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Definition of Deformations and Stresses of Large Ship Blocks within Transportation and Manipulation

Abstract

Deformations and stresses during the transport and manipulation of large ship blocks within ship assembly and erection stages are a common and significant issue, particularly in the construction of complex ships and variable production mix, as is the case in many European shipyards. The appearance of deformations and stresses requires adequate addressing with the aim of their early determination and reduction with a goal to reduce a significant number of working hours spent for the large ship blocks transport preparation, for the transport and manipulation itself, and for the reworks. The appearance of residual stress in blocks that are not adequately addressed can be an issue in the exploitation, reducing the quality and ship service life. In this paper, the authors present the procedure of determining deformations and stresses in the large ship block. The procedure is based on computer modelling and numerical analysis of the selected ship block. Various scenarios of the foundations' arrangement and the arrangement of the transport hooks were analysed, and the optimal solutions were proposed. The procedure allows determining deformations and stresses at an early stage of ship technology design to define the adequate preparation for ship block foundations layout, transportation and manipulation before production starts. In doing so, it is expected to reduce deformations and stresses itself, necessary working hours for block accommodation, transportation and manipulation and to reduce repair works. Such procedure application is expected to raise the efficiency of the overall ship production process and the quality of the final product. Finally, further research is proposed regarding various scenarios of technological procedures, ship blocks structures or used materials.

Keywords: shipbuilding, deformations, stresses, transport of large ship blocks, 3D Experience model, numerical analysis, efficiency

1. Introduction

Assembly is the process of joining and manipulating several steel parts and joining them in one larger structure, called blocks, [1]. The production of the block is usually situated as an extension of the shipyard's panel line, creating a more fluent flow of material from the panel line to the block assembly area, [2]. The blocks are transported to a dry dock or the slipway upon assembly. Therefore, the transportation of the building materials is an essential part of the shipbuilding assembly process. It summarises procedures that involve horizontal, vertical or/and complex movements of materials and finished products, thus securing the continuity of workflow and finalisation of the final product, [3]. It is essential to predefine, predict and develop proper transformation procedures, as deformations and stresses can occur during the transport and manipulation of large ship sections. These deformations can negatively impact overall process duration, cost, and quality, due to corrective actions needed for correcting them. Therefore, the article's goal is to describe and elaborate on the process of early detection of deformations and stresses. The described procedure is based on the selected ship block computer-aided modelling and finite element analysis. Several scenarios were tested in terms of the block foundations number and their spacing and the number of transport mounting points and their position on the given ship block. The established procedure determines deformations and stresses at an early stage of designing shipbuilding technology. It also supports decision-making within defining technological procedures, particularly the block position on foundations and its adequate preparation for transport and handling. Furthermore, it is expected to reduce deformations and stresses in the ship block, reduce the required working hours for adequate section preparation for accommodation and transport, and reduce subsequent repair work. At the same time, the application of this procedure is expected to increase the efficiency of the production process and the quality of the final product.

2. Ship block modelling

A chemical tanker ship's double bottom block, [4], (block dimensions 22.50 m x 32.20 m x 5.00 m, with a total mass of 467.34 t) was modelled using software 3D Experience within its Structure Functional Design app. The model was detailed to the level needed for targeted FEM analysis and scenarios in question. Using the methodology described in [5, 6], all primary elements were modelled, alongside secondary stiffeners, creating the model from available documentation. The final model of the double bottom block can be seen in Figure 1.

