Timber-Frame House Resistant to Dynamic Loads - Analysis of Wall Panel Filled with Polyurethane Foam

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Abstract

The present study shows the experimentally and numerically determined response of a single timber-frame house wall panel filled with polyurethane (PU) foam under dynamic loads. The harmonic tests were conducted for the following frequencies: 0.5 Hz, 1.0 Hz, 2.0 Hz and 5.0 Hz for various values of the specified displacement. Based on the results of the comparison between the experimental tests and the numerical analyses, the numerical model has been verified to be correct. The model can be used in further analyses so as to investigate the behaviour of the whole building under dynamic loads, including seismic and paraseismic excitations. Using such a numerical model, it will be possible to evaluate the improvement in resistance against dynamic loads for the case when PU foam is used instead of mineral wool.

Keywords: timber-frame house, earthquake resistance, dynamic loads, numerical model

1. Introduction

The use of timber-frame houses is very popular in many places around the world. The resistance of small building, including wooden houses, under seismic and paraseismic excitations (see, for example, [12, 11]), in terms of cost effectiveness is one of the most attractive aspects. The possibility of improving the dynamic resistance in existing houses is another positive and desired issue (see [5, 2]).

Correctly designed structures are marked by good resistance against dynamic loads, for example extreme earthquakes [9]. OSB/3 and MFP waterproof boards are used as slab, wall and roof sheathing. Those boards increase the structural stiffness of the building due to their relative high strength and because of their good resistance against shear forces and they reduce the forces transmitted to the structure during dynamic loads [9, 10, 11].

With the experience gained in North America and Japan, it can be stated that wooden houses are able to survive the catastrophic earthquake with little damage. In many cases, extremely effective design solution is to use a plywood wall panels. This material has a beneficial effect on the level of shear forces due to stiffening effect [5, 6]. Structures with such walls panels are relatively rigid and therefore resistant to dynamic actions, such as earthquakes, paraseismic excitations or impact loads [7, 1].

The use of thermal insulation in form of wool in sheathed timber-frame elements shows almost none influence on the timber-frame in terms of dynamic resistance [8].

The purpose of this article is to present the results of experimental studies of the wall panel of a skeletal wooden building of traditional technology filled with polyurethane (PU) foam, that have been adopted to create a whole building numerical model. This model was subjected to horizontal forces so as to verify the behaviour of a PU foam filled building in comparison to a mineral wool filled structure.

2. Experiment setup

The experimental setup consisted of especially designed steel frame, in which the tested specimen were mounted - see Fig 2 and Fig. 3. A PARKER dynamic actuator was used to generate harmonic excitation. For the purpose of this study, a typical timber frame house wall panel was built with dimension as shown in Fig. 1. The frame was covered with OSB3 sheaths and then the space inside was filled with PU foam. This frame was then mounted into the previously fabricated steel frame and connected with the actuator.

Figure 1. Example of real size wooden house with basic element (shown in red)

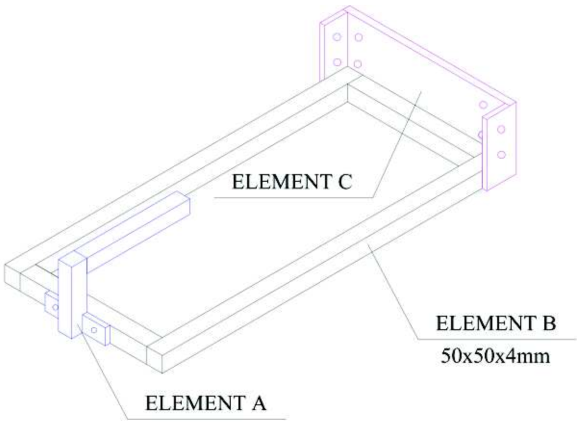


Figure 2. Steel frame used in the experiment

3. Analysis Description

During the test, the specimen has been exposed to harmonic loads with the following frequencies: $f = 0.5$ Hz; $f = 1.0$ Hz; $f = 2.0$ Hz; $f = 5.0$ Hz and different displacements. During the tests, force has been recorded with a force meter KMM40 with a range up to 50 kN as well as the resulting displacement (for the induced dynamic displacement) was recorded by a laser meter optoNCDT1302 with a range of +-100 mm (see Fig 3).

