Experimental substantiation by choosing basic variant of plates with cylindrical dowels

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Abstract. The article is devoted to the experimental substantiation of the choice of the basic version of plates with cylindrical dowels for joints of wooden structures - pusher plates of the TsNIISK-KirPI system. The actuality of the study is due to the lack of experimental data on the bearing capacity and stiffness of the joints regarding various types of dowel plates used for joining (increasing of cross section) of wooden elements working according to an asymmetric pattern. The purpose of this article is to determine the bearing capacity and stiffness of such joints on various types of nail plates and, based on the analysis of experimental data from short-term tests, to justify the choice of the basic version of TGk type dowel plates.

1. Introduction
One of the most important scientific and technical problems of our time in the field of wooden structures is the development of new types of joints with necessary qualities to increase the efficiency of load-bearing wooden structures.

The use of traditional mechanical means of connecting structures in combination with natural (non-glued) wood [1-4] does not allow to obtain satisfactory solution to this problem. It turns out that technical efficiency of such structures directly depends on the volume of use of high-quality material with increased cross-sectional sizes.

Mostly for these reasons, industrial production of load-bearing structures with increased load-bearing capacity, both in Russia and abroad, is based on the use of glued wood [5-7]. Glued constructions have a number of undoubted advantages, however, the increased laboriousness of manufacture and the high cost practically exclude the possibility of their use in mass construction - the use of glued constructions is justified mainly in large-span structures of increased responsibility, or structures under special operating conditions.

Despite the fact that the volume of production of glued wooden structures in the developed western countries is very significant, however, the manufacture of wooden structures for mass use there is focused mainly on the use of mechanical means of joining. So-called stamped gear plates are particularly widespread [8-12], which undoubtedly should be attributed to the number of the most advanced connecting elements for the manufacture of wooden structures (planks and, therefore, a small span and limited bearing capacity).

Taking into account obvious tendencies to reduce the size of the cross section of market lumber, any increase in the efficiency of wooden structures is associated with the development of new joint
types that could provide an increase in the bearing capacity of structures, including through the use of composite lumber rods of limited cross section.

The most promising direction for improving dowel joints is associated with the transition from traditional technologies for the manufacture of joints, which are characterized by the sequential installation of several single dowels, to technologies based on the simultaneous installation of a generalized group of dowels in combination with metal sheet elements.

The development and research of such compounds, the problems of manufacturing building elements and the organization of the production of load-bearing wooden structures have been devoted to the long-term activities of Vyatka state university employees [13-16].

2. Preliminary data
A characteristic feature of nail dowel plates with cylindrical dowel [13, 16] is the use of pointed dowels of increased diameter (compared to traditional dowel joints) with a more saturated arrangement (i.e., with a reduced distance between dowels in the longitudinal and transverse directions). The fundamental possibility of this approach to the formation of nugget plates is based on the following physical premises:

- stress field that occurs in the wood as each of the dowels penetrate is characterized by the fact that simultaneously with the breaking stresses caused by it, compressive stresses opposing them arise, caused by insertion of adjacent dowels;
- during insertion of the injection plates by means of press-in, negative impact of the dynamics of the shock method of immersion is excluded, which initiates (in combination with the natural oscillations of the arches) fragile components of wood destruction;
- the need for through punching of joined wooden elements is eliminated, which significantly increases the risk of splitting, typical of conventional nail joints.

The validity of these assumptions is confirmed by numerous theoretical and experimental studies [17-19], including the study of stress fields in the wood of connected elements that arise during insertion of dowels and subsequent loading of compounds.

General classification of nail dowel plates with cylindrical nails [13] is made according to the following main features:

- base material;
- type of dowels based on geometric and structural features;
- method of fixing the dowels relative to the base.

The purpose of the framework is as follows: a) union of the dowels when installing them in the wood of the elements to be connected; b) formation of the boundary conditions of the plug; c) transfer of effort when using DP in nodal connections.

Depending on the purpose, the basis may be:

- M – from non-rigid materials with a small modulus of elasticity (wood, plywood, plastic, etc.);
- T – from hard materials with a high modulus of elasticity (steel, rigid structural plastics);
- S – from individual metal rods of curved shape.

Dowels are made of steel wire or rods with a diameter of 5 ... 8 mm when installing them in wood without first drilling holes and 10 ... 12 mm when installing in drilled holes. Depending on the end part of the dowel, the plates are divided into types:

- G – nail - with dowels sharpened on both sides;
- N – dowel - with non-pointed dowels;
- K – combined - with dowels of both types.

Fastening the dowels on the base can be performed:

- p – by tight fit in pre-drilled holes in the base;
- z – according to the method of casting masses when combining dowels with a non-rigid base;
- k – by welding (for example by means of contact welding) of dowels to the base.
In the framework of the target experiment, the main types of dowel plates were considered, which are used for joints to increase the cross section of wooden elements:

- **TGk** – with a metal base of steel with thickness 4 mm (T), double-edged nail dowels (G), which are fixed to the base by resistance welding (k);
- **TGp** – with a metal base of steel with thickness 4 mm (T), double-edged nail dowels (G), which are fixed to the base by means of tight installation in drilled holes (p);
- **MGp** – with a base of organic glass with thickness of 8 mm (M), double-edged nail dowels (G), which are fixed to the base by means of tight installation in drilled holes (p);
- **SGk** – with a base of curved metal rods - wire (C), double-edged nail dowels (G), which are fixed to the base by resistance welding (k). The main types of plug plates are shown in Figure 1.

