CALCULATIONS OF THE MOTIONS OF A SHIP MOORED WITH MOORMASTER™ UNITS

By

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ABSTRACT

Container ships should only make very small horizontal movements at the berth for efficient (off)loading of containers. This is especially a concern in ports directly facing the open ocean, where high swells at sea can cause harbour oscillations and low-frequency surge motions of the ship. Cavotec MSL has developed a new mooring unit, the MoorMaster™, which replaces conventional mooring lines. The hydraulics of the system have a strong reducing effect on the motions of the moored ship. Measurements at a container terminal have shown that the surge motion of container ships was reduced from an amplitude in the order of 1 metre to an amplitude in the order of 5 centimetres, by using MoorMaster™ units. However, before MoorMaster™ units can be installed with confidence in other (new) terminals and comparisons can be made with other mooring systems, the characteristics of MoorMaster™ units should be included in numerical models for motions of moored ships. This paper compares the results of numerical simulations and measurements for motions of ships moored with MoorMaster™ units. The comparison shows that the effect of the MoorMaster™ units on the ship motions is taken into account well by the numerical model. However the exact magnitude and frequencies of the motions of the moored ships differs for measurements and simulations, mainly because of several unknown parameters during the measurements.

Keywords: boussinesq wave modeling, MoorMaster™ units, ship mooring, ship motion measurements, vacuum mooring

1 INTRODUCTION

When a ship is moored at a quay wall or jetty, certain problems can occur:

- Mooring lines can break, which has resulted in (lethal) accidents in the past.
- Large motions of moored ships can result in inefficient handling of cargo by the cranes at the quay wall or jetty, especially in case of container handling. The surge motion of a moored container ship is very critical. The surge amplitude should be smaller than 0.5 metre for efficient container handling (PIANC, 1995).

MoorMaster™ units (Figure 1) can offer a solution for both these problems. MoorMaster™ units consist of a vacuum pad which is attached to the ship hull. Hydraulic cylinders, connected to the vacuum pad, generate forces in the horizontal plane to control the horizontal motions of the moored ship. Four to twelve units are required to moor a ship depending on size of the ship, the cargo handling requirements and the local environmental conditions.

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MoorMaster™ units have been installed in several ports based on practical experience instead of based on numerical or physical modeling results. Measurements have shown that ships moored with MoorMaster™ units move much less than ships moored with mooring lines.

Figure 1: MoorMaster™ unit

Numerical models are an important tool for port engineers to make a port design, which provides acceptable conditions to handle the cargo efficiently. MoorMaster™ units have been modeled in numerical models, but without the hydrodynamic behaviour of the ship and the results have not been compared with measurements. This paper describes the validation of numerical simulations of motions of ships moored with MoorMaster™ units. The validation is done by comparing the results of simulations with prototype measurements that have been done in June 2007 at a port.

2 MOORMASTER™ UNITS

In 1999 Cavotec installed the first MoorMaster™ units at a ferry terminal in New Zeeland. Currently the units have been installed at about 10 locations in the world, mainly ferry terminals. The main advantage of MoorMaster™ units for a ferry terminal is quick mooring and instant release of the ship, without use of mooring lines.

Apart from a quick fastening of the vessel using vacuum pads, the hydraulics of the system showed to have a strong reducing effect on the motions of the moored ship. Therewith, MoorMaster™ units include a method to reduce (large) vessel motions and reduce operational downtime, which makes them suitable for mooring large container ships.
The force capacity of a MoorMaster™ unit varies between 200 kN and 500 kN, depending on the type. The direction and magnitude of the forces are controlled by a PID (Proportional Integral Derivative) controller, which can be set to calculate the forces based on (integrated) displacements and velocities of the ship. The PID coefficients can be tuned to optimize the transfer of forces from the mooring unit to the ship.

To improve cargo handling efficiency, controlling the vertical motion of the container ship is not relevant since vertical motions of the container ship can be compensated by the container crane operator. Therefore the units are constructed on 2 vertical rails, which allow the units to move freely in vertical direction.

MoorMaster™ units control horizontal motions of moored ship better than mooring lines, because:

- MoorMaster™ units are stiff and generate efficient forces in magnitude and direction to control ship motions. Forces generated by mooring lines only respond to (relatively large) displacements of the moored ship.
- The MoorMaster™ force is being generated for 100% in the horizontal plane. Only a percentage of the force generated by a mooring line (40%-80%, depending on the angle of the mooring line) acts in the horizontal plane.

The feasibility of MoorMaster™ units mainly depends on environmental conditions and operational requirements in a port and is eventually an economic consideration. Possible economic advantages of MoorMaster™ units compared to mooring lines are:

- Increasing efficiency of cargo handling and extending the operational period of cargo handling, because of higher reduction of ship motions.

- MoorMaster™ units can allow higher waves in the harbour basin, while still keeping the ship motions within the motion criteria for efficient cargo handling. This can result in considerable savings on breakwaters.

