Brodogradnja/Shipbuilding/Open access Volume 72 Number 2, 2021

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http://dx.doi.org/10.21278/brod72203 ISSN 0007-215X
eISSN 1845-5859

STRUCTURAL ASPECTS DURING CONVERSION FROM GENERAL CARGO SHIPS TO CEMENT CARRIERS

UDC 629.542.2: 629.5.083.6
Review paper

Summary

An approach to converting general cargo ship to cement carrier is analysed in the present study, emphasising the structural aspects of the conversion. A comprehensive re-appraisal of the conditions of the ship hull, considering her history and present condition of the structure, is provided. Two case studies are presented where the strength assessment has been performed using 2D sectional and 3D finite element models, generated according to the available hull drawings and thickness measurement reports. The results of the two studies are interpreted with respect to the structural modifications carried out during the conversion process, and some general conclusions are drawn.

Keywords: *Ship structures; general cargo ships; cement carriers; major conversion; finite element method*

1. Introduction

A cement carrier is a bulk carrier provided with a cement loading and discharging plant. Presently, about 300 such ships in service range from 2000 to 29000 dwt, with an average age of about 30 years [1]. Cement carriers are obtained mainly by a significant conversion of the existing ships, either general cargo or small containerships, imposing a great need for life extension of these ships beyond their designed lifetime.

The major ship conversion represents a special type of the essential modernisation of the vessel, comprising dimensional modernisation with a survey of all her parts as new ones, i.e. on full compliance to the International Conventions and the Rules requirements of Classification Society. Conversion allows remediating problems of life prolongation and maintaining the safety at a satisfactory level and with smaller overall expense than it is necessary for new construction. Perhaps the most known ship conversions in the past two decades are conversions of oil tankers to Floating Production, Storage and Offloading (FPSO) Units [2]. More than two-thirds of all such ship-shaped offshore installations worldwide are currently thought to be built from converted tankers.

Ship conversion requires accounting for defects that were accumulated during operation of the vessel before the conversion, e.g. corrosion and mechanical wear of hull structural elements and welded joints, especially local thinning, which are poorly documented and not considered at the traditional strength calculations, deformations of the inner bottom and inner side as a result of contact with cargo and cargo handling gauges in ports, deformation of the outer shell as a result of contact with the ground at shallow water etc. [3]. The most important failure mode to be considered in assessing the condition of an aged ship is the ultimate strength of plates, stiffened panels and whole hull girder, as reviewed by Tekgoz et al. [4]. Also, the accumulated fatigue damages at the stress concentration zone, especially small cracks that cannot be found in regular surveys, are considered [5]. Moreover, recent researches indicate that the mechanical properties of the material of the aged hull may be reduced compared to the as-built properties [6].

Before planning the conversion of an existing vessel, it would be necessary to perform her condition assessment, which requires extensive structural analysis and estimation of corrosion diminution based on the hull thickness measurement. Classification societies have been developing software packages for ships in service that have integrated module for a corroded structure analysis using Finite Element Analysis (FEA) and taking into account the survey report from hull inspections [7].

Two case studies conversions to cement carriers are presented in the present study. The two converted ships are built initially as general cargo ships, with continuous double bottom and double sides. Both ships have cargo holds designed for carrying containers and strengthened for heavy cargo. Double bottom and double side spaces are used as ballast tanks. The smaller ship has only one large rectangular cargo hold, while the larger one has three separated cargo holds. To verify compliance with the set of the international and national requirements for the building date of the vessel under conversion, the application of modern calculation methods and technologies is mandatory. Thus, ship structural analyses are performed using FEA commercial software, where the thickness of finite elements is defined using available structural drawings and results of the ultrasonic thickness measurements. Besides, 2D sectional models are created to verify ship longitudinal strength and check the local strength of plates and stiffeners.

The present study is organised as follows. In the first section after the Introduction, the cargo system of cement carriers is briefly described. After that, a general overview of the structural analysis of ships in service is provided. Case studies of conversions of general cargo ships to cement carriers are presented in Sections 4 and 5. Some important considerations during the conversion process, other than structural aspects, are reviewed in Section 6. Finally, general conclusions and recommendations are provided.

2. Cargo system of cement carriers installed on general cargo ship

The cargo system for loading and discharging of cement cargo, with all accompanying equipment, is installed on-board during conversion. The dry bulk self-discharging pneumatic transfer system is specifically designed for installation on-board. The system is suitable for loading and transferring dry products so that loading of the holds can be done by gravity, pneumatically or mechanically. In contrast, discharging can be done pneumatically directly into a silo or shed or directly into the trucks. Loading and discharging equipment is generally located in four 40 feet containers secured to the existing hatch covers with the existing container twist locks and supporting structure. New vent houses have also been added to the permanently welded hatch covers. The dry bulk transfer system is a fully automated system controlled via the local control panels.

Loading the dry bulk into the atmospheric cargo holds from shore, using the air slides (by gravity) or pneumatic transportation. The air slides are fed mechanically or by gravity with a maximum feeding rate, or the cargo holds can be loaded pneumatically by using the quick connection couplings.

The “cement hold” structures comprise steel plates, and stiffeners fitted into existing ship holds. The new cement holds are separated by transverse bulkheads that penetrate the existing hatch covers and are sealed using collar plates. A special cylindrical tank, operating during the unloading process, is fitted inside each cement cargo hold.

3. Structural analysis of ships in service

To assess the performance of the existing ship concerning the rules, different structural assessment procedures are generally required.

The most important analysis type is the longitudinal strength assessment, consisting of checking ship sectional modulus and shear stress distribution caused by global bending moments and shear forces. For ships longer than 150 m, ultimate longitudinal strength is also to be verified. Longitudinal strength assessment is performed using two-dimensional sectional models by employing MARS 2000 software [12] package in the present study [8].

MARS 2000 software is also used to analyse local structures, i.e. plate between stiffeners and stiffeners supported by the primary supporting members. This is performed according to the rule requirements to ensure that these local structures, exposed to the combined global and local loads, are satisfactory. Several sections along the ship length are normally modelled in program MARS 2000. The local strength of plates and stiffeners on transverse bulkheads is also assessed using MARS 2000. As determined by rule calculations, structural scantlings are the “net” values obtained by deducing the value of the rule corrosion addition from the as-built thickness. In structural verification of an aged ship, the measured corrosion deduction may be used instead of the “rule” corrosion. This enables the structural assessment of the existing ship structure when converting and estimating the minimum allowable thickness below which the ship should be dry-docked to replace corroded plates.

The longitudinal strength of converted cement carriers should normally be satisfactory, as new elements, which partially contribute to the longitudinal strength, are added to the existing ship structure. The existing hatch covers are welded to the hatch coamings during cement carrier conversion, contributing to the longitudinal strength. While on the general cargo ship, hatch covers have been only supported by hatch coamings before its conversion, thus not contributing to the longitudinal strength. Also, a new sloped inner bottom (fluidising bed) is added in the cement carrier hold above the existing inner bottom. This new sloped structure is also, to some extent contributing to the longitudinal strength. To find to which extent these new structural elements improve the ship’s longitudinal strength, the FEA of the ship hull is performed. It is impossible to estimate the hatch covers and fluidisation bed contribution to the longitudinal strength without performing an FEA. Except for that purpose, the FEA is necessary to verify the behaviour of primary supporting members (web frames, longitudinal girders, floors etc.).

Furthermore, bending of primary supporting members may cause significant compressive stresses in attached plating that may cause plate buckling failure. Verification of such buckling behaviour, especially of the bottom plating, is another specific purpose of the FEA. Similarly, as for the MARS models, the FEA may be performed using either the “rule” corrosion deduction or the measured corrosion deduction value to get more realistic results.