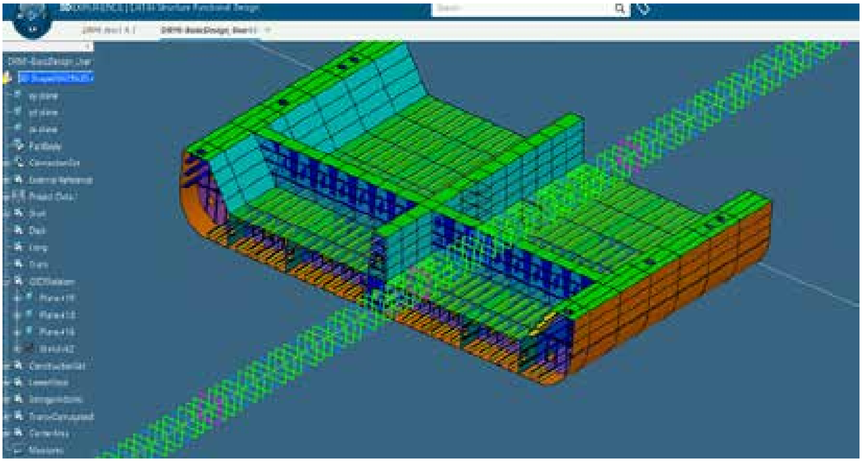


Figure 1: Model of ship double bottom block [7].

The modelling of the structural details was up to the level of stiffeners and large openings. The brackets, penetrations smaller than 600x400 mm were not taken into consideration. The slots and profile end-cuts were not defined. Possible piping and outfitting elements that may be installed in the actual section during the phase of block assembly were not modelled. Some adjustments on the placement of the stiffening elements were taken to minimise the time needed to repair the mesh, keeping in mind that the mesh will be automatically generated from the Structural Functional Design model (SFD model). The detailed modelling can be seen in Figure 2.

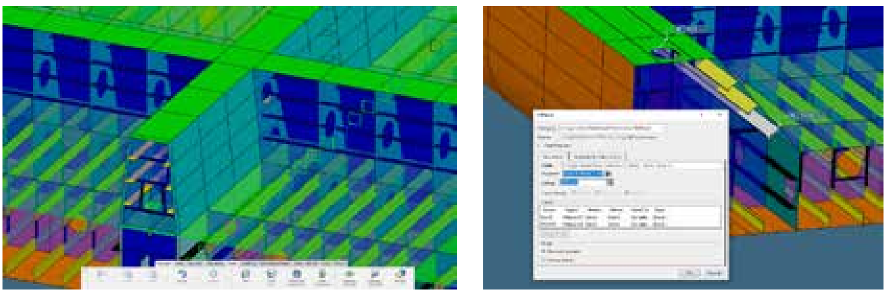


Figure 2: Structure details level [7].

3. Finite elements model creation

The SFD model was meshed automatically using the automatic meshing process available in 3D Experience platform. The FEM and proxy geometry models needed to be created prior to activation of the automated meshing, as shown in Figure 3. The mesh size for 1D and 2D elements was set to 200 mm, resulting in a total of 1253670 elements. The stiffeners were meshed as 1D beam elements, while the plating was meshed using the 2D triangular and quadrilateral mesh elements. The properties of the stiffeners and plating elements were taken directly from the SFD model. Thus, no additional input was needed for defining the beam and shell elements. The automatic meshing menu and mesh model can be seen in Figure 3.

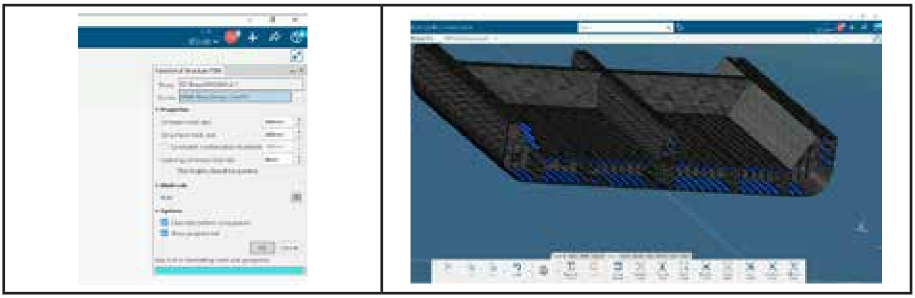


Figure 3: Automatic meshing menue and model mesh [7]

Though the meshing in 3D Experience is an automated process, some areas need to be repaired manually, especially around the openings. The mesh quality was checked alongside mesh connectivity and free edges, and the mesh was repaired and prepared for scenario definition.

