

Selected problems concerning strength of a floating dock with roof

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ABSTRACT

The paper presents models and results of the structural strength analysis of a roofed floating dock. Computed thickness of the roof structure walls capable of withstanding the environmental loads is 24 mm. Heavy sliding roof segments generate the dock pontoon floor plate stresses reaching 25% of the permissible stress value. The dock pontoon structure effort under the roof and docked ship weight load was minimized by seeking an optimum balancing ballast distribution. The problem was solved in two ways: analytically, by means of a simplified model of a continuous beam on elastic foundation and numerically, using the linear programming method to construct an accurate discrete FEM model.

Key words: floating dock structure and strength, FEM computations, linear programming

INTRODUCTION

The authors' task was to evaluate structural strength of the ecological floating dock designed by the SINUS company. Additionally, extensive theoretical analyses and considerations were performed in order to investigate the influence of various dock parameters on the keel block loads (from the docked ship weight) and the dock hull stress values. Solutions were sought to minimize those loads and stresses.

Main dock parameters are the following :

- * lifting capacity: $Q_d = 10\ 000$ tons
- * pontoon length: $L = 170$ m
- * width: $B = 42$ m
- * internal width between the side walls: $B_w = 34$ m
- * pontoon depth in the dock plane of symmetry: $h_p = 3.5$ m
- * dock height: $H = 13$ m
- * height of the dock with roof, in the plane of symmetry : $H_z = 42$ m.

The designed dock is a novel solution as the ecological requirements made it necessary to install a roof, i.e. to mount on the dock side walls a big steel hall constructed of segments slidable along the dock. Large dimensions and weight of such hall (approximately 2000 tons) made a significant impact on the dimensions of the dock itself.

Securing the dock stability, with the side wind pressing on the large windage area and the high up situated heavy roof structure, made it necessary to enlarge the dock width B comparing with classical docks of the same lifting capacity. The relatively large dock width means greater bending moment values in the pontoon bulkheads with the bottom and deck inner plating strakes, induced by the docked ship weight. This in turn makes a relatively great pontoon depth necessary in order to maintain reasonable pontoon bottom and deck plating thicknesses. Because of that, the dock pontoon is very robust in comparison with classical floating docks of similar lifting capacity.

The here described strength analyses indicate that a dock structure with the B/L and h_p/L quotient values greater than in

the classical docks is rigid and resistant to the pontoon general bending and middle bulkhead bending by the keel block transmitted forces.

DESIGNING OF FLOATING DOCKS IN ACCORDANCE WITH THE CLASSIFICATION SOCIETY RULES

The dock hull structure strength was evaluated in accordance with the requirements and criteria of the Polish Register of Shipping rules [1]. The rules include requirements of the dock structural element arrangement and strength. For example, longitudinal bulkhead in the pontoon plane of symmetry (PS), side longitudinal bulkheads and transverse bulkheads every 10 to 12 frame spaces must be installed in the pontoon.

The structural strength requirements have a form typical of the floating structures. They include general strength (bending in the vertical plane), transverse strength (bending of the pontoon transverse bulkheads) and local strength (bending of the plating stiffeners and plates). Very simple dock load models are used for the purpose.

The overall bending strength of a dock should at least be sufficient for conventional loading with the weight of a docked ship with symmetrical weight distribution along the dock, as shown in Fig. 1.

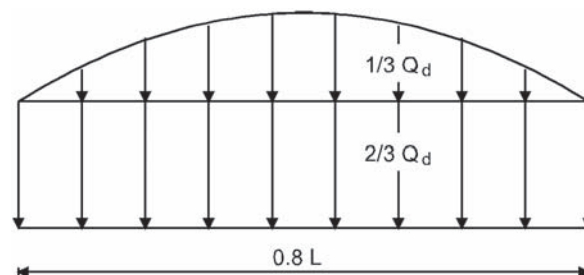


Fig. 1.

The balancing ballast in the dock tanks should be uniformly distributed along the dock length L .

The transverse bulkhead strength should be checked for the condition of loading the dock PS longitudinal bulkhead with a concentrated force :

$$P = 1.5 \frac{Q_d}{L} \cdot d \quad (1)$$

where :

- Q_d – dock lifting capacity
- L – dock length
- d – transverse bulkhead spacing.

The bulkhead is loaded also with the weight of ballast in the dock tanks and with the dock buoyancy force. These are continuous loads (along the bulkhead) of a value of the respective pressure multiplied by the bulkhead spacing d .