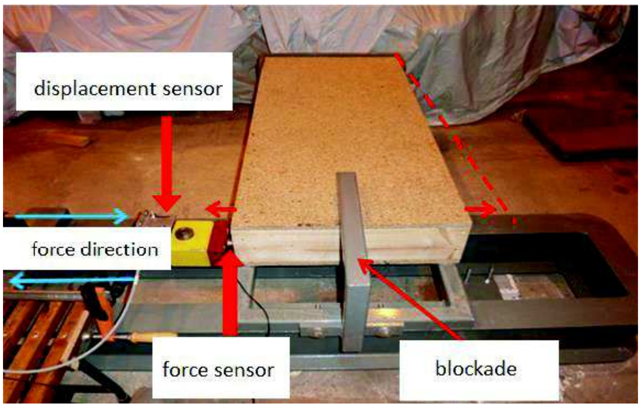


Figure 3. Experiment setup details (see [12])

The test was conducted with traditionally constructed wall panels, as described before. The panels have been fixed at one end, while the other end was subjected to displacement from 8 mm to 75 mm. The examples of the results, for the frequency of 2 Hz, are shown in Fig. 4 and Fig. 5.

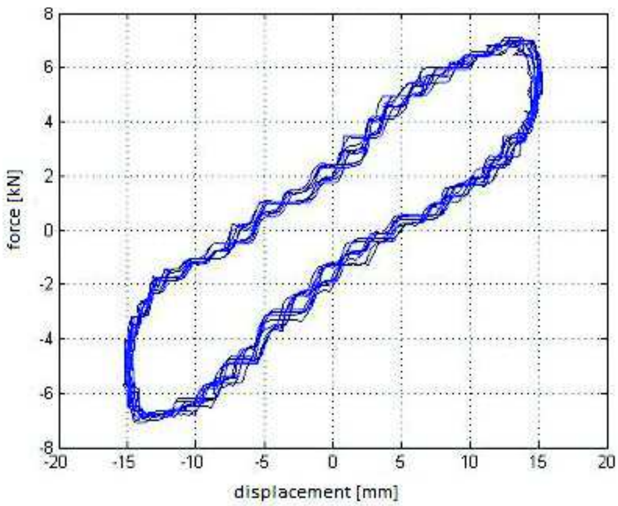


Figure 4. Hysteresis loop at 2 Hz (PU foam filling)

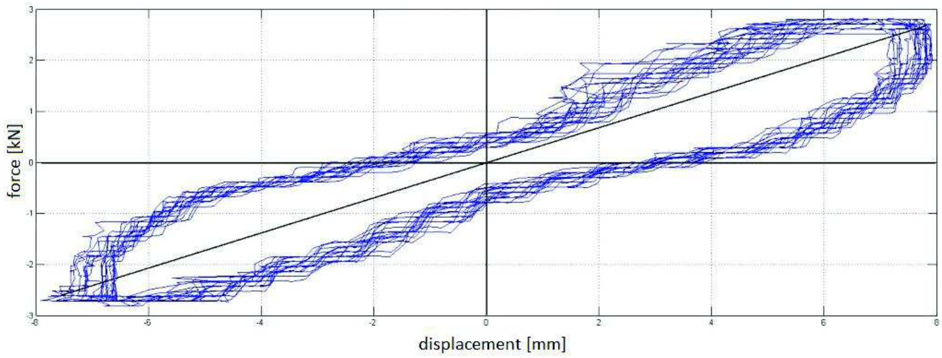


Figure 5. Hysteresis loop at 2 Hz (mineral wool filling)

The tested specimen filled with PU was able to withstand higher frequencies as well as a larger force in comparison to a wool filled wall panel, where a frequency of 2 Hz and a displacement of 28 mm caused the OSB3 sheathing to break from the wood frame as well as cracking in the connection in the wood frame itself (see [12]).