4. Scenario definition

Following the finite elements model creation, scenario cases were defined and analysed to improve solutions regarding block foundations number on the ground and hooks number in transport, in correlation with identified structure deformation and stress. A total of five cases of foundations layout and five hook layouts were analysed, varying foundations and hook positions and numbers, thus creating 10 different scenarios.

Scenarios were defined and analysed within 3D Experience Structural Scenario Creation module in the SIMULIA application. The linear elastic material was defined as shipbuilding grade A steel with properties shown in Table 1. The factor of safety of 1.5 for the linear FEA model was considered, and therefore, the allowed von Mises stress in the structure should be under 180 MPa (with dynamic factor for lifting included in the factor of safety and may allowable stress).

Table 1: Material properties – shipbuilding steel grade A.

Density [kg/m^3]	7850
Young's Modulus E [GPa]	210
Yield Strength [MPa]	235
Tensile Strength [MPa]	400-520
Poisson's ratio	0.3

The load was applied as gravity load in the z-direction of the model, as seen in Figure 4. The gravity load was calculated and increased to 10.33 m/s^2 to compensate for missing weights not modelled in SFD model. The gravity load was used for both foundation and hook scenarios. The foundations were modelled using simplification on the safe side and constraining the translation and rotation. The same constraints were applied to the hooks in the model analysing hook positions.

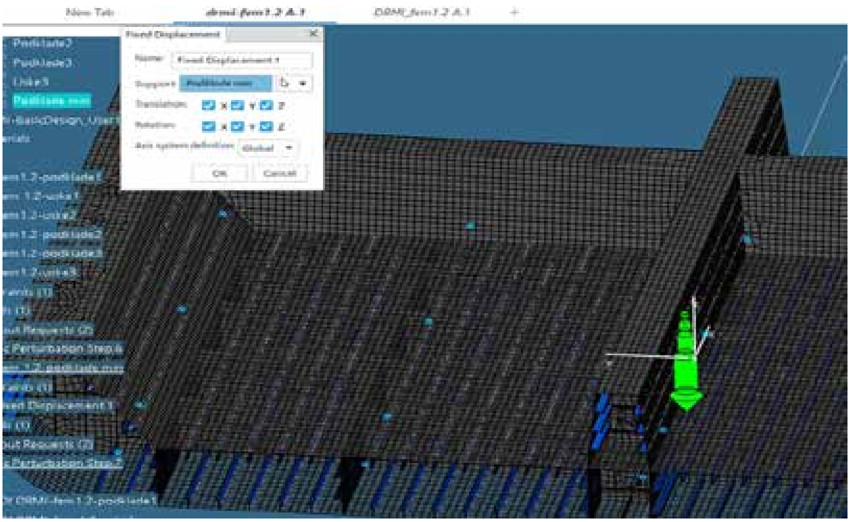
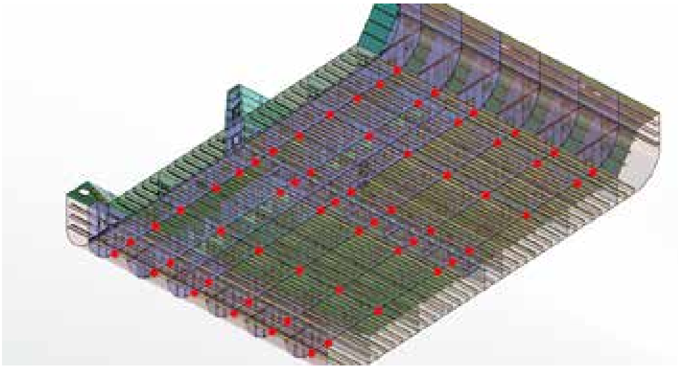


Figure 4: Mesh model representing boundary and loading condition [7].

