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Asphalt Carriers from *Kraljevica Shipyard* – Constructional and Technological Aspects

Professional paper

After presenting the design development of the asphalt carrier *Asphalt Seminole* and her sister-ships in the article published in the previous issue of *Brodogradnja* (No. 1/2006), in this article the structural analysis made in the design stage and some constructional and technological specifities during the building stage are presented. Special emphasis is given to the presentation of the structional connection between the hull and the cargo tanks with the description of the elastic vertical supports and of structural antipitching, antirolling and antifloating keys, and of the procedure of simultaneous hull assembling and the cargo tanks installing into it, as well as of the temporary cargo tank positioning procedure on wooden keel blocks during the building phase on the berth, and the final tank lowering procedure on the elastic vertical supports after launching.

Keywords: *asphalt carriers, ship construction, structural analysis*

Brodovi za prijevoz asfalta iz *Brodogradilišta Kraljevica* **– konstrukcijske i tehnološke osobitosti**

Stručni rad

Nakon što je u članku objavljenom u prošlom broju *Brodogradnje* (br. 1/2006) prikazan razvoj projekta asfaltnog tankera *Asphalt Seminole* i njegovih blizanaca, u ovom članku je prikazana strukturna analiza provedena u projektnoj fazi te neke konstrukcijske i tehnološke osobitosti tijekom pojedinih faza gradnje broda. Posebni je naglasak stavljen na prikaz nestrukturne veze između trupa i tankova tereta s opisom elastičnih vertikalnih oslonaca i strukturnih *antipitching*, *antirolling* i *antifloating* ključeva, postupka istovremene montaže trupa i ugradnje tankova tereta u trup, te postupka privremenog pozicioniranja tankova tereta na drvenim potkladama u fazi gradnje na navozu kao i postupka spuštanja tankova u konačni položaj na elastičnim vertikalnim osloncima nakon porinuća.

Ključne riječi: *brod za prijevoz asfalta, brodska konstrukcija, strukturna analiza*

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1 Introduction

This article is in some way a logical continuation of the article about the asphalt carriers from *Kraljevica Shipyard* published in the previous issue of *Brodogradnja*. While the first article deals with the design development, this one considers the specific constructional and technological features of these ships that were particularly prominent during individual building phases. For more complete information and for those readers who did not have the opportunity to read the first article, in Table 1 the basic data (name, yard no., client, important dates) for the four asphalt carriers ordered from *Kraljevica Shipyard* are given.

2 Structural design

During the design stage an extensive structural analysis was carried out. The main assignments of the analysis were:

a) Strength evaluation of the primary structural members (web frames, longitudinal girders, stringers)
b) Calculation of reaction forces in vertical cargo tank supports

Table 1 **Asphalt carriers from** *Kraljevica Shipyard*
Tablica 1 **Tankeri za prijevoz asfalta iz** *Brodogradilišta Kraljevica*

Yard No.	Name	Client	Status
531	*Asphalt Seminole*	*Asphalt (Caribbean) Ltd.*, Isle of Man	Delivered
532	*Asphalt Sailor*	*Asphalt (Gulf of Mexico) Ltd.*, Isle of Man	At late stage of outfitting
533	*Asphalt Transporter*	*Asphalt Transporter Shipping Company,* Cyprus	Launched
534	*Asphalt Carrier*	*Asphalt Carrier Shipping Company,* Cyprus	On the berth

c) Calculation of forces in the «antipitching» and «antirolling» keys
d) Analysis of relative hull and cargo tank deformation
e) Assessment of combined stresses in the vertical supports.

For the entire analysis the finite element method (FEM) was employed. In one of the next issues of the journal the author of the analysis [3] will give a detailed description of it. Thus here, for illustation, only some aspects of the asignments a), b) and e) are presented.

2.1 Strength evaluation of the hull and cargo tanks

In Figure 1 the finite element model of the hull and cargo tanks is presented. The model includes the entire cargo space as well as a part of the bow and stern because of the boundary conditions.

