Hull strength assessment of the designed ships

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ABSTRACT

The paper presents the method and scope of analysis of the hull strength of four ships designed in the Eureka project. Criteria of the Det Norske Veritas rules for classification and construction of ships were used in the analysis. Specific features of the structure of each hull have been described and the resulting problems connected with ensuring adequate strength.

Keywords : hull strength, FEM calculations

INTRODUCTION

The strength analysis was performed
for the following four ships :

- product tanker (length overall L_{OA} = 138.10 m, breadth B = 22.50 m, depth D = 12.80 m, draught T = 8.70 m)
- ro-ro ship (L_{OA} = 156.72 m, B = 24.80 m, D = 19.60 m, T = 6.50 m)
- „river-sea" ship (L_{OA} = 89.45 m, B = 11.40 m, D = 5.45 m, T = 4.40 m – at sea, T = 2.80m – in river)
- container carrier (L_{OA} = 138.10 m, B = 22.50 m, D = 11.20 m, T = 8.55 m).

The design requirement of those ships was their ecological cleanness, i.e. a CLEAN DESIGN symbol given in the Det Norske Veritas class description [1].

The ecological cleanness of a ship is first of all connected with its installations and equipment. It does not impose any specific requirements on the internal subdivision or structure of the hull. A sufficient precaution is the use of classic solutions, i.e. double bottom and double side in the case of a product tanker. However, double bottom and double side have been used in all the designed ships as they are classic solutions for those ship types. They protect the sea against pollution in the emergency situations, e.g. grounding, collision with another ship etc. The ecological cleanness feature does not mean, however, that the hull strength standards have to be raised.

The structure strength assessment was performed
in accordance with the rule requirements [1, 2, 5].

The following structure strength levels had to be checked :

- overall strength
- zone strength
- local strength.

Additionally, the criteria of total normal stresses in the longitudinal girders and in longitudinal stiffeners of side shell, decks etc. from the general, zone and local bending have to be fulfilled.

The overall strength involves the longitudinal bending of the hull in the vertical plane. In the case of ships with wide hatch openings, also torsion and bending in the horizontal plane should be analysed. The calculations are relatively simple as the rules require a bent beam model to be used in the analysis of bending in the vertical or horizontal plane. In the torsion analysis, the use of constrained torsion theory of thin-walled bars is admissible. However, it is recommended to use a shell-bar FEM (Finite Element Method) model of the whole hull and then the calculations are time-consuming.

The zone strength involves bending of the hull girder system. Calculations are often time-consuming as in general it is required to use a shell-bar FEM model. The rules [2] generally allow to use also simpler models – space frames, grids, flat frames, continuous beams. Such calculations are still relatively time-consuming.

The simplest are local strength calculations. The respective formulae for plate thickness or stiffener section modulus are given in the rules.

In the above mentioned analyses the stress level is checked, by the permissible stress criterion. The structure should also fulfil the criteria given in the rules [1] for the structure element stability and fatigue life.

Specific hull strength problems of individual ships
are described below.

PRODUCT TANKER

The most labour consuming problem of the hull strength
assessment was the zone strength analysis.

The cargo section of the hull is divided with transverse bulkheads into 6 compartments. Compartments no.2 to 6 (counting from the bow) are additionally divided with a longitudinal bulkhead in the hull plane of symmetry.

An FEM model in the form of space frame was created comprising a hull fragment of the length of ½ + 1 + ½ cargo compartment (Fig.1). The possibility of asymmetric liquid cargo distribution made it necessary to develop a full hull breadth FEM model.

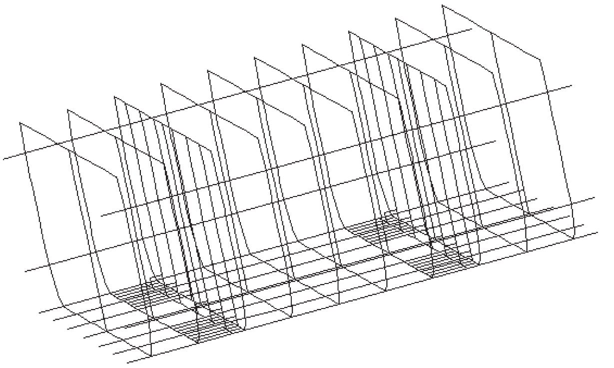

Fig. 1. *FEM model of a product tanker hull module frame*

Calculations revealed a high level of the reduced stresses in floors and transverse web frames coming from shear in the area of lightening and communication holes. It was necessary to correct the original version of the structure. The holes were made smaller and thicker plates were used. Also the original transverse corrugated bulkheads appeared not strong enough. They had to be made thicker.

Difficulties were met with ensuring local strength in the specific product tanker conditions of dynamic loads in partially filled tanks (sloshing). The problem was connected with the deck structure and upper parts of bulkheads in the first fore cargo tank. It was necessary to correct the original plate thicknesses and stiffener sizes as well as the main girders in that region.

