On long-term prediction of stresses in principal members of ship hull structures

Current report

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ABSTRACT

The paper presents a discussion on the strength criteria and load cases required in the rules of classification societies for direct FEM strength analysis of ship hull structures, which show some differences to each other. The conclusion of it is that detail studies on stress values in ship structures are necessary to improve the requirements. With this end in view an effective method for long-term prediction of stresses in ship hull structure principal members is proposed. The method is based on the concept of influence coefficients and spectral analysis of wave loads. A FEM model of the principal member system in the form of 3D frame is applied to calculate values of the influence coefficients. Next, the concept is used of correlation factors for combining characteristic long-term stress values caused by global and local loads, with combined stresses due to general bending of the ship, zone bending of the principal members and local bending of longitudinals. As an example, results of stress prediction and correlation factors calculated in some points of hull structure of a panamax bulk carrier are presented and discussed.

Key words : Rules for classification of ships, spectral analysis of wave loads on ships, dynamic stresses in ship hull structures

INTRODUCTION

Ship hull structures are usually designed according to safety standards given by classification societies in their rules for the classification and building of ships, e.g. [1] to [6]. An important issue of the rules are strength standards for the structures. Ship strength appraisal on the basis of such rules is performed according to the scheme given in Fig.1.

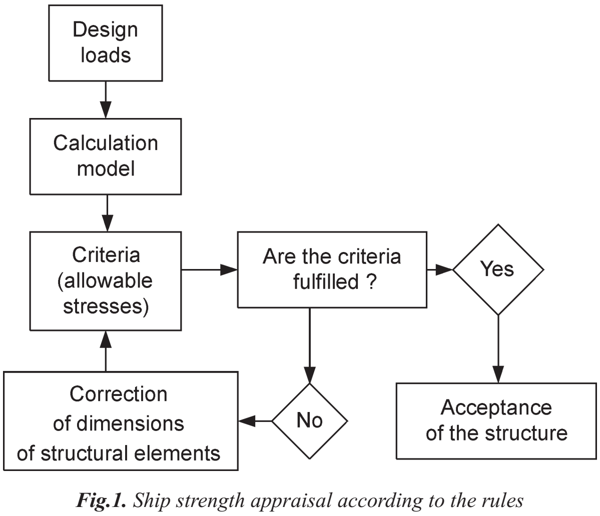

Fig.1. *Ship strength appraisal according to the rules*

There are considerable differences in the rules [1] to [6] concerning design loads, and only in very few cases the IACS member societies apply common requirements. Such case is the wave bending moment and shear force for hull general bending in vertical plane, defined in [7].

An especially important issue for ship safety is strength of hull structure longitudinal members such as double bottom girders, bottom and inner bottom stiffeners (longitudinals), etc.

In these members normal stresses due to general bending of the ship, bending of the principal members (zone strength) and local bending of the stiffeners are superimposed (Fig.2).

