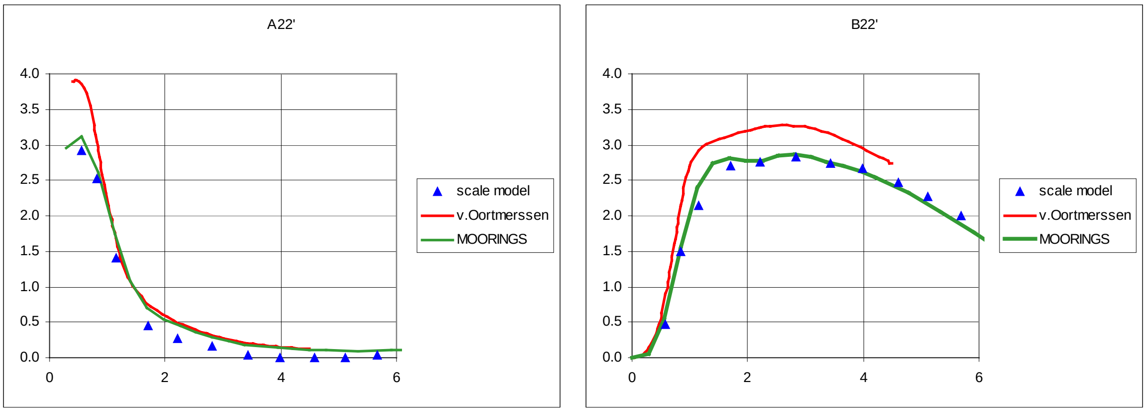


Figure 2.6 Added mass and damping for sway

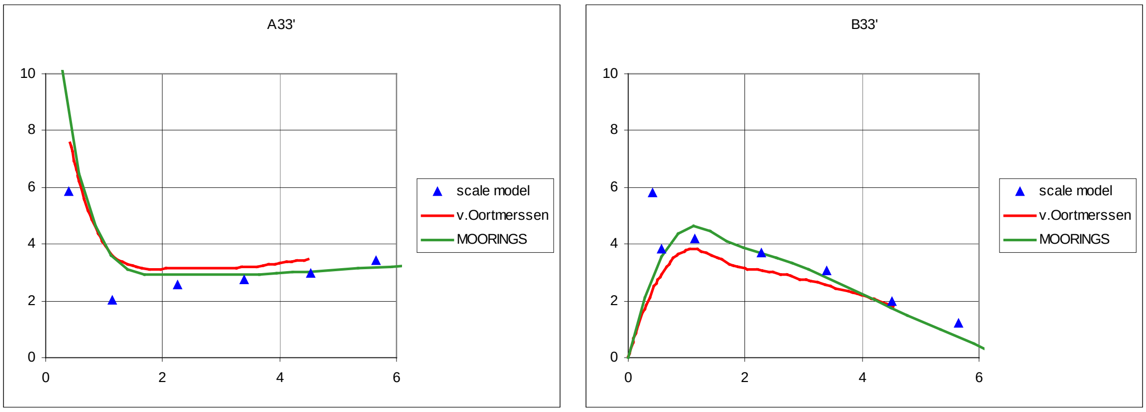


Figure 2.7 Added mass and damping for heave

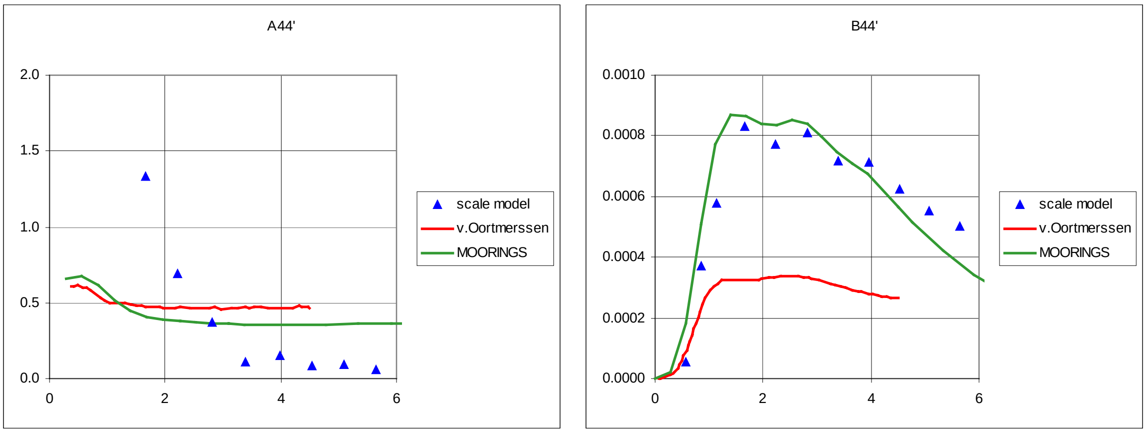


Figure 2.8 Added mass and damping for roll

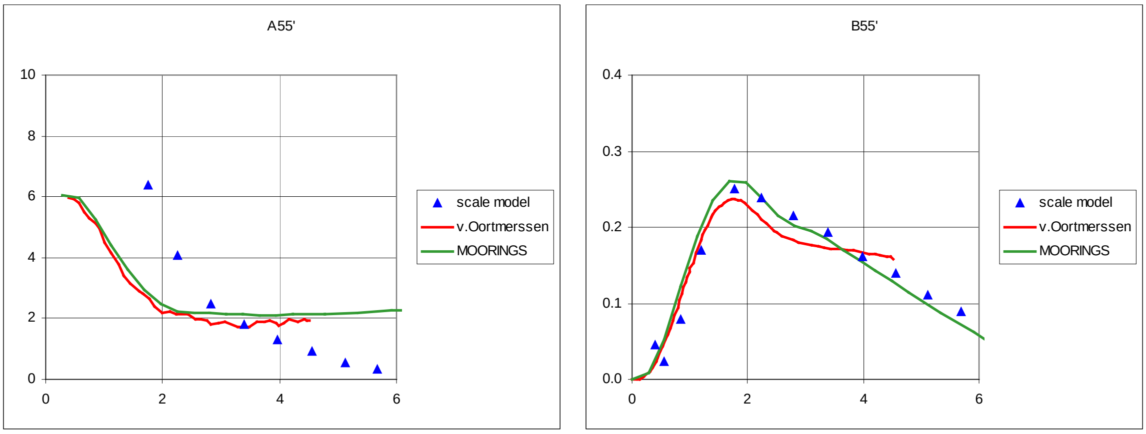


Figure 2.9 Added mass and damping for pitch

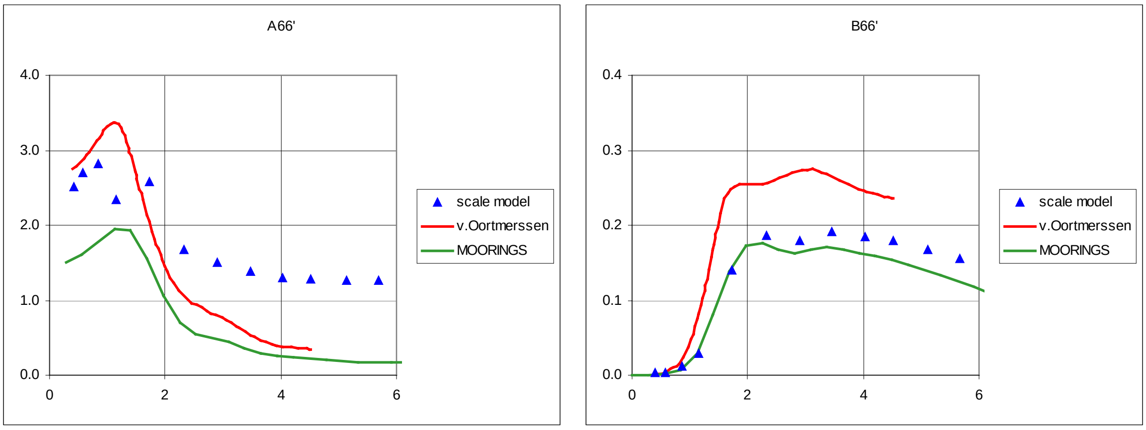


Figure 2.10 Added mass and damping for yaw

Wave forces and moments

The wave forces and moments computed with the Alkyon schematisation and the values measured in the experiments compare very well.
The most important discrepancy between measured and calculated forces is found for the surge and yaw in beam waves. These forces and moments originate from the asymmetry in the hull shape. This could be a result of minor differences in the schematisation of the bow and stern of the ship.

