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Strengthening the bulk carriers corrugated bulkheads by fitting shedder or gusset and shedder plates

SUMMARY

Effectiveness of strengthening the bulkheads by fitting shedder or gusset and shedder plates is considered in the paper in connection with the new IACS unified requirement concerning the strength of the foremost corrugated bulkheads of existing bulk carriers in flooding conditions. The requirement will compel shipowners to strengthen bulkheads in many ships.

The considerations are illustrated by results of the finite element method (FEM) calculation of stresses in bulkhead corrugations under lateral load in flooding conditions.

INTRODUCTION

At the end of 1980's the number of bulk carriers which sank each year increased rapidly. Over 100 bulk carriers sank and 600 lives were lost during the period 1990 ÷ 1995 [1].

Typical scenarios of bulk carriers sinkage are reported in [2]. The catastrophe begins with a failure of the side structure or hatch cover. Then the collapse occurs of the corrugated bulkheads loaded by cargo and the water which flooded a hold. Progressive flooding of subsequent holds leads to ship's sinking. So, the bulkheads form a secondary safety barrier in bulk carriers. If they had been strong enough many lost bulk carriers might have survived the flooding.

The catastrophes forced the International Maritime Organization (IMO) to increase safety standards for not only to-be-built but also existing bulk carriers. SOLAS 74 was amended by the new Chapter XII containing the requirements of the stability and strength in flooding conditions of the double bottom and corrugated bulkheads of the single-side-skin bulk carriers with length $L \geq 150$ m, carrying bulk cargoes with density of 1.78 t/m^3 or above. It is directly stated in Annex 2 to [3] that the bulk carriers of single-side-skin construction should comply with IACS Unified Requirements, and in Annex 3 to [3] that the requirements are the basis of the SOLAS amendments. The newly prepared IACS requirement [4] which concerns the strength of corrugated bulkheads between holds Nos 1 and 2 of existing bulk carriers is discussed in this paper.

RETROACTIVE IACS REQUIREMENTS FOR CORRUGATED BULKHEADS OF BULK CARRIERS

The requirement [4] will be applied to single-side-skin bulk carriers of 150 m in length and above, intended for the carriage of solid bulk cargoes having bulk density of 1.78 t/m^3 or more. The requirement should be complied with in accordance with the following time schedule :

- for ships which will be less than 15 years of age on 1 July 1998, by the due date of the third special survey, at the latest
- for ships which will be 15 years of age or more but less than 20 years of age on 1 July 1998, by the due date of the first special survey, to be held after 1 July 1998, but not later than 1 July 2002
- for ships which will be 20 years of age or more on 1 July 1998, by the first intermediate or special survey to be held after 1 July 1998, whichever comes first.

The design loads acting on the foremost corrugated bulkhead in flooding conditions and strength criteria are defined in [4]. The criteria concern the following 3 items:

- local bending of the plating of corrugations
- shear and buckling of the corrugation webs
- overall bending of the corrugations.

The third criterion discussed below is the most important because it is not fulfilled, in the first place, by the bulkheads of existing bulk carriers.

The load acting on a bulkhead in flooding conditions is composed of the hydrostatic water pressure and cargo pressure (at the lower part of the bulkhead), shown in Fig.1 :

$$p = \rho g h_f + [\rho_c - \rho(1 - perm)] g h_1 tg^2\gamma \qquad (1)$$

where :

ρ - water density
g - gravity acceleration
h_f - flooding head (the distance from the point considered to the free surface of flooding water)
ρ_c - bulk cargo density
perm - permeability of cargo (nondimensional coefficient which is the measure of void spaces between the cargo particles)
h_1 - the distance from the point considered to the upper surface of the volume occupied by the cargo
γ - angle $45^0 - \frac{\varphi}{2}$
φ - angle of cargo repose.

Formula (1) is valid in the case where the free surface of water is above the upper surface of the cargo for points on the bulkhead below the surface of cargo. The formula for p for other relations between h_f and h_l and for different positions of the point considered can be easily obtained by modifying (1).

