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Designing Of Tube Trusses Without Gusset Plate With Joint Connections

ViktorijaAnatolievnaZinkova,

BelgorodStateTechnologicalUniversitynamedafterV. G. Shukhov,
Russia, 308012, Belgorod, Kostyukovstreet, 46

AlexanderGavrilovichYuriev,

Belgorod State Technological University named after V. G. Shukhov,
Russia, 308012, Belgorod, Kostyukov street, 46

ElenaVladimirovnaPeshkova,

BelgorodStateTechnologicalUniversitynamedafterV. G. Shukhov,
Russia, 308012, Belgorod, Kostyukovstreet, 46

Abstract

Inthispaperfocusismadeonthemostefficientkindofrolledstockconstituting the compelling alternative to its traditional kinds – this is profile in the form of a square tube. The use of such profile allows constructing transformable, rapidly-erected and light-weight structures of buildings and facilities. Thestressed-deformedconditionoftrusses from such profile has been considered. Specialattentionwaspaidtotheperformance ofthetruss units since the truss bearing capacity is determined by the strength of its joint connections. Thedesignsolutionofanassemblythechordofwhichhas the non-common spatial orientation – is turned around its axis forming a rhombus, i. e. with its diagonal lying in the truss plane - was presented. Thestress pattern has been described and the advantages of such design solution have been specified. Theefficientarrangementof struts in a pin-jointed truss according to the load applied has been studied. Thetendencyofthematerialconcentrationattheloaded joint connections has been established.

Keywords. Steelrooftruss, trussframe, tubetruss, jointconnection, roll-weldedsection, tubesection, structuraltopology, strain potential energy, optimality criterion.

Introduction.
The analysis of dynamics of the Russian market allowed detecting the increase in investments in construction of the sports-recreational complexes, shopping and entertainment malls, business centers, warehouse and other facilities. The rapidly-erected and transformable buildings become more and more popular.

For a few decades already manydazzlingsitesintheEuropean, AsianandAmericancountries have been erected with the use of the roll-welded sections [1]. In Russia the buildings and facilities impressing with their freshness and beauty constructed with the use of the tube sectional structures appeared just recently.

OneoftheleadersintheRussianmetallurgicalindustry – theUralPipeWorks (Uraltrubprom), JSC – providesthedata on the impressing volume of production and scope of delivery of products made from shaped tubes [2]. The steel structures are produced by the OJSC “Uraltrubprom” both on the basis of the standard and individual designs.

Astostandarddesigns, in its days the plant implemented the large-scale project on design of the standard construction series “UNITEK” within the frameworks of which a shaped tube was designed.

In the development of steel structures a promising scientific-engineering direction is design and implementation of light-weight structures of buildings and facilities allowing making efficient use of material resources.

Wideuseofthelight-weighttrussesfromtubeshapesduetothehighconstructionprogressratescombinedwiththefavorabletechnicalandeconomicfeatures(highmanufacturability, functional reliability and durability, minimal number of pieces and welded joints, advantages in terms of applying a coating, enhanced illumination, low air-flow resistance as well as modern architectural design)results in cheapening of construction as compared to the use of traditional materials by 25-30%, and in some cases – by 40 %.

Though featuring the above-mentioned advantages trusses are not guaranteed against crashes caused by the unit damage. This can be explained by the fact that the bearing capacity of the tube trusses is to a large extent determined by the strength of their joint connections [3]. Thetrusstopologyisalsoimportant– thearrangementofstructural units and method of connecting them in order to form a geometrically stable structure.

Mainpart.
Bydesigningoftubetrussesone should seek to put the axis of the lattice structure bars together in a single point of a joint. This allows excluding the bending moments caused by eccentricity. Inrealitysomedeviationsfromthisarrangementarepossibleas the result of which bending moments may arise. Theymaybeaccounted theoretically: $M=Ne$, where $N$is the axial force in the bar, e – eccentricity of application.

The physical structure of a welded tube truss consists of single-piece chords to which the frame pieces are welded whereby joints are formed. Undertheaction of the external load the truss is distorted – the chord bending $y$is observed. In the general case the truss chord axis forms the curves $y=ax^3+bx^2+cx+d$. The differential equation explains the presence of bending moments in the truss chords.

$$\frac{d^2y}{dx^2}=\frac{M_x}{EI_x} \qquad (1)$$

However, incaseofidealized pin-jointed trusses it is commonly supposed that in the bars forming the joint only the axial forces arise. Stressderivedfromtheseforcesistakenforprimary one. Thereversalinthestrutstakesplaceaccordingtothelaw of statics shown as balance of forces against the joint center at the chord axis. Theaxesofallbarsshallbelinear and lie in one plane.