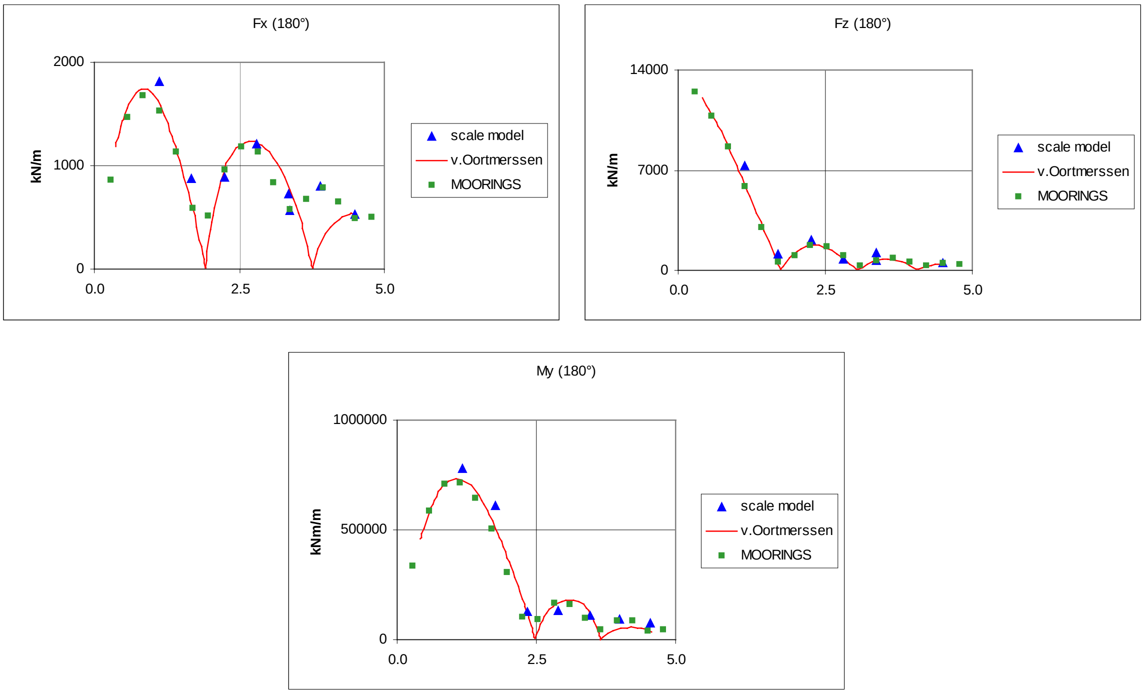


Figure 2.11 Transfer function of wave forces and moments for α = 180°

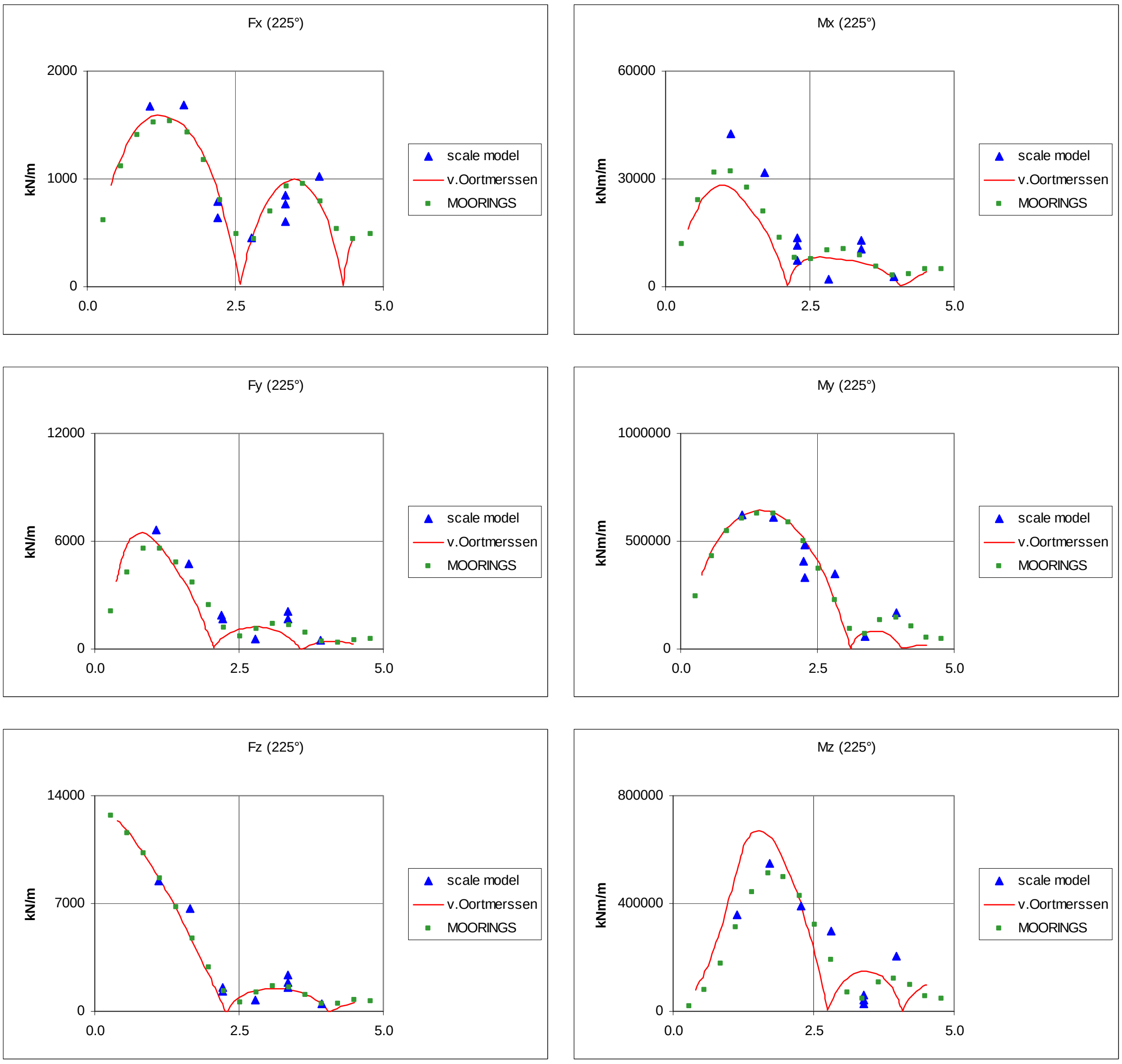


Figure 2.12 Transfer function of wave forces and moments for $\alpha = 225°$

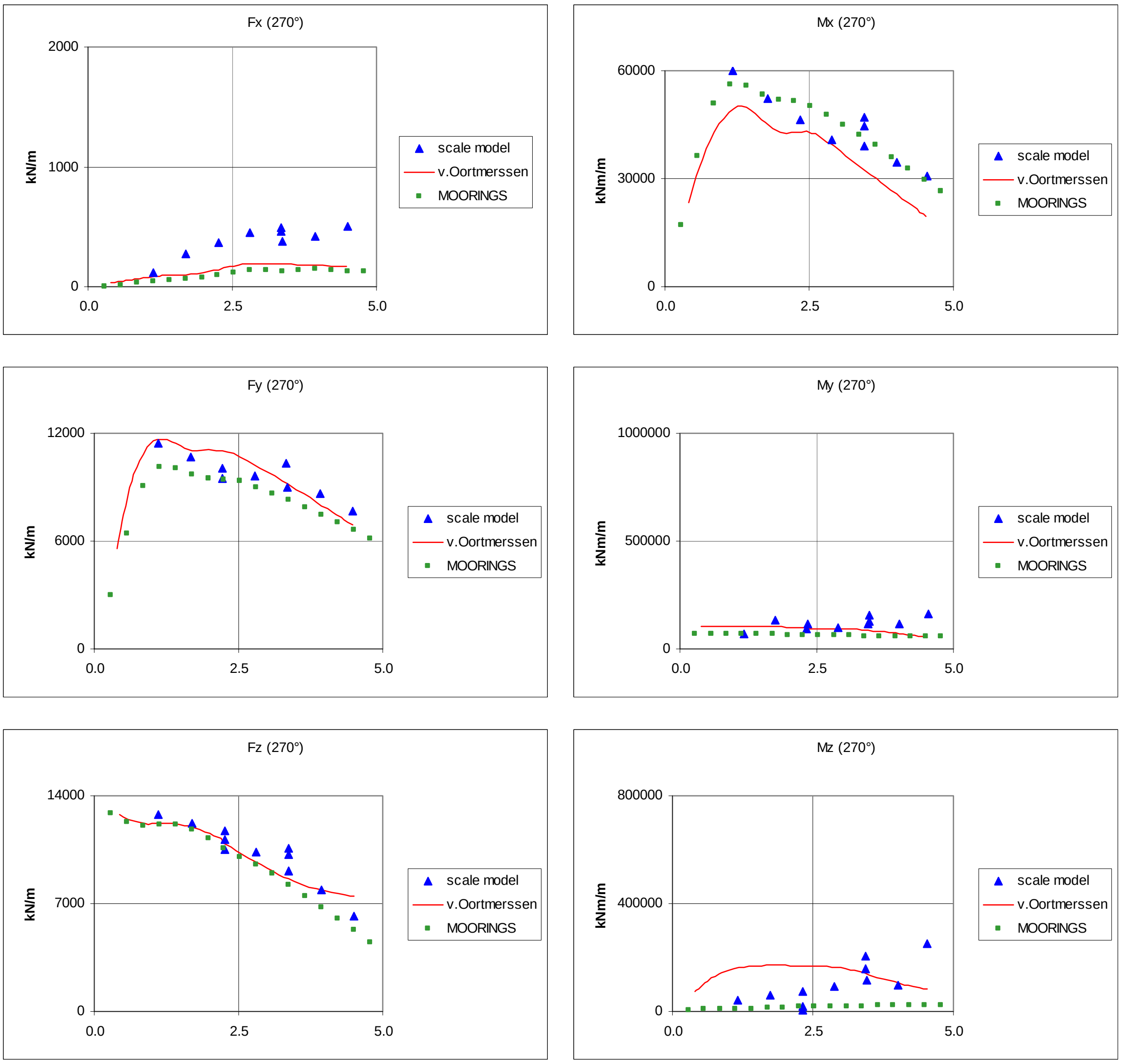


Figure 2.13 Transfer function of wave forces and moments for $\alpha = 270°$

3 Schematisation of mooring layout

The mooring layout used for the comparison between SHIP-MOORINGS, the model test and the Van Oortmerssen model is shown in Figure 3.1.

