Laboratory work №1

FATIGUE DESIGNING OF ELEMENTS WITH HOLES AND FITTINGS

The purpose of the work is to study the influence of the ratio of the hole diameter to the strip width on its durability, as well as the ratio of the elements geometric parameters in the fillet to their durability. The choice of rational parameters of the strip with a hole, providing a given durability.

The content of the work

1. Acquaintance with typical variants of constructive design zones of an airframe with holes and fillets.
2. The study of typical variants of structural elements with holes and fillets, zones and the nature of their fatigue damage.
3. Acquaintance with the method of calculating the cyclic durability of structural elements with holes and fillets.
4. The study of the influence of design parameters on the durability of plates with holes and elements with fillets.
5. The choice of rational thickening of the strip in the area of the hole to ensure its specified durability.

All calculations are carried out on a computer according to the developed program.

Calculation of the cyclical durability of the strips with holes and fillets

The airframe design contains structural irregularities - openings for fuel overflow, fuel and other fittings wiring, condensate drainage, drainage (Fig. 1.1), as well as structural irregularities of fillet transitions (Fig. 1.2). Their shape is usually of two types: the first type is the transition of an element with a line of fillet located parallel to the element being joined and perpendicular to the action of the main force flow; the second type is a semi-elliptical transition. The fillet transition radius is from 3 to 5 mm. In some cases, fillet transitions replace the bevels or increase their radius to 15 ... 20 mm.

In laboratory work we investigate the influence of the ratio of the diameter of the hole to the width of the strip on its durability, as well as the ratio of the geometric parameters of the power elements in the zone of fillet transitions on their durability. We carry out a selection of rational parameters of plates with holes that ensure their given durability.

