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Mass efficiency determination for shear joint

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Formulae permitting to determine parameters of jointed members and fasteners influence to joint mass are given.

Keywords: loads, material, fasteners, dimensions, mass.

When selecting the joint type, it is necessary to ensure not only provision of strength (static and fatigue), but also an expense of the least mass.

As mass efficiency criterion of the constructive solution of joint the factor determined by the relation can be adopted:

$$K_{мэ} = \frac{M_n + M_{кэ}}{P},$$

where M_n – mass of the modular structure in a joint zone; $M_{КЭ}$ – total mass of fasteners; P – load transmitted by joint.

The mass of joined members from the same material in the joint zone is equal to:

$$M_n = \rho_n \ \delta_n (K\eta bl - \sum_{i=1}^{m} \frac{\pi d_i^2}{4}),$$

where ρ_n - specific material density of joined members; δ_n - pack (joined members) thickness; K – static notch-sensitivity index; b, l – width and length of the joint zone accordingly; m – number of fasteners in the joint; d_i – diameter of the fastener; η - form factor characterizing the difference of the real joint form in plan from the rectangular one.

The mass of fasteners can be determined by the relation:

$$M_{кэ} = \rho_{кэ} \ \sum_{i=1}^{m} \frac{\pi d_i^2}{4} (\frac{\delta_n}{d_i} + \alpha_{ri}\beta_{ri}^2 + \alpha_{бi}\beta_{бi}^2),$$

where $\rho_{кэ}$ - specific material density of fasteners; $\alpha_r, \alpha_б, \beta_r, \beta_б$ - coefficients of proportionality between geometric parameters of nuts (closing heads), bolts (manufactured heads), fasteners and their diameters which are determined by relations:

$$\alpha_\eta = \frac{h_{ri}}{d_i} \ ; \ \beta_{ri} = \frac{D_{ri}}{d_i} ; \ \alpha_{бi} = \frac{h_{бi}}{d_i} ; \ \beta_{бi} = \frac{D_{бi}}{d_i} ,$$

where D_i, $D_б$ – diameters of nuts and bolts or closing and manufactured heads of nuts, h_r, $h_б$ – depths of nuts and bolts. It according to corresponding tables in standards are taken

Values of factors $\alpha_r, \alpha_б, \beta_r, \beta_б$ are determined by static processing of geometric parameters for fasteners of various type sizes. If fastener diameter in the joint is equal (that especially typically for riveted and bolt-riveted joints), total mass of shear joint is determined by expression:

$$M = M_n + M_{кэ} = \rho_n \delta_n (K_\eta dl - m \frac{\pi d^2}{4}) + \rho_{кэ} m \frac{\pi d^3}{4} (\frac{\delta_n}{d} + \alpha_r \ \beta_r^2 + \alpha_б \ \beta_б^2)$$

The condition of balanced life is the necessary one (but not enough) ensuring the minimum joint mass.:

$$P = P_{ср.кэ} = P_{ср} = P_{разр} = P_{см} \qquad (1)$$

where $P_{ср.КЭ}$ – breaking shear force of fasteners; $P_{ср}$, $P_{разр}$, $P_{см}$ – breaking force of shear, tensile and bearing load of a joint pack.

From the condition (1) we shall determine the geometric parameters of the shear joint ensuring fulfillment of these conditions. To analyze the joint parameters effect on their mass the following assumptions will be taken, when calculating:

a) the force is distributed between fasteners uniformly;

b) material of joined members is equal;

c) there are no limitations on geometrical sizes of the joint.

Then, from the condition $P_{ср.КЭ} = P$ we obtain:

$$d = \frac{2\sqrt{P}}{\sqrt{mn\pi\tau_{кэ}}}, \qquad (2),$$

where n – number of shear planes of a fastener; $\tau_{кэ}$- breaking shear stresses of fastener material.

From the condition $P_{см} = P$, subject to (2), we find:

$$\delta_n = 2\delta \frac{\sqrt{P}\sqrt{n\pi\tau_{кэ}}}{\sigma_{см}\sqrt{m}}, \qquad (3),$$

where $\sigma_{см}$ - breaking bearing stresses of a joint pack material.

The joint width will depend on bolt number in the first row m_1, and this number, in its turn, will be determined by width b and recommended sizes of strips.

