ABSTRACT

The conditions of competition within ship yards are changing. The current market situation requires a new orientation of the Pella Sietas ship yard with flexible solutions for new ship types. Complex, heavy and ice-going ships show one way for future designs. In view of all the technical difficulties involved in such challenging projects, the first question must be how to handle these heavy constructions with the yards building facilities available. The Pella Sietas yard is using a floating platform for newbuildings. The question arises whether or not this platform is still capable and suited for this kind of ship types.

The docking procedure is a complex multi-body interaction that copes with hydrostatic and structural challenges. The docking operation is regulated by the sequence of flooding and emptying ballast water tanks of the dock. At any time of this dynamic operation the hydrostatic stable equilibrium of ship and dock must be ensured.

When the ship is drained, the block system transfers its whole weight on the structure of the dock. It must be ensured that the resulting tensions and deformations do not exceed the maximum permissible values.

This paper describes a fast calculation method that determines the mentioned hydrostatic as well as the structural investigations during the docking procedures.

The method implies a numerical progressive flooding simulation that calculates the hydrostatics of ship and dock under consideration of their interaction by dock blocks together with the ballasting sequence in the time domain. Furthermore it calculates the block forces distribution by applying the deformation method. In the calculation process ship and dock are modeled as Timoshenko beams and the dock blocks as non-linear spring elements. Moreover the shear force and bending moment distributions of ship and dock are calculated and the deflection lines are presented.

Therefore, the described method enables the ship yard to evaluate quickly the possibility of building new types of ships on the existing building platform and allows evaluating which modifications are useful to enlarge the capacity of the platform even further.

It provides a useful tool to minimize local and global stresses and deformations of the interacting bodies during the whole docking procedure by fast optimization of the block system arrangement and the ballasting sequences.

As a result the described method could expand the range of flexibility of a given floating dock structure. In addition, the whole hydrostatic and structural integrity of docking sequences can be computed faster and more accurate even at a very early project stage.

INTRODUCTION

A new type of ship shall be built at the Pella Sietas yard. The question arises if this and future newbuildings can be fabricated on the available floating platform. The challenge is that the water depth in the harbor basin is limited. One possibility to increase the flexibility would be to tug out the floating platform together with the loaded ship towards deeper water, which would allow a deeper lowering of the platform leading to larger possible lightsip draughts of the ships. During this whole ballasting process it must be ensured that ship and dock will neither capsize nor sustain structural failure.

This paper provides a first estimate on the feasibility of this project by taking into account hydrostatic and structural calculations. The combination of different calculation methods ensures a comprehensive investigation. The flooding simulation
controls the ballasting of the floating platform and calculates the quasi-hydrostatic equilibrium of ship and platform at each time step. For several time points the structural computations calculate the block forces. The shear forces and bending moment distribution for ship and platform is determined by considering these interaction forces. The structural calculations result in the deflection lines of the two bodies. In the case of high deflection the ballasting in the flooding simulation is changed and a new calculation starts. This iteration procedure enables the optimization of the investigation.

**FLOODING MODEL**

The applied flooding simulation method has initially been developed to investigate real scale ship accidents. An elaborate description of the computational and the theoretical background can be found in the thesis (Dankowski, 2013) together with its validation with experiments.

The computational method will shortly be sketched in the following. It is in general a combination of a hydraulic model to determine the water fluxes through possible openings and the efficient calculation of a quasi-hydrostatic equilibrium at each time step. A dynamic motion extension of the method is sketched in (Lorkowski, et al., 2014).

The fluxes depend on the water levels of both sides of the opening, which again depend on the current amount of water in the neighboring compartments. The floating equilibrium to be determined depends on the current distribution of the floodwater inside the vessel. In addition, special situations have to be taken into account like the propagation through completely flooded compartments. Since the whole flooding process is highly non-linear, a predictor-corrector scheme for the integration in the time domain is applied.

**Application on Ballasting**

This method has already been successfully applied to investigate the deballasting of a semi-submersible vessel to unload its cargo as described in (Dankowski, et al., 2013). In this paper the described kind of application is further extended to be coupled with structural computations of the involved floating bodies.