Thesimplifiedprocedures of the truss design allow using the idealized hinged joints by estimation of the axial forces in the truss elements if the ratio of the depth of such element to its length is $h/l \leq 1/10$[4].

Structuralstressconcentrators in trusses are their joint connections constituting a complex spatial structure with a high stress gradient. The joint strength depends directly on the design solutions and stress pattern.

Therefore, bydesigningofa tubetrussthestressed-deformedconditionofitsjoints shall be thoroughly investigated.

Takingintoaccountthatinelementsof a traditional tube truss the shaped structure is hollow, the axial forces in the struts without reaching the joint center of gravity are taken by the chord upper wall (Fig. 1). Therebythetransverse forces arise in the chords determined by the component of the axial force in the frame members. This results in the non-uniform distortions of the chord cross section and appearance of the local bending moments. Moreover, alongwiththenormalstressthe axial forces induce the comparable shearing stress.

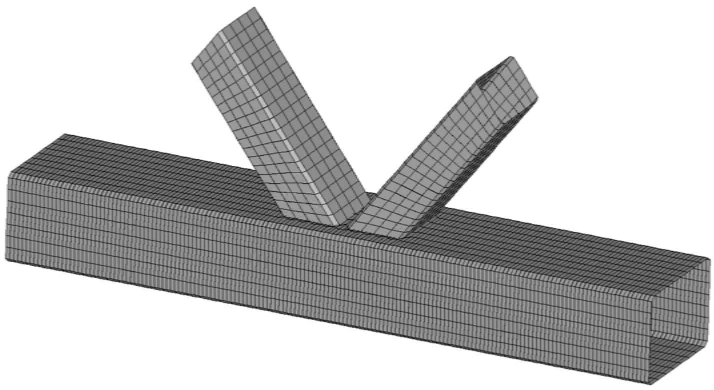


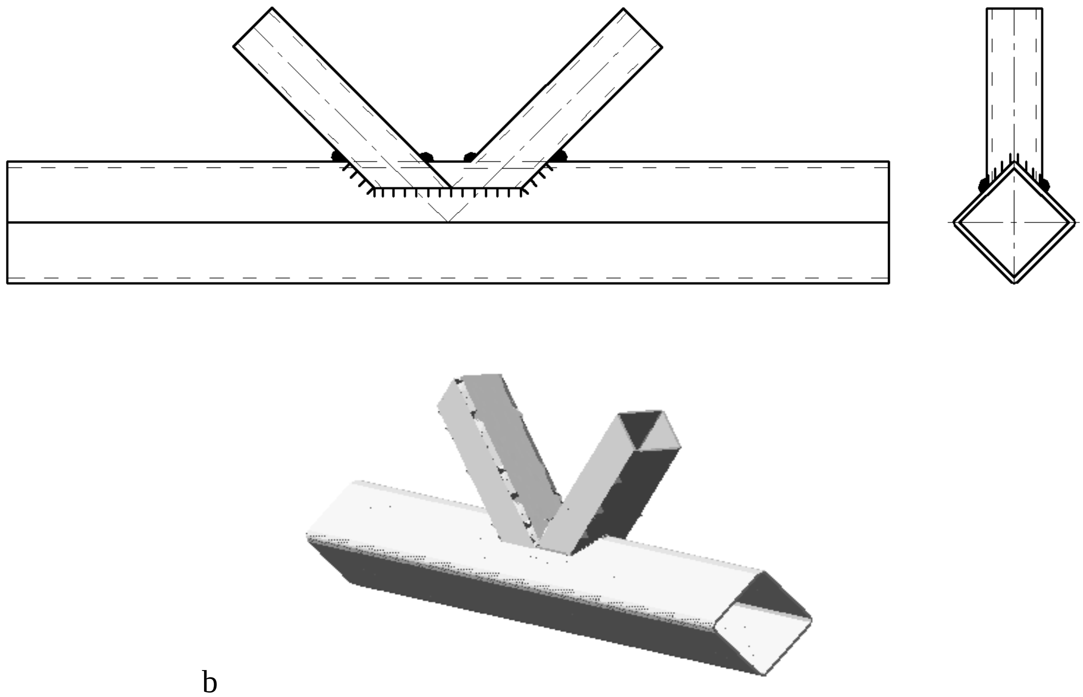
Fig. 1. Assembly of a traditional tube truss

Asthestrutsareattacheddirectlytotheplane wall of the tube chord it is distorted at this point in a non-uniform way –along the lines of the forces action. Besides, thesidechordwallsarepressed under the stretched strut and buckled under the compressed one.

