The use of a floating quay for container terminals.

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Abstract
The increase of global shipping leads to competition between container terminals. In order to meet the demands of the shipping companies (service time < 24h.) innovation is necessary. A new indented berth layout is used at Amsterdam Container Terminals to achieve a berth productivity of 300 moves per hour. Since there is a scarcity of land within ports, the use of a floating quay with portainer cranes seems to be feasible to stimulate higher berth productivity and obtain more flexibility within ports as well. The idea of a floating quay consists of several elements which connected together should provide a working system which is useable within the logistic process of a container terminal. The design of such a flexible system is different for each port. Two designs were made which should be capable to receive the latest ships. The first design is build up of 3 pontoons (160x40.5x16m), the second design is build up of 1 pontoon (480x40.5x15.5m). For both designs the static and dynamical stability is determined. For the smallest design the hydrodynamic behavior of the construction is analyzed. The construction is schematized as a mass spring system and the hydrodynamic behavior is computed using DELFRAC. The output of DELFRAC consists of the Response Amplitude Operator for six degrees of freedom. At first glance the static stability due to wind at the portainer is a problem for the designed floating quays.

Keywords: flexibility, floating, quay.

1. Introduction

An increase in world economics leads to an increase in global container transport. In order to decrease the transport costs per container larger vessels are used. The largest vessels sailing on the main trunk routes have a capacity of 12,500 TEU. Due to the scale increase of the vessels the call sizes within ports increase as well. In order to keep the service time of the largest vessel within 24 hours extra (un)load capacity is needed. This extra capacity is normally offered by adding more portainers. To further decrease the service time several innovations have been investigated. One new concept is the indented berth as currently used by Amsterdam Container Terminals (former Ceres terminal). An indented berth makes it possible to (un)load ships from both sides. In this way the berth transfer capacity can be increased up to 300 moves/hour. Container terminals want to expand their quay capacity but there is a scarcity of space in ports as well. A concept which fulfils both wishes is the use of a floating quay. A floating quay is based on the indented berth principle. During (un)loading of the vessel, the quay offers extra capacity which increases the berth capacity. The floating quay needs to be transported to the ship and then positioned. The flexibility of the container terminal can be increased, because the floating quay can be replaced. Due to draught increase of container vessels the water depth within ports increases as well. Existing quay walls need to be deepened to make it possible to moor the latest vessel along the quay. Rising sea water levels and earthquakes cause problems for fixed quays. Taking future developments into account, a floating quay becomes a very attractive solution. Future container terminals may
have new cargo handling systems, cranes, layouts and structures. The question arises whether a floating quay can be used to add extra capacity for an existing container terminal.

2. Design considerations

A floating quay can be used and designed in various ways and consequently differ for each port. Choices to be made are for example; the number of end-users (dedicated or multi-user?), the allowance of stacking and the number of cranes working on the quay. Each choice at system level has a consequence in a later stage. For example the allowance of stacking offers additional stacking capacity, but leads to an increase in the dimensions of the quay. Besides the possibilities for the use of a floating quay, there are several possibilities for the construction. The floating quay exists of several floating elements which together form a working system. The floating elements can be constructed as pontoon, catamaran or semi-submersible. Other aspects to design further are amongst others, the position system and the connections between elements.

The chosen design is a floating quay for several users, with cranes working on one side of the construction and without stacking space, see Figure 1. The transport of containers over the floating quay could be done by AGV’s. Advantages of this design are: a high utilisation of the construction, relatively small dimensions which provide a better manoeuvrability and a flexible construction. Disadvantages of this design are: it is not possible to (un)load ships on both sides of the floating quay and direct transhipment is limited. As a starting point a pontoon was selected as an element.

