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RESEARCH OF THE STRESS-STRAIN STATE OF CONNECTIONS OF TIMBER STRUCTURAL ELEMENTS ON METAL PLATES

Xu Yun, V.N. Glukhikh*

Saint Petersburg State University of Architecture and Civil Engineering (SPSUACE),

Vtoraja Krasnoarmejskaja ul. 4, St. Petersburg, 190005, Russia

*e-mail: glukhikh1234@gmail.com

Abstract. In this paper we have suggested original design of connection based on metal plates which includes an additional nail-plate which allows increasing the bearing capacity of the connection (up to 31.15 %). We have substantiated the method of rational design and calculation of the bearing capacity of the connection on metal plates according to the finite element method by using the *Ansys 15.0* software.

1. Introduction

A connection on the *SHERPA* [1] type metal plates consists of two aluminum parts forming a classic dovetail rigid coupling and is attached to the timber structural elements by means of screws. Low bearing capacity is determined by low bearing wood strength in comparison with the strength of metal plates. Bearing stress can be reduced by extending the bearing surface. It can be achieved by addition of a nail-plate to the connection design, due to which redistribution of loads taken by each element of the connection appears.

2. Analytical Investigation

Bearing capacity of connection with metal plates for stretching, compression and shear along three mutually perpendicular axes is dependent on pulling and shear resistance of the screws, by which the metal plates are attached to the timber elements.

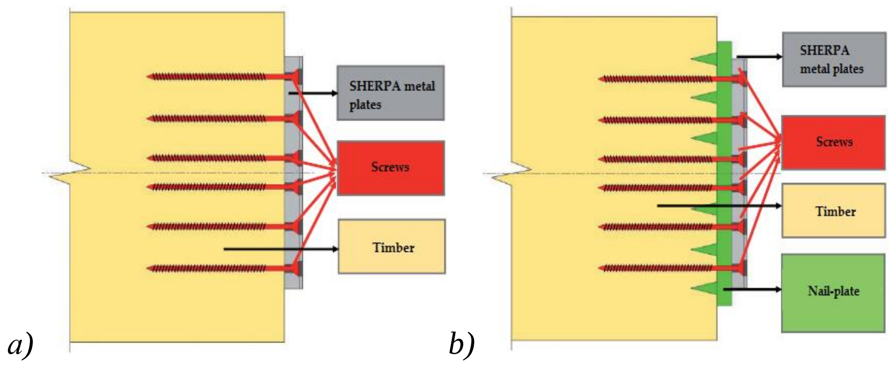

Fig. 1. Structural drawing of the timber elements connection on the metal plate and screws: *a*— without nail-plate reinforcement; *b*— with nail-plate reinforcement.

The results of the analytical investigations in accordance with various standards and scientific researches allowed creating a new mathematical model for testing the bearing capacity of the connection (Fig. 1).

Computational scheme of testing the bearing capacity of the connection on metal plates is represented in Fig. 2, which shows that their bearing capacity depends on the following factors: the screw shear strength on the metal plate at an angle to the filaments of the timber elements; vertical intensity of the screw pulling resistance at an angle to the filaments of the timber elements; frictional force between the aluminum plates and the timber elements depending on the horisontal intensity due to the screw pulling resistance at an angle to the filaments;

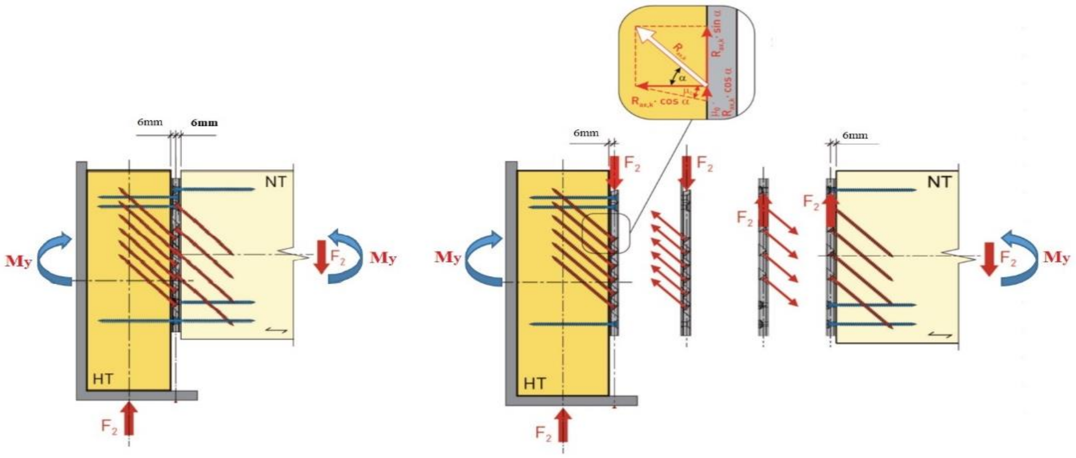

Fig. 2. Structural drawing of testing the bearing capacity of the connection of the timber structural elements on metal plates.

