The effect of active motion dampening systems on the behaviour of moored ships

by

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ABSTRACT

Active motion dampening systems may significantly reduce the horizontal motions of a moored ship. Therewith, the efficiency of the loading and unloading increases and a reduction of downtime may be realised. The results of computer simulations are presented in this paper to show the potential of Cavotec Moormaster™ and ShoreTension® to reduce the horizontal ship motions compared to conventional lines. The surge, sway and yaw motions have been calculated for a 3,000 TEU container ship moored at an exposed jetty. Wind and short wind generated waves are considered. The calculated results show that both systems effectively reduce the low frequency horizontal motions. The reduction of the motions, however, does not automatically imply a similar reduction of downtime. For this the relevant criteria for safe mooring for each mooring configuration should be taken into consideration.

1 INTRODUCTION

The efficiency of the loading or unloading of a moored ship may reduce significantly in case of large motions induced by wind, waves and current. In even more severe conditions, large mooring line and fender forces may occur and mooring could become unsafe. Under those conditions ships need to leave the berth and wait until they can be re-berthed. This implies operational downtime, which is not in the interest of a port or terminal operator.

To overcome large vessel motions, one may contemplate stiffer mooring lines, but this will increase the forces on bollards or quick release hooks. An alternative method, as highlighted by PIANC (2012) and De Bont (2010), would be the application of active motion dampening systems. Two examples of active motion dampening mooring systems that are currently available on the market are Cavotec Moormaster™ and ShoreTension®.

Cavotec MoorMaster™ is a vacuum-based automated mooring technology that eliminates the need for conventional mooring lines. ShoreTension® is a flexible stand-alone mooring system, based on a permanent tension of shore mooring lines. When the tension in the lines exceeds the Safe Working Load the lines are paid out. Tension peaks in the lines are avoided in this way. Figure 1 depicts photos of both systems.

Both Cavotec MoorMaster™ and ShoreTension® may realise a significant reduction of the motions of moored ships. Therewith the efficiency of the loading and unloading increases and a reduction of downtime may be realised, when a ship would be moored with these active motion dampening systems.

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Figure 1: Cavotec MoorMaster™ and ShoreTension®

The potential of both active motion dampening systems to reduce the horizontal ship motions compared to a mooring arrangement with conventional lines is illustrated in this paper. The results of a Dynamic Mooring Analysis (DMA) are presented, in which the response of a 3,000 TEU container ship has been calculated for three different mooring arrangements:

1. A conventional mooring arrangement (mooring lines and fenders);
2. An arrangement with Cavotec Moormaster™ Automated Mooring System;
3. A conventional mooring arrangement to which ShoreTension® mooring system has been added;

In this case study, the ship is moored to an unprotected terminal, fully exposed to wind and wind generated waves. The results demonstrate for which particular environmental circumstances the active motion dampening systems show to have an advantage over a conventional mooring arrangement. By comparing spectra of vessel motions the paper also demonstrates at what frequencies the differences are found and where active motion dampening systems are most effective.

2 METHOD

2.1 Computational model and simulation time

The DMA software package used to calculate the response of the moored container ships was originally developed by Wim van der Molen (2006). This program comprises a time domain simulation to analyse the dynamic behaviour of a moored ship subject to wind, waves and current. The program predicts the mooring loads and vessel motions when the system is exposed to operational environmental conditions. It solves the equations of motion of the vessel in the time-domain, so that nonlinearities, such as the characteristics of fenders and mooring lines, drift forces and current forces, can be treated.

The characteristics of the Cavotec MoorMaster™ and ShoreTension® systems have been implemented in this software package used for the calculations in cooperation with both parties. The response characteristics of both systems, however, are subjected to a Non-Disclosure Agreement between Royal HaskoningDHV and respectively Cavotec S.A. and ShoreTension® Holding B.V. They are therefore not included in this paper.

2.2 Ships

Table 1 shows the main dimensions of the 3,000 TEU container vessel.

Table 1: Main dimensions container ships

Item	Unit	3,000 TEU
L_{oa}	m	237
L_{pp}	m	225.8
B	m	31.9
D	m	17.5
T	m	8.3
Displacement	m^3	34,015
Projected front area	m^2	1380
Projected side area	m^2	6390

2.3 Mooring configurations

The mooring lines used were Atlas® lines. They were assumed to be six-strand ropes made from nylon. The line diameter was 44 mm, yielding a breaking strength of 491 kN. A pretension has been used of 5% of the total breaking strength of the line.

The quay was equipped with super cone fenders at a centre-to-centre distance of 15 m. The maximum reaction force was 3039 kN. The parallel body length of the ships was assumed to be 60% of L_{oa}, yielding 10 mobilized fenders.

Conventional Mooring

Figure 2 depicts a schematic representation of the mooring configuration of the 3,000 TEU container vessel with 10 conventional lines. The bollard spacing on the quay was 15 m. A starboard mooring was considered.