Figure 1. Possibilities with the moving floating quay.
3. Stability of designs

Two designs of a floating quay were made, with a cross section according to Figure 2. The first design consists of one large element and the second design consists of three elements, see Table 1. Both designs are made of concrete, which over the life cycle of the construction is the most durable material. The draught of the elements can be calculated with the law of Archimedes:

\[ F = \rho_w \cdot g \cdot V \text{ Eq. 1.} \]

In which:
\(\rho_w\) = density of water [kg/m\(^3\)]
\(g\) = gravitational acceleration [m/s\(^2\)]
\(V\) = volume of displaced water [m\(^3\)]
\(F\) = buoyancy force [N]

The designs must be static and dynamically stable. The static stability of a pontoon is normally guaranteed when the height of the meta centre is larger than 0.5m (\(h_m>0.5\text{m}\)). From calculations it was found that the meta centric height for both roll as pitch is sufficient, see Table 2.

![Figure 2. Cross section of pontoon.](image)

### Table 1. Characteristics of design

<table>
<thead>
<tr>
<th>Design</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Draught laden</th>
<th>Draught empty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design 1</td>
<td>480 m</td>
<td>40.5 m</td>
<td>15.5 m</td>
<td>11.9 m</td>
<td>9.4 m</td>
</tr>
<tr>
<td>Design 2</td>
<td>160 m</td>
<td>40.5 m</td>
<td>16.0 m</td>
<td>11.3 m</td>
<td>8.8 m</td>
</tr>
</tbody>
</table>

During operational conditions the crane legs on the floating quay are unequally loaded. As a result a moment is working on the floating quay. Because of this external heeling moment, the structure will heel with an angle \(\phi\). The heel angle can be determined using the method of Scribanti, which can be used for all wall-sided floating structures. According to the method of Scribanti a linear relationship between heel angle and heel moment can be used, as long as
the heel angle of the construction is small (\( \varphi < \pm 10^6 \)). In a stability curve the relationship between moment and angle is drawn, see Figure 3.

The maximum heel moment caused by the four cranes of Design 1 equals 540.000kNm (during operational conditions), which gives a heel angle between 1,6\(^0\) and 2,5\(^0\) for an empty and full laden pontoon respectively. The maximum heel moment caused by the two cranes of Design 2 equals 270.000kNm, which gives a heel angle between 2,4\(^0\) and 2,6\(^0\) for an empty and full laden pontoon respectively. The heel angle is small and the construction will go back to equilibrium, but the container at the end of the crane boom will be displaced vertically about 3,0m. This displacement is unacceptable since the heave amplitude for efficient (un)loading of container vessels according to standards (eg. PIANC 1995) should be smaller than 1,0m.

![Stability curves of designs](image)

**Figure 3. Stability curves of both designs (roll rotation).**

The dynamic stability can be checked by calculating the eigen period. The dynamical behaviour of the floating quay due to waves is worked out in more detail in Hydro dynamical behaviour. A first calculation of the eigen period (see Table 2), without added mass and damping, for a pontoon is given by:

\[
T_0 = \frac{2\pi \cdot j}{\sqrt{h_m g}}
\]

Eq. 2.

In which:
- \( g = \) gravitational acceleration [m/s\(^2\)]
- \( h_m = \) height of meta centre [m]
- \( j = \) polar inertia radius [m]
- \( T_0 = \) eigen period [sec]
Table 2. Static and dynamic stability of designs

<table>
<thead>
<tr>
<th>Design</th>
<th>( h_m ) laden roll (m)</th>
<th>( h_m ) empty roll (m)</th>
<th>( d_m ) laden pitch (m)</th>
<th>( d_m ) empty pitch (m)</th>
<th>( T_0 ) roll (sec)</th>
<th>( T_0 ) pitch (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design 1</td>
<td>5.64</td>
<td>11.43</td>
<td>1715</td>
<td>2178</td>
<td>8.4</td>
<td>6.7</td>
</tr>
<tr>
<td>Design 2</td>
<td>7.73</td>
<td>10.70</td>
<td>175</td>
<td>222</td>
<td>8.6</td>
<td>6.1</td>
</tr>
</tbody>
</table>

4. Hydro dynamical behaviour

The dynamical stability has been determined by calculating the eigen period, but a more detailed calculation is necessary to check the behaviour of the construction during wave attack. By schematizing the floating quay as a mass spring system it is possible to investigate the hydro dynamical behaviour of the floating quay, see Figure 3. The mass spring system makes use of uncoupled linear equations for the six degrees of freedom, see Figure 4. The behaviour of a mass spring system can be described with a general differential equation:

\[(m + a)\ddot{x} + b\dot{x} + cx = F(\omega)\] Eq. 3.