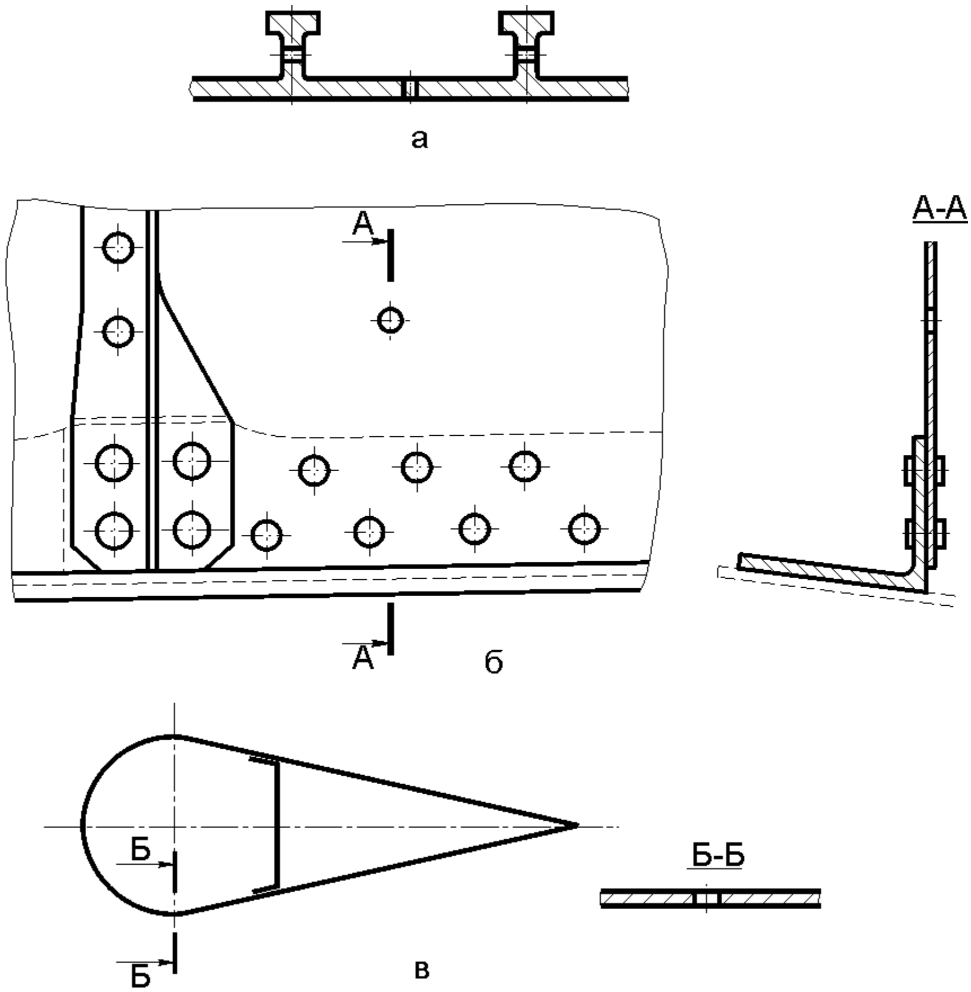

Fig. 1.1. Structural elements with holes:
a - in the longitudinal set of the wing;
b - in the spar web; в - drainage hole in the aileron

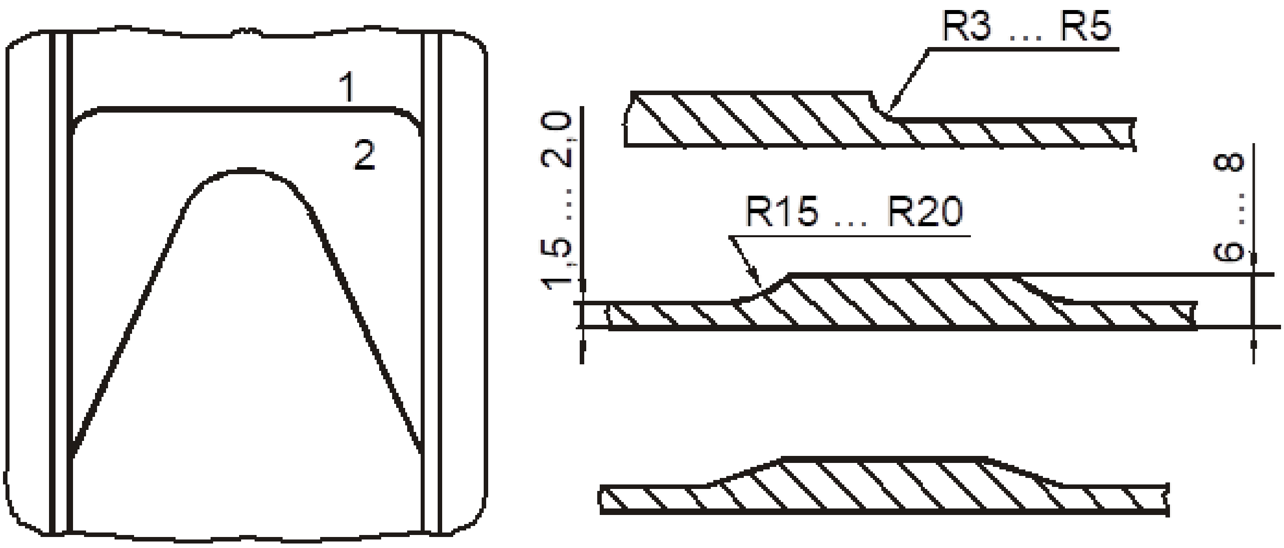

Рис. 1.2. Typical versions of skins thickness changings

Durability of smooth structural elements made of aluminum alloys under cyclic loading is calculated from the dependence:

$$\sigma_{a\ sm} = 10^{0,37}(\sigma_в - \sigma_{m\ sm})^{0,63}[0,64 + 43,3(lg\,N)^{-2,1}],$$

$$\text{или } lg\,N = \left[\frac{\sigma_{a\ sm}}{101,505(\sigma_в - \sigma_{m\ sm})^{0,63}} - 0,01478\right]^{-0,47619}. \tag{1.1}$$