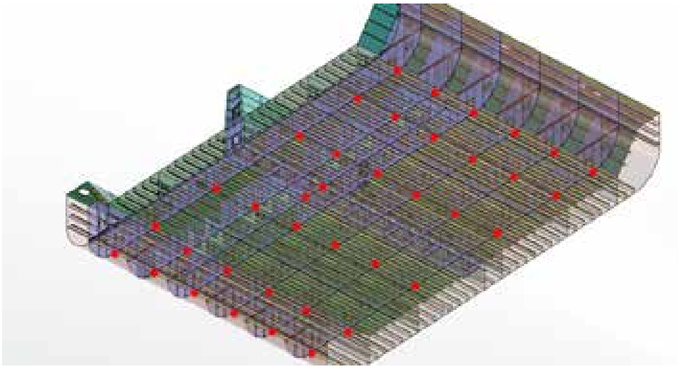
5. Scenario simulation and analysis

The foundations are usually placed under the stiffened parts of the structure. Therefore, their arrangement will depend on the topology of the section and the placement of the primary structure in the section. A total of 5 different placements for foundation elements were analysed, differing their position and number used in the model. The foundation arrangement for each case can be seen in Figure 5. The foundations are presented with red dots.

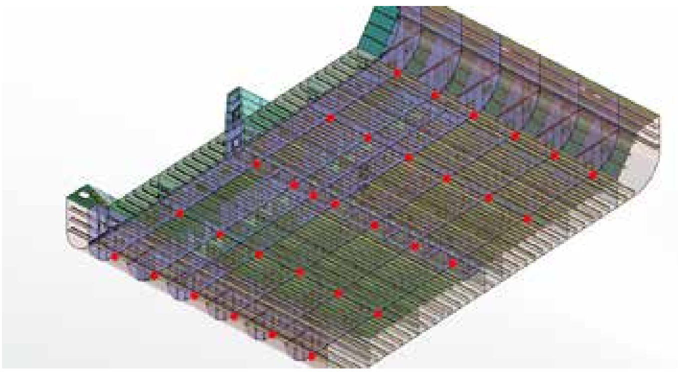
Case 1
58
foundations



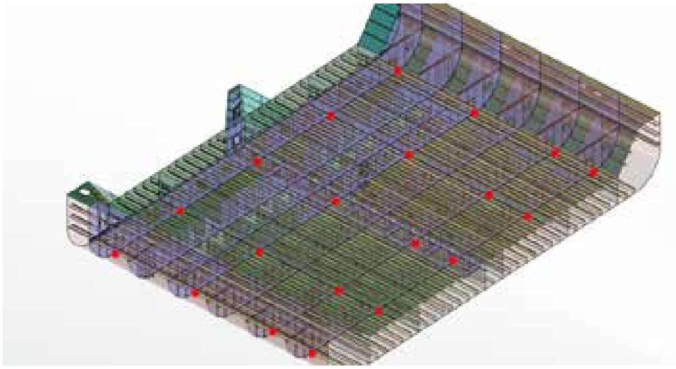
Case 2
38
foundations



Case 3
31
foundations



Case 4
20
foundations



Case 5
15
foundations

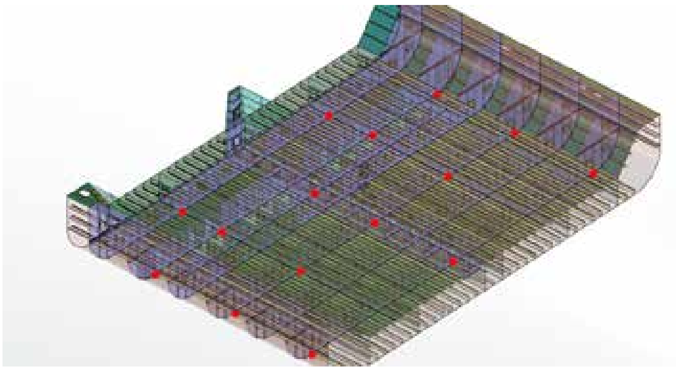


Figure 5: Foundation position for five cases.

