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Design of Inner Gate for CRIST Shipyard Dry Dock

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ABSTRACT

The paper deals with a removable steel inner gate which was designed to separate two parts of a dry dock of about 70 m in width and 380 m in length. The gate allows for independent assembly of ship structures in the two separated parts of the dock. The fore part of the dock can be flooded while the after part is dry. The gate was designed by IDEK Company Ltd in 2011 and it was soon constructed and used by CRIST Shipyard in Gdynia.

Keywords: shipyard; dry dock; dock inner gate; FEM strength analysis

INTRODUCTION

CRIST Shipyard in Gdynia, Poland specializes in the construction of medium-sized ships and offshore facilities. That is why there was a need for an inner gate to split a 380-metre-long dry dock to allow for an independent assembly of ship structures in two parts of the dock. Structures whose assembly require more time are built in the after part of the dock. At the same time other structures, not longer than 130 m, can be assembled in the fore part of the dock and then launched.

Ships, barges or pontoons transporting some structures or equipment for the objects assembled in the dock after part can enter the fore part. Then, a dock gantry crane of lifting capacity 900 tons can take these components to the dock after part.

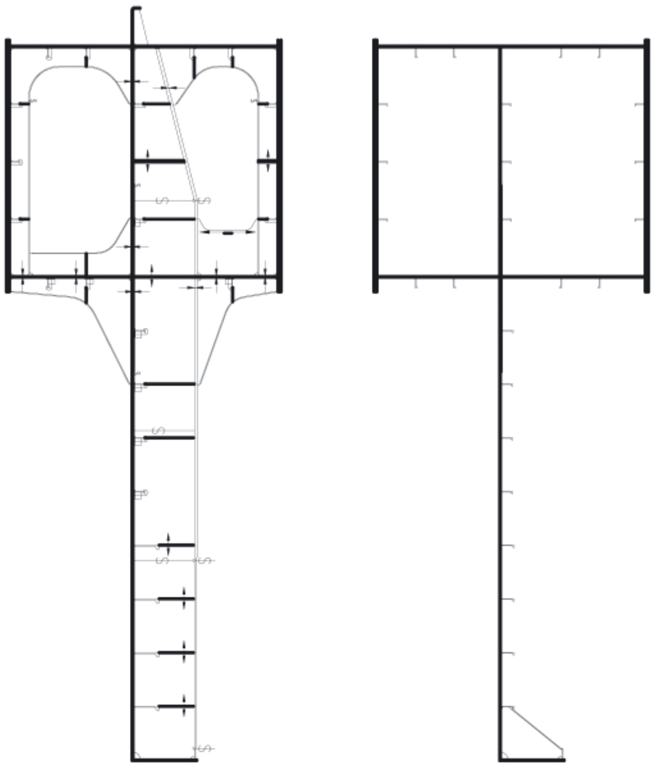
The customer, namely CRIST Shipyard submitted the following design requirements regarding the gate:

- the gate width (measured along the dock) is to be as little as practicable not to take up too much space in the dock;
- the gate mass should not exceed 400 tons to be readily operated by the dock gantry crane;
- the maximum water depth in the flooded dock is 9.5 m.

CONCEPT AND DESIGN OF THE INNER GATE

Some examples of inner gates for dry docks are described in [1].

The design of the gate in question has a structure slightly different from the examples given in [1]. Their transverse cross-sections in the planes parallel to the dock plane of symmetry are shown in Fig.1.



a) **b)**

Fig. 1. *Transverse cross-sections of the gate:*
a) *in the web frame planes,* ***b)*** *between the web frames*

The gate is constructed of steel with the yield point 355 MPa, as a watertight vertical wall. At its upper part, a box-type structure 3.5 m wide and 3.0 high was arranged. The length of the gate is 70.3 m which is only 0.15 m less than upper part dock width.

The spacing of web frames shown in Fig. 1a is 2.5 m. The web frames support horizontal stiffeners of the watertight wall are spaced at intervals of 0.75 m.

Figures 5 and 6 showing a FEM model of the gate facilitate understanding of the gate steel structure.

The plates of the deck and bottom of the box type structure are 10.0 mm thick. The plates forming the side walls of the box type structure are 40 mm thick in the middle portion of the gate and 30 mm in way of the gate side edges.

