Worn Condition Ship Set Stability Estimation

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Worn Condition Ship Set Stability Estimation

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Abstract. The work studies the influence of wearing and corrosion of vessel bridging elements on the rigidity of the longitudinal framing reinforced plates. An assessment method of a potential plates stability loss between the reinforcing plates until the moment of reinforced plate general stability loss.

1. Introduction

Stability is one of the most important qualities of any engineering structure including a vessel hull. In the structure of a vessel hull many elements and constructions – beams, plates, bridging – work in the conditions of axial compression or plane stress condition, in which stability loss is possible and it poses a great threat to integrity and durability of the hull.

In this connection the problem of plates stability reinforced with stiffening ribs has a significant practical interest. For this purpose it is important to determine ribs stiffness value so that they could serve as the plates rigid support. Then to determine the necessary distance between the stiffening ribs of vessel bridging and to assess the ability of vessel bridging elements to resist strains, which appear during vessel exploitation, taking into account a possible deterioration of connections.

This problem is solved by the methods of vessel construction mechanics. And the solutions known in study and research works [1 - 3] basically take into account elastic deformations and do not reflect the possibility of losing plates stability between the ribs until the moment of losing the general stability of a reinforced plate. A rigorous solution of this problem, taking into account the influence of Hook's law deviation and floor plates or skin stability loss, is mathematically complicated and demands using the methods of finite elements analysis.

It is worth noting that despite a great number of works devoted to reinforced plates stability the question of critical assessment of deterioration and corrosion influence on such plates stability has not been paid enough attention to. Uneven character of reinforced plates elements deterioration makes this influence quite substantial, which is reflected on the quantitative results as well as on the qualitative picture of stability loss.

Due to problems complexity in stability assessment in order to solve them approximate methods are used in practice, which enable to reduce the problem of bridging stability solution to the assessment of isolated beams stability, however, an assessment of these solutions correctness with due regard to connections deterioration has not been performed. Taking into account the abovementioned, the deterioration and corrosion influence analysis for vessel bridging stability as well as the assessment of approximate solutions correctness of reinforced plates stability assessment can be considered quite timely.

2. Problem Statement

The demand of hull structures stability is an integral part of strength standards and vessel construction standards of the leading registries of shipping. Stability of hull constructions longitudinal elements under compression stresses from general bend must be checked by comparing critical (corrected Eulerean) stresses $\sigma_{кр}$, which are determined taking into account the decrease of normal elasticity and connections deterioration module by the middle of predicted durability with predicted compression stresses.

The basic supporting macroelement of a vessel hull is bridging. When the stability of longitudinals is provided the bridging stability depends on transverse beams rigidity (deep beams and ground timbers). The required inertia moment of these connections under the longitudinal framing system is determined according to P.F. Papkovich's formula [4]

$$J = \left(\frac{\pi}{\mu}\right)^4 \left(\frac{B_1}{l}\right) \frac{B_1}{b} i\varphi x_{jmax}(\lambda_\sigma) \tag{1}$$

where μ – coefficient depending on the degree of beam supporting section restraint; B_1- beam case bay; l – distance between deep beams; b – distance between longitudinal beams; i – inertia moment of longitudinal beam cross section;

$$\varphi = \frac{\sigma_{кр}}{\sigma_э}$$

Coefficient taking into account Hook's law deviation; x_{imax}- function depending on the number of bridging case bay, the number of stability loss half-waves and parameter

$$\lambda_\sigma = \frac{\sigma_э}{\sigma_{э.б}} = \frac{\sigma_{кр}}{\varphi\sigma_{э.б}},$$

where $\sigma_{э.б}$ – Eulerean stress of longitudinal beam.

Applied to the conditions of deep beams fastening to the board and on girder taking into account the formula for critical stresses and approximal dependence of function $x_{imax}(\lambda_\sigma)$ the initial function (1) will take the form of

$$J = 0{,}76 \left(\frac{B_1}{l}\right)^3 \frac{B_1}{b} i\varphi x_{jmax}(\lambda_\sigma) \tag{2}$$

As a result of a decreasing of vessel hull resistance moment due to connections corrosion deterioration general transverse stresses in the process of a vessel exploitation can increase by 10-30% for the vessels of 200-100 metres correspondingly.