For Case 1, a total of 58 foundations were modelled. The maximum stress of 35.5 MPa will occur in the foundations near the bilge plating, while a maximum resulting displacement of 1.86 mm occurs near the edges of the section on unsupported plating. In Case 2, the number of foundations is reduced, which resulted in a slight increase of stress to 58.5 MPa, with a resulting maximum resulting displacement of 2 mm, still positioned near the free edge of the section. Foundations arrangement for Case 3 yields slightly higher stresses. The maximum stress for this case is 82.4 MPa, with a resulting displacement of 1.91 mm occurring at the free edge of the section. Case 4 was calculated for a total of 20 foundations. The resulting displacement of the structure is 1.91 mm, and the maximum stress is 110 MPa. The arrangement with 15 foundations, designated as Case 5, yielded stresses of 171 MPa, which was close to the limit of allowable stress. Still, the resulting displacement of the section was 2.19 mm, occurring on the free edge of the section. However, the resulting displacement of the structure in any other part of the structure is under 1 mm. The comparative results for the stresses and displacements are presented in Table 2.

Table 2: Comparative results for stress and displacement for five different cases.

Scenario case	No. of foundations	Stress [MPa]	Displacement [mm]
Case 1	58	35.5	1.86
Case 2	38	58.5	2.00
Case 3	31	82.4	1.91
Case 4	20	110	1.91
Case 5	15	172	2.19

Stresses for cases 1,2,3 and 5 can be seen in Figure 6, occurring in the structure just above the foundations (Case 4, being similar to Case 3, was omitted from representation). However, the maximum displacement is visible on the edges of the section, and it is uninfluenced by the support number and arrangement, as seen in Figure 7.

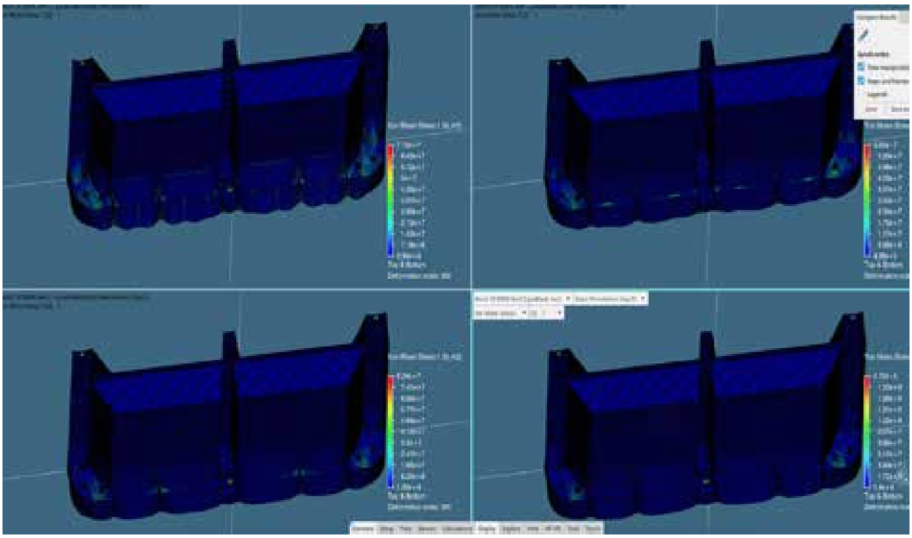


Figure 6: Stress on section for cases 1,2,3 and 5 [7].

