

Mitigating the effects of waves on a moored vessel

THROUGH THE APPLICATION OF AUTOMATED MOORING SYSTEMS



TECHNICAL PAPER

ABSTRACT

Increasing operational efficiencies is a key goal of many ports and the shipping industry as a whole. External forces such as inclement weather, long period waves and the effects from passing ships can reduce berth efficiencies by increasing the motions of a vessel at berth.

This study analyses the motions of a container vessel berthed at an outer harbor location near a breakwater. In this location, a breakwater provides good attenuation of the offshore wave energy (wind, sea and swell) at the berth but only has limited sheltering effect from long period (infragravity) wave energy. A comparison between the vessel subject to long period waves when moored with traditional lines versus an array of Trelleborg AutoMoor units showed that the peak and average motions in surge and sway were reduced substantially. The reduction in vessel motions indicates an increase in berth operability for product transfer from 65% to 95%.

Keywords: Infra-gravity Wave, Long-Period Wave, Vessel Motion, AutoMoor, Automated Mooring.

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INTRODUCTION

The port industry continually faces the challenge of maximizing berth utilization to allow product or passenger transfers to occur as seamlessly as possible with minimal downtime. In general, this challenge arises from the need to:

- Prepare port infrastructure to cater for the ever-increasing vessel size.
- Discover innovative ways to reduce capital investment.
- Increase vessel traffic due to higher demand on ports and terminals.
- Find ways to lower operational costs and make the port more attractive.
- Reduce frequency of incidents that jeopardize port safety and cause downtime.
- Minimize the effects of adverse environmental and met-ocean conditions.
- Minimize the effects of passing vessels.

Focusing on factors that affect moored vessels at berth; in the simplest of terms, for a mooring system to be effective, it must counteract external forces acting on the vessel to restrain the motion sufficiently to allow efficient product transfer. External forces can be grouped into two main categories:

Static – forces that for analysis can be considered not to change significantly over a short time including current, constant wind and short period waves.

Dynamic – forces that change significantly over a short time including long-period waves, gusting winds or the effects of passing ships.

The efficiency of a mooring system is dependent on several factors:

- The 'human element' – lack of timely information to make informed decisions; inaction to changing conditions, or suboptimal practices.
- Ineffective facility designs or mooring pattern selection.
- The environment - met-ocean conditions or passing vessel.

One specific met-ocean condition is infragravity waves which are waves with periods greater than 30 seconds. The wave height is generally smaller than a regular wave when in deep water but can increase as water depth decreases. Due to having longer periods they are less affected by breakwaters, can travel uninhibited into harbors and as a result, can have significant impact on vessels moored within. There are significant risks associated with these waves including lines snapping and vessels drifting from berth. The downtime caused to operations can be significant, as the wave has a high level of energy transfer to the vessel and causes large vessel motions.

The use of automation in port operations is becoming more commonplace, with applications ranging from offshore autonomous ships to onshore fully automated container yards.



Fig 1. AutoMoor T20 Gen2.

The Trelleborg AutoMoor system (Figure 1) is a passive automated vacuum mooring system that maintains a vessel mooring through the use of spring damping. Each vacuum pad has a rated capacity of 20T in sway and 12T in surge. The passive system is engaged at the position of vessel berthing and provides corrective force to keep the vessel at the fender-line.

OBJECTIVE

The objective of this paper is to demonstrate the effectiveness of automated mooring technology that expand the window of operation for product transfer by reducing vessel motions. This is achieved by modelling the wave field in the harbor, applying the wave forces to a moored vessel, and benchmarking the AutoMoor solution against a conventional static mooring line arrangement.

SETUP

A mooring analysis was performed for a vessel berthed at a container terminal located near a breakwater entrance where it is unprotected from the effects of infragravity waves (Figure 2).

