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Research Article

STRENGTHENING TECHNOLOGY OF TIMBER TRUSSES BY PATCH PLATES WITH TOOTHED-PLATE CONNECTORS

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ABSTRACT

Most textile buildings, erected at the beginning of the XX century, have roofs with timber trusses. The trusses damage after continuous operation, the increased load on the bottom chord and others make it necessary to strengthen tensile members of the trusses. It is proposed to strengthen the tensile trusses members with the help of toothed-plate connectors. They are the shear elements involving the patch plates in structure performance.

The paper has the results of shear tests of the wooden samples connected by toothed-plate connectors with post-clamping. The load-carrying capacity of the connection was determined.

These results formed the basis for the strengthening technology of tensile elements of segmental trusses by wooden patch plates with toothed-plate connectors. The proposed method of strengthening was applied in Arkhangelsk facilities.

INTRODUCTION

Timber bearing structures for the roofs of industrial and civil buildings were designed since the beginning of XX century. In addition to known joggle trusses, there were widely used nailed trusses with solid web (the analogs of K.E. Lembke's bridge trusses), segmental nailed trusses and three-hinged arch trusses. Later the other types of trusses appeared: wood-and-metal trusses consisting of large panels and glued chords trusses (Dmitriyev 2010). Many buildings were erected with analogue timber roofs. However, one of the most common roofs was a timber segmental truss.

The segmental trusses are used for span from 10 to 40 m at a load up to 20 kN per 1 rm. For the covering of long spans the segmental trusses are used in the form of three-hinged arches links. These arches have spans of 75 m. Segmental trusses can be classified: by the outline of the top chord (the arc of the circle, the arc of the parabola, the elliptical arc and other curves,

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which are symmetrical about any axis); by the truss height; by the truss web scheme; by the section of the top or bottom chord, etc. (Kuznetsov, 1937).

There are two types of top chord structures: structures of bent bars and structures of curved piece boards. The first ones are the most common because manufacturing of the last type of structures requires more labor. The whole truss design is determined by section of the top chord. In the simplest case the chord comprises two branches moved apart by the thickness of web members, with a cant board between them. When the width of the branches is more than 70 mm, the two-branch chord should be replaced by the three-branch chord to improve the economic efficiency of nailed connection.

Similar to the top chord branches, the bottom chord boards are driven apart at the distance of web members thickness. The main type of connections for the joints of the bottom chord is cylindrical steel gun nail. With small thickness of the joint, in cases, when the chord consists of two boards, it is better to use nails instead of gun nails. Compared to the gun nails, the nails less weaken the chord section and more uniformly distribute the force over the section. Draw bolts must be put in gun nailed and nailed joints to prevent the growth of construction joints of the connection. The joints are either end-to-end, or moved apart within the panel.

In the simplest case, when the chords are made up of two branches, the web members have the entire section of one board. Having high flexibility, the boards are strengthened by plates on nails along the entire length. Connecting nails have operation shears in both seams of the section. Two-branch web members are obtained for the types of chords of three branches. In this case, nailed gaskets are set between the branches. It provides stiffness of the structure and behavior of both branches. The gaskets may be continuous or split (distributed throughout the length of the member).

Based upon the character of force transferring from one chord to another, heel joints can be divided into two groups. For the 1st group, the loads are transferred through the gaskets or the patch plates, connected with the bottom chord by steel gun nails or nails; for the 2nd group, the loads are transferred along the outer surface of the chords. The heel joints from group 1 are: bridle joints, joints with straight tie rods and joints with tie rods operating on the principle of ideal cable. They are the most widely used for building. The heel joints from group 2 are typically constructed with cross-head clamps plates of boiler steel, which are transferred the forces from one chord to another. The connection of the cross-head clamps with the bottom chord is carried by gun nails, bolts or claw plates.

BOTTOM CHORD STRENTENING METHODS

Splits, biological damage and other defects appear in timber trusses after long operation. This reduces strength and stiffness properties of structure elements. Installation of suspended ceilings, navigating bridge and processing equipment increases the load on the trusses. In this case axial force in truss members increases and individual elements no longer satisfy the requirements of strength and stability. Top and bottom- chord stresses have approximately the same value, but the design tensile strength of the wood is lower than the compressive strength, so the strengthening of the bottom (stretched) chord is required.