Here $\sigma_{a\ sm}$, $\sigma_{m\ sm}$ – alternating and mean cyclic stress values in a smooth sample, MPa; $\sigma_в$ – tensile strength of the sample material, MPa; N – durability, cycles;

$$\sigma_{a\ sm} = \frac{\sigma_{max\ sm} - \sigma_{min\ sm}}{2}; \qquad \sigma_{m\ sm} = \frac{\sigma_{max\ sm} + \sigma_{min\ sm}}{2}, \tag{1.2}$$

where $\sigma_{max\ sm}$, $\sigma_{min\ sm}$ – maximum and minimum cycle stress, MPa.

Calculations are carried out for the load-load cycle, i.e. $\sigma_a = \sigma_m$.

Modeling of structural elements with holes and fillets can be carried out on samples according to GOST 25.502-79.

In fig. 1.3, 1.4 depicts samples with stress concentrators – a hole and fillets.

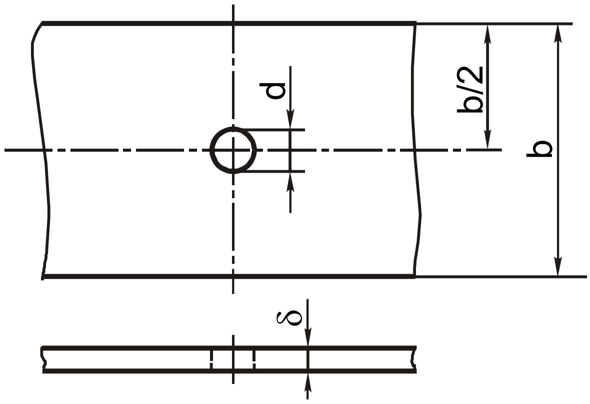

Fig. 1.3. The central part of the sample with a round hole

Using S-N curve of a smooth sample and the value of the stress concentration factor ($K_\sigma = \sigma_{a\ sm} / \sigma_{a\ nom}$), depending on the number of loading cycles to failure, it is possible to obtain nominal cyclic alternating stresses over the “gross” section for structural elements with concentrators

$$\sigma_{a\ nom} = \sigma_{a\ sm} / K_\sigma, \tag{1.3}$$

where K_σ – stress concentration factor.

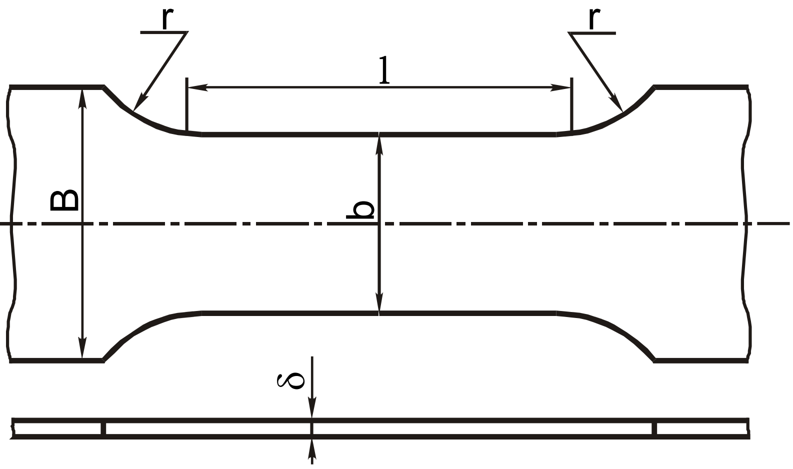

Fig. 1.4. The working part of the rectangular sample with fillets

Factor K_σ determined by calculation using the expression for the coefficient of sensitivity to stress concentration

$$q = \frac{K_\sigma - 1}{\alpha_\sigma - 1}, \quad (1.4)$$

where α_σ – theoretical stress concentration factor.

From formula (1.4) for given N = const (in this laboratory work, the calculation is carried out for the case N = 10^4, 10^5 и 10^6 load cycles) can determine the effective stress concentration factor: $K_\sigma = 1 + q(\alpha_\sigma - 1)$.