Possible disadvantages of using MoorMaster™ units, compared to using mooring lines are:

- Higher capital costs (of the units only, not considering possible cost savings of more efficient operations and reduced length of breakwaters).
- High maintenance level, especially in a saline environment of a sea port.
- Higher power consumption.
- Uncertainties about the benefits of the system. Results of research such as described in this Paper can lead to more insight into the effect of MoorMaster™ units.

3 COMPUTATIONAL METHOD

A chain of numerical models is used to calculate the motions of moored ships inside a harbour basin. With this approach the motions of the moored ship are determined taking into account coastal bathymetry, harbour geometry and shape of the ship hull. A flow diagram of the coupled numerical models is formulated as follows:

Ocean waves from measurements or output from another wave model (Mike 21 BW input)
↓
Wave propagation (Mike 21 BW calculation)
↓
Surface elevations and horizontal fluxes in the harbour (Mike 21 BW output / Harberth input)
↓
Vertical velocity profile (Harberth calculation)
↓
Pressure and fluid velocities at the hull (Harberth calculation)
↓
Wave diffraction (Harberth calculation)
↓
Wave forces on the ship (Harberth output / Quaysim input)
↓
Wave radiation and interaction with the mooring system (Quaysim calculation)
↓
Ship motions and mooring forces (Quaysim output)

Mike 21 BW (Boussinesq Waves; Madsen et al, 1991, 1992) is used to calculate the propagation of waves into the harbour basin. The model does not consider the presence of a ship. Irregular multi-directional waves can be generated at an offshore boundary. Bound long waves will develop as the waves propagate into shallower water. Therefore, Boussinesq models can also be used to analyse low-frequency harbour oscillations due to wave group forcing (Woo & Liu, 2004). Partial reflection of (long) waves from the shore and from breakwaters can be modeled for which the reflection coefficient is tuned for the dominant wave periods.

The output of Mike 21 BW consists of surface elevations and horizontal fluxes (depth-integrated velocities). An inverse transformation of the Mike 21 BW model equations is used in Harberth to retain the depth-varying fluid velocities and pressures at the ship hull.

Integration of the pressures in the incident wave (from Mike 21 BW without the ship) leads to the Froude-Krylov forces. The diffraction force due to scattering of the incident wave by the presence of the ship is computed with Harberth (Van der Molen, 2006, 2008). Harberth is a panel model based on the time-domain free surface Green function. Reflections of the incident waves against the quay wall are included in Mike 21 BW, but the reflections against the quay wall of waves scattered by the ship are treated in Harberth. Bound long waves and low-frequency harbour oscillations are part of the Mike 21 BW results. Therefore, the forces due to these waves are computed directly in Harberth without additions. Wave drift forces can be determined using the pressure integration method.

The wave forces are the exciting forces in the dynamic simulations of the moored ship with Quaysim. Quaysim is a time-domain moored ship motion simulation program based on Cummins' equation of motion (Cummins, 1962), (1).

$$(\mathbf{M}+\mathbf{A})\ddot{\vec{X}}(t)+\int_{0}^{\infty}\mathbf{K}(\tau)\dot{\vec{X}}(t-\tau)d\tau+\mathbf{C}\vec{X}(t)=\vec{F}(t) \qquad \textbf{\textit{(1)}}$$

where X is the ship motion in six degrees of freedom: surge, sway heave, roll, pitch and yaw. **M** is the inertia matrix, **A** is the infinite frequency added mass matrix, **K** is the matrix with retardation functions and **C** is the hydrostatic restoring matrix. The force vector F includes the contributions due to waves (from Harberth), wind, current, mooring lines, fenders and Moormaster™ units. The retardation functions can be determined with Harberth directly or from damping coefficients as function of frequency using the inverse cosine transform. Nonlinear characteristics of mooring lines and fenders can be incorporated straightforwardly, since the equation of motion is solved in the time-domain. Therefore, also complex characteristics of Moormaster™ units can be considered.

4 MEASUREMENTS

The layout of the Port of Salalah where the measurements have been executed is shown in Figure 2. The port is located at the Arabian Gulf, where high waves occur during the Khareef season (from mid May to mid September). Long waves occur in the ocean, bound to the swell waves. The height of the long waves increases with the shoaling of the swell waves in shallow water. In contrary to the swell waves, the long waves do not break on the shore but reflect from the shore. The long waves penetrate into the harbour basin by diffraction around the breakwaters and reflection from the Northern beach.

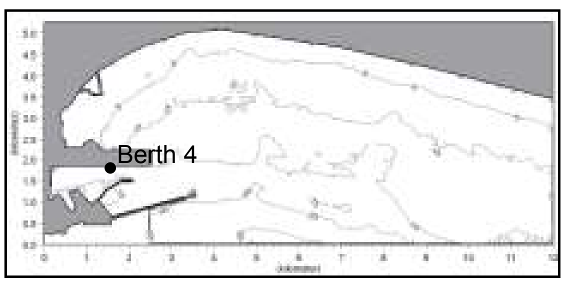

Figure 2: Port lay out

The periods of the long waves in the harbour basin have similar periods as the natural surge periods of moored container ships at the port. Therefore they induce large surge motions of the moored container ships, resulting in reduced container handling efficiency.
The quay wall of the port contains 6 container berths. At berth number 4, four MM600 MoorMaster™ units have been installed in 2005 to reduce the surge motions of the moored container ships.

