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Structural Analysis in Shipbuilding Production Process

Professional paper

The paper concerns the use of numerical structural analysis in shipbuilding technology as a tool for easier decision-making in the early production stage. Relevant state-of-the-art software packages are user-friendly so the users may focus on model generation, setting up the loads and other calculation parameters and, finally, on the analysis of the results. Once the model of the structure is generated it could be used for different cases studies. The necessary changes in the structure are easily modelled and analyzed again.

The problems related to early outfitting are explored using the finite element method. Structural analysis is performed, first, to determine behaviour of the structure during outfitting at the ground level. Then, it is applied to analyze the lifting of the outfitted block for the assembly into a ship superstructure. Deformations and stresses will be evaluated and critical issues detected. As a result, feasibility of the early outfitting will be evaluated and commented.

Keywords: *shipbuilding production process, structure analysis*

Strukturna analiza u brodograđevnom proizvodnom procesu

Stručni rad

U članku se razmatra korištenje strukturne analize u brodograđevnom proizvodnom procesu. Razvoj računala i programskih paketa omogućuju strukturnu analizu u svim fazama proizvodnog procesa, a primjena suvremenih aplikacija dovodi do korisnih rezultata koji olakšavaju donošenje odluka u proizvodnoj fazi. Prednost današnjih programskih paketa je što su prilagođeni širokoj primjeni. Korisnik ne troši vrijeme na programiranje ili testiranje koda već se fokusira na modeliranje, eksperimente i analizu rezultata. Jednom kad je računalni model gotov može se koristiti za brojne numeričke eksperimente. Isto tako, promjene u modelu se mogu vrlo brzo napraviti te pokrenuti nove proračune i analize rezultata.

U članku je razmatran problem uranjenog opremanja bloka nadgrađa broda za prijevoz putnika i automobila primjenom metode konačnih elemenata. Strukturna analiza je korištena da bi se razmotrilo ponašanje strukture tokom faze opremanja te tokom transporta opremljenog bloka nadgrađa kroz osam različitih scenarija. Za svaki scenarij analizirana su naprezanja i deformacije te detektirana kritična mjesta strukture. Zaključno su ocijenjene i komentirane mogućnosti uranjenog opremanja karakterističnog bloka nadgrađa broda.

Ključne riječi: *brodograđevni proizvodni proces, strukturna analiza*

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1 Introduction

Modern ships are very complex products. Shipyards have to fulfil different demands from the building and outfitting point of view such as good product quality, short production cycle and low building costs. Throughout history, building methods have developed with a main objective to shorten the production process and costs. The functional method was used first and after that the functional-space, zone and integrated methods were developed.

Today, the integral method is widely used to enable overlapped activities on structure assembly, outfitting, blasting and painting [1]. Modern shipyards wish to outfit structural blocks in earlier stages as that is much easier and cheaper. Dimensions of the structure and the quantity of mounted equipment depend on technological capabilities of the shipyard, which means transport devices capacities, production lines, and transport ways width.

The shipbuilding industry is dependent on global market conditions. If shipyards want to successfully compete in the world market they have to offer products at a price that is lower than actual market prices. To do this, the development of technology and flexibility of the production processes and an adequate organizational level is necessary [2]. This is especially important for shipyards that build complex types of ships like ROPAX.

ROPAX is a ship for vehicle and passenger transport. Such type of ships has a large number of decks and a long superstructure with important characteristic that it is made of tiny plates. Also, dimensions of the typical block are huge, while the mass of the block is relatively small. The spans between bulkheads are large with significant influence on the structure stiffness. Dimensions, mass arrangement, welding procedure and transport of the block cause problems with deformations and strains of the structure. Usually, superstructure outfitting is performed on a quay after assembly and launching. If production cycle is to be shortened, it is necessary to analyze the possibilities of block outfitting in earlier production phases.

Structural analysis by finite element method is a modern engineering tool for detection of elevated stresses and deformations in the structure [3, 4]. Early outfitting of the superstructure block with cabins imposes additional demands to the structure strength and deformation and therefore structural analysis must be used to check the structure response in these new conditions.

