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ROD BUTT BOLTS BOLT JOINTS OF TENSION RODS USING SLANTING FLANGES

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Abstract. A new technical solution for the mounting joints of metal structures in the form of bolted joints on oblique flanges located at an angle of 30 degrees relative to the longitudinal axes of the rod elements and equipped with support tables is given. In such joints, the longitudinal forces that fall on the flanges are decomposed into normal and tangential (tangential) components. Normal components are transmitted to bolted fasteners, and tangents are perceived by support tables. At the same time, in oblique flanges, the bolts are loaded two times less than in straight ones. Butt joints have the necessary and sufficient bearing capacity, provide a reduction in the consumption of structural material and are equally strong with docked rod elements. A practical method for calculating such compounds is proposed, confirmed by the results of a trial (control) series of studies of prototypes.

Keywords: mounting joints of metal structures, bolt fasteners, connections on flanges, oblique flanges, support tables, calculation method

СТЫКОВЫЕ БОЛТОВЫЕ СОЕДИНЕНИЯ СТЕРЖНЕВЫХ ЭЛЕМЕНТОВ С КОСЫМИ ФЛАНЦАМИ И ИХ РАСЧЕТ

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Аннотация. Приведено новое техническое решение монтажных стыков металлических конструкций в виде болтовых соединений на косых фланцах, расположенных под углом 30 градусов относительно продольных осей стержневых элементов и снабженных опорными столиками. В таких стыках продольные усилия, приходящиеся на фланцы, раскладываются на нормальные и касательные (тангенциальные) составляющие. Нормальные составляющие передаются на болтовые крепления, а касательные – воспринимаются опорными столиками. При этом в косых фланцах болты нагружены в два раза меньше, чем в прямых. Стыковые соединения обладают необходимым и достаточным запасом несущей способности, обеспечивают уменьшение расхода конструкционного материала и являются равнопрочными со стыкуемыми стержневыми элементами. Предложена практическая методика расчета таких соединений, подтвержденная итогами пробной (контрольной) серии исследований опытных образцов.

Ключевые слова: монтажные стыки металлических конструкций, болтовые крепления, соединения на фланцах, косые фланцы, опорные столики, методика расчета

INTRODUCTION

Flange connections are currently among the most common and mass types of bolt fasteners, differing in the mechanisms for transmitting external forces. Here, these forces are perceived mainly due to overcoming the compression resistance of the flanges from the pre-tension of high-strength bolts. Flange joints are one of the most effective types of bolted joints, since the very significant bearing capacity of high-strength bolts is used directly and almost completely. The field of rational and effective use of flange joints is quite large. It covers the connections of elements subject to stretching, compression, bending or their joint action. This area can also be extended for the transmission of cyclic loads, but in this case appropriate calculation and experimental checks are necessary [1].

It is known that the butt joint of the stretched elements of the closed profile is known, including the ends of the rod elements with flanges, additional ribs and tightening bolts installed along the perimeter of the closed profile in pairs symmetrically relative to the ribs [10]. The disadvantage of the connection is the large dimensions of the flange and a significant number of connecting parts, which increases the consumption of material and the complexity of the structure. The closest to the proposed technical solution is the mounting butt joint of the lower (stretched) belt of trusses from bent welded closed profiles, including the ends of the rod elements with flanges, additional ribs, tightening bolts and a sheet gasket between the flanges for attaching the rods of the truss grate and connections between the trusses [11]. The disadvantage of the connection, as in the previous case, is the material intensity and laboriousness of the mounting joint on the flanges.

The main task, the solution of which is aimed at the flange connection of the stretched elements of the closed profile, is to reduce the mass (consumption) of the structural material. The result is achieved by the fact that in the flange connection of the stretched elements of the closed profile, including the ends of the rods with flanges, tightening bolts and the sheet gasket between the flanges, the flanges are installed at an angle of 30 ° relative to the longitudinal axes of the rod elements, and the sheet gasket consists of paired support tables, rigidly fastened to the flanges and in the assembled connection mutually resting on each other [12].

The proposed flange connection has a fairly universal technical solution. So, it can be used in the mounting joints of lattice structures from pipes of round, oval, elliptical, rectangular (Fig. 1), square, pentagonal (Fig. 2) [13, 14] and other closed cross-sections. As another example of the use of the proposed connection, similar joints can be given in the installation of structural elements from paired and single corners, channels, I-beams (Fig. 3), taurus, Z-, H-, U-, V-, Λ-, X-, C-, U-shaped and other open (unclosed) profiles. The proposed flange connection of stretched closed profile elements 1 contains attached using welds are solid leaf flanges 2 mounted at an angle of 30° relative to the longitudinal axes of the stretched elements. The support tables 3 are rigidly fastened to the flanges 2 by means of welded seams. In the protruding parts 4 of the flanges 2 and the support tables 3 there are coaxial holes 5, in which, after assembling the joint, tightening bolts 6 are installed on the mount. For the attachment of the rod element of the grille 7 in the proposed flange connection, the support tables 3 are extended beyond the protruding parts 4 of the flanges 2 in such a way that additional bolts 8 can be placed in them, as is done in a typical mounting joint on the flanges. In the case of using the proposed flange connection for the stretched elements of the unclosed profile 9, the coaxial openings 5 in the flanges 2 and the support tables 3, as well as the tightening bolts 6, may be located not only outside the cross-section (transverse or oblique) of the unclosed (open) profile, but also in its internal zones. In the complete absence of tightening bolts 6 in the outer (external) areas of the open profile 9, the proposed flange connection is more compact.