In June 2007 Cavotec has executed several simultaneous measurements, which have been used for this paper:

- Waves
- Ship motions
- Displacements and generated forces of the MoorMaster™ units

4.1 Wave measurements

The wave radar as shown in Figure 3 (left) continuously measured the elevation of the water level at one point in the harbour basin. The wave radar was located at the quay wall at berth 4, indicated in Figure 2.

Figure 3 (right) shows a typical wave energy spectrum of the measurements. The spectrum shows the presence of long waves in the harbour basin.

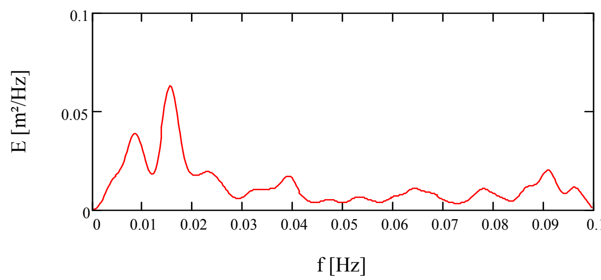

Figure 3: Wave radar at berth 4 (left), typical measured wave spectrum (right)

4.2 Ship motions measurements

The ship motion measurements have been done at container ships with a length around 300 metres. Three GPS antennas were installed on each ship during the time that it was moored in the port. The motions of the three GPS antennas have been recorded, from which the ship motions in 6 degrees of freedom have been calculated. A GPS antenna at the bow of a ship is shown in Figure 4.

Figure 4: GPS antenna at a ship

The results of 2 cases will be presented in this paper:

- Case 1: A ship moored with mooring lines and fenders
- Case 2: A ship moored with mooring lines, fenders and 2 MoorMaster™ units

Table 1 shows the main dimensions of the moored ship in both cases.

Table 1: Dimensions of the moored ship

Ship dimensions	
Length Over All (m)	294
Breadth (m)	32
Draft (m)	9

The mooring arrangements have not been documented during the 2 cases. It is assumed that the ship was moored with 16 polypropylene mooring lines. Trellex fenders are installed at berth 4.
Other important aspects have not been documented during the measurements and have been estimated for the simulations:

- Pretension in the mooring lines
- Wind conditions
- Loading conditions of the ship during the whole mooring cycle

During the measurements there was not enough confidence (yet) in the reliability of the MoorMaster™ units; therefore a combination of mooring lines and MoorMaster™ units was used to moor the ships. The MoorMaster™ units were set only to control the surge motions of the ships, so mooring lines and MoorMaster™ units would not counteract each other in sway direction.

Figure 5 (left) shows the surge energy spectrum of the moored ship in case 1, with a significant surge motion of 1.45 metre. The frequency band of the surge motion is 0.005 Hz – 0.02 Hz, which corresponds to the frequency band of the long waves in the harbour basin. Figure 5 (right) shows the surge energy spectrum of the moored ship in case 2 (mind the differences of the scales), with a significant surge motion of 0.09 metre. The wave energy spectrum of case 2 has a wider frequency band than the spectrum of case 1. The frequencies of the surge motion of case 2 are smaller than 0.04 Hz, so the surge motions are being induced by the long waves in the harbour basin.

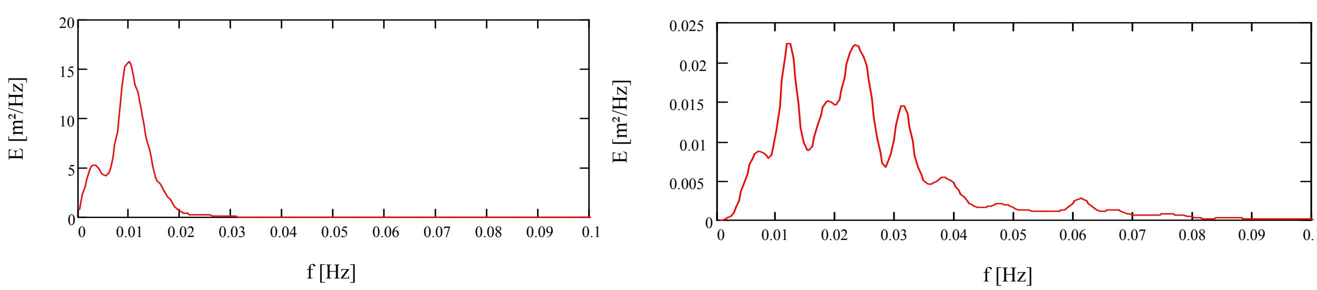

Figure 5: Surge energy spectrum case 1 (left), Surge energy spectrum case 2 (right)

The results of the surge measurements of case 1 and case 2 show the reducing effect of the MoorMaster™ units on the surge motions of the moored ship. The measured long wave conditions (which induce the surge motion of the moored ship) for both cases are more or less similar, as will be shown in Figure 16 and Figure 17.
The spectra for the other 5 directions of motions of the moored ships show similar results for case 1 and 2, because they are less influenced by the MoorMaster™ units.