Dependencies $q = f(N)$ for aluminum alloys D16 и V95 shown in Fig. 1.5.

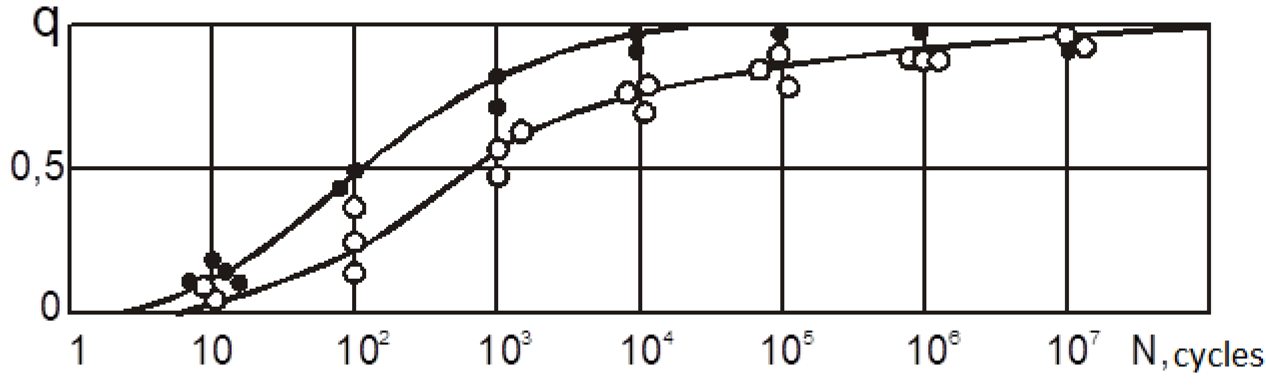

Fig. 1.5. The effect of the number of loading cycles on the magnitude of the coefficient of sensitivity to stress concentration for aluminum alloys:
• – V95 aluminum alloy; o – aluminum alloy D16T

Plots $\alpha_\sigma = f(d/b)$, $\alpha_\sigma = f(r/B)$ for concentrators as a hole and fillet are shown in Fig. 1.6 и 1.7.

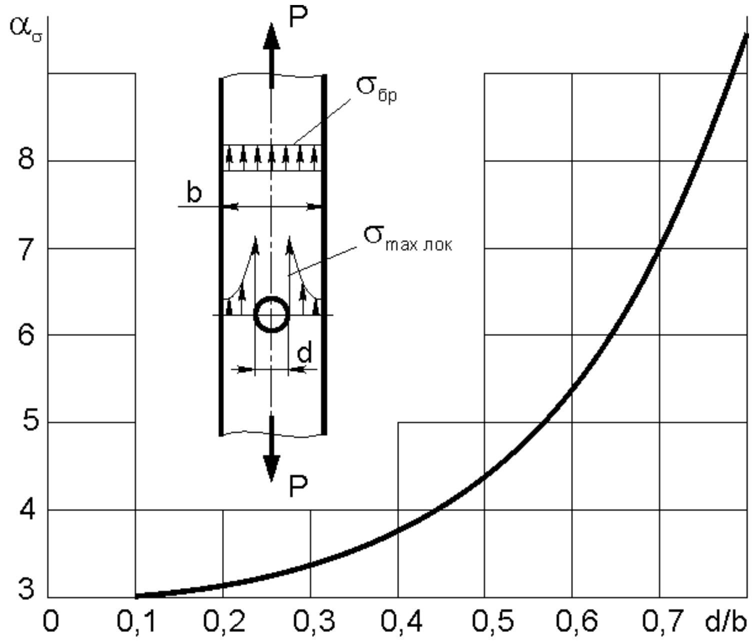

Fig. 1.6. The theoretical stress concentration coefficient for a strip of finite width with a free unloaded hole, calculated as the ratio $\sigma_{max\ loc}$ to $\sigma_{gr} = P / b\delta$,