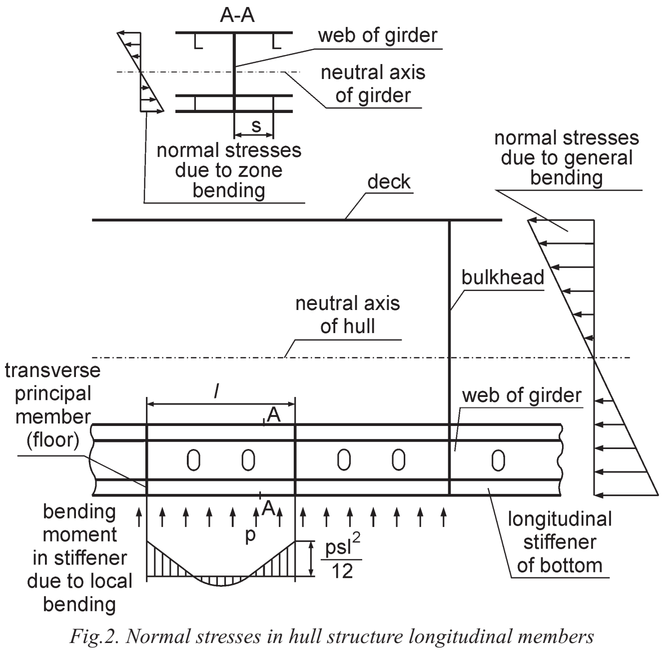

Fig.2. Normal stresses in hull structure longitudinal members

The rules [1] to [6] require that strength of the principal members is to be appraised by applying FEM model of ship hull structure module at the midship region. The FEM model should usually correspond to 3 successive holds. Some of the standard combined load cases are to be applied in the calculations. The combined load cases are composed of global load components (bending moments and shear forces at general bending of the ship, for example) and local load components (external water pressure, pressure of the cargo, etc.).

To compose the load cases, characteristic values of dynamic loads related to sailing in ocean waves, are multiplied by numbers from the range {-1;1}, called the correlation factors for combined load cases. The characteristic values of the loads are extreme values, i.e. usually those with the probability of exceedance equal to 10^{-8}.

For example, one of the combined load cases for strength appraisal of primary members, according to the requirements of DNV rules ([2 , 3]) and PRS rules ([4 , 5]), is to be composed of the dynamic loads shown in Fig.3.

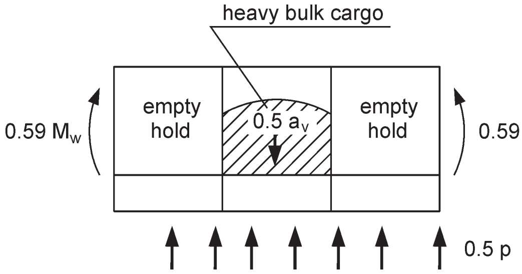

Fig.3. Dynamic load components acc. to DNV and PRS rules

So, the correlation factor for the wave bending moment M_w takes the value 0.59, for the dynamic external water pressure - the value 0.5 and for the dynamic load corresponding to vertical accelerations a_v - the value 0.5.

Quite different values of correlation factors for the load case shown in Fig.3 are required by the rules [1] and [6]. According to [1] the value 1.0 is to be applied for M_w , 0.4 - for a_v and 0.5 - for p. Whereas according to [6] the values : 0.625 for M_w , 0.0 for a_v and 0.5 for p are to be applied.

Characteristic load values in the above mentioned rules of classification societies are usually defined at different probability levels and are to be calculated by applying quite different parametric formulae. Values of the allowable stresses are also different.

These remarks allow to state that the determining of required scantlings of ship hull structure members is based on very simplified assumptions. FEM analyses required by the rules would give quite accurate values of the stresses if values of the design loads corresponded to real loads accurately. The above given short comparison of some rule requirements of the classification societies clearly shows that the required simply combined load cases must differ from the real loads.

So, a.o. in the author's opinion the searching for more accurate design loads is the most important and urgent task for development process of the rules. Therefore in PRS a research task has been undertaken to find long-term stress distributions in longitudinal members of typical ship hull structures. Results of long-term stress predictions have been compared with stress values calculated as response of the structure to the design loads defined in [4]. Analysis of the obtained results will make it possible to modify and improve the requirements concerning design loads [4].

LONG -TERM PREDICTION OF STRESSES IN LONGITUDINAL MEMBERS OF SHIP HULL STRUCTURES

For many years PRS has been developing theoretical models and software for prediction of ship's motions and loads on ship sailing in waves. The calculations based on the linear theory are performed according to the scheme shown in Fig.4.

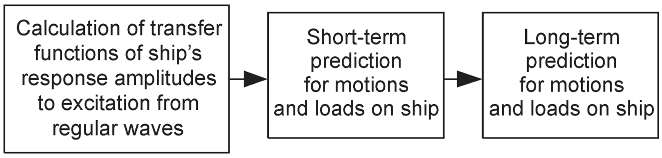

Fig. 4. *Block diagram of the method for prediction of motions and loads on ships*

The transfer functions are calculated by using WAVE3D computer program developed in PRS. Three-dimensional water flow around the ship is taken into account.

