Immediate and long-term strength tests of connections in the wood-framed structure

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1. Introductions

Various kinds of round pins are used to connect structural members made from different kind of materials. Common form of pin-type connections are nails, rivets, bolts and dowels. The wood-framed buildings with sheathing constitute timber framing with one or both sides of the wood-derivative boards. Composed in this way three-dimensional structural element should be able to transfer vertical and horizontal lateral and perpendicular to the plane loadings according to standard requirements and assignment of the building. Significant role belongs to the fasteners linking structural elements [1], [2]. These are the mechanical fasteners. These fasteners are employed widely in timber structures. The wood-framed structure with sheathing is commonly used in residential building construction as one of the ecological and energy saving constructions widely applied in North and Western Countries and lately in Central Europe.

The investigations of immediate and long-term loading of the wood derivative board-to-timber nailed connections remain the main objectives of the work.

2. Object of the tests

Pin-type connections are used widely in mechanical joints employed in building and the other kinds of constructions.

Fig. 1 Single fastener: a - view, b - section through the fastener

Fig. 1 presents individual fastener linking structural elements usually working for shear.

The wood-framed buildings with sheathing constitute timber framing with one or both sides of the wood-derivative boards. Composed in this way three-dimensional structural element should be able to transfer the vertical and horizontal lateral and perpendicular to the plane loadings according to standard requirements and assignment of the building. Typical wood-framed building and its wall and floor diaphragms are presented in Fig. 2.

3. Immediate tests of connections slip

The main objective of the test is the evaluation of load-slip characteristics and strength characteristics of mechanical fastener linking two timber elements. The maximum expected lateral load on the fastener has been evaluated from standard failure mode of connection and corresponding equations referring to these modes. The standard modes of failure are presented in Fig. 3.

Fig. 2 Typical cross-section of the wood-framed structures and building under construction: a - building under construction, b - wall diaphragms, c - floor and roof panel

Fig. 3 Standard modes of failure of fasteners

Fig. 4 presents the connection scheme, the test setup and the diagram of immediate test loading.
4. Results of load-slip characteristic of sheathing to framing connection

Experimental tests of load-slip characteristic of chipboard to framing connection were conducted according to the procedure indicated in standard [3]. Twenty samples of connections were tested where displacements were measured for the increment of loading. Maximum loading of lateral fastener was assumed from standard modes of failure and then compared with the results from immediate test of the connection. Considering nailing used in the joint fastening the sheathing to the framing maximum lateral load was 1.22 kN. The slip increments under individual increment of loading were measured with the accuracy 0.001 mm. Average displacements of the fastener under each phase of loading are set in Table 1. Table 1 presents also the slip of a joint obtained from mathematical function describing load-slip characteristics of connection.

The load-slip characteristics of the fastener under shear load and the deformation in results of bearing to the dowel are presented in Fig. 5.

Mathematical function describing the load-slip characteristics of the joint behaviour was adopted from Foschi according to Hunt [4]. This function was used in the description of dowel bearing to the surrounding wood. The function used in the description of the fastener load-slip characteristics of connection

\[
R_d = \min \left\{ f_{h,1,d}t_d \beta \right\}
\]

\[
f_{h,1,d}t_d \beta = \frac{f_{h,1,d}t_d}{1 + \beta} \left[ \sqrt{\beta + 2 \beta^2 \left( 1 + \frac{\delta}{t_d} + \left( \frac{\delta}{t_d} \right)^2 \right)} + \beta \left( \frac{\delta}{t_d} \right)^2 \right] - \beta \left( 1 + \frac{\delta}{t_d} \right)
\]

\[
R_d = \min \left\{ f_{h,1,d}t_d \beta \right\}
\]

\[
R_d = \frac{f_{h,1,d}t_d}{1 + \beta} \left[ \sqrt{\beta + 2 \beta^2 \left( 1 + \frac{\delta}{t_d} + \left( \frac{\delta}{t_d} \right)^2 \right)} + \beta \left( \frac{\delta}{t_d} \right)^2 \right] - \beta \left( 1 + \frac{\delta}{t_d} \right)
\]

(1)

