Validation of numerical models for motions of ships moored with MoorMaster™ units, in a harbour under influence of ocean waves

Master Thesis Presentation
at Ports Seminar 2010

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Quay wall based MoorMaster™ units

- Vacuum pad for attachment to the ship hull
- Vertical rails for freedom in vertical direction \( \Rightarrow F_{\text{Heave}} = 0 \)
- Hydraulic cylinders for horizontal forces

\[ \begin{align*}
F_{\text{Surge}} & \\
F_{\text{Sway}} & \\
F_{\text{Heave}} & = 0
\end{align*} \]
Motion reducing effect of MoorMaster™ units
Comparison MoorMaster™ units and mooring lines

- Hydraulic cylinders act stiffer than mooring lines
- More efficient angle of mooring forces
- Control system can be set to let the MoorMaster™ units respond to displacements, velocities and accelerations of the ship

\[ F_{\text{hor}} = 20\%-70\% F_{\text{line}} \]
(Dis)advantages MoorMaster™ units

Advantages
- Less ship motion $\rightarrow$ faster container handling
  - Criteria: decreasing efficiency with surge $> 0.5$ metre
- Higher allowable waves in the harbour basin $\rightarrow$ savings on breakwaters

Disadvantages
- High capital expenditures
- Operational expenditures
  - High maintenance level in saline environment
  - Energy consumption costs
- Limited knowledge about effect and reliability of the system
Container terminal with MoorMaster™ units

- 4 MoorMaster™ units, located at container berth 4
Validation of numerical models for motions of ships moored with MoorMaster™ units, in a harbour under influence of ocean waves

Purpose of thesis objective:
- Reliable numerical models including MoorMaster™ units can be used for (new) port designs
Wave measurements

Shortcomings:
- No wave directions measured
- Measurements at only 1 point
Wave measurement analysis case 1

- Long wave peaks at 0.01 – 0.02 Hz (T = 50 – 100 s)
- Swell peak at 0.13 Hz (T = 8 s)
Mooring lay out ship motion measurements

Case 1
- Mooring lines and fenders control surge and sway motions

Case 2
- Mooring lines and fenders mainly control sway motion
- 4 MoorMaster™ units ONLY control surge motion

Most important uncertainties of the measurements:
- Mooring lines (types, allocation, pretension)
- Loading conditions
Case 1 (only mooring lines)
- Surge amplitude order of 1 metre

Case 2 (mooring lines and MoorMaster™ units)
- Surge amplitude order of 0.05 metre

Conclusion 1:
- Measurements show that MoorMaster™ units have a large reducing effect on surge motions of moored ships
Measured ship motion spectra

Magnitude of surge motions:
- Case 1: $\text{Surge}_m = 1.45\ \text{metre}
- Case 2: $\text{Surge}_m = 0.09\ \text{metre}$

Frequency of surge motions:
- Typical frequencies of surge motion $< 0.04\ \text{Hz (T > 25 s)}$

Conclusion:
- Surge motions induced by long waves ($T > 25\ s$)
Mike 21 BW simulations

- **Goal:** simulate long waves similarly at berth 4 as the long waves that have acted on the ship during the ship motion measurements.

- Ocean waves tuned to obtain similar wave conditions at the berth.

- Long waves penetrate in the harbour basin by:
  - Diffraction long waves around breakwater into harbour basin.
  - Reflection long waves from Northern beach into harbour basin.

![Diagram of wave radar at berth 4 and reflection and diffraction of ocean waves into the harbour basin.]
Validation simulated waves at wave radar case 1

- Simulated long waves ($f < 0.04$ Hz) show similar frequency peaks as the measured long waves
- Simulated long waves ($f < 0.04$ Hz) show a similar magnitude with measured long waves
- Wave directions cannot be compared
- Comparison at only 1 location
Calculations by Harberth

Wave propagations at the berth (Mike 21 BW, DHI)

↓

Wave forces on the ship (Harberth, TU Delft)
Calculations by Quaysim

Wave propagations at the berth (Mike 21 BW, DHI)
↓
Wave forces on the ship (Harberth, TU Delft)
↓
Ship motions and mooring forces (Quaysim, CSIR)
Validation surge motions case 1

Amplitude of surge motion:
- Measured: $\text{Surge}_{m0} = 1.45 \text{ m}$
- Simulated: $\text{Surge}_{m0} = 1.20 \text{ m}$

Peak frequencies of the surge motion:
- Measured: $f_p = 0.012 \ (T_p = 83 \text{ s})$
- Simulated: $f_p = 0.017 \ (T_p = 58 \text{ s})$
Amplitude of surge motion:
- Measured: $\text{Surge}_{m0} = 0.09$ m
- Simulated: $\text{Surge}_{m0} = 0.04$ m

Peak frequencies of the surge motion:
- Measured: $f_{\text{peak}} = 0.022$ (T = 45 s)
- Simulated: $f_{\text{peak}} = 0.028$ (T = 36 s)

Conclusion 2:
- Effect of MoorMaster™ units on the magnitude of the surge motions can be simulated in Quaysim
Conclusions & recommendations

Conclusion 1:
- Measurements show that MoorMaster™ units have a large reducing effect on surge motions of moored ships

Conclusion 2:
- Effect of MoorMaster™ units on the magnitude of the surge motions of moored ships can be simulated in Quaysim
- The magnitude and frequency of the simulated surge motion of the ship is not accurate compared to measurements, due to uncertainties:
  - Wave conditions (directions)
  - Mooring lines (types, pretension, allocation)
  - Loading condition of the ship

Overall conclusion:
- With reliable input (and a calibrated wave model) the order of magnitude of ship motions in a harbour can be simulated, including the effect of MoorMaster™ units