From the condition $P_{разр} = P$, subject to (2) and (3), we obtain:

$$b = \frac{2\sqrt{P}}{\sqrt{mn\pi\tau_{кэ}}} (m \frac{\sigma_{см}}{\sigma_в} + m_1), \qquad (4)$$

from the condition of providing allowable strips between rows –

$$b = (m_1 - 1)\gamma d + 2\psi d , \qquad (5)$$

where γd - distance between rows; ψd - distance from an axis of fasteners up to an edge of a joined member.

From (4) and (5) we find

$$b = \frac{2\sqrt{P}}{\sqrt{mn\pi\tau_{кэ}}} \left[\frac{\gamma (m \frac{\sigma_{см}}{\sigma_в} + 1) - 2\psi}{\gamma - 1} \right], \qquad (6)$$

$$m = \frac{m\dfrac{\sigma_{см}}{\sigma_в} + \gamma - 2\psi}{\gamma - 1}.$$

Length of the joint zone will be represented by the relation:

$$l = 2a + \varphi d(\frac{m}{m_1} - 1), \qquad (7)$$

where a - strip width of a joined member shear zone; φd - distance between fasteners in a row.

From condition $P_{cp} = P$,in view of adopted assumptions, we obtain:

$$a = \frac{\sigma_{см}\sqrt{P}}{\sqrt{mn\pi\tau_{кэ}\tau_{cp}}},$$

where τ_{cp} - breaking shear stresses of the joined members material.

In view of obtained previously relations the expression (7) is written in such a way:

$$l = \frac{\sqrt{P}}{\sqrt{mn\pi\tau_{кэ}}}\left\{\frac{\sigma_{см}}{\tau_{cp}} + 2\varphi\left[\frac{m(\gamma-1)}{m\dfrac{\sigma_{см}}{\sigma_в} + \gamma - 2\psi} - 1\right]\right\}.$$

Then

$$M_n = \frac{\rho_n P^{3/2}}{\sigma_{см}\sqrt{mn\pi\tau_{кэ}}}\left\{\frac{2K\eta}{m}\left[\frac{\gamma(m\dfrac{\sigma_{см}}{\sigma_в}+1) - 2\psi}{\gamma - 1}\right]\left[\frac{\sigma_{см}}{\tau_{cp}} + \frac{2\varphi m(\gamma-1)}{m\dfrac{\sigma_{см}}{\sigma_в} + \gamma - 2\psi} - 2\varphi\right] - \pi\right\};$$

$$M_{кэ} = \frac{2\rho_{кэ}P^{3/2}}{\sqrt{mn}(n\tau_{кэ})^{3/2}}\left(\frac{n\pi\tau_{кэ}}{2\sigma_{см}} + \alpha_r\beta_r^2 + \alpha_б\beta_б^2\right).$$

With the help of obtained expressions the effect of parameters of shear joint on its mass will be estimated:

1. The mass of a pack and fasteners grows with increase of transmitted load in extent 3/2.

2. The mass of a pack is proportional to the relation $\rho_n / \sigma_{см}\sqrt{\tau_{кэ}}$, i.e. application of fasteners from stronger material results in mass reduction of a pack.

3. The mass of fasteners is reduced with reducing the relation $\rho_n / \tau_{кэ}$.

4. The mass of a pack and fasteners are reduced with increase of their number.

5. The relation of pack mass on the value of strips between fasteners in a row has linear character and from value of strips between rows – nonlinear one. Depending on

number of fasteners prevailing effect on mass is rendered by one or other type of strips: with increase of number of fasteners the effect of strips between fasteners increases and between rows reduces.

6. Effect of a static notch-sensitivity index on pack mass is reduced with increase of fastener number.

7. Mass efficiency of the shear joint is reduced with increase of load.

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Определение массовой эффективности срезного соединения

Представлены формулы, позволяющие определить влияние на массу соединения параметров соединяемых элементов и крепежа.

Ключевые слова: нагрузка, материал, крепеж, размеры, масса.

Визначення масової ефективності зрізного з’єднання

Наведено формули, що дозволяють визначити вплив на масу з`єднання параметрів з’єднуваних елементів і кріплення.

Ключові слова: навантаження, матеріал, кріплення, розміри, маса.