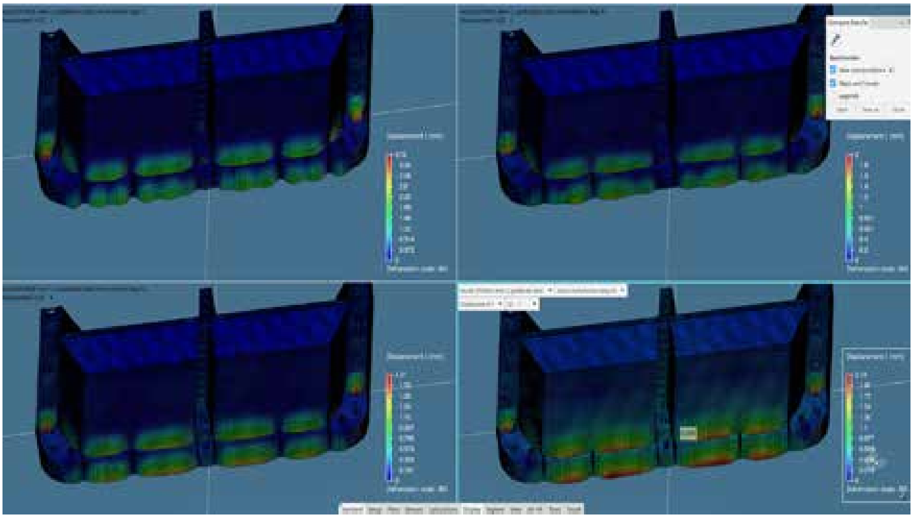
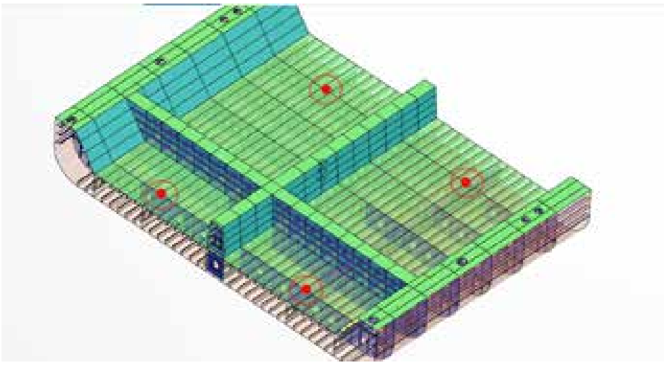


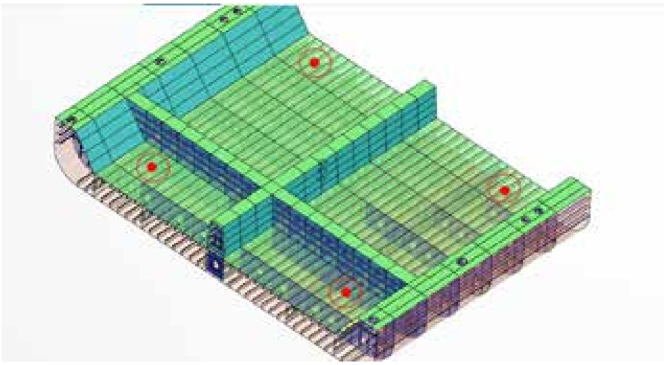
Figure 7: Displacement on section for cases 1,2,3 and 5 [7].

Simulation for different lifting arrangements was made for five cases in total. Cases are numbered from Case 6 to Case 10, respectively. Case 6 and Case 7 have the same number of hooks, but the attachment in Case 7 was placed on the unsupported plate without any primary stiffening member beneath the attachment point. Case 8 attachment points were placed closer to the centre of gravity of the section. Two hooks were attached near the stool section on each side of the centreline, and four hooks were placed on the tank bottom plating above the floor element in the double bottom structure. The placement was symmetrical to the centre line. The attachment points for Case 9 were the same as in Case8. The number of hooks attached to the stool remained the same, while the number of hooks in the tank bottom plating was four on each side. In Case 10, the hooks were attached to the longitudinal double bottom girder. The attachment points are marked with red circles, while hook arrangements are presented with red dots, see Figure 8.

