Laboratory Work № 6

INFLUENCE OF DESIGN AND TECHNOLOGICAL FACTORS ON DURABILITY OF SHEAR BOLT CONNECTIONS

Purpose of the Work – study of the design features of transversal shear bolted joints, methods for calculating the fatigue life of shear bolted joints; study of the influence of structural and technological parameters of bolted joints on their durability and weight; the choice of parameters and the design of the structure of the compound with a given fatigue life

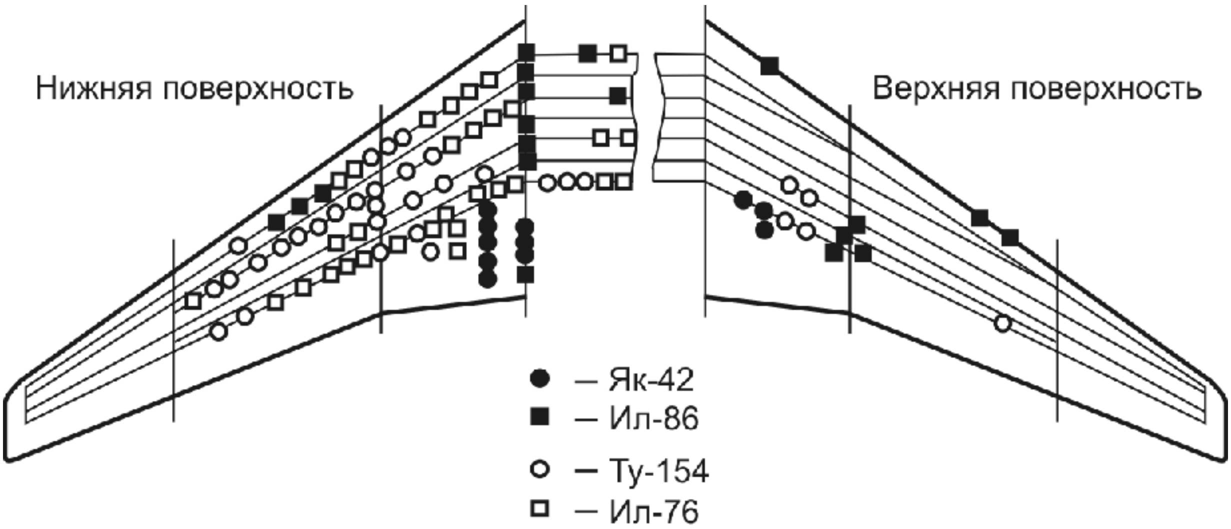
Content of the Work

1. Acquaintance with typical designs of shear bolted joints, their features and the nature of fatigue failure.
2. Acquaintance with the method of parameters calculation of the stress state in a joint under static loading at the operating level of cyclic loads.
3. The study of methods for calculating the durability and design of joints of a given fatigue life.
4. The study of the influence of design and technological parameters on the durability and mass of the joints.
5. Development of a sketch of a transversal shear bolt joint of a given durability.

Transversal shear bolted connections are used in aircraft wings structure (Fig. 6.1). There are two typical zone, depending on the location of a joint along chord of the wing: panels skin joints (Fig 6. 2 and 6. 3, b). joint in the zone of the stringer set of the panel (Fig. 6. 2 , b , 6. 3 , a). In static strength calculations, these two zones are often combined, assuming the stringer is located in the middle of a joint, the width of which is equal to the pitch of the stringer panel set. Design Characteristic of this joints are:

- multi - row bolt arrangement (2-7 rows);
- the tendency to increase the number of shear planes of fasteners;
- change the stiffness of the joined elements along the length of the joint.

