Optimization of constructions with the grids of lenticular pipes

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Abstract. Presented a new technical solution, which is a highly efficient technical and economic indicators and massively used in industrial civil engineering. Development work and optimization design calculations of lattice structures using video surveillance from core pipes. Their new technical solution has been developed, the originality of which is confirmed by patent examination. Worked gussetless node connections of belts and grids with direct connection of core elements to each other without misalignments, as well as constructive eccentricities limited by 0.25 height of belt elements, which allows not to take them into account in the calculations, provides an increase in the degree of unification of the nodes of the upper and lower carrier zones designs. The whole diagram of changes in the design parameters of the lenticular pipes is given during the transformation of their cross sections from vertical to horizontal configurations, including a transition through a circular shape. The prospects of using a new technical solution in light metal structures of buildings and structures are shown. The area of its rational use is outlined, where, using alternative design of known and new solutions, a quantitative assessment of the resources of their carrying capacity is given.

Key words: calculation of optimal parameters, shaped pipes, core systems, trusses, lattice girders, light metal structures.

1. Introduction

Due to its high performance and aesthetic properties, rectangular and square pipes (welded profiles) have found mass distribution in the domestic and foreign construction practice. Due to the constructive form, they very effectively combine increased thin-walledness with not less increased rigidity. This can explain the fact that already in 1964, 80 thousand tons of square and rectangular profiles were used at construction sites in England [1]. Since then, the total number of round, square and rectangular pipes have been supplemented with new profiles. In particular, GOST R 54157-2010 “Profile steel pipes for metal structures. Specifications” regulates such profiles as oval, flat-oval, semi-oval, semi-plano and some others [2]. During the same time, light metal structures were developed and introduced for the complete delivery of spatially pivotal (structural) systems of the Moscow Architectural Institute, “Kislovodsk” of round pipes, as well as “Molodechno” truss and subrafter trusses of rectangular profiles [3].

The most widely used in tubular structures were gussetless node connections with direct connection of the lattice rods to the belts. Here, in order to avoid pushing (pulling out) the diameter of the grate pipe, at least
1/3 of the diameter of the belt pipe should be taken [4, p. 38]. In the construction of rectangular (square) pipes, this restriction is tightened twice, that is, the width of the lattice rod should be taken at least 0.6 of the transverse size of the belt [5, p. 26]. At the same time, the cutting of the end edges of rectangular and square pipes for their direct junction in the unit-free units, as a rule, is ensured by flat cuts at the angles specified by the design. The manufacture of gussetless nodes of round pipes requires additional expenses for figured cutting of the end edges due to the complex mating outlines of cylindrical shells. Therefore, in practice, quite often to simplify the faceless units, the ends of round pipes are subjected to partial or complete flattening. The formation of transitional and flattened sections of the rod elements of the tubular section of the gratings is recommended to ensure the slope of the transition section 1/6 ... 1/4 [3, p. 152; 4, s. 47-49; 6, s. 102]. Victor Ivanovich Trofimov has a priority in the creation of faceless assemblies with the flattening of all core elements in relation to structural structures. To obtain a knot, the ends of the pipes are flattened and cut in braces at an angle equal to the inclination of the brace. The rods are closed on the end faces and fixed in the conductor with the formation of free space with a width of about 3 cm, which is filled with melting metal. The time of welding of a single node is about 20 ... 25 minutes, and its weight does not exceed 2 ... 2.5% of the weight of the whole structure [7].

Similar design of connecting nodes without gussets is also characteristic of steel bar structures of coatings that have a longer history in construction science and technology, and the priority in their creation belongs to Vladimir Grigorievich Shukhov [8]. The lattice of such structures is made of a single round steel rod in the form of individual V-shaped, W-shaped (zigzag) elements or a continuous “snake” and at the points of inflection it has areas quite sufficient in length for welding the grid to the belts [9]. Therefore, in search of new technical solutions, it is very effective to take into account the practice and experience of steel bar structures of coatings, replacing zigzag lattices from rods with lattices of shaped tubes similar in shape. For the direct connection to the belts and the formation of gussetless nodes, the tubular profile in the places specified in the design is flattened and double-zigzag give a zigzag appearance. The length of the strip (tape) blank tubular profile (strip) can be chosen so that it is enough for the entire length of the structure or the entire length of the shipping mark. Compared with bar, such grids have a higher bearing capacity (especially in compression), which allows increasing the load on the structure or at a fixed load to reduce its material consumption.