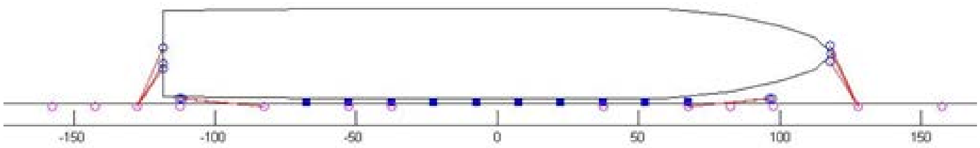

Figure 2: Mooring line configuration 3,000 TEU

Cavotec MoorMaster™

Cavotec proposed to use MoorMaster™ 200, capable of delivering 200 kN in sway direction and 100 kN in surge direction. They are free to move vertically. By installing the MoorMasters™ in pairs, the capacity to withstand large yaw moments can be increased, without increasing the total number of MoorMasters. The distance between two MoorMasters within a pair was 7 m centre to centre. The distance between pairs is 30 m, centre to centre. Based on a 60% of L_{oa} parallel body length, in total 8 MoorMasters were mobilized (see Figure 3). Each pair of MoorMasters was allocated to execute a force in either surge or sway direction. The two 2 outermost pairs were allocated to exert a sway force; the two pairs around midships a surge force.

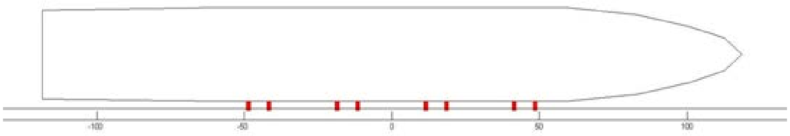

Figure 3: MoorMaster configuration 3,000 TEU

<u>ShoreTension®</u>

ShoreTension® cylinders were added to the conventional mooring layout. The lines used in combination with the Shoretension® cylinders were Dyneema® lines, 54 mm in diameter, with 200 t breaking strength. ShoreTension® advised on the position of the cylinders and their settings. Two ShoreTension® cylinders were added as breast lines. The maximum force that the cylinder allows before it pays out was 60 t.

An additional setting on the ShoreTension® is the swell chamber, which may be opened or closed. A closed swell chamber implies a much stiffer reaction of the cylinder; if the swell chamber is open the cylinder acts much weaker, similar to a weak tail on a conventional mooring line. For these calculations the swell chamber was closed.

Figure 4 depict a schematic representation of the mooring layout using conventional mooring lines and ShoreTension®. The blue ellipses indicate the position of the Dyneema® lines.

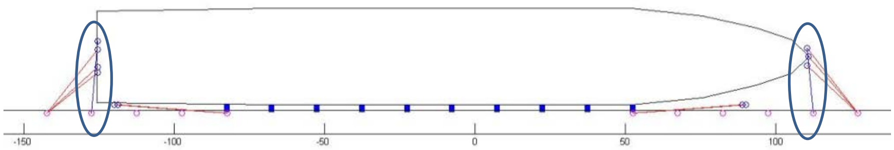

Figure 4: Mooring line configuration 3,000 TEU, including ShoreTension®

2.4 Environmental conditions

Four relative directions between the ship axis system and the wind have been chosen to illustrate the effect the active motion dampening systems (see Figure 5). The relative direction has been defined in the ship axis system in which wind blowing or waves propagating in the direction of the positive x-axis is defined as 0° and wind blowing or waves propagating in the positive y-axis as 90°.

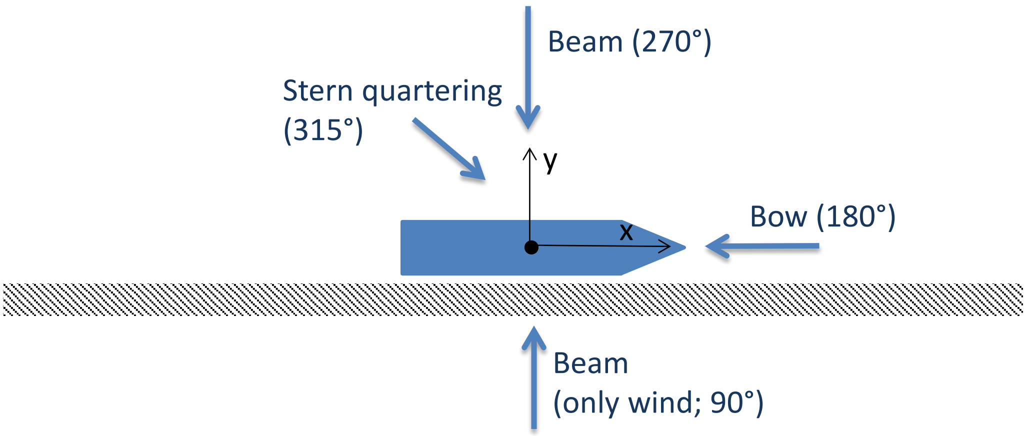

Figure 5: Relative wind directions

The wave parameters were determined by wind fetch calculations. For each combination of wind speed and direction a significant wave height, peak period and direction were determined based on the available fetch. The simulated wave conditions were short wind generated waves. Neither swell waves nor current were considered. The wave spectrum used in the simulations was a Jonswap wave spectrum. For the relative wind direction beam on coming from land there were no waves. Figure 6 and Figure 7 respectively depict the relation between wind speed and significant wave height and between wind speed and peak period. The wave directions were:

- Bow: 180° wind direction - 192° wave direction
- Stern quartering: 315° wind direction - 296° wave direction
- Beam: 270° wind direction - 273° wave direction

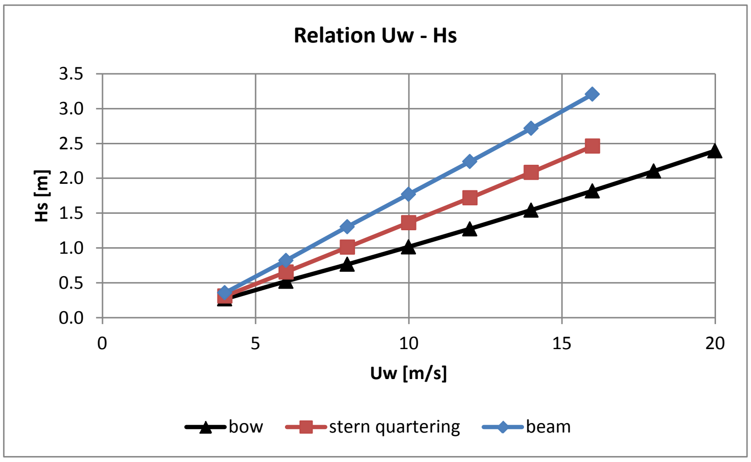

Figure 6: Relation between wind speed and significant wave height

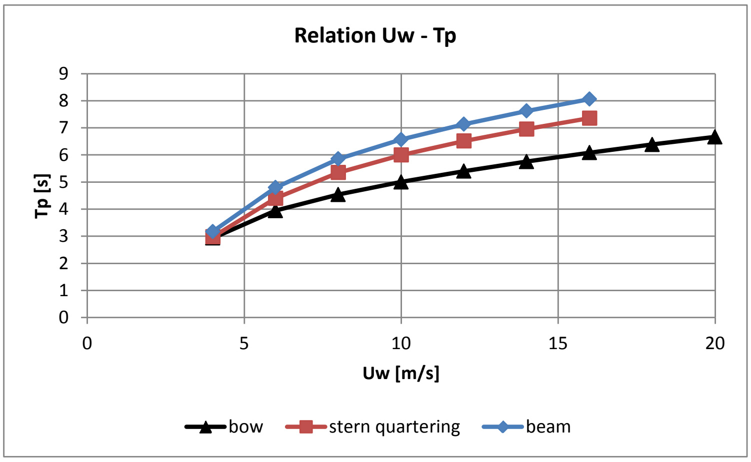

Figure 7: Relation between wind speed and peak period

3 RESULTS

3.1 Bow wind and waves

Figure 8 shows a typical time series of the surge, sway and yaw motion of the 3,000 TEU container vessel in bow wind and waves. The simulated wind speed was 14 m/s. Large surge motions were to be expected in this wind direction using conventional lines. The relative wave direction was 192°. Therefore, sway and yaw motions were also observed. Both Cavotec MoorMaster™ and ShoreTension® were able to reduce the horizontal motions significantly (the sway and yaw motions were nil).

The advantage of Cavotec MoorMaster™ is that the vacuum pads immediately exert a reaction force when the vessel shows small displacements. They prevent the vessel from moving in horizontal direction. By applying the ShoreTension® system the ship is pulled into the fenders, restricting the vessel to move in sway and yaw direction. At the same time the fender friction has been increased, which results in reduced surge motions.