Typically used materials in aircraft structures are В95пчТ2 (V95pchT2) (for upper panels) and Д16чТ (D6chT) (lower panels), as well as modifications to these alloys, the bolts of steel ЗОХГСА (30HGSA) or titanium alloy ВТ 16 (VT 16). Typical designs of shear bolted connections are shown in fig. 6. 2 - 6. 3



Самолет	Тип конструкции			Тип НДС	
	панель	лонжерон	прочие	однопараметрическое	многопараметрическое
Ту-154	72%	27%	-	44%	50%
Ил-76	47%	52%	-	44%	50%
Як-42	27%	24%	49%	28%	72%
Ил-86	26%	44%	30%	28%	72%

Рис. 6.1. The zone of aircraft wings destruction in full-scale resource tests

The joint static strength calculation consists of preliminary selection of the number of connection row, the diameter of the fasteners, and the thickness of the parts to be joined. Material of connected elements are selected, as a rule, earlier, at the stage of preliminary design of the wing.

In multi-row joints, there is a load distribution irregularity across the rows of the joint, which affects the static strength and fatigue life. Method of load distribution calculation in rows of a joint by structural mechanics methods given in [10]. Design scheme is a statically indeterminable system, where the shear forces in bolts or the tensile load in connectable parts between the bolts (Fig. 6. 4).

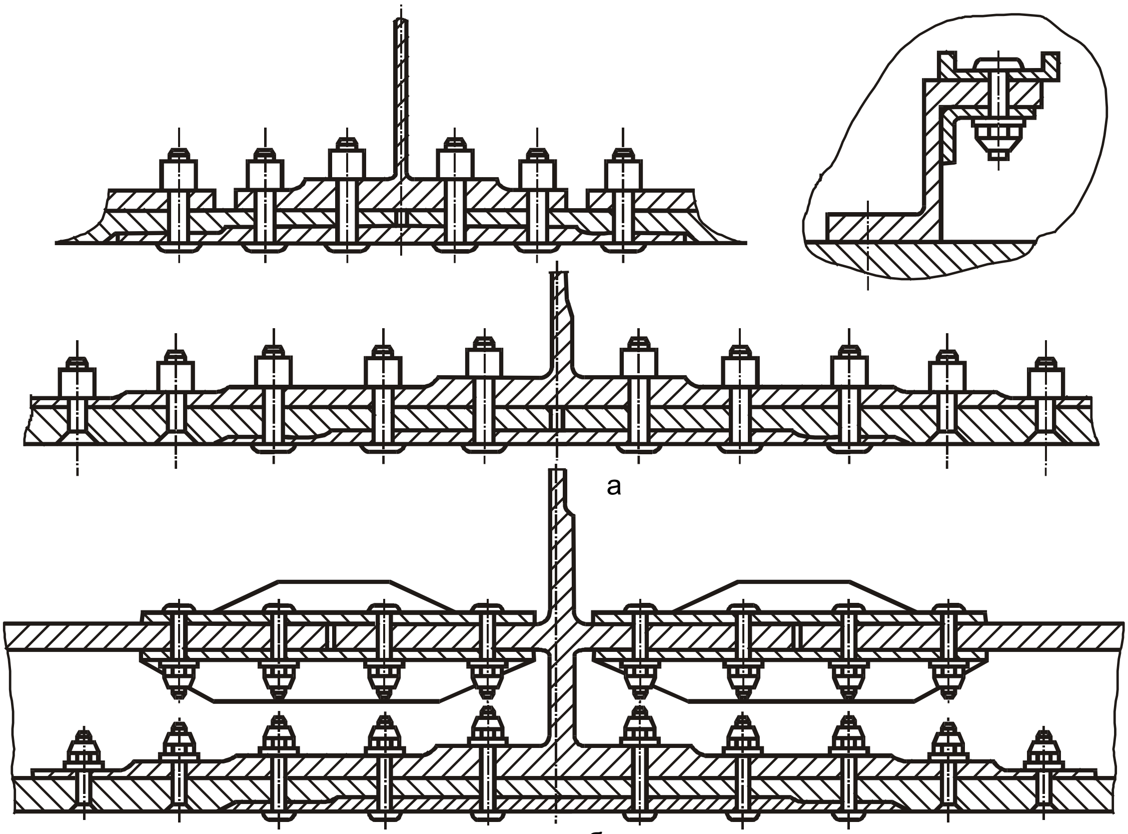


Рис. 6.2. The design of the panel rearranging zones and the stringer set of the Yak-42: a - panel and wing; b - the first set of stringer