In the present study, the so-called 3-hold method for the ship FEA is performed. The principle of the 3-hold method is to make a model consisting of three holds, separated by transverse bulkheads. Fore and aft holds are considered influenced by the boundary conditions, while the mid-hold results are considered relevant. Thus, the 3-hold FE model reduces the unrealistic effects of the boundary conditions to a minimum in the assessed middle hold. The 3-hold model is loaded by pressure loads along the length and by global shear forces and bending moments at the model ends. According to classification society rules, appropriate boundary conditions are applied at the ends of the model [8]. The model should be balanced to have "target" shear forces and bending moments in the mid hold.

In the present study, the strength analyses of the structure of the ship are performed by the FE software package Femap with NX Nastran [13]. The model, calculations, and post-treatments are carried out using VeriSTAR Hull Version 5.14 r1 [14], which automatically imposes loads and boundary conditions and checks the rule failure criteria after performing the structural analysis. The mesh density used in 3-hold modelling is s x s, where s denotes stiffener spacing. The structure is modelled by quadrilateral isotropic shell elements with four nodes, triangular shell elements with three nodes, and two-nodes beam elements.

In the cases of ships without clearly defined the strength deck, as passenger ships or in the cases when the maximum stresses are obtained at the ends of the cargo holds, as container ships, the 3-hold methodology is not applicable and complete ship modelling (CSM) should be employed [9]. The mesh density used in CSM is s x s in the midship region, while the coarser mesh may be employed in the fore and aft peaks.

Following the global structural analysis, the stress concentration analysis may be performed in the zones with increased stresses. Structural connections as brackets and openings in web frames are typical details requiring a stress concentration analysis. A mesh density of 50 x 50 mm is normally used in the stress concentration analysis. Also, the top-down technique is used, where only one portion of the model is refined with 50 x 50 mm mesh density, while nodal displacements obtained from the global model are imposed on the boundaries of the refined mesh. There is another level of refinement when fatigue analysis is required, typically at welded joints in the regions of high stress concentration. Mesh size t x t, where t is a plate thickness, is used in fatigue analysis. Stress concentrations and fatigue are problems typically increasing with ship size. For cargo ships of about 100 m in length, like those analysed in the present study, stress concentrations and fatigue are not considered a very important issue, and for that reason, they are not covered herein.

The FEA is performed for the following typical loading conditions that are usually decisive for ship structural safety:

1) Ballast case - or the light ballast of the ship, in the hogging condition.
2) Full load on the scantling draught, in the sagging condition.
3) Partially loading conditions, with alternate cargo holds full or empty.

The structural response in the form of hull displacements, stresses and adequacy parameters are verified for compliance with the requirements of the Croatian Register of Shipping (CRS) Rules, Part 2-Hull [10].

4. Case study 1

The first ship studied had a single cargo hold of 52,6 m in length and 10,2 m in breadth. During conversion, one large hold is divided into two parts by a new corrugated transverse bulkhead fitted. Consequently, the converted ship has two separate holds for the cement cargo. General ship arrangement after major conversion is shown in Figure 1, while the main particulars of the ship are presented in Table 1.

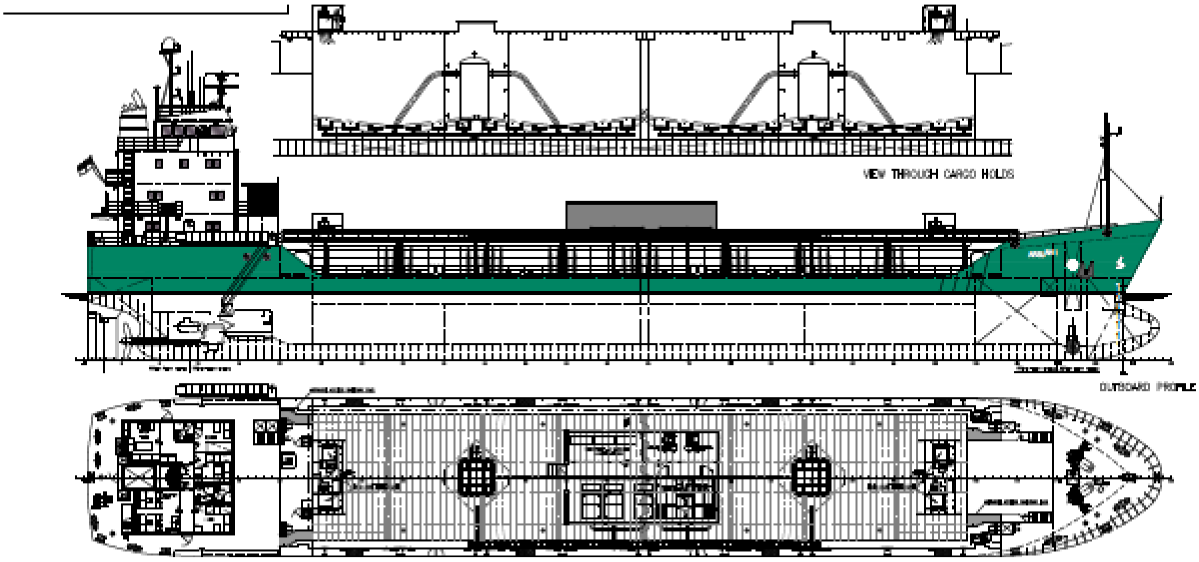

Fig. 1 General arrangement of ship no.1 after major conversion

Table 1 The main characteristic of general cargo ship no.1 converted to a cement carrier

Length overall	L_{oa}	85.4 m
Breadth	B	12.8 m
Depth	D	6.5 m
Scantling Draught	T_{sc}	5.6 m
Deadweight	DWT	3000 tons

The two cement cargo holds are fitted with a raised steel hold bottom, located above the existing tank top and supported by the transverse and longitudinal structure. The new raised hold bottom is outfitted with a fabric covering, fitted to the hold bottom plate with a series of studs, flat bars, and rubber protection strips. This arrangement forms a fluidising bed for the aeration of the cement cargo. This conversion has not included any changes to the existing water ballast system. The local structure (stiffeners and frames) of some ballast tanks has been reinforced to accommodate the new fluidising bed without changing the ballast tank's capacity.

In Figure 2, the modified cargo hold structure of ship no.1 during conversion in the shipyard is shown. One may notice a new transverse corrugated bulkhead, raised sloped inner bottom and special vertical batch tanks for the cement discharging process, as described in Section 2.

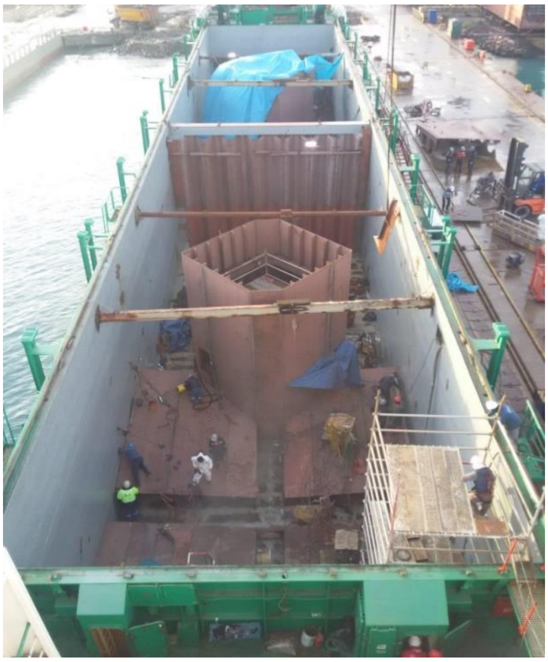

Figure 2 Ship no.1 cargo area photo taken in the shipyard during major conversion and new parts installation into existing hull

The original vessel's single skin hatch covers have their wheels, seals and hydraulic cylinders. Those elements have been removed, and sides of hatch covers have been reinforced with thick insert plates and welded to the existing hatch coamings using an arrangement of flat bars and half tube connections. The cargo hatch covers (eight pcs.) are permanently connected and reinforced with longitudinal stiffeners, creating a new continuous trunk deck.