The strengthening of the bottom chord of a truss can be performed by the following methods (Bardin and Karelskiy, 2016):

- stress variation (using of ties, strut-framed beams, truss bars, etc.)

- the structural scheme change (setting of additional supports, struts, etc.)

- change of the geometric characteristics of the cross section (setting of patch plates, using of additional elements, etc.).

The method of stress variation is difficult. Besides, applying of tie-bars and truss rods spoils the aesthetic of the structure. On the other hand, installation of additional supports and struts reduces the internal space of the room.

The use of patch plates is considered to be the most effective. Wooden fish-plates are connected to the truss chord with glue or by mechanical bonds (nails, bolts, gun nails, gun nailed groups, glued in rods, dowels, connectors, etc.) (Kochenov, 1953; Lennov, 1958; Aghayere and Vigil, 2007; Andrews, 1967; Erdodi and Bodi, 2004; Erman, 2002; Linville, 2012; Parisi and Piazza, 2000; Rammer, 2001; Roche. *et al*., 2015; Tomasi, *et al*., 2004).

A glued joint is definitely one of the most reliable. However, this connection is technologically difficult and to perform its quality on the construction site is very problematic and, in many cases, impossible. Nailed, bolted and other gun nailed connections weaken the cross section of strengthened wooden member and require large material consumption. The strengthening of tensile members of a timber truss with the help of gun nail connectors is shown in (Fox, 2008; Klajmonová and Lokaj, 2015; Lokaj and Klajmonová, 2015; Loferski, *et al*., 2013; Munafò, *et al*., 2015; Walkup, *et al*., 2016).

The main task in strengthening by patch plates is the selection of connections with the lowest weakness sections. The authors propose to fix the wooden patch plates to the bottom chord of the truss with tightening cross-head clamps. The connectors, taking up shear, should be placed between the patch plates and the bottom chord then. As most of the operation in such connection will be performed by the connectors, the adequate choice of them is supposed to be very important.

PLATE CONNECTOR TYPE JOINTS BEHAVIOR

M.V. Ariskin (Ariskin, 2011; Ariskin and Nikishina, 2013; Ariskin and Kutsenko, 2013), V.M. Vdovin (Vdovin, *et al.,* 2012; Vdovin, *et al.,* 2013; Veshnyakov, 1999; Galakhov, 2002), B.V. Labudin (Popov, *et al.,* 2016; Popov, *et al.,* 2015; Rimshin, *et al.,* 2016; Chernykh, 2013; Rimshin, 2016) researched wood members connections with plates.

The most common types of mechanical connectors are given below.

The toothed-ring connector of "Alligator"

It is a closed ring of corrugated steel, having jagged ridges on both sides (Fig. 1a). The connector stability is provided by the cylindrical ring stiffness, greatly weakened by the ridges. This limits the diameter of the ring to 160 mm. The dimensions of the washers and bolts depend on both conditions of the perception of stay brace and conditions of the overcoming of elastic back pressure while the connector is pressed in. The bolt holes are pre-drilled in the connecting members of the pre-assembled construction (or with the help of the markup), then the construction members are strung on the centering bolts with connectors between them and pressed. The allowable load on the toothed-ring connector of "Alligator" is 7-30 kN;

M.M. Horkov's toothed-ring connector

It is a closed ring of asymmetrical shape with teeth. The cutting edge of the teeth is sharped so that they do not tear the wood fibers while they are pressed in (Fig. 1b). The joints with the toothed-ring connectors do not require drilling. The formation of the slot takes place simultaneously with the connector's being pressed in the timber. So, the joints with the toothed-ring connectors have high density equaled about density of nailed joints and constant in all radial directions of the ring. The allowable load on M.M. Horkov's toothed- ring connector is 6.5-35 kN (49 kN for the concentric set of connectors);

The connector of "Buffo"

It is a square plate of thin steel with a ring double-sided corrugation (Fig. 1c). There is a hole for the bolt in the center of the plate. When the connector is pressed in the timber, its corrugation does not cut the fibers. The bolt tightly adjoins to the hole in the connector. During the connector performance, the force, transferring through the corrugations, causes the bolt tension. With the failure of the connection. The toothed plates of PZD3 having the dimension of 75 × 26 mm are taken for the strengthening of the bottom chord of trusses (Fig. 2) (Table 1).