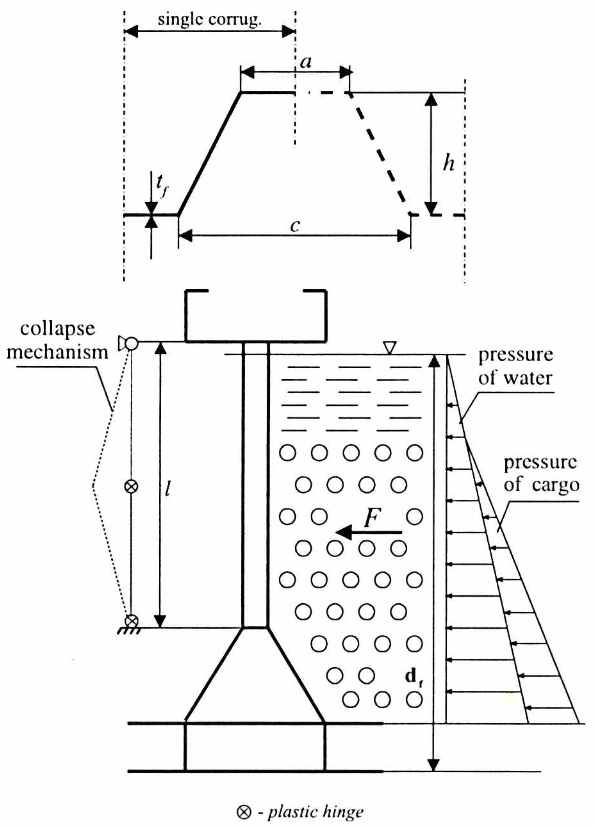

Fig.1. Load of the bulkhead and collapse mode

The height of flooding d_f (Fig.1) which takes the value of (0.95÷1.0) D, depending on size of the ship, roughly takes into account dynamic components of the load caused by the ship's motions on waves. D means the hull depth at the midship.

While creating [4], nonlinear FEM calculations of corrugations response to gradually increasing transverse load (Fig.1) till collapse of the corrugations, were performed.

During corrugation collapse process the following characteristic phenomena were observed :

* excessive yielding and buckling of the compressed corrugation flange at the corrugation lower end occurs at some value of increasing transverse load on the bulkhead
* further increase of the load causes the plastic hinge to occur at the lower end of corrugation and redistribution of internal bending moment in the corrugation takes place
* if the load still increases the plastic hinge in the middle part of the corrugation is formed and soon after that collapse of the corrugation is observed.

On this basis IACS formulated the criterion for overall bending of the corrugation in the following form, [4] :

$$\frac{\frac{1}{8}Fl}{\sigma_F\left(0.5Z_l + Z_m\right)} \leq 1.0 \qquad (2)$$

where :

F - resultant transverse force acting on the single corrugation (equivalent to pressures of cargo and water-see Fig.1)
l - span of the corrugation (see Fig.1)
σ_F - yield stress of the steel used for the corrugation
Z_l - section modulus at the lower end of corrugation (in elastic range)
Z_m - section modulus at the mid-span of corrugation.

The criterion (2) is based on the ultimate strength of corrugations. The collapse mode of two plastic hinges was assumed (Fig.1).

The effective width concept is applied when calculating Z_l and Z_m to take into account that compressed flanges of corrugations are not fully effective at the collapse. The width „a" of the compressed flange is reduced by multiplying it by the following coefficient :

$$C_e = \frac{2.25}{\beta} - \frac{1.25}{\beta^2} \qquad (3)$$

where:

$\beta = \frac{a}{t_f}\sqrt{\frac{\sigma_F}{E}}$ - plate slenderness parameter (a - see Fig.1)
t_f - net flange thickness (see Fig.1)
E - modulus of elasticity of the material.

An additional safety margin is introduced by applying the elastic section moduli Z_l and Z_m in (2) instead of the plastic ones.

IACS assessed the consequences of retroactive applying [4] to existing bulk carriers, by checking the strength of corrugated bulkheads of 117 selected at random bulk carriers which were 1÷25 years old [5].