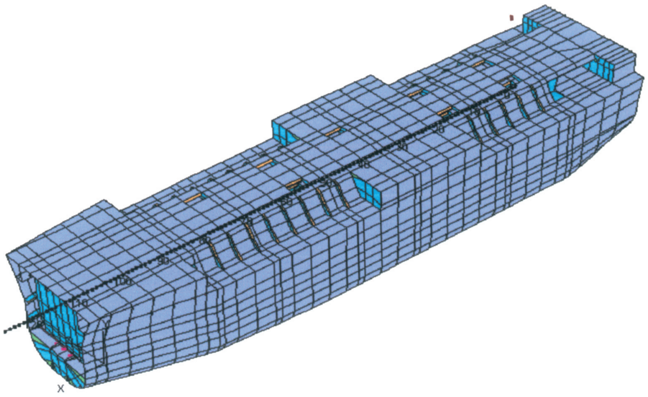


Figure 1 **Finite element model of the hull and cargo tanks**
Slika 1 **Model s konačnim elementima trupa i tankova tereta**

In Figure 2 the finite element model of the cargo tanks space is presented. The flat bulkheads separating the tanks can be seen. In the initial design corrugated bulkheads were foreseen, but during the design development the flat bulkheads have shown to be a better solution than the corrugated ones.

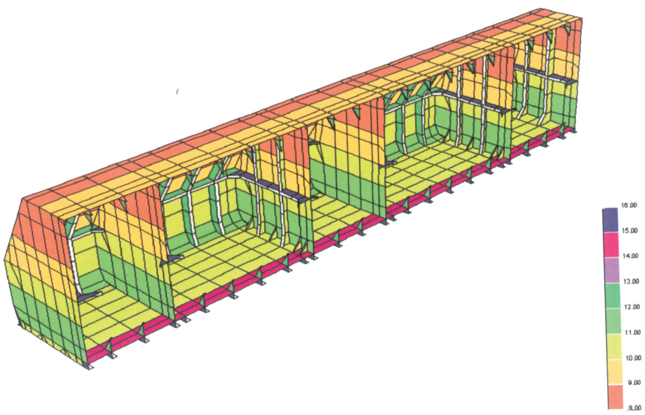


Figure 2 **Finite element model of the cargo tanks space**
Slika 2 **Model s konačnim elementima prostora tankova tereta**

In Table 2 the loading cases (LC) relevant for the structure dimensioning are presented. These are the most unfavourable LC according to the Preliminary Trim and Stability Book. Attention should be paid to the still water bending moment (SWBM).

Table 2 **Unfavourable load cases**
Tablica 2 **Nepovoljna stanja krcanja**

LC No	Description	Characteristics		Filled compartments
8	Full load – design bending moment	Draught SWBM	8.034 m - MNm	All cargo tanks full with equivalent cargo density (see note above)
1	Ballast condition	Draught SWBM	4.77 m 220 MNm	All ballast tanks
7b	Alternate condition ρ = 1.25 t/m^3	Draught SWBM	6.60 m -7 MNm	Cargo tanks 1,3 & 5 full
3	Full load – scantling draught	Draught SWBM	8.36 m -105 MNm	All cargo tanks full with equivalent cargo density (see note above)
-	Flooded condition	Draught SWBM	8.34 m 110 MNm	All ballast tanks full, hold no. flooded

The total load for each LC is obtained by combining the SWBM and the bending moment due to waves according to the *Bureau Veritas* rules.

One of the most important results of the analysis was the thickness increase of the hull bottom and side shell plating due to warping, see Figure 3. Warping of the shell plating is a specificity of asphalt carriers.

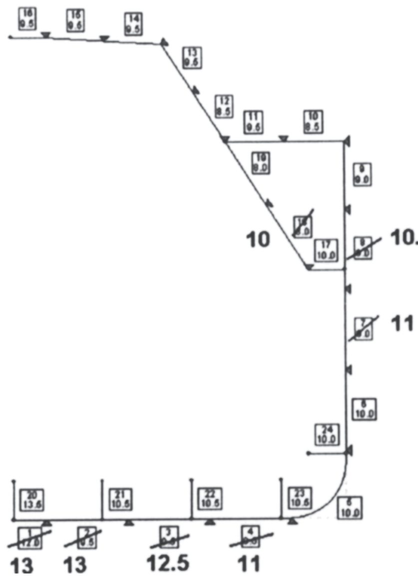


Figure 3 **Thickness increase of the hull bottom and side shell plating**
Slika 3 **Povećanje debljine oplate dna i bočne oplate trupa**

2.2 Reaction forces in vertical supports

In Figure 4 the diagram of the reaction force transverse distribution on a typical web frame is given (the numeration of the longitudinals from PS to SB is given from –14 to +14, 0 is the C.L.). It can be seen that the maximum reaction forces are concentrated in the region of the tank longitudinal bulkheads, i.e. in the region of the greatest stiffness.