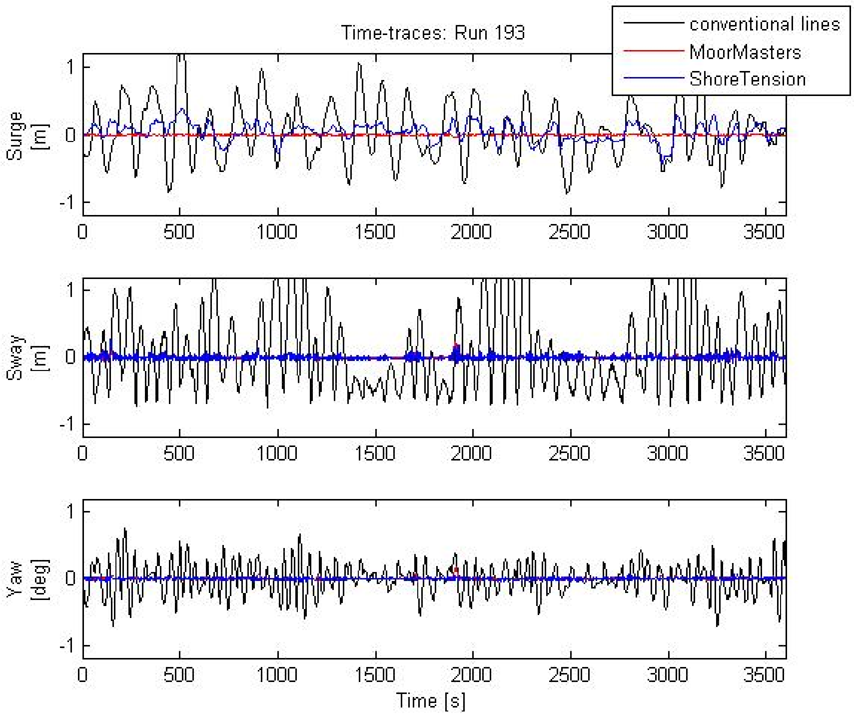

Figure 8: Typical time series horizontal motions in bow wind and waves

The horizontal motions surge, sway and yaw of a moored ship are low frequency motions. The mooring lines act as soft springs, yielding low natural frequencies. The active motion dampening systems are effective in reducing the low frequency motions as can clearly be seen in motion spectra for surge, sway and yaw (see Figure 9 to Figure 11). The energy in the surge motion spectrum when Cavotec MoorMaster™ was applied the energy was less than 10^{-3} m^2/Hz (and is therefore not visible).

Figure 12 to Figure 14 show the significant surge, sway and yaw motions for increasing wind speeds in bow wind and waves. The PIANC 2012 motion criteria for (un)loading of container vessels have been plotted as well to illustrate the order of magnitude of the response. For significant motions larger than these criteria it may be expected that the (un)loading of containers will be more difficult. This reduces the throughput of containers.

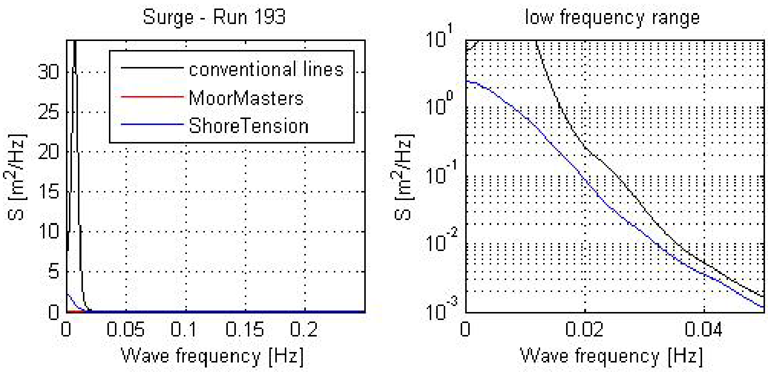

Figure 9: Typical surge motion spectrum in bow wind and waves

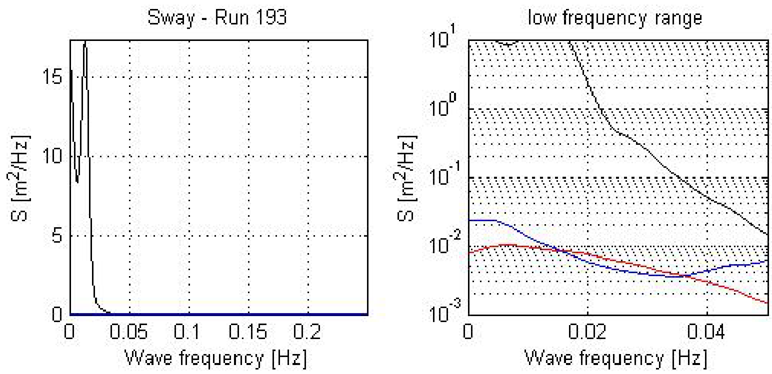

Figure 10: Typical sway motion spectra in bow wind and waves

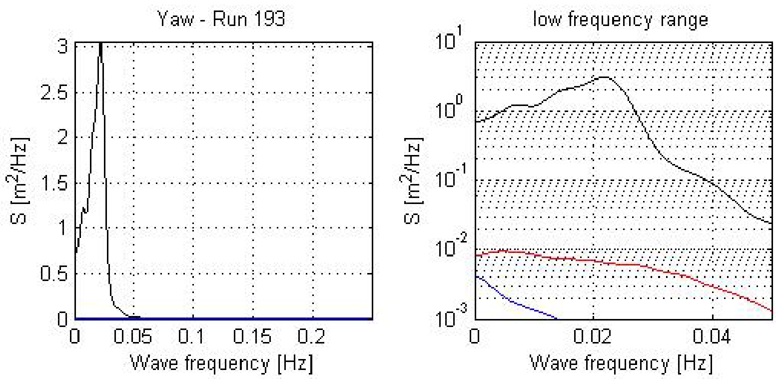

Figure 11: Typical yaw motion spectra in bow wind and waves

For a fair comparison only the simulations, for which the criteria for safe mooring were met, were considered. The Safe Working Load of the conventional mooring lines, 55% of the breaking strength, may not be exceeded, neither the maximum reaction force of the fender. A MoorMaster vacuum pad may travel +/-0.40 m in surge direction and +/- 1.1 m in sway direction. The maximum allowable stroke of the ShoreTension® cylinders is 3 m and the maximum cylinder velocity is 30 cm/s.

