Laboratory work № 4

FATIGUE DURABILITY OF HINGE JOINTS

<u>Purpose of work</u> – studying of the nature of fatigue damage of experimental and full-scale structures.

The content of the work

The content of the work is the theoretical definition of the fatigue life of a hinge joint in the areas of possible fatigue damage.

The most probable zones of fatigue damage of hinge joints are in places of maximum stress concentration of a transversely loaded bolt (for example, in the area of the lubrication hole) and in eyes (holes for the bolt) (Fig. 4.1).

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$$lg\,N = 3{,}0 + \frac{lg\,\sigma_в - lg\left\{K_\beta \frac{k\sigma_в}{2}\left[\frac{\sigma_{-1}}{\sigma_т}(1+r) + K_f(1-r)\right]\right\}}{\frac{1}{3}lg\frac{\sigma_в}{\sigma_{-1}}}, \qquad (4.1)$$

where $\sigma_в$ – tensile strength of the bolt material; $k = P/P_в$ – the relative value of the variable load; σ_{-1} – fatigue limit of a smooth standard sample with a symmetric loading cycle (Fig. 4.2); $\sigma_т$ – the yield strength of the material of the bolt; r – he asymmetry coefficient of the joint loading cycle; K_f – effective stress concentration ratio (instead of it, with a certain durability calculation error, the value of the geometric stress concentration coefficient can be used); $K_\beta = \frac{\sigma_{max}/\sigma_в}{k}$ – coefficient of tension of the bolt, characterizing the magnitude of the normal (maximum) stresses in the plane of symmetry of the joint, according to which the bolt fatigue failures occur most frequently.

The magnitude of normal stresses in a transversely loaded bolt is influenced by the following factors

– generalized joint parameters

$$\beta_1 = \frac{\delta_н}{\sqrt{2}}\sqrt[4]{\frac{G_{см\,1}}{EJ}}; \quad \beta_2 = \frac{\delta}{2\sqrt{2}}\sqrt{\frac{G_{см\,2}}{EJ}}, \qquad (4.2)$$

where $2\delta_н$ – total thickness of the covering eye;

δ – the thickness of the inner eye;

$G_{см\,1}$, $G_{см\,2}$ – crumpling modules of covering and middle eyes materials;

E – the elastic modulus of bolt material;

J – the moment of inertia of the bolt in the cross section of the smooth part;;

$n = 2\delta_н / \delta$ – the ratio of the thickness of the eyes;

$\bar{h} = h / d$ – the ratio of the height of the bolt head to its diameter;

$G_{см\,1} / G_{см\,2}$ – the ratio of crumpling modules.