As it can be seen, this computational model assumes a 50% of the mean load overload of the bulkheads from the maximum weight Q_d of a docked ship.

The above described computational loads are supposed to secure a sufficient dock strength to take the real loads dependent on many factors, e.g. docked ship bottom deformability, unintended ship bottom non-rectilinearity, dock pontoon deformability etc. These problems are discussed in the next chapter.

The use of these simple computational models in the rules [1] is probably confirmed by the practice. Classification societies modify their requirements by applying their own experience from the periodical overhauls of the classed objects.

EFFORT OF THE DOCK AND KEEL BLOCKS

Safe docking of a ship depends on the stress level in the dock structural elements and on the forces in keel blocks. These parameters are determined by: (a) size and weight distribution of the dock and docked ship, (b) ship and dock structure, (c) distribution and relative height of keel blocks, (d) dock ballasting method.

The main dock load comes from the docked ship weight. Other loads are dock own weight, ballast weight and movable weights: travelling cranes and slidable roof. The weights are counterbalanced by external water pressure on the bottom. In the dock side walls and PS area, the gravity forces locally overbalance the buoyancy force, in other parts of the pontoon (if there is no ballast there) the buoyancy force predominates. In effect, stresses are generated in the pontoon structural elements and in the dock side walls.

Force differences in keel blocks come from the non-uniform weight distribution of the docked object and from differences in its local rigidity. The non-uniformity of ship weight distribution is caused by equipment locations: heavy parts are the engine room and forepeak with the anchoring equipment as well as the transom stern, sometimes with a ramp. The impact of ship bottom local stiffness on the keel block forces comes from the fact that the ship - keel blocks - dock system is statically indeterminate (over-rigid) and the rigidity differences are mainly caused by the presence of transverse bulkheads. The dock itself does not generate disturbances in the keel block force distribution – the pontoon weight and rigidity are almost constant along its entire length.

The ship and dock are given, non-controllable objects, but effects of their mutual interaction may be corrected by changed configuration of keel blocks and ballasts. The flexibility of use of those two measures is different: the keel block positions may be modified before the docking operation is started, but ballasting is always possible.

Here below the impact of ship and dock weight and structure on the dock and keel block effort is analysed and evaluation is made of the possibility of correcting the effort level by dock ballasting.

Computational models

The computational models of the roof-dock and dock-ship systems and their corresponding internal forces may describe the analysed phenomena in different ways and with different accuracy. There are two groups of models. **The first group** comprises models describing structural details of the dock and ship - discrete models. Solutions are of a numerical character – obtained by the finite element method – and pertain to a concrete data set; generalization is possible only by analysing different variants of the structure and loads, which requires rebuilding of the model.

The second group comprises more or less simplified models, described by continuous functions and leading to analytical solutions. They are useful when the analysed process is subject to many parameters changing in wide ranges. In such a situation even qualitative solutions are valuable as they indicate directions of seeking admissible solutions.

The basic computational model in the first group was a system of two flat grids modelling the arrangement of ship and dock pontoon bottom, sides, side walls and bulkheads, connected by the keel block-modelling bars. The model allowed to represent the ship and dock general bending rigidity as well as the local bottom rigidity to the keel block pressure. The ship weight was distributed along its sides and the dock weight was applied to the side walls and floor plates. The ballast and outboard water pressure was transferred from the bottom shell plating and stiffeners to the pontoon longitudinals and floor plates. In the outboard water impact calculations the dock structure deformability was accounted for.

The general model in the second group was a system of two beams connected by an elastic foundation [5]. It is described in more detail later in this paper.

Dock stresses induced by the slidable roof

The roof is a specific element of the ecological dock. It has a form of segments slid along the rails on the dock side wall deck. The segments may be inserted one into another, their total weight reaches 20% of the dock lifting capacity.

The roof weight is counterbalanced by the water pressure on the whole dock pontoon bottom. The action is transferred from the shell plating to stiffeners, to floor plates and longitudinals and to side walls. With a uniform ballast distribution, the following stresses are generated :

	Centre longitudinal	Side wall	Floors
Roof spread uniformly	–	–	9%
Roof pushed together – middle	8 MPa	13%	10%
Roof pushed together – both ends	9 MPa	15%	13%
Roof pushed together – one end	–	4%	25%

The „–” symbol means negligible stresses and the percentage values are related to the permissible stress values [1].

The dock should be so designed that the loads other than those from the docked object do not generate significant structural stresses. As it can be seen, the centre longitudinal stresses are very low. The side wall stresses arise when the roof segments are pushed together, i.e. when a floating crane must have access to the docked ship. The floor stresses are noticeable (10%) even in normal operation, and during the roof segment handling the additional stresses are quite big (25%).