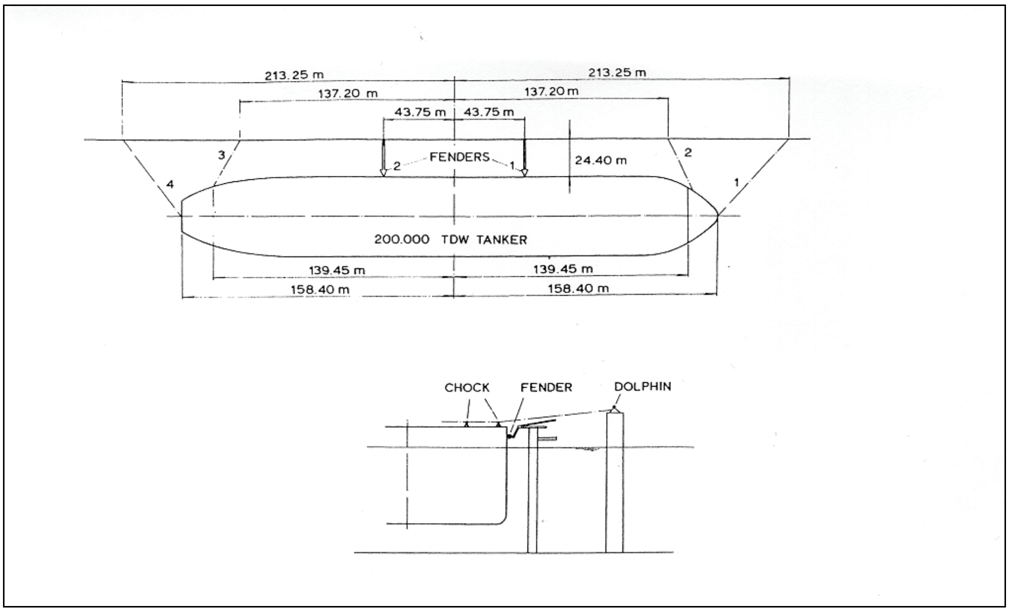


Figure 3.1 Mooring layout used in scale model and numerical simulation [I]

A photograph of the set-up as modelled in the scale model is shown in Figure 3.2.

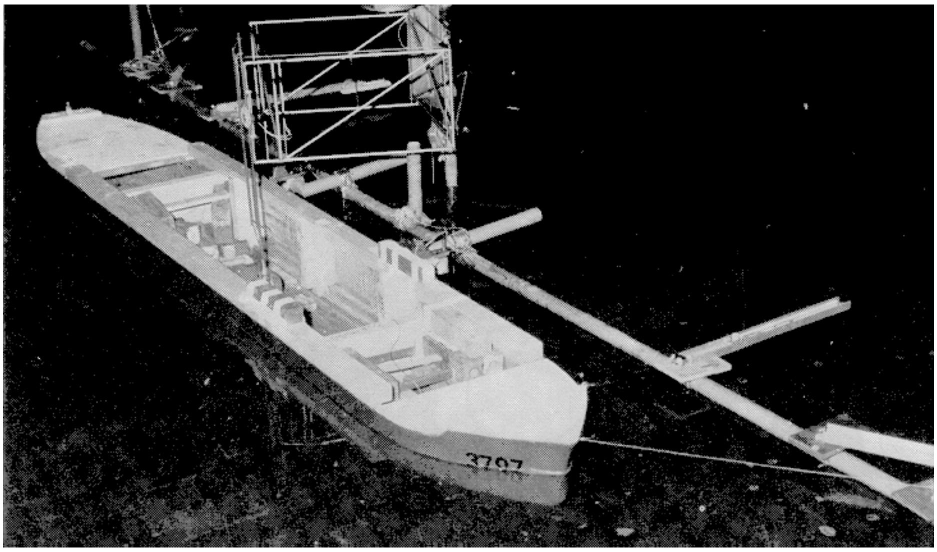


Figure 3.2 Experimental layout of moored ship

Mooring lines

Four mooring lines are used, two at each end of the vessel. Each line corresponds to two or three wires with nylon tails in reality. The non-linear force-elongation characteristic of the lines is shown in Figure 3.3.

The Figure shows the characteristics of the lines as used in the numerical SHIP-MOORINGS simulations and in the scale model. The curve presenting the characteristics of lines 1 and 4 are valid for the scale model in [I] and the SHIP-MOORINGS model. For lines 2 and 3 there is a small discrepancy between the scale model and the SHIP-MOORINGS model for small elongations. This difference is even larger between the scale model and Van Oortmerssen's numerical model (not shown in this Figure).

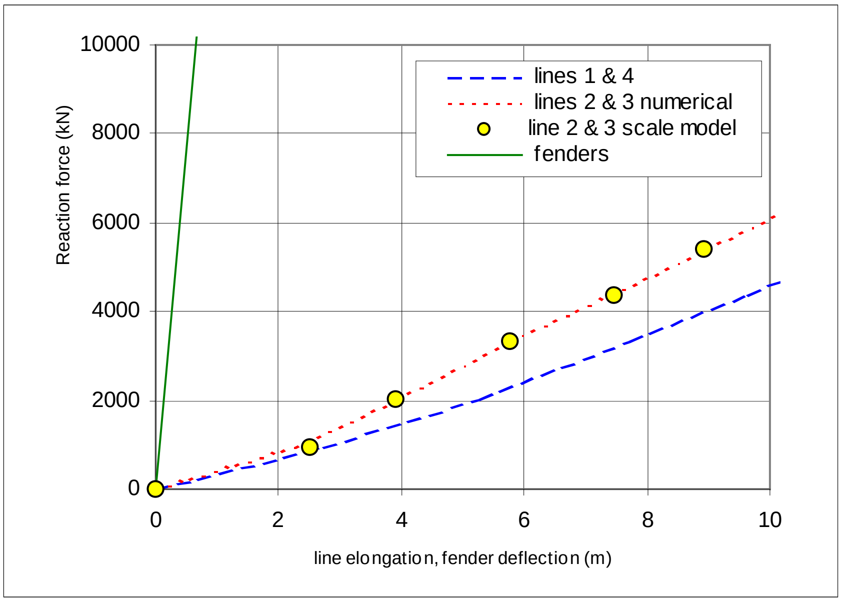


Figure 3.3 Mooring line and fender characteristics

Fenders

Two fenders were used, one slightly forward and one slightly aft of the ship's centre. The force-deflection characteristic of the fenders were linear, as is shown in Figure 3.3, with a spring stiffness of 15451 kN/m. As can be seen from the graph, the fenders have a much stiffer characteristic than the mooring lines.

A photograph of the fender model set-up is shown in Figure 3.4.

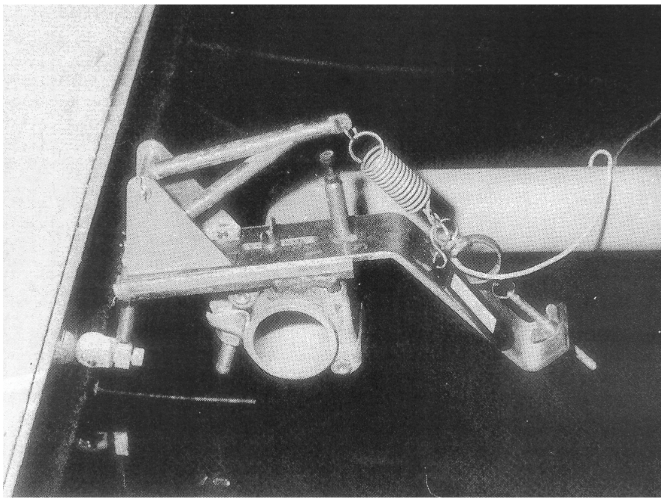


Figure 3.4 Fender set-up in scale model

Uncertain input

A number of input variables were unclear or undefined in [I]. For these variables a best guess was made and used as input in SHIP-MOORINGS. These variables were:

a) Vertical co-ordinates of the fairleads on the ship.
   Used in SHIP-MOORINGS: 8 m above WL for the two lines at the bow and 5 m above WL for the two lines at the stern.
b) Lateral co-ordinates of the fairleads for lines 2 and 3 on the ship.
   Used in SHIP-MOORINGS: 19.6 m off the ship's centre line.
c) Vertical co-ordinates of the bollards on the dolphins.
   Used in SHIP-MOORINGS: 8 m above WL for all lines.
d) Length of mooring line on-board.
   Used in SHIP-MOORINGS: based on the photographs of the scale model in [I] no length on-board was applied.
e) Vertical co-ordinates of the fenders.
   Used in SHIP-MOORINGS: 2.5 m above water level.
f) Pretension in the mooring lines.
   In [I] it says that each line was pre-tensioned with a force of 20 t. However it is not absolutely clear that 20 t for each "model" line is meant or 20 t for each "real" line (as each line corresponds to two or three lines in reality).
   Used in SHIP-MOORINGS: 20 t pretension per "model" line.
g) Friction characteristics of the fenders.
   In [I] it is remarked that the friction between model and fender was minimised by using vertical wheels. However, no further details are given.
   Used in SHIP-MOORINGS: horizontal friction coefficient of 0.2 and a vertical friction coefficient of zero.

