Polski Rejestr Statków

RULES

AMENDMENTS NO. 1/2005

to

PUBLICATION NO. 45/P

FATIGUE STRENGTH ANALYSIS
OF SHIP STEEL HULL STRUCTURE

1998

GDAŃSK

Amendments No. 1/2005 to *Publication No. 45/P – Fatigue Strength Analysis of Ship Steel Hull Structure – 1998* were approved by the PRS Board on 16 November 2005 and enter into force on 15 December 2005.

The requirements set forth in Amendments No. 1/2005 apply, in full, to all sea-going ships classed with PRS.

PRS/HW, 12/2005

The following amendments to Publication No. 45/P – Fatigue Strength Analysis of Ship Steel Structure – 1998 have been introduced:

1. *(This amendment concerns the Polish version only).*

2. *In Table* **2.2.8.4**, *item 24, column 3, the existing wording:*

   $r < 0.5h$ or $\varphi < 20°$

   has been replaced by:

   $r < 0.5h$ or $\varphi > 20°$.

3. *In Table* **2.4.3-2** *in the last column, the reduction factor value* 2.54 *has been changed to* 2.13.

4. *Sub-chapter* **2.4.4** *has been added*:

2.4.4 Prototype Fatigue Tests

2.4.4.1 In the case of prototype structures featuring non-typical structural details, the fatigue strength assessment using laboratory fatigue tests may be required.

The fatigue tests may be performed for constant amplitude loadings, taking the following precautions:

– the steel used for the test model is to be of the same grade as that provided for the actual structure;
– welding procedures are to be the same as those applied at the actual structure construction;
– the stress ratio $R = \frac{\sigma_{\min}}{\sigma_{\max}}$ is to remain constant during the experiments; it is recommended that R be taken between 0 and 0.1.

2.4.4.2 Detailed requirements relating to fatigue tests are specified by PRS in each particular case.

2.4.4.3 In addition to the fatigue tests, it is recommended that 3D FEM structural analyses should be performed for the test model to validate the calculation procedure for determination of hot spot stresses in the actual structure.

It is recommended, in particular, that theoretical stresses should be calculated at locations where stress measurements are carried out during the fatigue testing.

5. *The formula* (2.5.3) *has been amended to read:*

$$\Delta\sigma_2 = \frac{\Delta\sigma_1}{\left(\frac{t_B}{t}\right)^{0.3}} \tag{2.5.3}$$

6. *Paragraph* **2.6.1** *has been amended to read:*

2.6.1 General

The standard of hull structural members fatigue strength, applied in the present *Publication*, is based on the assumption that the ship can be operated for at least 20 years in the North Atlantic Ocean.

If it is predicted by the Owner that the ship will be operated on a route with less adverse (statistically taken) sea and weather conditions, it is permitted that the calculations of structural members fatigue strength be made for long-term stress distribution, calculated directly for the predicted route – in accordance with Chapter 3.

In such case, subject to a separate consideration, PRS may also give consent to performance of simplified calculations using long-term stress distribution, determined according to 2.3 for $\Delta\sigma_R$ reduced by 20 % ($\Delta\sigma_R$ is determined for design loads taken according to the Rules).

The fatigue strength criterion may be approximately verified according to 2.6.8.

7. *The formula* (2.6.5-1) *has been amended to read:*

$$D_0 = \sum_{i=1}^{I_p} \frac{n_i}{N_i} \tag{2.6.5-1}$$

8. *Table* **2.6.7-1** *has been amended as follows:*

– *for* n = 2.40, the value $\Gamma(n+1) = 2.9812$ has been used instead of the value 3.9812
– *for* n = 6.50, the value $\Gamma(n+1) = 1871.3$ has been used instead of the value 1571.3.

9. *Paragraph* **3.2.1** *has been amended to read:*

3.2.1 When making short-term prediction for stress ranges in hull structural members, m_0 and m_2 moments of stress range spectral density function $S_{\Delta\sigma}$, which determine the so-called Rayleigh distribution (3.2.4) or the number of load cycles (3.4), are to be calculated:

$$m_i = \int_0^{\infty} \omega^i S_{\Delta\sigma}(\omega) d\omega \tag{3.2.1}$$

i = 0.2 – order of density function moment;
ω – wave frequency, [1/s];
$S_{\Delta\sigma}(\omega)$ is to be calculated according to 3.2.2.

10. Paragraph **3.2.2** *has been amended to read:*

3.2.2 Spectral density function $S_{\Delta\sigma}(\omega)$ is to be calculated from the formula:

$$S_{\Delta\sigma}(\omega) = |Y(\omega)|^2 \; S_\zeta(\omega) \qquad (3.2.2)$$

where:

ω – wave frequency, [1/s];

$Y(\omega)$ – stress transfer function, i.e. the value of $\Delta\sigma$ corresponding to hull loads in regular waves of unit amplitude, wave frequency ω, ship speed V (see 3.1.4) and the ship course angle μ ($\mu = \pi$ when the ship moves opposite to wave direction, perpendicular to wave crest).

