EFFECT OF PRESSED-IN FIBER GLASS BUSHINGS ON THE BEARING CAPACITY AND DEFORMABILITY OF NAILED CONNECTIONS OF WOODEN STRUCTURES

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Abstract

The article presents the results of experimental studies of two types of nailed connections on metal plates: compounds without sleeves and joints modified with pressed fiberglass sleeves; Recommendations for the calculation of nailed connections with sleeves have been developed. The tests used mathematical planning methods of the experiment, which allowed to significantly reduce the number of test samples of compounds and to obtain a mathematical relationship as a response function for the condition load effect factor \( m^b_w \), taking into account the increase in the bearing capacity of the nailed connection due to the presence of a pressed fiberglass sleeve, from three factors: the angle between the direction of the current force and the direction of the wood fibers, the diameter of the dowel and the wall thickness of the glass-plastic howl sleeves. The dependence obtained allows us to determine the coefficient values \( m^b_w \) for the nailed connections with bushings, without testing. In accordance with the plan of the experiment, 15 series of compounds were tested with pressed-in fiberglass bushes and 9 series of traditional nailed connections without bushings. According to the test results, the authors determined the destructive loads for two types of connections \( N^I_I \) and \( N^II_{II} \); loads \( N^I_{I-II} \) and \( N^II_{I-II} \) corresponding to the upper boundary of the elastic behavior of the connection; determined the coefficient of condition load effect factor \( m^b_w \) experimentally and obtained a mathematical relationship to determine the coefficient of condition load effect factor \( m^b_w \); The bearing capacity of the nailed connections with pressed-in fiberglass bushes has been evaluated; A comparison of the deformability of the two types of joints was made, a method was proposed for finding the calculated bearing capacity of nailed connections with sleeves, recommendations were developed for
making calculations for nailed connections on metal plates with fiberglass sleeves pressed into the drift sockets.

Keywords: Timber, nailed connection, load bearing capacity, deformation property, condition load effect factor.

I. Introduction

Improvement of the nailed connections occurs mainly in the following directions: changes in the constructive form of mechanical connections [XVII-I]; clarification of methods for calculation of connections and the use of computer modeling [IV-II, IX]; reinforcement of crushed wood with glue-plastic washers [VII]; increasing the degree of pinching of the dowel in the mating elements, by gluing it into the dowel nest [XXIII-XVI], applying new materials for dabbing [XXIV], modifying the technological processes of connections manufacturing [VI-IV]. Connections with pressed-in fiberglass bushings, proposed by the authors of the article, are intended for use in all types of nailed connections with steel, fiberglass and other cylindrical pins [XIV]. Due to the increased load bearing capacity and reduced deformability, they can be used in all types of wooden structures: continuous, though, spatial, and operated both in normal conditions and in chemically aggressive environments. This is a new type of nailed connections, therefore, in current standards for calculating and designing wooden structures [XX] there are no recommendations for calculating this type of connections.

II. Research Purposes and Objectives

The purpose of this study is to develop recommendations for the calculation of nailed connections, modified with pressed fiberglass sleeves, using the existing method of designing brass joints without bushings [XX].

III. Materials and Methods of Research

The authors have carried out short-term tests of two types of nailed connections on metal plates:

Type I - traditional connections without sleeves;

Type II – nailed connections the middle elements of which were reinforced with pressed-in fiberglass bushes.

The tests were carried out according to the loading scheme with steps with periodic loading and unloading with a constant loading and unloading rate, in accordance with [XIX].

When conducting tests and experiments methods of mathematical planning of the experiment were used. The experiment was planned as three-factor and three-level. Three factors that have the greatest influence on the carrying capacity and deformability of the joint are considered: angle α between the direction of the current force N and the direction of the wood fibers; the diameter of the dowel d; wall thickness of fiberglass sleeve $t_w^b$. Each of the factors ranged on three levels:
As a parameter of the experiment the following was considered:
- the coefficient of condition load effect factor of the connection $m^b_w$, taking into account the increase in the carrying capacity of the nailed connection due to the presence of a pressed-in fiberglass sleeve.

The calculated bearing capacity of type I connection $N^I_n$ was determined by the current method for the design of nailed connections without sleeves:

$$N^I_n = N^{i\text{c}}_n/n_n n_j$$

where,
- $N^{i\text{c}}_n$ - the calculated bearing capacity of the connection per 1 dowel and 1 joint seam;
- $n_n$ - amount of dowels in the connection;
- $n_j$ - amount of seams in the connection.