General appreciation of the set-up for validation purposes

The mooring layout is characterised by the lack of longitudinal restraint. This means that the ship will be susceptible to long periodic surge motions. These will be affected by any wanted or unwanted long wave energy present in the physical or numerical models. As it is impossible to fully control the occurrence of this long wave energy, the resulting ship response may well be influenced by small inaccuracies in this respect.

Another aspect of concern is the uncertainty of several input variables. Especially the lack of friction data of the fenders resulted in the need to guess these values. In our experience, the amount of fender friction has a considerable effect on ship response and especially in the case of a validation, this may influence the capacity to match the original response data.

Finally the unusually small distance between the two fenders (less than 30% of the ship's length) opens the possibility for considerable yaw oscillations around the two fenders, even with a beam-on wave attack. In that case, small differences in schematisations at the bow and the stern may result in considerable differences between models.

4 Schematisation of wave input

Three types of wave force excitation were used in the various validation tests. They are further described in this section.

Sine force signal

For each motion component a sine function of that motion was input in the equations of motion, using a mass and mass moment of inertia corresponding to a 135,000 m^3 LNG carrier. That way a sine function of the excitation force was manually computed.
That sine force signal was then applied in SHIP-MOORINGS, with the aim to produce a simulated motion response identical to the original sine motion.

Regular long-crested waves

Regular waves were used for checking the SHIP-MOORINGS model for any unwanted distortions during the entire chain of processes in the SHIP-MOORINGS model sequence. This sequence consists of transforming the frequency domain DIFFRAC results to the time domain through retardation functions, producing wave forces, solving the equations of motion and spectrally post-processing the results. When applied to a free-floating object the resulting response spectrum should be identical to a response spectrum obtained directly by applying the DIFFRAC RAO's.

Irregular long-crested waves

Irregular long-crested waves were applied in the tests with the 200,000 DWT tanker moored to a jetty. The long-crested waves were modelled according to the wave spectrum measured in the scale model tests reported in [I].
The measured scale model spectrum is shown in Figure 4.1. It is defined between 0.4 and 1.15 rad/s.

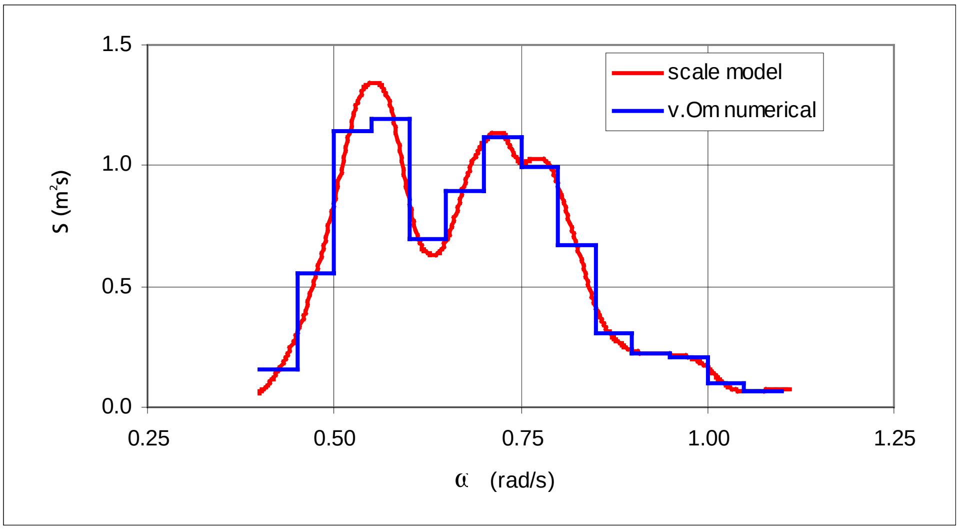


Figure 4.1 Wave spectrum measured in scale model and as used in Van Oortmerssen's model (Hs = 2.8m, Tm = 8.9 s)

The spectrum as used in the numerical simulations in [I] is also shown in Figure 4.1. A total of 15 spectral components were used, i.e. a band width of 0.05 rad/s.
For the SHIP-MOORINGS simulations, the frequency interval used was 0.0015 rad/s, which results in more exact reproduction of the measured spectrum.

General appreciation of wave input accuracy for validation purposes

In SHIP-MOORINGS, the wave spectrum shown in Figure 4.1 was exactly reproduced, i.e. without any wave energy below 0.425 rad/s.
Although generally great care is taken to avoid unwanted long wave phenomena in experimental scale models, in reality avoiding such long waves is almost impossible. These long waves may have a large impact on the moored ship response, especially in a case as tested in [I], where a large ship is moored with relatively elastic mooring lines (especially longitudinally). Such mooring results in long horizontal natural response periods, where the hydrodynamic damping is very low. Given even the smallest amount of long wave energy, the ship will then exhibit very large horizontal oscillatory motions.
Other unwanted disturbances are created by unwanted primary wave reflections from the boundaries, which result in the wave attack not being totally unidirectional. Again, this may influence the comparison, especially in the case of a head on (180°) wave attack.
Therefore, any comparison with a scale model and a numerical model and any conclusions based on such a comparison should be viewed with a certain amount of care.

5 SHIP-MOORINGS computations

Three sets of SHIP-MOORINGS computations have been carried out, viz.:

- basic sine force signal excitation tests;
- free-floating regular wave tests and
- irregular wave tests with ship moored to open jetty.

The input for these tests has been described in Sections 2 to 4. The results of the tests are described in this section.

5.1 The software package SHIP-MOORINGS

SHIP-MOORINGS is a computer program that simulates the dynamic behaviour of a ship moored to a quay or a jetty under conditions of wind, waves and current. The ship is moored against fenders and is secured with mooring lines.

In SHIP-MOORINGS the ship motions are computed by solving in the time domain the equation of motion in six degrees of freedom:

$$\frac{d}{dt}(M\underline{u})=\underline{F}_{total} \tag{1}$$

with

M … the (6x6) inertia matrix
$\underline{u}$ … the velocity vector with the 6 velocity components
$\underline{F}_{total}$ … total sum of all external forces acting on the ship

In SHIP-MOORINGS, the following forces are included in the external force vector:

- hydrostatic reaction forces
- hydrodynamic potential theory reaction forces
- wind forces
- flow forces including viscous reaction forces
- viscous roll damping (as a special case of the flow forces)
- mooring line forces
- fender forces
- wave forces due to first and second order waves
- mean wave drift forces

For the sine excitation force tests none of the above forces were used but instead a fixed sine force signal was excerted on the body.

For the free-floating regular wave tests all the above forces except mooring line, fender and mean wave drift forces were used. It should be noted that in that case, the wind forces included only the reaction force induced by the movement of the ship, no external wind was applied.

For the tests with a moored ship in irregular wave, all the possible external forces were applied (again with the same note for the wind forces). The mean wave drift force was applied only in a limited number of test cases.

Hydrodynamic potential theory reaction forces

An important aspect when transferring from the frequency domain DIFFRAC results to the time-domain SHIP-MOORINGS model is the introduction of retardation functions to represent the ship motion induced hydrodynamic reaction force. This is done according to the formulation by Cummins [II]:

$$F_i = \sum_{j=1}^{6} \left[m_{ij}\, \dot{u}_j(t) + \int_{\tau=-\infty}^{t} K_{ij}(t-\tau)\, u_j(\tau)\, d\tau \right] \tag{2}$$

with:

F_i … the i-th component of the hydrodynamic reaction force

m … added mass coefficient at infinite frequency

u_j … the j-th velocity component

K_{ij} … retardation function for i-th component due to j-th velocity

The added mass at infinite frequency and retardation functions are transformed from the frequency dependent added mass and hydrodynamic damping coefficients. This transformation should be done with care, as especially in the low frequency domain it is possible to introduce a negative hydrodynamic damping if the DIFFRAC results in this area are a bit erratic.

The SHIP-MOORINGS test with the regular waves, which will reproduce the original DIFFRAC rao is partly meant as a check to determine whether this process is working correctly. This test is described in Section 5.3.

5.2 Basic sinusoidal force signal excitation tests

Basic response tests were carried out with a mass subject to a sinusoidal force signal. This signal was created by substituting a theoretical sine-motion in the equations of motions. When running SHIP-MOORINGS the object was to produce a simulated motion response, which was identical to the substituted theoretical sine motion. This should prove that the equations of motions are solved correctly by the SHIP-MOORINGS solver and that the various transformations in the rotating system of axes and the various transformations between dimensionless and dimension-full data do not distort the basic system of equations.

