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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.

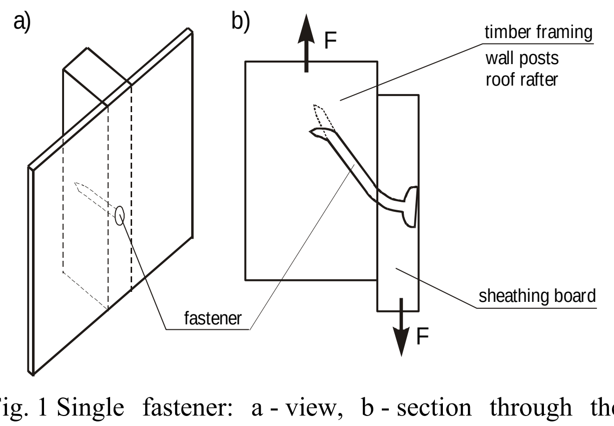

Fig. 1 Single fastener: a - view, b - section through the fastener

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.

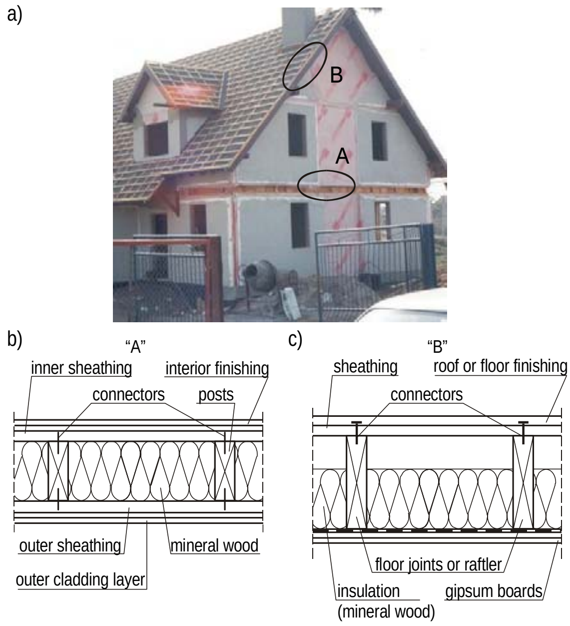

Fig. 2 Typical cross-section of the wood-framed structures and building under construction: a - building under construction, b - wall diaphragms, c - floor and roof panel

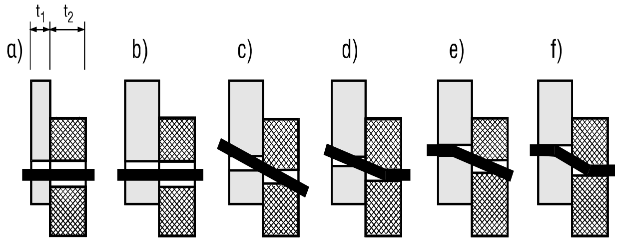

Fig. 3 Standard modes of failure of fasteners

Fig. 4 presents the connection scheme, the test setup and the diagram of immediate test loading.