By applying the as-built scantlings of corrugations to the requirements of [4], it was obtained that the foremost bulkheads of 60% of ships loaded alternately (cargo in every second hold) and 39% of ships loaded homogeneously were too weak. The percentage is equal to 76% and 68%, respectively, if 2 mm corrosion diminution of corrugations and 1 mm of corrosion addition, required by [4], is assumed. In consequence many existing bulk carriers will have to be strengthened after 1 July 1998 according to the time schedule mentioned earlier. The most effective way of strengthening is applying the effective shedder plates or gusset and shedder plates at the lower ends of corrugations (Fig.2).

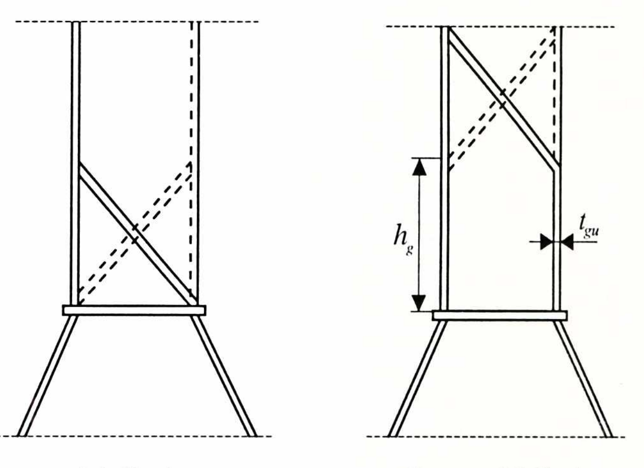

Fig.2. Shedder plates and gusset and shedder plates

„Effective" means in this case that:

- shedder plates are not knuckled, they are fitted with the minimum slope of 45^0, their lower edges are in line with the stool side plating and they are welded by one-side penetration welds or equivalent
- gusset plates are fitted in line with the stool side plating, their material properties are at least equal to those provided for the corrugation flanges and are welded by one-side penetration welds or equivalent.

Applying the shedder or gusset and shedder plates allows, according to [4], to increase the value of Z_l applied in (2). This permits, in almost all cases of corrugated bulkheads of existing bulk carriers, to fulfil the criterion of corrugation bending (2).

If the effective shedder plates are fitted, the cross-section area of corrugation flanges may formally be increased, while calculating Z_l, by the following value :

$$\Delta A_f = 0.25a\sqrt{t_f \cdot t_{sh}}\sqrt{\frac{\sigma_{Fsh}}{\sigma_{Ffl}}} \tag{4}$$

where :

- a - width of the corrugation flange (see Fig.1)
- t_f - flange thickness
- t_{sh} - shedder plate thickness
- σ_{Fsh} - minimum upper yield stress of the material used for the shedder plates
- σ_{Ffl} - as above, for the corrugation flanges.

Formula (4) shows that fitting the effective shedder plates, where $t_{sh} = t_f$, $\sigma_{Fsh} = \sigma_{Ffl}$, increases the value of Z_l by at least 20% because the webs of trapezoidal corrugations are only 30% effective [4] if they are not supported by local brackets below the stool top or the inner bottom.

If the effective gusset and shedder plates are fitted the cross-section area of corrugation flanges may be increased, while calculating Z_l, by the following value :

$$\Delta A_f = 0.7h_g t_{gu} \tag{5}$$

where: h_g and t_{gu} - height and thickness of the gusset plates, respectively (see Fig.2).

A_f must not be taken greater than $s_{gu} t_{gu}$, where: s_{gu} - width of the gusset plate.

It can be seen from (5) that fitting the gusset plates is a very effective way to increase the value of Z_l.

STRESSES IN CORRUGATED BULKHEADS IN FLOODING CONDITIONS

Results of calculations for a typical corrugated bulkhead are given below to illustrate the positive effect of gusset and shedder plates on stress values in corrugation flanges.

FEM stress calculations for two halves of adjacent holds of a panamax bulk carrier model were performed. The calculations were based on a linear elastic model of the structure. The coarse-mesh FEM model shown in Fig.3 and alternate loading of the ship was assumed. The hold filled with cargo was additionally flooded while the adjacent hold was empty. The static pressures from the cargo and flooding water were calculated according to [4]. The external hydrostatic water pressures were assumed adequate to ship design draught.