The midship section is analysed by MARS 2000 to ensure that longitudinal and local strength are satisfactory (Figure 3).

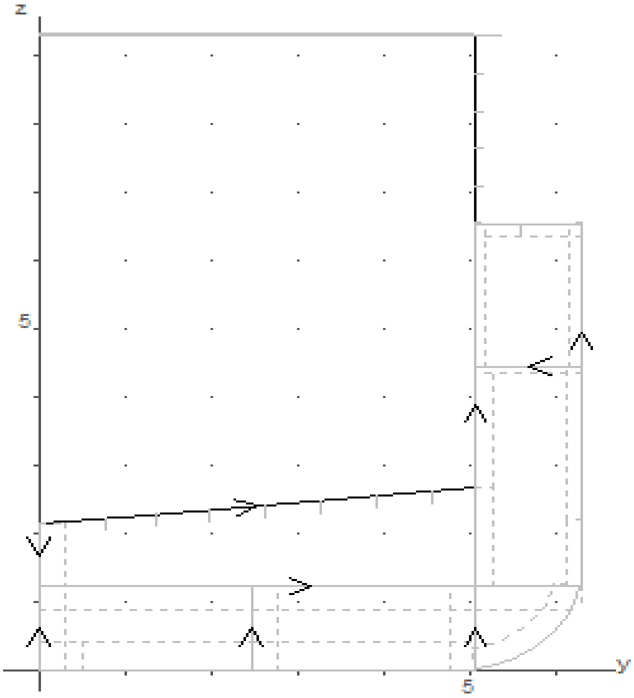

Figure 3 MARS 2000 model of the midship section of ship no.1

The FE model of the cargo hold region is presented in Figure 4. Hatch covers are removed for clarity of presentation. Parts of aft and fore peaks are included in the model to impose boundary conditions, while results only in the cargo hold region are considered credible. The reduced ("net") thickness of all structural members has been used in relation to as-built thicknesses shown on the submitted hull drawings.

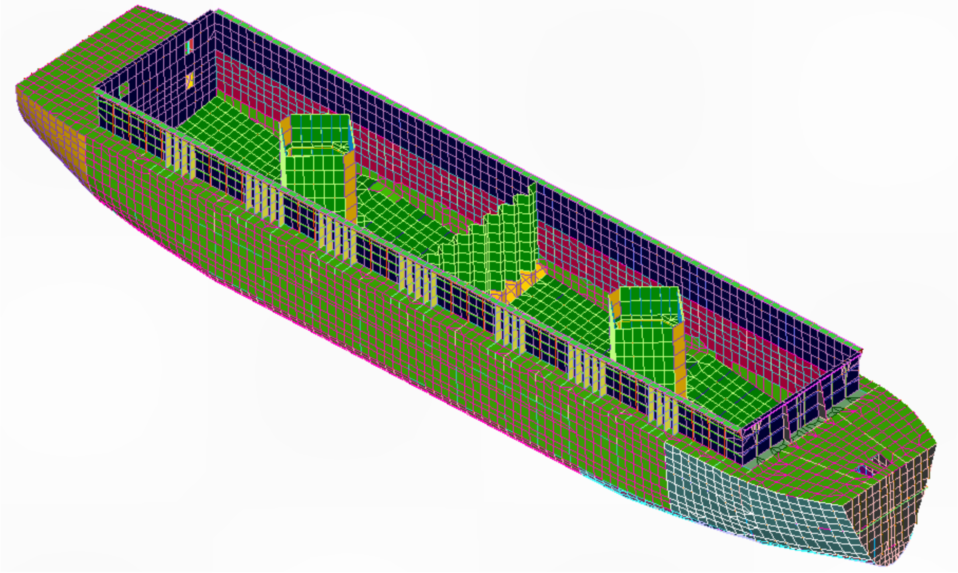

Figure 4 FE model of general cargo ship no.1 after major conversion (hatch covers removed for clarity of presentation)

Except for hydrostatic and hydrodynamic wave loads and cargo and ballast pressure loads, solid masses and concentrated vertical forces have also been applied to simulate heavy equipment such as the batch tanks in the cargo hold region. The model was balanced to achieve the total bending moments and the shear forces following the diagrams obtained from the submitted Stability Report, provided by the designer and the rule global wave load distribution.

The material properties within the FE model for case study 1 has been used based on two types of shipbuilding steel: mild steel grade A with Young's modulus of 206 000 MPa, Poisson's ratio of 0.3, the yield stress of 235 MPa and tensile strength of 450 MPa is employed in the majority of the hull, while high tensile steel grade AH36 with a yield stress of 355 MPa and tensile strength of 500 MPa is used for the bottom plate and hatch coamings.

Global hull-girder bending stresses in the hogging and sagging conditions are presented in Figure 5.