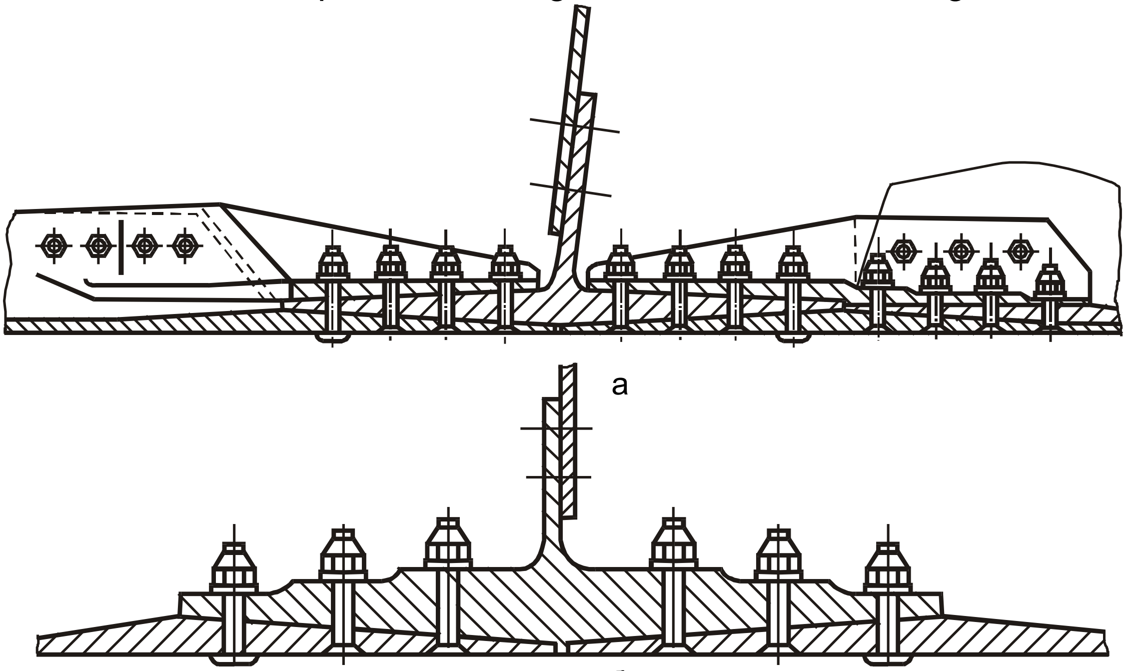


Рис. 6.3. Rearranging zone design:
a - panels of the wing of the IL-86; b - IL-76 wing panels

After determining the joint parameters, tensile and bearing stresses are calculated along the rows of bolts according to work [10].