Dimensions of the bulkhead corrugations were as follows (see Fig.1) :

- a = 900 mm
- c = 1760 mm
- h = 800 mm
- t_f = 13 mm

- the length of the corrugated part of the bulkhead located on the lower stool of 3.2 m height is equal to 9.6 m.

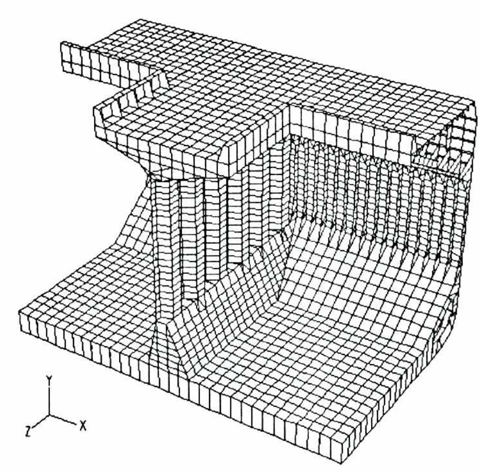

Fig.3. Coarse-mesh FEM model of the hull module

MAESTRO computer program was applied to the calculations based on the coarse-mesh FEM model.

The calculated values of displacements of the floors below the lower stool and displacements of the upper end of corrugations, at plane of symmetry of the hull, were then applied to the fine-mesh models of a single corrugation shown in Fig.4.

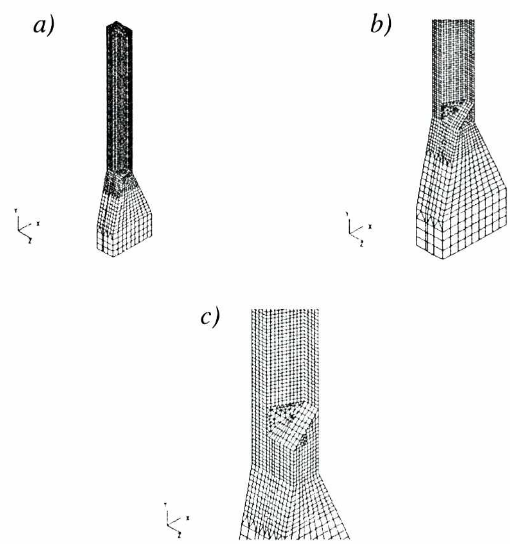

Fig.4. Fine-mesh FEM models of a single corrugation

The fine-mesh models represent the single corrugation of the bulkhead together with a part of the lower stool and double bottom.

Symmetry conditions were assumed along the vertical edges of the models. The pressure values calculated according to (1) were applied to the fine-mesh models. Three fine-mesh models (Fig.4) were considered to illustrate the effect of shedder or gusset plates on membrane stresses in the lower part of corrugation flanges due to overall corrugation bending. Gusset and shedder plates with the same thickness as that of the corrugations, and the height of the gusset plate h_g = 1000 mm were assumed.

An insignificant effect of the gusset and shedder plates on displacements of the double bottom and deck structure was neglected. The displacement values calculated from the coarse-mesh model shown in Fig.3, were applied as the boundary conditions at the bottom and deck levels to all three fine-mesh models shown in Fig.4. VAST computer program was applied to calculate the fine-mesh models.

The distribution along the corrugation of the mean membrane stress values in the corrugation flange is shown in Fig.5.

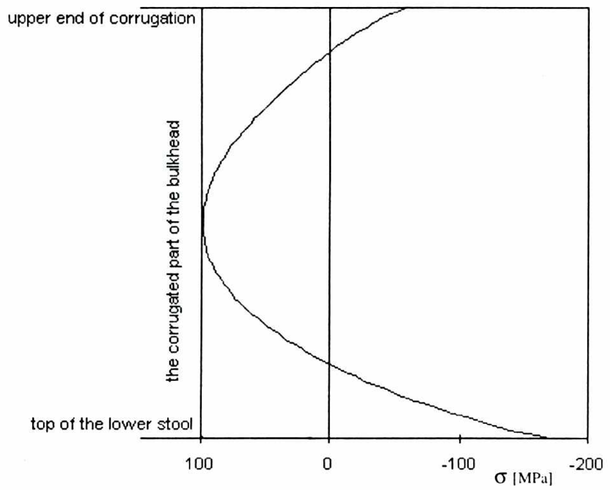

Fig.5. Mean membrane stress values of the corrugation flange

The membrane stresses σ in the flange, gusset and shedder plates, calculated in the rows of finite elements just above the lower bulkhead stool, are shown in Fig.6. The results presented in Fig.6 relate to the tension flange and shedder/gusset plates whose lower edges are at the plane of the flange.