$$\alpha_\sigma = \sigma_{max\ loc} / (P / b\delta)$$

When choosing a material for structural elements, analyze the S-N curves of smooth samples and samples with typical stress concentrators, obtained experimentally in research laboratories (Fig. 1.8, 1.9). These curves can be used as the basis for calculating the durability of structural elements with other similar concentrators. For example, fatigue tests of samples of plates with holes are usually carried out at a ratio of plates width b to hole diameter d equal to 6. The results of fatigue tests are given in reference books, for example, as dependencies

$$N(\sigma_{net} / 10)^m = A, \tag{1.5}$$

where σ_{net} – nominal cyclic stresses over the net section for a structural element with a concentrator, MPa; m и A – experimental coefficients (table. 1.1).

Substituting the relation (1.5) values m and A, taken from the table. 1.1, and σ_{net}, MPa, can get the value of cyclic durability $\boldsymbol{N}$.

At the stage of preliminary design of structural elements with a hole, which are characterized by $\boldsymbol{b/d}$, not equal 6, durability assessment can be done using dependency

$$N \cdot \left(\frac{\sigma_{net\,1}}{10} \frac{K_{\sigma 1}}{K_\sigma} \right)^m = 10^A, \tag{1.6}$$

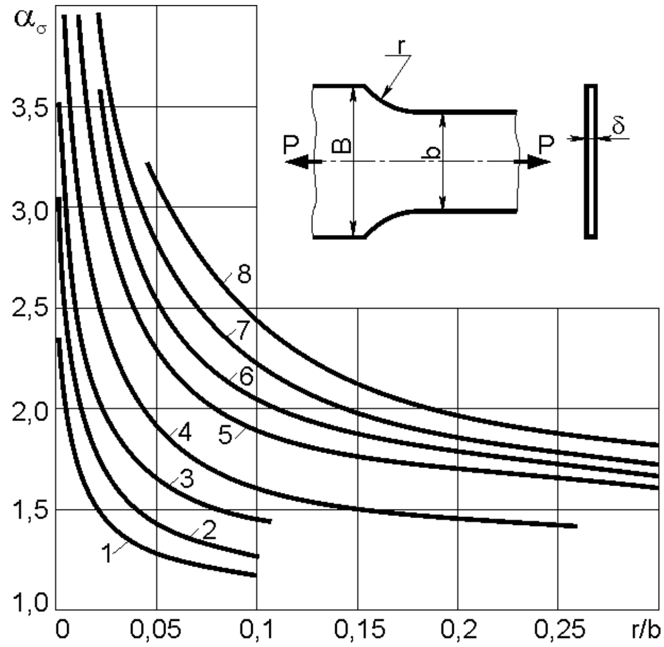

Fig. 1.7. Theoretical stress concentration factor
for flat rod with symmetrical fillets:
B/b for 1 – 1,01; 2 – 1,02; 3 – 1,05; 4 – 1,1; 5 – 1,2; 6 – 1,3; 7 – 1,5; 8 – 2,0