At the level of optimization and variant design, several versions of roof trusses of run-through and rootless coverings with belts made of rectangular and square pipes, as well as with triangular and diagonal zigzag outlines of profile pipes (rhombic, round, oval, flat oval, lenticular) were worked out [10]. The solutions found were convincing enough to pass a patent examination with a positive outcome. All of them have their own distinctive features, but a number of common features allows us to conditionally consider them in a single cycle. Lines of bends in the power plane of the bearing structure form sheet hinges, close to ideal hinges (the calculated length of the compressed element is equal to its geometric length), and from the plane - frame mounts, close to rigid fittings (the calculated length of the squeezed element is half the length of its geometric length). Then, for stability (flexibility or rigidity) of the core elements of the gratings, which are the same from the plane and in the plane of the structure, it is possible to select cross sections, the inertia radii of which differ in terms of their values by two times. In practice, this is quite feasible with a noticeable positive effect due to the conversion of square pipes into rhombic, and round pipes into oval, flat-oval, lenticular. Additionally, for fabricated profiles, the technology of their manufacture using compressed air is applicable [11]. After the publication of the positive decision of the patent examination, the supporting structures with lattices of lenticular pipes are presented here as the proposed (new) solution, and the structures with lattices of oval and flat-oval pipes are the prototype of the new solution. On the other hand, such a representation of a technical solution, as well as its analogues and prototype, can be viewed as summing up some results of a small cycle started from rhombic pipe grids. Their knots are rather universal, unified, due to the sheet hinges, they eliminate the need to take into account the rigidity of the nodal, non-faceted joints of welded structures made of tubular profiles and help reduce the consumption of structural material [12].
Thus, the main idea of this publication is to identify the relevance, prospects and effectiveness of the systematic use of zigzag grids of core pipes for the development and research, design and implementation of new forms of supporting structures of buildings and structures.

2. Literature review
The proposed solution relates to the construction and can be used in the manufacture of trusses, girders, columns, arches, frames and other lengthy supporting grid structures of pipes. Currently, the most economical and common tubular structures include trusses of coverings (floors) of rectangular and square pipes (closed arc-welded profiles), whose effectiveness especially increases in the presence of off-site loads [6; 13, p. 461-463; 14, p. 294-296; 15, s. 29-35; 16-29]. In these truss structures, type assemblies are faceless joints with direct connection of core lattice elements to one of the four faces of the waist pipe, which is a source of stress concentration. Such junction is more often one-sided, where compliance with the ratio of transverse dimensions given in the introduction contributes to a more uniform distribution of stresses. A further decrease in the stress concentration ensures a reversal of the square pipe of the belt by 45° around the longitudinal axis when it occupies a rhombic position relative to the plane of the structure (Fig. 1, a) [30]. Even earlier, the rhombic position was adopted for the core elements of the lattice (Fig. 1, b) [31–34].

![Figure 1](image)

**Figure 1.** Axonometry of the node (a) and a snapshot of a fragment of a truss from square pipes (b)

The direct connection of the gratings to the belts to the tubular trusses was initially successfully tested in rod girders of coatings (Fig. 2) [9; 14, p. 370; 15, s. 25; 35; 36, p. 56-59].

To increase the carrying capacity (carrying capacity) of the run, its modifications were developed, including several zigzag lattices in the form of flat continuous “snakes” made of round rods or a pair of lattices in the form of one spatial continuous “snake” made of ribbon (strip) rods reinforced with stamped ribs (Fig. 3) [37, 38]. In addition, continuous “snakes” of lattice structures can be profiled with an open or closed cross section (Fig. 4) [39, 40].

In relation to bare surfaces, a truss (lattice) design has been developed, the belts of which are made of triangular pipes, and the grille has two layouts: from W-shaped (V-shaped) round rods or from round tubular rods with ends flattened in the plane of the structure and cut off at an angle of inclination of the braces (Fig. 5) [41].
Figure 2. Steel truss construction (lattice girder) using rods

Figure 3. The design of runs with grids of three flat "snakes" (a) and one spatial snake (b)
Figure 4. The design of the girders with grids of flat "snakes" open (a) and closed (b) cross-section
**Figure 5.** Scheme nodes truss (lattice) design of purlinless coverage: 

- **a** - the top belt with a bar lattice; 
- **b** - upper belt with a tubular lattice; 
- **c** - lower belt with a tubular grid and suspension crane equipment
Belt elements of rectangular tubes in purlinless coverage work more efficiently than similar elements of triangular profiles. Therefore, a supporting structure with a lattice in the form of a continuous “snake” of rhombic pipes, whose flattened sections provide the local (local) stability of rectangular and square belt elements in gussetless nodes, has been developed. If we take into account the fixing of the lattice rod elements (designs hinged in the plane and rigid from the plane), the greatest positive effect will be in a thin-walled tubular section of a rhombic shape with a diagonal ratio of 1/2, where the larger diagonal is located in the design plane and the smaller one is from the plane (Fig. 6). For the running coverings, the supporting structure with a lattice of rhombic profiles was modified with the replacement of belt elements from rectangular (square) pipes with rhombic (Fig. 7) [42].