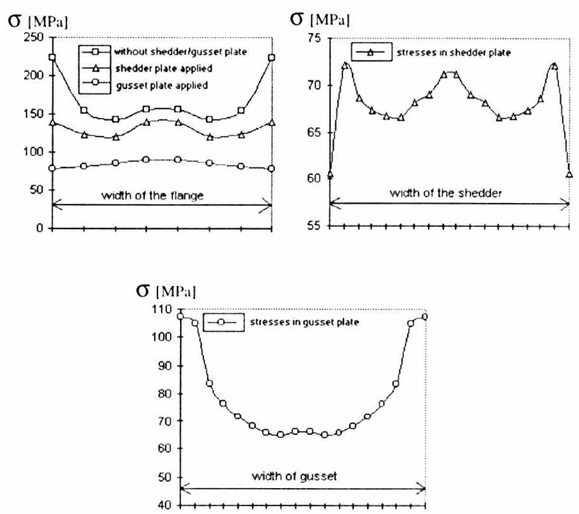

Fig.6. Membrane stresses of the flange, gusset and shedder plates just above the lower stool

Mean membrane stress values in the flange, gusset and shedder plates due to bending the bulkhead by lateral load, at the same cross-section as in the case shown in Fig.6, are given in Tab.1.

Tab.1. Values of the membrane stresses just above the lower stool, [MPa]

σ_f	σ_{fs}	σ_{fg}	σ_s	σ_g
169.6	132.3	82.9	55.9	77.9

where :

σ_f - mean stress in the flange for the fine-mesh model shown in Fig.4a

σ_{fs} - as above, for the model shown in Fig.4b

σ_{fg} - as above, for the model shown in Fig.4c

σ_s - mean stress in the shedder plate shown in Fig.4b (the membrane stress in the direction normal to the horizontal edge of the lower bulkhead stool)

σ_g - mean stress in the gusset plate shown in Fig.4c (in the vertical direction).

The calculation results given in Tab.2 make it possible to roughly compare the actual strengthening effect of the gusset and shedder plates on the considered bulkhead with that achieved by applying the simplified method of [4].

Tab.2. Comparison of the stress values calculated by using FEM and the simplified requirements [4]

σ_{fs}/σ_f	σ_{fg}/σ_f	W/W_s	W/W_g
0.78	0.49	0.78	0.53

where :

W - section modulus of the lower end of a single corrugation (corresponds to the case shown in Fig.4a) calculated according to [4] assuming 30% effectiveness of the corrugation web and effective breadth of the compresed flange according to (3)

W_s - as above, assuming the strengthening effect of the shedder plates according to (4) (corresponds to the case shown in Fig.4b)

W_g - as above, assuming the strengthening effect of the gusset plate according to (5) (corresponds to the case shown in Fig.4c)

The results presented in Tab.2 show that the requirements [4] give slightly conservative results in comparison with the results of the direct FEM calculations in the case of the considered bulkhead.

FINAL REMARKS

● The results of the FEM calculations performed in elastic range, given in Fig.6, Tab.1 and 2, clearly indicate that the application of the shedder or gusset and shedder plates is a very effective way of strengthening the corrugated bulkheads of bulk carriers.

● The collapse of the bulkhead is a non-linear phenomenon. However the reported results of the linear calculations indicate that formation of the plastic hinge at the lower end of the corrugation strengthened by the shedder or gusset and shedder plates occur at a considerably higher value of the lateral load than in the case of the corrugation without such strengthening.

● Experience of the Polish Register of Shipping in applying the requirements [4] to existing bulk carriers allows to state that the application of the shedder or gusset and shedder plates makes fulfilling the requirements possible in the case of moderately corroded bulkheads.

Appraised by Krzysztof Rosochowicz, Assoc.Prof.,D.Sc.

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