4.3 MoorMaster™ unit measurements

During the measurements the control system of the MoorMaster™ units was set in a very simple manner; the units generated surge forces linearly related to the surge displacements of the ship. An example of time series of the surge displacements and surge forces of one unit is shown in Figure 6 (left).

The MoorMaster™ properties have been derived with a least squared method analysis. The derived force displacement diagram of the unit is shown in Figure 7. The relation shows that the MoorMaster™ units generate surge forces linearly with the surge displacements. In case the units exceed a certain displacement, the unit reaches its maximum force of 250 kN. The maximum vacuum holding force of the unit is 650 kN, so this will not be exceeded by the generated forces.

Figure 6 (right) shows the comparison between the measured surge force and the surge force as calculated from the measured surge displacement and the derived Moormaster™ unit characteristics (Figure 7). The correspondence between measured and calculated forces is good, so that the derived characteristics can be used for the ship motion simulations.

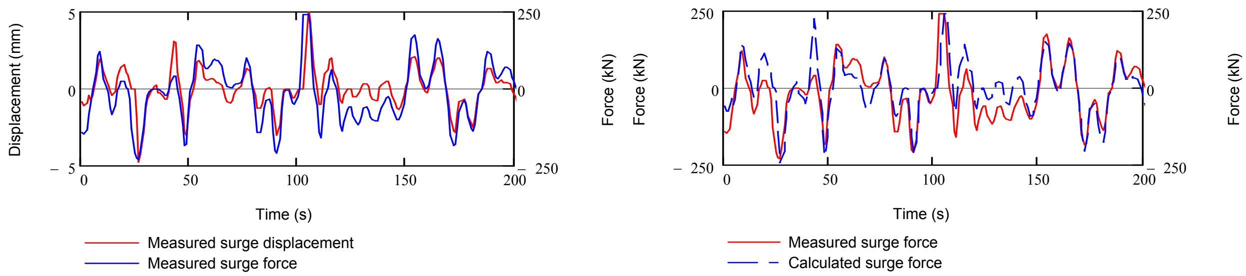

Figure 6: Measured surge forces and displacements in a MoorMaster™ unit (left), Directly measured MoorMaster™ forces and forces calculated from the measured surge motions (right)

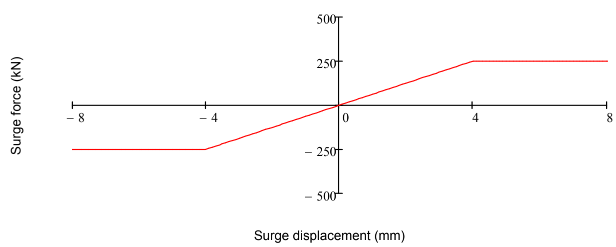

Figure 7: MoorMaster™ unit properties during measurements

5 SIMULATION RESULTS

5.1 Results wave simulations

The objective of the Mike 21 BW simulations is to simulate the long waves (inducing the surge motions of the moored ships) correctly compared to the measured long waves. The Mike 21 BW model of the port has been set up and calibrated by DHI. It has not been calibrated any further for the simulations of this research project.

The Mike 21 BW model area of the port is shown in Figure 2. The area has been chosen relatively wide, because long waves reflect from the beach and penetrate into the harbour basin. The shape of the bay enables waves that are generated in the surf zone up to 8 kilometres Eastward of the harbour basin to reflect on the beach and enter into the harbour basin. The incoming waves in the simulation enter the model area over the entire width of the southern border of the model area. A swell spectrum (without the presence of long waves) serves as an input for Mike 21 BW at the boundary of the model area. The long waves are being generated inside the model area, bound to the incoming swell wave groups. The incoming waves at the border of the model area have not been measured simultaneously with the other measurements; therefore the properties of the incoming waves have been estimated. The estimated properties are:

- Wave spectrum
- Wave direction
- Directional spreading

A Sensitivity analysis has been done to obtain insight in the behavior of the model. The results of the analysis show that all three factors play an important role in the generation of long waves in the simulation, which penetrate into the harbour basin. Therefore it can be concluded in general that measurements are very important to set up and calibrate a proper Mike 21 BW model. Comparison between simulated and measured wave spectra at the wave radar for case 1 and case 2 are shown in Figure 8. The figures show that the long waves have been simulated quite accurately in comparison with the measurements. The swell waves have been simulated less accurately, because the focus in the model calibration was on the long waves.
The comparison can only be made for the wave height (no direction) at 1 point in the harbour basin. It would be better to have more measurement points in the harbour basin, to make a better comparison between simulation and measurements for the waves in the whole harbour basin. This is particularly important because wave directions have a large influence on the motions of the moored ship in all 6 directions. Another shortcoming of the comparison between measured and simulated waves is that the presence of the ship has not been taken into account by Mike 21 BW. The wave measurements have been done by the wave radar between the ship and quay wall, so the presence of the ship has an influence on the measured waves. A measurement point further away from the ship would have been better in that respect. The Harberth simulations do take the presence of the ship into account. A comparison between the wave measurements and the simulated waves by Harberth will be made in the next section.