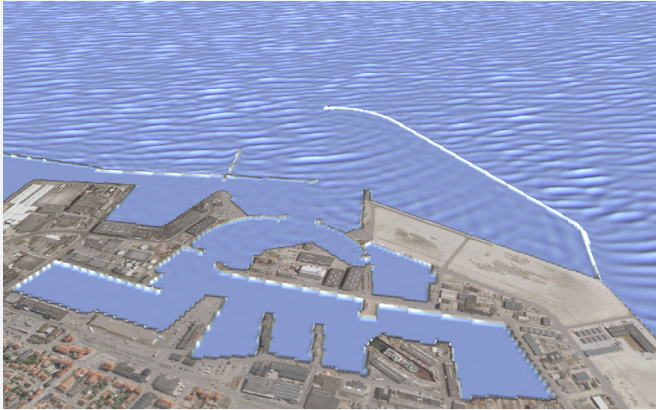


Fig 2. Image showing infragravity waves entering harbour.

Using the newly developed AutoMoor supported module in DHI's truly dynamic mooring analysis software, MIKE 21 MA [1], which is capable of extremely fast and high precision hydrodynamic simulations, a study was conducted comparing motions of a vessel when moored with mooring lines and AutoMoor T20 units. The combined sea, swell and infra-gravity wave forcing was created using the industry standard wave agitation software MIKE 21 BW model of the entire port domain. The vessel considered was a 10,000 TEU container vessel.

The analysis was performed on the vessel when moored in an 'optimal' conventional mooring (Figure 3) arrangement of 14 lines; 5 lines at bow and stern, 2 spring lines at bow and stern, all at 10T pretension. These lines were modeled as broken-in polyester polypropylene with MBL 110T. Typical polypropylene mooring lines have an elasticity of approx. 4.5%, and as such, considerable pretension must be applied to the mooring lines from the ship's winches in order to achieve similar stiffness characteristics to the AutoMoor units. The results from this analysis were used as a baseline to compare to the Trelleborg AutoMoor system. Several cases were conducted where the number of units and locations along the berth were varied.

The results compare motions of the vessel when moored with mooring lines to that with 12 x T20 AutoMoor units and 24 x T20 AutoMoor units. Using an AutoMoor arrangement, the vessel is berthed with 5T pretension and a maximum rated sway load of 20T per unit.

The AutoMoor units apply force directly in the surge and sway motions of the vessel, compared to a mooring line that applies force in the vector from bollard to fairlead, equating to a low translation of line tension to restoring force. The arrangement of the AutoMoor units along the berth has impacts on the vessel's yaw, as clustering towards the bow and stern would have positive effects but be traded off against universality across vessel sizes.

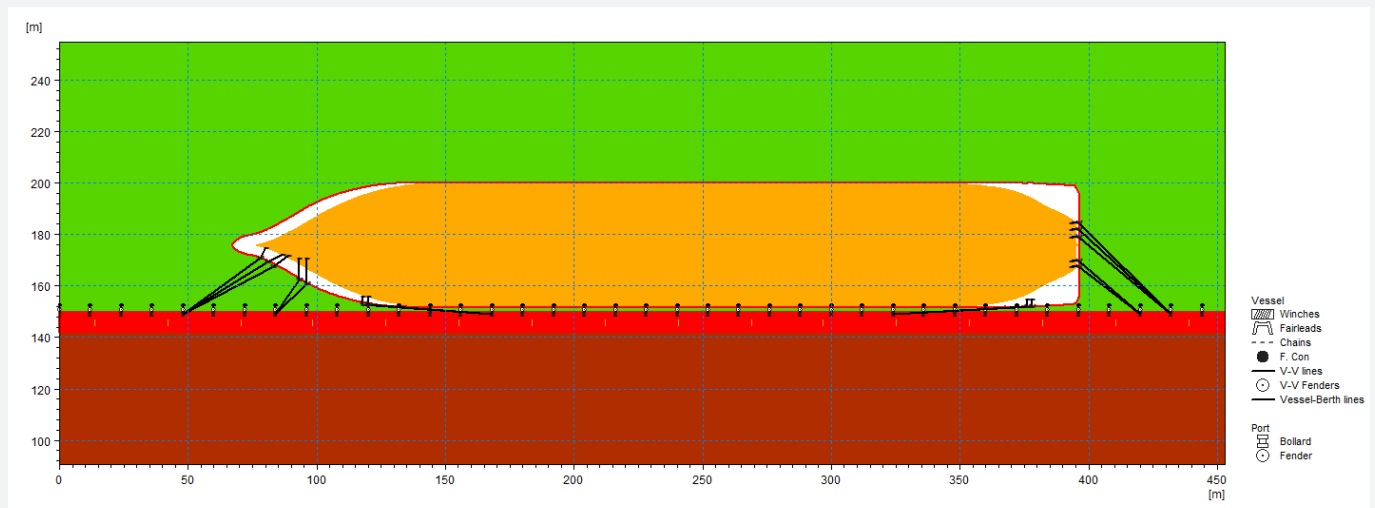


Fig 3. Plan view of mooring line arrangement.