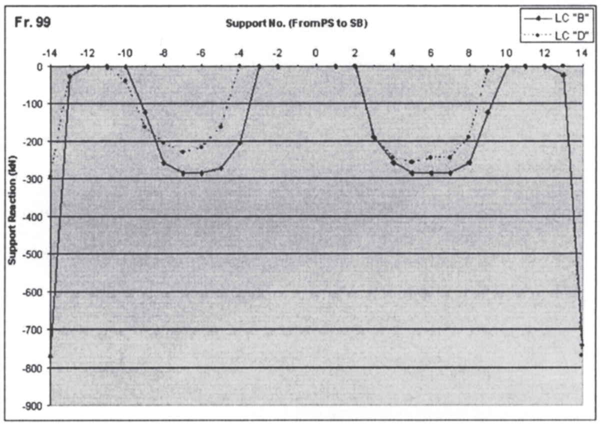


Figure 4 **Reaction force ditribution in vertical supports of cargo tanks**
Slika 4 **Raspodjela sila reakcije u vertikalnim osloncima tankova tereta**

2.3 Stress analysis in the vertical supports

In Figure 5 the finite element model with a fine mesh of the ship structure in the vicinity of a vertical support is presented.

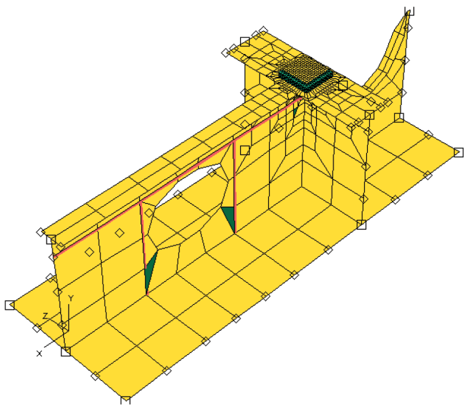
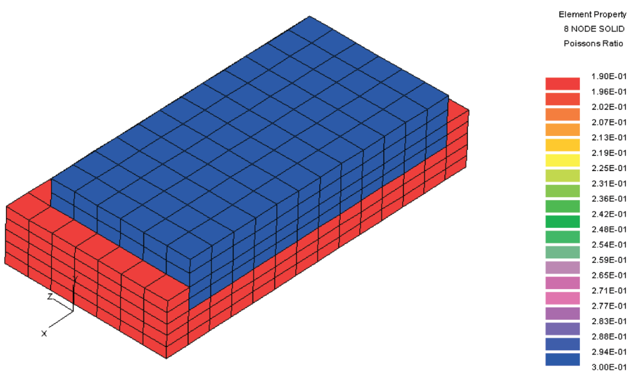


Figure 5 **Finite element model of the ship structure in the vicinity of a vertical support**
Slika 5 **Model s konačnim elementima brodske strukture u blizini vertikalnog oslonca**

Figure 6 **Finite element model of the vertical support sandwich structure**
Slika 6 **Model s konačnim elementima *sandwich* strukture vertikalnog oslonca**



In Figure 6 the finite element model of the vertical support sandwich structure is presented. The structure is modelled by means of volumetric elements using the real properties of the material that composes the support. It can be seen in the figure that the blue material (ceramics) has a different Poisson's ratio than the red composite material.

In Figure 7 von Mises (equivalent) stresses in the support structure are presented. The stresses are the result of the combined loading from the vertical force due to the tank weight and the horizontal friction force due to the relative motion between the tank bottom and the support.

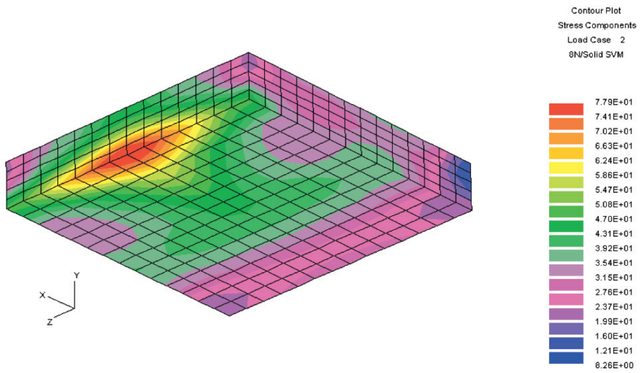


Figure 7 **Von Mises (equivalent) stresses in the vertical support structure**
Slika 7 **Naprezanja Von Mises (ekvivalentna) u strukturi vertikalnog oslonca**

3 Specific design qualities of the non-structural cargo tanks connection to the ship hull

Due to the fact that the cargo tank blocks are not an integral part of the ship hull, here the design solution of their non-structural connection, accomplished via vertical tank supports and via structural keys is presented.