Especially important for such ballast investigations are the control options to direct the motion of the platform. The following controls are in this case used:
- Pressure head criteria
- Time-dependent closing of openings
- Pump elements

The most simple and efficient way to fill up the ballast tanks of a dock (or ship) is done by gravity flooding. This can be simply achieved by opening certain (bottom) valves of the ballast tanks.

To simulate this in the calculation, the pressure head criteria can be applied as the simplest one. The closed opening at the beginning is given a certain breaking pressure head value. If the opening is submerged that far, that this threshold is exceeded, it is than assumed to be open. Typically, this criterion is also applied to doors and windows in sinking simulations.

Another method is to assign certain time-dependent conditions to selected openings. Again, the opening is for example initially closed and will be opened at a certain time step and can of course also be closed again. This gives a better and more detailed control of the ballasting sequence, but becomes easily also more complicated.

The last method, which is an even finer control option, is to use pump elements representing ballast water pumps. These are defined by a certain possible volume flux, an operating pressure head and a maximum possible height before the pump power is exceeded.

In this case, a combination of these three control options is used. The targets are in this case to prevent an excessive trim and to keep a certain distribution of the ballast water in longitudinal direction. It will be shown that both influence highly the deflection of the platform during the ballasting sequence.

**STRUCTURAL INTEGRITY**

**Calculation of Block Forces**

The calculation to determine the block forces is based on the deformation method and is originally implemented by (Greulich, 2013).

**Mechanical System**

In longitudinal direction dock and ship are divided into elements of equal length. These elements are Timoshenko beams and provide the stiffness of dock and ship regarding inertia and in advantage over Euler-Bernoulli beams, regarding shear forces as well. On the nodes in between, loads are applied and deflections are calculated. The keel blocks, on which the ship rests during docking, are modelled as non-linear spring elements. The non-linearity is important for modelling the particular compressive strength of the wood layers.

The described system is shown in Fig. 1.

![FIGURE 1: SUBSTITUTED MECHANICAL SYSTEM](image)

**Equation System**

The unknown deflections \( \{u\} \) of the nodes are calculated by the following equation system:

\[
[K]\{u\} = \{P\}
\]
\[ [K] \] is the stiffness matrix and \([P]\) are the external forces at the nodes. The external forces \([P]\) are calculated as equivalent node forces due to weight and buoyancy distribution of ship and dock. The conversion is based on the energy theorem that implies the equality of the resulting deflection due to single and distributed load:

\[
[u]^T [P] = \int_0^L w(x) \cdot q(x) dx
\]  

(2)

\(w(x)\) is the deformation function that is a cubic function for bending and a linear function for shear. The load distribution \(q(x)\) is assumed trapezoidal about element length.

The system stiffness matrix \([K]\) is composed of the stiffness matrices of all beam elements and all spring elements. At every node of the system all related entries of the different elements are added up.

The stiffness matrix of one Timoshenko beam is given as:

\[
\begin{bmatrix}
12K_y & -6K_y \cdot l & -12K_y & -6K_y \cdot l \\
(4 + \phi_2)K_y \cdot l^2 & 6K_y \cdot l & (2 - \phi_2)K_y \cdot l^2 \\
\cdot & \cdot & \cdot & \cdot 12K_y \\
\cdot & \cdot & \cdot & \cdot 6K_y \cdot l \\
\end{bmatrix}
\]

(3)

\(K_y\) is the characteristic factor for stiffness:

\[
K_y = \frac{E \cdot I_y}{l^3 \cdot (1 + \phi_2)}
\]  

(4)

\(\phi_2\) is the influencing factor for shear:

\[
\phi_2 = \frac{12E \cdot I_y}{G \cdot A_S \cdot l^3}
\]  

(5)

\(G\) is the shear modulus:

\[
G = \frac{E}{2 \cdot (1 + \nu)}
\]  

(6)

The stiffness matrix of one keel block, modelled as spring element between two nodes, is:

\[
\begin{bmatrix}
 c_b & 0 & -c_b & 0 \\
 \cdot & 0 & 0 & 0 \\
 \cdot & \cdot & \cdot & \cdot c_b \\
 \cdot & \cdot & \cdot & \cdot 0 \\
\end{bmatrix}
\]

(7)

\(c_b\) is the stiffness factor of one keel block. It depends on the geometric and material properties of the different wood layers. Each layer can be described as a non-linear spring element. The series connection of these different spring elements results in the overall stiffness factor \(c_b\). The keel block stiffness factors in this calculation method are based on the spring characteristics of Kunow, who did different investigations during launching in the mid-eighties (Kunow, 1974).