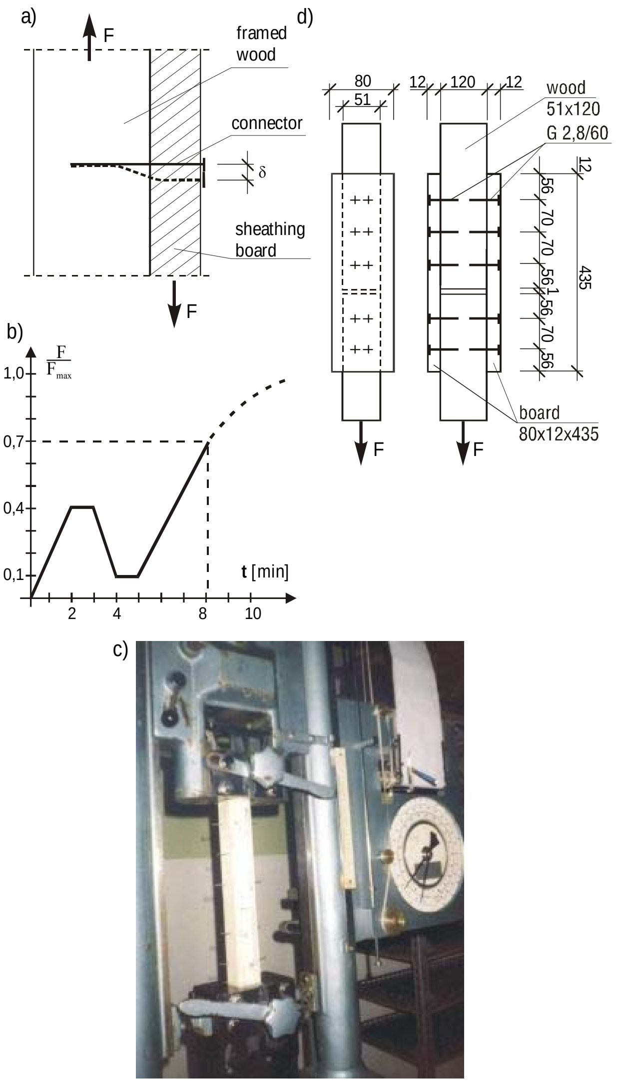

Fig. 4 Scheme of pin connection and diagram of loading used in test: a - scheme of connection; b - scheme of loading; c - test setup; d - tested specimen of connection

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

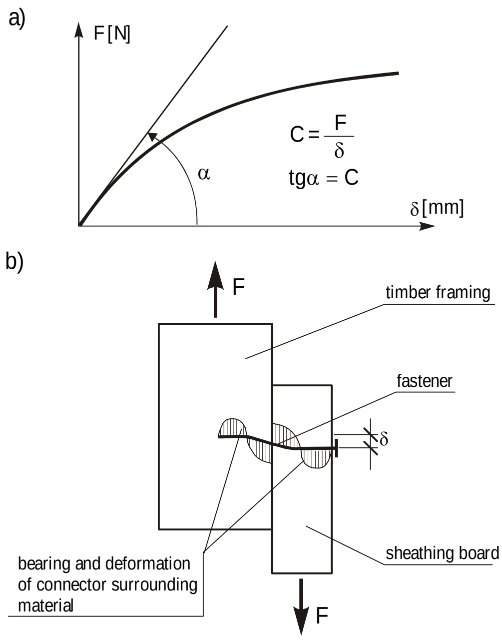

Fig. 5 Load-slip characteristics describing the fastener behaviour: a - schematic characteristic; b - diagram of loading

Standard load on the fastener corresponding to each failure mode can be evaluated from the formula

$$R_d = min \text{ of } \begin{cases} f_{h,1,d} t_1 d \\ f_{h,1,d} t_2 d \beta \\ \dfrac{f_{h,1,d} t_1 d}{1+\beta}\left[\sqrt{\beta + 2\beta^2\left[1+\dfrac{t_2}{t_1}+\left(\dfrac{t_2}{t_1}\right)^2\right]+\beta^3\left(\dfrac{t_2}{t_1}\right)^2}-\beta\left(1+\dfrac{t_2}{t_1}\right)\right] \\ 1.1\dfrac{f_{h,1,d} t_1 d}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\dfrac{4\beta(2+\beta)M_{y,d}}{f_{h,1,d} d t_1^2}}-\beta\right] \\ 1.1\dfrac{f_{h,1,d} t_2 d}{1+2\beta}\left[\sqrt{2\beta^2(1+\beta)+\dfrac{4\beta(2+\beta)M_{y,d}}{f_{h,1,d} d t_2^2}}-\beta\right] \\ 1.1\sqrt{\dfrac{2\beta}{1+\beta}}\sqrt{2M_{y,d} f_{h,1,d} d} \end{cases} \tag{1}$$

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 $F1 = f(\delta)$ characteristics has been applied in the form

$$N = (A + B\delta)\left[1 - exp\left(-\frac{C}{A}\delta\right)\right] \tag{2}$$

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

Displacements in the connection under lateral load of the fastener F_δ

Number of reading	Loading F acting in joint, N	Number of loaded fasteners, No	Loading $F1$ acting on indyvidual fastener, N	Mean displacements in the joint δ, mm	Displacement δf from function describing the load-slip characteristic, mm	Standard deviation
1	0	4	0	0	0	0
2	300		75	0.0297	0.0305	0.0142
3	500		125.0	0.0473	0.0528	0.0200
4	750		187.5	0.0785	0.0838	0.0236
5	1000		250.0	0.1018	0.1187	0.0137
6	1250		312.5	0.1587	0.1587	0.0278
7	1500		375.0	0.2255	0.2055	0.0417
8	1750		437.5	0.2950	0.2817	0.0425
9	2000		500.0	0.3802	0.3320	0.0383
10	2250		562.5	0.4942	0.4249	0.0237
11	2500		625.0	0.6632	0.5592	0.0507
12	2750		687.5	1.1023	0.7850	0.0930
13	3000		750.0	1.4348	1.2354	0.1640
14	3250		812.5	1.9492	1.9492	0.1660
15	3500		875.0	2.5938	2.7245	0.1430
16	3750		937.5	3.5040	3.5040	0.1970

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, C.