![Figure 6](image1.png)

**Figure 6.** Axonometry of the supporting structure with a triangular (a) and diagonal (b) grid of a rhombic pipe

![Figure 7](image2.png)

**Figure 7.** Diagrams of the supporting structure of rhombic pipes for the purlinless coverage of a triangular (a) and diagonal (b) lattice

If zigzag lattices from rhombic profiles in supporting structures are replaced with lattice made of round, oval or flat-oval tubes of similar in shape (Fig. 8), due to the absence of angular zones of cross sections, the stress concentration and metal hardening will decrease, and the margin of safety will increase. The maximum positive effect will be in a thin-walled tubular section of an oval shape with a ratio of dimensions of 1 / 2.5 and a flat-oval shape with a ratio of dimensions of 1 / 2.63 (where the larger envelope is located in the plane of the structure and the smaller one is from the plane). In such lattices, all other things being equal, the flat-oval profile is more compact than the oval profile [43, 44]. Flattening and double bends of tubular lattice elements provide the layout of gussetless nodes joints without constructive eccentricities (Fig. 8, a), characteristic of rafter truss and subrafter trusses from rectangular (square) bent-welded closed profiles, which eliminates the appearance of bending moments and positively affects the consumption of structural material. However, at the same time, to increase the degree of unification of the nodes of the upper and lower belts, it is fully justified to use constructive eccentricities (Fig. 8, b), limited to 0.25 height of the belt elements, which allows not to take them into account in the calculations [5, p. 24].
Figure 8. Schemes of fragments of supporting structures with grids of round, oval and flat-oval pipes: a - without eccentricities in nodal joints; b - with constructive eccentricities for unification of the nodal joints of the upper and lower belts

For the manufacture of oval profiles, you can use round longitudinal pipes, which, after molding and welding, orient at a certain angle relative to the minor axis of the oval (approximately 39°32'). After orientation of the weld, the round tube enters the two-roll stand, where it is ovalized with dimensions of 440 × 650 mm (Fig. 9, a, b) [45]. Such a method of manufacturing tubular profiles should be refined to optimize oval and flat-oval pipes for truss (or beam) structures (Fig. 9, c, d) [46, 47].

Figure 9. Scheme of ovalization of a round pipe (a) and a diagram of bending moments in cross section during its unraveling deformation (b), as well as a reduction scheme for oval (c) and flat oval (d) pipes

As already noted, the supporting structures with grids of oval and flat-oval pipes served as a prototype for a new technical solution, which are similar designs with grids of lenticular profiles [48]. Such profiles can be manufactured according to the technologies adopted in the practice of pipe production, including the above. However, the practical interest is noted in the introduction technology of their manufacture using compressed air.

Thus, oval tubes are 76 ... 85% more expensive than “cylindrical shells of lenticular cross-section” (Fig. 10) [49, 50]:

- according to tabular data from a journal publication for November 2012, a ton of steel mini-shells cost 20,000 rubles [51];
- according to the price list of 04/01/2008 OJSC Moscow Pipe Plant (Moscow, Barclay St., 6) a ton of an oval pipe cost 37090 rubles (37090/20000 = 1.85);
- according to the price list dated July 27, 2012 LLC “StallIntech” (Moscow, Federativny Prospect, 5, building 1) a ton of an oval pipe cost 35,200 rubles (35,220,200 = 1.76).
Figure 10. Schemes of formation of cylindrical shells of a lenticular cross-section of rolled materials: a - billet to blow up; b - preform after blowing up; 1 - half-foldable blanks; 2 - welds; 3 - consoles; 4 - fitting; 5 - shell sections

Completing the review part and comparing the new technical solution with its prototype, it can be concluded that the curved profile tubes are quite promising for optimization in relation to the gratings of supporting structures of buildings and structures.