Parameters \( A, B, C \) were evaluated applying programme Statistica and for experimentally tested chipboard to framing joints had the values: \( A = 600.00; B = 100.91; C = 2498.93 \).
Table 1

<table>
<thead>
<tr>
<th>Number of reading</th>
<th>Loading $F$ acting in joint, N</th>
<th>Number of loaded fasteners, No</th>
<th>Loading $F_1$ acting on individual fastener, N</th>
<th>Mean displacements in the joint, $\delta$, mm</th>
<th>Displacement $\delta_f$ from function describing the load-slip characteristic, mm</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td>0</td>
<td>0</td>
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<tr>
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<tr>
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<tr>
<td>11</td>
<td>2500</td>
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<td>625.0</td>
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<td>937.5</td>
<td>3.5040</td>
<td>3.5040</td>
<td>0.1970</td>
</tr>
</tbody>
</table>

Fig. 6 presents load-slip characteristics of the fastener obtained from experimental tests and analytical description according to the formula with evaluated parameters $A$, $B$, and $C$.

$$ N = (600 + 100.91\delta)^{1 - \exp\left(\frac{2498.93}{600}\delta\right)} \quad (3) $$

where $F_1$ is loading of a single fastener, $N$; $\delta$ is slip displacements [mm] of the fastener.

Similar characteristics were obtained on the base of experimental tests for different sheathing materials.

![Fig. 6 Load-slip fastener characteristics for chipboard sheathing](image)

![Fig. 7 Load-slip characteristics of sheathing to framing connectors for different wood-derivatives boards](image)

![Fig. 8 The load-slip characteristics and theoretical function describing the fastener behaviour](image)

Load-slip characteristics of the fasteners linking framing with different boards of sheathing in the connections are presented in Fig. 7. The best fitted curve describing fastener behaviour depending on sheathing material has been selected for $A$, $B$ and $C$ parameters, where these parameters were obtained from results of tests for different sheathing material used in construction. These diagrams are presented in Fig. 8.

$A$, $B$, $C$ parameters for different sheathing boards are set in Table 2.

The immediate tests and load-slip curves were done according to the requirements of Standard PN-EN 26891 (PN-ISO 6891):1997 [3] in order to define the basic deformability. These characteristics $N = f(\delta)$ describing load-slip behaviour and strength of mechanically fastened boards-to-timber connections with dowel type of fasteners are set in Fig. 7.
5. The long-term tests of load-slip characteristics

Time-depending slip process of connection has been conducted under varying loading levels selected on the base of immediate tests. The values of test loading were assumed for minimum standard design capacity of the fastener for its failure modes depending on the kind of wood-based board. Specimens, and test setup are shown in Fig 9.

![Diagram of specimen used in test and the test setup](image)

Fig. 9 Scheme of specimen used in test and the test setup: a - the specimen; b - the test setup

6. Material properties and the load-displacements characteristics of the fasteners

Results of the tests of wood and wood-derivative material basic characteristics are set in Table 3.

<table>
<thead>
<tr>
<th>Material</th>
<th>$E_{11}$, MPa</th>
<th>$E_{22}$, MPa</th>
<th>$G$, MPa</th>
<th>$\rho$, kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>11500</td>
<td>530</td>
<td>585</td>
<td>340</td>
</tr>
<tr>
<td>Plywood</td>
<td>10900</td>
<td>8700</td>
<td>790</td>
<td>450</td>
</tr>
<tr>
<td>Chipboard</td>
<td>4500</td>
<td>3800</td>
<td>800</td>
<td>620</td>
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<tr>
<td>Gypsum board</td>
<td>3900</td>
<td>3500</td>
<td>1800</td>
<td>950</td>
</tr>
</tbody>
</table>

Table 3

The creep behaviour as a result of immediate tests of connections was investigated under different levels of loading.

The values of loading were fixed on the levels:

- $P = 400$ and $410$ N – connections with the chipboard;
- $P = 400$ N – connection with the chipboard with the effect of unloading;
- $P = 400$ and $410$ N – connection with OSB board;
- $P = 200$ N – connection with gypsum board.