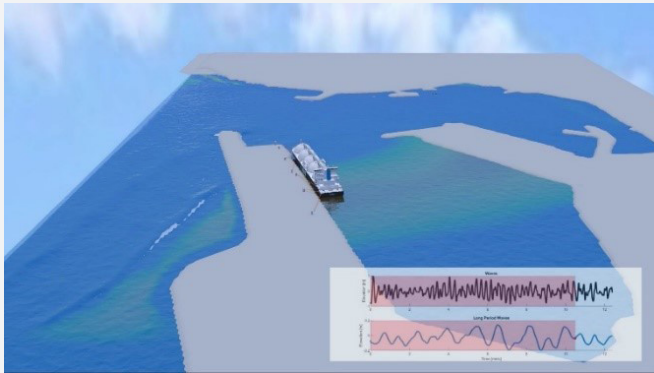


Figure 4 shows an example of vessel (LNG carrier) motion calculation using DHI's MIKE 21 MA at berth caused by offshore waves (sea and swell, the white foam indicates wave breaking at the coast) and infragravity waves (long waves, colored) simulated by MIKE 21 BW software.

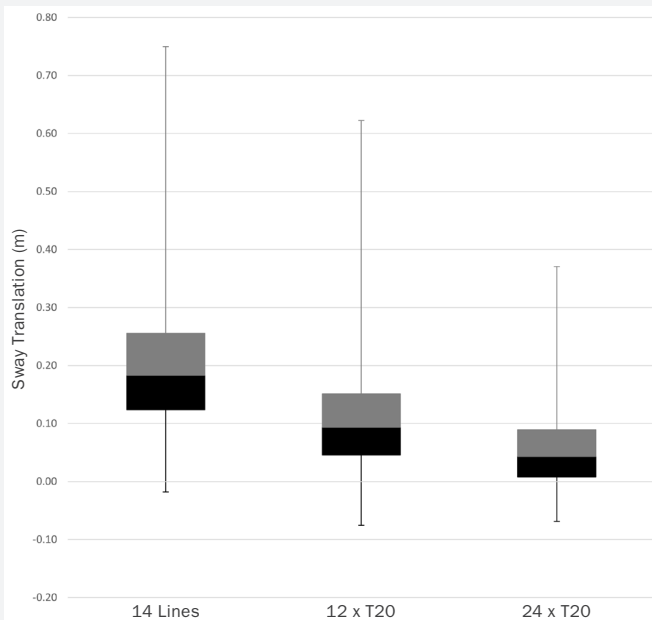


Fig 5. Box plot illustrating distribution of vessel sway motions.

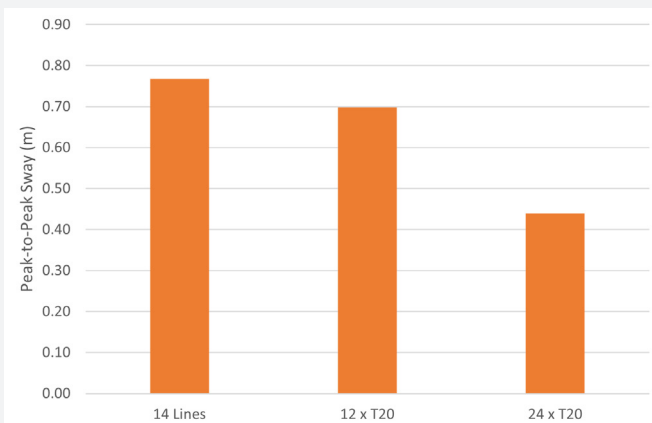


Fig 7. Bar chart denoting peak-to-peak sway motion.

RESULTS

The minimum number of AutoMoor units required to safely moor the vessel in this scenario is 12 x T20 units, to achieve lower motions than with mooring lines. By increasing the number of AutoMoor units, vessel motions are further reduced.