One of the important causes for the difference between measurements and model results for the swell waves are the properties of the coastline of the Northern beach, which are difficult to define correctly in a numerical model. The properties of the coastline have a large influence on the reflection of the waves in the model. The model set up is still subject to improvement by DHI to obtain better results for the simulated swell waves and long waves in comparison with measurements.

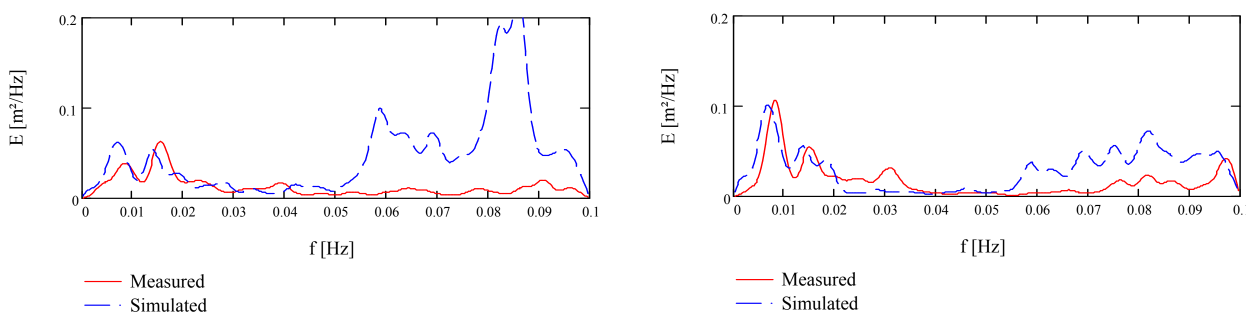

Figure 8: Measured and simulated wave spectra case 1 (left), Measured and simulated wave spectra case 2 (right)

5.2 Results wave force calculations

The ship hull in Harberth is discretized by a mesh with 672 panels (Figure 9) assuming a constant pressure over each panel. The interaction effects between the ship and the quay wall are considered for which the quay wall is assumed infinitely long. Harberth calculates time series of forces on the ship hull from the fluxes and surface elevations calculated by Mike 21 BW. Furthermore Harberth calculates a hydrodynamic file, containing the added mass and retardation functions of the ship moored at the quay wall.

The presence of the ship causes a disturbance to the waves. Waves diffract around the ship and waves are being generated by the motions of the ship (radiated waves). Figure 10 shows the results of the calculated waves by

Harberth for case 1. Especially the swell waves are being influenced by the presence of the ship, because the waves scatter around the ship. The long waves are hardly influenced by the presence of the ship, because the ship length is small relative to the wave length. The waves caused by the motion of the ship (radiated wave spectrum) hardly influence the total simulated waves.

The simulated waves in Harberth take the presence of the moored ship into account, so the results can be compared with the measured waves (Figure 11). The simulated long waves show good resemblance with the measured long waves, as they are similar to the long waves from the Mike 21 BW simulations. The swell waves simulated by Harberth show an even larger difference with the measured swell waves than the simulated swell waves in Mike 21 BW. The horizontal ship motions are induced by the long waves, so for the purpose of this research project the results of the Mike21-Harberth simulations are acceptable.

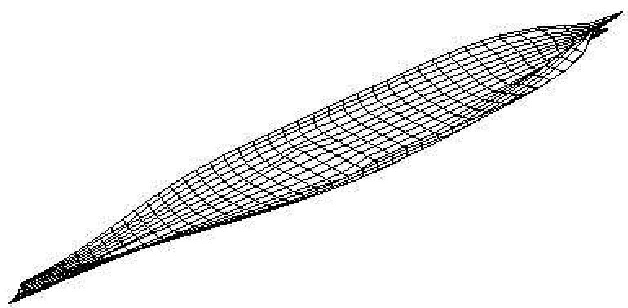

Figure 9: Mesh of the container ship with 672 panels

The significant wave forces calculated by Harberth are shown in Table 2. Figure 12 shows the calculated surge force spectra for case 1 and case 2. The calculated significant wave forces are larger for case 1 than for case 2 (except for the significant heave wave force), this is caused by the higher simulated swell waves in case 1. The surge force spectra show the distribution of the forces over the frequencies, which shows that the low frequent wave forces in surge direction have a similar order of magnitude for both cases.