Taking into account the above-mentioned defects there has been designed and studied a truss unit from the roll-welded shaped structure of square section with struts directly adjacent to the chord. The X-axes of struts pass through the joint center and lie within the truss plane. Thedistinctivefeatureofsuchsolutionisthatthechordcrosssectionis turned around its axis forming a rhombus, i. e. with its diagonal lying in the truss plane. The frame members have at the point of attachment to the chord a though V-shaped cut that is completely repeating the geometry of this junction. At the same time the junction of each of the frame members with the chord is performed both along the V-shaped cut edges and the two side faces. The specified structure was acknowledged as an invention and protected by a patent [5].

The analysis of this joint accompanied by comparison of its results with the results of analysis of the traditional design (Fig. 2) revealed its efficiency due to the favorable stress distribution in the bars.

a



b

Fig. 2. DesignsolutionfortheK-shapedjointconnectionofthetubetrussmemberswithoutgusset plate: *a*– front and side view, *b*– axonometric projection

According to the solution proposed the struts were attached to the chord in such a way that their ends envelop with a through V-shaped cut the two adjacent chord walls. Thisresultsinthequiteclosearrangement of the struts ends against the joint center and, correspondingly, against each other. Therebythepathoftransfer of shear (transverse) forces passing through the chord is reduced as the result of which the stress along the chord axis is equalized. The new method of the strut attachment prevents from loss of stability of the chord walls which is directly related to the increase in the load-carrying capability and reliability of the unit under consideration. At the same time the spare load-carrying capability is assured due to the increased yield point in the rounding area, i. e. , the hardening process.

Alongwiththatintheproposedassemblythelengthoftheweld is increased which allows making it thinner and reduce the progress of permanent distortion and thermal stresses in the welding area. Thereby the concentration of stresses in the joint connection is reduced resulting in the more uniform stress distribution over all the truss structure. Aneasieraccesstotheassembly heel area allows making a weld joint of a higher quality with minimum efforts.

AttheendofthelastcenturytheGermanscientistsRouks formulates the law of the "battle of elements" in a body according to which the maximum of work is performed by the minimum of material. Constant functional irritation results in strengthening of the acting organ by means of the increased substance delivery. Absence of irritation allows transferring the substance to other organs where, on the contrary, the enhanced irritation is present. Thisistheprocessof "coating" thestress field by the matter. Thisexplainstheabilityoflivingsystemstoadapttothelastingandmultipleexposures of the external factors of moderate intensity by means of both functional and morphological rearrangements of separate structures and systems [6].

Ashasbeensaidabove, thestructureformationrulesarisingfromtheprinciplesofstationary action shall be traced both in the nature organization and the engineering structures brought to perfection.

Thebook[7] providestheformulationsandproofs of the three theorems of the structural changes;the application of these theorems for optimization of the hinged structures topology is demonstrated. Also, the analysis of the topological changes in the structures is presented in order to identify the factors affecting their topology.

This paper provides the substantiation of the matter arrangement according to the stress field for truss structures [8, 9]. A plane truss was selected as the study subject (Fig. 3). Inordertoensurethestabilityofitsgeometricalshapethe two struts suffice that are indicated by dash lines until the optimal topology is found. There are four variants of their combinations. The variants of attachment of both struts within one panel resulting in the change of the truss geometrical shape are excluded [10].

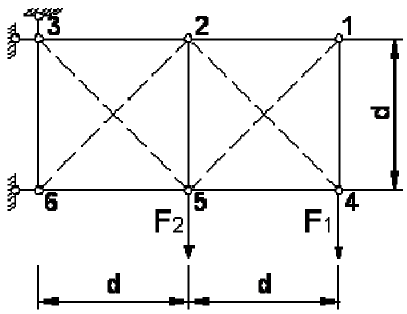


Fig. 3. Plane truss design

In the Table 1 the forces in the bars for two variants of loading and four strut combinations are presented.