The bearing of the timber under the connector corrugation and its jamming between the connected members occur. In this case, the bolt begins working in shear. The dimensions of the tightening bolt and the external washers should be sufficient for fully pressing the washers in the wood, without external

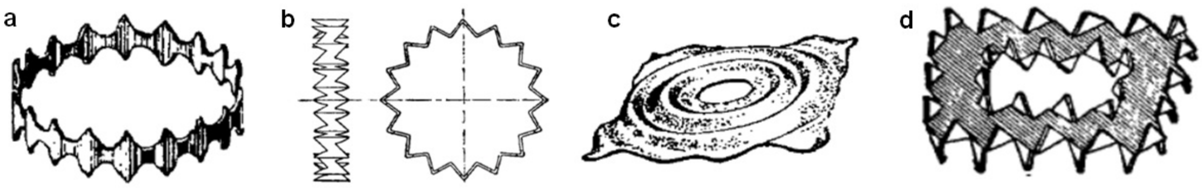

Fig. 1 Types of mechanical connectors:
a – toothed-ring connector of "Alligator"; b – M.M. Horkov's toothed- ring connector; c – connector of "Buffo"; d – square plate connector of "Bulldog".

Table 1. Characteristics of PZD toothed plates

Plate name	Dimension	Plate diameter, mm	Hole diameter, mm	Material thickness, mm	Weight **pcs., kg**
PZD1	48x17x1	48	17	1	0.02
PZD3	75x26x1.3	75	26	1.3	0.05
PZD4	95x33x1.5	95	33	1.5	0.09

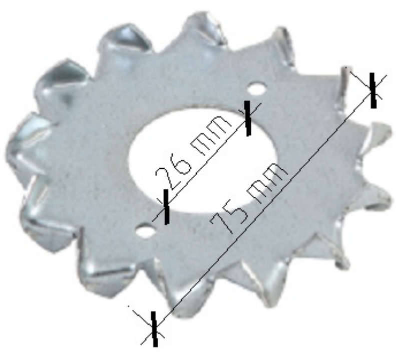

Fig 2 The PZD3 toothed plate dimensions.

washers pressing in and without bolt stretching. Using of wet lumber has a negative effect, as the resulting clamping of the washers disappears completely. The allowable load on the "Buffo" connector is 7.5-30 kN (Kuznetsov, 1937);

The toothed-plate connector of "Bulldog"

It is a round, square or an oval plate of thin steel (1.0-1.2 mm) with triangular-shaped claws, bent perpendicular to the plane of the plate (Fig. 1d). The toothed-plate connectors are denoted as Type C in prEN 912 (Timber fasteners - Specifications for connectors for timber). There are two types of "Bulldog" plate connectors : with single sided or double sided bending of teeth. The former is used for transfer of the force from the wood to the metal plate; the latter is for timber-to-timber force transfer. A number of sharp teeth provides a firm contact between the toothed plates and the timber, ease in operation (the impression of plates without pre-drilling of slots) and higher performance reliability, which is common for connections having bearing failure (Connectors and metal plate fasteners for structural timber, 1996). The allowable load on the "Bulldog" plate connector is 2-35 kN.

MATERIAL AND TEST METHODS

In accordance with the recommendations, tests were performed to determine the connection compliance (Regulations for the test of wooden structures connections)

Three boards with section 240 h 100 × 50 mm were used for the manufacturing of the connection model (Fig. 3). The central board was 30 mm shifted from the other two. The toothed plates (2) were installed between the boards (1). The plates were pressed into the connection with the help of the cross-head clamps (3). Three samples were used for the test. The 12% moisture content of wood samples was taken.

In accordance with the recommendations, the toothed-plate connection is from the second group of connections that is with nonlinear load dependence from the applied force. The samples with such connection are tested in steps as the load increases.