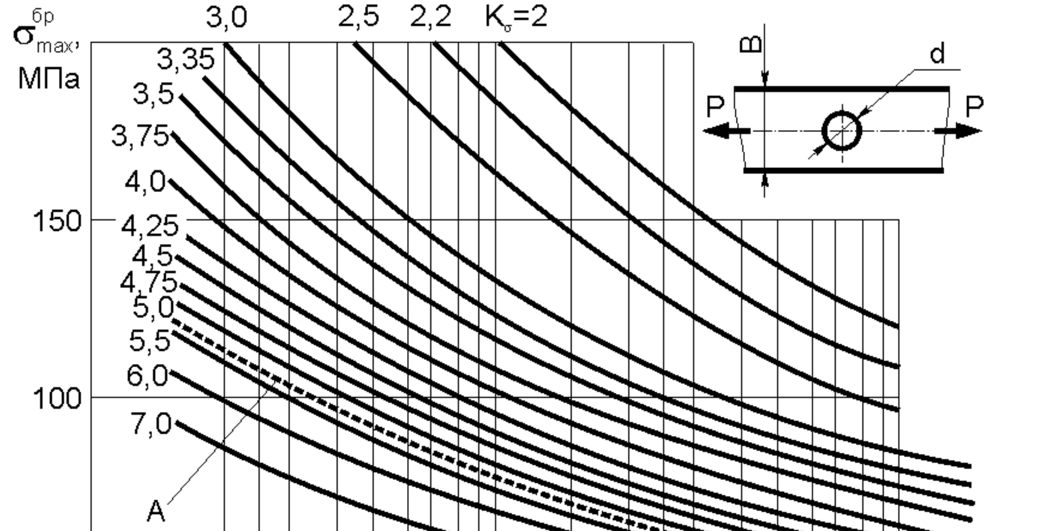

Fig. 1.8. S-N curves of the strip of sheet material D16T with a free unloaded hole: A – eye b = 30 mm, d = 12 mm

where m, A – coefficients obtained by processing the test results of basic samples of structural elements (for example, with $b/d=6$);

K_σ – the effective stress concentration ratio in the base sample $(b/d=6)$;

$K_{\sigma 1}$, $\sigma_{net\,1}$ – effective stress concentration and stress ratio in the “net” section in the designed structural component with the ratio $b/d \neq 6$.

Table 1.1

Experimental values of the coefficients of the S-N curve of a plate with a hole

Material	m	A	b/d	α_{σ}	$\sigma_{в}$, MPa
D16ChT profile	4,03	$10^{9,979}$	6	3	486
1163T	4,36	$10^{10,449}$	6	3	463
D16T profile	4,55	$10^{10,742}$	6	3	510
V95PChT2	4,88	$10^{10,99}$	6	3	520
D16ChT plate	3,95	$10^{9,776}$	6	3	440

Using dependencies (1.5) and (1.6), it is possible to calculate the durability of structural elements with stress concentrators in the form of a free hole or fillet with different geometry, and also perform design calculations of their parameters for a given durability.

At the stage of preliminary design, it is possible in relation (1.6) to replace the factor concentration coefficients with the factor of the corresponding geometric concentration coefficients.

In fig. 1.9 shows the nature of the destruction of the sample strip with a hole during fatigue testing