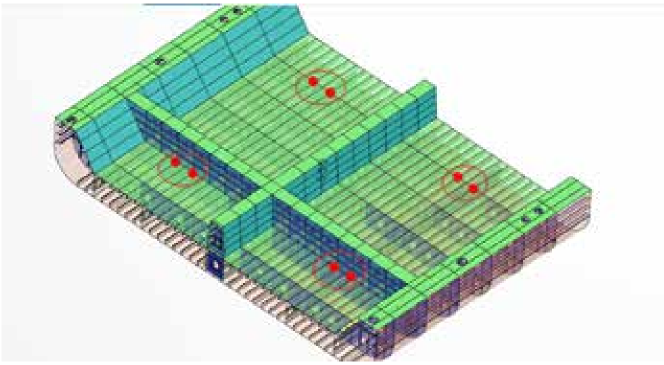
Case 6
4 attachment points
4 hooks



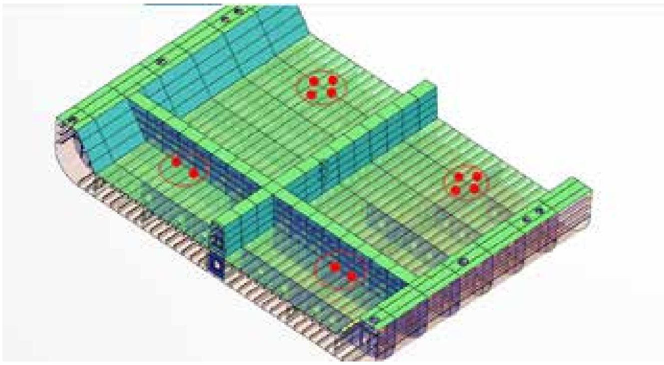
Case 7
4 attachment points
4 hooks



Case 8
4 attachment points
8 hooks



Case 9
4 attachment
points
12 hooks



Case 10
4 attachment
points
10 hooks

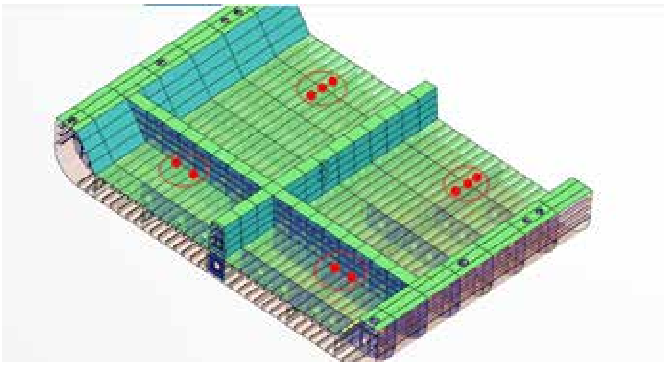


Figure 8: Hook position for five cases.

The resulting stress and displacement values are presented in Table 3. The stress on the structure for cases 6 and 8 was above the 180 MPa, and Case 7 arrangement yielded maximal stress of 458 MPa, which is close to the breaking strength of the steel plating. Case 7 also exhibits the highest deformation. However, this is usually not a real case scenario, as the hooks are not placed on any supporting structure; thus, higher loads and higher displacements are calculated. Stress for Case 9 and Case 10 is below the limit. The arrangement with 12 hooks in Case 9 is marginally better than in Case 10. However, considering that Case 10 can be done with fewer attachment points, thus reducing the welding cost and time. The author must stress out the fact that these cases, Case 9 and Case 10, have unusual hook arrangements to cover the different variations of lifting to test different lifting arrangements (theoretical and real-life case scenarios). The results for stress and displacement can be seen in Figure 9 and Figure 10, respectively.

Table 3: Comparative results for stress and displacement for five different hooking arrangements.

Scenario case	Number of hooks	Stress [MPa]	Displacement [mm]
Case 6	4	247	4.83
Case 7	4	458	14.2
Case 8	8	254	4.87
Case 9	12	139	4.40
Case 10	10	142	4.55

Similarly to foundation calculation, the displacement is maximal in the edge area of the section. The position and number of hooks do not significantly influence the maximal displacement, as it occurs due to the section's unsupported and unstiffened edge. The exception is Case 7. However, Case 7 can be excluded, as it is not a real case scenario, while Case 9 was very similar to Case 10 and was omitred from the presentation.