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

where $F1$ is loading of a single fastener, N; δ is slip displacements [mm] of the fastener.

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

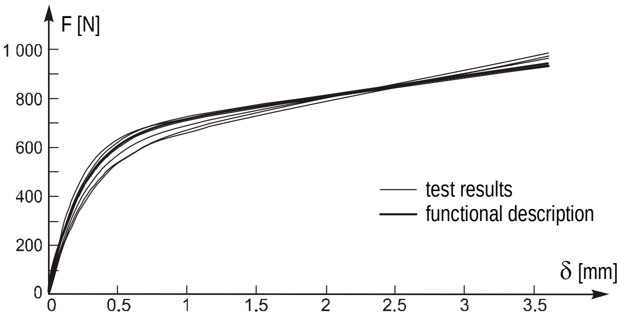

Fig. 6 Load-slip fastener characteristics for chipboard sheathing

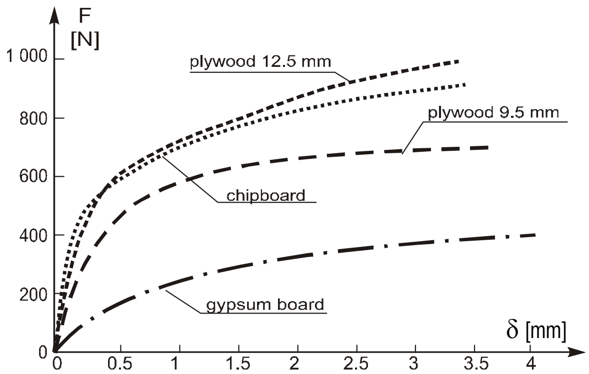

Fig. 7 Load-slip characteristics of sheathing to framing connectors for different wood-derivatives boards

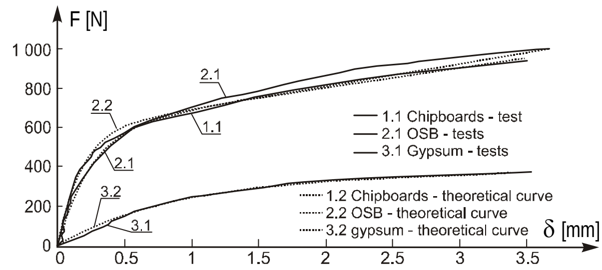

Fig. 8 The load- slip characteristics and theoretical function describing the fastener behaviour

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 preseted 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.

Table 2

Parameters A, B, C for different sheathing

Parameters	Sheathing material			
	Plywood 12.5 mm	Plywood 9.5 mm	Chipboard 12.5 mm	Gipsum board 12.5 mm
A	0.597	0.587	0.600	0.315
B	114.72	29.13	100.91	17.96
C	3491.76	1557.50	2498.93	421.10

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.

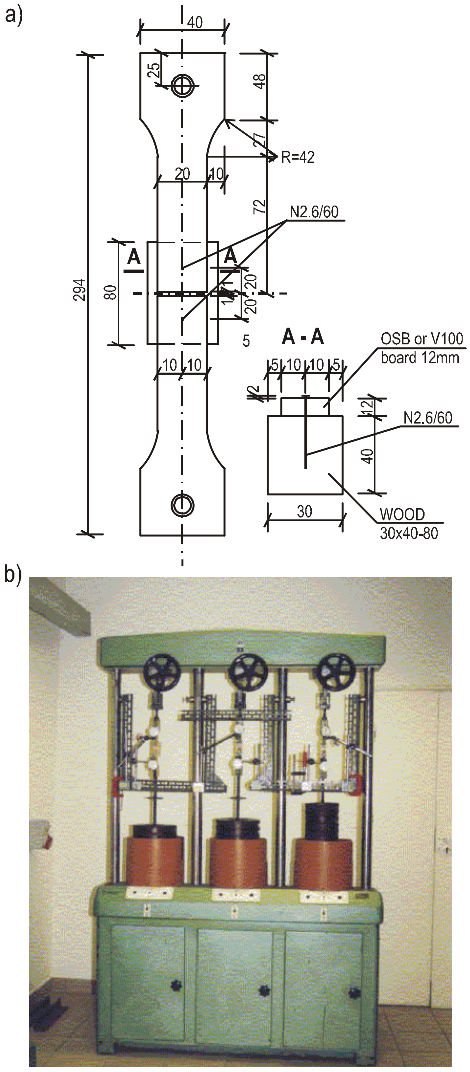

Fig.. 9 Scheme of specimen used in test and the test setup: a - the specimen; b - the test setup

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 3

Material basic characteristics

Material	E_{11}, MPa	E_{22}, MPa	G, MPa	ρ, kg/m^3
Wood	11500	530	585	340
Plywood	10900	8700	790	450
Chip-board	4500	3800	800	620
Gipsum board	3900	3500	1800	950

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.