3.1 Cargo tank vertical supports

The cargo tank blocks are not joined by welding to the hull structure, but are lying on vertical supports that are mounted on the hull bottom structure.

Each support consists of an open box having dimensions 280x280x50 mm, into which a "Feroform" plate of dimensions 240x240x35 mm is set, fixed by screws and cast with epoxy resin (see section 5.3 for details). Each support below blocks 2 and 3 is placed mainly on a strip (strip thickness 25 mm) laid on the structural knot longitudinal–floor. The supports of the smallest tank block 1 are placed on extra foundations that are mounted on the double bottom. The "Feroform" plate must be levelled for uniform loading of the supports and fixed. The plate levelling is carried out by 4 screws M16x70, and retaining is done by two diagonally retention bolts M22x95 that pass through the "Feroform 3637" plate and are retained by a nut below. The groove for the screw head is after tightening additionally covered by a tephlone plug to prevent the heat transmission via the screws from the tank into the hull structure.

3.2 Structural keys of the cargo tanks

The motion of the cargo tanks during exploitation in any direction is prevented by means of the so-called structural keys. On the bottom of the tank blocks there are antipitching keys (to prevent tank motion during the ship's pitching) and antirolling keys (to prevent tank motion during the ship's rolling), and on the tank sides and top there are antifloating keys (to prevent the tank vertical motion in case of the flooding of the hold).

The antipitching and antirolling structural keys of tank blocks 2 and 3 consist of steel boxes that are placed on the hull bottom structure (in the symmetry axis of each web frame – antirolling keys, and 18 boxes on the defined frames – antipitching keys) and through the corresponding region of the tank bottom structure. Block 1 is fixed with 6 boxes of antipitching keys on the tank bottom, and with 5 and 3 boxes of antirolling keys on the tank bottom and top respectively.

In the case of flooding of the space between the tank blocks and the hull shell plating during the exploitation, the tank block floating may occur, causing thus immense damage. To prevent such a possibility, on the upper edge of the tank block sides and on the lower part of the wing tanks, the antifloating keys are mounted with about 100 mm of clearance.

The antirolling and antipitching keys are provided with "Feroform" plates, while the antofloating keys do not have these plates.

4 Specific technological aspects of the ship hull erection

The great complexity of the ship hull, particularly of the hull–cargo tanks non-structural connection, required a very careful planning of all building phases, because each of them had its own specifities. Special attention had to be paid to the simultaneous hull erection and the cargo tanks insertion into it during the building phase on the building berth and after the ship launching. Here, a review of the mentioned specificities in each building phase is given.

4.1 Technological division of the hull and the cargo tanks

The mass of the hull amounted to 2700 t. The technological documentation was split into 53 groups. The hull was divided into 182 sections, where the average mass of one section was about 15 t. The length of the ship midship section amounted to 6800 mm. The maximum carrying capacity of the sections to the building berth was 38 t.

The total mass of the cargo tank blocks amounted to 733 t, where block 1 – 87 t, block 2 – 360 t and block 3 – 286 t, which makes about 27% of the hull mass. The tank geometry required a great number of sections, therefore 62 sections were established.

4.2 Specific features of the section constructing

A very dense structure of the hull and the cargo tank bottom in the region of the antipitching structural keys required a time-consuming constructing.

The sections of the hull bottom were due to a limited carrying capacity assembled as a whole with the non-welded connection in the plane of symmetry.

4.3 Assembling on the building berth

For the hull the pyramidal way of assembling was applied. That means, the assembling started with the bottom of the pump room and then approximatelly the same number of sections with an equal hull mass was assembled towards the ship fore and aft end (without the superstructure).