Taking into account that the parameter $\frac{1}{0{,}76}\frac{J\delta}{i}\left(\frac{B_1}{l}\right)^3\frac{B_1}{b}$ with the course of time always exceeds the initial value characteristic for a new vessel, because an even deterioration is more noticeable on the smaller beams with inertia moment of cross section i in comparison to a framing anchor having inertia moment $J_б$, then beam rigidity in rundown condition exceeds the rigidity necessary for providing bridging stiffness on the level of a longitudinal beam stiffness. If the initial rigidity of deep beams provides a desired bridging stability, then in the rundown condition their inertia moments will guarantee the bridging stability at the level of longitudinal beams stability.

Thus, bridging stability in rundown condition is determined by the stability of panels reinforced with longitudinal ribs (longitudinal framing system). In order to assess the stability of such reinforced panels the following formula is used when using longitudinal framing system

$$Ei = \frac{\sigma_1 a^2}{\pi^2}\left(\frac{F}{n^2} + bs\psi_g\right), \tag{3}$$

where - n a number of half-waves developing at the moment of stability loss within the limits of bay length a; ψ_σ – function depending on critical stresses level, geometrical and physical parameters as well as on stiffening ribs number and the number of half-waves both in longitudinal and transverse directions; F – surface area of transverse section of stiffening rib; S – plate thickness; σ_1 – stress.

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There is a critical value of stiffening ribs transverse section inertia moment where ribs are rigid supports for the plate. The increase of inertia moment in excess of the critical value does not lead to the increase of reinforced panel stability. In order to determine the critical value of inertia moment in the formula (3) it is necessary to accept stresses σ_1 as equal to Eulerian stresses for the plate with sizes a and b, simply supported by stiff contour, that is to consider the ribs to be absolutely stiff.

In the presence of sufficiently great number of ribs function ψ_σ tends to one. Taking this into account, in the practice of vessel constructions engineering it is recommended to report stability condition (3) in terms of

$$Ei = \frac{\sigma_1 a^2}{\pi^2}\ (F + bs) \tag{4}$$

However, using the formula (4) it should be noted that while increasing the number of stiffening ribs the value of minimal frame space is limited by the technology specifications.

Corrosion deterioration influences Eulerean stresses due to decreasing of beam geometrical characteristics as well as a significant reduction of an attached belt. However, using formula (4) as a particular variant of formula (3) can lead to logical misbeliefs and incorrect quantitative evaluations. The analysis of the connections deterioration influence on their stability taken in this work proves the possibility of incorrect conclusions if formula (4) is used to assess vessel bridging beams stability.

Beams elements deterioration can lead to the increase of Eulerean stresses under the general decrease of Eulerean forces value. Taking into consideration that while calculating the imaginary hull girder the present moment stresses in the points of hull section are determined, an incorrect statement can appear about the growth of connections stability while their deterioration. From here it follows the conclusion that the assessment of framing wide-flange beams by the value of Eulerean stresses is not always eligible.

Further analysis of reinforced plates taking into account deterioration and corrosion is taken on the basis of the correspondence (3).

In the general case

$$\sigma_{кр} = k_с\, \sigma_с \tag{5}$$

where $\sigma_{кр}$ - critical stresses of construction and its elements; $\sigma_с$ – compression stresses acting in the constructions elements; $k_с$ – stability coefficient.

According to Sea vessels strength standards as of 1991 $k_с = 1$ for beams of longitudinal framing and bridging in general; $k_с = 0.8$ - for sheerstrake steel plate elements, upper-deck stringer, flat keel and bilge strake; $k_с = 0.6$ - for other steel plate elements of the hull included into the composition of imaginary hull girder.

Thus, proceeding from Sea vessels strength standards the criterion of deck grillage plates stability is written as

$$\sigma_{кр} \leq \sigma_{экспл.}$$

where $\sigma_{экспл.}$ – the greatest stresses acting in operation conditions and a criterion of stiffening ribs stability is written as

$$\sigma_{кр} \leq R_{ен}$$

where $R_{ен}$ – steel fluidity limit.

In other words, the plates stability is checked for the action of service condition and stiffening ribs stability for load appearing in vessel hull limit state. Taking into account the possibility of the bridging plates stability loss before the moment of the general loss of stiffened panel stability, there is a necessity to assess the plates transverse deformations influence (bridging antiplane) for stiffened panels stability taking into account the deterioration of the plates and stiffening ribs section elements.

3. Study results

A rigorous solution of this problem with respect for deviations of the Hook's law and losses in stability of floor or shell plates is extremely complex. However, due to a certain conditionality of

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computational models, an approximate solution based on the solution of elasticity problem can be used.