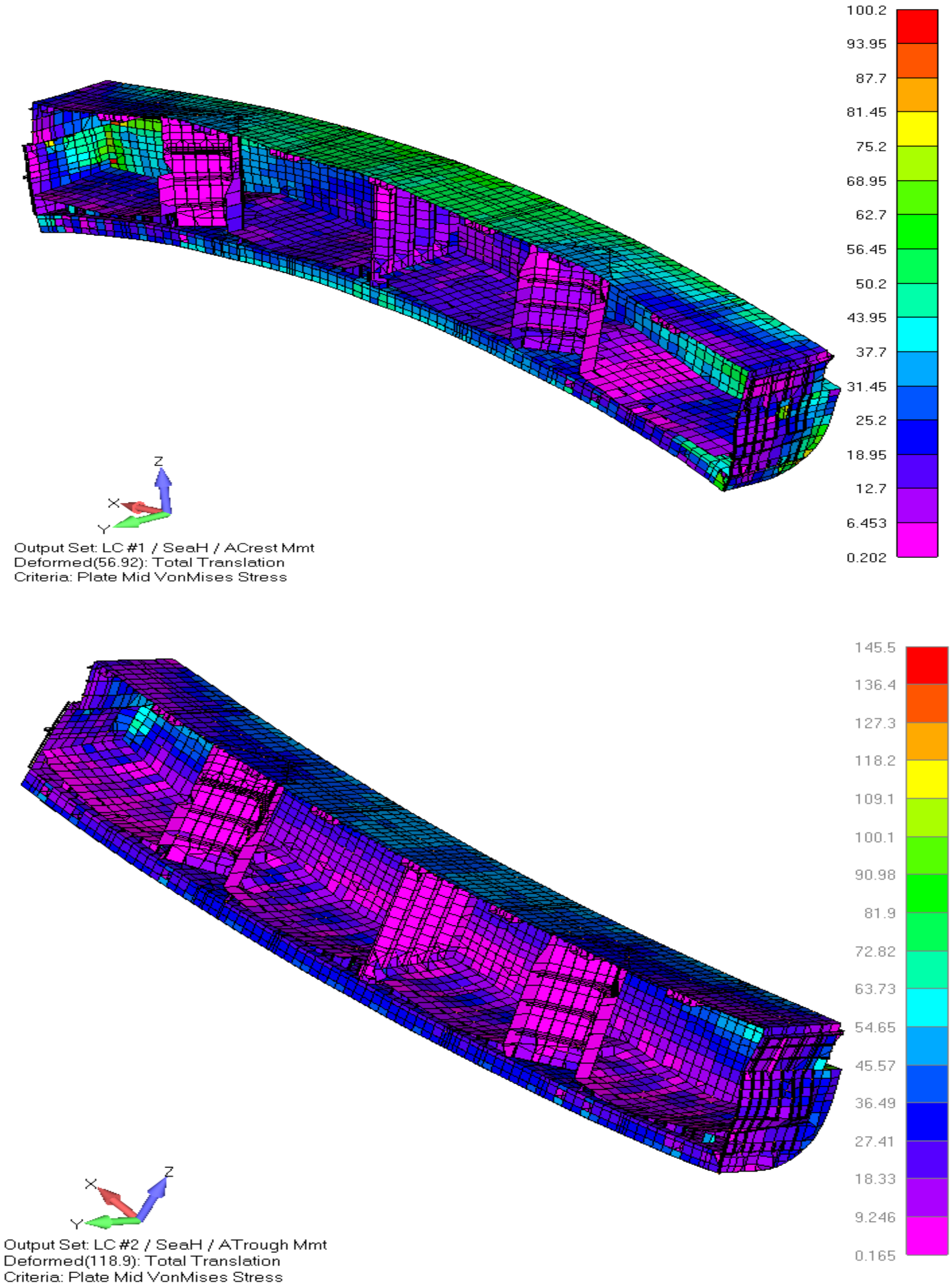

Figure 5 Von Mises stresses of FE model of ship no.1 Upper figure – hogging; Lower figure – sagging

The stress ratio in the typical web frame of the cargo area is presented in Figure 6. The stress ratio represents the ratio between stresses in the structural element, obtained from FEA, and the allowable stress values based on the Rule requirements. Stress ratio below unity means that stresses values are acceptable concerning the Rule requirements.

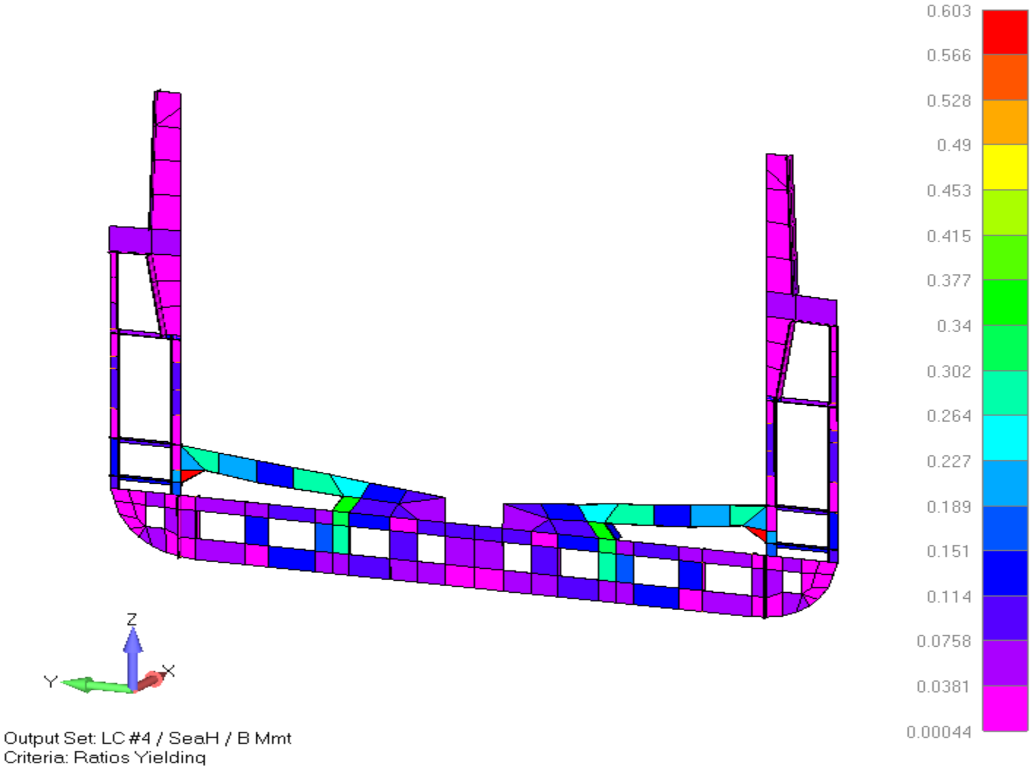

Figure 6 Stress ratios in the typical web frame (values above unity means that stresses are not acceptable)

The existing hatch covers become the structural part of the main deck by welding with hatch coamings. In sagging condition, the hatch covers show high values of buckling stress ratios, above permissible levels. The problem is solved by adding longitudinal stiffeners in critical regions. The buckling stress ratio in hatch covers is presented in Figure 7.

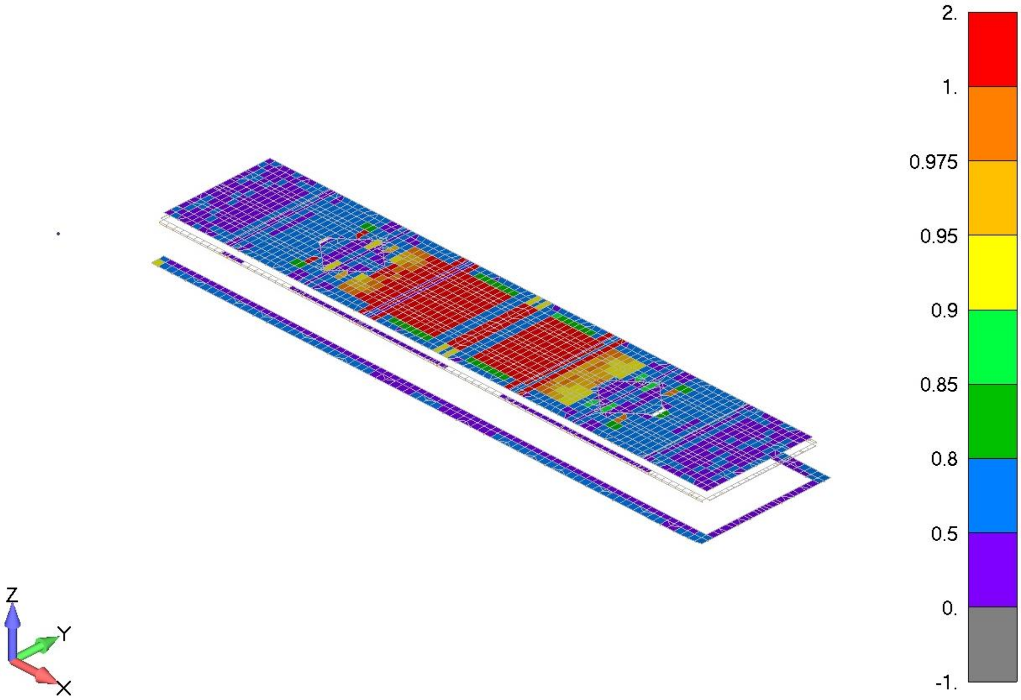

Figure 7 Buckling stress ratio in hatch cover plating (Stress ratio above unity means that compressive stresses are above acceptable level)

In heavy storms, the waves and ship motions can become so large that water flows onto the deck of a ship. This problem is generally known as “green water”. In extreme cases, green water loading can risk the ship, its crew, and its sensitive equipment. Therefore, it should be considered in the structural analysis [8]. A separate analysis was performed for hatch covers exposed to the green water loads, showing acceptable stress levels. The model deformation and resulting stresses for green water loading are shown in Figure 8.