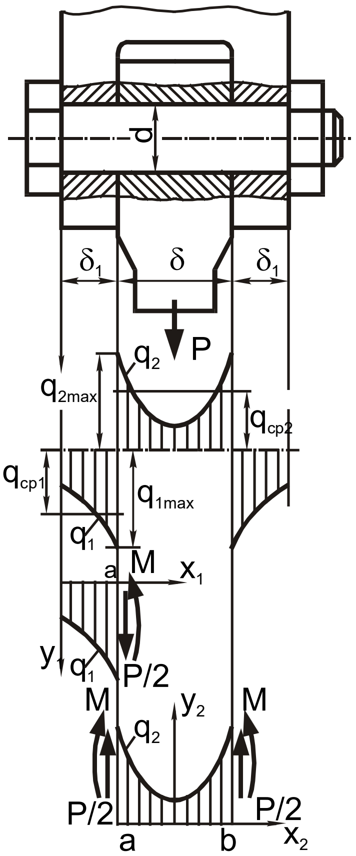

Fig. 4.1. Hinge joint

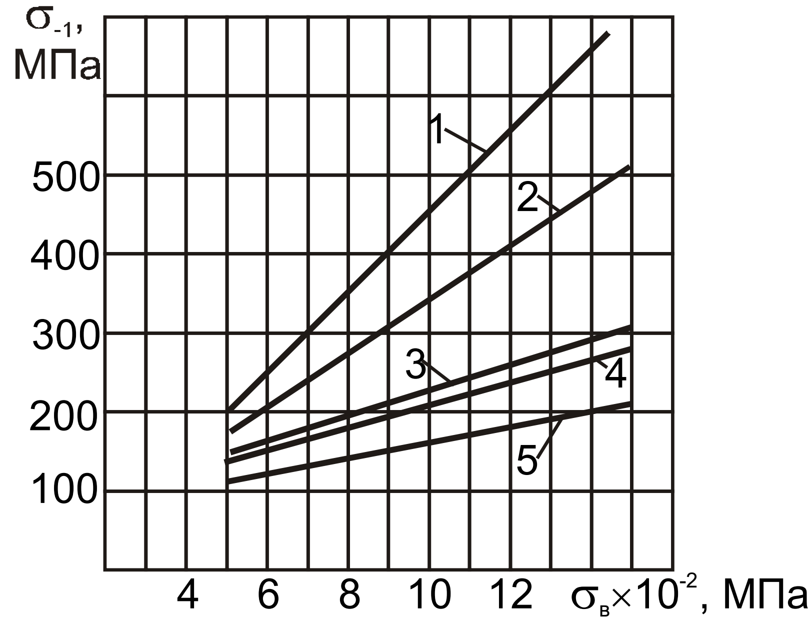

Fig. 4.2. The dependence of the fatigue limit of a smooth stationary sample with a symmetric loading cycle on the tensile strength:
1 - polishing; 2 - grinding; 3 - milling;
4 - turning; 5 - stamping

Figure 4.3 shows the value of the bolt tension ratio K_β with varying values δ and $2\delta_н / \delta$ (ratio of crumpling modules slightly influenced on the value K_β).

If the transversely loaded bolt does not have a lubrication hole in the design section, then it should be approximately assumed that in formula (4.1) K_β = 1,0.

The initial data for the evaluation of durability of transverse loaded bolts (including hollow) are:

– connection geometrical dimensions: d, $d_в$ – external and internal diameters of the hollow bolt; δ, $2\delta_н / \delta$ - thickness of the middle and covering eyes

– bolt and eye material;

– P load on the connection.

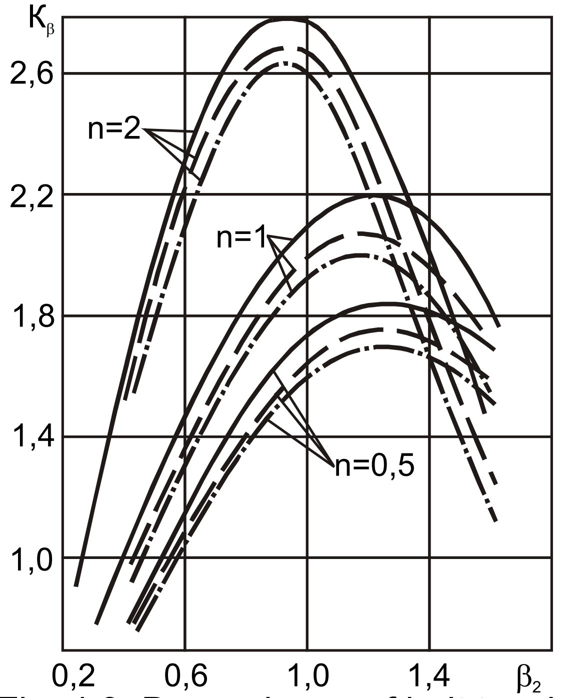

Fig. 4.3. Dependence of bolt tension coefficient on parameters β_2 and $\bar{h}$:

——— – $\bar{h}$ = 0,6;

– – – – – $\bar{h}$=0,8;