Table 1 Variants of truss topology

Bars	Struts 2-4 and 3-5		Struts 2-4 and 2-6		Struts 1-5 and 3-5		Struts 1-5 and 2-6	
	$F_1 = F_2 = F$	$F_1 = F$, $F_2 = 2F$	$F_1 = F_2 = F$	$F_1 = F$, $F_2 = 2F$	$F_1 = F_2 = F$	$F_1 = F$, $F_2 = 2F$	$F_1 = F_2 = F$	$F_1 = F$, $F_2 = 2F$
1-2	0	0	0	0	F	F	F	F
2-3	F	F	$3F$	$4F$	F	F	$3F$	$4F$
4-5	$-F$	$-F$	$-F$	$-F$	0	0	0	0
5-6	$-3F$	$-4F$	$-F$	$-F$	$-3F$	$-4F$	$-F$	$-F$
1-4	0	0	0	0	F	F	F	F
2-5	$-F$	$-F$	F	$2F$	0	0	$2F$	$3F$
3-6	0	0	0	0	0	0	0	0
2-4	$\sqrt{2}F$	$\sqrt{2}F$	$\sqrt{2}F$	$\sqrt{2}F$	□	□	□	□
3-5	$2\sqrt{2}F$	$3\sqrt{2}F$	□	□	$2\sqrt{2}F$	$3\sqrt{2}F$	□	□
1-5	□	□	□	□	$-\sqrt{2}F$	$-\sqrt{2}F$	$-\sqrt{2}F$	$-\sqrt{2}F$
2-6	□	□	$-2\sqrt{2}F$	$-3\sqrt{2}F$	□	□	$-2\sqrt{2}F$	$-3\sqrt{2}F$

Theoptimalitycriterionforatrussfromauniformlinear-elasticmaterialisstrengthuniformityofthevirtualsystemwiththeinternalforcesN_i/[fi]where[fi]istheratioofreductionofthedesignstrength$R$. For the stretched bars it is equal to 1, and for the compression one it is taken on the basis of the limitation of flexibility of the chord and frame members. Therequiredcross-section areas $A_i$of the compression bars shall have the corresponding minimal radii of gyration.

Theabove-mentionedcriterioncorrespondstothevariationalprincipleofstructuralsynthesis: the potential system energy in the state of stable equilibrium reaches the absolute minimum of displacement within the functional space enhanced by means of the fields of configuration functions and (or) material elasticity modulus. Incaseofauniformlinear-elasticmaterialthis equals to the minimal strain potential energy [11, 12]:

$$J = \sum_{i=1}^{m} \frac{N_i^2 \ell_i}{2E\varphi_i^2 A_i}, \qquad (2)$$

Where $m$is the number of bars.

In the example for the variants of loading considered

$$J_{(1)} = 7{,}94 k_1 \frac{RFd}{E}, \; J_{(2)} = 9{,}83 k_2 \frac{RFd}{E}, \qquad (3)$$

and the corresponding volume of material

$$V_{(1)} = 13{,}67 k_3 \frac{Fd}{R},\ V_{(2)} = 17 k_4 \frac{Fd}{R}. \qquad (4)$$

In the Table 2 the coefficient values k_1, k_2, k_3, $k_4$for four strut combinations are presented.

Thus, in terms of the minimal strain potential energy and the related minimal consumption of material the 1st and the 3d strut combinations appeared to be the optimal ones. The 1stvariantshallbepreferredas the two "zero" bars 1-2 and 1-4 are not essential which enables additional saving of the material.

Table 2 Coefficients in the formulas (3) and (4)

Coefficients	Struts 2-4, 3-5		Struts 2-4, 2-6		Struts 1-5, 3-5		Struts 1-5, 2-6	
	$F_1 = F_2 = F$	$F_1 = F$, $F_2 = 2F$	$F_1 = F_2 = F$	$F_1 = F$, $F_2 = 2F$	$F_1 = F_2 = F$	$F_1 = F$, $F_2 = 2F$	$F_1 = F_2 = F$	$F_1 = F$, $F_2 = 2F$
k_1	1		1, 049		1		1, 22	
k_2		1		1, 13		1		1, 27
k_3	1		1, 024		1		1, 19	
k_4		1		1, 098		1		1, 23

The tendency of "coating" the stress field by the matter is shown here in the "turning'' of the two struts to the loaded joints. Unfavorable combinations include one strut of such a kind.

Summary.
Bydesigningofthetubetrussesthejoint connections being the structuralstressconcentratorsshall be considered individually. There has been proposed a design solution the distinctive feature of which is the non-common arrangement of the chord cross-section. Itisturnedarounditsaxisformingarhombus. Duetothefavorabledistributionoftheinternalforcesthissolutionallowsincreasingthestrengthandreducingtheunitdeformability as the result of which the load-carrying capacity of the tube truss is increased. Seekingforthefavorabledistributionofforcesinthestructural bars promotes to the design of an efficient truss meeting the up-to-date requirements to lightness and reliability. The rationalization of its topology from the perspective of the variational principle of structural synthesis also contributes to this.

Conclusions.

Metallic tube trusses combine the high load-carrying capacity and lightness with the high esthetic properties. Thissets them apart from trusses made from traditional shaped structures. These properties are mostly shown in case of their rational topology.

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