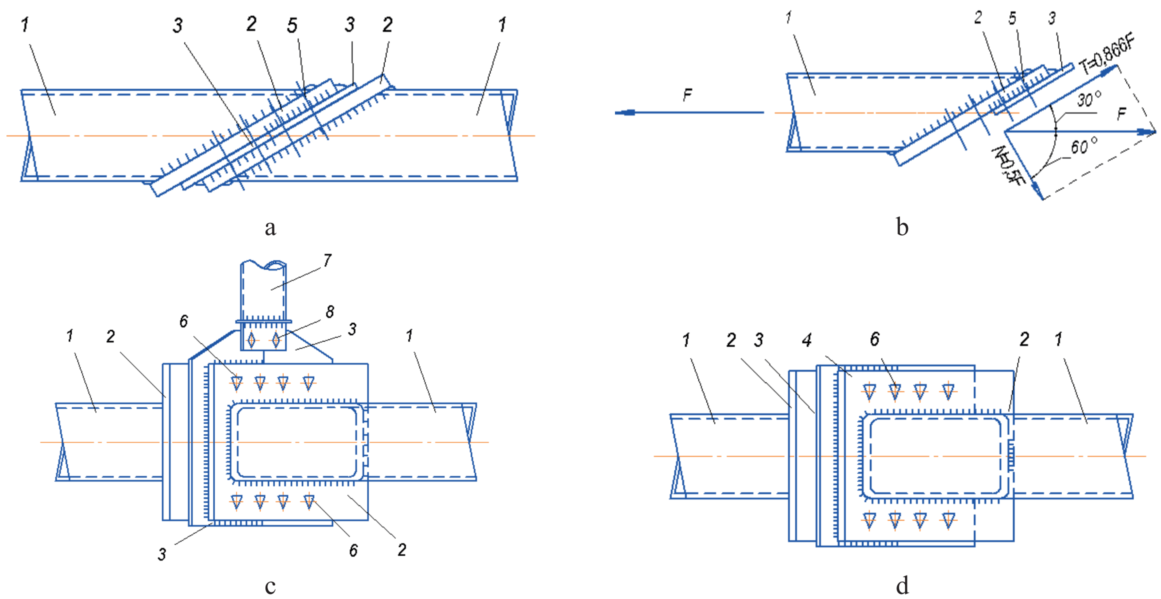
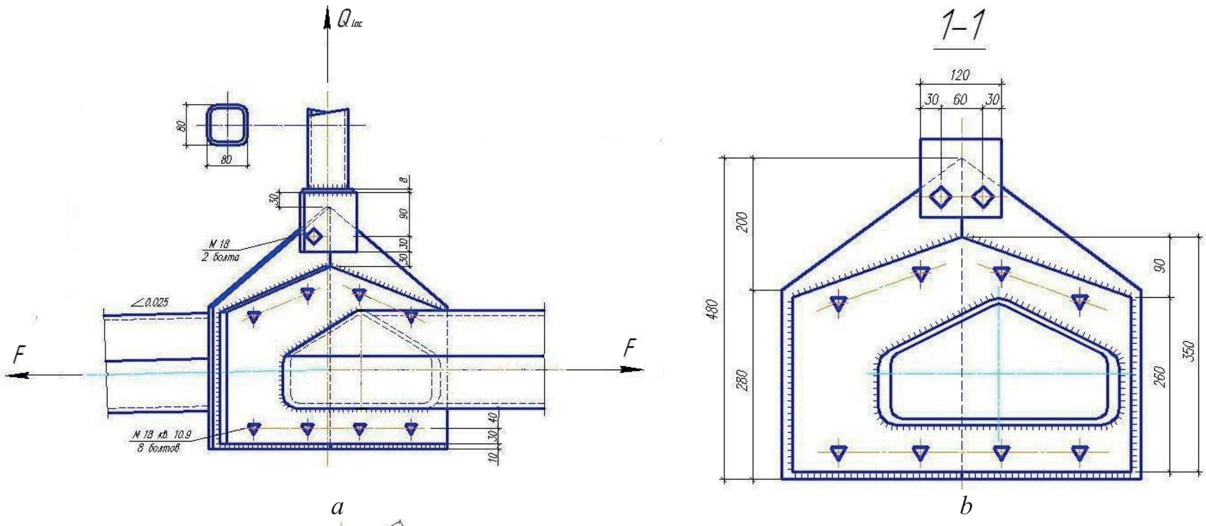


Figure 1. Schemes of flange connections of rectangular closed bent-welded profiles: a - top view; b - design diagram of an element with an oblique flange and a support table; c – side view; d – side view in the absence of lattice rod elements; 1 - lower (stretched) truss belt; 2 - oblique flange; 3 - support table; 4 - protruding part of the flange in the outer zone of the profile; 5 - bolt hole; 6 - coupling bolt; 7 - rod element of the lattice; 8 - bolted fastening of the lattice element; F is the longitudinal tensile force; N is the normal component; T - tangential (tangential) component