Shipyards commonly construct each superstructure block at the ground level. Due to its heavy weight, large dimensions and relatively thin plate structure, a certain amount of elastic deformation is inevitable. Due to that, *supporting pillars* are usually welded below the lowest deck to prevent excessive deformation. If early outfitting with cabins is considered, additional weight will accentuate these deformations and only if they are within certain tolerances, cabins may be safely attached.

At the next stage, the superstructure block is lifted for assembly in the ship superstructure. During the lifting, the superstructure block, particularly when outfitted with cabins, will deform and this deformation must be controlled. The same is valid for stresses. Due to that, shipyards always add *stiffening pillars* in-between decks to tighten the structure. The number and position of stiffening pillars must be adequate for the fully laden. In addition, the number of lifting pads, attached to block during lifting, must be determined.

2 Characteristics of the shipbuilding production process

In the shipbuilding technological process there are a few subprocesses related to the processes of assembly and outfitting of the ship [5]. The subprocesses related to ship structure assembly are prefabrication and fabrication of the plates and bars, structure subassembly, and hull assembly. The subprocesses related to ship outfitting are equipment fabrication, subassembly, and assembly.

Ship, as a complex product, has to be technologically divided according to different criteria. One of the basic criteria is functional division where the ship is divided according to her functions. Usually, this criterion is used in the design stage. Another important criterion of division is spatial criterion. This criterion is important to the production phase and it is dependent on the technological possibilities of the shipyard. Basic spatial division of the ship, widely used for most types of ships, is division on macro spaces as follows:

1. aft peak,
2. machinery space,
3. cargo space,
4. fore peak,
5. superstructure.

Elementary terms in ship outfitting are ‘stage’ and ‘zone’ of outfitting. The ‘stage’ is related to time or period and ‘zone’ is related to space. There are four basic stages:

1. outfitting during the section subassembly,
2. outfitting on interim store of the finished sections,
3. outfitting on the building berth,
4. outfitting on the quay.

3 Subassembly and outfitting of the superstructure block

3.1 Subassembly of the superstructure block

A typical superstructure block is considered. The block size and topology is defined by shipbuilding assembly practice and drawings of the ship, designed and produced in a Croatian shipyard. Block overall dimensions are 30.5x12x6 meters (width x length x height), Figure 1.

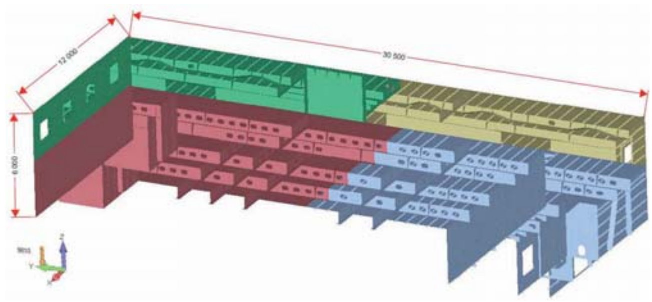

Figure 1 **Typical superstructure block – overview and scantlings**
Slika 1 **Tipičan blok nadgrađa – opći plan i dimenzije**

Block consists of two decks between sidewalls, denoted as Deck 9 (upper) and Deck 8 (lower), Figure 2. Each deck consists of two sections S1 and S2. Sections joint is located near the central line. In the same figure a number of supporting and stiffening pillars are indicated. They are removed later, once the block is assembled in the ship superstructure. The block length spreads from Fr.146+400 to Fr.161-400. Several girders are of importance, in particular girders at y = 4800 mm portside and starboard.

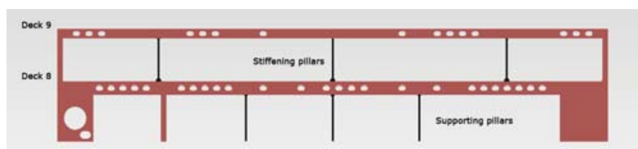

Figure 2 **Block decks and pillars**
Slika 2 **Palube i upore na bloku**

3.2 Outfitting of the superstructure block

Outfitting of the ship superstructure includes work activities from deck 8 to the wheelhouse. The main part of all activities is related to mounting of the cabins and installations for the crew and passengers accommodation.