Crep tests were conducted after preliminary loading of the fastener at the value of $P = 0.4P_{\text{max}}$ and then released loading to the value of $P_{\text{min}} = 0.1P_{\text{max}}$. $P_{\text{max}}$ value of loading was assumed from immediate tests characteristics for particular kind of sheathing boards in connection. Fig. 10 presents diagram $P = f(\delta)$ as a result of preloading to the value of $P = 400$ N.

7. Selected results of tests

Fig. 10 presents the immediate test diagram of loading-slip characteristics obtained as a result of preloading to the value of $P = 0.4P_{\text{max}}$ and then unloading to the value of $P_{\text{min}} = 0.1P_{\text{max}}$ of the chipboard-to-timber connection.

![Diagram of creep as results of preloading for wood derivatives boards-to-timber joints immediate test diagram](image)

The function describing creep process of the connection has been applied in mathematical approach to mechanical model. This function [5] adopted in the description of creep of the connections is presented in the Fig. 11 with diagram of creep from experimental tests.

Fig. 12 presents a part of creep diagram in the time range from the beginning of the creep process to unloading for the investigated connections with chipboard under loading of 410 N.

The following function [6] has been applied in the model description

$$\delta = c - at^{m+bt}$$

where $\delta$ is slip in joint mapping displacements as the result of creep of wood surrounding fastener and creep of fastener dowel; $c$ is asymptotic displacement in the joint for infinite time $t = \infty$, $a$, $m$, $b$ are model constants.

The constants were evaluated for the selected creep characteristics:

- connections with the OSB boards under creep loading $P = 400$ N;
- connection with the chipboard under creep loading $P = 410$ N.

Parameters $a$, $b$, $m$ were obtained:

- creep of OSB-to-timber joint: $a = 2.48775$, $b = -8.83279*10^{-5}$, $m = -0.015569$;
- creep of chipboard-to-timber joint: \( a = 1.06929, b = -4.58472 \times 10^{-9}, m = -0.0057283 \).

On the basis of selected results of tests the mechanical model describing duration of load effect in mechanically fastened connections with dowel kind of links was fitted to match the time-depending behaviour of the connection. The functions describing creep correspondingly were chosen and applied in mathematical formulation of time-depending phenomenon of the joint behaviour. These adopted formulae for connections of chipboard sheathing to framing on the early beginning stage of loading were plotted in Fig. 13.

The constants for selected characteristics of creep of connections were evaluated for upper and lower limits of creep and curves were plotted reflecting the time depending behaviour of dowel type connection.

Slip creep described applying the function in the form \( \delta = f(t) \) for determined parameters \( a, b, m \) fits well to the experimentally obtained results. Experimental tests and analytical descriptions were conducted for different kinds of sheathing boards used in wood-framed connections.

8. Experimental tests of fasteners set linking board to framing in the diaphragms

Experimentally investigated wall diaphragm, its geometry and long-term test setup is presented in Fig. 14. Sheathing chip-boards were fastened by 12 mm thick with 2.6 mm nails spaced on the perimeter at 150 mm to spruce studs 45x135 mm spaced on 625 mm form the wood-framed wall diaphragm. The walls were loaded with lateral force applied at the top of the diaphragm. Fig. 14 presents the scheme of wall diaphragm and test setup.

![Fig. 14 Long-term investigation of wall diaphragm, a - wall geometry and construction; b - setup for tests of wall panel](image)

The value of loading 12 kN corresponds to design capacity of the fasteners used in the slip creep of connections, and 15.0 kN corresponds to 0.6 \( P_f \), for \( P_f \) – the immediate fastener capacity.

Lateral characteristic load to diaphragm has been evaluated according to the standard requirements from formula describing the minimum design load to the wall

\[
N_{w} = R_s \sum \left( \frac{b_i}{h_i} \right)^2 \frac{b_i}{s_i}
\]
where $R_d$ represents minimum fastener load from standard modes of failure; $b_i$ is the width of the sheathing boards; $b_1$ is the width of the widest sheathing board; $s$ is perimeter spacing of the fasteners.

Fig. 15 presents the first stage of loading and load-slip immediate characteristics.