The loading was made on the testing machine of Shimadzu AG-50 kNX with automatic time load and deformation recording. The 3 kN step was taken.

The total duration of the test was determined by the formula:

$$t_1' = n^2 \cdot t' \tag{1}$$

n = 11 – the number of the load steps until failure;

t' = 10 sec. – the duration of the force variation by the amount of one step.

Thus, the total duration of the test was equal 1210 sec.

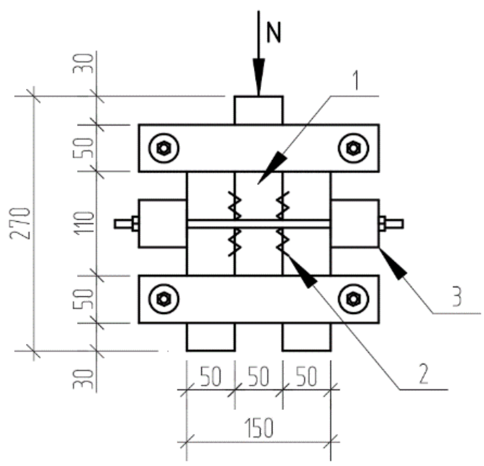

Fig. 3 Test samples with the toothed plates:
1 – the sample consisting of three boards; 2 – the PZD3 toothed plates of 75x26 mm;
3 – the members replacing cross-head clamps.

Fig. 4 Tested samples after failure.

The duration of the load until failure, given to the invariable effect of the breaking force Nt, was determined by the formula:

$$t = \frac{t_1'}{38,2} \quad (2)$$

The failure of the samples (Fig. 4) was partly due to the bearing of the teeth plates, partly due to the bearing of the wood. The shear occurred on the central board. All the samples had ductile type of the failure.

The coefficient of reliability at ductile failure was determined by the formula:

$$K_{дл} = 1,38 \cdot (1,94 - 0,116 \cdot \lg t) \quad (3)$$

Based on the results of the test, calculations and processing, the coefficient of reliability for the connection with 75 × 26 mm PZD3 toothed plates is 2.44.

Breaking force Nt and the amount of deformation δt, corresponding to Nt, were determined from the measuring equipment. The force NI-II, corresponding to the upper boundary of the elastic work of the connection, and the amount of deformation δI-II, corresponding to NI-II, were determined by the diagram in (Fig. 5). The bearing capacity of the tested connection with allowance for long-term effects is:

$$N_{II} = \frac{N_t}{k_{дл}} \quad (4)$$

Evaluation of the bearing capacity of the second group connection is made by the inequality (Regulations for the test of wooden structures connections):

$$\frac{N_{I-II}}{N_{II}} \geq 1,3 \quad (5)$$

For the obtained results equation is satisfied.

Thus, the bearing capacity of 75 × 26 mm PZD3 toothed plate is equal to 6,85 kN.

RESULTS

Fig. 6 shows the scheme of the truss bottom chord (1) strengthening with wooden patch plates (3), 75 × 26 PZD3 toothed plates (2) and cross-head clamps (4).

The technology of tensile members strengthening should be performed in accordance with the following:

1. Condition survey, defect and damage list, documentation and detailed schemes of present defects location are performed. The work is performed in accordance with the requirements of normative documents on the survey of buildings and structures.

2. The forces for development of truss strengthening are determined and the member that needs strengthening is identified

3. According to obtained forces the necessary section of the truss bottom chord is selected and section of bilateral wooden patch plates is shaped. To make patch plates work, the required number of toothed -plate connectors is selected by the formula:

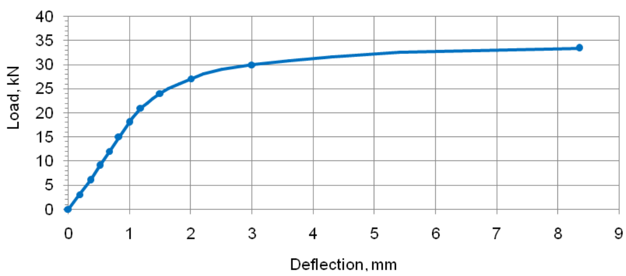

Fig. 5 Stress-strain diagram N-f at a shear test of toothed plates connection of timber structures.

$$n = \frac{N_P}{n_H \cdot N_\Pi} \qquad (6)$$

N_p– stretching stress in the member;

n_H– the number of wooden patch plates.