11. Paragraph **3.2.3** *has been amended to read:*

3.2.3 Environmental wave spectrum is to have the following form:

$$S_\zeta(\omega) = \frac{H_s^2}{4\pi}\left(\frac{2\pi}{T_0}\right)^4 \omega^{-5} \exp\left(-\frac{1}{\pi}\left(\frac{2\pi}{T_0}\right)^4 \omega^{-4}\right) \qquad (3.2.3)$$

where:

ω – see 3.2.1;

H_s – significant wave height, [m];

T_0 – the average zero-up crossing wave period, [s].

12. In paragraph **3.3.1**, symbol „T_1” *has been replaced by* „T_0”, symbol „T_{1j} *has been replaced by* „T_{0j}”. Symbol „m_{ijkl}”, *under formula 3.3.1-4, has been replaced by*„m_{2ijkl}”.

13. Paragraph **3.3.2** *has been amended to read:*

3.3.2 When making calculations according to formula 3.3.1-1, it will be sufficient to use H_{si} and T_{0j}, as well as P_{ij} given in Table 3.3.2.

The values of P_{ij} in Table 3.3.2 define the probability of seaways in the North Atlantic.

Table 3.3.2
Probability of sea states (x 100000)

H_s [m] \ T_0 [s]	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5
0.5	0.0	0.0	1.3	133.7	865.6	1186.0	634.2	186.3	36.9	5.6
1.5	0.0	0.0	0.0	29.3	986.0	4976.0	7738.0	5569.7	2375.7	703.5
2.5	0.0	0.0	0.0	2.2	197.5	2158.8	6230.0	7449.5	4860.4	2066.0
3.5	0.0	0.0	0.0	0.2	34.9	695.5	3226.5	5675.0	5099.1	2838.0
4.5	0.0	0.0	0.0	0.0	6.0	196.1	1354.3	3288.5	3857.5	2685.5
5.5	0.0	0.0	0.0	0.0	1.0	51.0	498.4	1602.9	2372.7	2008.3
6.5	0.0	0.0	0.0	0.0	0.2	12.6	167.0	690.3	1257.9	1268.6
7.5	0.0	0.0	0.0	0.0	0.0	3.0	52.1	270.1	594.4	703.2
8.5	0.0	0.0	0.0	0.0	0.0	0.7	15.4	97.9	255.9	350.6
9.5	0.0	0.0	0.0	0.0	0.0	0.2	4.3	33.2	101.9	159.9
10.5	0.0	0.0	0.0	0.0	0.0	0.0	1.2	10.7	37.9	67.5
11.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.3	13.3	26.6
12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	4.4	9.9
13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.4	3.5
14.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.2
15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4
16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Sum	0	0	1	165	2091	9280	19922	24879	20870	12898

Table 3.3.2 cont.

H_s [m] \ T_0 [s]	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	SUM
0.5	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3050
1.5	160.7	30.5	5.1	0.8	0.1	0.0	0.0	0.0	22575
2.5	644.5	160.2	33.7	6.3	1.1	0.2	0.0	0.0	23810
3.5	1114.1	337.7	84.3	18.2	3.5	0.6	0.1	0.0	19128
4.5	1275.2	455.1	130.9	31.9	6.9	1.3	0.2	0.0	13289
5.5	1126.0	463.6	150.9	41.0	9.7	2.1	0.4	0.1	8328
6.5	825.9	386.8	140.8	42.2	10.9	2.5	0.5	0.1	4806
7.5	524.9	276.7	111.7	36.7	10.2	2.5	0.6	0.1	2586
8.5	296.9	174.6	77.6	27.7	8.4	2.2	0.5	0.1	1309
9.5	152.2	99.2	48.3	18.7	6.1	1.7	0.4	0.1	626
10.5	71.7	51.5	27.3	11.4	4.0	1.2	0.3	0.1	285
11.5	31.4	24.7	14.2	6.4	2.4	0.7	0.2	0.1	124
12.5	12.8	11.0	6.8	3.3	1.3	0.4	0.1	0.0	51
13.5	5.0	4.6	3.1	1.6	0.7	0.2	0.1	0.0	21
14.5	1.8	1.8	1.3	0.7	0.3	0.1	0.0	0.0	8
15.5	0.6	0.7	0.5	0.3	0.1	0.1	0.0	0.0	3
16.5	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.0	1
Sum	6245	2479	837	247	66	16	3	1	100000

Notes: The H_s and T_0 values are coordinates of the midpoints of 1 m and 1 s intervals. respectively.

14. *In paragraph* **3.4***. the following amendments have been introduced:*

– *(This amendment concerns the Polish version only)*

– *The symbol* $Y(\omega_E, \mu)$ *has been replaced by* $Y(\omega)$.

15. *Paragraph* **4.1.2** *has been amended to read:*

4.1.2 Calculation Method

Calculation of stress ranges. the values of which are directly applied to the fatigue strength analysis may be carried out in two stages. in linear-elastic range.