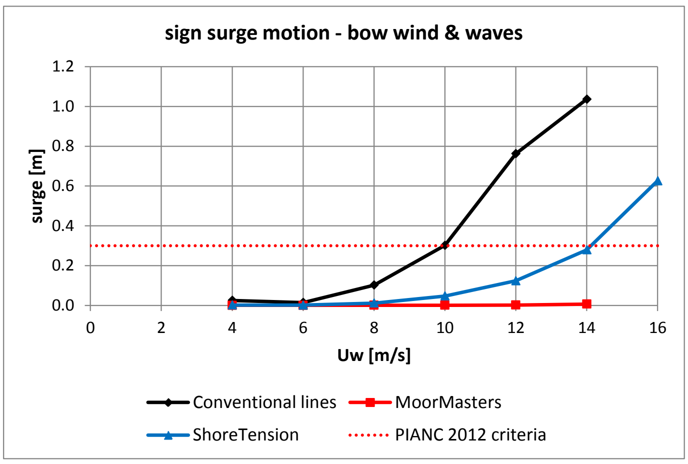

Figure 12: Significant surge motion in bow wind and waves

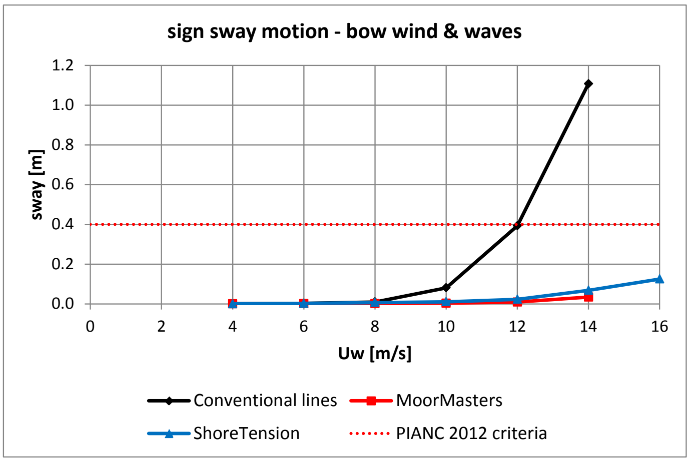

Figure 13: Significant sway motion in bow wind and waves

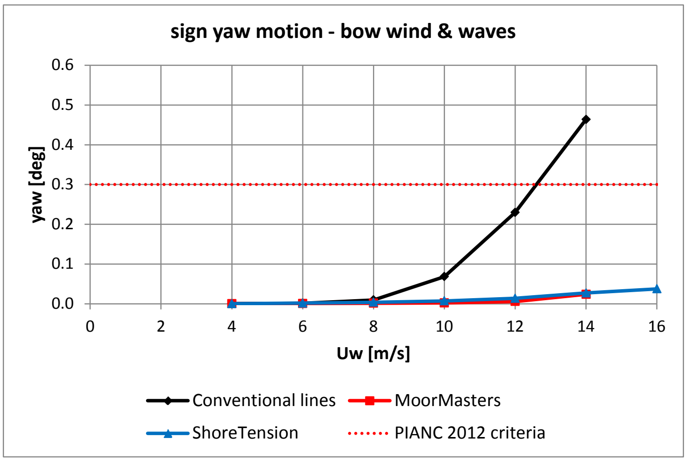

Figure 14: Significant yaw motion in bow wind and waves

For increasing wind speeds, and consequently for increasing wave heights (see Figure 6), the vessel showed large horizontal motions when it was moored with conventional lines. The mooring was safe up to 14 m/s wind speeds. For the configuration of MoorMaster units chosen in this case the mooring was safe up to 14 m/s wind speeds. Cavotec MoorMaster™ effectively counteracted the motions up to 14 m/s. At wind speeds higher than 14 m/s the forces required to maintain the vessel in position would require additional MoorMaster units to increase the holding capacity of the system. ShoreTension® also reduced the motion significantly and could be applied up to 16 m/s wind speeds.

3.2 Stern quartering wind and waves

Figure 15 to Figure 17 show the significant surge, sway and yaw motions for increasing wind speeds in stern quartering wind and waves. Up to 8 m/s wind the motions using conventional lines were moderate. The motion reduction that could be realised using active motion dampening systems was therefore limited. For wind speeds higher than 8 m/s the configuration and placement of the Cavotec MoorMaster™ units selected was not suitable and could no longer be applied. ShoreTension® could be applied up to 10 m/s, before the maximum stroke of one of the cylinders was exceeded. Conventional lines could be applied in higher wind speeds, up to 12 m/s.