Creep tests were conducted after preliminary loading of the fastener at the value of $P = 0.4P_{max}$ and then released loading to the value of $P_{min} = 0.1P_{max}$. P_{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 $P = 0.4\ P_{max}$ and then unloading to the value of $P_{min} = 0.1P_{max}$ of the chipboard-to-timber connection.

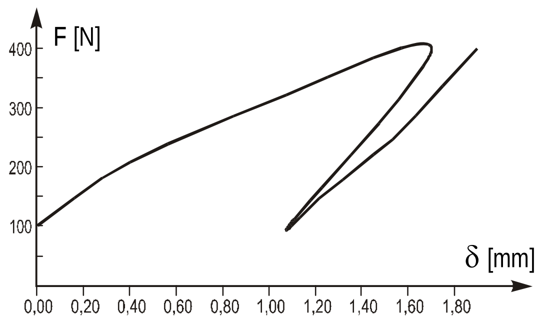

Fig. 10 Diagrams $P = f(\delta)$ as results of preloading for wood derivatives boards-to-timber joints immediate test diagram

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

$$\delta = c - at^{m+bt} \tag{4}$$

where δ 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, m, b were obtained:

- creep of OSB-to-timber joint: a = 2.48775, b = = -8.83279*10^{-9}, m = -0.015569;

- creep of chipboard-to-timber joint: a = 1.06929, b = = -4.58472*10^{-9}, m = -0.0057283.

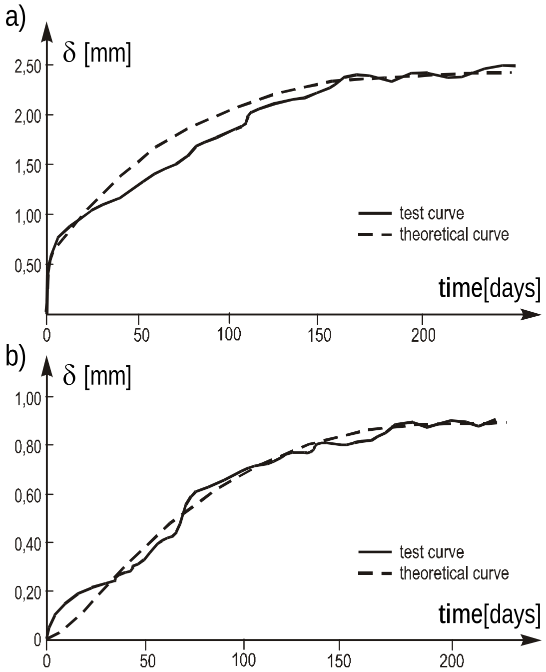

Fig. 11 Creep diagram of the connection and the function applied in the description. a - connection with chipboard under P = 400 N loading, b - connection with OSB board under P= 400 N loading

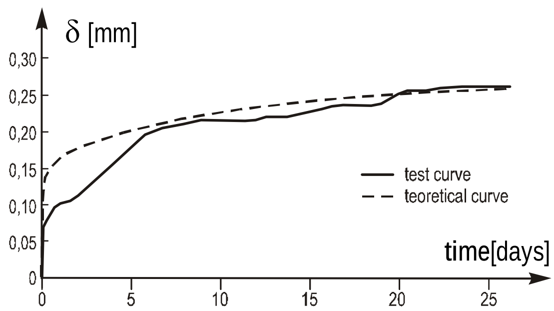

Fig. 12 Diagrams of creep test $\delta = f(t)$ under evaluated loading level: a - creep of connection with chipboard under loading P = 410 N

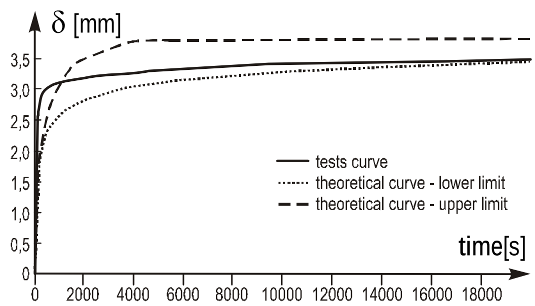

Fig. 13 Diagrams with adopted in description mathematic function for early process of creep of the connection with chipboard

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.