The authors propose to find calculated bearing capacity of type II of nailed connections with pressed fiberglass bushes $N^\text{II}_n$ by multiplying the calculated bearing capacity of conventional nailed joints without bushings $N^I_n$, calculated from [XX], by the coefficient of condition load effect factor $m^b_w$, taking into account the presence of a pressed fiberglass bush:

$$N^\text{II}_n = N^{i\text{c}}_n/n_n n_j m^b_w = N^I_n m^b_w$$

According to [XIX], the bearing capacity of the nailed connections $N_n$ was evaluated in two ways:

1. By the magnitude of the destructive force divided by the reliability coefficient determined from the test results:

$$N_n/k \geq N$$

reliability coefficient is determined by the formula:

$$k = 1.38(1.94 - 0.116 \lg t)$$

where, $t$ - is the duration of short-term testing of samples, in seconds.
2. By the magnitude of the force \( N_{I-II} \) corresponding to the upper boundary of the elastic behavior of the connection, divided by the reliability coefficient 1.3 for the force \( N_{I-II} \):

\[
\frac{N_{I-II}}{1.3} \geq N_n
\]  

(5)

where \( N_r \) is the breaking load of the compound,

\( N_{I-II} \) - is the load corresponding to the upper boundary of the elastic region of the joint,

\( N_n \) -is the calculated bearing capacity of the connection.

### IV. Results and Discussion

In accordance with the plan of the experiment, 15 series of compounds were tested with pressed-in fiberglass bushes and 9 series of traditional jointing compounds without bushings. To obtain reliable test results, the number of repeated experiments in the row of the matrix was assumed to be 3. The total number of tested samples amounted to: for connections with bushings - 45, for connections without bushings - 21.

The results of short-term tests of samples of two types of nailed connections on metal plates with embedded fiberglass bushings and without sleeves are shown in Table 1.

Due to the use of mathematical planning methods for the experiment, the authors obtained a dependence for the coefficient of the load effect factor of the connection \( m^b_w \), taking into account the increase in bearing capacity due to the presence of a pressed fiberglass sleeve on three connection parameters: the angle between the force direction and the direction of the wood fibers \( \alpha (^\circ) \), the fiberglass diameter bushings, dowel diameter \( d (cm) \), fiberglass sleeve wall thickness \( t_w (cm) \):

\[
m^b_w = 2.7 + 0.156 \alpha - 0.27d + 0.096t_w
\]  

(6)

Formula (6) shows that according to the degree of ranking the factors are arranged in the following sequence: the angle between the direction of force and the direction of wood fibers (\( \alpha \)), the diameter of the dowel (\( d \)), the thickness of the wall of the sleeve (\( t_w \)).

The resulting formula (6) is a response function, it allows you to determine the values of the coefficients of condition load effect factor \( m^b_w \) for bolt-on connections with embedded fiberglass bushings on metal lining without testing under various combinations of three factors (\( \alpha, d, t_w \)).

Comparison of the values of the coefficient of condition load effect factor \( m^b_w \) obtained by the formula (6) with the actual experimental values of the coefficient are...
presented in Table 1, which indicates a good convergence of results and confirms the acceptability of this method for determining the coefficient $b_w^m$. The average percentage of the discrepancy in the ratio value of coefficient $b_w^m$ is 6.26%.

Table 1: Comparison of experimental and calculated values of the coefficient of condition load effect factor, taking into account the presence of a pressed fiberglass sleeve $m_w^b$.