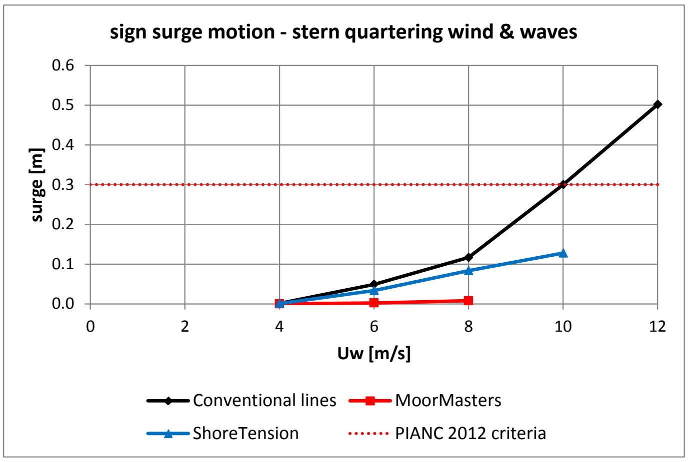

Figure 15: Significant surge motion in stern quartering wind and waves

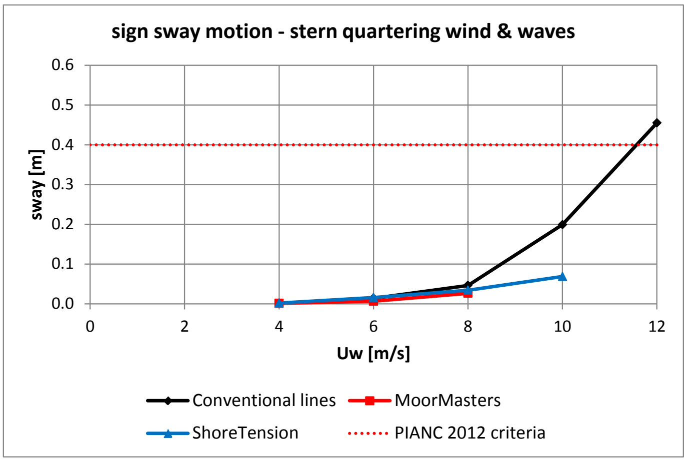

Figure 16: Significant sway motion in stern quartering wind and waves

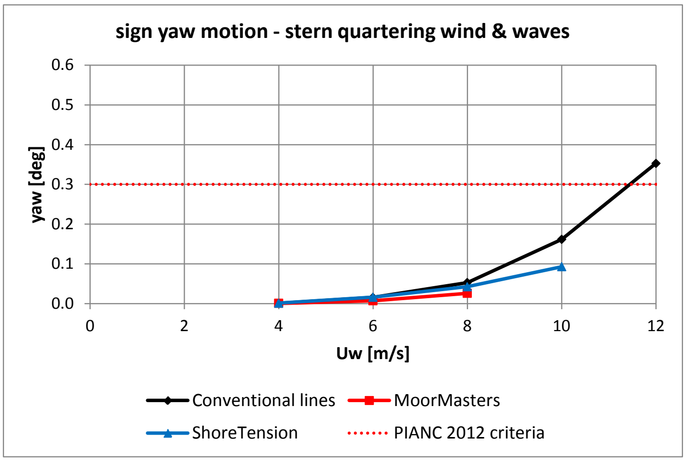

Figure 17: Significant yaw motion in stern quartering wind and waves

3.3 Beam wind and waves

Figure 18 shows that in beam wind and waves the low frequency sway motion could be reduced using Cavotec MoorMaster^{TM} or ShoreTension$^{®}$. Similar motion spectra were found for the surge and yaw motion. Figure 19, however, shows that above 6 m/s wind speeds none of the mooring configurations was safe.