The thickness of the watertight vertical wall of the gate is equal to 10 mm.

Horizontal stiffeners of the watertight wall are arranged as follows: BP 180x8 – in the lower portion, BP 160x8 – in middle height region and BP 140x8 – in the upper portion.

Vertical girders shown in Fig. 1a are T-type beams with web 800x10 at the lower part and 800x15 at the upper part. Their flanges are flat bars 300x20 in the lower part and 300x40 in the upper part. In the region near the side edges of the gate, T-shaped beams become slightly smaller as they are more effectively supported by the box-type structure there.

In the design process, an assumption was applied that the pressure of water acts on the side of the vertical watertight wall where its girders and the plating stiffeners are located.

The lower edge of the gate is supported by a steel threshold connected to the dock bottom concrete slab by a system of bolts (see Fig. 2). In Fig. 2, sealing system design is also shown. A rubber gasket is placed between two oak planks directly transmitting the load induced by the water filling the dock fore part to the threshold structure. The planks restrict the value of gasket deflection, too.

The gate is put in its working position by the dock gantry crane. First, the gate is put near the threshold. Then special turn-buckles connected to the threshold, to the side supporting structure and to the gate are used to exert initial compression of the gasket. Then the pressure of water filling the dock fore part acts on the gate watertight wall thus tightening the gate.

The gate is supported at its side edges by a special steel structure. In its lower part, the structure is welded to corrugated steel sheet walls of the dock. In the upper part, the supporting steel structure is connected with bolts to massive concrete girders forming side walls of the dock and resting on the corrugated side walls. These supporting structures are schematically shown in Fig. 3.

The systems for transmitting the load from the gate to the supporting structure and for tightening the gate at its side edges are similar to those shown in Fig. 2.

A considerable part of the transverse force induced by the filling water and acting on the gate, loads the upper box-type structure supporting vertical girders shown in Fig.1a. The remaining part of the force loads the threshold positioned at the lower edge of the gate.