Outfitting of the block superstructure in the first stage includes mounting of pipes, pipes connections and girders, ventilation, doors, windows, cable ways and girders, bases for devices.

In the second stage, when the whole superstructure block is finished, outfitting activities are related to mounting of the equipment which was not mounted in the previous phase and the equipment like platforms, fences, hand-holds and ladders. After this stage, corrosive protection of the superstructure block is due and then pipe outfitting and cabin installation is performed.

Outfitting zone on a building berth could be defined in a different way, because it could contain several superstructure blocks. In this phase, huge equipment like elevators, separators and cabins will be mounted.

Finally, outfitting on a quay contains finalization activities and control of all systems in the superstructure.

Cabin fitting on the superstructure block is limited by several factors. Only the lower deck may be used for cabin fitting as the upper deck is used during lifting. Cabins cannot be located on the very edge of the block as adequate space must be left for section joining and subsequent activities. Due to this, a total of 18, out of maximum 24 cabins, may be early outfitted on the block, Figure 3. Cabins are coloured in green and blue for visualization purpose. The remaining 6 cabins need to be fitted in a latter outfitting stage.

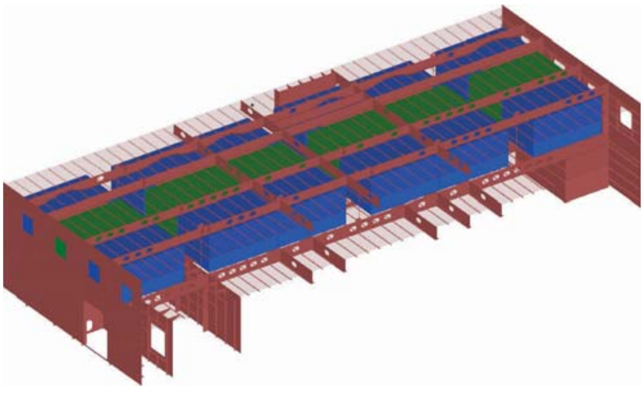

Figure 3 **Early cabin outfitting – arrangement**
Slika 3 **Uranjeno opremanje kabinama – razmještaj**

4 Structural analysis of the superstructure block

4.1 Analysis scenarios

The completed block weighs 83.3 tons. The steel structure itself weighs 75.3 tons, additional welding material adds to approx. 4%, i.e. 3 tons, and other equipment weighs additional 5 tons. Due to its heavy weight and large span, a block on the ground must be supported with the supporting pillars.

Fitting the block with cabins increases the total weight. Two-bed cabins weigh 1200 kg, while four bed cabins weigh 1300 kg. According to technical documentation, 4 two-bed cabins and 14 four-bed cabins are installed on the block adding additional 23 tons on the block. Due to that, the number of needed supporting pillars will be checked during the structural analysis.

As significant deformation of the block is expected during lifting, stiffening pillars are temporarily welded between the block decks. Their position is determined by the stiffness of the surrounding structure, as they need to be attached to strong members, but at the same time it is restricted due to outfitting process. The number and location of the stiffening pillars therefore must be determined and their effect on structure evaluated.

Lifting of the block may be performed using four or eight lifting pads. Their optimal number, with corresponding deformations and stresses, needs to be determined by structural analysis as well.

Table 1 lists all the considered scenarios, load and boundary conditions applied, and the number of pillars modelled, with corresponding location [6]. For example, 3(F158) means 3 stiffening pillars are located at Frame 158. Load on the standing structure is gravity only and it is increased by 10% when the structure is being lifted, taking thus into account dynamic effects. Boundary conditions are fixed in the vertical direction (z-axis) in the case of standing structure while lifting pads are fixed during lifting. Boundary conditions will be elaborated in detail further on.

4.2 Finite element model

Finite element model of the superstructure block is generated using Femap/Nastran software and is presented in Figure 4. The model consists of 136694 plate and beam finite elements. Decks, girders, walls and brackets are modelled using 3- and 4-noded plate elements, while longitudinals are modelled using 2-noded beam elements. All the openings (windows etc.) are modelled. Certain common simplifications are assumed during the modelling of beam and plate element connections, but otherwise the structure is modelled in detail, as realistically as possible. The average size of the plate elements is 150x150 mm.