On the basis of the works mentioned above the authors suggest the mathematical model, represented in the following equations: the screw shear bearing capacity in the *CLT* and *LVL* timber elements without reinforcement and with the nail-plate, N:

$$F_{v,\alpha,k} = \min \begin{cases} b_1^{M_1} \cdot f_{h,\alpha,k} d + \dfrac{V_{ax,\alpha,k}}{4} + 0{,}01 f_3 d \cdot t_2 \\ b_1^{C_1} f_{h,\alpha,k} d + \dfrac{V_{ax,\alpha,k}}{4} + 0{,}01 f_3 d \cdot t_2 \\ b_1^{M_2} f_{h,\alpha,k} d + \dfrac{V_{ax,\alpha,k}}{4} + 2\mathrm{f}_{y,k} b_2 d + 0{,}01 f_3 d \cdot t_2 \\ b_1^{M_3} f_{h,\alpha,k} d + \dfrac{V_{ax,\alpha,k}}{4} + 2\mathrm{f}_{y,k} b_2 d + 0{,}01 f_3 d \cdot t_2 \\ b_1^{C_3} f_{h,\alpha,k} d + \dfrac{V_{ax,\alpha,k}}{4} + 2\mathrm{f}_{y,k} b_2 d + 0{,}01 f_3 d \cdot t_2 \\ b_1^{4} f_{h,\alpha,k} d + \dfrac{V_{ax,\alpha,k}}{4} + 2\mathrm{f}_{y,k} b_2 d + 0{,}01 f_3 d \cdot t_2 \end{cases} \quad (1)$$

where $F_{v,\alpha,k,1}$ - screw shear bearing capacity without nail-plate at angle α to the filaments, N; $F_{v,\alpha,k,2}$ - screw shear bearing capacity with nail-plate reinforcement at angle α to the filaments, N; f_3 - strength of metal plates under bearing stress, MPa; $f_{h,\alpha,k}$ — strength of the wood in the mortise under bearing stress at angle α to the filaments, MPa; for *CLT* and *LVL* at α =

0°, $f_{h,0,k} = 0,15d^{-0,3} \cdot \rho_k$; at α = 90°, $f_{h,0,k} = 0,15 \cdot 1,58d^{-0,3} \cdot \rho_k$ [*SIA 265:2003*]; $f_{y,k}$ - screw stretching strength, MPa; $f_{y,k}$ = 600 MPa [*Europäische technische Zulassung ETA-12/0067*]; t_1 - effective length of screw thread, mm; $V_{ax,k}$ - screw pulling bearing capacity at angle α to the filaments, N; for *CLT* $V_{ax,k} = \frac{f_{ax,90,k} \cdot d \cdot l_{ef}}{(\sin\alpha)^2 + 1,5(\cos\alpha)^2}$, $V_{ax,90,k} = 0,0872\rho_k \cdot d^{-0,4119} \cdot \frac{1}{\pi}$ [*DIN 1052:2008*]; for *LVL* $V_{ax,k} = \pi \cdot d \cdot l_{ef} \cdot f_{ax,\alpha,k}$, $V_{ax,\alpha,k} == \frac{V_{ax,90,k}}{(\sin\alpha)^2 + 1,5(\cos\alpha)^2}$, $V_{ax,90,k} = 0,003(\pi d \cdot l_{ef})^{-0,2} \cdot \rho_k$ [*SIA 265:2003*]; vertical intensity of the screw pulling bearing capacity at an angle to the filaments of the timber elements, N;

$$F_{2,K,1} = R_{ax,k} \cdot \sin\alpha, \tag{2}$$

friction force between the aluminum plates and timber elements depending on the horisontal intensity of the screw pulling bearing capacity at an angle to the filaments, N;

$$F_{2,k,2} = \mu \cdot R_{ax,k} \cdot \cos\alpha \tag{3}$$

bearing capacity of connection with metal plates without reinforcement and with nail-plate in timber structures of the wall panel and joist according to criteria of screw pulling and shear resistance, N;

$$F_{v,k,panel,sherpa} = n \cdot (F_{v,\alpha,k} + F_{2,k,1} + F_{2,k,2}), \tag{4}$$

$$F_{v,k,joist,sherpa} = n \cdot (F_{v,\alpha,k,1} + F_{2,k,1} + F_{2,k,2}), \tag{5}$$

$$F_{v,k,sherpa} = \min \cdot (F_{v,k,panel,sherpa}, Fv,k,\text{joist},sherpa), \tag{6}$$

where: $F_{v,k,panel,sherpa}$ — bearing capacity of the connection in the wall panel according to the criteria of screw pulling and shear resistance, N; n — number of screws; $M_{1/2}$— screw shear modes in complience with the *Johansen* theory; μ — friction force coefficient; μ= 0,25; $F_{v,k,sherpa}$ — bearing capacity of the connection for the screws pulling and shear resistance, N; $F_{v,k,joist,sherpa}$ — bearing capacity of the connection in *CLT* and *LVL* joist according to the screws pulling and shear resistance, N; $R_{ax,k}$ — screw pulling bearing capacity at an angle to the filaments, H.