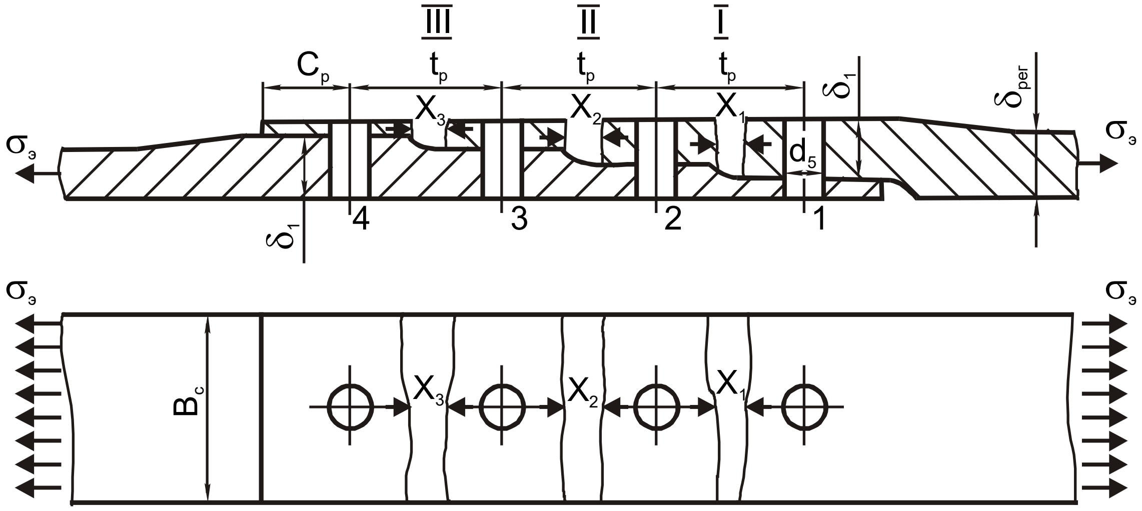


Рис. 6.4. Design scheme and geometrical parameters of a multi-row shear bolted joint (bolt heads and nuts not shown)

The system of canonical equations for determining unknown constants (tensile forces in a sheet) has the form

$$\begin{cases} \delta_{11}X_1 + \delta_{12}X_2 + \Delta_{1P} = 0; \\ \delta_{21}X_1 + \delta_{22}X_2 + \delta_{23}X_{2P} = 0; \\ \delta_{32}X_2 + \delta_{33}X_3 + \Delta_{3P} = 0, \end{cases}$$

where $\delta_{11} = \alpha_1 + \beta_1 + C_1 + C_2 = \gamma\ t_p\left(\dfrac{1}{E_1F_1} + \dfrac{1}{E_2F_2}\right) + C_1 + C_2;$

$\delta_{12} = \delta_{21} = -C_2;\ \delta_{23} = \delta_{32} = -C_3;\ \delta_{22} = \alpha_2 + \beta_2 + C_2 + C_3;$
$\delta_{33} = \alpha_3 + \beta_3 + C_3 + C_4;\ \Delta_{1P} = -P_э\alpha_1;\ \Delta_{2P} = -P_э\alpha_2;$
$\Delta_{3P} = -P_э(\alpha_3 + C_4),$

here $P_э$ – the value of the operational load on the connection; C_1, C_2, C_3, C_4 – compliance of fasteners along the rows of the joint; α_i, β_i – compliance of the upper and lower parts of the sheet in section "i"; $E_1F_1 = E_1B_c\delta_{1i}$ – tension stiffness of the upper sheet; $E_2F_2 = E_2B_c\delta_{2i}$ – tension stiffness of the lower sheet; t_p – step between rows of bolts, t_p = 3 … 4$d_б$; γ =1,2 – empirical coefficient; E – the modulus of elasticity of the material of the connected parts (72000 MPa for aluminum alloys).

After calculating the values X_1 – X_3 force on the bolt at the place of probable fatigue failure is determined by the dependence

$$P_{б1} = P_э - X_1.$$

Values of compliance of bolts are given in table. 6.1.

Table 6.1

Experimental values of bolt compliance for joints from aluminum alloys, type Д16Т (D16T)

Ductility the bolt	Bolt Material	Bolt diameter mm					
		5	6	8	10	12	14
$C_б \cdot 10^3$, mm/H	30ХГСА	3,65	3,3	2,7	2,25	1,6	1,15
	ВТ16	6,35	5,8	5,2	4,35	2,9	2,3

Then bearing stress

$$\sigma_{см\,1} = \frac{P_э - X_1}{d_б \delta_1}.$$

It is necessary to check that the founded value $\sigma_{см\,1}$ did not exceed the allowable value according to the condition sheet strength.

After calculating the geometrical parameters of the joint according to the condition of its static strength, the cyclic durability should be determined. Analytical-experimental method for estimating the cyclic durability of joints by the magnitude of nominal stresses is based on the dependence [9]

$$\sigma_0 = k_{см}\sigma_{см} + k_л\sigma_л + k_и\sigma_и,$$

where $k_{см}$, $k_л$, $k_и$ – experimentally determined damage factors for the corresponding types of stress; $\sigma_{см\,1}$ – the nominal bearing stresses the sheet on the first row of bolts; $\sigma_л$ – rated bending stress at the place of fatigue failure.