At the first stage. nominal stresses are to be determined by solving the FEM model of a hull structure part or the whole hull. The values of nominal stresses may be applied directly to the fatigue strength calculations using appropriate S-N curves according to Table 2.4.2. The FEM model is to comply with the requirements set forth in 4.1.3. Loads for the model are to be taken according to the *Rules* – where the long-term prediction was not made or is to be calculated directly for a ship in regular wave according to Chapter 3.

At the second stage. hot-spot stresses are to be determined by solving a fine FEM model of the hull structure part under consideration. Detailed requirements for such calculation model are given in 4.2.

In the calculations. the load acting on the model boundaries. corresponding to stress values calculated at the first stage of analysis or the stress values obtained from the solution of girders or stiffeners beam models. is to be applied. Forced displacements of the nodes on the model boundaries can be also applied.

Where hull loads in regular wave are calculated directly. the second stage is to be followed by the long-term prediction for stress ranges made according to the requirements of Chapter 3.

16. *At the end of paragraph* **4.1.3.1.** *the following wording has been added:*

Nominal stresses are to be determined taking into account the effect of stress concentrations due to abrupt geometric changes of the detail. large cut-outs in plates. etc.

If the stress field is more complex than an uniaxial compression/tension field. the grater value of the principal stresses adjacent to the potential crack location is to be used in fatigue strength calculations.

17. *In paragraph* **4.1.3.4.** *after the second sentence. the following text has been added:*

A uniform mesh is to be used with smooth transition and avoidance of abrupt changes in mesh size.

18. Paragraph **4.2.4.1** *has been amended to read:*

4.2.4.1 When developing a fine FEM model for hot-spot stresses calculation. the following principles are to be used:

– the model is to represent an idealized structure geometry. i.e. disregarding accidental misalignments (possible minor misalignments are accounted for in the S-N curve; major misalignments are to be taken into account in the form of an additional stress concentration factor. according to 4.2.4.3);
– the applied meshing near the notch (the weld. in the majority of cases) is to be fine enough to allow stresses to be determined in points used for strain gauges;
– the finite elements applied are to ensure a linear variation of normal stresses in the direction of plate thickness. The application of 4-node shell or 8-node three-dimensional elements is permitted. In case of steep stress gradient. 8-node three-dimensional elements are recommended;
– where shell finite elements are used. the stiffness of the weld intersection is to be taken into account in the FEM model – e.g. by modelling the welds by inclined shell elements. Shell finite elements are to be located in mid-surface of the plate. Three-dimensional finite elements used are to precisely represent the plate thicknesses. as well as location of plates and welds;
– near the notch. (e.g. the crossing of transverse plates edges). the edge lengths of 4-node shell finite elements and 8-node three-dimensional finite elements are to be about the thickness of the plate in which the fatigue crack may initiate. In the case of 8-node shell finite elements. the length of side may be equal to twice the plate thickness;
– in areas located far from the notch. the application of finite elements having larger dimensions is permitted. The increase in element dimensions with the distance from the notch is to be gradual and the aspect ratio is not to be greater than 3;
– hot-spot stresses are to be determined using extrapolation procedure. shown in Fig. 4.2.4.1. Extrapolation is to be made for the values of principal stresses having the largest absolute values. determined on the surface of the plate; the angle by which the direction of the principal stresses deviates from line AB is to be not greater than 45^{o};
– the principal stresses. which are the basis of extrapolation (Fig. 4.2.4.1). are to be determined by linear extrapolation (in the direction of the weld edge). at points comparable with the extrapolation points used in computer program (usually these are Gauss points). then by linear extrapolation in the direction of AB edge (Fig. 4.2.4.1) and finally. by extrapolation along AB edge;
– where 4-node shell finite elements are used. the principal stresses at the distance of $t/2$ and $3t/2$ from the weld edge. which are the basis of extrapolation. may be determined by linear interpolation of the values of principal stresses on the surface of the plate. in the nodes of particular finite elements lying on AB line.

19. Paragraph **4.2.4.5** *has been added:*

4.2.4.5 Where notches in the structure do not allow to calculate hot spot stresses according to 4.2.4.1 or give ambiguous results. PRS may allow that the values of principal stresses in the finite element at the notch will be applied as hot-spot stresses.

20. Paragraph **4.3** *has been amended to read:*

4.3 Calculation of Stresses having Regard to Weld Dimensions and Shape

The most advanced method of welded joints fatigue strength analysis is direct calculation of stresses in the weld using the FEM model.

Such model is to comprise a part of the hull structure similar to that presented in 4.2. but the dimensions of the finite elements used in the weld and in the vicinity of the weld are to be even smaller than those required in 4.2.

For plates thicknesses ≥ 5 mm. the following should be observed when developing a FEM model:

– an effective weld root radius of $r = 1$ mm is to be considered;
– flank angles of 30^{o} for butt welds and 45^{o} for fillet welds may be considered.

The application of such FEM calculation method and the selection of the appropriate S-N curve will be specially considered by PRS after verification of the submitted calculation results.