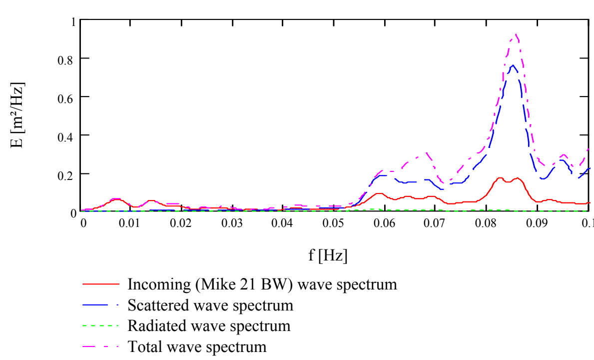

Figure 10: Simulated wave spectra by Harberth

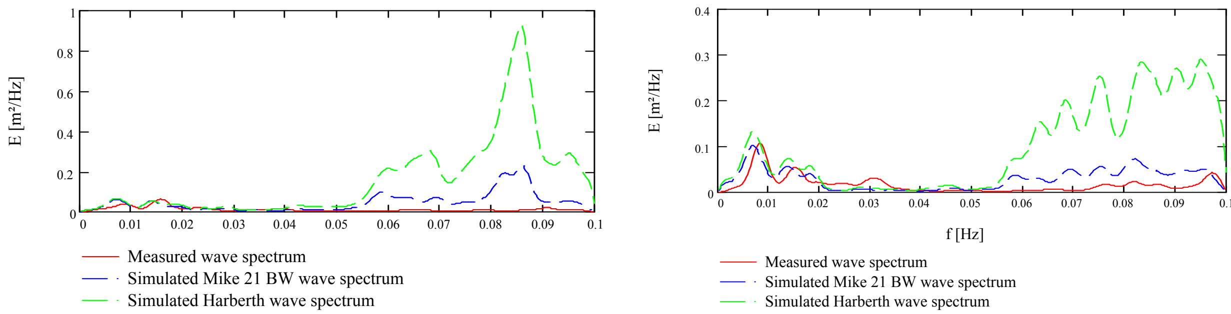

Figure 11: Measured and simulated wave spectra case 1 (left) and case 2 (right)

Table 2: Calculated significant wave forces

F_{m0}	Case 1	Case 2
Surge (kN)	649	475
Sway (kN)	1668	1403
Heave (kN)	7193	7515
Roll (kNm)	13787	11505
Pitch (kNm)	342619	249434
Yaw (kNm)	64044	54230

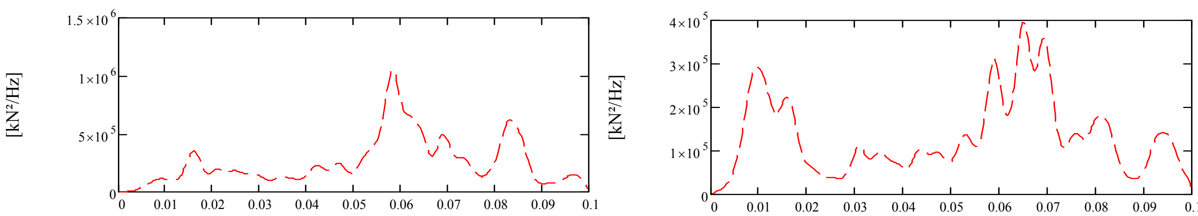

Figure 12: Calculated surge force spectrum case 1 (left) and case 2 (right)

5.3 Results ship motion simulations

Quaysim calculates time series of the ship motions and mooring forces. The unknown parameters during the measurements have been estimated in the Quaysim simulations. The assumed values are shown in Table 3. Sensitivity analyses have been made to obtain insight in the influence of the unknown parameters. The unknown parameters have been chosen to fit the results of the simulated ship motions as good as possible with the measured ship motions.

Table 3: Mooring properties for Quaysim simulations

Mooring properties	
$F_{pretension}$ stern and head lines (kN)	35
$F_{pretension}$ spring lines (kN)	10
Breaking strength mooring lines (kN)	700
F_{max} fender (kN)	1200
Fender friction coefficient (-)	0.2

Table 4 shows the measured and simulated significant value of the low frequency (f < 0.05Hz) ship motions for case 1 and case 2. Only the low frequency ship motions have been considered, because the loads of the high frequency waves (f > 0.05Hz) have not been simulated well in Harberth in comparison with wave measurements.

Table 4: Low frequent significant ship motions

$X_{m0;lf}$	Surge (m)		Sway (m)		Heave (m)		Roll (°)		Pitch (°)		Yaw (°)	
	Meas	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas	Sim
Case 1	1.45	1.20	0.17	0.26	0.11	0.13	0.21	0.79	0.05	0.10	0.18	0.33
Case 2	0.09	0.04	0.10	0.13	0.11	0.13	0.27	0.48	0.05	0.08	0.07	0.13

The significant motions in Table 4 and the horizontal motions spectra in Figure 13 show that the magnitude and frequency of all simulated motions is not very accurate in comparison with the measurements. This is caused by the unknown parameters during the measurements. For example, if the sway and yaw wave forces are smaller during the measurement than during the simulation, a less stiff mooring configuration could be used in the simulation than during the measurement to fit the measured sway motions. The stiffness of the system influences the natural frequency of the ship motion. Therefore it can be concluded that the uncertainties influence the magnitude as well as the frequencies of the ship motions.