For the considered construction and its design scheme (see Fig. 6. 4) stresses $\sigma_л$ are

$$\sigma_л = \frac{P_э - P_{б1}}{B_c\delta_1} = \frac{X_1}{B_c\delta_1}.$$

Bearing stresses $\sigma_{см\,1}$ calculated as nominal , and flexural strength H e at the area of the first row of the compound is approximately found as follows:

$$\sigma_и = \frac{P_э\varepsilon}{W_1} = \frac{\sigma_э B_c \delta_1}{W_1}\varepsilon.$$

where ε –eccentricity of the load transfer at the place of sheet destruction;

$$\varepsilon = 0{,}5(\delta_в + \delta_н)P_б,$$

where $\delta_в$, $\delta_н$ – thickness of the upper and lower joined sheets at the place of destruction; $P_б$ – part of the load, coming to outer row of the bolts; $W_1 = \dfrac{B_c\delta_1^2}{6}$ – moment of resistance of the sheet being destroyed.

Value $k_{см}$ depends on the type of bolts used, their fit into the hole, the magnitude of the axial tightening, the number of loading cycles. Values $k_{см}$ and

$k_и$ and their expressions are shown in fig. 6. 5.. For the calculation we accept $k_л$ = 1. Consequently, according to [9]

$$\sigma_{пл}(N) = \sigma_0(N),$$

where $\sigma_{пл}(N)$ – expression for the curve of the cyclic durability of the plate with a filled nonleaded hole (base curve); $\sigma_0(N)$ – expression for curve cyclic durability of the joint.

Solve this equation for N (cycle durability) can be graphically or by approximation method. The expressions for the base curves of cyclic durability and the base curves themselves are shown in fig. 6. 5 .

After determining the cyclic durability of a joint with geometrical parameters selected from the condition of static strength, it must be compared with the given one, and if the given durability larger than calculated is necessary to hold the joint rework. One very common ways to improve durability of joints is to reduce the magnitude of the nominal stresses by increasing the thickness of the joined sheets according to probable place of fatigue failure, which would increase its weight

On the other hand, joints modification available. To study the effect of structural and technological parameters on the fatigue life and the mass of a compound, we consider the following technical solutions (modification variants), shown in Fig. 6.6 :

- the basic version of the compound (Fig. 6. 6 , a);
- reducing the diameter of the first row of bolts (Fig. 6. 6 , b);
- replacement countersunk bolts of the first row of connection on bolts with a non-countersunk head (Fig. 6. 6, c) .

Analysis of the proposed technical solutions.

1. Reducing the diameters of the first row of bolts compared with the diameters of the bolts of the inner rows leads to an increase in the compliance of the outer rows of bolts, which causes a decrease in their workload. But at this, the static strength of the joint decreases and the bolt bearing stresses increase in the zone of probable fatigue failure. To study the effect of this decision, it is necessary to perform calculations of static strength, durability and mass efficiency of this decision.

2. Replacing countersunk bolts to non-countersunk. We believe that the load of bolts on the rows of the connection is the same as that of the base connection. Improving the fatigue life has reached due to the fact that the fatigue fracture area realized non-countersunk filling hole and calculation durability of such a joint is performed using plate fatigue curve with filled non-countersunk opening. When the same level of stresses durability of non-countersunk joint 1.5 - 2.5 times higher than the durability of the countersunk. This method is good for ensuring fatigue life, it is technologically beneficial, however, it leads to a decrease in the aerodynamic quality of the aircraft due to the presence of bolt heads protruding onto the aerodynamic surface.