Several motion combinations were tested. Figures 5.1-5.3 show the results of a de-coupled horizontal motions test where the excitation force signal was obtained from a theoretical motion with a surge amplitude of 0.5 m, a sway amplitude of 1.0 m and a yaw amplitude of 5.3°.

The force signal is applied over a period of 10,000 s of which the first 2,500 s are used as a slow-start; i.e. the force signal is slowly increased to the required value. As can be seen from the plots the model after the slow start returns almost these exact values.

Also very important is that the response in the SHIP-MOORINGS model does not deviate from these values due to numerical “drifting”, even with the very long 10,000 seconds test period.

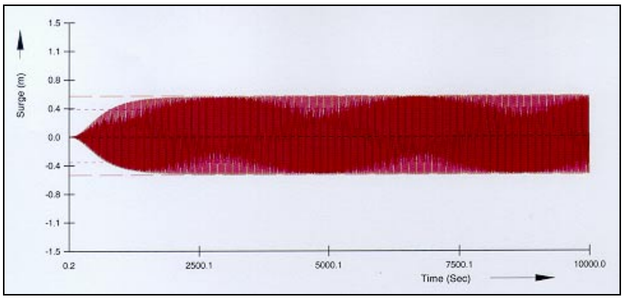


Figure 5.1 Sine force surge response

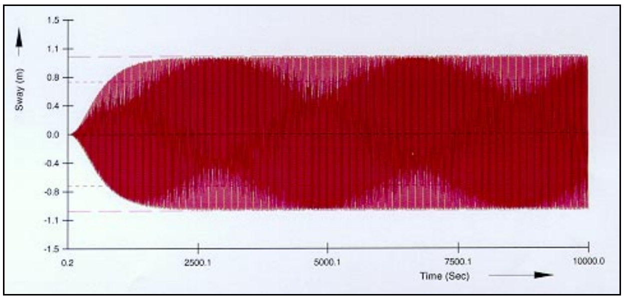


Figure 5.2 Sine force sway response

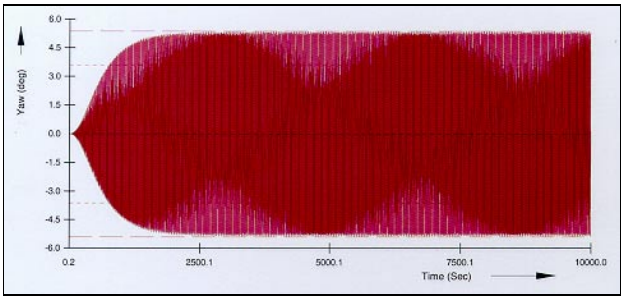


Figure 5.3 Sine force yaw response

5.3 Regular wave tests with free-floating ship

As explained in Chapter 4, tests were carried out for checking the SHIP-MOORINGS model for any unwanted distortions during the entire chain of processes in the SHIP-MOORINGS model sequence. The runs were carried out with a free-floating ship in regular long-crested waves. The tests were carried out with waves with an ω of 0.2, 0.3 and 0.4 rad/sec. coming from 132° with respect to the ships x-axis. The wave height was 1.0 m so the results could be compared directly with the RAO's determined with DIFFRAC. The graphical presentation is given in Figure 5.4. As can be seen from these results, the correspondence is good. The only, relatively, large difference is for the rotations Roll and Yaw. This can be explained by the fact that in DIFFRAC no viscous damping was added, but in the model SHIP-MOORINGS it was. This viscous damping does not only decrease the amplitude of the motion, but does also shift the natural response frequency. This is clearly visible for the rotation Roll. The mooring results for roll are well comparable with the experimental results given in [I] (not presented in this report).

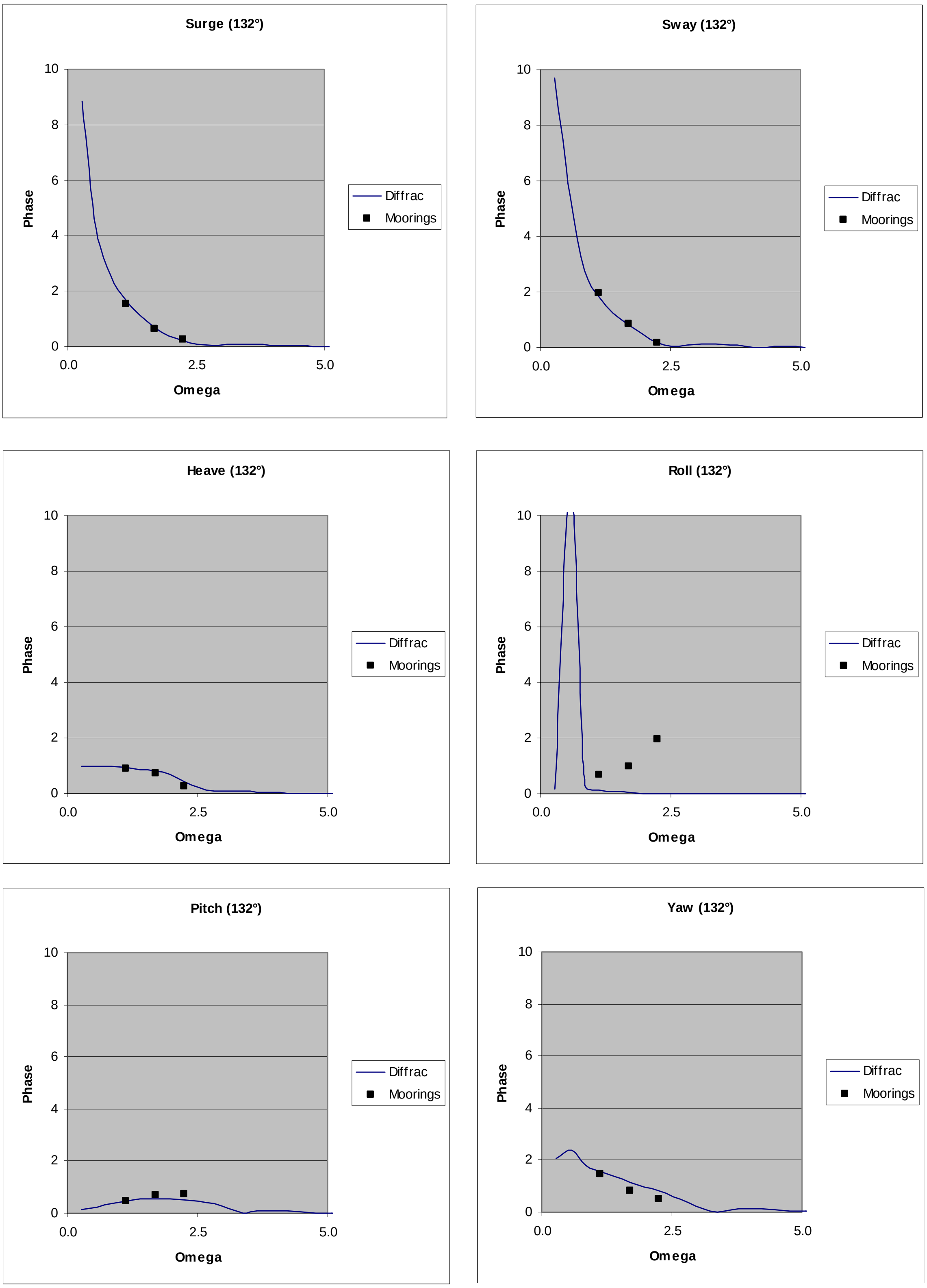


Figure 5.4 regular wave test results compared with the RAO's of DIFFRAC

5.4 Irregular wave tests with moored ship

SHIP-MOORINGS simulations in irregular waves were carried out for a 200,000 DWT tanker moored to an open jetty and compared to scale model tests and numerical computations presented in [I].

The ship modelling is discussed in detail in Section 2, the mooring system schematisation in Section 3 and the wave modelling in Section 4.
Three tests were carried out, all with the same wave spectrum with the directions 90°, 135° and 180° relative to the x-axis. Figure 5.5 shows the directions with the arrows pointing towards the direction the waves are going to.

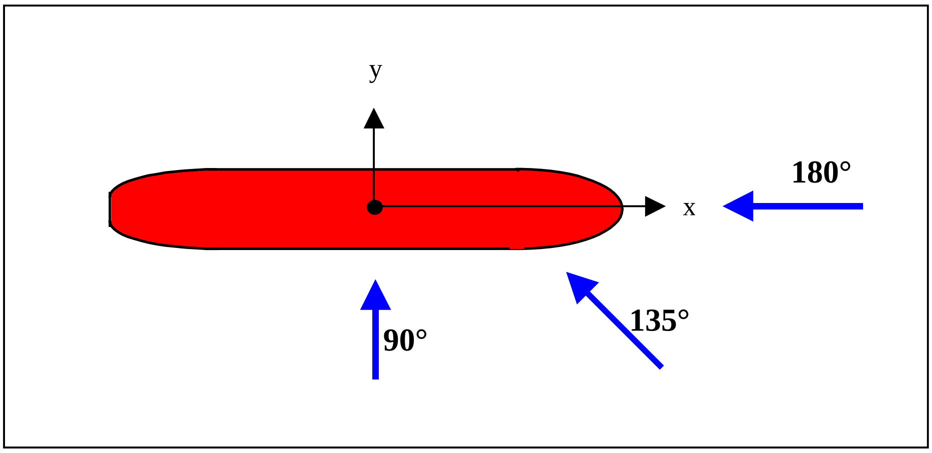


Figure 5.5 Definition of wave directions

Results for 135° wave direction

Figure 5.6 shows the significant motion response amplitudes for the six motion components. It includes the simulation results from SHIP-MOORINGS, the scale model and Van Oortmerssen's numerical model.