The keel block forces from non-uniform ship weight distribution

The merchant ship hull weight is non-uniformly distributed: the stern-located engine room is much heavier than the rest of the hull (Fig.2).

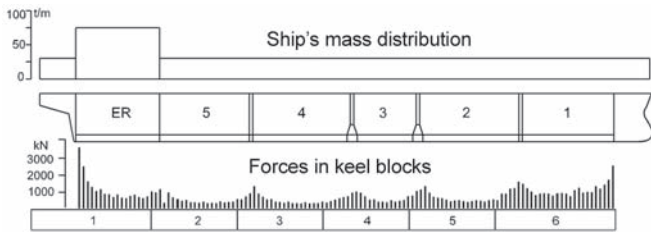


Fig. 2.

In order to investigate how the ship weight distribution and dock ballasting influence the keel block forces, an analytical model [5] was used, including (Fig.3) :

- ✦ the „upper” beam representing the ship hull deflection, loaded with the ship weight
- ✦ the „lower” beam representing the dock deflection, loaded with the difference between the ballast weight and buoyancy force
- ✦ linear elastic foundation, connecting the two beams and representing the ship and the dock pontoon bottom rigidity.

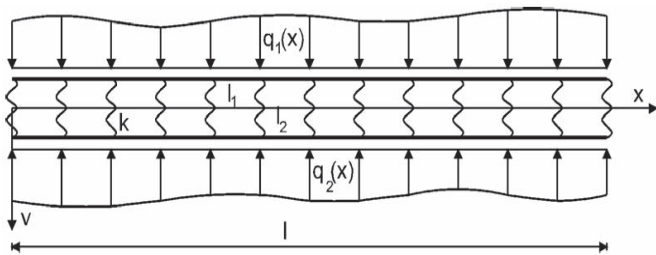


Fig. 3.

The model is described by the set of differential equations :

$$\begin{aligned} EI_1 v_1^{IV} + k(v_1 - v_2) &= q_1(x) \\ EI_2 v_2^{IV} - k(v_1 - v_2) &= -q_2(x) \end{aligned} \quad (2)$$

which may be reduced to one equation :

$$EI v^{IV} + kv = \frac{EI}{EI_1} q_1(x) + \frac{EI}{EI_2} q_2(x) \quad (3)$$

where :

$$EI = \frac{EI_1 \cdot EI_2}{EI_1 + EI_2}, \quad v = v_2 - v_1$$

Equation (3) may be used for docking analysis, when :

- ★ ship length is the same as dock length and keel blocks are positioned in the dock PS along the entire length
- ★ the ship and dock structure rigidity is constant along the entire length
- ★ the ship and the dock pontoon bottom structural element system is limited to the floor plates
- ★ the ship weight and the dock ballast are described by continuous functions.

With additional assumptions that the ship-keel blocks-dock system is symmetrical in relation to the dock middle section and that the weight of ship and of the dock ballast is expressed by linear functions (Fig. 4), the model may be limited to 1/2 dock length.

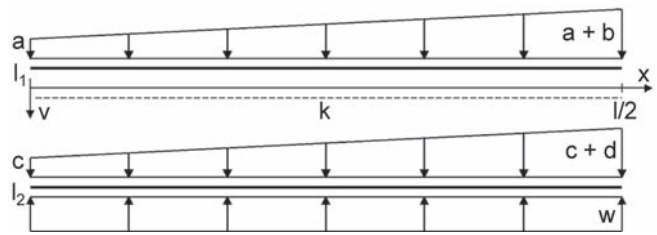


Fig. 4.

By solving equation (3), the keel block pressure forces are obtained :

$$\begin{aligned} n(x) = k \cdot v(x) &= a + \frac{1}{EI} \frac{b+d}{2} + \\ &+ \frac{\bar{EI} \cdot b - d}{1 + \bar{EI}} \left\{ 2 \frac{x}{l} + \frac{\sqrt{2}}{\beta} \left[\frac{V_0 V_2 + V_3^2}{V_0 V_1 + V_2 V_3} V_0 \left(\beta \frac{x}{l} \right) + \right. \right. \\ &\left. \left. - V_1 \left(\beta \frac{x}{l} \right) + \frac{V_2 + V_1 V_3}{V_0 V_1 + V_2 V_3} V_2 \left(\beta \frac{x}{l} \right) \right] \right\} \end{aligned} \quad (4)$$

where :

$\bar{EI} = EI_2 / EI_1$ – the bending rigidity ratio of dock and ship

$$\beta = \sqrt[4]{\frac{kl^4}{EI_2} \frac{1 + \bar{EI}}{4}}$$

$V_0() \dots V_3()$ – normal functions [5]

$V_0 \dots V_3$ without argument mean $V_0(\beta/2) \dots V_3(\beta/2)$.