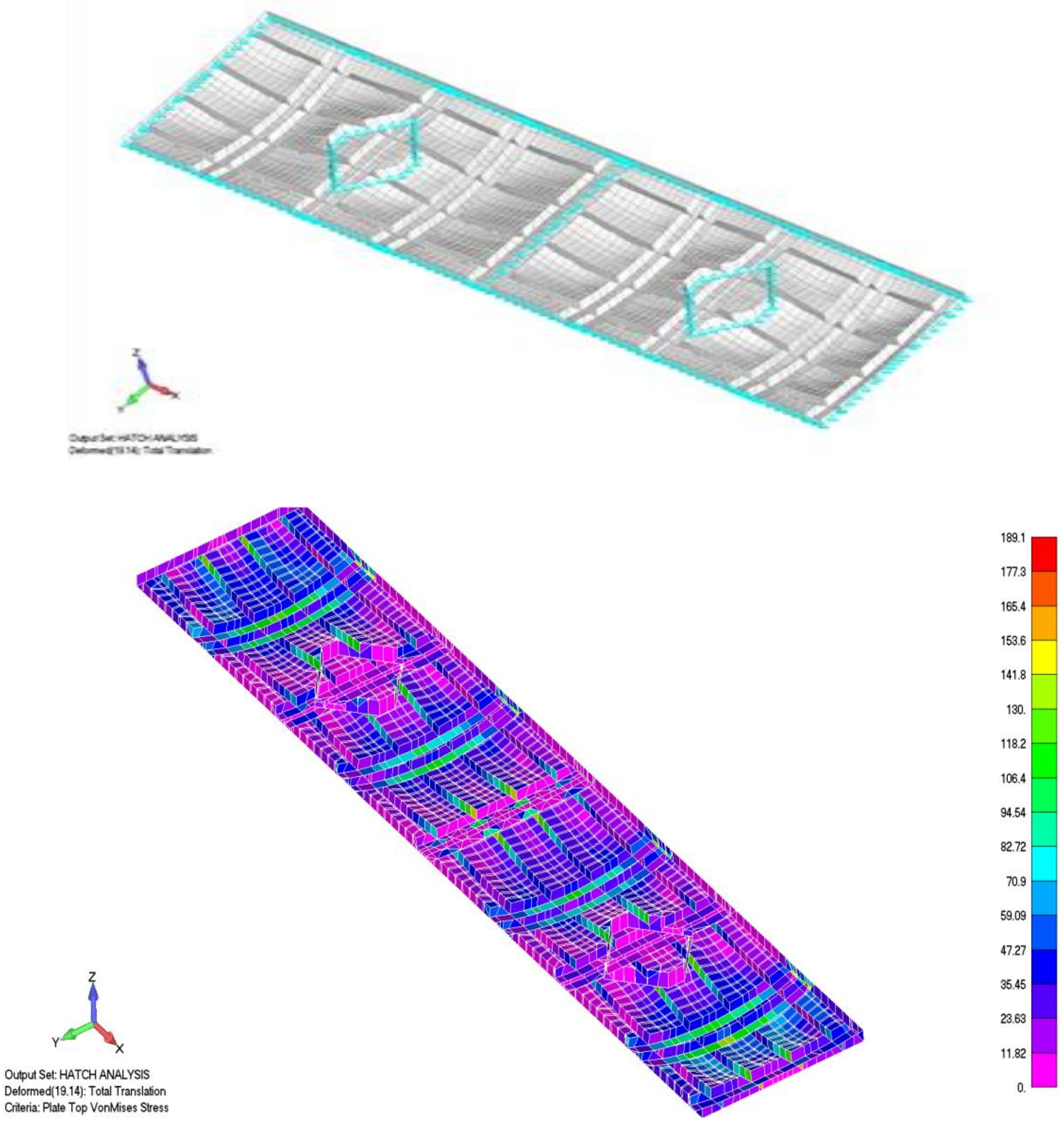

Figure 8 Hatch covers loaded by green water loads, boundary conditions and deformations (up); von Mises stress on deformed model (down)

As described in Section 3, new raised inner bottom (fluidising bed) is added to the existing structure before the conversion. As this is a new structure, it should be carefully analysed. Stress ratios in the plates of the fluidising bed are presented in Figure 9, showing that stresses are at an acceptable level.

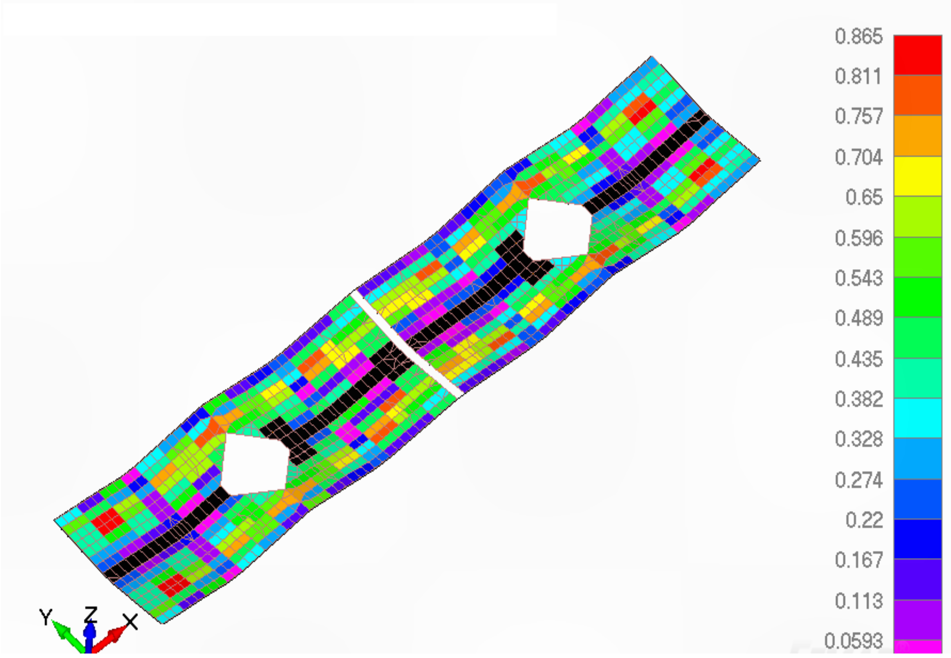

Figure 9 Stress ratios in the fluidising bed (new inner bottom structure)

5. Case study 2

General arrangement after major conversion of the second converted ship is shown in Figure 10, while main particulars of the ship are presented in Table 2.

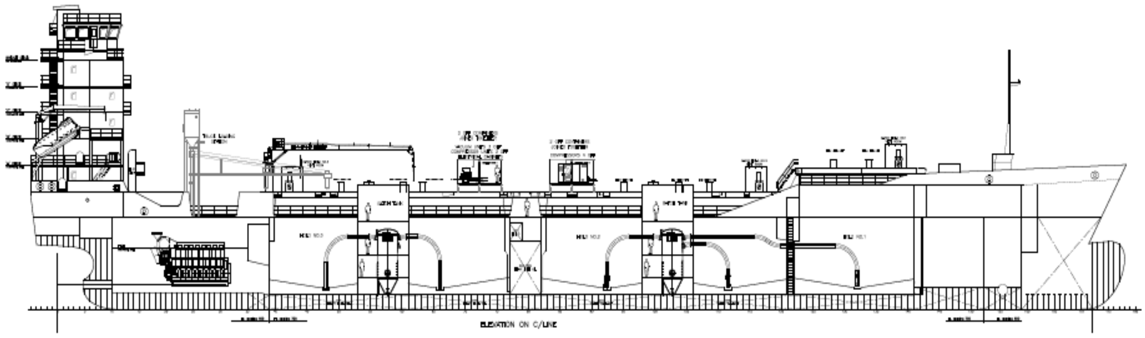

Figure 10 General arrangement of ship no.2 after major conversion

Table 2 The main characteristic of general cargo ship no.2 converted to a cement carrier

Length overall	L_{oa}	121.9 m
Breadth	B	19.2 m
Depth	D	9.1 m
Scantling Draught	T_{sc}	7.52 m
Deadweight	DWT	7650 tons

Grade A (mild steel) with Young’s modulus of 206 000 MPa, Poisson’s ratio of 0.3, the yield stress of 235 MPa and tensile strength of 450 MPa are used in most hull structural elements. Grade D32 (high tensile steel) with a yield stress of 315 MPa and tensile strength of 450 MPa is used in sheer strake and main deck plates and the lower part of hatch coamings. Steel grade AH36 (high tensile steel) with a yield stress of 355 MPa and tensile strength of 500 MPa is employed in the upper part of hatch coamings (60 mm thick plates).