![Figure 1. Main types of nail dowel plates.](image)

The choice of the basic version of the plate was carried out by experimental study of the influence on the bearing capacity and rigidity of the main structural parameters of the plate with subsequent analysis of the complexity of manufacturing and cost. The influence of the main parameters was studied: the base material and the method of attachment of the dowels. The diameter of the dowels, the length and arrangement of dowels in the composition of the puff plate have been sufficiently studied previously [18, 19].
3. Experimental investigation

Experimental investigation was carried out in accordance with the recommendations [20, 21] for 4 series, each containing 8 identical samples. The loading of the samples was carried out according to a single-section asymmetric test scheme of dowel joints on compression. The load was applied on the dowels through wooden elements in steps with a constant speed of 0.25 kN per minute. The tests were performed on the R-10 universal testing machine, which passed the test of the Federal State Institution of Kirov Center for Standardization, Metrology and Certification immediately before the performance of these works. Shear strains were measured by dial gauges ICh-10 with a division value of 0.01 mm.

Samples were made by installing a dowel plate between two wooden beams with subsequent pressing on a hydraulic press without drilling holes in the wood under the dowel. The tests were carried out on the plates of all types with 5 dowels with a diameter of 5 mm, with length of 60 mm (working length 27 mm). The test design is shown in Figure 2.

![Test scheme of joints](image)

Figure 2. Test scheme of joints.

As a result of the tests, deformation dependence of the total deformations from the force on the conditional cut of the plug $T - \Sigma \delta$ was determined; force corresponding to the upper boundary of the region of elastic work $T_u$ and the destructive force on the shear $T_{razr}$. Dowel. According to the test results, statistical processing of the obtained data was carried out: breaking load and total deformations along the loading steps.

Comparison of the research results in order to determine the effect of each design parameter of the plate on the strength and rigidity of the joint was carried out with the same quality of wood (density, strength, humidity and uniformity), as well as under equal conditions in the structural relation of the plate and test methods.

The relative humidity of the wood at the time of the test ranged from 4.6 to 6.0%.
The test process of samples with the location of measuring instruments - indicators of the sentry type ICh10– are shown in Figure 3.

![Sample photo](image1.png) ![Asymmetric destruction of the dowel](image2.png)

**Figure 3.** Photos of experimental samples during testing.

4. Results

To assess the quality of wood used for manufacture of wood samples, strength and stiffness parameters of wood were previously determined in accordance with the current GOST [22-23]: a short-term modulus of elasticity in bending and a short-term resistance of wood in compression along the fibers were determined.

The final values are as follows: $E=11200$ MPa (13000); $R=47.6$ MPa (44.0).

Based on the data obtained and average values given in the standards [1] (indicated in brackets), we can conclude that the presented wood is of average statistical quality in terms of strength and rigidity.

According to the test results in table 1 the main quantitative average statistical characteristics of the strength properties of the compounds are shown. The graphs of Figure 4 show a comparison of the stiffness characteristics of the joints, where, according to the test results, the dependences of the force per one slice of the Dowel T on the total deformations $\Sigma \delta$ are plotted.

**Table 1.** Results of experimental tests.

| Experimental parameters                      | Series 1 | Series 2 | Series 3 | Series 4 |
|---------------------------------------------|----------|----------|----------|----------|
| Base material                               | Metal    | Metal    | Plastic  | Wire     |
| Plate Type                                  | TGk      | TGp      | MGp      | SGk      |
| Resistance to wood compression MPa          | 46.90    | 48.96    | 47.85    | 46.75    |
| Breaking load, kN                           | 2.65     | 2.38     | 2.40     | 2.17     |
| Coefficient of variation                    | 0.002    | 0.001    | 0.003    | 0.002    |
| The force of the upper boundary of the elastic work kN | 1.75     | 1.60     | 1.45     | 1.00     |

Row 5 of the table 1 shows variational coefficients of the breaking load for a single value:

$$V = \sigma / X,$$

where $X$ is the average value; $\sigma$ is the standard deviation.
Figure 4. Deformation diagrams when testing joints with various types of napping plates: 1 - TGk; 2 - TGp; 3 - MGp; 4 - SGk.

An analysis of the experimental curves shows that the strength of the joints on TGk plates is 11...22% higher than the strength of all other joints. The stiffness of the joints (in the operating range at the level of loading of 1.0 kN per cut of one dowel) for TGk plates is higher than the stiffness of the joints on TGp plates by 40%; for MGP plates by 50% and for SGK plates by 62%.

Results: experimental studies of asymmetric joints of wooden structures on plates with cylindrical dowels of various types were carried out; based on the obtained strength and deformation characteristics of the joints, we can make conclusion that the priority use of various types of dowel plates for uniting of wooden elements.

5. Conclusion
Experimental studies have established that joints on the nugget plates with a metal base on TGk-type dowels welded to its faces have the greatest strength and stiffness.

The effect of a substantial increase in strength and stiffness is justified by the fact that dowels are rigidly (by means of resistance welding) attached to a metal base. Such attachment changes the nature of the deformation of the plug (Figure 3b) and significantly increases the rigidity of the joint itself.

Distinctive features of TGk dowel plates in general: a rigid metal base; geometric shape of the end part of the dowels; a method of fixing the dowels relative to the base; orientation of the dowels in relation to the base.

The TGk plug-in plate is subsequently adopted as the basic version of plates with cylindrical dowels for joining wooden elements together.

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