As it can be seen, it is possible to obtain $n(x) = \text{const}$, when $d = \bar{EI} \cdot b$. It means that the best dock ballasting method is a „triangular” ballast distribution, depending on the ship weight distribution and on the bending rigidity ratio of dock and ship.

The usefulness of this solution is strongly limited by the lack of transverse bulkheads and longitudinal girders and the full length support assumptions.

Optimum ballasting during docking a ship with transverse bulkheads

An admissible docking condition is determined, among other parameters, by a minimum dock pontoon freeboard and maximum permissible keel block forces. Differences in the keel block forces are caused by the non-uniform ship weight distribution and the presence of transverse bulkheads (Fig.2); the greatest pressure is on the last stern keel block. An attempt may be made to reduce those forces by using the balancing ballast.

The dock has 24 ballast tanks grouped in 6 compartments along the dock. In order to find an admissibility criteria fulfilling solution, a linear programming problem was formulated :

$$\begin{aligned} 0 < N_i^0 + \sum_j a_{ij} b_j < \bar{N} \\ \sum_j b_j &= \min, \quad \sum_j b_j \leq B \\ -M &\leq \sum_j b_j x_j \leq M \\ \bar{b}_j &\geq b_j \geq 0 \end{aligned}$$

where :

N_i^0 – keel block force for a ballast-free condition

\bar{N} – admissible keel block force

a_{ij} – impact matrix of the weight of ballast in tank on the keel block forces

- b_j – ballasts sought
- \bar{B} – admissible total weight of ballast
- b_j – admissible ballast weight in a tank
- x_j – ballast tank centre abscissa
- M – admissible trimming moment.

Solution of the problem not always exists as the amount of ballast is limited by the tank capacity and the dock ponton freeboard. Such situation occurred in one of the analysed computational conditions. The optimization criterion was then changed from the minimum ballast weight to a minimized value of the maximum keel block force. The keel block forces computed for that condition are presented in Fig.5.

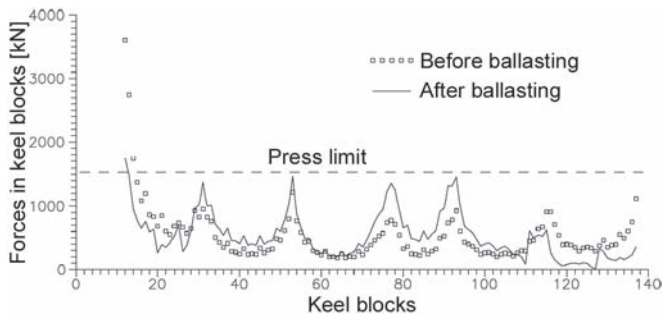


Fig. 5.

THE DOCK ROOF STRENGTH

The dock roof, proposed by the authors of this paper, has a form of the steel hall positioned on the dock upper deck. The hall consists of two segments, which may be slid on/under each other. The hall structure diagram is shown in Fig.6.

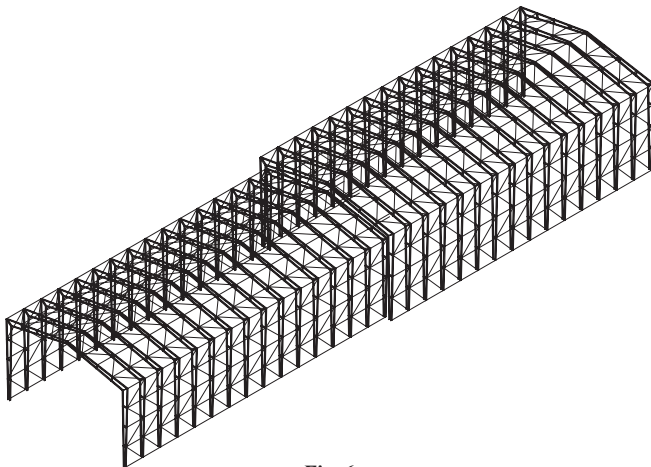


Fig. 6.

The structure consists of transverse frames positioned with a 5.7 m spacing and connected by horizontal and diagonal braces. The so constructed skeleton will be covered with shaped plating.