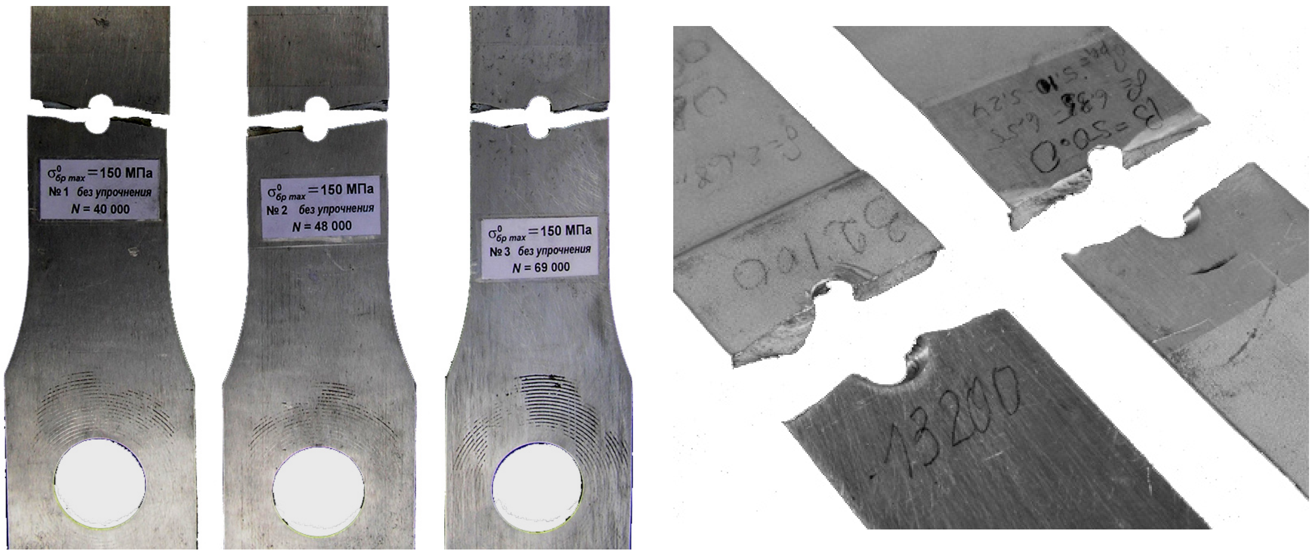

Fig. 1.9. Характер разрушения образцов полосы с отверстием при усталостных испытаниях

Table 1.2 – Individual tasks for laboratory work

№	Material	$\sigma_в$, MPa	σ_a, MPa	σ_m, MPa	Plate with a hole		Fillet	
					d/b variant 1	d/b vriant 2	r/b	B/b
1	Д16Т – pressed panel	510	120 100	100 50	0,16	0,3	0,1	1,1
2	Д16Т – pressed panel	510	115 105	90 70	0,2	0,32	0,05	1,2
3	Д16Т – pressed panel	510	100 50	100 70	0,17	0,34	0,6	1,3
4	Д16Т – pressed panel	510	130 105	90 45	0,18	0,36	0,7	1,5
5	Д16Т – pressed panel	510	130 110	100 90	0,19	0,4	0,8	2,0
6	Д16чТ	486	120 100	100 50	0,16	0,3	0,1	1,1
7	Д16чТ	486	115 105	90 70	0,2	0,32	0,05	1,2
8	Д16чТ	486	100 50	100 70	0,17	0,34	0,6	1,3
9	Д16чТ	486	130 105	90 45	0,18	0,36	0,7	1,5
10	Д16чТ	486	130 110	100 90	0,19	0,40	0,8	2,0
11	Д16чТ – pressed panel	479	120 100	100 50	0,16	0,3	0,1	1,1
12	Д16чТ – pressed panel	479	115 105	90 70	0,2	0,32	0,05	1,2
13	Д16чТ – pressed panel	479	100 50	100 70	0,17	0,34	0,6	1,3
14	Д16Т – pressed panel	510	140 100	130 90	0,16	0,3	0,1	1,1
15	Д16Т – pressed panel	510	120 100	100 50	0,16	0,3	0,1	1,1
16	Д16Т – pressed panel	510	115 105	90 70	0,2	0,32	0,05	1,2
17	Д16Т – pressed panel	510	100 50	100 70	0,17	0,34	0,6	
18	Д16Т – pressed panel	510	130 105	90 45	0,18	0,36	0,7	1,5
19	Д16Т – pressed panel	510	130 110	100 90	0,19	0,4	0,8	2,0
20	Д16чТ	486	120 100	100 50	0,16	0,3	0,1	1,1
21	Д16чТ	486	115 105	90 70	0,2	0,32	0,05	
22	Д16чТ	486	100 50	100 70	0,17	0,34	0,6	1,3
23	Д16чТ	486	130 105	90 45	0,18	0,36	0,7	1,5

Note. The diameter of the hole for all cases of calculation is 5 mm.

Report content

1. The task and initial data for the calculation of the durability of plates with holes and elements with fillets.

2. Sketches of typical variants of samples of structural elements with holes and fillets.

3. A brief description of the method for calculating the durability of plates with holes and power elements with fillets.

4. Sketches of zones of destruction of plates with holes and power elements with fillets.

5. Calculation of durability and fatigue curves of a smooth plate, a plate with a hole and a power element with fillet transition, as well as a design calculation of the parameters of plate thickening in the hole area to ensure a given durability.

6. Conclusions from the results of calculations.