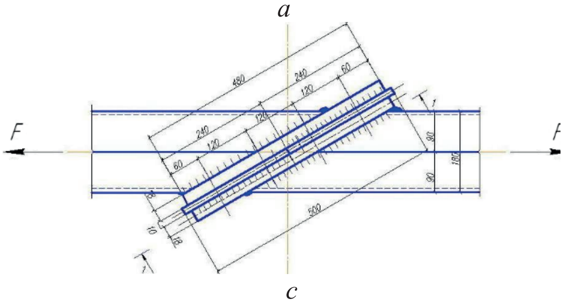
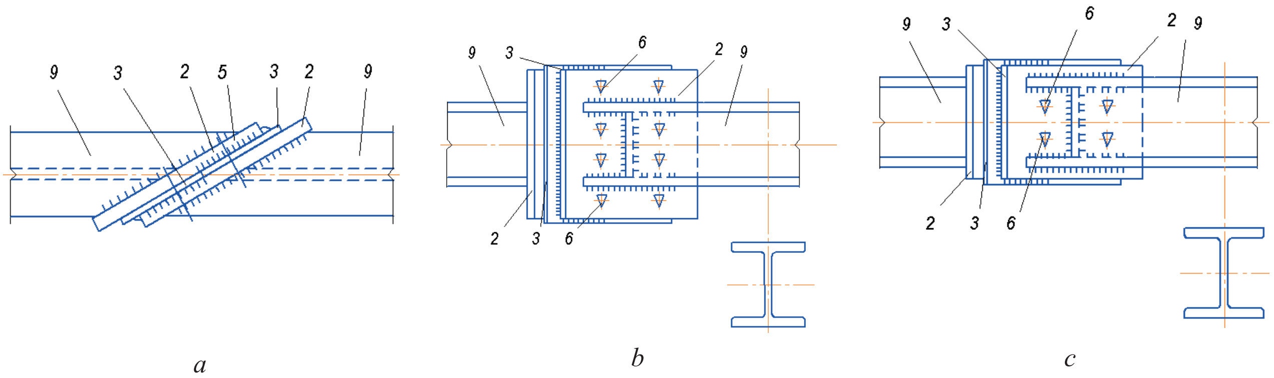


Figure 2. An example of designing an assembly joint on oblique flanges of the lower (stretched) chord from a pentagonal closed bent-welded profile of a truss with a span of 42 m and a design load of 20.6 kN/m [11]: a – side view; b - section along the line of contact of the oblique flange and the core element of the belt; c - top view



<u>Figure 3.</u> Schemes of flange connections of I-profiles: a - top view; b – side view; c - side view in the absence of bolts in the outer zones of the profile; 2 - oblique flange; 3 - support table; 5 - bolt hole; 6 - coupling bolt; 9 - I-profile

METHODS

In trusses of rectangular and square pipes (bent welded closed profiles), the angles of adhesion of the braces to the belt should be at least 30 ° to ensure the density of the weld section from the side of the sharp angle [15]. Therefore, in the proposed flange connection of the stretched closed profile elements 1, the flanges 2 and the support tables 3 fastened to them are mounted at an angle of 30° relative to the longitudinal axes.
In this case, the longitudinal force *F*, which causes the tensile of the closed profile element 1, is decomposed into two components (Fig. 1, g):

- normal, perceived by tightening bolts [6],

$$N = Fcos60° = 0.5F \qquad (1)$$

- tangential, transmitted to the support tables 3,

$$T = Fcos30° = 0.886F. \qquad (2)$$

Reducing the bolting forces by half the same number of times reduces the moments that bend the flanges, and this allows you to use thinner sheets for them, thereby reducing the consumption of structural material. In addition, the material capacity of the proposed joint is positively affected by a possible reduction in the diameters of the tightening bolts 6, a decrease in their number or a combination of the first and second.

Here, the strength of the bolts of the flange joints of the rod elements of the closed (tubular) profile is ensured if

$$\frac{N}{0.9n_b \cdot N_{bt}} \leq 1, \qquad (3)$$

where n_b is the total number of bolts; N_{bt} is the calculated force perceived by a single bolt for the tension with which it must first be pulled (flange connection of type A), and calculated by the formula

$$N_{bt} = R_{bt} \cdot A_{bn}, \qquad (4)$$

where R_{bt} is the calculated tensile resistance of the bolted joints; *Abn* is the cross-sectional area of the "net" bolt.

The calculated bolt connection shall be positioned momentlessly (symmetrically) relative to the centre of gravity of the belt element cross-section, as close as possible to it and taking into account the minimum allowable distances from the profile to the axis of the bolt $_{bb}$ and from the axis of the bolt to the edge of the flange *cb*. In this case, each of the bolts must be equidistant from the profile. The diameter of the holes can be taken 3 mm larger than the diameter of the bolts. The bending strength of the flanges is ensured if σ

$$\frac{\sigma_{fl}}{\gamma_c Ry,fl} = \frac{M}{W_{fl}\gamma_c Ry,fl} \leq 1 \quad (5)$$

where γ_c is the coefficient of working conditions; σ_{fl}, W_{fl} and $R_{y,fl}$ - respectively normal voltage, design resistance of steel and moment of cross-sectional resistance of the flange, W_{fl}=$b_1 t_{fl}2/6$ (b_1 - pitch of bolts, t_{fl} - thickness of oblique flange); M is the highest value of the calculated bending moment.