The material of the block is structural steel. Material density is increased 10.62 % so that the total model mass is equal to actual structural mass. In this way, additional mass (welds etc.) is evenly distributed over the model.

Table 1 **Scenarios considered**
Tablica 1 **Razmatrani scenariji**

Load case	Scenario	Scenario case	Load	Pillars	Cabins	Boundary
1	Block lifting – number of spots	4 spots – no pillars	1.1*Gravity	-	18	Fixed spots
2		8 spots – no pillars	1.1*Gravity	-	18	
3	Block lifting – number of stiffening pillars	All cabins, stiff. pillars on Fr.158.	1.1*Gravity	3(F158)	18	
4		All cabins, all stiff. pillars	1.1*Gravity	3(F158), 2(F149)	18	
5		No cabins, all stiff. pillars.	1.1*Gravity	3(F158), 2(F149)	-	
6	Standing block – number of supporting pillars	All cabins, no pillars	Gravity	-	18	Fixed z
7		All cabins, all pillars	Gravity	All	18	
8		No cabins, all pillars	Gravity	All	-	

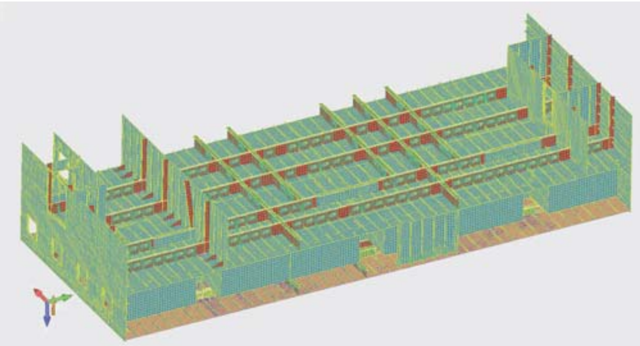

Figure 4 **FE model of the block**
Slika 4 **FE model bloka**

Cabins are modelled as prismatic boxes using plate elements and beam elements only at the cabin base frame. Figure 5 presents the cabin base frame only (cabin hidden) and the connection with the deck. Small beam elements, holding cabin base frame and cabins, are introduced on the deck with a twofold purpose. They simulate screw type cabin-to-deck connection, but also prevent stress concentration that would arise from a single node force (weight) transfer.

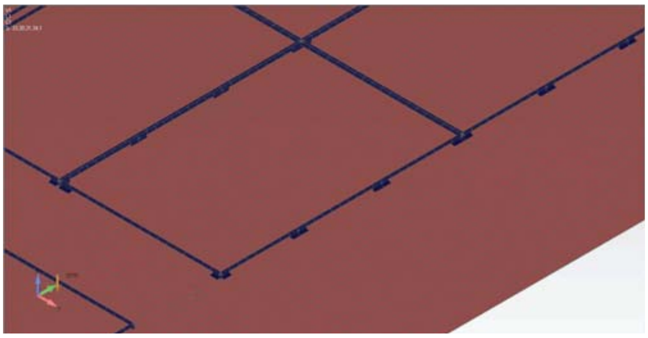

Figure 5 **Modelling cabin to deck connection**
Slika 5 **Modeliranje spoja kabine i palube**

The cabins themselves are made of composite materials and filled with furniture and other elements. The entire weight of the cabin is taken into account through cabin finite elements, maintaining the centre of the mass somewhat below the geometric centre of the cabin model. Average cabin material density of 3.26 t/mm^3 resulted in correct total cabin mass. A 100 MPa modulus of elasticity is chosen after a series of analysis, which verified that block deformations and stresses would not be affected by cabin stiffness in such a case.

4.3 Analysis of the block lifting

By lifting the block with or without cabins, its entire weight gets transferred to the crane via, in this case, four or eight special lifting pads, Figure 6. They are of standard design and are temporarily added above the stiff parts, i.e. frames, of the structure upper deck. In this way deformation due to lifting gets more or less evenly distributed. The distance between lifting pads is 4800 mm when there are eight lifting pads, and 7750 mm when four lifting pads are used.