3. Results of research
The technical result of the proposed solution is to reduce the complexity of the manufacture of supporting structures and reduce their costs. It is achieved by the fact that in supporting structures, including belts and lattices rigidly attached to them, made with flattened ends of curved zigzag outline elements, the core elements of lattices have ocular sections with an aspect ratio of $1 / 2.414$, where large dimensions are located in the planes of the structures, and the smaller ones are perpendicular to these planes (Fig. 11) [48].
To derive the above ratio and quantify the resources of the bearing capacity, it is advisable to calculate the axial inertia moments $I_x$ and $I_y$, as well as the sectional area $A$ of the curved tubular profile. The cross section of this profile can be considered as hollow in the form of lentils (Fig. 12) [52]:

$$I_x = R^3 t(2\alpha - \sin 2\alpha) ;$$  \hspace{1cm} (1)  
$$I_y = R^3 t(2\alpha(2 + \cos 2\alpha) - 3\sin 2\alpha) ;$$  \hspace{1cm} (2)  
$$A = 4\alpha R t ,$$  \hspace{1cm} (3)

from where

$$R = \frac{A}{4\alpha t}.$$  \hspace{1cm} (4)

where $R$ – is the arc radius of the cross section of the lenticular tube along the centerline; $t$ – wall thickness of the lenticular tube; $\alpha$ – half of the central angle that tightens the arc of the cross section of the lenticular tube along the middle line.

To the reference formulas we need to add one more:

$$n = \frac{U}{V},$$  \hspace{1cm} (5)

here $n$ – is the ratio of the smaller to the larger; $U$ – smaller envelope of the cross section of the lenticular pipe along the midline; $V$ – larger envelope of the cross section of the lenticular pipe in the midline.

To obtain a reduced ratio, to simplify the calculations, it is advisable to consider a special case when $\alpha = \pi / 4$ or $\alpha = 45^\circ$, when

$$I_x = R^3 t(2\alpha - \sin 2\alpha) = R^3 t(\pi / 2 - \sin(\pi / 2)) = R^3 t(3.14 / 2 - 1) = 0.57 R^3 t$$  \hspace{1cm} (6)  
$$I_y = R^3 t(2\alpha(2 + \cos 2\alpha) - 3\sin 2\alpha) = R^3 t((\pi / 2)(2 + \cos(\pi / 2)) - 3\sin(\pi / 2)) =$$

$$= R^3 t((3.14 / 2)(2 + 0) - 3 \times 1) = 0.14 R^3 t$$  \hspace{1cm} (7)  

$$\frac{I_x}{I_y} = \frac{0.57}{0.4} = 4.0714285 \approx 4$$  \hspace{1cm} (8)

with errors $100(4.0714285 - 4) / (4.0714285...4) = 1.75...1.79%$;

$$\frac{i_x}{i_y} = \sqrt[0.57]{0.14} = 2.0177781 \approx 2$$  \hspace{1cm} (9)
with errors $100\left(\frac{2.0177781 - 2}{2.0177781...2}\right) = 0.881...0.889\%$;

Figure 12. The design scheme of cross sections of the lenticular pipes (a) and a snapshot of the slice of different-sized profiles (b)

$$R = \frac{A}{4\alpha t} = \frac{A}{4(\pi/4) t} = \frac{A}{3.14 t} = 0.3184713 \frac{A}{t}; \quad (10)$$

$$I_x = 0.57R^3t = 0.57\left(0.3184713 \frac{A}{t}\right)^3 t = 0.0184113 \frac{A^3}{t^2}; \quad (11)$$

$$I_y = 0.14R^3t = 0.14\left(0.3184713 \frac{A}{t}\right)^3 t = 0.004522 \frac{A^3}{t^2}; \quad (12)$$

$$i_x = \sqrt{\frac{0.0184113A^3}{t^2A}} = 0.135688 \frac{A}{t}; \quad (13)$$

$$i_y = \sqrt{\frac{0.004522A^3}{t^2A}} = 0.0672458 \frac{A}{t}. \quad (14)$$

As can be seen, there is a two-fold difference in the inertia radii of the considered cross section with an error that is quite acceptable in practical calculations. Therefore, it remains to determine the dimensions of this section and their relationship. The larger dimension of the cross section along the middle line $V$ on the design diagram of a hollow profile in the form of lentils is a diagonal of a square with a side equal to the
radius of the arc \( R \), and half of the smaller envelope \( U \) is the difference of the same radius and half of the same diagonal (or half of the larger dimension), that is

\[
V = \frac{2R}{\sqrt{2}} = \frac{2 \times 0.3184713A}{\sqrt{2}} = 0.4503864 \frac{A}{t}; \quad (15)
\]

\[
U = 2(R - \sqrt{R^2 - 0.25V^2}) = 2(0.3184713 - \sqrt{0.3184713^2 - 0.25 \times 0.4503864^2}) = 0.1865562 \frac{A}{t}.
\]

\[
n = \frac{U}{V} = \frac{0.1865562}{0.4503864} = 0.4142135 \approx 0.4142 = \frac{1}{2.414}. \quad (17)
\]