In the flange joints of the rod elements of the closed (tubular) profile, as well as in the outer zone of the joints of the elements of the open (unclosed) profile, the bending moments of the flanges can be determined according to a conditional design scheme, as in a beam pinched from the side of the belt, hinged with an operte along the edge of the flange and loaded with a force in the bolt N_b [8, 9]:

$$M_1 = \frac{N_b \cdot l_1 \cdot b_b \cdot (l_1 + c_b)}{3l_1^2 - c_b^2};$$
$$M_2 = \frac{N_b \cdot b_b^2 \cdot (3l_1 - b_b)}{3l_1^2 - c_b^2}, \quad (6)$$

where $N_b \leq 0.9 N_{bt}$; l_l is the span of the beam, $l_l = b_b + c_b$; b_b and c_b are the minimum allowable distances.

The same design scheme makes it possible to determine the deflections of the oblique flange [18]:

- along the axis of the bolted connection

$$f_{fl} = \frac{N_b \cdot b_b^3 \cdot c_b^2 \cdot (3b_b + 4c_b)}{12 \cdot l_1^3 \cdot EI_{f1}}; \quad (7)$$

- highest value

$$f_{fl,max} = \frac{0.0098 \cdot N_b \cdot l_1^3}{EI_{fl}} \quad (8)$$

where E is the modulus of elasticity of the flange material; I_{fl} is the moment of inertia of the flange cross-section, $I_{fl} = b_l t_{fl}^3/12$.

The calculated oblique flange of the stretched joints is welded to the belt element by unilateral angular seams. They must be checked by the calculation of strength:

- on the metal of the seam

$$\frac{F}{\beta_f \cdot k_f \cdot l_w \cdot R_{wf} \cdot \gamma_{wf} \cdot \gamma_c} < 1; \quad (9)$$

- on the metal of the fusion boundary with the belt element

$$\frac{F}{\beta_z \cdot k_f \cdot l_w \cdot R_{wz} \cdot \gamma_{wz} \cdot \gamma_c} < 1; \quad (10)$$

- on the metal of the fusion boundary with the flange in the direction of the thickness of the rolled products

$$\frac{F}{\beta_z \cdot k_f \cdot l_w \cdot R_{th} \cdot \gamma_{wz} \cdot \gamma_c} < 1, \quad (11)$$

where F is the load on the welds; k_f - angular seam roll, $k_f \leq 1{,}2t\min$ (t_{min} - thickness of the thinnest of the welded elements); l_w - the calculated length of the seam, it is taken to be less than its full length by 1 cm; R_{th} is the calculated resistance of the oblique flange material across the rolled products, $R_{th}=0{,}5R_{y,fl}$.

Supporting slats (support tables) of oblique flanges are advisable to take in 1.5 ... 2 times thinner than flanges [19]:

$$t_{cr} = \frac{t_{fl}}{(1.5 \ldots 2)}. \quad (12)$$

The support bar is welded to the oblique flange by one-sided angular seams along its three edges, and the fourth edge is milled to ensure a tight contact in the assembled joint for the transmission and perception of the tangent component T. Checking the welds is as follows:

- on the metal of the seam

$$\frac{T}{\beta_f \cdot k_f \cdot l_w \cdot R_{wf} \cdot \gamma_{wf} \cdot \gamma_c} < 1; \quad (13)$$

- on metal fusion boundaries with flange

$$\frac{T}{\beta_z \cdot k_f \cdot l_w \cdot R_{wz} \cdot \gamma_{wz} \cdot \gamma_c} < 1, \quad (14)$$

where T is the load on the welds; k_f - angular seam cathlete, k_f≤1.2tmin; l_w - the calculated length of the seam, is taken to be less than its full length by 1cm.

The support bars (support tables) of oblique flanges must also be checked by calculation of the crumpled strength condition:

$$\frac{T}{b_{cr} \cdot t_{cr} \cdot R_p} \leq 1, \qquad (15)$$

where b_{cr} is the width of the support bar in the contact zone (crumple); R_p is the calculated resistance of the steel to the crumpling of the end surface.

The Q_{loc} transverse force in the assembled joint is transmitted through an additional fastening between the lining of the truss lattice rod with a thickness *of* t_k *and the* support bars of the oblique flanges on two bolts, under the conditions of unification of the same flanges as the bolts. They can be installed without prior tension, so the additional bolted connection must be checked by calculation from the strength conditions:

- per slice

$$\frac{Q_{loc}}{N_{bs} \cdot n_b} \leq 1; \qquad (16)$$

- On Confusion

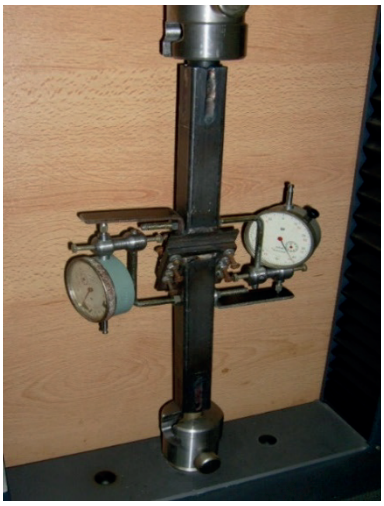
$$\frac{Q_{loc}}{N_{bp} \cdot n_b} \leq 1, \qquad (17)$$

wherein N_{bs} and N_{bp} are the design forces that can be perceived by a single bolt respectively per cut and crumpled; n_b is the number of bolts in the connection, n_b=2.