As the factor \(c_b\) varies with the deflection of the keel block, the calculation is an iterative process. After each calculation it must be checked if \(c_b\) has changed. When the deflections of all keel blocks remain constant after calculation, the process is finished. Furthermore it must be considered that keel blocks are only pressure springs and do not absorb tension. For this reason the keel block stiffness is set to zero in the case that the related keel block force has been a negative value in the previous calculation.

**Boundary Conditions**

Although the external forces on the described system are calculated by hydrostatic methods and are therefore in balance, the deformation method needs boundary conditions. For this reason the deflection of the first and last node of the dock is suppressed during calculation as shown in Fig. 1.

**Calculation of bending line**

The bending line results from the fourth integration of the line load:

\[
E \cdot I \cdot w^{IV}(x) = -q(x)
\]  

(8)

For the platform and ship the particular loads of buoyancy, weight and keel block forces are added up to a resulting load distribution. By integration and division by elastic modulus and second moment of area for each Timoshenko beam the bending lines of platform and ship are calculated.

**FIGURE 2: SETUP OF THE SHIP ON THE PLATFORM**
THE INITIAL SITUATION

In the past, most of the ships build at the yard were standard cargo ships with a large steel fraction of the total lightship weight. New specialized ship types will have a higher fraction of outfitting and be of a more compact size. In addition, these ships will typically be equipped with high structural enforcements for sailing in Polar Regions. All this lead to a higher total weight concentrated on a shorter longitudinal distance.

One example for such a new type of ship is shown in Fig. 2, where the side sketch of the vessel is shown located on the building platform down below. This ship is a current project for the Russian market.

To be able to float out this ship safely, the buoyancy of the platform must be enlarged. This is achieved by adding two buoyancy columns at the aft end of the platform. It is also expected that these columns will increase the floating stability of the platform during the ballast operation, especially in longitudinal direction.

Since the ship will actually build on this platform, i.e. the different steel blocks are assembled on the platform, the position of the ship is selected in such a way, that no trim exist even without any ballast water. In addition, a homogenous keel block distribution is used to distribute the ship weight preferably uniform to all keel blocks.

The whole weight of the fully equipped ship is located on the middle section in longitudinal direction of the floating platform. To prevent a high deflection of the platform, ballast water tanks at the end sections have to be filled. The calculation based on the whole ship weight indicates that the outer ballast water tanks must be nearly completely filled in order to achieve a reasonable deflection of the platform. In this situation the freeboard to the pontoon deck is too low for transportation.

For this reason the ship weight is reduced by about 30%. The omitted equipment items have to be retrofit at the pier. The load distribution of ship and platform is shown in Fig. 3.

SITUATION

In the area of the position of the keel blocks, the ballast water tanks of the platform are empty so that only the self-weight of the platform is added up to the light ship weight. Towards the endings of the platform the ballast water tanks are filled up to seventy percent. The resulting deflections of ship and floating platform are shown in Fig. 4. The large overhangs at the ship endings result in opposite deflections of ship and dock.

FIGURE 3: LOAD DISTRIBUTION AT THE INITIAL SITUATION

The ballast sequence and the behavior of the platform and ship are illustrated by selected time steps in Fig. 5. This shows snapshots from the animation of the computed flooding sequence. Beside the platform and the ship shown in gray, also the fillings of the ballast tanks are shown in colors depending on the rate of filling where red means completely flooded. Furthermore, the trim in meter (negative to the stern), the heeling angle and the relative displacement of the platform is shown in Fig. 6. The time dependent flooding of the 12 different ballast tanks can be depicted from Fig. 7. The tanks have a consecutive numbering scheme. Tank 1 is located at the front of the platform while tank 12 is located aft, as shown in Fig. 2.
The ballast sequence is controlled by the use of the followings controls listed in Tab. 1.