4. Testing of the design circuit
The results can be tested using the Huygens formula for arc length \([53]\):

\[
p \approx 2l + \frac{1}{3}(2l - L) = \frac{8l - L}{3} = \frac{8\sqrt{0.25U^2 + 0.25V^2} - V}{3} = \frac{8\sqrt{0.25n^2V^2 + 0.25V^2} - V}{3} = \frac{8\times 0.5V\sqrt{n^2 + 1} - V}{3} = \frac{V(4n^2 + 1 - 1)}{3} = 0.4503864 \frac{A}{t} \times \frac{4\sqrt{0.4142^2 + 1}}{3} = 0.4998609 \frac{A}{t} \approx (18)
\]

with errors \(100(0.5 - 0.4998609)/(0.5...0.4998609) = 0.028\%\),

where \( p \) – is the length of one of the two arches of the lenticular profile along its midline, \( p = 0.5(A/t) \); \( l \) – a half arc chord, \( l = \sqrt{0.25U^2 + 0.25V^2} \); \( L \) - chord of the whole arc, \( L = V \).

The verification calculation is rather correct, since its relative error slightly differs from the error of the Huygens formula, which is approximately equal to \( \alpha = 45^\circ \) the angular parameter which is \( 0.02\% \).

5. Comparison of the calculated parameters of the new solution and its prototype
After testing, the obtained results for the new technical solution are interesting to compare with the similar results for its prototype, which is an oval tube with attitude \( n = 0.4 = 1/2.5 \). Then, taking with, in relation to the prototype can be written down \([43]\):

\[
U = 0.182 \frac{A}{t}, \quad V = 0.455 \frac{A}{t}, \quad n = \frac{U}{V} = \frac{0.182}{0.455} = \frac{1}{2.5};
\]

\[
I_x = 0.0203346 \frac{A^3}{t^2}, \quad J_y = 0.0050281 \frac{A^3}{t^2}, \quad \frac{I_x}{I_y} = 4.044192 \approx 4
\]

with errors \(100(4.044192 - 4)/(4.044192...4) = 1.093...1.105\%\);

\[
i_x = 0.1425994 \frac{A}{t}, \quad i_y = 0.0709090 \frac{A}{t}, \quad \frac{i_x}{i_y} = 2.0110197 \approx 2
\]

with errors \(100(2.0110197 - 2)/(2.0110197...2) = 0.548...0.551\%\).

Comparison of the results allows to conclude that the estimated parameters of the prototype in absolute value exceed the calculated parameters of the proposed solution:

\[
\Delta U = \frac{0.182}{0.1865562} = 0.9755773,
\]
that is, under the given conditions, when $A = \text{const}$ and $t = \text{const}$, and $i_x = 2i_y$ ($I_x = 4I_y$), for the lenticular pipes, the cross sections in height are 1.024% more compact than those of the oval, while for oval pipes, the geometrical characteristics of the sections are $5.4...12.4\%$ larger than those of the lenticular.

6. Example of optional design

As an object of alternative design for comparing the proposed (new) technical solution with its counterparts and prototype, a steel truss from shaped pipes (bent-welded profiles) with a span of 18 m was adopted to cover an industrial building:

- truss with a grid of square pipes [36, p. 157-172];
- truss with a rhombic pipe grille [42];
- truss with a round pipe grille [43];
- a truss with an oval pipe grille [43];
- a truss with a grating of a flat-oval pipe [44];
- a farm with a grill of a lentil tube,

where the transitional and flattened sections of the core elements of the lattices of tubular profiles, it is advisable to form with a slope of $1/4$ [6, p. 102].

The results of the calculation of the consumption of structural material are summed up in a tabular form (table 1), from which it is obvious that modifications with lattices of oval, flat-oval and curved pipes are more economical. The cost of making a tube is cheaper, so all other things being equal, a new technical solution is more preferable.