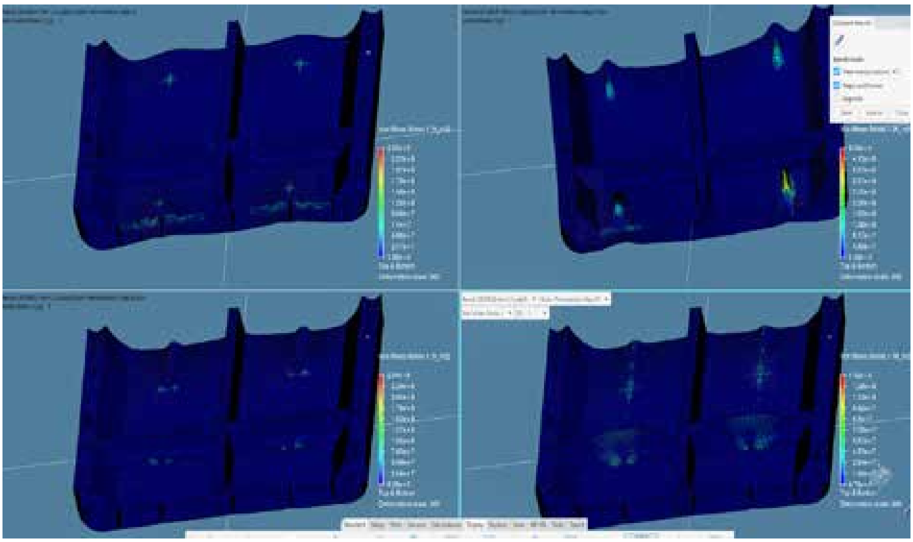


Figure 9: Stress on section for cases 6,7,8 and 10 [6].

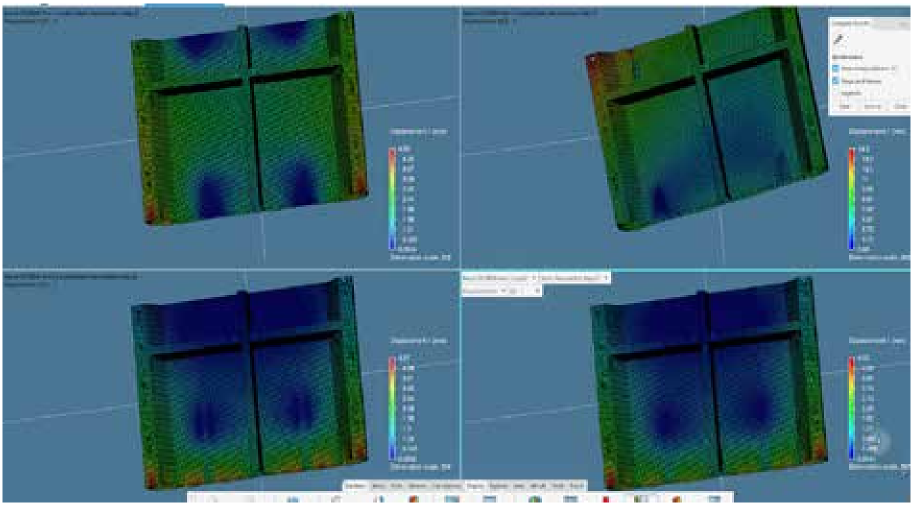


Figure 10: Displacement on section for cases 6,7,8 and 10 [7].

6. Conclusion

The presented procedure enables the definition of stress and deformation in ship blocks in the early phase of planning the layout and number of foundations and the layout and number of hooks for transport, which primarily enables:

- Reducing the number of foundations and related works
- Early prediction of stress and deformation in blocks during production and transport
- Early prediction of adequate positions of transport hooks, especially for complex outfitted structures
- Predicting adequate positions for temporary structural supports
- Reducing working hours and resources while increasing the overall efficiency and quality

The case study was made using the shipyards documentation for transportation and placement of the different sections. Cases were calculated based on the experience and workflow in a well-known shipyard. However, more cases could be analysed in future work using the optimisation tools, and optimal solutions could than be presented.

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