Figure 11, taken after conversion of ship no.2, shows the existing hatch covers welded to the coamings and equipped with new cargo (cement) compression and blowers' units placed in the 40 feet specially designed containers.

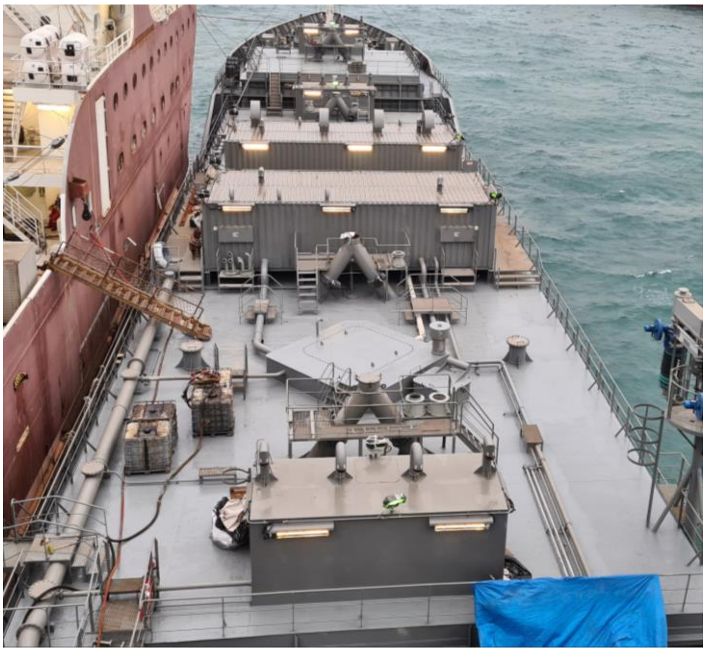

Figure 11 Ship no.2 new cargo (cement) compression and blowers' units placed in the 40 feet specially designed containers placed on the existing hatch covers that are welded to the hatch coamings

MARS 2000 model of the midship section and new added structural parts of ship no.2 are presented in Figure 12.

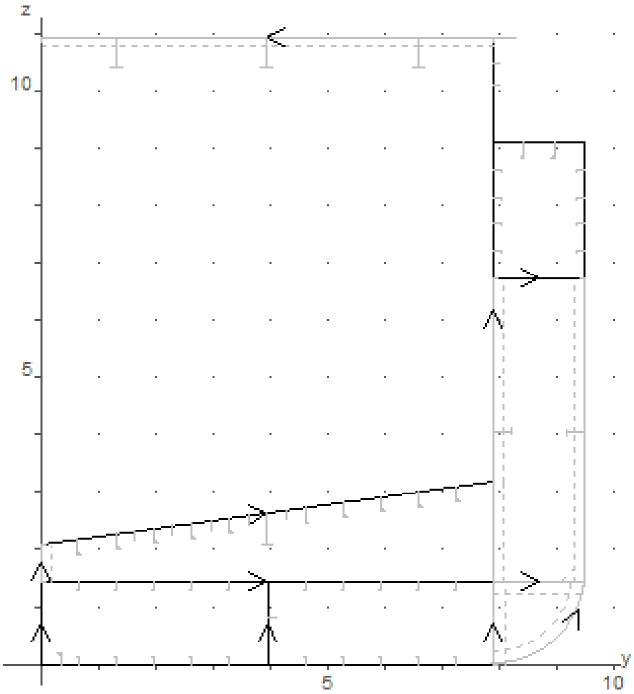

Figure 12 MARS 2000 model of the midship section of general cargo ship no.2 after major conversion to a cement carrier

The FE model has been made based on the submitted design documentation, and it is shown in Figure 13 and 14.

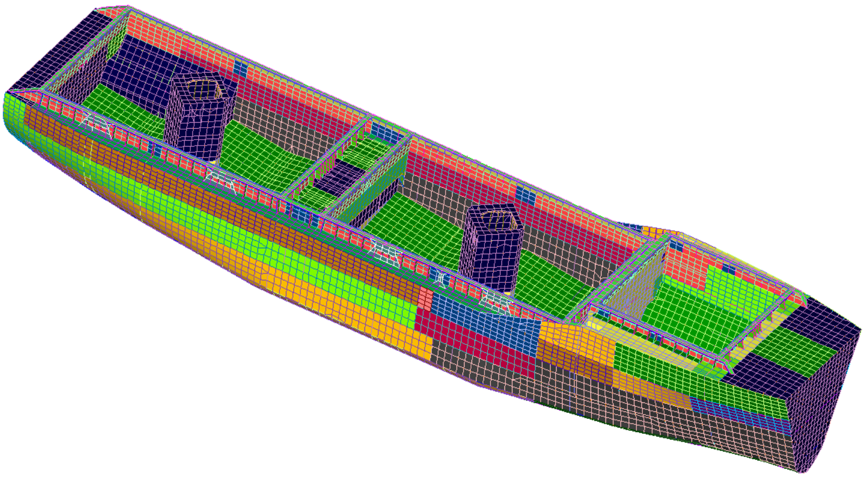

Figure 13 FE model of general cargo ship no.2 after major conversion to cement carrier (hatch cover omitted for the clarity of presentation)

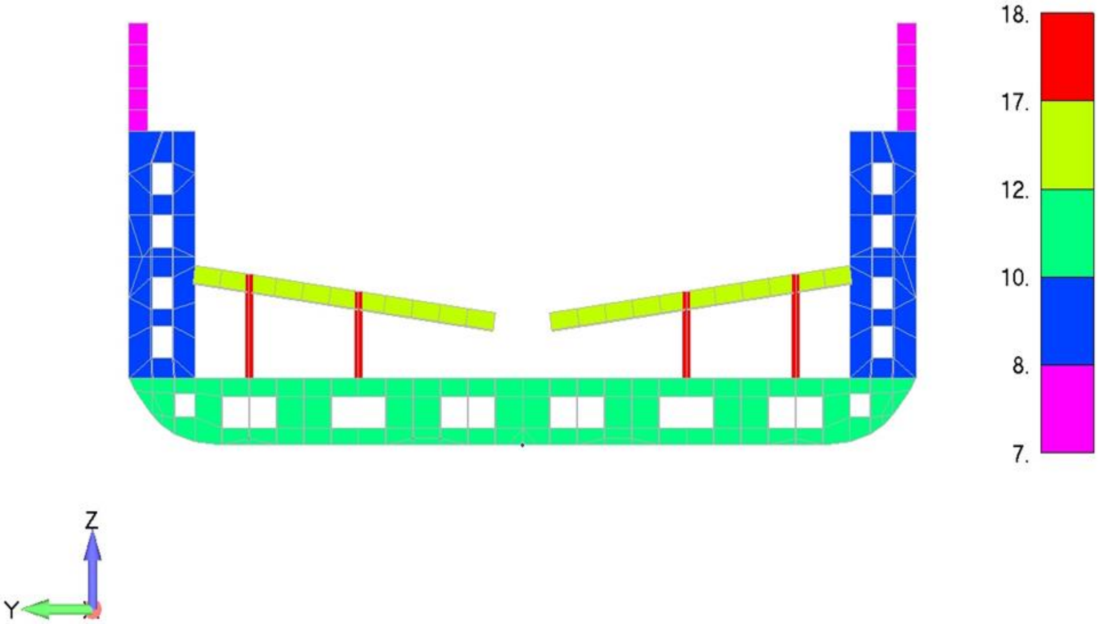

Figure 14 Web frame model thickness in the cargo hold of ship no. 2

Global hull-girder bending stresses in hogging condition are presented in Figure 15, showing acceptable values.