Short-term prediction calculations take the form of spectral analysis in which Pierson-Moskowitz spectrum in terms of the significant wave height and the mean wave period, is applied [11].

The spectrum is narrow-banded and probability density function for the wave maximum values (peak values) takes the form of Rayleigh distribution, [8, 9, 10].

Long-term prediction concerns the whole life span of a ship (usually 20 years). The results of short-term predictions and statistical data in the form of joint frequency of significant wave height and mean wave period are used.The data for North Atlantic are used as usual. Detail description of PRS procedure for long-term prediction is given in [8] and [9].

The rules of classification societies should allow ship designers to assess characteristic values of stresses in the hull structure as effectively and accurately as possible. The characteristic values are those exceeded with sufficiently small probability value - e.g. 10^{-8}.

So, before formulating design loads and combined load cases for rule requirements one should start with analysis of long-term stress distributions in hull structures.

The problem is that stress values in a transverse cross-section of primary member depend significantly on the loads acting on a rather large portion of the hull structure because the primary members are mutually connected.

To make the long-term prediction of stresses in primary members as effective as possible the influence coefficients of the loads on stress values at selected points of the primary members are to be calculated before the calculations according to the scheme shown in Fig.4 start. The concept of influence coefficients is explained in Fig.5.

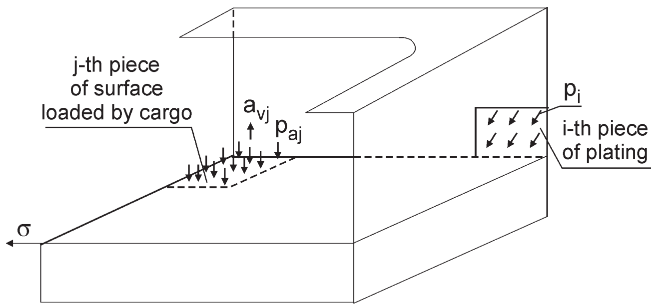

Fig. 5. *The concept of influence coefficients*

The surface of ship hull plating loaded by the external water pressure p is divided into N_p relatively small pieces under the assumption that p = const on each piece.

Similarly the areas of inner bottom and decks loaded by pressure of cargo are divided into N_a pieces. Now the stress value σ at a point of principal member can be calculated from the formula :

$$\sigma = \sum_{i=1}^{N_p} A_i \cdot p_i + \sum_{j=1}^{N_a} B_j \cdot \overbrace{C_j \cdot a_{vj}}^{p_{aj}} \qquad (1)$$

where :

N_p , N_a - as defined above
p_i - external water pressure at i-th area
a_{vj} - vertical acceleration at j-th area
A_i - the influence coefficient of p_i on σ
B_j - the influence coefficient of $C_j \cdot a_{vj}$ on σ
C_j - a coefficient to calculate p_{aj} (see Fig.5) corresponding to a_{vj} (cargo density multiplied by height of the cargo).

The values of A_i and B_j can be calculated by applying a FEM model of hull structure and assuming $p_i = 1$ or $p_{aj} = 1$ on individual pieces of external plating surface, inner bottom or deck area, and zero values at the other pieces. The FEM model in the form of a 3D frame is sufficient for the system of primary members.

To calculate transfer functions for amplitudes of σ, the amplitudes of p_i and a_{vj} (the complex numbers) calculated for the unit amplitude wave should be put into (1).

The next steps of the calculations are to be performed according to the scheme shown in Fig.4. In the double bottom girders some components of σ are superimposed (Fig.2).