The necessary and sufficient reserve of bearing capacity of bolted joints of stretched rod elements with oblique flanges was confirmed by the results of a trial (control) series of studies of prototypes conducted in the construction laboratory of Pyatigorsk State Technological University (Fig. 4). The breaking forces of the prototypes exceeded the level of design loads of 1.7... 2.5 times, and the experimental and calculated deformations had a fairly acceptable convergence. Experimental deformations were determined from the readings of mechanical indicators in the direction of action of longitudinal forces in the rod elements (Fig. 5). The calculated deformations were calculated as the total deflection of two oblique flanges in the projection on the longitudinal axis of the prototype:

$$\Delta = \frac{2f_{fl,max}}{sin30°} = 4f_{fl,max} \qquad (18)$$

where $f_{fl,max}$ is the deflection of one flange defined by the formula (8).



a

b

Figure 4. Pictures of experimental studies of prototypes of mounting joints on oblique flanges: a - general view; b - type of bolted joints after rupture

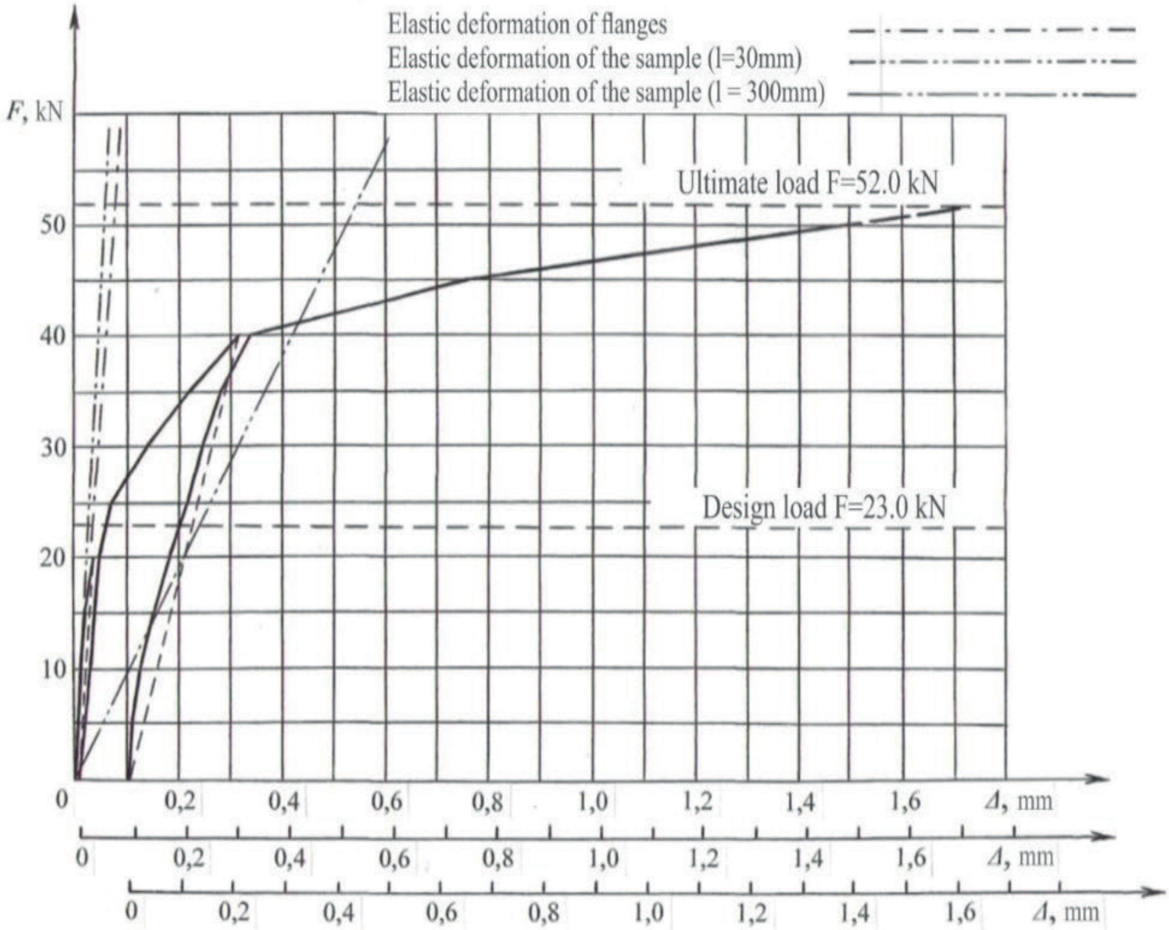


Figure 5. Stretch diagram of one of the prototypes of butt bolt joints of rod elements with oblique flanges, built on average readings of two mechanical indicators

RESULTS AND DISCUTION

Summarizing the results of the first series of tests given in Chart 1, we can conclude that butt joints on oblique flanges are not only equally strong with rod elements, but are also quite suitable for use in load-bearing structures of buildings and structures. In the future, it is planned to continue testing and experimental studies of bolted joints on oblique flanges, combining them with a laboratory workshop on metal structures as part of the educational process for the training and advanced training of civil engineers, for which a corresponding installation with a capacity (load capacity) of 50 tons has already been manufactured and tested (Figure 6).

To compare the proposed (new) technical solution with the known one, a standard assembly connection on the flanges of roof trusses from bent-welded closed profiles of the Molodechno system was taken as the base object [12]. The material consumption of the compared options is shown in Chart 2, from which it can be seen that in the new solution it decreased by 54.7 / 26.8 = 2.04 times.