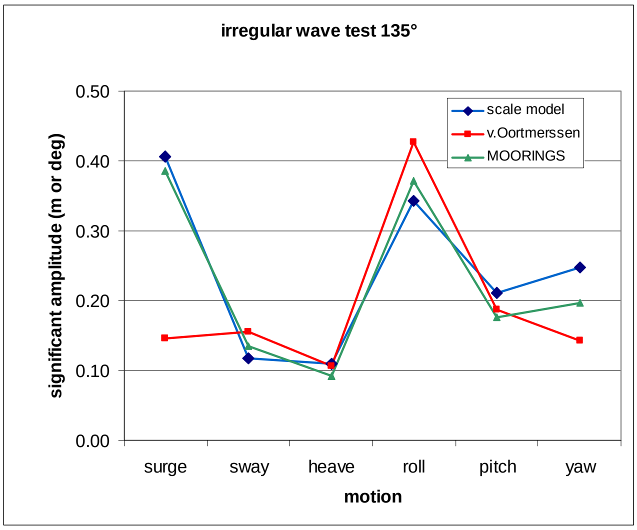


Figure 5.6 Significant motion response for 135° wave angle

As can be seen from the figure the SHIP-MOORINGS results correspond very well with the scale model test. Mainly in surge and yaw, but also in roll the results of SHIP-MOORINGS show a better correlation than the old numerical model. This is especially interesting for surge, since this difficult motion in this case is mainly generated by second order effects caused by the non-linearity of the mooring system.

Figure 5.7 shows the motion response spectra of the moored vessel. Apart from the SHIP-MOORINGS simulations, it also includes the results of the scale model tests and Van Oortmerssen's numerical model.

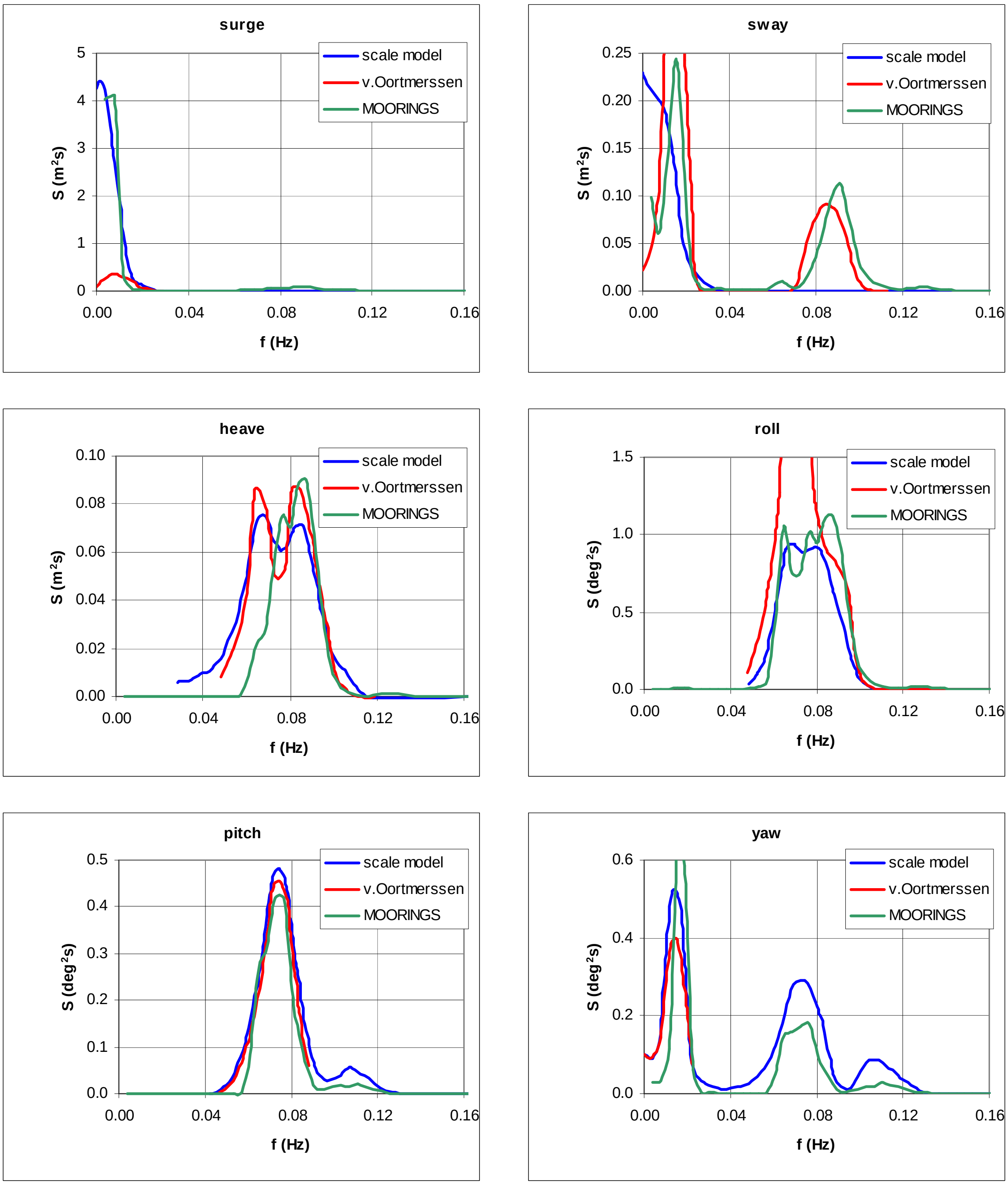


Figure 5.7 Motion response spectra for 135° wave angle

Figure 5.7 includes graphs of the six motion components. It shows that there is a considerable sub-harmonic response in the horizontal motions, i.e. at frequencies where the wave spectrum does not contain any energy. This is an effect of the non-linearity of the mooring system and the lack of damping in that area. SHIP-MOORINGS manages to reproduce this difficult phenomenon very well, considerably better than the older numerical model, especially in surge.

For the other motions roll and pitch are reproduced very well. It must be noted that the roll response not only depends on the potential damping computed by DIFFRAC but also very much on the viscous roll damping applied in SHIP-MOORINGS. The results show that the basic formulation of viscous roll gives very acceptable results.

The largest differences are found in heave between 0.04 and 0.06 Hz. This we can not explain since the vertical motions (especially heave) are generally directly dependent on the availability of wave energy and are not subject to disturbances of the mooring system. The response found with SHIP-MOORINGS is consistent with this expected behaviour.

Results for 90° wave direction

Figure 5.8 shows the significant motion response amplitudes for the six motion components for the beam wave condition.

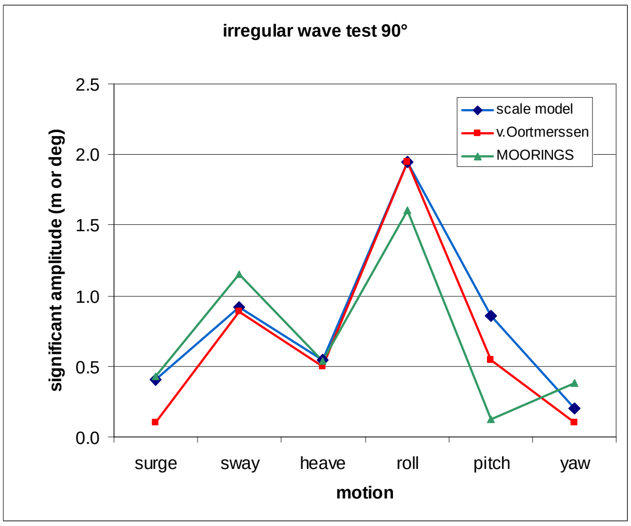


Figure 5.8 Significant motion response for 90° wave angle

As with the quartering waves, there is a very good correlation between the SHIP-MOORINGS results and the scale model tests, with the exception of pitch.