The phase angles of individual components of σ for the ship on regular wave are usually different. This means that the characteristic values of the components can not be added directly. The characteristic value of σ corresponding to two components with characteristic values σ_1 and σ_2 can be written in the following form:

$$\sigma = \mathrm{Max}(\sigma_1, \sigma_2) + c \cdot \mathrm{Min}(\sigma_1, \sigma_2) \qquad (2)$$

where :

Max (σ_1 , σ_2) - the greater value of σ_1 and σ_2
Min (σ_1 , σ_2) - the smaller value of σ_1 and σ_2
c - the correlation factor for combination of σ_1 and σ_2 ; this is a number from the range {-1 ; 1}.

Such form of (2) corresponds to the above described method of combining global and local loads according to the rule requirements of classification societies, where the correlation factors are used.

RESULTS OF EXAMPLE CALCULATIONS

Long-term prediction of normal stresses σ was performed at 8 points of double bottom girders of a panamax bulk carrier, schematically shown in Fig.6.

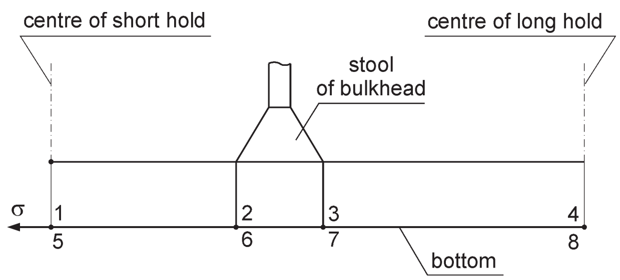

Fig. 6. *Points in bulk carrier structure where long-term prediction of normal stresses σ was performed*

Points 1 to 4 belong to the side girder 5.6 m distant from the ship's plane of symmetry. Points 5 to 8 belong to the central girder.

The influence coefficients of external water pressure and cargo inertia forces on σ were calculated by applying (1), and using the FEM model for the hull module principal members between the middles of two successive holds (see Fig.6), in the form of 3D frame.

Symmetry of frame displacements was assumed at the ends of the model, i.e. girder's transverse cross-section angles of rotation around the axis perpendicular to ship's plane of symmetry were assumed equal to zero.

Full draught of the ship d =12.2 m was assumed. The cargo inertia forces corresponding to static cargo pressure on the inner bottom equal to 100 kPa were assumed constant over the whole inner bottom area. The long-term prediction calculations were performed by applying the above described method for the following locations of the FEM model along the ship :

A - the transverse bulkhead located at the midship
B - the transverse bulkhead 50 m distant from the midship, in the bow part of the ship
C - the transverse bulkhead 50 m distant from the midship, in the aft part of the ship.

The c-factor values calculated acc. to (2) for values of σ, σ_1 and σ_2 at the probability of exceedance = 10^{-8}, at points 1 to 8 (Fig.6) are listed in the table.

Calculated values of c-factors

Point	A			B			C		
	A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	C-3
1	0.05	0.65	0.79	0.06	0.75	0.96	0.06	0.43	0.50
5	0.10	0.77	0.81	-0.04	0.77	0.99	0.10	0.49	0.65
2	-0.06	-0.56	-0.17	-0.39	-0.37	-0.62	0.12	-0.33	0.28
6	0.12	-0.49	-0.52	-0.40	-0.39	-0.94	0.13	-0.31	0.21
3	0.05	-0.56	-0.20	-0.36	-0.43	-0.67	0.12	-0.29	0.24
7	0.12	-0.48	-0.56	-0.38	-0.42	-0.96	0.14	-0.27	0.15
4	0.09	0.71	0.75	-0.50	0.70	0.99	0.12	0.40	0.68
8	0.13	0.80	0.78	-0.50	0.76	0.99	0.14	0.48	0.66

The symbol A-1 in the table means the first case of σ_1 and σ_2 combination for the location A of the FEM model, and so on.

For the locations A, B and C of the FEM model the following combinations of normal stresses were considered :

1. $$\sigma_1 = \sigma_p \ , \ \sigma_2 = \sigma_a$$

where :

σ_p - the stresses in the girders, at the level of the bottom, due to zone bending by external water dynamic pressure
σ_a - as above, but caused by cargo inertia pressure.