While choosing the original sizes of flooring (shells) and stiffening ribs, the stability conditions will be defined as follows:

$$\bar{\sigma}_{\text{кр}} \geq k_c \sigma_{\text{т}}^{\text{н}} \approx k_c R_{\text{ен}}$$

where k_c – coefficient; $R_{\text{ен}}$ – steel flow point, MPa.

In the general case the following will be assumed: $0 \leq k_c \leq 1$.

Hence, the thickness of plates upon the given level of critical stress can be defined via the following functions:

$$\sigma_{\text{кр}} = \sigma_{\text{э}} \quad \text{where} \quad \bar{\sigma}_{\text{э}} \leq 0.6,$$

$$\bar{\sigma}_{\text{кр}} = 1.63 - 0.8/\sqrt{\bar{\sigma}_{\text{э}}} \quad \text{where} \quad 0.6 \leq \bar{\sigma}_{\text{э}} \leq 1.6,$$

$$\bar{\sigma}_{\text{кр}} = 1 \; where \; \bar{\sigma}_{\text{э}} \geq 1.6,$$

where $\bar{\sigma}_{\text{кр}} = \sigma_{\text{кр}}/\sigma_{\text{т}}$; $\bar{\sigma}_{\text{э}} = \sigma_{\text{э}}/\sigma_{\text{т}}$,

Calculations of steel plates rely on the approximate equation

$$\sigma_{\text{э}} = 80\left(100\,\frac{s}{b}\right)^2, \text{MPa} \tag{6}$$

Then, if we define the critical stress for plates being $\sigma_{\text{кр}}^{\text{пл}} = k_c R_{\text{ен}}$, $R_{\text{ен}} \approx \sigma_{\text{т}}$, we get

$$s = \frac{b}{100^1}\sqrt{\frac{k_c \sigma_{\text{т}}}{80}} \text{ where } k_c \leq 0.6, \tag{7}$$

$$s = \frac{0{,}08b}{(1.63 - k_c)\sqrt{\frac{80}{\sigma_{\text{т}}}}} \text{ where } 0.6 \leq k_c \leq 1, \tag{8}$$

Differential equation of stability of the considered field being a part of a stiffened plate will be written as

$$D\nabla^2\nabla^2 w + \sigma_{\text{ср}} s \frac{\partial^2 w}{\partial x^2} = 0$$

The average stress value can be calculated via

$$\sigma_{\text{ср}} = \varphi_0 \sigma_{\text{кр}}^{\text{р.ж.}}$$

where for the longitudinal framing system $\varphi_0 = 0.5\left(1 + \frac{\sigma_{\text{кр}}^{\text{пл}}}{\sigma_{\text{кр}}^{\text{р.ж}}}\right)$

Also, since the reference conditions are that

$$\sigma_{\text{кр}}^{\text{пл}} = k_c \sigma_{\text{кр}}^{\text{р.ж.}}$$

Then we get

$$\varphi_0 = 0.5(1 + k_c)$$

$$\sigma_{\text{ср}} = 0.5(1 + k_c)\sigma_{\text{кр}}^{\text{р.ж.}} = \varphi_0 \sigma_{\text{кр}}^{\text{р.ж.}}$$

In the considered case the influence of local deformations on D plate stiffness will be ignored that will naturally affect the accuracy of solution. However, due to the fact that the bending stiffness of ribs is many times as high as the bending stiffness of plate, the error will not exceed the accuracy of engineering computations.

Nonzero solutions of equations are found as

$$w_k = f_n^{(k)}(y)\sin\frac{n\pi x}{a} \tag{9}$$

And function $f_n^{(k)}(y)$ is as follows

$$f_n^{(k)}(y) = A_n \operatorname{ch}\alpha_n y + B_n \operatorname{sh}\alpha_n y + C_n \cos\beta_n y + D_n \sin\beta_n y$$

where

$$\alpha_n = \sqrt{\left(\frac{n\pi}{a}\right)^2 + \frac{n\pi}{a}\sqrt{\varphi_0\frac{\sigma_{кр}^{р.ж.}s}{D}}}, \qquad \beta_n = \sqrt{\frac{n\pi}{a}\sqrt{\varphi_0\frac{\sigma_{кр}^{р.ж.}s}{D}} - \left(\frac{n\pi}{a}\right)^2}$$

The presented expressions are different from common expressions [5] only in the value of φ_0 parameter.