The assembling of the cargo tanks was integrated in the ship hull assembling, however, some preliminary operations on the hull bottom had to be done:

- Measurement of the deviation from the plane of the hull bottom structure on the positions of the vertical supports;
- Mounting of the structural antipitching and antirolling keys;
- Mounting of 308 boxes for the vertical supports;
- Drilling and screw-stocking for the screws of the vertical supports and the keys (1248 threads and 906 holes).

The assembling and temporary positioning of the cargo tank blocks started by bringing the sections of the tank bottom into the right position, which means that the grooved structure of the tank bottom had to be set exactly above the boxes mounted on the hull bottom structure that form the structural keys. The permitted deviation of one structure in relation to the other one was ± 5 mm. Then the tank bottom section was put on wooden keel blocks of the height of about 250 mm, which were fit in the places where no boxes of the vertical supports were fixed, in order to enable a free access to the boxes of the supports. After that, the other tank sections (inner longitudinal and transverse bulkheads, outer bulkheads, sides, top) were assembled to the tank bottom. Before closing the tank top, about 8 km of thermal oil heating coils and cargo pipelines were installed inside all cargo tanks.

4.4 Assembling after the launching

The assembling of the superstructure was performed in a way that at one time three superstructure decks having a total mass of 57 t were assembled.

<u>Before lowering</u> the cargo tanks into the final position, the following operations were performed:

- Mounting of the cargo tank hatches;
- Fixing by welding of the thermal oil pipe carriers;
- Mounting and joining by welding of the cargo pipelines;
- Pressing of the cargo tanks – liquidtightness test;
- Fixing by welding of the insulation carriers;
- Anti-corrosion works on the tank bottoms;
- Anti-corrosion works in the dry (void) space below the cargo tank bottom.

The lowering of the cargo tanks from the wooden keel blocks onto the vertical supports was performed in 5 steps by means of air cushions. The procedure is described in section 5.4. It is important to mention, that the cargo tank blocks could be put down only vertically with respect to the hull bottom structure. Therefore, for the final assembling it was very important to perform carefully the described temporary positioning of the cargo tanks.

<u>After lowering</u> the cargo tanks into the final position, the following operations were performed:

- Alignment and retaining of the "Feroform" vertical supports;
- Underlaying and retaining of the "Feroform" supports on the keys;

- Casting of the vertical supports with “Epocast” resin (type: “Epocast 36”);
- Fixing by welding of the mounting stick on the inclined wall of the wing tank on the tank side;
- Mounting and fixing by welding of the antifloating keys on the side of the hull;
- Anti-corrosion works on the tank sides and top, as well as in the dry spaces;
- Setting of the insulation on the cargo tanks.

5 Cargo space and its main systems

In this section the cargo system itself and the thermal oil cargo heating system, then the cargo tank supports and the tank lowering technique on the supports, and finally, the insulation and anti-corrosion protection of the hull and tanks are presented.

5.1 Cargo system

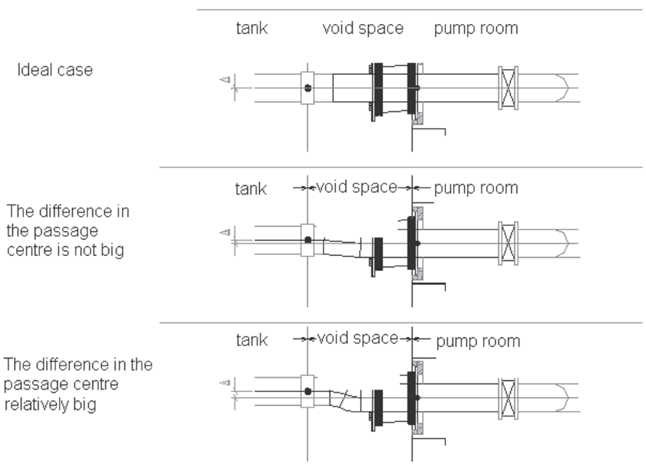
The cargo system serves for cargo manipulation, i.e. for the cargo loading and unloading. The main parts of the system are the driving gear of the cargo pumps, cargo pumps, and cargo pipeline.

The cargo pumps are driven by the electro-hydraulic aggregate *PG Marine* of the following characteristics: power 3x230 kW; pressure 260 bar; maximum capacity 1350 l/min (“power pack”). The drive is placed in a separate space on the trunk deck behind the pump room. A hydraulic pipeline leads from the space of the electro-hydraulic aggregate to the cargo pumps on the bottom of the pump room.