| Cross section | length, mm* | Qty, PC. | 1 m | 1 pc. | Weight, kg all | total | Note. |
|---------------|-------------|----------|-----|-------|----------------|-------|-------|
| □ 160×120×5  | 9000        | 2        | 20.7| 186.3 | 372.6          | 880.4 | Belts |
| □ 120×4      | 7500        | 2        | 14.3| 107.3 | 214.6          | 880.4 | Belts |
| □ 100×4      | 2390        | 8        | 11.8| 28.2  | 225.6          | (100%)| Grate |
| □ 80×3       | 2390        | 4        | 7.07| 16.9  | 67.6           |       |       |
| □ 160×120×5  | 9000        | 2        | 20.7| 186.3 | 372.6          | 881.7 | Belts |
| □ 80×4       | 2390        | 12       | 9.22| 22.04 | 264.5          | (96.7%)| Grate |
| □ 160×120×5  | 9000        | 2        | 20.7| 186.3 | 372.6          | 831.0 | Belts |
| □ 120×4      | 7500        | 2        | 14.3| 107.3 | 214.6          | (94.4%)| Grate |
| ○ 102×3,5    | 2390        | 12       | 8.50| 20.32 | 243.8          |       |       |
| □ 160×120×5  | 9000        | 2        | 20.7| 186.3 | 372.6          | 799.3 | Belts |
| □ 120×4      | 7500        | 2        | 14.3| 107.3 | 214.6          | (90.8%)| Belts |
The obtained results of the optimization and variant design show that the proposed technical solution allows depending on the design decisions by appropriate selection of the ratio of the dimensions of the section of the tubular pipes, as well as the arrangement of these dimensions in the planes of the supporting structures to adjust their stress-strain states. Such regulation is not limited to the given values \(1/2,414\) \((n = 0,4142)\) and \(1/1\) \((n = 1)\), but has a very wide range (Fig. 13) and, in general, can ensure the effectiveness of further optimization of the supporting structures of buildings and structures.

* * *
ratio of their dimensions, where \( d \) – is the diameter of a round pipe along its midline when \( A = \text{const} \) and \( t = \text{const} \).

7. Conclusion

Thus, summing up some results, we can formulate a number of key conclusions.

1. Review and analysis of the research, development and design work, as well as optimization and variant design show that the systemic use of the proposed zigzag outlines of shaped pipes seems to be quite relevant, promising and effective for developing and researching, designing and introducing new forms load-bearing structures of buildings and structures.

2. The sheet hinges in the gussetless nodal joints provide the approach of the lattice structures to their design schemes (models) in the form of hinged-rod systems, which increases the degree of reliability and structural safety of buildings and structures.

3. An approximate calculation of the occipital sections confirmed its correctness and simplicity for the practical solution of problems of optimizing load-bearing structures.

4. Selection of the optimal parameters of shaped pipes and their use in supporting structures instead of square, rhombic and round profiles provides an increase in rigidity (or decrease in flexibility) of the core elements of the grids.

5. Comparison of the proposed and well-known solutions on the same basic object revealed a decrease in the consumption of structural material (steel), which ensures the maintenance and increase of the competitiveness of the supporting structures during their modernization.

References

[1] Mel'nikov N P, Vinkler O N, Levitanskii I V 1973 Kholodnognutye zamknutye svarnye profili – wysokoeffektivniiy material dlya legkih konstruktsii Promyshlennoe stroitel'stvo 6 pp 24-27
[2] GOST R 54157-2010. 2011 Truby stal'nye profil'nye dlya metallokonstruktsii Tekhnicheskie usloviya (Moscow Standartinform) p 74
[3] Trofimov V I, Kaminskii A M 2002 Legkie metallicheskie konstruktsii zdani i sooruzhenii (razrobotka konstruktsii, issledovaniya, raschet, izgotovlenie, montazh) (Moscow : Izd-vo ASV) 574 p
[4] Rekomendatsii po proektirovaniyu stal'nykh konstruktsii s primeneniem kruglykh trub 1973 (Moscow: TsNIISK im. V.A. Kucherenko) 94 p
[5] Rukovodstvo po proektirovaniyu stal'nykh konstruktsii iz gnutosvannykh zamknutych profili (Moscow: TsNIIProektstal'konstruktciya) 44 p
[6] Packer J A, Wardenier J, Zhao X-L, van der Vegte G J and Kurobane Y 2009 Construction with hollow steel sections. Design Guide for rectangular hollow section (RHS) joints under predominantly static loading (CIDECT) 156 p
[7] Trofimov V I, Begun G B 1972 Strukturnye konstruktsii isssledovaniem, raschet i proektirovaniem (Moscow: Stroiizdat) pp 47-48
[8] Shukhov V G 1977 Stroitel'naya mekhanika. Izbrannye trudy (Moscow: Nauka) pp 71-82
[9] Podlipskii A A 1954 Stal'nye prutkovye konstruktsii pokrytii (Moscow: Gos izd-vo lit po str-vu i arkhitekture) 144 p
[10] Maruyama A S 2016 Profil'nye truby novykh modifikatsii dlya stroitel'nykh metallokonstruktsii, vkluchaya moduli «Pyatigorsk» i «Novokislovodsk» (Pyatigorsk: Izd-vo PF SKFU) 168 p
[11] Rashchepkina S A 2009 Vestnik MGU Spetsvyupusk 3 pp 147-150
[12] Pokrovskii A A 2011 Ob uchete zhestkosti uzlov v raschetakh ferm s elementami maloi gibkosti Stroitel'naya mekhanika i raschet sooruzhenii 3 pp 31-32.
[13] Gorev V V 2004 Metallicheskie konstruktsii (Moscow: Vysshaya shkola) vol 1 pp 461-463
[14] Kudishin Yu I 2007 Metallicheskie konstruktsii (Moscow: Izdatel'skiy tsentr «Akademiya»), 688 p
[15] Trishhevskii I S, Klepanda V V 1978 Metallicheskie oblegchennye konstruktsii (Kiev: Budivele'nik), 112 p
[16] Kuz'menko S M 1984 Ratsional'nye printsiy razrabotki tipovykh seriyakh stroitel'nykh konstruktsii na primere proektirovaniya besprogonnogo pokrytiya «Molodechno» Promyslennoe stroitel'stvо 12 pp 34-37