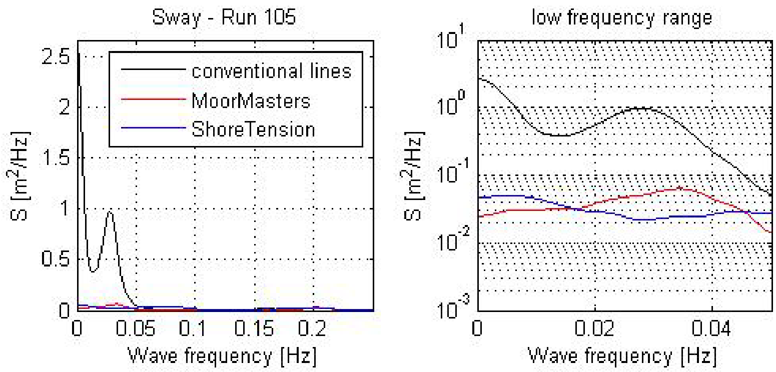

Figure 18: Typical sway motion spectra in beam wind and waves

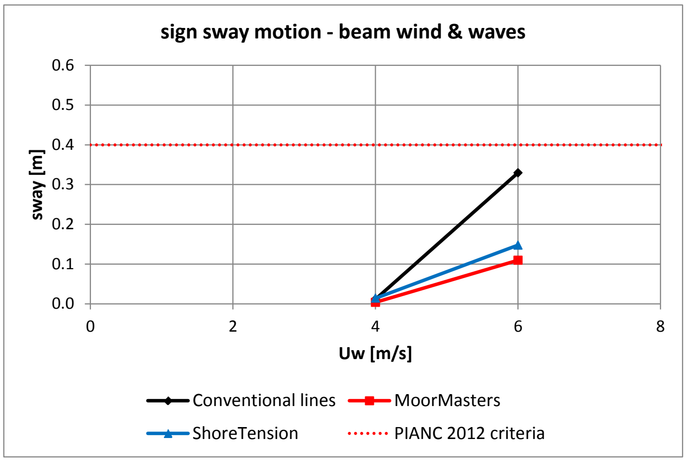

Figure 19: Significant sway motion in beam wind and waves

3.4 Beam wind

Figure 20 shows a typical time series of the surge, sway and yaw motion of the 3,000 TEU container vessel in beam wind (no waves). The simulated wind speed was 8 m/s. Large sway motions occur in this wind direction using conventional lines. Using either Cavotec MoorMaster™ or ShoreTension® all horizontal motions were reduced to zero.

Figure 21 shows the sway and yaw motions spectra in this condition. Both systems are very effective in eliminating the low frequency wind induced ship motions (spectral energy is nil).

Figure 22 to Figure 24 show the significant surge, sway and yaw motions for increasing wind speeds in beam wind coming from land. The ship is blown away from the quay. Large mooring line forces occur in the conventional lines. The Safe Working Load of the lines has been exceeded for wind speeds greater than 8 m/s. Cavotec MoorMaster™ effectively reduced the motions. The wind forces, however, also become too large for the Cavotec MoorMaster™ configuration chosen to withstand for wind speeds greater than 8 m/s.

ShoreTension® proved to be very effective in beam winds blowing the ship away from the quay. The permanent tension in the Dyneema® lines prevented the ship to start moving. More motion was observed at 12 and 14 m/s wind speeds. Here, the cylinders often had to pay out to avoid high tension peaks in the lines. Above 14 m/s wind speeds the maximum stroke of the cylinders was reached.