2. $$\sigma_1 = \sigma_{pa} \ , \ \sigma_2 = \sigma_M$$

where :

σ_{pa} - the stresses in the girders, at the level of the bottom, due to zone bending by external water dynamic pressure and cargo inertia pressure acting together
σ_M - the stresses due to general bending of the ship in vertical plane.

3. $$\sigma_1 = \sigma_p \ , \ \sigma_2 = \sigma_l$$

where :

σ_p - as at p.1, but at the level of bottom stiffener flange
σ_l - the local bending stresses in the flange of bottom stiffener, where :

$$\sigma_l = \frac{psl^2}{12W}$$

s , l - see Fig. 2
W - section modulus of the stiffener with strip of the plating.

CONCLUSIONS AND FINAL REMARKS

Values of c-factors listed in the table suggest that combination of global and local stresses σ in hull structure longitudinal members is a complicated problem.

The following interesting features of such combination method can be observed :

a. The c-values for double bottom side and central girders with the same x-coordinate along the ship are almost the same, in general. This suggests that the method of stress combination in the form of (2) is reasonable.
b. There are considerable differences between c-values for individual cases of the combination (A-1, A-2, A-3, B-1, etc.). It is interesting that the values of |c| in the cases A-1 and C-1 are rather small.
c. The c-values considerably depend on x-coordinate of the points in the girders.
d. The c-values can be positive or negative. This is logical because the combination of stresses was considered. If combinations of global and local loads which cause, at a point of hull structure, stress σ equal to the result of long-term prediction based on direct calculations, were considered, then correlation factors would be the numbers of the same sign – independently of a position of a considered point.

❒ The paper deals with the problem of combining the stresses. According to the rules of classification societies global and local loads are to be considered to create the load cases for FEM calculations. The above listed features b. and c. of stress combination suggest that the load cases required in [1] to [6] created by means of rather simple algorithms, can lead to prediction of stress values considerably different from the real ones.

❒ The designing of hull structures on the basis of the rule requirements means that simplified loads are applied. The FEM calculations give quite accurate results for these loads, but calculated values of stresses can differ considerably from their real values.

❒ For this reason in PRS a research task aimed at formulating the load cases to be used in the rules [4] in order to obtain more accurate results of stress prediction in longitudinal hull members has been carried out. The first step of the task is to gather a set of information on stress combinations. Then the load cases which cause sufficiently accurate stress values in the structure will be searched for.

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NOMENCLATURE

a_v - vertical acceleration
A_i , B_j - influence coefficients of pressure on normal stress
c - correlation factor for normal stresses
C_j - coefficient to calculate pressure values from acceleration values
l - spacing of floors
M_w - wave bending moment
N_a - number of pieces to which the inner bottom area is divided
N_p - number of pieces to which the area of plating is divided
p - external water pressure
s - spacing of stiffeners (longitudinals)
W - section modulus of stiffener cross-section
σ - normal stress.

Acronims

DNV - Det Norske Veritas
FEM - Finite Element Method
IACS - International Association of Classification Societes
PRS - Polish Register of Shipping

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Conference

Scientific Meeting of Regional Group

On 25 March 2004 the Mechanical and Electric Engineering Faculty of Polish Naval University, Gdynia, hosted the first-in-the year scientific meeting of the Regional Group of the Section on Exploitation Foundations, Machine Building Committee, Polish Academy of Sciences.

During the seminar three papers were presented :

★ *Recycling problems in shipbuilding - research state-of-the-art, issues to be solved* – by W. Jurczak (Polish Naval University)

★ *Research on influence of fuel charge nonuniformity of combustion engine on spectrum of torsional vibration of shafting* – by St. Bruski(Polish Naval University)

★ *Research on compression process to be applied to diagnosing ship piston combustion engines* – by M. Lutowicz (Polish Naval University)

After interesting discussion the participants were acquainted with a modern ship navigation bridge simulator and computer stands serving as training labotratories for navigation officers.