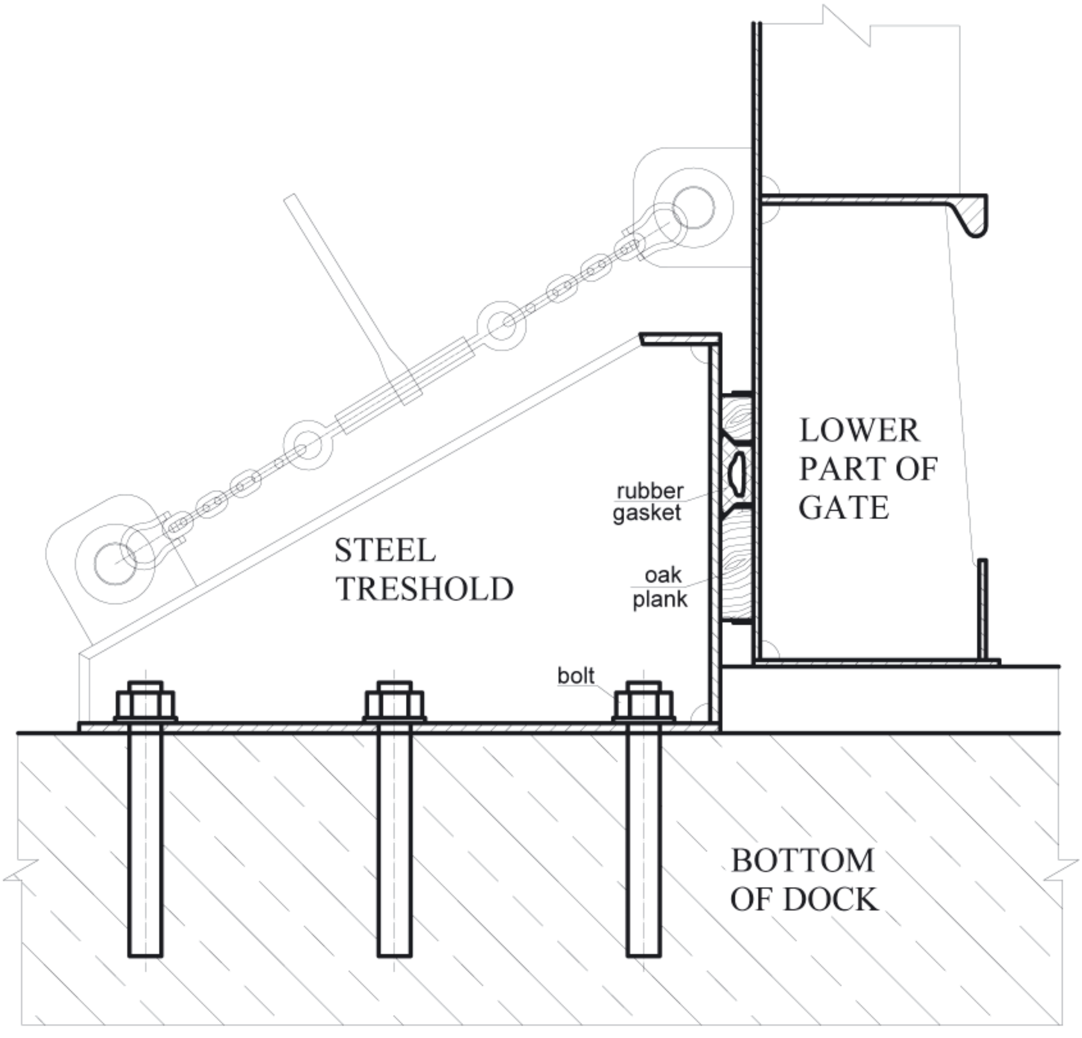


Fig. 2. *Threshold structure and gasket system*

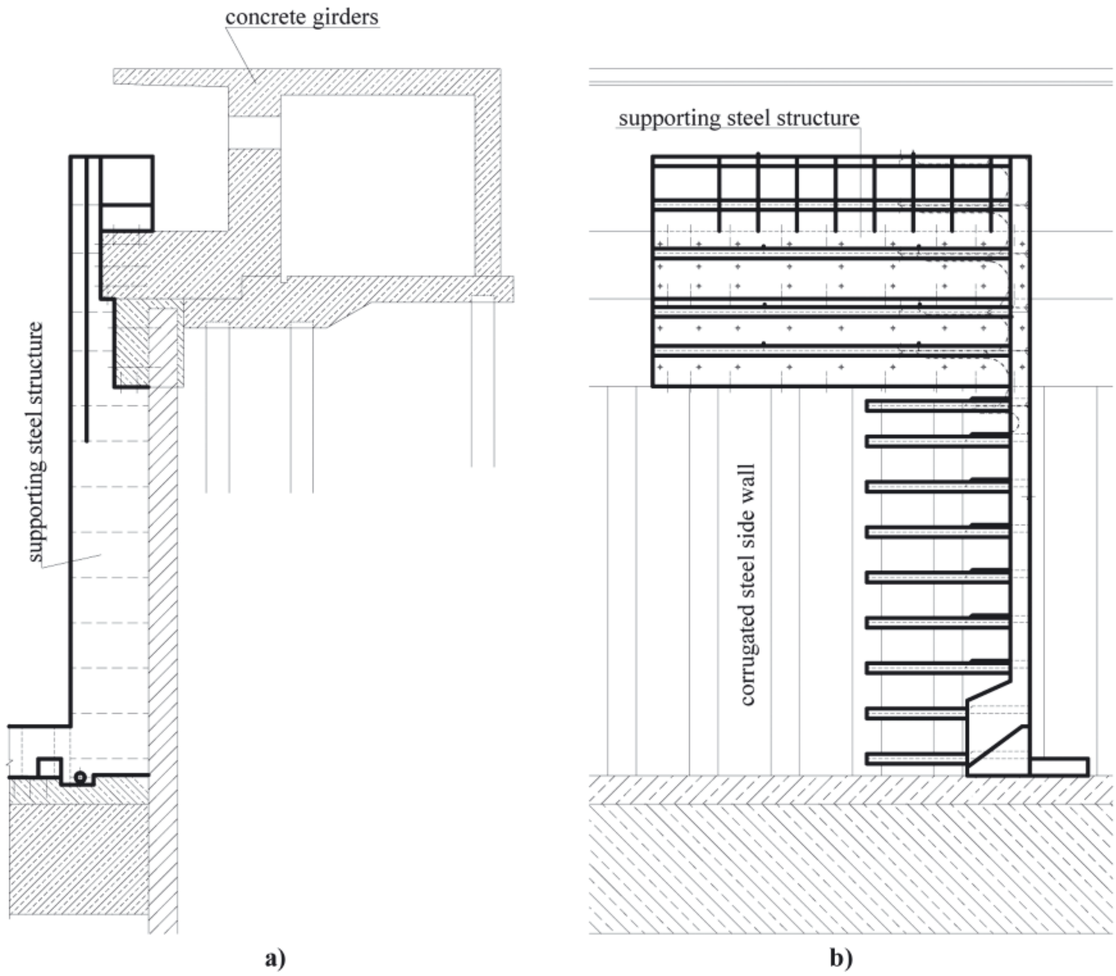


*Fig. 3. Supporting structure at the dock side walls: **a)** transverse cross-section, **b)** side view*

The box-type structure is supported at its ends by a special supporting structure connected to the dock sides (see Fig. 3). A simple assessment of reaction force values supporting the ends of the box-type structure gives result equal to 1/3 of the total force corresponding to the water pressure acting on the watertight wall. This was confirmed by FEM calculations described further in the paper.

This means that a reaction force equal approximately to 5 MN is developed at each end of the box-type structure for the water depth of 9.5 m. Such a great value of the reaction force requires applying a strong steel supporting structure connected to the concrete dock side walls at their upper regions. Moreover, high pressure values occur between the oak planks and the steel structure, close to the strength of the planks.

Another problem with supporting the box-type structure at its ends is related to its deflection caused by the water pressure. The structure is deflected between the end supports and twisted in relation to its longitudinal horizontal axis – as a result of supporting the gate at its lower edge by the threshold. Such type of deformation means that the reaction forces must be non-uniformly distributed along the height of the box-type structure. Much greater pressure values on the oak planks are expected at the level of the box deck than at the level of its bottom which causes some problems with the strength of the planks and keeping the gate watertight. This means that the end parts of the box-type structure should be fairly elastic while subjected to torsion – to minimize the difference between these pressure values at the deck and the bottom levels.

This quality of the box-type structure was obtained by a special construction of its ends. The closed rectangular transverse cross-section was replaced by an open type one, along the distance of 2.5 meters at each end. A part of the structure at one side of the watertight wall was removed and a strong flange was arranged there instead of a part of the box side wall. Furthermore, a platform was arranged at the level of the mid-height of the box. The platform is subjected to a shear force corresponding to the reaction force at the end of the box-type structure. Strong brackets connected to the platform and to the vertical watertight wall were arranged at the ends of the structure. Their vertical edges are loaded by pressure values developed at the oak planks.

The end regions of the box-type structure are schematically shown in Fig. 6 in the course of the paper, in the form of a FEM model developed to assess the gate structure strength.

The vertical watertight wall of the gate was placed near the middle of the box-type structure width to obtain as small values of displacements of its vertical end edges as possible. These displacements directed along the width of the dock are caused by considerable bending displacements of the box-type structure. Arranging this watertight wall at the plane of the side wall of the box-type structure would result in the value of these displacements up to 20 mm. Such considerable displacement values could cause the damage of the oak planks and the rubber gasket. The applied solution allowed to reduce the maximum value of the displacements to as little as 2 mm.