In which:
- \( m \) = mass of construction [kg]
- \( a \) = added mass [kg]
- \( b \) = hydrodynamic damping coefficient [Ns/m]
- \( c \) = spring constant [N/m]
- \( x \) = displacement [m]
- \( F(\omega) \) = excitation forcing [N]

The water is assumed to be ideal and thus to behave as in a potential flow. As the system is linear, the resulting motion in waves can be seen as a superposition of the motion of the body in still water and the forces on the restrained body in waves \((F(\omega) = F_h + F_w)\). Two loads will be distinguished; a hydromechanical load \((F_h)\) and a wave exciting load \((F_w)\).

The hydromechanical forces are the reaction forces of the fluid on the oscillating body, caused by motion in initially still water: \(m\ddot{x} = F_h\) with \(F_h = -a\ddot{x} - b\dot{x} - cx\). The equation of motion for the body with a decaying motion in still water becomes:

\[(m + a)\ddot{x} + b\dot{x} + cx = 0\] Eq. 4.
The wave exciting forces can be described with the Froude-Krilov forces which follow from an integration of the pressures on the body in undisturbed waves. The Froude-Krilov force is given by:

\[ F_w = a \cdot \dot{\xi}^* + b \xi^* \cdot \dot{\xi} + c \xi^* \cdot \dot{\xi} \] Eq. 5.

In which:
\[ \xi^* = e^{-kT} \cdot \xi \cos(\omega t) \]
\[ c = \text{spring constant [N/m]} \]
\[ k = 2\pi / L \text{ with } L = \text{wave length in m} \]
\[ \xi = \text{wave amplitude [m]} \]
\[ T = \text{draught [m]} \]
\[ \omega = \text{wave frequency [rad/sec]} \]

Both added mass and damping depend on the wave frequency. The coefficients for added mass and damping can be determined with a numerical model. The numerical model used is DELFRAC, developed at the TU Delft. The input for DELFRAC consists of the geometry of the wet part of the body, the mass inertia radius, the water depth and the position of the centre of gravity of the construction relative to the free surface line. DELFRAC uses the added mass and damping coefficients to determine the Response Amplitude Operator (RAO) for each degree of freedom. The RAO for the heave motion is given in Figure 6. The RAO is given for different wave directions, with 0 degrees for head waves and 90 degrees for beam waves. The calculated eigen frequency for this pontoon, without added mass and damping, was 0.70 rad/s.
With use of the RAO it is possible to obtain a motion spectrum for the rigid body from a wave spectrum (or vice versa), or in formula:

$$S_x(\omega) = \left| \frac{x}{\eta} \right|^2 \cdot S_{\xi}(\omega) = |RAO|^2 \cdot S_{\xi}(\omega) \quad \text{Eq. 5.}$$

In which:

- $S_x(\omega) = \text{motion spectrum}$
- $S_{\xi}(\omega) = \text{wave spectrum}$

For each port the wave spectrum can be determined. The motion spectrum follows from spectrum formation, for which an example is given in Figure 5. The amplitudes of motion can be determined with a spectrum analysis and compared with standards.

![Figure 5. Spectrum transformation (Journeé, J.M.J and Massie, W.W, 2001).](image)

![Figure 6. Response Amplitude Operator for heave motion (Design 2).](image)
5. Conclusions

-A floating quay increases the quay capacity and the flexibility of a container terminal. Two designs of a floating quay consisting of pontoons were made. For both designs the static and dynamic stability have been checked. The static stability of the floating quay is guaranteed.

-However in both designs, efficient (un)loading of container vessels is not possible, because the amplitude of the displacements is too large. The dynamic stability of the pontoons should not lead to major problems. The motions of the floating quay in waves can be checked using the motion spectrum.

-The static stability of the floating quay can be effectively improved by increasing the width of the construction. Several other options to increase the static stability of the construction are for example a larger freeboard or an increased width.

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References