The larger segment has the following dimensions :

- ★ external width approx. 42.5 m
- ★ side wall height 24.9 m
- ★ total height 28.75 m
- ★ roof inclination angle 10°.

The height and width of the smaller segment are smaller by approx. 3.8 m and 2.6 m, respectively.

Structures of such a big size are subject to significant environmental loads, e.g. wind pressure and weight of snow accumulated on the roof. The structure own weight is also an important load component.

Classification societies in their rules for floating docks do not give any requirements for the roofed floating docks. Therefore, it was proposed that the roof structure strength be checked in accordance with the civil engineering criteria for steel halls. The computational loads from snow were taken from the standard [2] and those from wind – from the standard [3].

Hence, the computational loads for the Gdańsk area are the following :

- ★ roof load (pressure) from snow : ≈ 0.94 kPa
- ★ wind pressure and suction on the roof : 1.88 kPa and - 2.0 kPa respectively
- ★ wind pressure and suction on the walls : 0.92 kPa and - 0.92 kPa respectively
- ★ load from the shaped plating weight : $\approx 0,13 \frac{t}{m^2}$

In order to find the cross section dimensions of transverse frames, variants of FEM calculations were carried out with a criterion that the reduced stresses should not exceed the 160 MPa level (for a 235 MPa yield point steel). The FEM model assumed the frame restrain at the dock upper deck. Examples of the FEM calculation results are presented graphically in Fig.7.

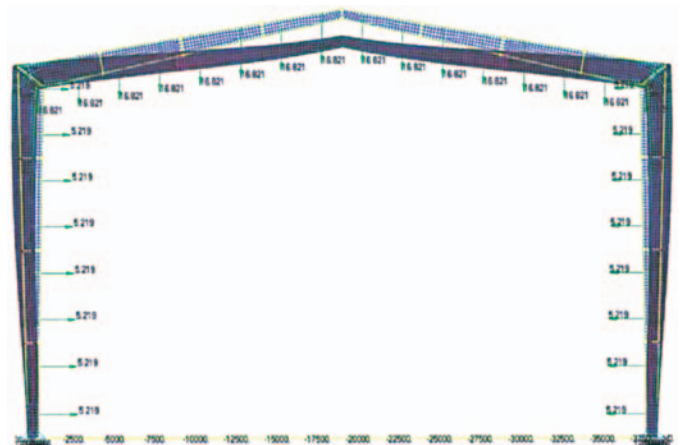


Fig. 7.

The FEM calculations allowed to determine the necessary cross section dimensions of the hall transverse frame beams. In the upper part of the hall, tee bars with 440 mm by 24 mm flanges and 24 mm thick, 660 mm to 1700 mm variable height webs. The frame dimensions are very big indeed.

The impact of dock hull deflections under the docked ship weight upon the roof carrying structure stresses was not analysed. The problem of separable connection of the hall skeleton with the dock upper deck must first be solved, in order to be able to move the hall segments along the dock and to fasten the hall to the dock deck. It may be presumed that the dock overall deflections of 100 mm may cause stresses of significant values in the frame horizontal and diagonal braces. The side wall upper part transverse displacements from the dock ponton deflections under the docked ship weight may also cause significant stresses in the hall skeleton transverse frames.

FINAL REMARKS AND CONCLUSIONS

The floating dock in question has significantly greater dimensions than its classic version with a similar lifting capacity. The adequate strength of the roof hall structure subjected to the environmental loads from snow weight and wind pressure may be secured by structural elements of solid cross sections. The hall weight appears considerable – it makes 20% of the dock lifting capacity.

The dock pontoon stresses generated by the roof weight reach 25% of the admissible stresses. Heavy ship engine room in the stern part and rigid transverse bulkheads result in much differentiated keel block forces along the dock. The linear programming method allows to find an optimum ballast distribution in the dock tanks, such that the admissible keel block forces are not exceeded.

BIBLIOGRAPHY

1. Polish Register of Shipping : *Rules for the classification and construction of floating docks*. Gdańsk, 1987
2. Polish standard PN – 80/B – 02010 : *Loads in structural analysis. Snow loads*
3. Polish standard PN – 77/B – 02011 : *Loads in structural analysis. Wind loads*
4. Polish standard PN – 90/B – 03200 : *Steel structures. Structural analysis and design*
5. Konieczny L., Kurski W., Wituszynski K.: *Exercises in the ship structural mechanics* - Part 1. Gdańsk University of Technology. Gdańsk, 1967