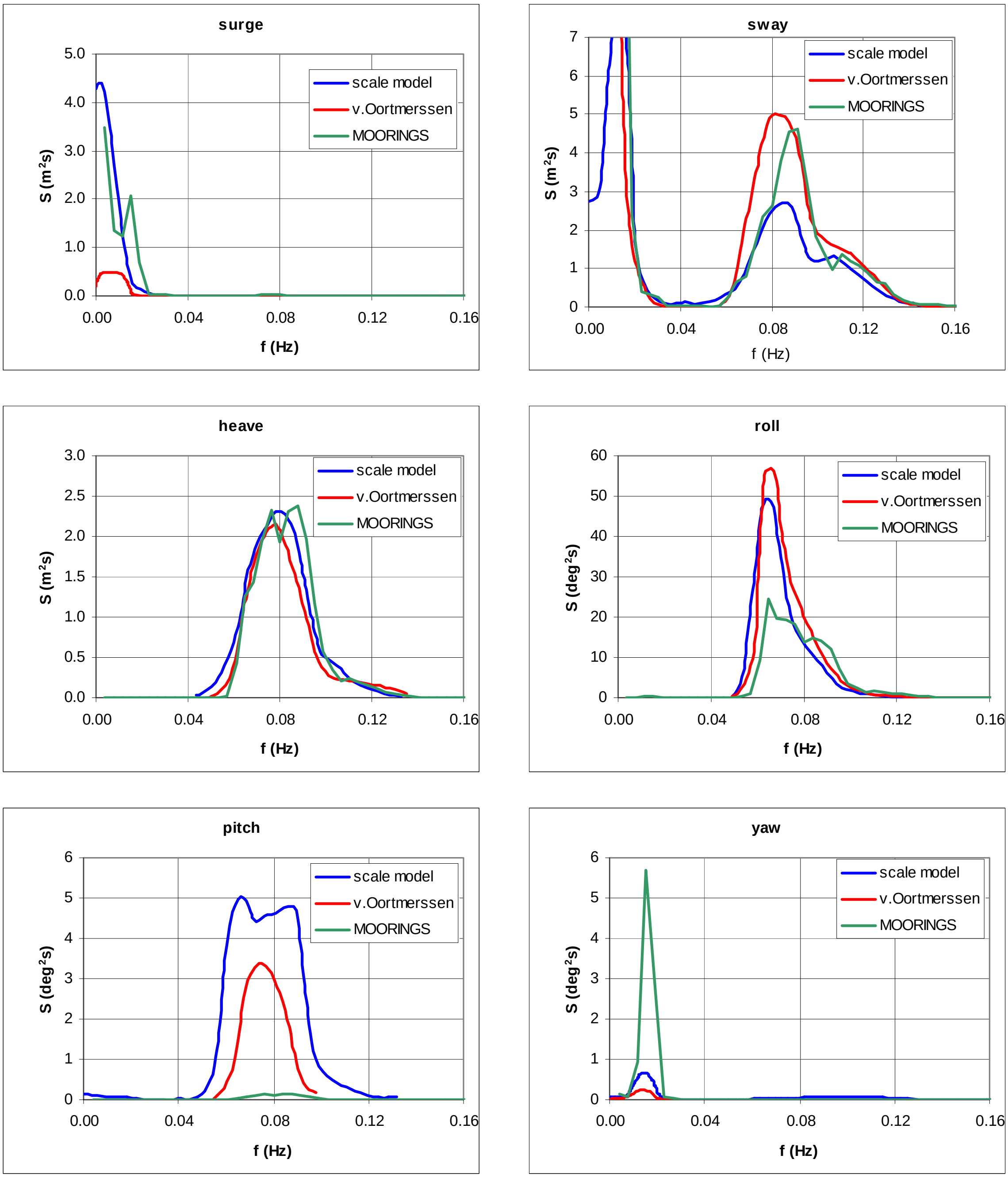


Figure 5.9 Motion response spectra for 90° wave angle

In addition, from the motion response graphs in Figure 5.9 it can be seen that the comparison between SHIP-MOORINGS and the scale model is good.

There is some difference in the sub-harmonic response of the yaw, but this is a small motion and with a beam attack very much dependent on small changes of the modelling of the bow and stern. As stated above the pitch is much lower than the pitch response in the other models. As pitch is hardly influenced by the mooring system and since the SHIP-MOORINGS pitch response totally complies with the DIFFRAC RAO's for pitch no explanation of this discrepancy can be given.

Results for 180° wave direction

A good comparison between the scale model tests and the SHIP-MOORINGS program is not possible here, since [I] indicates that introduction of slowly-varying drift-forces is needed to get a good correlation between numerical and scale model, especially for the surge motion. The numerical model in [I] obtains this good correlation only after applying a force time series with an estimation of slowly varying drift force. Reference [I] however does not give the magnitude and form of this force so this cannot be reproduced with SHIP-MOORINGS in this study.

Therefore, only a comparison is made between SHIP-MOORINGS and the numerical model in [I] of the results without a slowly varying drift force. If those results are satisfactorily then one can cautiously assume that with the application of the same force time series as applied in [I] the SHIP-MOORINGS results would also yield a good comparison with the model tests.

The only results in [I] from the numerical computations without the slowly varying time series are given in the form of maxima and minima of the horizontal motions. The comparison with SHIP-MOORINGS is given in Table 5.1 below.

			V.Om.	SHIP-MOORINGS
surge	– min	(m)	-0.43	-0.45
surge	– max	(m)	-0.02	0.01
sway	– min	(m)	0.02	0.02
sway	– max	(m)	0.02	0.02
yaw	– min	(deg)	0.005	0.001
yaw	– max	(deg)	0.01	0.01

Table 5.1

As can be seen, the results compare very well.

Introduction of directly computed slowly varying wave drift forces is presently being developed for the newest version of SHIP-MOORINGS.

Conclusions from irregular wave tests with moored ship

The results from the tests with the moored ship in irregular waves show a good correlation between SHIP-MOORINGS and the scale model for the 135° and 90° wave direction. Especially the sub-harmonic motions, which are very important for large moored vessels, are correctly reproduced.

Differences are found in the vertical motions for heave (135°) and pitch (90°). These differences could not be explained, but it is believed that the SHIP-MOORINGS results correctly compute these motions based on the DIFFRAC schematisation.

The 180° wave direction tests could only be set against the numerical model in [I] since a comparison with the scale model would require modelling the slowly varying drift forces. The comparison of SHIP-MOORINGS with the numerical model in [I] is good.

6 Conclusions

Based on the tests carried out with SHIP-MOORINGS and the comparison with the scale model tests and numerical tests reported in [I] it is possible to draw a number of conclusions.

1. It is important to remark that any model of the reality, albeit a numerical model or a physical scale model, introduces inaccuracies and model disturbances. A comparison between two such models is therefore nothing more than a comparison between two approximations of reality. This means that even an absolute correlation between the models will not guarantee the total accuracy of either of the models.
2. The frequency domain boundary element 3-D potential theory wave diffraction program DIFFRAC provides basic input data for the time domain moored ship simulation program SHIP-MOORINGS. This study shows that the hydrodynamic reaction forces and wave exciting forces obtained with DIFFRAC show a good correlation with scale model measurements. Overall, the finer schematisation used in this study to model the ship results in a better correlation with the scale model than the very coarse schematisation in [I].
3. The basic formulation of the equations of motion and the specific solver used in SHIP-MOORINGS were tested with the application of sinusoidal force signals and showed a very satisfactory return of the expected motion, without any “drift” in the results.
4. The time-domain formulations and solving techniques in SHIP-MOORINGS were tested by free-floating regular wave tests. The results show the expected reproduction of the frequency-domain RAO values as computed in DIFFRAC.
5. The results from the tests with the moored ship in irregular waves show a good correlation between SHIP-MOORINGS and the scale model for the 135° and 90° wave direction. Especially the low-frequent motion response, which is very important for large moored vessels, is reproduced much better than with the numerical model in [I].
6. Differences in the moored ship tests are found in the vertical motions for heave (135°) and pitch (90°). These differences could not be explained, but it is believed that the SHIP-MOORINGS results correctly compute these motions based on the DIFFRAC schematisation of the ship used in this study.
7. According to [I], 180° wave direction scale model tests can only be reproduced with the introduction of slowly varying drift forces. These forces are not modelled in SHIP-MOORINGS v5.02. It must be noted that the model tests in [I] were carried out with long-crested waves. Use of directionally spreaded waves will result in surge motions that will reduce the relative importance of the slowly varying drift forces. It must be noted that the introduction of slowly varying wave forces is currently being tested in the newest version of SHIP-MOORINGS.

Overall conclusion

The use of SHIP-MOORINGS as a tool to predict the motions of a moored ship (and therefore also the forces in the mooring lines and fenders) compares very well with the use of a scale model.

References

[I] Oortmerssen, G. van, 1976. *The motions of a moored ship in waves*, Thesis; Delft University of Technology 16 June 1976

[II] Cummins, W.E., 1962; *The impulse response function and ship motions*; Symposium on ship theory, Institut für Schiffbau der Universität Hamburg, Hamburg, Germany, 25-27 January 1962

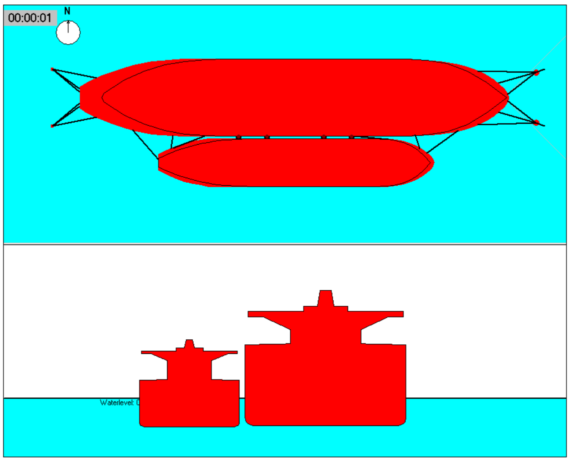
Appendix

Examples of project-based validation

The review, testing and development of SHIP-MOORINGS is a continuous process that is embedded in the research consultancy practice at Alkyon. Alkyon annually carries out numerous moored ship projects, which often contain validation components. A few examples of on-going projects are given below.