<table>
<thead>
<tr>
<th>Tank</th>
<th>Time [sec]</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank 7</td>
<td>800</td>
<td>Close</td>
</tr>
<tr>
<td></td>
<td>2200</td>
<td>Open</td>
</tr>
<tr>
<td>Tank 8</td>
<td>800</td>
<td>Close</td>
</tr>
<tr>
<td></td>
<td>2800</td>
<td>Open</td>
</tr>
<tr>
<td>Tank 9</td>
<td>800</td>
<td>Close</td>
</tr>
<tr>
<td></td>
<td>3400</td>
<td>Open</td>
</tr>
<tr>
<td>Tank 10</td>
<td>1500</td>
<td>Open</td>
</tr>
<tr>
<td>Tank 11</td>
<td>2000</td>
<td>Open</td>
</tr>
<tr>
<td>Tank 12</td>
<td>800</td>
<td>Open (partly)</td>
</tr>
</tbody>
</table>

The ballast sequence is best described by looking at the trim development over time: First, the trim only increases moderately until the deck of the platform together with the lower end of the aft buoyancy columns become submerged. At around 700 sec. the trim increases rapidly caused by the sudden loss of longitudinal stability. To slow down this process, the bottom valves of tank 7, 8, 9 and 12 are closed. This can also be seen in the development of the tank fillings. When these tanks are no longer flooded, more ballast water enters the platform in the front of the platform, which reduces further the trim. To prevent it from becoming positive (to the bow), the tank 10 is flooded again at 1500 sec. The trim is further controlled by the successive re-flooding of tank 7, 8 and 9.

After around 4300 sec., the draught of the platform becomes finally large enough that the ships buoyancy reaches its weight and it becomes afloat. Interesting to observe is also the heeling angle in Fig. 6. It stays almost the whole time very small but only increases slightly at around 2700 sec. It is important to monitor these values to ensure that the whole system does not become hydrostatically
instable. In this case, only a short period of time of lower stability occurs, when the lower part of the ship becomes submerged. Furthermore, the flooding rate of the three ballast tanks 4, 5 and 6 in the center of the platform is right from the beginning reduced. This should reduce the increase of the deflection of the platform by keeping in principle a similar longitudinal distribution of the load in total. This aspect is addressed in more details in the following section.

**Structural Assessment**

As described in the theory of structural integrity the cross section values of ship and dock define their respective stiffness. In this case the stiffness of the ship is up to 12-times higher than the stiffness of the floating platform. Therefore the structure of the platform behaves very sensitive in respect of varying load distribution. The described flooding sequence of the different ballast tanks has a large influence on the deflection of the platform whereas the absolute ship deflection is limited. In the previous paragraph the flooding sequence is described. For this sequence the ballast water distribution at six points in time is shown in Fig. 8. The whole load distributions at the same points are shown in Fig. 9.

**FIGURE 8: BALLAST WATER DISTRIBUTIONS AT SIX POINTS IN TIME DURING THE FLOODING SEQUENCE**

In general the ballast water tanks at the forward position of the floating platform are most filled to prevent massive trim. At the first time points 300 sec. and 900 sec. the ship has no contact to the water. In order to achieve a moderate deflection of the platform, the central ballast water tanks are minimal filled. From 1500 sec. until 3000 sec. the ship increasingly refloats. This means that the keel block forces decrease and at the same time the central ballast water tanks are flooded. At the last time point the ship is completely floated and has no contact to the floating platform anymore. The central and forward ballast water tanks are filled almost simultaneously.

**FIGURE 9: MASS DISTRIBUTIONS AT SIX POINTS IN TIME DURING THE FLOODING SEQUENCE**

The deflections of the platform at the different time steps are shown in Fig. 10 and the deflections of the ship are shown in Fig. 11.