The body load (gravity) is increased by 10 % due to dynamic effects such as impulse loading, wind gusts, rotational acceleration etc. Boundary conditions fixed all the lifting pads. Due to that, weight will cause deformation mostly in the vertical, i.e. z-axis direction. Strictly speaking, there will be some x-y plane stretching of the structure between the connection spots but it was verified that this effect is of minor importance and was neglected.

Figure 7 presents deformation of the upper deck structure when the block is being lifted by four (left side) and eight (right side) lifting pads. In the latter case deformations are more uniformly distributed and their value is lower – the highest deformation of 195 mm occurs on the sides of the block. The highest stress of 704 MPa was found in the four lifting pads model and 484 MPa in the eight lifting pads model. Obviously, both values exceed permissible stress value. As a result of the analysis, the four lifting pads model was disregarded and the eight lifting pads model only is considered further on.

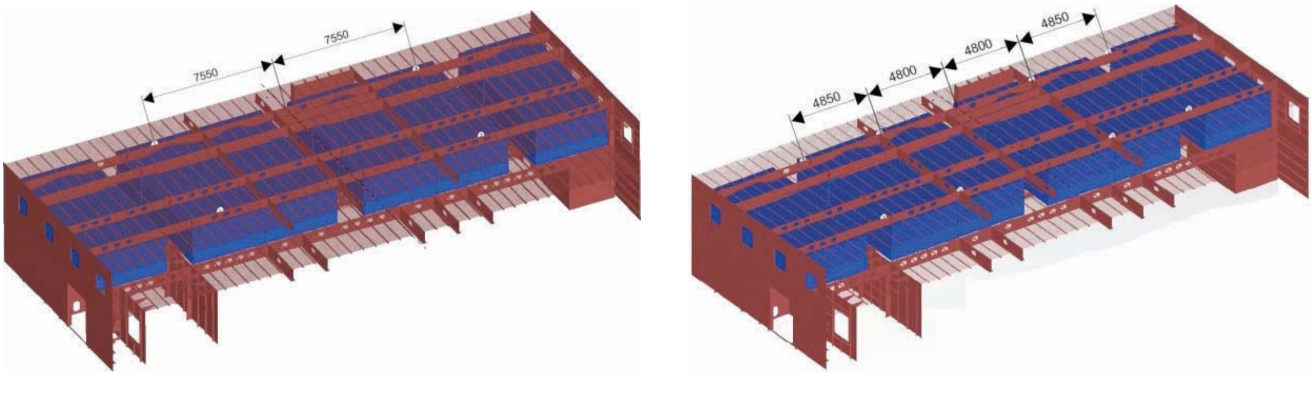

Figure 6 **Location of the lifting pads, 4 (left) and 8 of them (right)**
Slika 6 **Položaj uški za podizanje, 4 uške (lijevo) i osam uški (desno)**

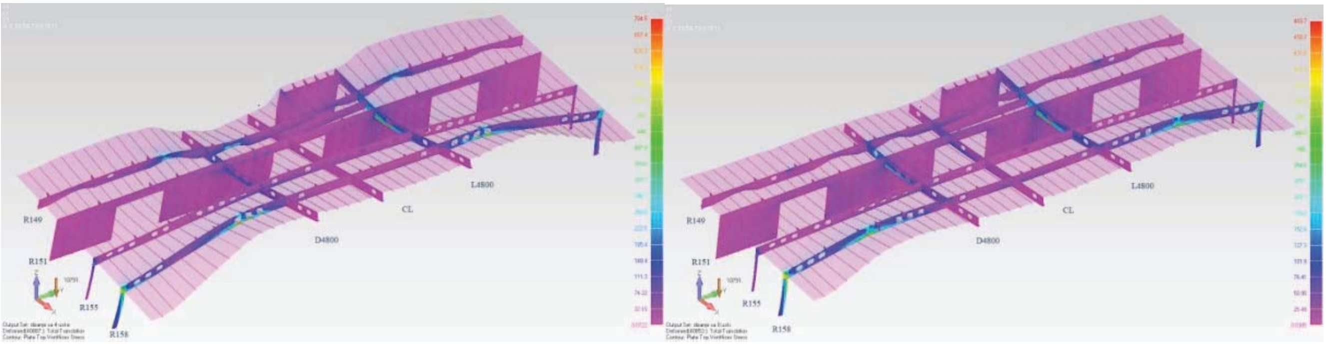

Figure 7 **Upper deck deformation during lifting with 4 (left) and 8 (right) lifting pads**
Slika 7 **Deformacija gornje palube pri podizanju s četiri (lijevo) i osam uški (desno)**