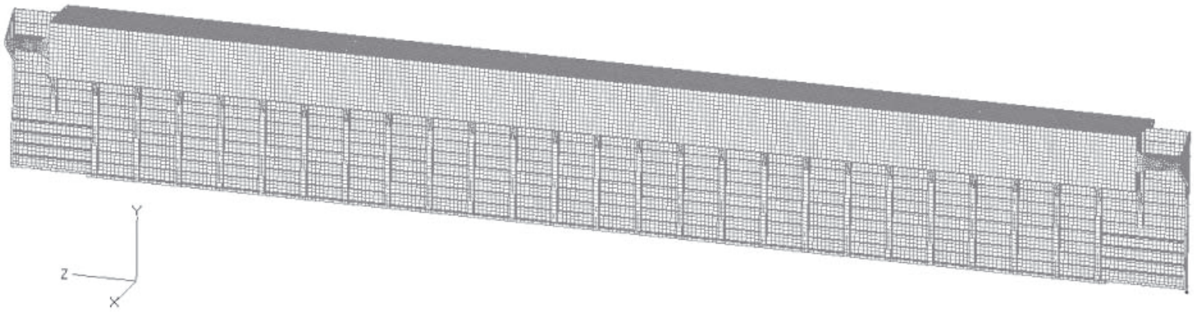


Fig. 4. *Gate steel structure mesh*

FEM STRENGTH ANALYSIS

A FEM strength analysis of the gate structure was performed to verify and correct its scantlings obtained through the initial simple calculations. The FEM model mesh is shown in Fig. 4.

4-node shell finite elements were used for the plating of sides and decks of the box-type structure, plating of the watertight wall as well as girder webs and plating stiffeners. Beam finite elements were used for both girder and stiffener flanges.

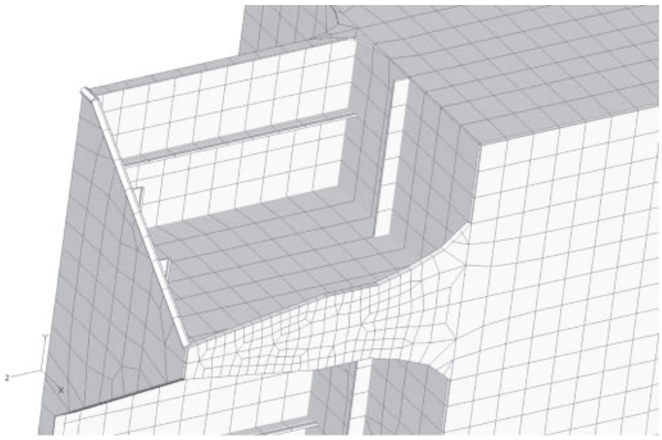


Fig. 5. *Deflection of the gate*

The FEM model was subjected to the pressure of water with the free surface at the level of 9.5 meters above the dock bottom. In the FEM model, this load was applied as a set of concentrated forces acting at the locations where the watertight wall horizontal stiffeners intersect the vertical girders shown in Fig. 1a.

A system of elastic rods was used to support the gate in the dock longitudinal direction. The rods approximately correspond to the elasticity of the rubber gasket.

Along the lower edge of the watertight wall, a similar set of vertical rods was used to support the structure in the vertical direction.

The deflection calculated with the FEM model is shown in Fig. 5.

Maximum deflection of the gate occurs at the upper deck level of the box-type structure, on the dock plane of the symmetry. Its value is 255 mm. The maximum value of normal stress due to bending of the box-type structure reaches the level of 150 MPa, in its side wall near its mid-length point.

The extreme level of Von Mises stress in the vertical girders (see Fig.1a) is of the order of 210 MPa. These stresses occur in central girder of the gate, near the bottom of the box.