The *PG Marine* cargo pumps are placed in the pump room in the middle part of the ship. There are 3 units of them with the following characteristics: capacity 2x400 m^3/h, 1x150 m^3/h; pressure 11 bar.

The cargo pipeline connects the cargo pumps in the pump room with the cargo tanks. The implementation of the pipeline passages through the bulkhead of the pump room and through the structural bulkheads that separate the tanks, as well as the shift compensation of the pipeline were of great importance during construction.

Figure 8 **Connecting element on the pump room bulkhead with the passage on the cargo tank wall**
Slika 8 **Spojni element na pregradi pumpne stanice s prolazom na stijenci tanka tereta**



Between the pump room bulkhead and the tank wall there was a void space of a certain length. Due to this, the problem of a difference in the passage mid-line on the pump room side and on the tank side occurred, as it can be seen in Figure 8.

This problem was solved by the design of flexible passages (compensators) through the pump room penetration. The penetration is watertight and gas-tight and does not intact the integrity of the bulkhead structure. The pretension of the compensator towards the centreline downwards and longitudinally was performed, because the cargo tank blocks become wider going from the centreline to the sides, going upwards and going towards the pump room. In Figure 9 the design of the flexible penetration is presented.

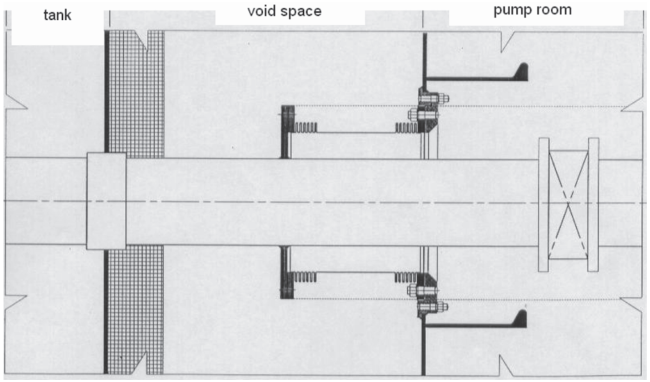


Figure 9 **Flexible passage through the pump room bulkhead**
Slika 9 **Fleksibilni prolaz kroz pregradu pumpne stanice**

The passage of the cargo pipeline through the structural bulkhead was solved by installing gas-tight and watertight flexible passage manufactured by *Rubber Design BV*.

The compensation of the pipeline shifting was achieved by installing the compensation liras, where the dimensions of the liras are determined according to the calculated (expected) displacements of the cargo tanks in three directions (forward/backward, upwards, left/right).

5.2 Cargo heating system

Two design requirements were to be satisfied. Requirement I: maintenance of the cargo temperature of 250 ºC at the sea temperature of 10 ºC and the external air temperature of 0 ºC. Requirement II: cargo heating from 10 ºC to 250 ºC in 24 hours in one tank at the above mentioned sea and air temperatures.

The medium used for the cargo heating is thermal oil that is heated in boilers and has the outlet temperature of 295 ºC.

About 8 km of thermal oil pipelines and heating coils were installed in all tanks. The pipeline was installed in each cargo tank, and in the cargo residual tank and the drip trays tank as well. The main pipeline forms inside the cargo tanks are: the serpentines, towers and verticals. They were all installed into the tanks before closing the tank tops.

To avoid an excessive thermal loss in the thermal oil pipelines from the boiler’s outlet to the cargo tanks, a special care was dedicated to the insulation of the pipeline penetrations through the pump room bulkhead, through the cargo tank top and in the ventilation station of the insulation valves with the purpose to eliminate the possible thermal bridges.

5.3 Cargo tank supports

After the final lowering from the temporary wooden keel blocks, the cargo tanks were placed on permanent vertical supports.

All together there are 308 vertical supports: tank-block 1 is placed on 34 supports, tank-block 2 on 148 supports and tank-block 3 on 126 supports.

Each vertical support has a sandwich structure that consists of two basic layers: “Feroform 3637” and “Epocast 36”. The “Feroform 3637” layer is a kind of textilite with good insulation and sliding properties, while “Epocast 36” is a two-component epoxy resin for casting, which serves as a distance washer. There are also retention bolts and the height levelling screws. The structure of the vertical supports is presented in Figure 10. The carrying capacity of one support makes 100 t of mass.