| Connection Series | Force $N_w$, kN | Force $N_{w,0}$, kN | Increase in load bearing capacity (times) | Coefficient $m_w^b$ | Percentage of difference for $m_w^b$ |
|------------------|-----------------|----------------------|------------------------------------------|-------------------|-------------------------------------|
|                  | with bushings $N_w^b$ | without bushings $N_w$ | $N_{w,0}$ | $N_{w,0}/N_w$ | by $N_w^b$ | by $N_w$ | according to the formula (6) | by experiment |               |
| 90°-24-6         | 17.0            | 34.0                 | 10.0          | 24.5          | 2.45          | 2.0      | 2.45          | 2.36          | 3.67          |
| 90°-14-6         | 13.0            | 30.5                 | 7.0           | 18.0          | 2.57          | 2.35     | 2.57          | 2.62          | 1.9           |
| 0°-24-6          | 37.0            | 76.0                 | 22.0          | 49.0          | 2.23          | 2.05     | 2.23          | 2.12          | 4.93          |
| 0°-14-6          | 24.0            | 50.0                 | 16.0          | 38.0          | 2.37          | 2.08     | 2.375         | 2.379         | 0.168         |
| 90°-18-8         | 14.0            | 32.0                 | 8.0           | 22.0          | 2.75          | 2.28     | 2.75          | 2.54          | 7.63          |
| 90°-18-4         | 14.0            | 31.0                 | 8.0           | 20.0          | 2.5           | 2.21     | 2.5           | 2.497         | 0.12          |
| 0°-18-8          | 28.0            | 56.0                 | 19.0          | 44.0          | 2.32          | 2.0      | 2.32          | 2.29          | 1.29          |
| 0°-18-4          | 28.0            | 54.0                 | 19.0          | 40.0          | 2.10          | 1.93     | 2.1           | 2.25          | 6.67          |
| 45°-24-8         | 26.0            | 45.0                 | 19.0          | 36.0          | 1.89          | 1.73     | 1.89          | 2.05          | 7.8           |
| 45°-24-4         | 26.0            | 43.7                 | 19.0          | 34.0          | 1.79          | 1.68     | 1.79          | 2.01          | 10.94         |
| 45°-14-8         | 18.0            | 34.0                 | 10.0          | 29.0          | 2.9           | 2.43     | 2.9           | 2.52          | 13.1          |
| 45°-14-4         | 18.0            | 32.0                 | 10.0          | 27.0          | 2.7           | 1.78     | 2.7           | 2.48          | 8.1           |
| 45°-18-6         | 20.0            | 40.0                 | 15.0          | 31.0          | 2.17          | 2.0      | 2.17          | 2.39          | 9.2           |
| 45°-18-6         | 20.0            | 43.0                 | 15.0          | 31.0          | 2.17          | 2.15     | 2.17          | 2.39          | 9.2           |
| 45°-18-6         | 20.0            | 41.0                 | 15.0          | 31.0          | 2.17          | 2.05     | 2.17          | 2.39          | 9.2           |

Comparison of the experimental bearing capacity of compounds with embedded fiberglass bushings.

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Analyzing table 2, it can be concluded that type II jointing compounds with pressed-in fiberglass bushings have sufficient bearing capacity, because inequations (3) and (5) are satisfied. It can also be seen that the values of the bearing capacity of compounds with bushings, obtained experimentally \( \frac{N_{II}}{k} \) and calculated by the formula (2), according to the method proposed by the authors, differ on average by no more than 6.37%.

During the tests, the characteristics of the deformability of the joint were determined: the total, elastic, residual deformations at each step of loading. Comparison of the

Table 2: Comparison of the experimental bearing capacity with the calculated bearing capacity of the nailed connections with bushings

| Connection Series | \( N^I_{II} \), kN | \( N^II_{II} \), kN | Reliability coefficient \( k \) | Experimental bearing capacity | Estimated bearing capacity \( N^II_{n} \), kN according to the formula (2) | Percentage of difference for \( \frac{N^II_{II}}{k} \) and \( \frac{N^II_{I II}}{1.3} \), kN |
|-------------------|-----------------|-----------------|-----------------|-------------------|--------------------------|-----------------------------|
| 90º-24-6          | 34.0            | 24.5            | 2.417           | 14.06             | 14.04                    | 0.14                        |
| 90º-14-6          | 30.5            | 18.0            | 2.45            | 12.45             | 11.24                    | 9.71                        |
| 0º-24-6           | 76.0            | 49.0            | 2.33            | 16.309            | 13.44                    | 17.59                        |
| 0º-14-6           | 50.0            | 38.0            | 2.38            | 21.008            | 16.66                    | 20.69                        |
| 90º-18-8          | 32.0            | 22.0            | 2.44            | 13.114            | 12.68                    | 3.3                         |
| 90º-18-4          | 31.0            | 20.0            | 2.45            | 12.654            | 12.32                    | 2.63                        |
| 0º-18-8           | 56.0            | 44.0            | 2.36            | 23.73             | 21.15                    | 10.87                       |
| 0º-18-4           | 54.0            | 40.0            | 2.37            | 22.785            | 20.52                    | 9.94                        |
| 45º-24-8          | 45.0            | 36.0            | 2.39            | 18.83             | 18.81                    | 0.106                       |
| 45º-24-4          | 43.7            | 34.0            | 2.41            | 18.13             | 18.0                     | 0.717                       |
| 45º-14-8          | 34.0            | 29.0            | 2.41            | 14.125            | 14.091                   | 0.24                        |
| 45º-14-4          | 32.0            | 27.0            | 2.33            | 13.734            | 13.86                    | 0.917                       |
| 45º-18-6          | 40.0            | 31.0            | 2.41            | 16.597            | 16.088                   | 3.066                       |
| 45º-18-6          | 43.0            | 31.0            | 2.40            | 17.92             | 16.088                   | 10.22                       |
| 45º-18-6          | 41.0            | 31.0            | 2.41            | 17.012            | 16.088                   | 5.43                        |