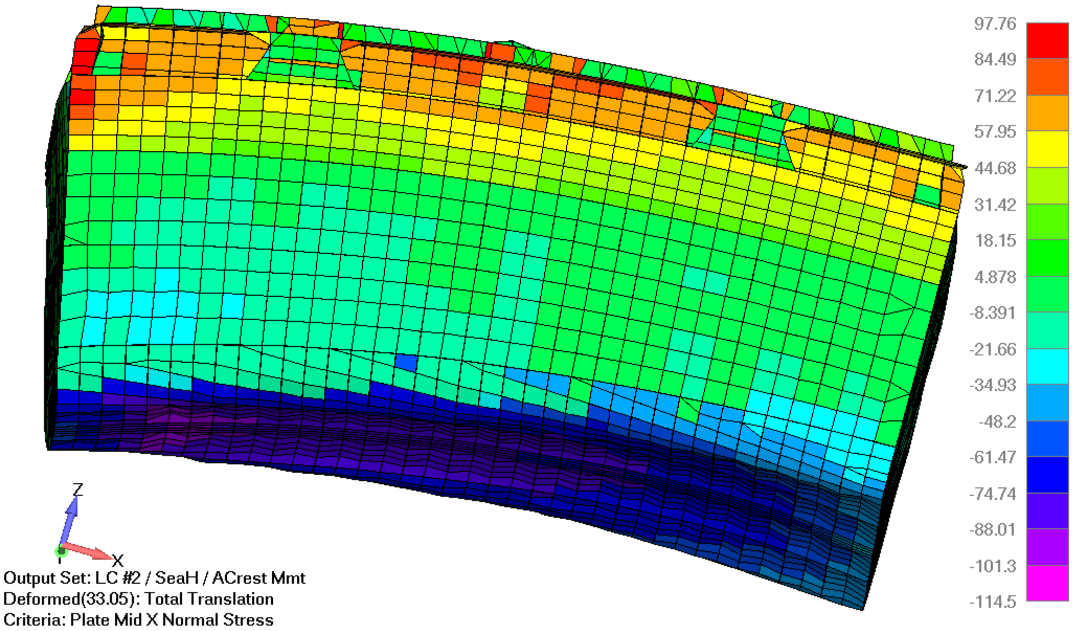

Figure 15 Von Mises stresses and model deformation in the hogging condition of ship no. 2

In the case of load conditions analysed, the maximum stress levels are regularly obtained in the new tank top area (fluidising bed) and the transverse floors and the ordinary vertical frames in the side ballast tanks of the existing hull structure. However, all stresses are below permissible values. The stress ratio on a typical web frame is shown in Figure 16.

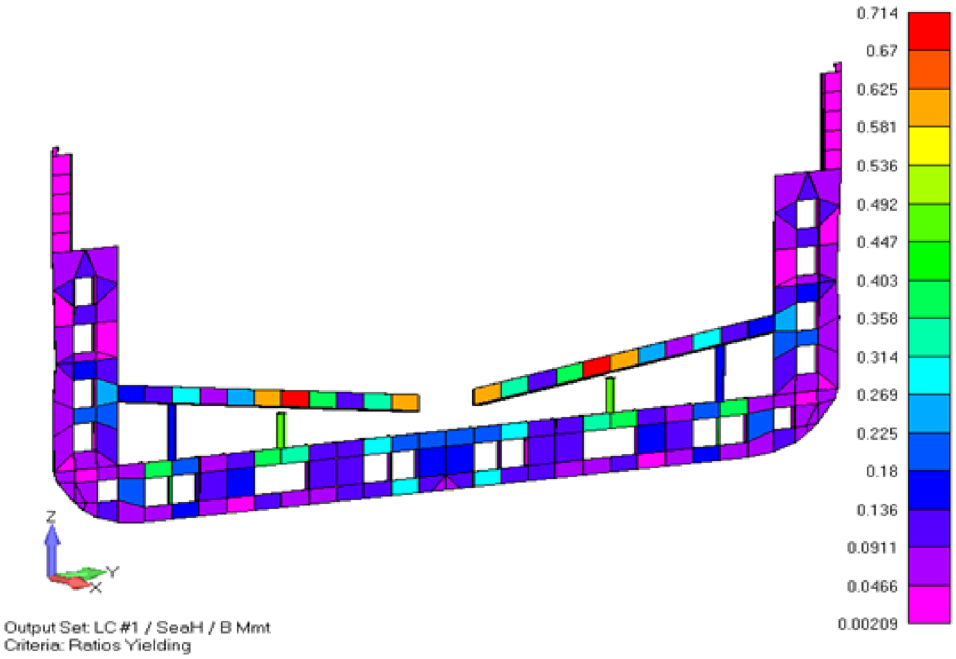

Figure 16 Stress ratios in typical web frame (values above unity would not be acceptable)

Total (static + dynamic) pressure loads on the fluidising bed (new double bottom structure) is shown in Figure 17.

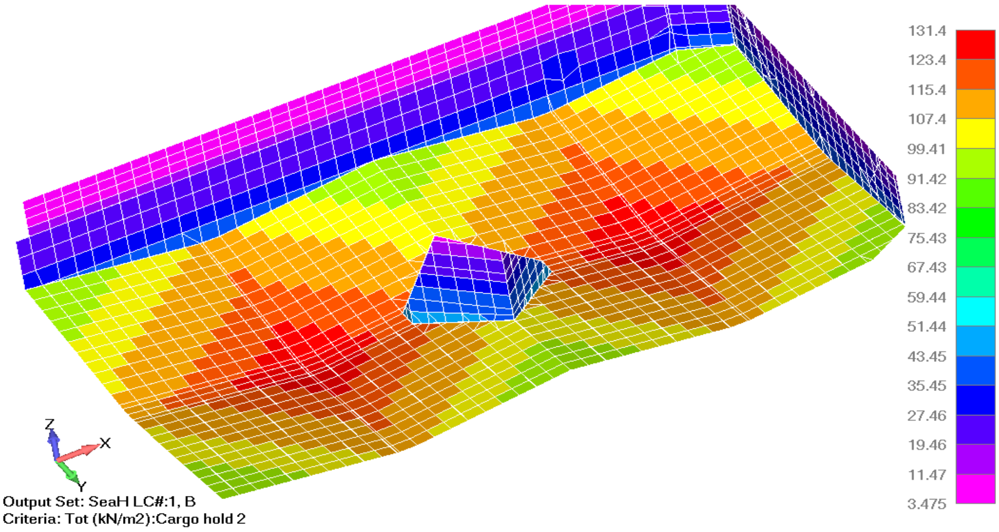

Figure 17 Static + dynamic cargo loads on the hold no.2 (fluidising bed) of ship no.2

The girder system of the new double bottom structure and the ship’s sides have been checked based on the pressure shown in Figure 17. As seen in Figure 18, allowable stresses regarding the Rules requirements are not exceeded.