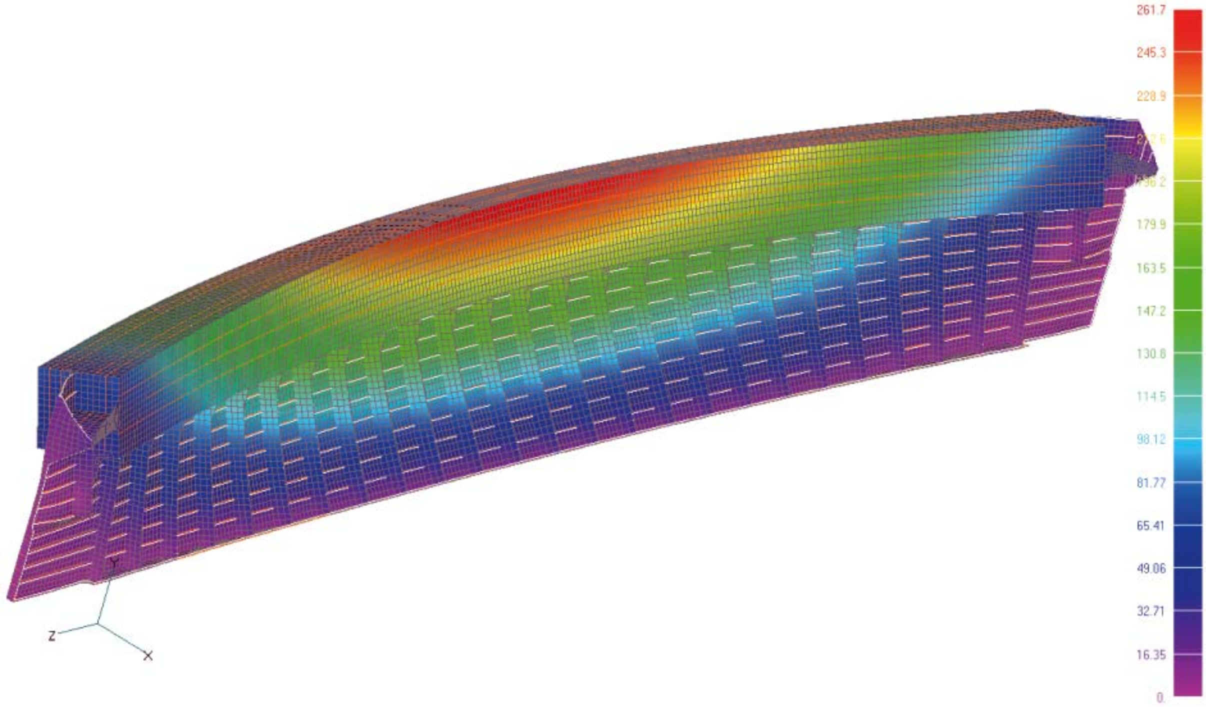


Fig. 6. *FEM model of the box end parts and stress values in the flange*

The results of FEM analysis showed that reaction forces along the lower edge of the gate are almost uniformly distributed while their distribution along the vertical edges is very far from a uniform one. The mean value of the continuous load on the oak planks, along the height of the box, measured in N/mm, is approximately 15 times greater than the mean value of such load along the remaining part of the vertical edge. In addition, the maximum value of this load occurring at the level of the box deck is 3 times greater than the minimum value occurring at the level of the box bottom.

2 meters below the bottom of the box, the value of the continuous load on the planks is approximately 5 times lesser than the mean value along the box height.

Such a distribution of load causes serious problems with the strength of the oak planks and the strength of the concrete side wall of the dock.

Many modifications of the structure were considered in the designing process to obtain a more even distribution of this load along the height of the box but it was impossible to obtain better results than those described above. This uneven distribution of the continuous reaction load along the vertical edges of the gate results from the box torsion. This reaction load must produce a torque value to counterbalance the torque induced by supporting the vertical girders of the watertight wall by the box. This torque is responsible for the complicated distribution of stress in the end parts of the box. The end parts should be fairly elastic to allow for a considerable angle of transverse cross-section rotation around the longitudinal axis of the box, over the distance of several meters only. On the other hand, the structure should be strong enough to withstand such a great torque. These two requirements are not easy to be fulfilled simulatneously.

After many attempts, an acceptable design of the box end parts in the form shown in Fig. 4 was found. An open type of box transverse cross-section was applied there, over the distance 2.5 meters.

The FEM model of these end parts and the calculated von Mises stress values in the strong flange installed in the plane of the box side wall are shown in Fig.6. The maximum value of the stress reaches 540 MPa there. The stress distribution in the flange domain is far from even and this is due to a simultaneous flange bending in both horizontal and vertical planes. It was necessary to apply the flange 60 mm thick which was made of steel with the yield point equal to 690 MPa while the whole gate steel structure is made of steel with the yield point 355 MPa.

SUMMARY

- The design of the gate appears quite simple except for the box-type structure end regions near the dock side walls. The structure should be strong and, simultaneously, it is to be rather elastic locally to allow for the rubber sealing compression throughout its length irrespective of the water level in the dock. It is a rather difficult task to fulfil both of the conditions simultaneously. A rather complicated construction of the gate at its ends was obtained by way of many modifications using a trial-and-error method to meet both of these conditions.
- The gate has been successfully used by the shipyard.

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