In addition, here it is necessary to take into account the consumption of material for the tie bolts. In the known and proposed flange connections, the number of coupling bolts is the same and is 8 pcs. If the first of them uses M24 bolts, then the second uses M18 bolts of the same strength class. Then it is obvious that in the new solution the material consumption is reduced in proportion to the decrease in the "net" cross-sectional area of the bolt, that is, by 3.52/1.92=1.83 times.

Table 1. Results of the Pilot Test Series of Prototype Studies

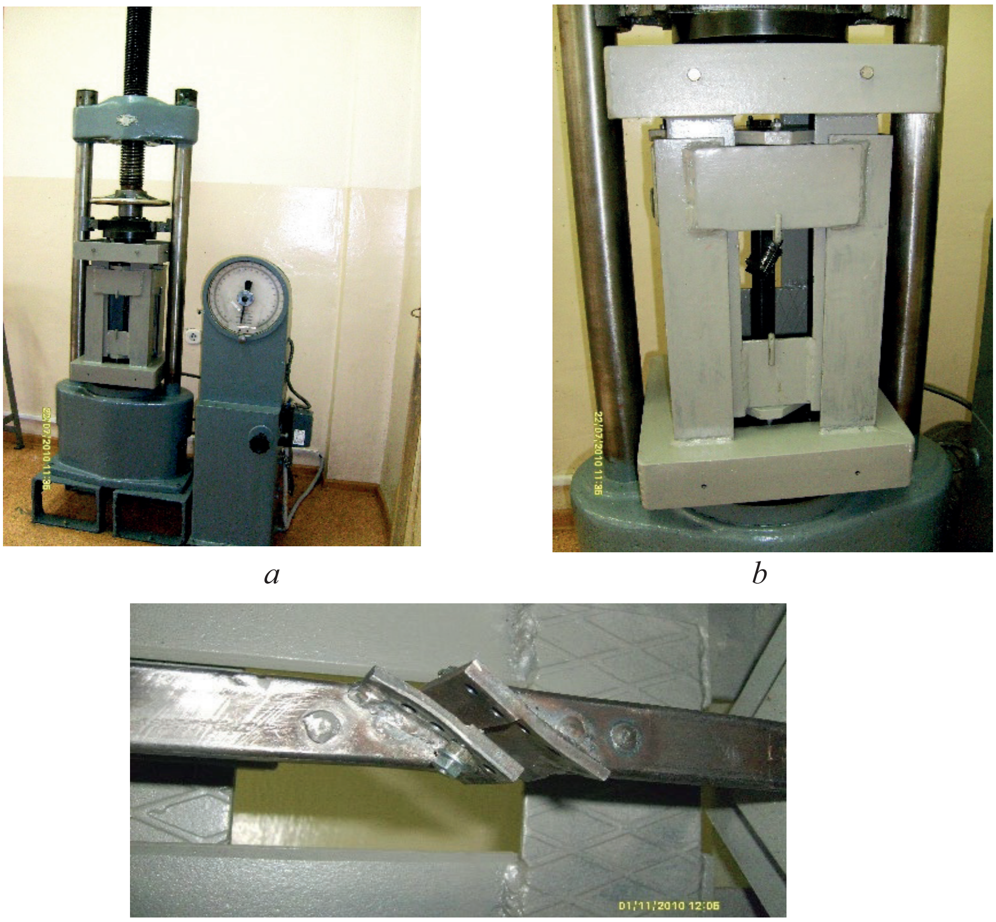
Parameters of prototypes (steel C235)					
№	Cross-section of rod elements, mm	Thickness, mm		Bolted connections	
		Flanges	Tables	diameter, mm	class
1	2	3	4	5	6
1	□25×25×1,5 GOST 8369-68	4	2	M4	5.8
2	□25×25×1,5 GOST 8369-68	4	2	M4	5.8
3	□25×25×1,5 GOST 8369-68	4	2	M5	5.8

Bearing capacity, kN							
№	Calculated				Experimental		
	core elements	oblique flanges	support tables	bolted connections	the cause of the destruction of the prototype	the ultimate in case of destruction	experiment. / Calculation
1	7	8	9	10	11	12	13
1	32,5	24,7	40,4	23,0	*Machine power	*40,0	*1,74
2	32,5	24,7	40,4	23,0	bolt break	52,0	2,26
3	32,5	24,7	40,4	40,2	bending of flanges	62,0	2,51

№	Deformations, mm					
	from design loads			from the maximum loads		
	Calculation	experiment.	experiment. / Calculation	Calculation	experiment.	experiment. / Calculation
1	14	15	16	17	18	19
1	0,035	0,044; 0,039	1,26; 1,12	0,060	1,14	19,0
2	0,035	0,052; 0,047	1,49; 1,34	0,078	1,61	20,7
3	0,037	0,061; 0,058	1,65; 1,57	0,093	2,07	22,3

Table 2. Consumption of structural material (steel)

Name	Dimensions, mm	Amount, pcs.	Weight, kg			Notes
			1 pc.	All	Joint	
Straight flange	300×300×30	2	21,2	42,4	54,7	Notable solution
Stiffening rib	140×110×8	8	0,5*	4,0		
Connecting gasket	400×300×8	1	7,5	7,5		
Welds (1.5%)				0,8		
Oblique flange	300×250×18	2	10,6	21,2	26,8	New Solution
Support table	270×150×8	2	2,6	5,2		
Welds (1.5%)				0,4		
* Triangular shape taken into account						



a b

c

Figure 6. Pictures of a general view of the test facility (a), its reverse part (b) and a prototype after destruction due to bending of oblique flanges (c)

CONCLUSION

Thus, the development of butt bolted joints of bar elements with oblique flanges, their calculation and the results of experimental studies of the first (trial) series of prototypes make it possible to recommend for implementation in construction practice and draw a number of main conclusions.