–·–·–·– – $\bar{h}$=1,0

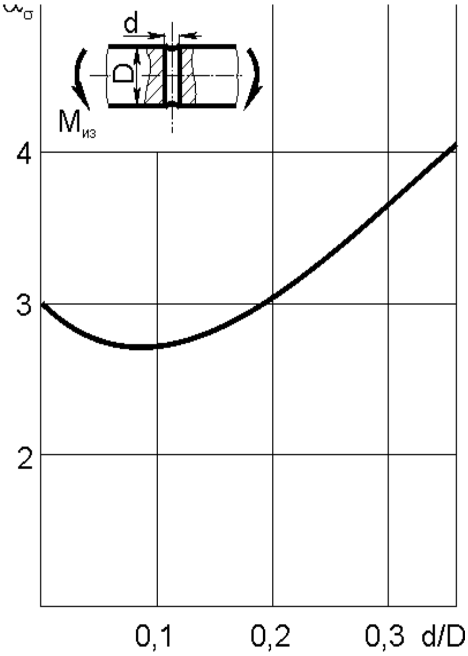

Fig. 4.4. Theoretical stress concentration coefficient depending on the bolt dimensions: $\sigma_{max} = \alpha_\sigma \sigma_н$; $\sigma_н$ – nominal stress in cross-secion

Thus, the calculation of number of cycles to failure for the bolt $N_б$:

– formulas (4.2) to determine it generalized parameters β_1 and β_2 ;

– calculating relative magnitude of the cyclic loading $k = P / P_в$;

– the graph (Fig. 4.2.) is provide smooth specimen endurance limit σ_{-1} for symmetrical cycle;

– depending upon the type of the bolt in design section calculating α_σ ;

– formula (4.1) determines $N_б$.

The fatigue life of the eye, taking into account the bending of the bolt, is estimated similarly using the dependence

$$lg N = 3 + \frac{lg\sigma_в - lg\left\{\dfrac{k\sigma_в}{2}\alpha_{\beta\,max}\dfrac{\sigma_{см}}{\sigma_в}\cdot\dfrac{1}{b/d-1}\left[\dfrac{\sigma_{-1}}{\sigma_т}(1+r)+\alpha_\sigma^н(1-r)\right]\right\}}{\dfrac{1}{3}lg\dfrac{\sigma_в}{\sigma_{-1}}}. \quad (4.3)$$

In the formula (4.3) values $\sigma_{см}$ and σ_{-1} characterize the material of the eye;

b – the width of the eye in section, weakened by the bolt hole;

$\alpha_\sigma^н$ – stress concentration factor, depending on the geometric parameters of the eye (Fig. 4.5) , calculated for the “net” section

$\alpha_{\beta\, max}$ – buckling deformation irregularity coefficient due to the bending of the bolt, which is defined as^

$$\alpha_{\beta\, max} = \frac{y_{max}}{y_{cp}} = \frac{q_{max}}{q_{cp}}$$

where y_{max}, y_{cp} – maximum and average movement of the bolt in the body of the eye;

q_{max}, q_{cp} – maximum and average reaction of the eye to the bolt $q_i = -G_{см\, i} y_i$; here is the index i = 1 refers to embracing, i = 2 - to the middle eyes.

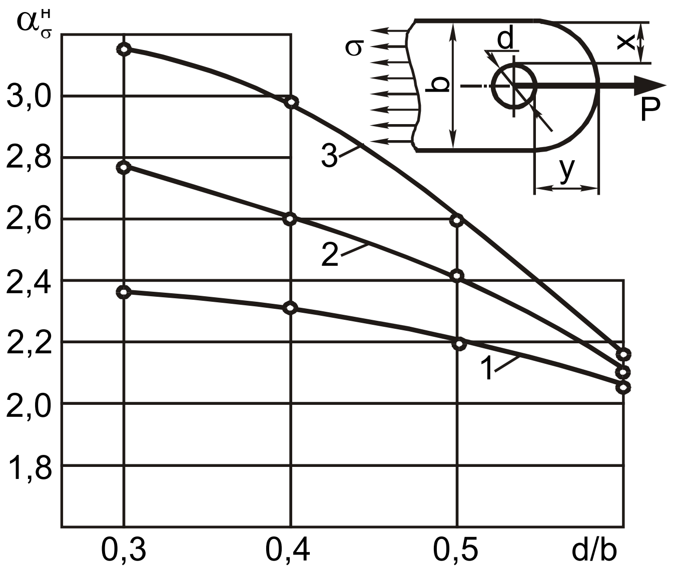

Fig. 4.5. Geometrical stress concentration factor $\alpha_\sigma^н$ calculated relative to the stresses in the “net” section depending on the geometrical parameters of the eyes ($C = y/x$): 1 – C=1,6; 2 – C=1,3; 3 – C=1,0

Coefficient values $\alpha_{\beta\, max}$ covering and middle eyes can be determined by the graphs of Fig. 4.6.