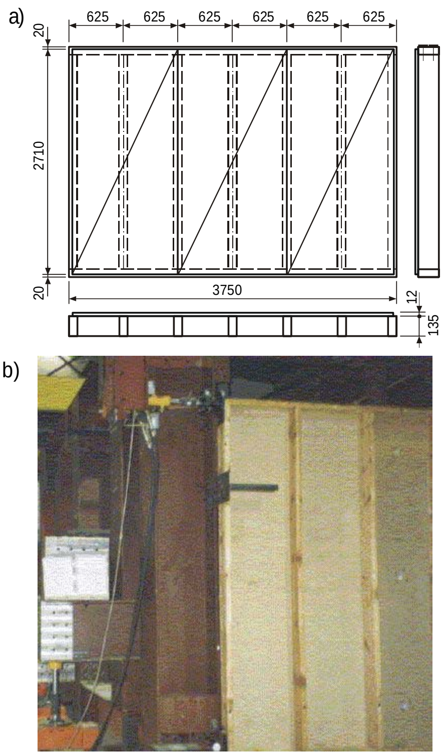

Fig. 14 Long-term investigation of wall diaphragm, a - wall geometry and construction; b - setup for tests of wall panel

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 $P_{f,1}$ for P_{fi} – 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

$$N_{hi} = R_d \sum \left(\frac{b_i}{b_1} \right)^2 \frac{b_i}{s} \tag{5}$$

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.

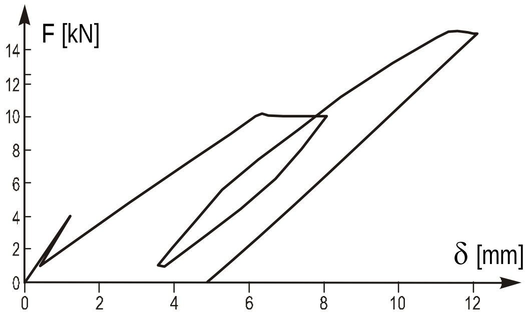

Fig. 15 The load-displacement characteristic of the wall under lateral immediate load

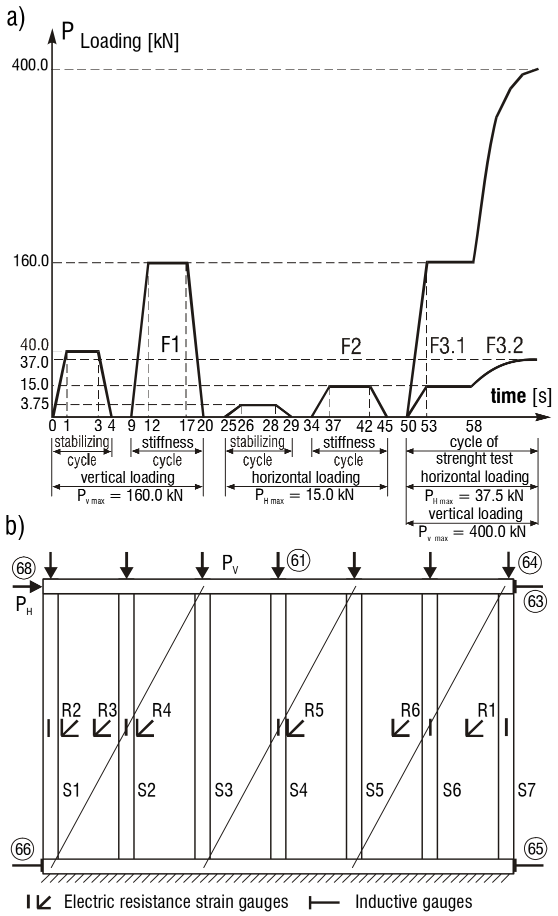

Fig. 16 Diagram of loading application to the wall in immediate load test: a - phases of loading; b - scheme of loading and reading points (displacements and strains)

Immediate tests of wall diaphragms were conducted under vertical and lateral load. The programme of tests and the stages of loading were selected according to Fig. 16.