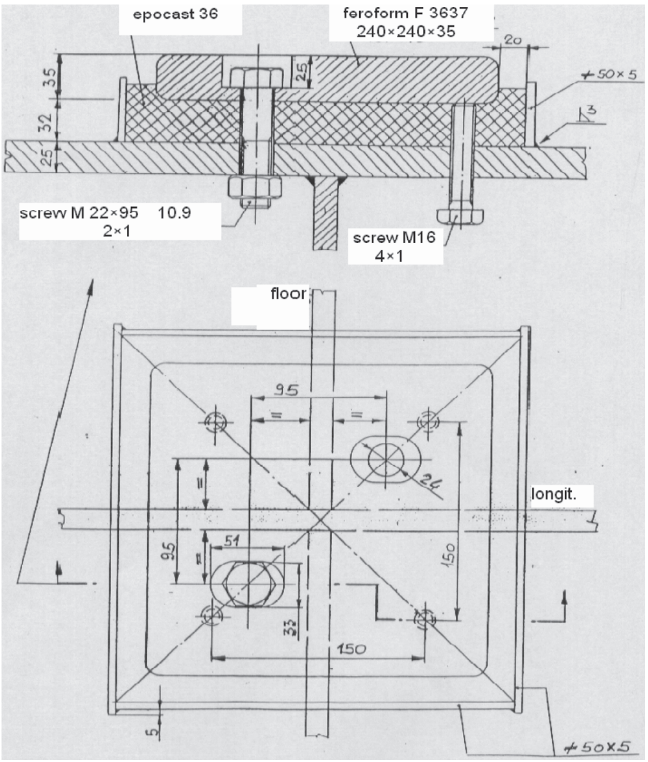


Figure 10 **Detail of the vertical support**
Slika 10 **Detalj vertikalnog oslonca**

5.4 Lowering of the cargo tanks

After the launching, when the ship hull was on an even keel, the lowering of the cargo tanks from the temporary wooden keel blocks onto the permanent vertical elastic supports was carried out. For this purpose a very complex procedure was developed in *Kraljevica Shipyard*.

The descending was performed by means of rubber air cushions, a distribution pipeline for delivering the air under pressure

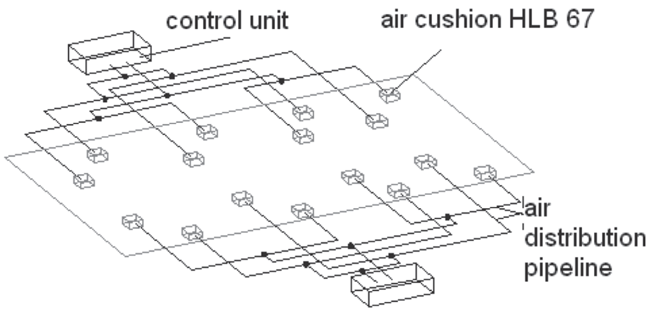
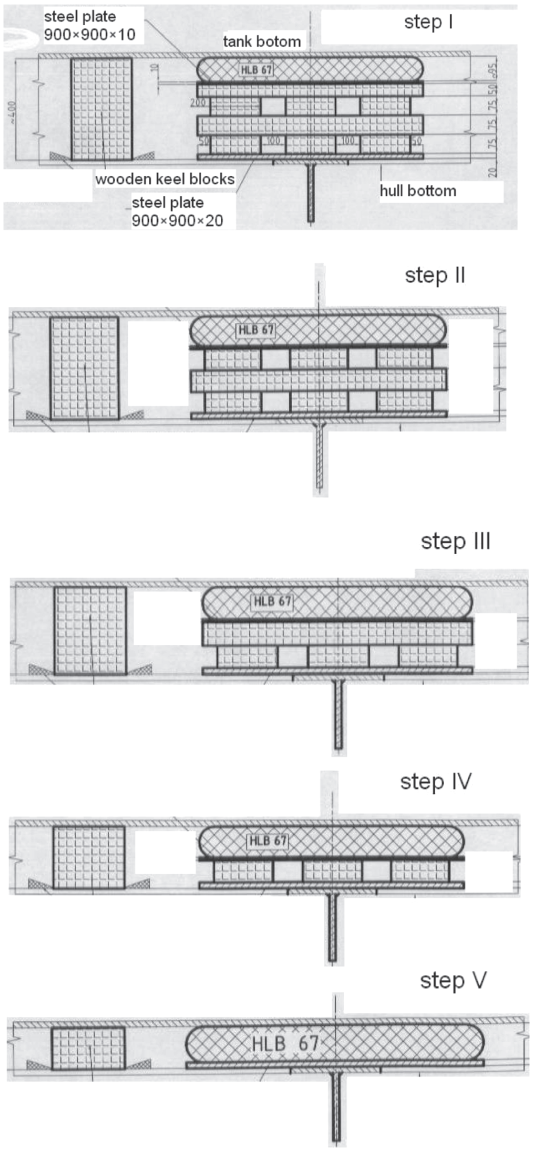