[17] Vedyakov I I 2007 Sovremennye tendentsii razvitiya rossiiskoi industrii stroitel'nykh konstruktsii Promyslennoe i grazhdanskoе stroitel'stvо 3 pp 8-9

[18] Fermennye konstruktsii sistemy TranskonTM 2009 (Obninsk: ООО «Ruukki Rus») p 88

[19] Specification for Structural Steel Buildings 2010 American Institute of Steel Construction June 22 2010 pp 425-436

[20] Markku Heinisuo, Teemu Tiainen and Timo Jokinen 2013 Tubular truss design using steel grades S355 and S420 35 p

[21] Corona E, Vaze S P 1996 Buckling of elastic-plastic square tubes under bending International Journal of Mechanical Sciences vol 38 (7) pp 753-775

[22] Reyes A, Langseth M, Hopperstad O S 2003 Square aluminum tubes subjected to oblique loading International Journal of Impact Engineering vol 28 (10) pp 1077-1106

[23] Karagiozova D, Jones N 2004 Dynamic buckling of elastic-plastic square tubes under axial impact-ii: structural response International Journal of Impact Engineering vol 30 (2) pp 167-192

[24] Zhao H, Abdennadher S 2004 On the strength enhancement under impact loading of square tubes made from rate insensitive metals International Journal of Solids and Structures 41 (24-25) pp 6677-6697

[25] Utsumi N, Sakaki S 2002 Countermeasures against undesirable phenomena in the draw-bending process for extruded square tubes Journal of Materials Processing Technology 123 (2) pp 264-269

[26] El-Hage H, Mallick P K, Zamani N 2006 A numerical study on the quasi-static axial crush characteristics of square aluminum-composite hybrid tubes Composite Structures 73 (4) pp 505-15

[27] Liu Y-B, Zheng N-N, Liu J-B, Han Q 2010 A simplified approach to define the yield surface of concrete-filled square steel tubes subjected to compression-bending Chongqing Daxue Xuebao 30 (10) pp 70-75

[28] Kol'zeev A A 2005 Otsenka vliyaniya tolshchiny polok na ustoichivost' vnetsentrenno-szhatykh sterzhnei iz pryamougol'nikh trub Izvestiya vuzov. Stroitel'stvo 6 pp 85-88

[29] Psyuk V V, Nikishina I A 2014 Raspredelenie ostatochnyh napryazhenii v stal'nykh trubakh kvadratnogo secheniya Sbornik nauchnykh trudov Ukrainskogo nauchno-issledovatel'skogo i proektionalnogo instituta stal'nykh konstruktsii im. V M Shimanovskogo 14 pp 129-135

[30] Sokolov A A, Logachev K I, Zin'kova V A 2007 Chislennye issledovaniya napryazhenno-deformirovannogo sostoyaniya uzlovykh besfasonnykh soedinenii elementov ferma Promyslennoe i grazhdanskie stroitel'stvо 8 pp 40-41

[31] Ono T, Iwata M, Ishida K 1994 Local failure of joints of new truss system using rectangular hollow sections subjected to out-of-plane bending moment. Proceedings VI International Symposium on Tubular Structures (Melbourne, Australia, Rotterdam, the Netherlands) pp 441-448

[32] Davies G, Owen J S, Kelly R B 2001 The effect of purlin loads on the capacity of overlapped bird-beak K-joints Proceedings IX International Symposium on Tubular Structures (Dusseldorf, Germany), pp 229-238

[33] Kuznetsov A F, Kuznetsov V A 2011 Pat. RF №116877, MPK E04S3/08 (2006.01). Ferma iz kvadratnykh trub; patentoobl. Yuzhno-Ural'skii gosudarstvennyi universitet №2011150569/03; zayavl. 12.12.2011; opubl. 10.06.2012. Byul. №16.