The following phases of loading in experimental tests of panels according to PrEN 594 were selected:

- stabilizing 1 (vertical loading F_{o1}) under concentrated load of $P_{v0} = 0.1\ P_v$, 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 $P_{v1} = 0.4\ P_v$,
- stabilizing 2 (horizontal loading F_{o2}) under concentrated horizontal load of $P_{Ho} = 0.1\ P_H$, where $P_H = 37.5$ kN for wall A and $P_H = 25.0$ kN for wall B,
- functional horizontal load (horizontal loading F_2) under concentrated load of $P_{H2} = 0.2\ P_H$,
- simultaneous vertical and horizontal loading F_3 up to the failure of tested elements, presented in Fig. 17.

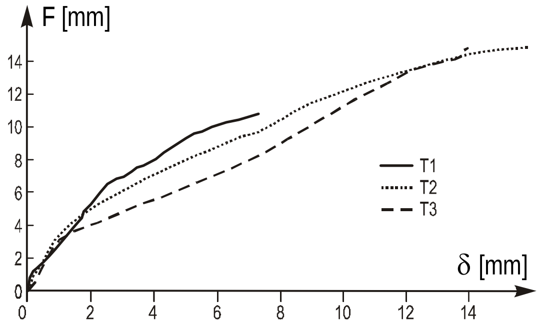

Fig. 17 Load-displacements immediate characteristics of the wall

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.

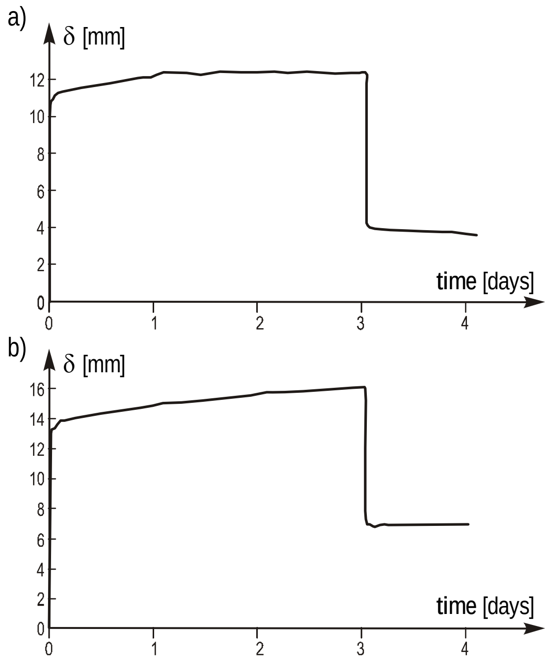

Fig. 18 Duration of load effect with recovery for wood-framed wall diaphragm under different loading level: a - lateral load $P_h = 12$ kN; b - lateral load $P_h = 15$ kN

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 exploitation 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.

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TIESIOGINIAI IR ILGALAIKIAI MEDINIŲ KARKASINIŲ KONSTRUKCIJŲ JUNGČIŲ EKSPERIMENTINIAI TYRIMAI

R e z i u m ė

Darbe pateikti tiesioginiai ir ilgalaikiai gyvenamųjų namų mechaninių medienos plokščių ir medienos karkasinių jungčių eksperimentinių tyrimų rezultatai. Eksperimentiškai ištirta cilindrinio tipo mediena-mediena ir medienos plokštė-mediena jungčių atsparumas ir jų valkšnumas, esant trumpalaikei ir ilgalaikei apkrovai. Medienos valkšnumas turi didelę įtaką jungčių deformavimui ir stiprumui veikiant apkrovai. Darbe pateikti panelinių gyvenamųjų namų karkasinių medienos sienų trumpalaikio ir ilgalaikio tyrimo rezultatai.

M. Malesza, C. Miedziałowski

IMMEDIATE AND LONG-TERM STRENGTH TESTS OF CONNECTIONS IN THE WOOD-FRAMED STRUCTURE

S u m m a r y

The paper presents results of the effect of immediate and of long-term load on timber joints and time depending 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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НЕПОСРЕДСТВЕННЫЕ И ДЛИТЕЛЬНЫЕ ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ СОЕДИНЕНИИ В КАРКАСНЫХ ДЕРЕВЯННЫХ КОНСТРУКЦИЯХ

Р е з ю м е

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 древесина-древесина и древесная плита-древесина и их скольжение в результате краткой длительной нагрузок исследовано экспериментально. Процесс ползучести древесины сильно влияет на деформацию и прочность соединений в течение времени нагрузки. В работе представлены результаты кратких и долгосрочных исследований каркасной деревянной стены панельного типа жилых зданий.

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