A characteristic feature is that the elements of a product tanker hull structure (total length of 138.1 m) with double ship side shell and double bottom, without hatch openings in the deck, dimensioned according to the local and zone strength criteria, ensure automatic fulfilment of the general longitudinal bending criteria.

RO-RO SHIP

Characteristic solutions of the ship are the following :

- three loading levels (inner bottom, main deck, upper deck with the loading ramp hatch openings)
- no transverse bulkheads in the cargo section of the hull
- double bottom, double side from bottom to main deck and single side above.

Assessment of the zone strength of such structure was performed by means of simple FEM models in the form of flat frames and grids loaded with the container or trailer weight. Additionally a shell FEM model was created of a typical web frame (Fig.2) in order to verify the structure correctness in the bottom and side joint region with communication openings.

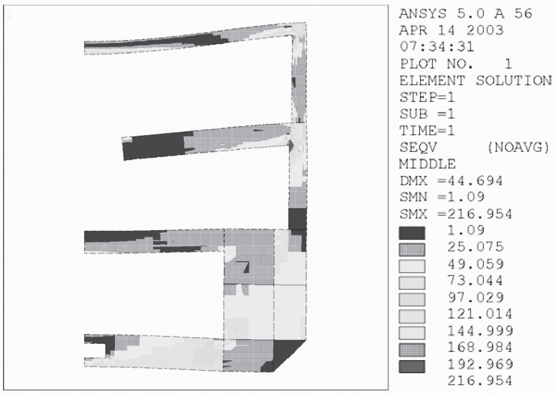

Fig. 2. *Transverse web frame shell FEM model*

Calculations indicated the necessity of strengthening that structure region in relation to the original version. Also the upper deck web beams in the side region appeared too weak. Their section modulus had to be increased.

In the case of a ro-ro ship, the deck shell and stiffener dimensioning load is that of the vehicle wheel load. The use of 80 t and 60 t roll-trailers and 30.5 t carrying capacity container stackers was assumed. That gives relatively great wheel load values. Increase of the originally proposed cargo deck shell thickness and beam strength appeared necessary.

As in the case of the product tanker, the structure dimensioned according to the local and zone strength criteria automatically fulfilled the general overall strength criteria. Important is here the relatively large depth of the ship and lack of hatch openings in the middle part of the hull.

RIVER-SEA SHIP

This is the smallest
of the four designed ships (L_{oa} = 89.45 m).

Characteristic features of the hull are: wide hatch opening as long as 62 m over the only hold of the ship, strong double bottom adjusted to relatively large local loads from cargo, double ship side and high hatch coamings on the main (single) deck.

The structure dimensioning loads
are those during the operation at sea.

It is interesting that the overall strength problems occurred in the case of a small ship. Normal stresses in the upper fibres of hatch coamings reached, in the general bending conditions, values near the admissible level.

In the case of that ship type, important is the problem of hull torsion on a course oblique to sea waves. Torsion analysis was performed with the use of thin-walled bar constrained torsion theory [5]. Torsional displacements of the hull appeared small but stresses reached significant values.

The greatest normal torsional stresses occurred in the hatch rear end area, in the upper edge of hatch longitudinal coamings (75 MPa). Total normal stresses in that place, from torsion, hull bending in the vertical and horizontal plane and from deck strake bending in the horizontal plane (due to bottom and side loads) reached the admissible stress level, i.e. 195 MPa.

In the zone strength analysis, it was necessary to use a FEM model in the form of a space frame, containing main structural elements in the whole cargo part of the hull and across the whole breadth of the hull, in order to analyse e.g. the structure stresses in the conditions of ship heel with containers on deck (Fig.3).

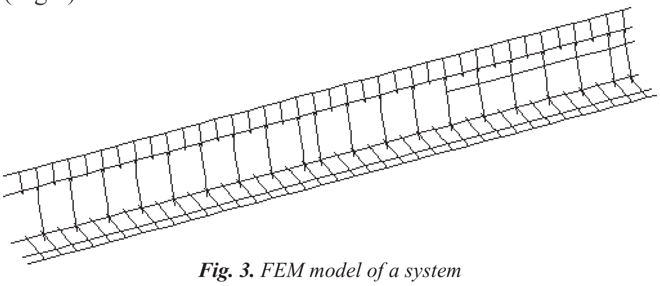

Fig. 3. *FEM model of a system of structure elements in the river-sea ship hold*

With the use of such computational model a relatively great deformability of the hull was demonstrated. Convergence of the ship sides in certain loading conditions was estimated at 65 mm, which may require special hatch covers to be used acting as hatchway beams.

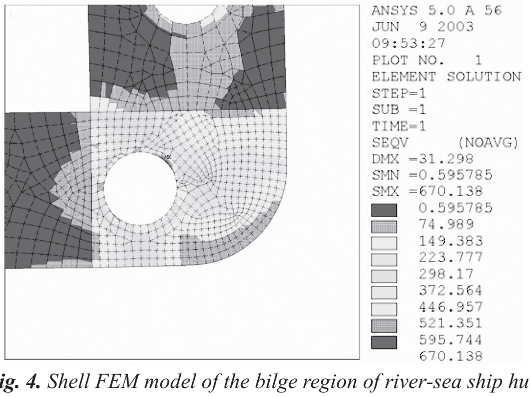

Fig. 4. *Shell FEM model of the bilge region of river-sea ship hull*

Computations showed also exceeded admissible stresses in the bilge region floors. Therefore, a more precise (shell) FEM model of that region was prepared (Fig.4). Calculations have shown that holes are inadmissible in that region.