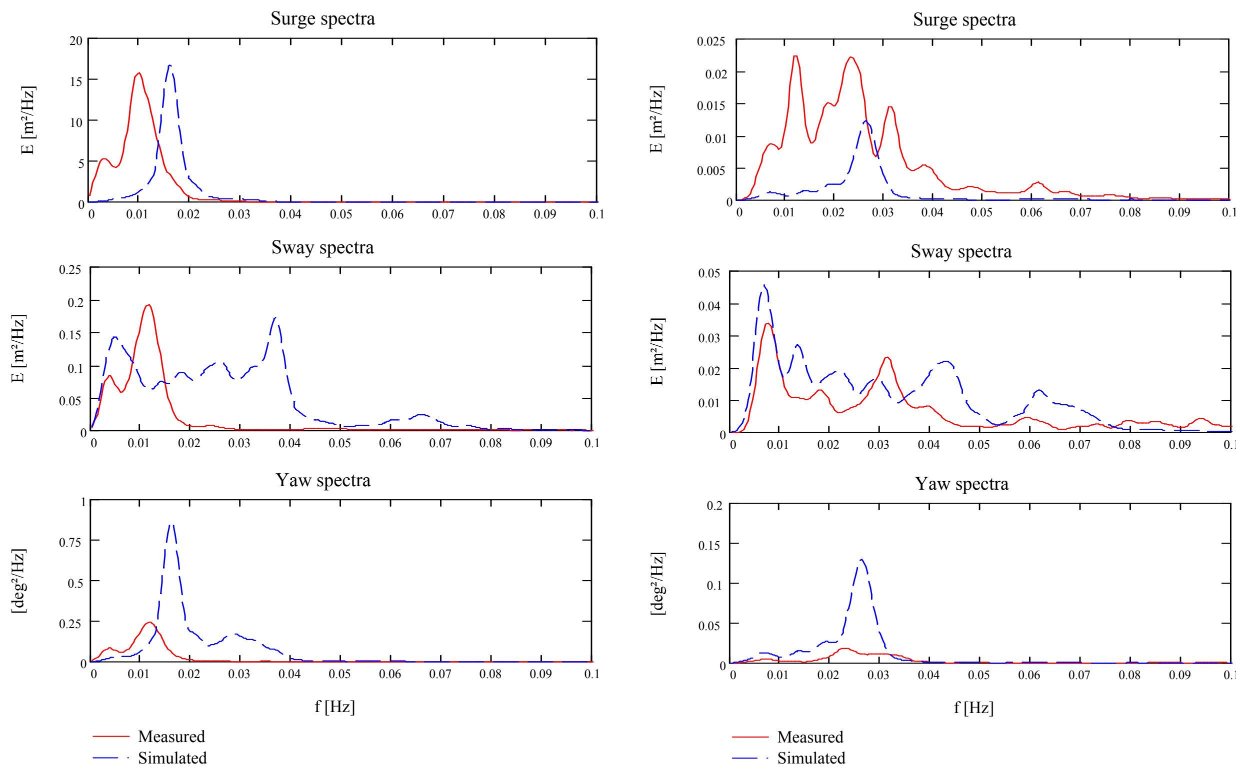

Figure 13: Measured and simulated horizontal ship motion spectra case 1 (left), and case 2 (right)

The simulations and measurements show a reduction of the same order of magnitude of the surge motions of the moored ship, due to the MoorMaster™ units. So it can be concluded that the effect of the MoorMaster™ units on the magnitude of the surge motions is taken into account correctly in the numerical simulations.

Another aspect that points out from measurements and simulations is that the surge and yaw motion are coupled for the ship that is moored with MoorMaster™ units. This can be observed by the similar peak frequencies in the motion spectra and by the surge and yaw time series of simulations and measurements (Figure 14).

The coupled surge and yaw motion can be explained by Figure 15. The surge motion of the ship is controlled with MoorMaster™ units, which allow a motion in the order of several millimeters (Figure 7). The sway direction of the ship motions is controlled by mooring lines, which have a much lower stiffness than MoorMaster™ units. Therefore the red crosses on the hull of the ship move over the black dotted lines, caused by the ship motions. The ship can make a relatively large yaw motion, because the MoorMaster™ units can move freely in sway direction. The surge motion of the CoG (Centre of Gravity) of the ship is mostly caused by the yaw motion of the ship. This also explains why the surge motion of the CoG of the ship in case 2 is in the order of centimetres and surge motion of the MoorMaster™ units is in the order of millimetres.