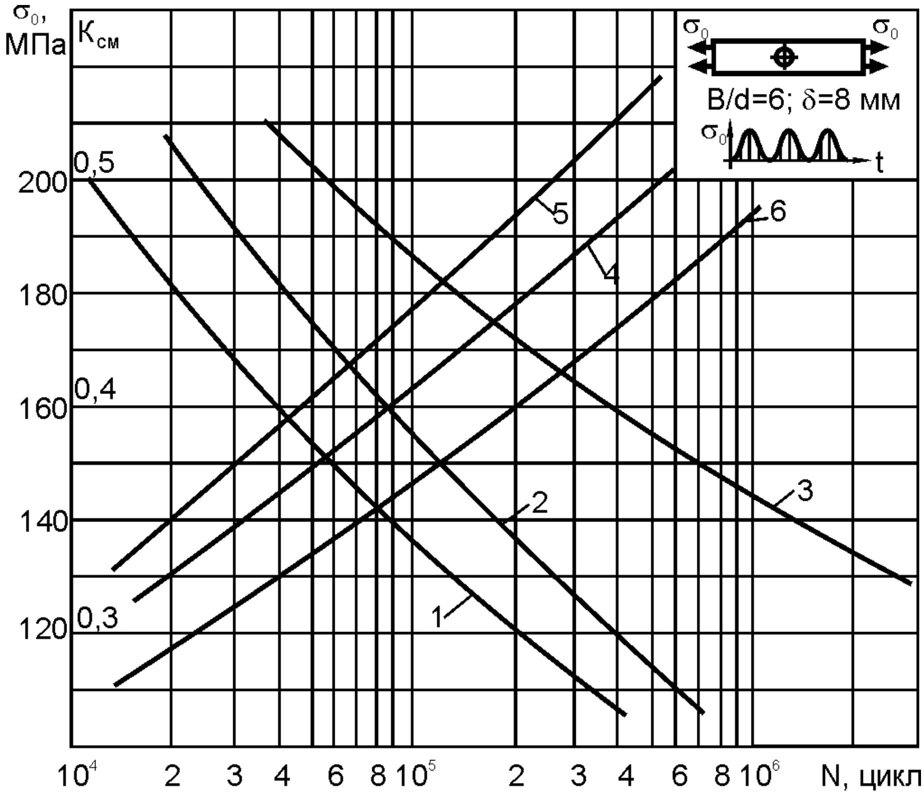


Рис. 6.5. Fatigue life curves of a plate with a filled hole and stress damage factors for shear bolts at different bolt
1 – fatigue curve of a plate with a filled countersunk hole, fit H7 / p6,
$\sigma_0 = 989N^{-0,1726}$;
2 – fatigue curve of plate whith filled non-countersunk hole fit H7 / p6,
$\sigma_0 = 1334N^{-0,188}$;
3 – fatigue curve of a plate with a filled countersunk hole, fit with tightness $\Delta_н$ = 1 %, $\sigma_0 = 894N^{-0,1359}$;
4 – the damaging coefficient effect on bearing stress for plates filled with countersunk hole, fit H7 / p6, $k_{см} = 0,089N^{0,132}$;
5 – factor of damaging influence on the bearing stress for the plates with the filled open hole, H7 /p6, $k_{см} = 0,09N^{0,13}$;
6 –damaging influence factor on the stress of the bearing for the plates with a filled countersunk hole, fit with tension

It is evident that the considered modification options have both advantages in terms of durability and mass, as well as disadvantages, and their use requires calculations of the increase in cyclic durability, mass efficiency of each option and the adoption of a compromise solution.