Figure 11 **Air distribution and air cushion disposition scheme for tank-block 2**
Slika 11 **Shema rapodjele zraka i položaja zračnih jastuka za blok tankova 2**

Figure 12 **Lowering of a cargo tank onto the elastic supports in 5 steps**
Slika 12 **Spuštanje tanka tereta na elastične oslonce u 5 koraka**



to the cushions, and the control unit *Holmatro*. The maximum carrying capacity of an air cushion makes 67t, and the cushion carrying capacity increases with the cushion height reduction. In Figure 11 the air distribution and the disposition of 16 air cushions for tank-block 2 is presented.

In this case the mass of the tank-block makes 360 t, the carrying capacity of a single air cushion makes 40 t for the height of 125 mm, which for 16 cushions makes the total carrying capacity of 640 t.

The lowering procedure was carried out in several steps due to a limited motion of the cushions. In Figure 12 the lowering procedure in 5 steps is presented, where the initial height on the wooden keel blocks from the ship bottom structure was 400 mm and the final height on the elastic supports was 50 mm. The elastic support was inserted between the 4^{th} and 5^{th} step.

5.5 Insulation and anti-corrosion protection of the cargo tanks

Insulation

The insulation had to satisfy the following design assignment: the maximum temperature drop in the cargo tanks during every 24 hours makes 5 ºC at the outside air ambient temperature of +5 ºC.

The insulation consists of:

- The needles that are welded to the tank structure (insulation carriers)
- The layers of mineral wool (Rockwool of 70 mm in thickness)
- The reinforced Al-foil as a final layer on the tank walls and bottom
- The substructure and corrugated steel plate as a final layer on the tank top (enabling the communication on the cargo tank top).

The thickness of the insulation layer makes 210 mm on the bottom and 140 mm on the walls and the top of the tanks.

Anti-corrosion protection

All ship parts are protected by means of standard epoxy paints, except the cargo tanks. The manufacturer of all paints, including the extra paints for the cargo tanks, was *INTERNATIONAL*.

For the cargo tanks the extremely demanded paint "Interline 22 Zn Silicate" was used, due to a very complex surface preparation and placement of the cargo tanks.

The surface preparation was performed by sand-blasting according to 21/2 ISO 8501-1, and the paint was deposited at a thickness of 75 microns DFT (dry film thickness); the maximum DFT makes 120 microns. The interior of the cargo tanks was not painted.

6 Conclusion

The design development of the asphalt carrier presented in the previous issue of the journal, and particularly the building of the vessel, the specific qualities of which are presented in this issue, lead to the conclusion that a highly sophisticated ship is in question. During the design development already, and especially during erection of the vessel, numerous problems were encountered. Due to the lack of earlier experience in building of such ships, many of these problems appeared for the first time not only in the Croatian shipbuilding practice but generally. Let us mention among others the trapesoidal shape of the cargo tank cross-section, simultaneous building (and installing) of the cargo tanks with the ship hull, equipping of the cargo tanks within the hull, etc. Thus, the building of the prototype was a good opportunity for the ship owner, designers, shipbuilders and relevant classification societies to gain new knowledge and experience. Numerous innovative design solutions applied on this prototype have finally resulted in an outstanding quality product, which by its commercial and technical particulars by far exceeds the ships of the same assignment built in the rival shipbuilding countries.

Acknowledgement

Here again, like in the first article, the author expresses his thanks to the management of *Kraljevica Shipyard* for giving the approval to use the building documentation. Thanks are also due to the shipyard's experts, cited in the References, for a fruitful cooperation in preparing of the manuscript.

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