The range of the vessel motion in surge and sway when using mooring lines is 1.1m and 0.77m respectively. The range when using 12 x T20's and 24 x T20's in surge are 0.64m and 0.29m respectively and 0.7m and 0.44m in sway respectively (Figure 8 and Figure 7). The 12 x T20 and 24 x T20 arrangements meet the 90% and 95% efficiency criteria for container vessel motions in sway and surge respectively, as per PIANC WG212 industry guidelines [2].

While the vessel is moored with AutoMoor the vessel is kept more stable at the fender-line. This is evident by the reduction in both the median and standard deviation of sway movement (Figure 5). Vessel surge motion (Figure 6) shows similar improvement with a median position closer to the zero position, with a tighter distribution. The combined effect is an estimated increase of berth operability from 65% to 95%.

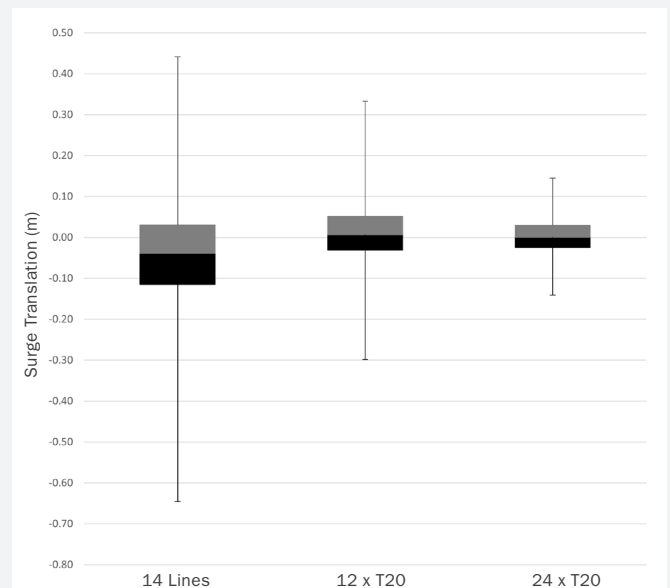


Fig 6. Box plot illustrating distribution of vessel surge motions.

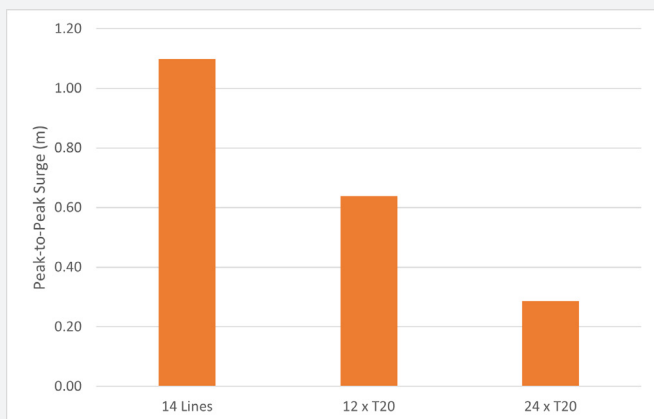


Fig 8. Bar chart denoting peak-to-peak surge motion.

DISCUSSION

The use of AutoMoor in this scenario adds a level of motion damping that cannot be achieved through mooring lines. The response from the AutoMoor passive system far exceeds that of the mooring lines within a small vessel displacement.

The consideration for the arrangement of AutoMoor units along the berth -line is dependent on the berth utilization by vessel lengths and the vessel motion to be reduced. Catering for a range of vessel types can lead to compromises in performances or higher equipment requirements.

The intended limit of vessel motions for a specific wave or across many waves can lead to varying requirements on the number of units. The plot displayed in Figure 9 shows the reduction of peak loads through the addition of further units. The sway plot (Figure 10) further shows the vessel motion with AutoMoor has a lower amplitude than for mooring lines. This is confirmed in Figure 7 showing the vessel is held within a smaller area of movement for a larger proportion of the time.

Another consideration is that the mooring lines have a maximum peak loading of 40% MBL followed by a minimum peak with slack lines; the range from maximum to minimum peaks would lead to fatigue in the lines and eventual line failure. The mooring line setup and arrangement is considered in the analysis to be in optimal condition. In practice, lines are frequently left untended with lines going slack, or sub-standard line arrangements used.