1. Bolted joints on oblique flanges have the necessary and sufficient margin of bearing capacity, which ensures their equal strength with the connected rod elements.
2. The engineering method for calculating bolted connections on oblique flanges is quite simple and correct for use in building design.
3. Butt bolted joints of rod elements with oblique flanges under the action of tensile forces significantly reduce the consumption of structural material compared to straight flanges, which predetermines the prospects for their use in load-bearing structures of buildings and structures.
4. It is advisable to continue experimental studies of bolted joints on oblique flanges and combine them with a laboratory workshop on metal structures as part of the educational process of training and advanced training of civil engineers.

REFERENCES

1. **Kuznetsova V.V.** (1998) Soedineniya [Connections]. *Metallicheskiye konstruktsii* [Metal structures], In 3 vols. T. 1. General part. Moscow, Publishing office ASV, pp. 179–204. (in Russian).

2. **Kharlanov V.L., Kharlanova S.V.** (2021) Metody fiktivnych reaksiy v modelirovanii kontaktnoy poverkhtnosty na primere flantsevich soyedineniy [Method of fictitious reactions in the modeling of the contact surface on the example of flanged connections]. *Stroitelnaya mechanika i raschet sooruzheniy* (electronic journal) [Structural mechanics and calculation of structures], no 2, pp. 73–78. (in Russian).
3. **Son M.P.** (2018) Eksperimentalnye issledovaniya prochnosti flantsevykh soyedineniy [Experimental studies of the strength of flange joints]. *Stroitel'naya mekhanika inzhenernykh konstruktsiy i sooruzheniy* (electronic journal) [Structural mechanics of engineering structures and structures], no. 4, pp. 344–355. (in Russian).
4. **Kriksunov E.Z., Perelmuter A.V., Yurchenko V.V.** (2010) Raschetnye modeli flantsevykh soyedineniy ramnykh uzlov metallicheskikh konstruktsiy i ikh programmnaya realizatsiya v SCAD Office [Calculation models of flange connections of frame units of metal structures and their software implementation in SCAD Office]. *Byulleten stroitelnoy tekhniki* (electronic journal) [Bulletin of construction equipment], no. 1, pp. 56–59. (in Russian).
5. **Mohamed Elflah, Marios Theofanous, Samir Dirar, Huanxin Yuan.** (2019) Behavior of stainless steel beam-to-column joints – Part 1: Experimental investigation, *Journal of Constructional Steel Research 152*, pp. 183–193.
6. **H.X. Yuan, S. Hua, X.X. Dua, L. Yangb, X.Y. Cheng, M. Theofanous.** (2019) Experimental behavior of stainless steel bolted T-stub connections under monotonic loading, *Journal of Constructional Steel Research 152*, pp. 213–224.
7. **Tchabremane Jean de la Croix Kombate, Kıvanç Tas¸kın.** (2022) State-of-the-art review on the behaviour of T-stubs and prying action, *Journal of Constructional Steel Research 191*, 107203.
8. **Yasin Onuralp Ozkılıc.** (2021) The capacities of unstiffened T-stubs with thin plates and large bolts, *Journal of Constructional Steel Research 186*, 106908.
9. **Kuznetcova V.V.** (1998) Stalnye konstruktsii zdaniy i sooruzheniy [In Steel structures of buildings and structures]. *Metallicheskiye konstruktsii* [Metal structures]. Moscow, Publishing office ACB, pp. 157, pic. 7.6, б. (in Russian).
10. **Goreva V.V.** (2001) Elementy konstruktsiy [Structural elements]. *Metallicheskiye konstruktsii* [Metal structures], In 3 vols. T. 1. Moscow, Higher School, Page 462. (in Russian).
11. **Marutyan A.S., Pershin I.M., Pavlenko Yu.I.** (2011) Flantsevoye soyedineniye rastyanutykh elementov zamknutogo profilya [Flange connection of tensioned elements of a closed profile], Application No. 2009139553/03 (056081), 10/26/2009, Patent No. 2413820. - 10.03.2011. Bull. No. 7. (in Russian).
12. **Marutyan A.S., Kobaliya T.L., Glukhov S.A., Yanukyan G.M., Pavlenko Yu.I.** (2011) Pyatiugolniy zamknutiy gnutosvarnoy profil [Pentagonal closed bent-welded profile], Application No. 2009147247/03(067318), 12/18/2009. - Patent No. 104582. - 05/20/2011. Bull. No. 14. (in Russian).
13. **Marutyan A.S., Glukhov S.A., Pavlenko Yu.I.**(2010) Pyatiugolniy zamknutiy gnutosvarnoy profil [Pentagonal closed bend-welded profiles]. *Stroitelnaya mekhanika i raschet sooruzheniy* [Structural mechanics and calculation of structures], No. 5, pp. 53–57. (in Russian).
14. **Kudishin. Yu. I.** (2007) *Metallicheskiye konstruktsii: Uchebnik dlya vuzov* [Metal structures: textbook for universities]. Moscow, Academy, p. 296. (in Russian).
15. **Sakhnovsky M.M.** (1984) *Legkiye konstruktsii stalnykh karkasov zdaniy i sooruzheniy* [Lightweight steel frame structures for buildings and structures]. Kyiv, Budivelnik, pp. 68-70. (in Russian).