The step of the toothed-plate connectors depends on the number of them and the length of the strengthened section.

4. The erection of staging, scaffolds and lifting apparatus is performed in accordance with accident prevention regulations.

5. The area of structure surface to be strengthened is prepared. The surface is leveled by manual or mechanized tool. The moisture content of the wood during the repair work is equal to 12-16%.

6. Unloading of the construction is performed to put the strengthening member into the work fully. For this purpose, underpinning or vertical members with girders are installed. If there is no possibility to install a retaining structure, the load relief system with struts or hangers is used.

7. The toothed-plate connectors are installed at places where the patch plates are located (Fig. 7a).

8. The wooden patch plates are fixed on two sides.

9. The cross-head clamps are fixed with the following tightening (Fig. 7b). When choosing the type and size of the cross-head clamps, their bending stiffness should be considered, the necessary area of bearing should also be provided to avoid the bearing stress of the patch plates.

10. Control of toothed-plate connectors pressing into the wood of the bottom chord and patch plates placing is performed.

11. The unloading members should be removed smoothly after strengthening of the structure.

12. The punched plate metal fasteners, fixing the patch plates to the bottom chord, can be installed

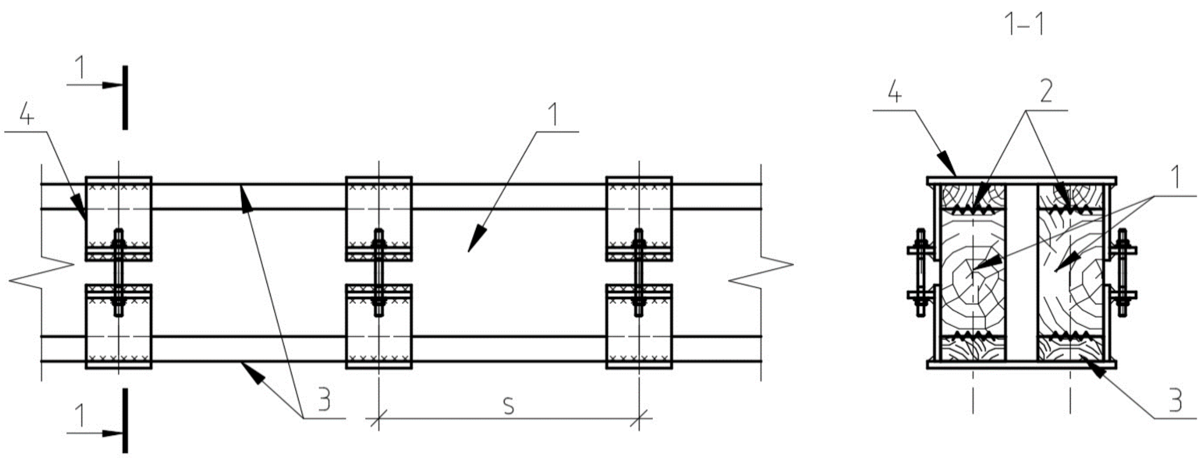

Fig. 6 The strengthening of the bottom chord of a wooden segmental truss:
1 – the bottom chord of the truss; 2 – PZD3 toothed plates of 75x26 mm;
3 – a member of strengthening – a board of hxb mm; 4 – a member of cross-head clamp – a steel sheet.

Fig. 7 Strengthening technology: a –toothed- plate connectors fixing; b – fixing of wooden patch plates and tightening cross-head clamps.

to make aesthetic form to the structure. Then it is possible to remove the cross-head clamps.

CONCLUSIONS

1. A new and effective way to strengthen tensile wooden members is developed;

2. The strengthening technology of the bottom chord of segmental wooden trusses is proposed;

3. The force taken up by the connection with PZD3 toothed plate of 75 × 26 mm is determined;

4. The proposed method of strengthening has been applied in Arkhangelsk facilities.

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