[34] Baikov D A, Lapshin A A, Kolesov A I 2014 Osobennosti raboty ploskikh ferma iz zamknutikh gnutykh profili, soedineniy v uzlakh na rebro 16-i Mezhdunarodnyi nauchno-promyshlenennyi forum «Velikiye reki' 2014» (N Novgorod: NNGASU), pp 197-201

[35] Streletskii N S, Geniev A N 1935 Osnovy metallicheskikh konstruktsii (Moscow-Leningrad: Glavnaya redaktsiya stroitel'noi literatury) pp 584-590

[36] Kuzin N Ya 1998 Proektirovanie i raschet stal'nykh ferma pokrytiy promyshlennykh zdani (Moscow: Izd-vo ASV), p 184

[37] Roberts A L 1949 United States Patent №2476386. Floor unit. 19.07.1949.
[38] Claude G Harding 1981 United States Patent №4291515. Int. Cl E04C2/42. Structural elements. 29.09.1981.

[39] Melvin L Ollman 1975 United States Patent №3882653. Int. Cl E04C3/02, E04CB1/343. Truss construction. 13.05.1975.

[40] Grubb L W 1961 United States Patent №3129493. Methods for manufacture of lightweight structural members. 20.06.1961.

[41] Orlik V M 1992 Avtorskoe svidetel'stvo SSSR №1760041, MPK E04V1/58, E04S3/08. Stroitel'naya metallicheskaya tonkostennaya reshetchataya konstruktsiya. №4776531/33. 07.09.1992. Byul. №33.

[42] Marutyan A S, Chernov P S, Orobinskaya V N, Galdin E V 2017 Improvement of truss bearing capacity by means of rhombic pipes Key Engineering Materials vol 736 pp 171-176

[43] Marutyan A S, Orobinskaya V N 2016 Optimizatsiya konstruktsii s reshketami iz kruglykh i oval'nykh trub Vestnik MGSU 10 pp 45-57

[44] Marutyan A, Kobaliya T, Galdin E 2018 Optimization of flat-oval pipes and perspectives of their application in core structures MATEC Web of Conferences 251, 03015 (2018)

[45] Zarankin V N 1989 Avtorskoe svidetel'stvo SSSR №1466827, MPK V21S37/08. Sposob izgotovleniya oval'nykh svarynykh pyramolineinykh trub; patentooobl. Ivanovskii zavod avtokranov. №4265826/29-27. 23.03.1989. Byul. №11.

[46] Nezhdanov K K, Tumanov V A, Nezhdanov A K, Rublikov S G 2007 Pat. RF №2304479, MPK V21D9/00 (2006.01). Sposob povysheniya nesushchei sposobnosti tsilindricheskoi truby na izgib. №2005115787/02. 20.08.2007. Byul. №23.

[47] Marutyan A, Kobaliya T, Galdin E 2018 Optimization of flat-oval pipes and perspectives of their application in beam structures MATEC Web of Conferences 251, 03016 (2018)

[48] Marutyan A S Pat. RF №2618771, MPK E04C3/08, E04B1/58 (2006.01). Nesushchaya konstruktsiya s reshketoi iz chechevidnych trub. №2016105868/11.05.2017. Byul. №14.

[49] Denisova A P, Rashchepkina S A 2009 K voprosu uprugoplasticheskogo deformirovaniya stal'nykh polos Promyshlennoe i grazhdansko stroitel'stvo 9 pp 31-32

[50] Zemlyanskii A A, Denisova A P, Rashchepkina S A, Rashchepkin S V 2001 Pat. RF №2175372, MPK E04N7/06 (2006.01). Sposob sooruzheniya emkosti iz rulonirovannykh materialov. №99117202/03. 27.10.2001. Byul. №29.

[51] Rashchepkina S A 2012 Formoobrazovanie innovatsionnykh metallicheskich konstruktsii razlichnogo naznacheniya Promyshlennoe i grazhdansko stroitel'stvo 11 pp 74-76

[52] Pisarenko G S, Yakovlev A P, Matveev V V 1988 Spravochnik po soprotivleniyu materialov (Kiev: Naukova dumka) pp 80-81

[53] Vygodskii M Ya 2006 Spravochnik po elementarnoi matematike (Moscow: Astrel'-AST) pp 342-343