Analyzing table 2, it can be concluded that type II jointing compounds with pressed-in fiberglass bushings have sufficient bearing capacity, because inequations (3) and (5) are satisfied. It can also be seen that the values of the bearing capacity of compounds with bushings, obtained experimentally \( \frac{N^I_{II}}{k} \) and calculated by the formula (2), according to the method proposed by the authors, differ on average by no more than 6.37%.
deformability of the two types of connections on metal plates with sleeves and without sleeves (Table 3) shows that the deformability of connections with sleeves is much less than the deformability of joints without sleeves. The value by which the deformability is reduced depends on the parameters of the connection, therefore, for each series there is its own value and can be taken from the table 3. The deformability of connections with metal plates with fiberglass bushings pressed into wood per 1 kN of load (within the elastic behavior of the connection) is less than the deformability of connections without bushings by 4, 43 - 8, 84 times (Table 3).

Table 3: Evaluation of the deformability of the nailed connections

| Connection Series | Deformability on 1 kN, mm (within the elastic behavior of the connection) | Reduction in deformability (times) |
|-------------------|-------------------------------------------------------------------------|----------------------------------|
|                   | With bushings | Without bushings |                                      |
| 90°-24-6          | 0.032         | 0.19             | 5.94                               |
| 90°-14-6          | 0.062         | 0.386            | 6.23                               |
| 0°-24-6           | 0.01658       | 0.0795           | 4.79                               |
| 0°-14-6           | 0.041         | 0.1815           | 4.43                               |
| 90°-18-8          | 0.0345        | 0.209            | 6.06                               |
| 90°-18-4          | 0.03018       | 0.209            | 6.92                               |
| 0°-18-8           | 0.01682       | 0.095            | 5.648                              |
| 0°-18-4           | 0.02225       | 0.095            | 4.27                               |
| 45°-24-8          | 0.0175        | 0.08276          | 4.73                               |
| 45°-24-4          | 0.018647      | 0.08276          | 4.44                               |
| 45°-14-8          | 0.025         | 0.221            | 8.84                               |
| 45°-14-4          | 0.02546       | 0.221            | 8.68                               |
| 45°-18-6          | 0.02427       | 0.1118           | 4.6                                |
| 45°-18-6          | 0.01847       | 0.1118           | 6.05                               |
| 45°-18-6          | 0.0195        | 0.1118           | 5.73                               |

According to the test results the following were determined:
- destructive loads for two types of compounds $N^I_t$ and $N^II_t$;
- loads $N^I_{f-II}$ and $N^II_{f-II}$, corresponding to the upper boundary of the elastic behavior of the connection;
- the coefficient of condition load effect factor $m^b_w$ was determined, taking into account the increase in the carrying capacity of the nailed connections due to the pressed-in fiberglass bushings, experimentally;
- dependence (6) is derived for finding the coefficient of condition load effect factor $m^b_w$;
- comparison of the values of the coefficient of condition load effect factor $m^b_w$ obtained experimentally and calculated by the proposed method was made;
- the proposed method for finding the calculated bearing capacity of nailed connections with bushings (formula (2));
- assessment of the bearing capacity of nailed connections with pressed fiberglass bushings;
- Comparison of the deformability of the two types of compounds.

V. Conclusions

Recommendations were developed on the basis of the conducted research for the calculation of nailed connections with pressed-in fiberglass bushes. For practical calculations of joints on metal plates with fiberglass bushings pressed into wood, it is proposed to use a technique recommended by the current standards for calculating and designing wooden structures [XX] for traditional connections without sleeves by introducing into it the the coefficient of condition load effect factor $m^b_w$ taking into account molded fiberglass bushings. The value of the coefficient of condition load effect factor $m^b_w$ depends on the connection parameters: the angle between the direction of the force and the direction of the wood fibers $\alpha$, the diameter of the dowel $d$, the wall thickness of the fiberglass sleeve $b_w$ and is calculated according to the formula (6) obtained by the authors of the article.

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