16. **Marutyan A.S.** (2006) *Proyektirovaniye stalnykh ferm pokrytiy* [Design of steel roof trusses], Pyatigorsk: PSTU, p. 60. (in Russian).
17. **Pisarenko G.S. (1988)** *Spravochnik po soprotivleniyu materialov* [Handbook of the strength of materials]. Kyiv, Naukova Dumka, pp. 346-347. CM drawings. See folio 44. (in Russian).
18. **Marutyan A.S.** (2010) *Kursovoye i eksperimentalnoye proyektirovaniye stalnykh ferm pokrytiy* [Course and experimental design of steel roof trusses], Pyatigorsk: PSTU, pp. 112. (in Russian).
19. **Stalnyye konstruktsii pokrytiy proizvodstvennykh zdaniy proletami 18, 24, 30 m** s primeneniyem zamknutykh gnutosvarnykh profiley pryamougol'nogo secheniya tipa «Molodechno» [Steel structures of the roofs of industrial buildings with spans of 18, 24, 30 m using closed bent-welded profiles of rectangular section of the Molodechno type]. Series 1.460.3-14. KM drawings. Pp. 44 (in Russian).

СПИСОК ЛИТЕРАТУРЫ

1. **В.В. Кузнецова.** Металлические конструкции. В 3 т. Т. 1. Общая часть. – М.: Изд-во АСВ, 1998. – С. 179–204.
2. **Харланов В.Л., Харланова С.В.** Метод фиктивных реакций в моделировании контактной поверхности на примере фланцевых соединений. – Строительная механика и расчет сооружений, 2021, № 2. – С. 73–78.
3. **Сон М.П.** Экспериментальные исследования прочности фланцевых соединений. – Строительная механика инженерных конструкций и сооружений, 2018, № 4. – С. 344–355.
4. **Криксунов Э.З., Перельмутер А.В., Юрченко В.В.** Расчетные модели фланцевых соединений рамных узлов металлических конструкций и их программная реализация в SCAD Office. – Бюллетень строительной техники, 2010, № 1. – С. 56–59.
5. **Mohamed Elflah, Marios Theofanous, Samir Dirar, Huanxin Yuan.** Behaviour of stainless steel beam-to-column joints – Part 1: Experimental investigation. – Journal of Constructional Steel Research 152 (2019) – Pp. 183–193.
6. **H.X. Yuan, S. Hua, X.X. Dua, L. Yangb, X.Y. Cheng, M. Theofanous.** Experimental behaviour of stainless steel bolted T-stub connections under monotonic loading. – Journal of Constructional Steel Research 152 (2019) – Pp. 213–224.
7. **Tchabremane Jean de la Croix Kombate, Kıvanç Tas¸kın.** State-of-the-art review on the behaviour of T-stubs and prying action. – Journal of Constructional Steel Research 191 (2022) 107203.
8. **Yasin Onuralp Ozkılıc.**The capacities of unstiffened T-stubs with thin plates and large bolts. – Journal of Constructional Steel Research 186 (2021) 106908.
9. **В.В. Кузнецова.** Металлические конструкции. В 3 т. Т. 2. Стальные конструкции зданий и сооружений. – М.: Изд-во АСВ, 1998. – С. 157, рис. 7.6, б
10. **В.В. Горева.** Металлические конструкции. В 3 т. Т. 1. Элементы конструкций. – М.: Высшая школа, 2001. – С. 462.
11. **Марутян А.С., Першин И.М., Павленко Ю.И.** Фланцевое соединение растянутых элементов замкнутого профиля. – Заявка № 2009139553/03 (056081), 26.10.2009. – Патент № 2413820. – 10.03.2011. Бюл. № 7.
12. **Марутян А.С., Кобалия Т.Л., Глухов С.А., Янукян Г.М., Павленко Ю.И**. Пятиугольный замкнутый гнутосварной профиль. – Заявка № 2009147247/03(067318), 18.12.2009. – Патент № 104582. – 20.05.2011. Бюл. № 14.
13. **Марутян А.С., Глухов С.А., Павленко Ю.И.** Пятиугольные замкнутые гнутосварные профили. – Строительная

механика и расчет сооружений, 2010, № 5. – С. 53–57.
14. **Ю.И. Кудишина.** Металлические конструкции: Учеб. для вузов. – М.: Академия, 2007. – С. 296.
15. **Сахновский М.М.** Легкие конструкции стальных каркасов зданий и сооружений. – Киев: Будивельник, 1984. – С. 68–70.
16. **Марутян А.С.** Проектирование стальных ферм покрытий. – Пятигорск: ПГТУ, 2006. – 60 с.
17. Справочник по сопротивлению материалов / Отв. ред. Писаренко Г.С. – Киев: Наукова думка, 1988. – С. 346-347.
18. **Марутян А.С.** Курсовое и экспериментальное проектирование стальных ферм покрытий. – Пятигорск: ПГТУ, 2010. – 112 с.
19. **Стальные конструкции покрытий производственных зданий пролетами 18, 24, 30 м** с применением замкнутых гнутосварных профилей прямоугольного сечения типа «Молодечно». Серия 1.460.3-14. Чертежи КМ. Лист 44.

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