4.4 The effect of stiffening pillars

It is a common practice for shipyards to add temporary stiffening pillars below lifting pads so that stress is reduced to an acceptable level. They are removed after the block is lifted and assembled in the rest of the superstructure. In the case of early outfitting, the presence of cabins limits the available space so stiffening pillars cannot be placed just anywhere. Normally however, there should be enough adequate locations. In this particular case, the location of the lifting pads is chosen so that five stiffening pillars may be welded directly beneath them. Pillars are located at Fr.158 and two of them at Fr.149, between lower and upper decks. Standard U14 profiles are chosen and modelled, although stronger profiles are commonly used in shipyards for the same purpose. In this way, present stress results will be on the safe side.

By applying gravity load increased by 10 % and fixing the lifting pads, both deformation and stress of the block with 18 cabins become as presented in Figure 8 and Figure 9, respectively. The locations of the stiffening pillars are clearly visible in these figures. Deformation is well controlled and maximum deformation of 21.5 mm is found on the positive-x, lower deck free edge, portside, as indicated by the arrow in Figure 8. The stress is greatly reduced and is now 175 MPa, occurring locally at the very stiff pillar and frame joints. It is unlikely that high stress concentrations will occur at these locations, but if they do, adequate brackets can be introduced into the structure or a more detailed, e.g. submodel, analysis may be performed.

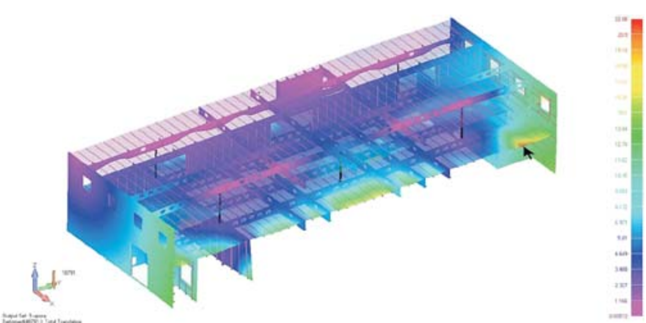

Figure 8 **Deformation of the lifted block with 18 cabins (cabins not displayed)**
Slika 8 **Deformacije podignutog bloka s 18 kabina (kabine nisu prikazane)**

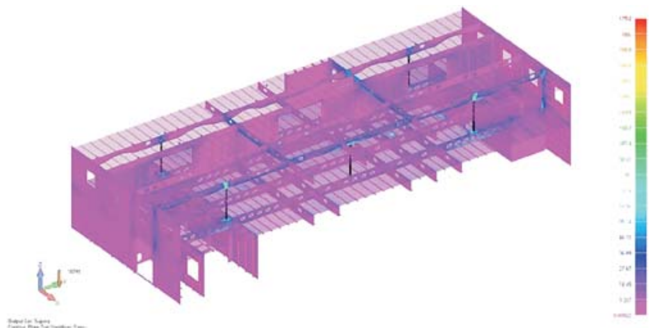

Figure 9 **Stress of the lifted block with 18 cabins (cabins not displayed)**
Slika 9 **Naprezanja u podignutom bloku s 18 kabina (kabine nisu prikazane)**

4.5 Standing block scenario

The complete outfitting of the block occurs on the ground level. The block side plating, parts of frames and some other members in contact with the ground support the block weight. Their vertical displacement is constrained in the finite element model and the load applied is the gravity only.