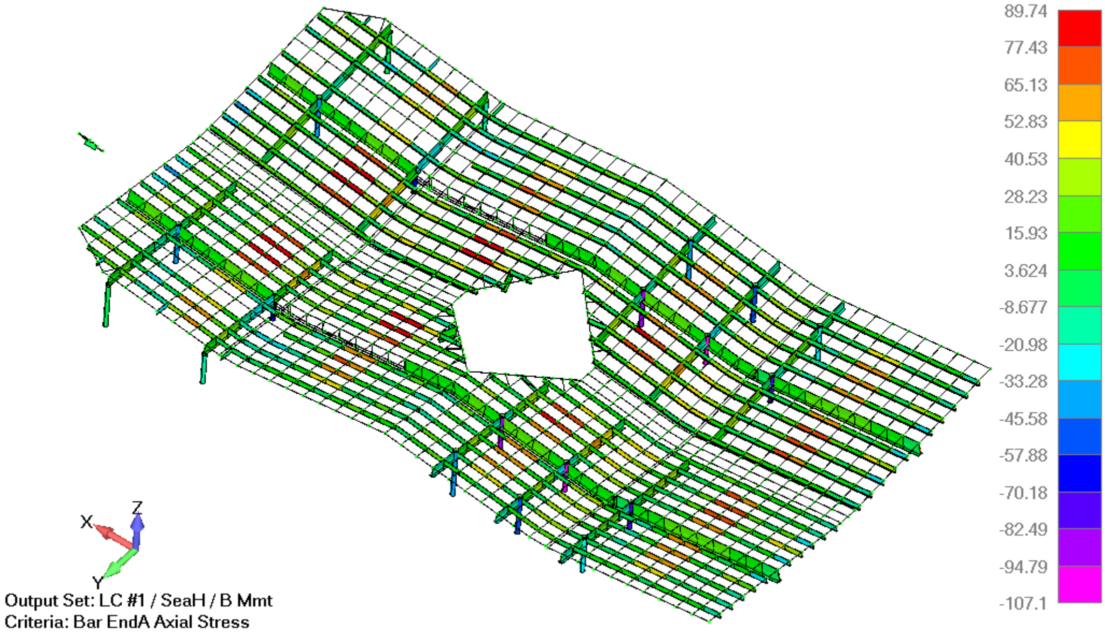

Figure 18 Axial stresses in bar elements of fluidising bed (new double bottom structure)

As the hatch covers after conversion become the structural part of the main deck, by welding to the hatch coamings (Figure 19), the stress ratio is above unity regarding plate buckling criteria. For that reason, longitudinal stiffeners are required to reduce the buckling span at hatch cover plating.

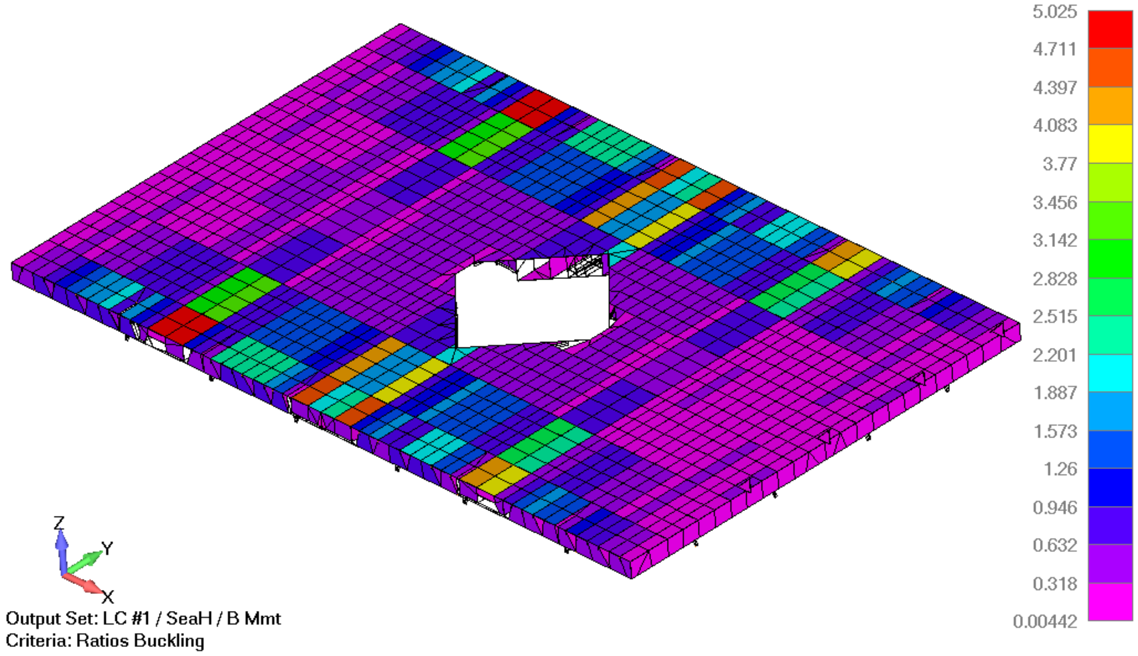

Figure 19 Buckling stress ratio of hatch covers welded to the hatch coaming before reinforcement (stress ratio above 1 are unacceptable)

6. Other issues of importance for the ship's service

During the major conversion of a ship, special attention is paid to the condition and possible changes in the ship's water ballast piping system and its accompanying hydraulic valves [11]. The problems generated by inappropriate ballast water operations - for example, leakage through the hydraulic valves of some ballast water tanks and consequently ballast water shifting between the tanks - easily endangers the overall stability of the vessel, even in not so severe sea conditions.

Though the case study ships no. 1 and 2 are not obliged by the rules to have a loading instrument installed, regarding their lengths and ship type, the ability for easy on-board assessment of longitudinal strength and stability characteristics of the service load conditions is recommended, taking into consideration ship's age. That is especially valid in the case of a damaged ship condition. After the possible damage scenario with seawater ingress, it can be easily and quickly ascertained by such certified on-board instrument that at specified read-out points, the still water bending moments and shear forces, in any load or ballast condition not exceed the specified permissible values. The results of such calculation also include the assessment of residual stability and floating characteristics of the damaged ship.

The installation of the loading (and stability) instrument is also found to greatly enhance the ability of the Master to successfully plan and control the demanding process of loading/unloading of cargo at the terminal while simultaneously managing the amount of water ballast to keep the ship in the allowable range of trim and list values. The required stability and strength parameters should be maintained in all situations.

Finally, it is to be noted the specific stability condition imposed by the loading of cement cargo, especially if pneumatic transportation of aerated cement is used: the free surface of such cargo exhibits the characteristics similar to that of liquified cargo, resulting in great danger of creation of significant shifting moments in holds. Consequently, the ship shall not depart until the cement cargo has been settled enough and de-aerated through the ventilation ports. Cement settling in holds shall be controlled before departure by the Chief Officer and recorded. Only upon completing settlement and ascertaining the ship's upright position can the ship sail to sea. This requirement is prescribed by IMO (International Maritime Organization) resolutions to avoid a cement cargo shifting during the voyage on the rough sea [15].

7. Conclusion

Under the major conversion to cement carriers, the strength assessment of two general cargo ships has been analysed in the present study. The analysis consists of two parts: firstly, MARS 2000 analysis of longitudinal and local strength, and then FE analysis of primary supporting members [11]. Structural models required for the analysis are generated according to the available hull drawings and thickness measurement reports provided by the owner.

The behaviour of the ship's structure in terms of stress level and other safety criteria has been found satisfactory in all considered load cases. Distributions of stresses obtained for selected load conditions in all cases have satisfied Croatian Register of Shipping rule requirements, indicating an appropriate and redundant ship structure. The obtained results show that the ships can be exploited with the intended loading conditions. However, due to safety reasons and bearing in mind ship age, control of the corrosion wastage on the critical structural areas ("hot spots") using non-destructive techniques and close-up surveys will be performed during the periodical hull annual special inspections.

Acknowledgements

The authors would like to acknowledge the assistance of Ratko Parunov and Rafael Kopčić-Rogoz from Centre of Technology Transfer ltd. in creating FE models. The Croatian Science Foundation has supported prof. Joško Parunov under the project lP-2019-04-2085.

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Submitted: 14.04.2021.
Accepted: 14.06.2021.

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