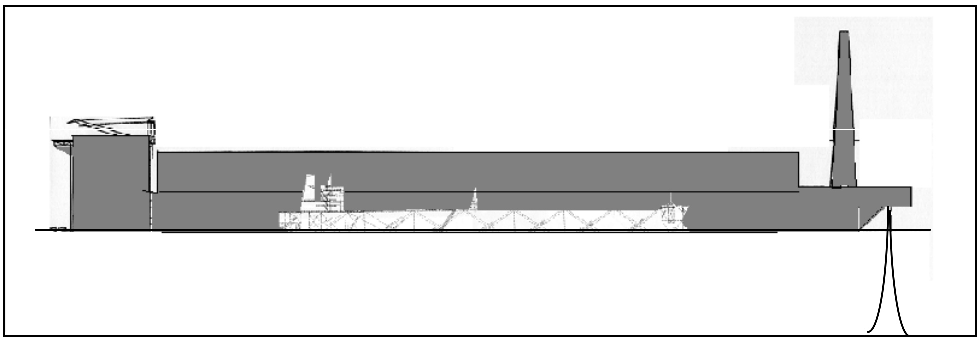
Ship moored to piles , buoys and anchors

At this moment, Alkyon is working on the development of SHIP-MOORINGS v6.02. This version includes multi-body applications.

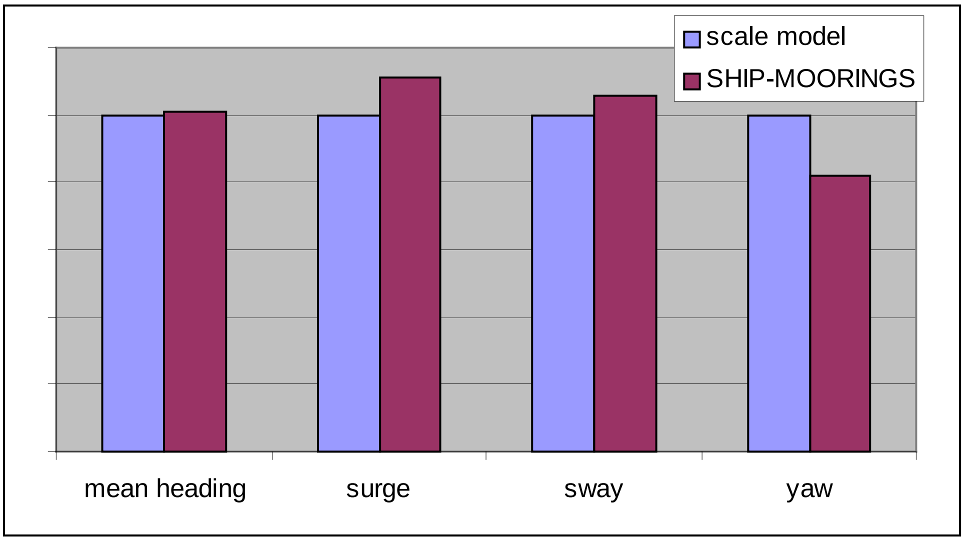


Example of a multi-body simulation. It concerns a 405,000 DWT tanker in ballast and an 85,000 DWT tanker in loaded condition. The large vessel was connected to two piles (at the stern) and two Buoys (at the bow). The smaller vessel was moored at the large vessel with floating fenders in between. The simulations aimed to reproduce the actual situation, which is presently experienced in a particular port, and define improvements for the mooring system.

Offshore application

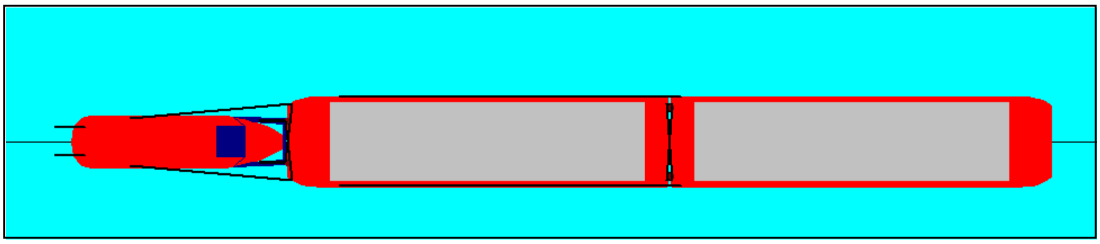


Picture of FPSO-like structure moored with 9 composite chains. This object was modelled in SHIP-MOORINGS and run in moorings/navigation combination mode (i.e. with large horizontal motions and use of thrusters).



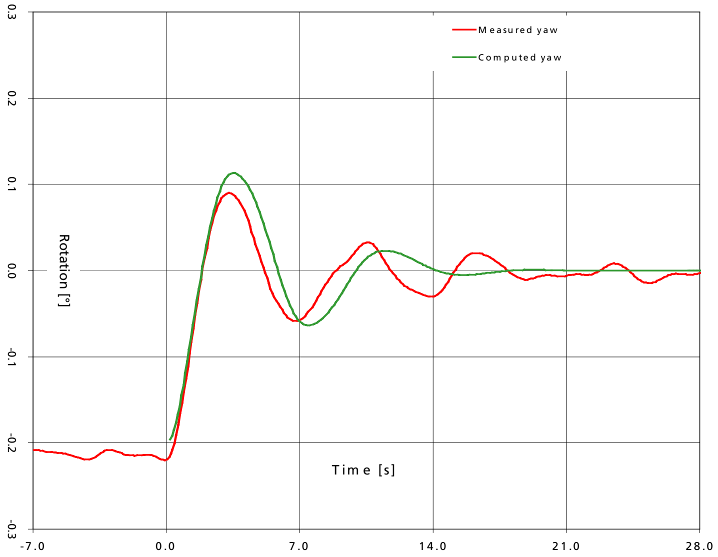
The results were compared with scale model measurements of a body with slightly smaller dimensions. The comparison still showed a good correlation as shown in the Figure above.

Inland pushtow manoeuvring in waves



This Figure shows a SHIP-MOORINGS model of a pushtow (one pusher, two barges) manoeuvring in waves. For this research project, prototype measurements in open water were carried out, aimed to validate the computer model.

Photograph of the pushtow sailing to open water to carry out prototype measurements for the SHIP-MOORINGS validation of pushtow simulation model.



Despite inherent difficulties when executing prototype measurements (especially when measuring on a detached moving body) the comparison found was of good quality and allowed a further development of the model. The Figure above shows the measured ((red) and computed (green) values of the relative motion between the two loaded barges when initiating a turning circle in waves.

Addendum

Slowly varying wave drift forces for 180° test

In the validation test with the moored vessel in head waves (180°) it was not possible to reproduce the surge motion in SHIP-MOORINGS v5.03. This is because according to Van Oortmerssen [I] this would have required the use of slowly varying driftforces which are not modelled in v5.03. Van Oortmerssen used a scaled measured force signal of the slowly varying forces to approximate this effect and succeeded in obtaining a good reproduction.

With the newest version of SHIP-MOORINGS (v6.02), which is still in the development and testing stage, it is possible to include directly computed slowly varying drift forces in the simulations.

In order to check whether the application of this new slowly varying drift force module would indeed result in surge motions of the magnitude of the measured scale model motions in head waves, it was decided to transform the validation ship from v5.03 to v6.02 and repeat the 180° irregular wave test.

The results of this test are given in the table below. It must be noted that the values given for maxima and minima are based on a signal with only about 10 oscillations, so these values are not statistically reliable. However, they do give a good impression for a general comparison.

				without slowly varying		with slowly varying	
			scale model	V.Om.	SHIP-MOORINGS	V.Om.	SHIP-MOORINGS
surge	– min	(m)	-1.39	-0.43	-0.45	-1.13	-1.27
surge	– max	(m)	0.58	-0.02	-0.22	0.68	1.08
sway	– min	(m)	-0.03	0.02	0.02	0.02	0.00
sway	– max	(m)	0.03	0.02	0.02	0.02	0.03
yaw	– min	(deg)	-0.13	0.005	0.001	-0.03	-0.04
yaw	– max	(deg)	0.25	0.01	0.01	0.04	0.04

The surge motion now is of the correct order of magnitude. The yaw rotation is not reproduced, but in our experience this is very difficult to achieve with longcrested head-on waves. In a scale model there is always some measure of directional spreading which can introduce a yaw motion. Such spreading is totally absent in a numerical model.

A quick review of the motion response spectra of the tests with the slowly varying forces shows (not presented here) also an almost exact reproduction of the measured surge spectral form (the surge energy is totally concentrated in the frequency range below 0.15 Hz). This also indicates that the differences in maxima and minima are certainly influenced by randomicity due to the short test duration.

The tentative conclusion is that the introduction of slowly varying drift forces correctly reproduces the scale model results in the case of pure head waves.