**FIGURE 10: DEFLECTIONS OF THE PLATFORM AT SIX POINTS IN TIME DURING THE FLOODING SEQUENCE**
During the whole flooding sequence the platform is in a sagging condition while the ship is in a hogging condition. The absolute deflection of the ship is much lower than of the dock. The more ballast water tanks of the platform are filled the higher is the deflection of the platform in general. Due to a decreasing trim and an inhomogeneous transfer of the ship weight over the keel blocks to the platform, at some points in time the deflection of the platform decreases although more ballast water tanks are filled. From 900 sec. onwards the ship takes off from the central keel blocks due to the deflection of the platform. With the increasing trim the deflection of the platform gets higher. After 2100 sec. the forward part of the platform sinks deeper into water so that the trim and the deflection get lower. At 3000 sec. the ship has only contact to the outer keel blocks. That results in an even lower deflection. After 5000 sec the ship is completely floated and no contact between ship and platform exist. In this situation the platform has the highest deflection due to the filled ballast water tanks that are needed to reach the necessary draught for the ships refloating.

DISCUSSION AND POSSIBLE IMPROVEMENTS

The calculations show that the flooding sequence of the platform must be considered thoroughly in advance to ensure enough stability regarding hydrostatic and structural response. It is often the case that several objectives interfere with each other. For instance the necessary buoyancy is reached by a rearwards trim to increase the water area whereas at the same time the trim causes an increased deflection. Furthermore the central ballast water tanks have to be flooded during the lowering process so that the loads are added up to the ships weight and result in increasing global stresses. Moreover the local keel block forces at the endings of the keel block system can rapidly increase due to the floating position and deflections. Besides all these occurring complications the paper shows that the calculation methods enable to overcome these barriers. The described flooding sequences are feasible and allow on the basis of controlled ballasting a carefully chosen lowering process. However, the application of the methods requires expertise knowledge and a comprehensive concept. Due to the internal influence factors and dependencies this kind of application is often an iterative process to get the best solution. Therefore the described process in this paper can also be improved. In the following an optimization of the keel block system is described. Different keel block force distributions in the initial situation are shown in Fig. 12.

FIGURE 11: DEFLECTIONS OF THE SHIP AT SIX POINTS IN TIME DURING THE FLOODING SEQUENCE

FIGURE 12: OPTIMIZATION OF KEEL BLOCK FORCE DISTRIBUTION IN THE INITIAL SITUATION.

The first keel block distribution is used for the described flooding sequence. It is well recognizable that the distribution has local load peaks at the outer keel blocks. These occur due to the overhang of the ship endings. Local supports at the endings will simply effect repositioning of the load peaks, but will not reduce them. Therefore the keel block system is modified. The outer keel blocks get softer due to other kind of wood layers and a higher wood covering in total. The resulting distribution is shown in the second graph in Fig. 12. The front peak is reduced even further by reduction of the initial forward trim of the ship, as shown in the third graph.

CONCLUSIONS AND OUTLOOK

Besides all the difficulties the presented calculation methods are an efficient tool to optimize the ballast operation and to make it possible. During the presented flooding sequence, the floating platform is lowered in the way that the ship refloats while the deflections are reasonable during this process.

The initial keel block forces at the endings of the keel block system are naturally higher due to the overhang of the ship. To achieve a more homogenous keel block force distribution the keel block system at the end must be softer. To reach this the relevant keel blocks can get a higher distance to each other or the wood layers of the keel blocks can be fitted. Moreover an additional support can be adjusted at the ship endings. To get a more precise estimation of the complex
structural behavior of the platform, a FEM model could be created and some modifications for increasing stiffness might be integrated.

The relatively large deflections which occurred during the flooding show that the whole ballast process must be monitored with great care. This is also the reason why the platform is equipped with several sensors to measure the current draughts at several points and local stresses, which are measured at different points in the pipe tunnel of the platform.

The presented calculation process, consisting of a combination of a flooding calculation and structural computations at selected time steps, allows a thoroughly study of the ballast sequence before it is performed in practice.

In the future, it is planned to further improve the coupling of both methods. Further interactive controls of the ballasting could be added to better reflect the real ballast sequence. In addition, different failure modes of valves and pumps could be investigated as well.

ACKNOWLEDGMENTS

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REFERENCES