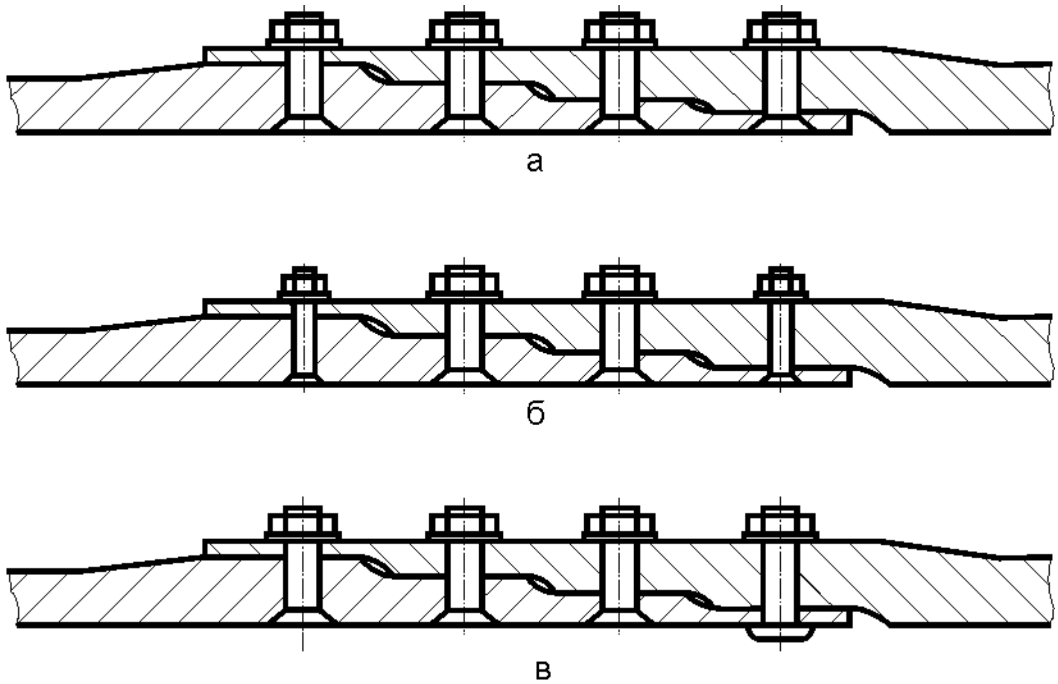


Рис. 6.6. Desighn-technological versions of the multi-row shear bolt joint: a - the basic version of the joint; b - variant with reduced diameter of bolts outer rows; c – variant with non-countersunk bolts in the outer row

Table 6.2 Individual tasks for laboratory work

№	$\sigma_{дир}$, MPA	$\sigma_{э}$, MPa	$\delta_{рег}$, mm	N, cyc. $\times 10^{-5}$	B_c, mm	Details material	Bolt material	$\Delta н$, %
1	320	80	4	1,9	30	Д16Т	30ХГСА	0
2	330	90	4,5	1,8	32	Д16Т	ВТ16	1
3	340	100	5	1,7	34	Д16Т	30ХГСА	0
4	350	110	5,5	1,6	36	Д16Т	ВТ16	1
5	360	120	6	1,5	38	Д16Т	30ХГСА	0
6	355	130	6,5	1,4	40	Д16Т	ВТ16	1
7	350	135	7	1,3	42	Д16Т	30ХГСА	0
8	345	140	7,5	1,2	44	В95	ВТ16	1
9	340	135	8	1,25	46	В95	30ХГСА	0
10	335	130	8,5	1,3	48	В95	ВТ16	1
11	330	125	9	1,35	50	В95	30ХГСА	0
12	325	120	8,5	1,4	48	В95	ВТ16	1
13	320	115	8	1,45	46	В95	30ХГСА	0
14	315	110	7,5	1,5	44	В95	ВТ16	1
15	310	105	7	1,55	42	В95	30ХГСА	0
16	305	100	6,5	1,6	40	В95	ВТ16	1
17	300	95	6	1,65	38	Д16Т	30ХГСА	0
18	310	90	5,5	1,7	36	Д16Т	ВТ16	1
19	320	80	5	1,75	34	Д16Т	30ХГСА	0
20	330	85	4,5	1,8	32	Д16Т	ВТ16	1
21	340	90	4	1,85	30	Д16Т	30ХГСА	0
22	345	95	4,5	1,55	32	Д16Т	ВТ16	1
23	350	100	5	1,5	34	Д16Т	30ХГСА	0
24	355	105	5,5	1,45	36	Д16Т	ВТ16	1
25	320	115	6	1,4	38	Д16Т	30ХГСА	0