Without any supporting stiffeners attached, lower deck deformation is as presented in Figure 10. This is not a realistic scenario, as supporting pillars are always used, but it helps to identify occurrence of unacceptable deformations. The highest deformation found in the model is 39 mm vertical displacement, spread over

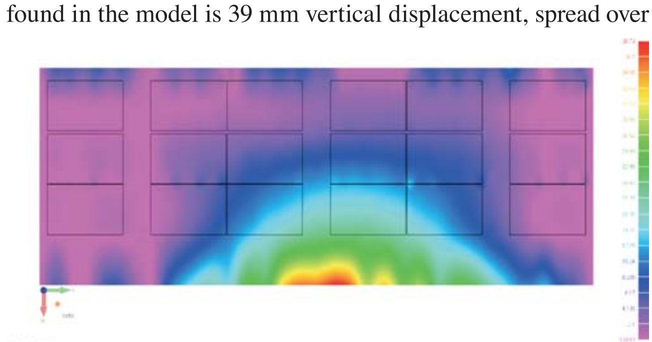

Figure 10 **Lower deck deformation due to block weight – no pillars**
Slika 10 **Deformacija donje palube bloka uslijed vlastite težine – bez upora**

a large lower deck area, near the positive-x free edge. Exact cabin positions are indicated with black squares. Cabin edges are affected by deformation of up to 25 mm. Stress is within permissible limits and does not exceed 148 MPa throughout the model. It is obvious that several cabins are strongly affected by deck deformation and their outfitting may be difficult or impossible.

As a remedy, a total of five supporting pillars are introduced in the model. They are located at the L4800 and D4800, and Fr.149 and Fr.158 intersections, and one is located at the Fr.158 midpoint. The resulting deformations obtained when the same load and boundary conditions are applied are presented in Figure 11. Maximum deformation now is less than 14 mm and is located at the lower deck free edge. Cabins are not affected with this deformation and early outfitting is obviously possible. Deck deformation close to cabin edges does not surpass 6 mm. Stress levels are within allowable limits as well and do not exceed 82 MPa overall. Additional pillars may be added temporarily in the case of any further concern.

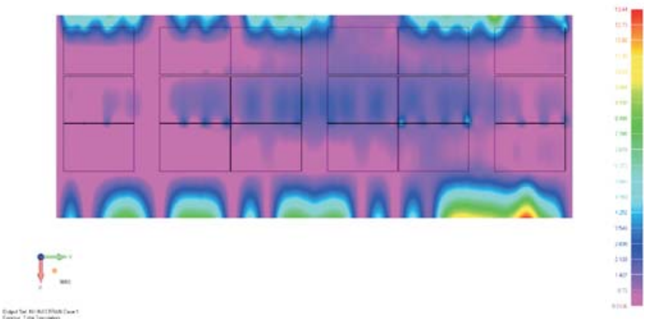

Figure 11 **Lower deck deformation due to block weight – five pillars added**
Slika 11 **Deformacija donje palube bloka uslijed vlastite težine – pet upora dodano**

5 Conclusion

Structural analysis by finite element method was used to evaluate the feasibility of the early outfitting of a typical superstructure block with cabins. Outfitting ads additional weight to the superstructure block: in the considered case cabins add additional 23 tons to 83.3 tons of the block itself. This significant increase in weight increases both stress and deformation of the structure on the ground level. Therefore, structure must be properly supported during outfitting. Structural analysis revealed that five supporting pillars are enough to hold deformation level within permissible limits. Only the free block edges are significantly deformed and these deformations are far from the cabins. Even more supporting pillars may be temporarily added without much effort, and they may further control the deformation.

During the lifting phase the block deforms in a different manner. Standard shipyard practice is to add temporary stiffening pillars between strong members and structural analysis proved their beneficiary effects. By using five properly placed stiffening pillars, the highest stress and deformation remain within permissible limits and do not affect cabins. However, certain restrictions in positioning the supporting pillars apply due to the presence of the cabins. This proved not to be a problem, as frames normally span over the entire block width and girders along the block length. In this way, stiffening pillars may be conveniently located in-between cabins.

Finally, the process of lifting is simulated through a static analysis by introducing additional load to the weight of the model. Lifting the block using four lifting pads created excessive deformation and stresses. Lifting with eight lifting pads easies the overall deformation and is much more suited to the problem and it is therefore recommended.

Early outfitting of the superstructure block with cabins was proved as feasible. Structural analysis using finite element method enabled evaluation of the deformation and stresses in structural members for a variety of design solutions and loading case scenarios.

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