Using the coefficient $\alpha_{\beta\, max}$ calculate the maximum normal stresses in a weakened section, determining the durability of the eye:

$$\sigma_{max} = \sigma_н \alpha_{\beta\, max},$$

where $\sigma_н = \dfrac{\sigma_{см}}{b/d - 1}$ – nominal stress in the cross-section of the eye, weakened by the hole.

The procedure for selecting the parameters of the eyes, taking into account fatigue life under the action of variable loads , taking into account the bending and the bolt, may be as follows:

– carrying out the calculations on static strength, the definition of the following geometrical parameters: d - the diameter of the hole in the eye; δ , $\delta_н$ - thickness of the middle and covering eyes; b - the width of the eye in the section, weakened by the bolt hole, taking into account the stress concentration factor, which takes into account the geometry of the eye (see Fig. 4.5);

– determining the load for evaluating durability of eye and r - the asymmetry coefficient of a loading cycle

– definition of generalized parameters β_1 and β_2 by the formulas (4. 2);

– calculation of the relative magnitude of the load $k = P_н / P_p$;

– finding the fatigue limit of a smooth sample for a symmetric cycle σ_{-1} according to the fig. 4.2

– stress concentration factor α_σ calculation according to the fig. 4.5

– determination of coefficients of non-uniformity of deformation $\alpha_{\beta\, max\, 1}$ and $\alpha_{\beta\, max\, 2}$ according to fig. 4.6

– calculation of the number of cycles to the failure of the eyes N by the formula (4.3).

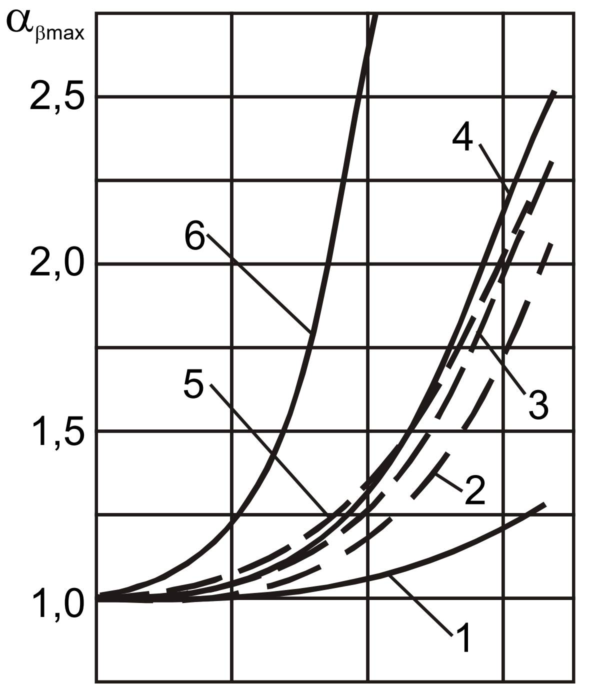

Fig. 4.6. The change in the coefficient of non-uniformity of deformation crumpling $\alpha_{\beta max}$ for covering and middle eyes:

1 and 2 – n=0,5; 3 and 4 – n=1,0; 5 and 6 – n=2,0;

——— – $\alpha_{\beta\, max\, 1}$; – – – – – $\alpha_{\beta\, max\, 2}$; $G_{см\, 1} / G_{см\, 2}$ = 1,0

Variants for individual tasks to perform laboratory work are presented in

Table. 4.1.

Table 4.1

Individual tasks for laboratory work

№	P, т	$k = P / P_B$	№	P, т	$k = P / P_B$
1	12	0,25	13	14,5	0,25
2	13	0,26	14	13,7	0,26
3	14	0,24	15	12,8	0,24
4	15	0,27	16	16,5	0,27
5	16	0,26	17	18,7	0,26
6	17	0,28	18	12,4	0,28
7	18	0,23	19	19,8	0,23
8	19	0,22	20	13,6	0,22
9	20	0,21	21	21,8	0,21
10	13	0,28	22	20,4	0,28
11	14	0,26	23	15,6	0,26
12	15	0,28	24	18,4	0,28