Fig. 15 The load-displacement characteristic of the wall under lateral immediate load

- stabilizing 1 (vertical loading $F_{\alpha 1}$) under concentrated load of $P_{\alpha 1} = 0.1 P_v$, where $P_v = 400$ kN for wall $A$ without opening and $P_v = 250$ kN for perforated wall $B$,
- functional live loading $F_1$ (vertical loading $F_1$) under concentrated load of $P_{\alpha 1} = 0.4 P_v$,
- functional horizontal load (horizontal loading $F_2$) under concentrated load of $P_{\alpha 2} = 0.2 P_v$,
- simultaneous vertical and horizontal loading $F_3$ up to the failure of tested elements, presented in Fig. 17.

Fig. 16 Diagram of loading application to the wall in immediate load test: a - phases of loading; b - scheme of loading and reading points (displacements and strains)

9. Creep behaviour of the wood-framed wall diaphragm

In the first stage the wall panels were investigated within the three days time of loading corresponding to the short-term loading resulting from wind pressure acting on the building.

Fig. 17 Load-displacements immediate characteristics of the wall

Wall diaphragms were investigated under lateral long-term load in the values of:
- 12 kN - corresponding the characteristics wind load.
- 15 kN - corresponding to design lateral load for the diaphragms of geometry and parameters presented in Fig. 15.

Creep slip of connections exhibit high sensitivity in time for the first stage of loading with evident decrease and stabilizing effect after 1 day of loading.

Creep of wall panel resulted in varying in time displacement. The top edge exhibits low sensitivity in time under exploita-

Fig. 18 Duration of load effect with recovery for wood-framed wall diaphragm under different loading level: a - lateral load $P_v = 12$ kN; b - lateral load $P_v = 15$ kN
tion level of loading. After three days of loading displacements are stabilizing, while the higher level of load corresponding to 15.0 kN leads to continuous increase of displacements in time.

Creep displacements of the wood-framed wall under specified above the lateral load levels are presented in Fig. 18.

Creep slip of connections exhibit high sensitivity in time for the first stage of loading with evident decrease and stabilizing effect after 120 days of loading.

Results from long-term loading of the fasteners and the effect of long-term loading on the wall is used in numerical model description.

10. Conclusions

1. Creep displacements in the joint grows up in time 40-60% comparing to the immediate test value.
2. Creep of the wall panel resulted in varying in time displacement. The top edge exhibits low sensitivity in time under exploitation level of loading. After three days of loading the displacements are stabilizing, while the higher level of load corresponding to 15.0 kN leads to continuous increase of displacements in time.
3. Mathematical description of the duration of load effect implemented in numerical model of wall and floor diaphragm prevail the prediction of time-behaviour of the structure.

References


M. Maleša, C. Miedzialowski
IMMEDIATE AND LONG-TERM STRENGTH TESTS OF CONNECTIONS IN THE WOOD-FRAMED STRUCTURE

Résumé

Le papier présente des résultats de l'effet de immédiate and of long-term load on timber joints and time de- pending behaviour of connections in the wood-framed structures. Strength of dowel type of timber-to-timber and board-to-timber joints and the load-slip characteristic of connections is examined under short-time and long lasting load. The process of wood creep influences strongly the strength of connection. The duration of load effect in joints significantly differs in contrast with the process of wood creep. The experimental test results of load duration effect in timber joints and wood-framed wall diaphragms are presented in the paper. The selected results of creep of sheathing to framing joints, their mechanical model and its mathematical descriptions are presented in the paper. Also some results of time depending behaviour of wall panel under different levels of lateral load are included in the paper.

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NÉPOSREDSTVENNYE I DLITEL'NYE EKSPERIMENTAL'NYE ISCHEDOVANII SOEDINENII V KARKASNIIKH DEREV'YANNYKH KONSTRUKTSIIKH

Резюме

В статье представлены экспериментальные результаты непосредственных и длительных исследований механических соединений древесных плит с древесиной в каркасных деревянных конструкциях жилых зданий. Сопротивление соединений нагельного типа древесины-древесина и древесина-плита-древесина и их скольжение в результате краткой длительной нагрузок исследовано экспериментально. Процесс получения древесины сильно влияет на деформацию и прочность соединений в течение времени нагрузки. В работе представлены результаты кратких и долгосрочных исследований каркасной деревянной стены пanelьного типа жилых зданий.

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