The AutoMoor units all operated within their performance ratings for the duration of the vessel motion and consistently limited vessel motions without reaching mechanical limits. The motion off the fenders is shown to occur at a lower occurrence rate (Figure 6) when moored with AutoMoor and to be focused within a smaller distance. The surge and sway of the vessel are contained within smaller ranges with AutoMoor, due to the mooring forces acting directly in-line with vessel motions, surge and sway.

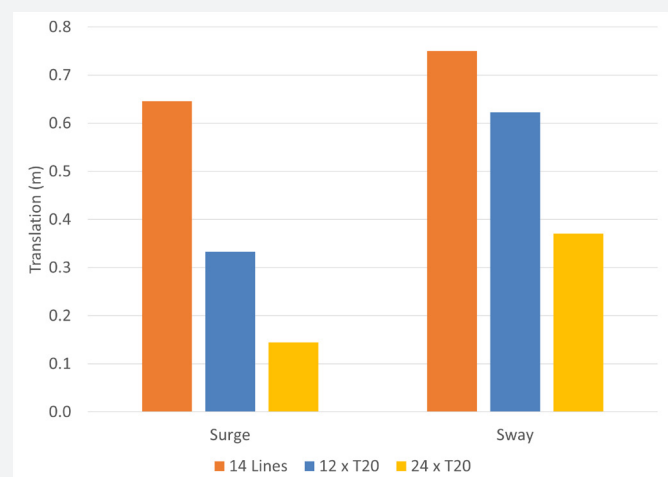


Fig 9. Summarized bar chart illustrating reductions in vessel motions from the implementation of AutoMoor units.

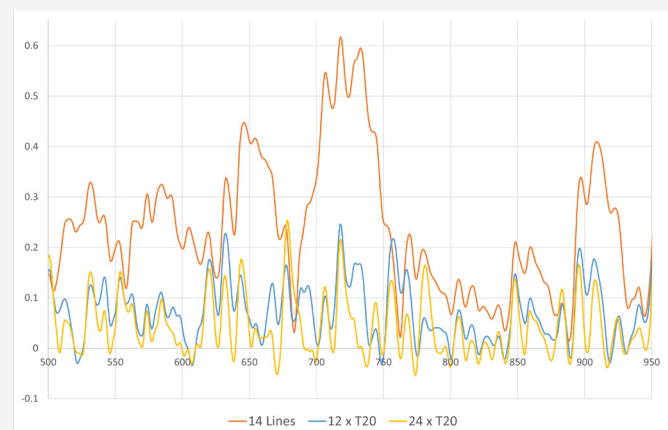


Fig 10. Sample time-series of vessel sway motions.

CONCLUSION

This study showed that:

- AutoMoor T20 units successfully moored the vessel with a significant decrease in vessel surge and sway if compared to mooring with lines.
- The reduction in vessel motions indicates an increase in berth operability for product transfer from 65% to 95% whilst complying with PIANC industry guidelines for allowable motions of a container vessel at berth.

Infragravity waves can have large effects on the motions of the vessel at berth due to their interaction, leading to higher vessel excitation than from a regular sea-state.

Vessels in these conditions will typically have motions that cannot be restrained by mooring lines effectively to maintain cargo operations or a safe mooring. From the two AutoMoor cases considered, there were significant improvements in both the median and standard deviation of vessel motions in sway and surge directions.

There are opportunities where addressing a particular magnitude of infragravity waves can lead to increasing the duration of the cargo transfer window. There may be occurrences of higher magnitude waves that remain outside this window, but the reduction in operational downtime can significantly improve port efficiency and vessel turn-around time. In a container terminal, the transfer rate of containers will be increased as the vessel motions are reduced.

RELATED APPLICATIONS

Wave effects on vessels are specific to the local conditions and are therefore common through all port and vessel types. The findings in this paper are an indication of the improvements possible when automated moorings are used in complex wave action that traditional mooring lines fail to capture.

[1] MIKE Powered by DHI software, <https://www.mikepoweredbydhi.com/>

[2] PIANC MarCom-WG-212 Movement of vessels at quay walls



Fig 11. AutoMoor unit at RoPax ferry terminal.

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