Arbitrary constants must be defined based on the compatibility relations between the considered plate field and a proximate field and stiffening ribs.

Elasto-plastic strains of ribs can be calculated through an experimental dependence between the Eulerian and critical stress for beams

$$\bar{\sigma}_{кр}^{р.ж.} = 1.12 - \frac{0.312}{\bar{\sigma}_э} \text{ where } 0.6 \le \bar{\sigma}_э \le 2.6$$

Of which it follows that $\bar{\sigma}_э^{р.ж.} = \frac{0.312}{1.12 - \bar{\sigma}_{кр}^{р.ж}}$

Matching condition for the neighboring plate sections on each rib and differential equation of k-stiffening rib bending under conditions of Hooke's law validity are as follows

$$\left.\begin{aligned} \frac{\partial w_k}{\partial y}(0) &= -\frac{\partial w_{k-1}}{\partial y}(0), \\ EJ\frac{\partial^4 w}{\partial x^4}(0) + \varphi_1\sigma_т F\frac{\partial^2 w}{\partial x^2}(0) &= r_{k-0} + r_{k+0} \end{aligned}\right\}$$

where EJ –is a bending stiffness of stiffening rib cross-section (with attached flange); F – is an area of stiffening rib cress-section; r_{k-0}, r_{k+0} – stress on k-stiffening rib from the plate situated between k-, (k-1) and (k+1)-stiffening ribs; $\varphi_1 = \left(\frac{0.312}{1.12-\bar{\sigma}_{кр}^{р.ж}}\right)\frac{1}{\bar{\sigma}_{кр}^{р.ж}}$.

Attached flange of a stiffening rib is calculated through an approximated equation with respect for the influence of the flange bending caused by stability loss

$$b_{пр} = \frac{b}{u_1}\sqrt{\frac{G_{пр}}{E_{пр}}}thu_1\sqrt{\frac{E_{пр}}{G_{пр}}}, \quad u_1 = \frac{\pi b}{21}.$$

Values of the considered elasticity modulus defined through the system of Karman equations can be found via the following formulas

$$E_{пр} = \frac{E}{1+\frac{\bar{w}_0^2}{1.465+\bar{w}_0^2}}, \qquad G_{пр} = \frac{G}{1+\frac{\bar{w}_0^2}{17.03+0.93\bar{w}_0^2}}$$

$$\bar{w}_0^2 = \frac{4}{3}\left(1 - \frac{s_{изн}^2}{s_0^2}k_c\right)\left[(1-\mu^2)k_c\frac{s_{изн}^2}{s_0^2}\right]^{-1}$$

Resolving equation with respect for stability loss of the plates between stiffening ribs and deviations from Hook's law will be as follows

$$EJ = \varphi_1\frac{\bar{\sigma}_{кр}^{р.ж.}a^2}{\pi^2}\left(\frac{F}{n^2} + bs\varphi\right)$$

where

$$\varphi = \frac{21J}{\varphi_1\sigma_{кр}^{р.ж.}}\left(\frac{\lambda}{n\pi}\right)^2 \frac{(u_n^2+v_n^2)^1\left(\cos\frac{j\pi}{g+1} - cos v_n\right)\left(\cos\frac{j\pi}{g+1} - chu_n\right)}{\frac{\sin v_n}{v_n}\left(\cos\frac{j\pi}{g+1} - chu_n\right) + \frac{shu_n}{u_n}\left(cos\, v_n - \cos\frac{j\pi}{g+1}\right)}$$

$$\varphi_0 = 0.5\left[1 + k_c\left(\frac{s_{изн}}{s_0}\right)^2\right], \; \lambda = a/b; \; u_n = \alpha_n b; \; v_n = \beta_n b,$$

j – is a whole number in the range $1 \le j \le g$; g – the number of stiffening ribs.

With the fixed value of critical stress $\sigma_{кр}^{р.ж.}$ the required second moment of stiffening ribs can be defined. The values n and j have to be selected in order to ensure the biggest second moment J.

4. Conclusion

These methods are applied to calculate the stability of stiffened plates with respect for wear, corrosion and possible stability loss of the plates between stiffening ribs before the general stability loss of stiffened plates.

Implementation of these methods can solve both direct and inverse problems, i.e. define the critical stresses of stiffened plates at the specified sizes of rib and plate sections or define the critical values of second moments of stiffening rib sections at the specified level..

5. References

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