3. Experiments

The experiments were conducted in the mechanical laboratory of the Saint-Petersburg State University of Architecture and Civil Engineering with the application of the *INSTRON 5989* universal testing machine having maximum operating mode up to 600, kN.

Comparison of computational and experimental results of the bearing capacity of the connection with metal plates for the screws pulling and shear resistance without reinforcement and with the nail plate are represented in Tables 1 and 2.

Table 1. Comparison of computational and experimental results of testing bearing capacity of connection without nail-plate reinforcement.

At the broad side of the *CLT* panel			At the narrow side of the *CLT* panel			Along the *LVL* joist filaments		
$F_{v,ф,CLT}$	$F_{v,p,CLT}$	μ, %	$F_{v,ф,CLT}$	$F_{v,p,CLT}$	μ, %	$F_{v,ф,LVL}$	$F_{v,p,LVL}$	μ, %
27,830	26,331	5.69	26,910	27,684	-2.80	22,600	32,036	-29.45

Table 2. Comparison of computational and experimental results of testing bearing capacity of connection with nail-plate reinforcement.

At the broad side of the *CLT* panel			At the narrow side of the *CLT* panel			Along the *LVL* joist filaments		
$F_{v,ф,CLT}$	$F_{v,p,CLT,nail\text{-}plate}$	μ, %	$F_{v,ф,CLT}$	$F_{v,p,CLT}$	μ, %	$F_{v,ф,LVL}$	$F_{v,p,LVL}$	μ, %
33,520	29,234	14,6	33,520	31,556	6,22	29,640	36,764	19,38

Notes: $F_{v,ф,n,CLT}$ — actual bearing capacity, H; $F_{v,p,n,CLT}$ — computational bearing capacity, H; μ_n — increment $F_{v,ф,n,CLT}$ and $F_{v,p,n,CLT}$; $\mu_n = \frac{F_{v,ф,n,CLT} - F_{v,p,n,CLT}}{F_{v,p,n,CLT}} \cdot 100\%$.

4. Numerical investigations according to the FEM

For checking the experimental and analytical results, we used the finite element method (FEM). In the process of calculation, we paid special attention to the contact zones between the bulges of the two metal plates, where significant loads are taken that cause elastic failure. For clarification of the local strain position, we have made the calculation of the bearing capacity of the connection with application of loading along the direction of the mortise, N. When using the three-dimensional model of the connection for each element we accepted physical and mechanical specification of the materials in accordance with *EN AW 6082*.

Comparison of calculation and experiment results.

Table 4. Comparison of calculation and experiment results of testing the principal stress on metal plates, MPa.

Location	$\sigma_{ex,b,CLT}$	$\sigma_{fem,b,CLT}$	$\sigma_{ex,b,LVL}$	$\sigma_{fem,b,LVL}$	$\sigma_{ex,c,CLT}$	$\sigma_{fem,c,CLT}$
Upper	-13.65	-58.18	96.95	51.60	182.28	159.12
Central	52.85	4.35	32.55	3.47	-11.83	7.93
Lower	-6.44	-73.02	18.13	64.32	103.04	177.01

Table 5. Comparison of calculation and experiment results of testing the principal strain on metal plates, 10^{-6} мм/мм.

Location	$\varepsilon_{ex,b,CLT}$	$\varepsilon_{fem,b,CLT}$	$\varepsilon_{ex,б,LVL}$	$\varepsilon_{fem,б,LVL}$	$\varepsilon_{ex,c,CLT}$	$\varepsilon_{fem,c,CLT}$
Upper	-195	-1240	1385	1083	2604	3492
Central	755	73	465	60	-169	160
Lower	-92	-1562	259	1339	1472	3588

Tables 4-5 show that in the process of calculation in accordance with the FEM there is an acceptable coincidence of the experiment and calculation results. Comparative analysis proved that by using the finite elements method and the *Ansys 15.0* software, one can investigate the stress-strain state on the metal plates. Thus, the assessment of the bearing capacity of a connection can be carried out when it is being constructed.

5. Conclusion

1. Original design of the connection based on metal plates with nail-plate has higher bearing capacity (up to 31.15 %).
2. We have suggested the mathematical model of calculating the bearing capacity of the connection.
3. We have confirmed reliability of the suggested mathematical calculation model of the bearing capacity of the connection on metal plates without reinforcement and with a nail-plate.

References

[1] SHERPA official web-site: list of *SHERPA* production series [Digital resource]. - Access mode: http://en.sherpa-connector.com/.