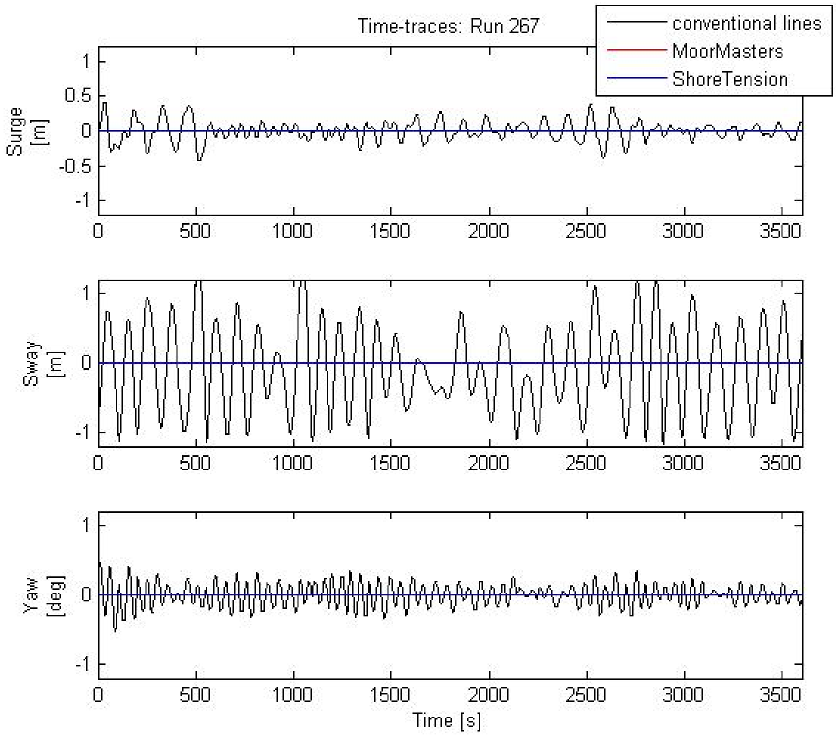

Figure 20: Typical time series horizontal motions in beam wind

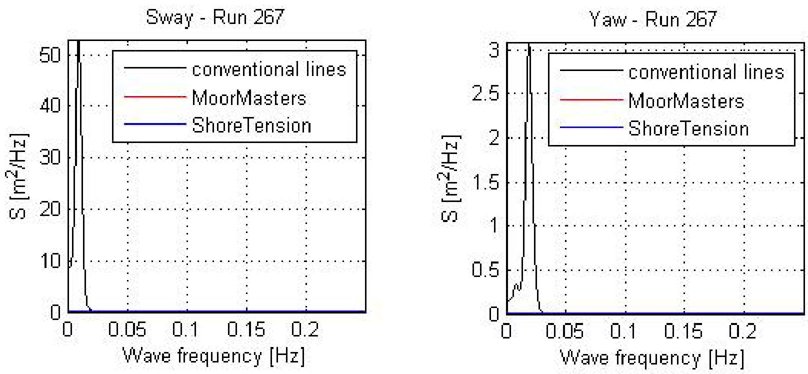

Figure 21: Typical sway and yaw motion spectra in beam wind

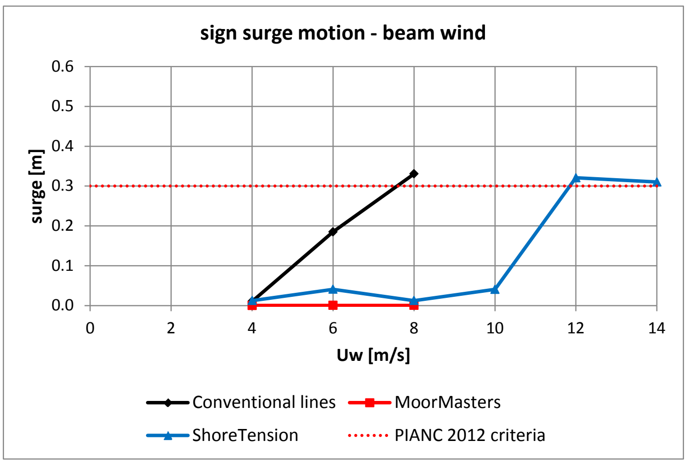

Figure 22: Significant surge motion in beam wind

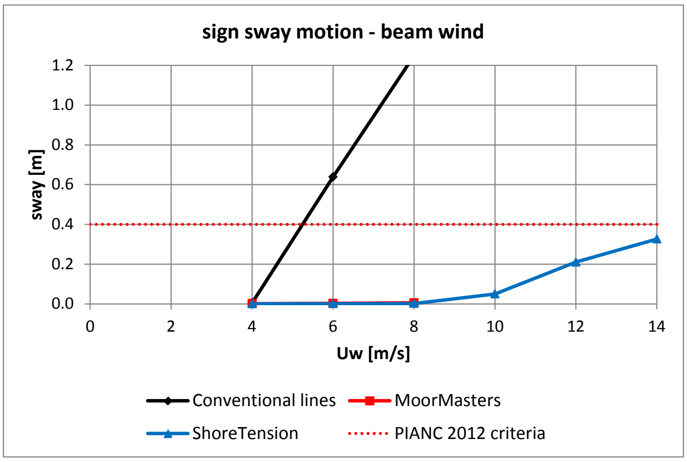

Figure 23: Significant sway motion in beam wind

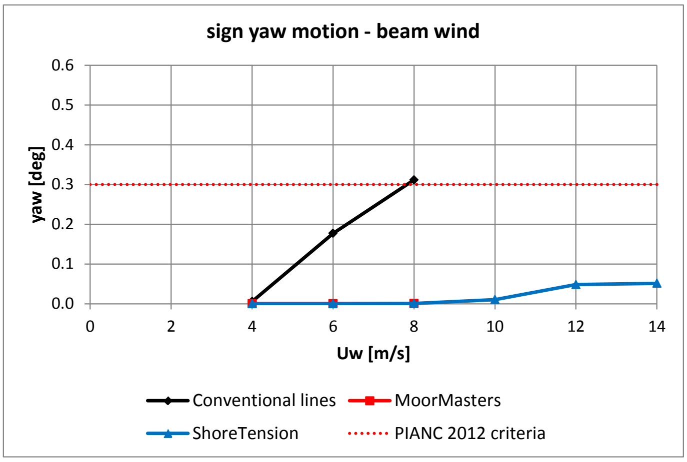

Figure 24: Significant yaw motion in beam wind

4 CONCLUSIONS

Both Cavotec MoorMasters™ and ShoreTension® significantly reduce the horizontal motions of the moored container vessel compared to conventional mooring lines. The advantage of Cavotec MoorMaster™ is that the vacuum pads immediately exert a reaction force when the vessel shows small displacements. They prevent the vessel from moving in horizontal direction. By applying the ShoreTension® system the ship is pulled into the fenders, restricting the vessel to move in sway and yaw direction. At the same time the fender friction has been increased, which results in reduced surge motions.

Each mooring configuration (conventional lines, Cavotec MoorMaster™ and ShoreTension®), however, has its own properties. For a downtime assessment the relevant criteria for safe mooring should be taken into consideration. For the overall operational downtime the motions should be tested against the motion criteria as well (PIANC 2012). The horizontal motions may be very well reduced by active motion dampening systems, although this not automatically implies that a similar reduction of downtime can be realised. In order to assess the expected downtime of exposed terminals a good modelling should include the probability of occurrence of all relevant combinations of wind, waves and currents into a Dynamic Mooring Analysis.

Trademarks

MoorMaster™ is a trademark of Cavotec S.A.
ShoreTension® is a registered trademark of ShoreTension Holding B.V.
Dyneema® is a registered trademark of DSM Dyneema

Acknowledgements

The results in this paper were made possible by Terminal Investment Limited. The authors would also like to thank Cavotec S.A. and ShoreTension Holding B.V.

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Van Der Molen, W. (2006). Behaviour of moored ships in harbours. PhD thesis, Delft University of Technology, the Netherlands