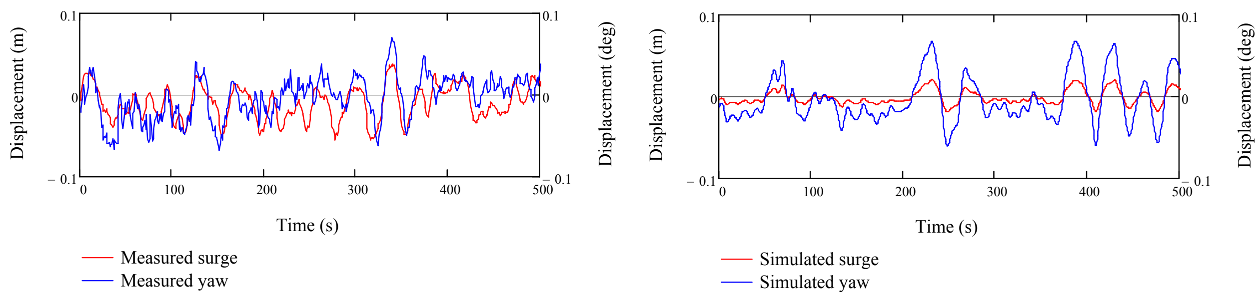

Figure 14: Measured surge and yaw motions (left), simulated surge and yaw motions (right)

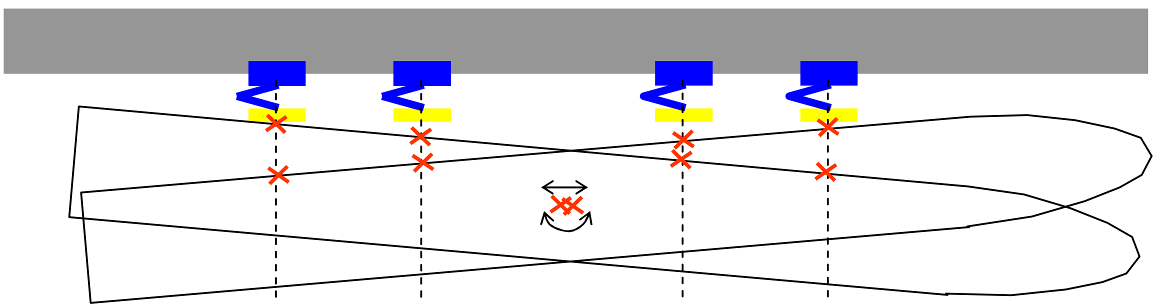

Figure 15: Coupled surge and yaw motions of a ship moored with MoorMaster™ units

5.4 Results additional Quaysim simulations

The control system of the MoorMaster™ units can also be set to generate forces in surge and sway direction.
With this setting mooring lines are not needed to moor the ship. As concluded from the measurements and simulations from case 2, the ship motions are mainly caused by the sway motion of the ship which is controlled by the (less stiff) mooring lines. Mooring the ship with MoorMaster™ units that control surge and sway directions will result in even smaller ship motions.

Quaysim simulations have been made with the MoorMaster™ control system set to control surge and sway direction, without interaction of mooring lines or fenders in the simulations. The wave conditions in the simulation are similar to case 1.

The low frequency motions of these Quaysim simulations are shown in Table 5. The simulated motions result in even smaller surge motions of the moored ship than in case 2, because the yaw motion of the ship is being controlled totally by the MoorMaster™ units.

Table 5: Simulated low frequent significant motions

$X_{m0;lf}$	Surge (m)	Sway (m)	Heave (m)	Roll (°)	Pitch (°)	Yaw (°)
Case 3	0.02	0.02	0.19	0.65	0.09	0.05

Unfortunately this type of mooring arrangement has not been used in the port, so there are no measurements to compare with.

6 CONCLUSIONS

This study compared measurements of waves and motions of moored ships in a harbour with results of numerical simulations. During the measurements the ships were moored with only mooring lines or with mooring lines and MoorMaster™ units. The objective of the comparison between measurements and simulations was to verify a numerical modeling method to calculate the motions of a ship moored with MoorMaster™ units. The conclusions from this study are:

- Measurements and numerical simulations show a similar reducing effect on surge motions of moored ships by MoorMaster™ units. Therefore it can be concluded that the effect of MoorMaster™ units on motions of moored ships have been simulated well in Quaysim.
- The coupled simulations (Mike 21 BW, Harberth and Quaysim) have resulted in surge and sway motions in the same order of magnitude as the prototype measurements. The simulated yaw motion of the ship is much larger than the measured yaw motion.
- The simulations have not led to accurate results for the frequencies of the ship motions compared to the measurements. This is caused by several parameters which have not been recorded and which result in unknown parameters for the simulations:
    - Spectral wave conditions at the offshore boundary.
    - Wave heights and wave directions in the whole harbour basin.
    - Mooring lines (number of lines, allocation, pretension, types).
    - Loading conditions of the ships.
- The additional numerical simulations show that surge motions of ships moored with MoorMaster™ units controlling surge and sway directions are smaller than the motions of ships moored with MoorMaster™ units controlling only the surge direction.

For future studies it is recommended to document and measure the parameters that were unknown in this study, to make more accurate simulations which can be validated with measurements.

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