Standard local strength calculations were also performed in the hull strength analysis. The design requirement that the ship should be able to transport iron ore, with its approximately 100 kPa static load on the inner bottom, resulted in a relatively massive structure of that hull fragment.

CONTAINER CARRIER

A characteristic feature of that ship hull
are wide hatch openings and narrow double sides.

There are 5 hatch openings in the deck, connected with batten plates. Such hull configuration causes the cross section neutral axis to be positioned much closer to the base plane than to the deck.

There were some problems with adequate general bending strength in the vertical plane. In the case of a small ship ($L_{oa} \approx \approx 140{,}0$ m), it appeared effective to provide high tensile steel (315 MPa yield point) girders in the middle part of the hull in the deck region.

The rules [1] require that torsion analysis be performed for ship hulls of the above mentioned characteristics. The calculations were carried out with a twisted bar model. Bending of a frame created by the side deck strakes and the batten plates (webs of the frame beams) was taken into account. The beam flanges are hatch coamings together with the internal and external side fragments or transverse bulkheads below deck. The calculations were performed in accordance with the procedure required in [6].

Normal stresses from bending of the deck strakes due to deformation of the above mentioned frame (hull cross section torsional deplanation) reached the 30 MPa level. This is a significant value.

The total normal stresses from hull bending in the vertical and horizontal plane, torsion (due to constrainment of the deplanation), deck bending (as described above) and deck bending from sea water pressure on ship sides, reached a 231.5 MPa level, which is as much as 95% of the admissible value. Those stresses occurred on the top of the no. 5 hatch rear end coaming.

Container carrier torsion is therefore
a significant problem, even in the case of a small ship.

The zone strength analysis was performed with a space frame model of the structural elements of halves of two adjacent holds (Fig.5).

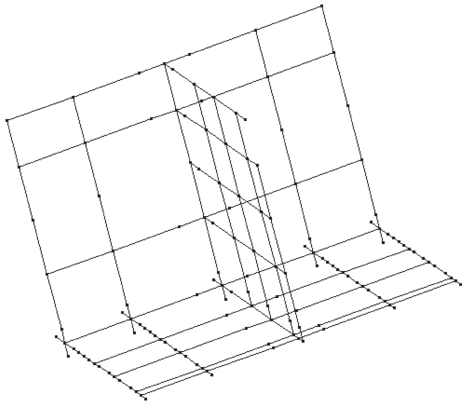

Fig. 5. *FEM model of the container carrier structure elements*

Also an FEM shell model of a single web frame was developed (Fig.6) in order to check the stress level in the web communication opening areas.

Standard local strength calculations were carried out in the same way as for the other ships. In the case of container carrier, it was necessary to check the strength of the bow section bottom structure subjected to slamming loads. This is connected with the relatively high service speed of those ships.

The calculations showed that the bottom plating
in the original version of the ship design was too thin.

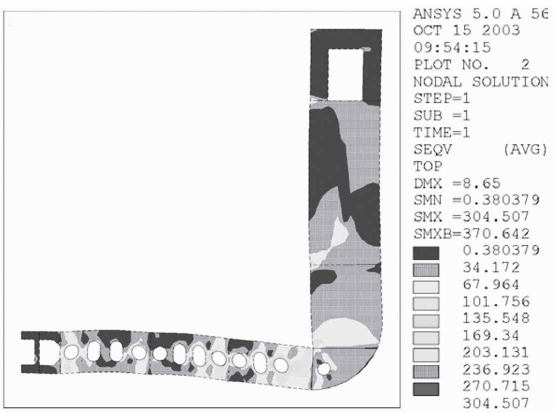

Fig. 6. *FEM shell model of a container carrier frame*

FINAL REMARKS AND CONCLUSIONS

- Four different ships have been designed in the EUREKA project. They are intended for different service and therefore their hulls are subject to specific loads.
- In the case of a product tanker, this is the sloshing pressure having a significant impact on the shell plate thickness as well as on the size of stiffeners and structural elements of ship sides, bulkheads and deck, particularly in the fore part of the ship.
- In the case of a ro-ro ship, characteristic are the vehicle wheel loads on decks.
- In the case of a relatively small river-sea ship, problems occurred with providing adequate general strength in the bending and torsion condition, with bottom strength under considerable local loads from cargo, and with the hull stiffness.
- The container carrier hull is significantly strained in the overall bending and torsion condition. In this case, the use of high tensile steel for girders in the upper part of the hull appeared effective.
- A common feature of all the hulls is double bottom and double sides – at least below the main deck.
- The ship hull design process proceeded in a rational way. The preliminary scantlings proposed by the designers were corrected „upwards" as a result of the performed strength analyses.

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