4. Numerical Model of the Polyurethane Foam Filled Panel

The program RFEM was used to create a numerical model of the tested panel (see Fig. 6). The geometry as well as the material characteristics and support conditions have been considered to be identical as in the experimental specimen. Shell elements have been used with material properties as for C30 wood. The thickness of the shell elements was 45 mm for the frame parts and 18 mm for the OSB3 sheaths and one shell with a thickness of 145 mm for the mineral wool filling. Polyurethane foam material parameters (see Fig. 7) have been established through the experimental tests. The support conditions have been modelled as shown in Fig. 6 – all translations were fixed but all rotations were free. Those support conditions have been considered as best approximation of the conditions of the experimental setup. The numerical model was calibrated by changing only the stiffness of the OSB3 sheathing in order to reflect the character of the connection between the frame and sheathing. In order to use damping, the following formulas were used in order to obtain the damping coefficents:

$$a_0 = 2\zeta\omega_1\omega_2/(\omega_1 + \omega_2) \quad (1)$$

$$a_1 = 2\zeta/(\omega_1 + \omega_2) \quad (2)$$

where:
a_0 – Rayleigh's damping factor,
a_1 – Rayleigh's damping factor,
ζ – damping coefficient obtained by experimental investigations [%],
$\omega_{1,2}$ – angular frequency [rad/s].

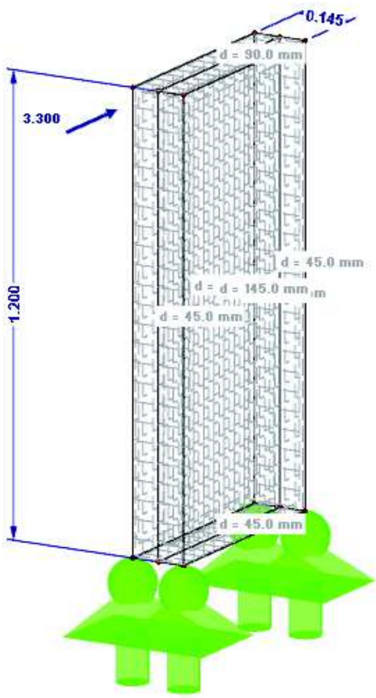


Figure 6. Numerical wall panel model

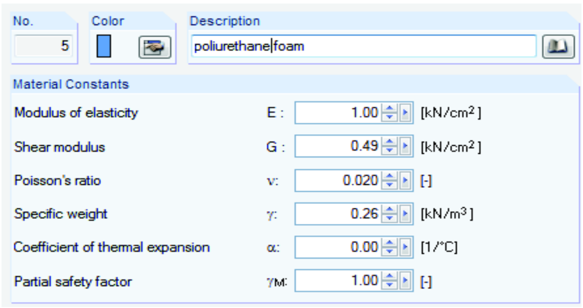


Figure 7. Polyurethane foam parameters

5. Numerical Analysis

The created numerical model was tested in order to verify its accuracy by subjecting it to the same loads as applied in the experiment and by comparing the resulting displacements. For example, for the hysteresis loop received at the frequency of 2 Hz, the resulting force was 3.30 kN and the displacement was U = 6.4 mm (see Fig. 8). Exactly the same results were obtained from the numerical analysis (see Fig. 9 and Fig. 10).

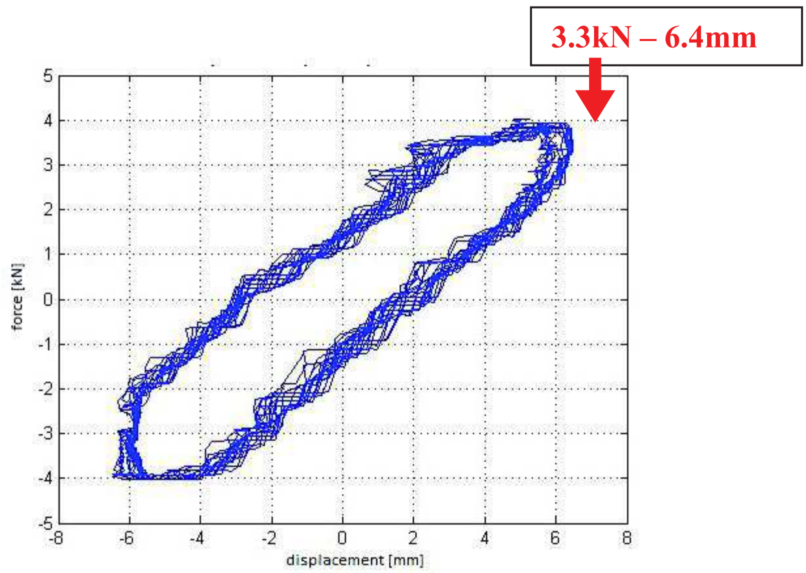


Figure 8. Hysteresis loop – maximum displacement and corresponding force

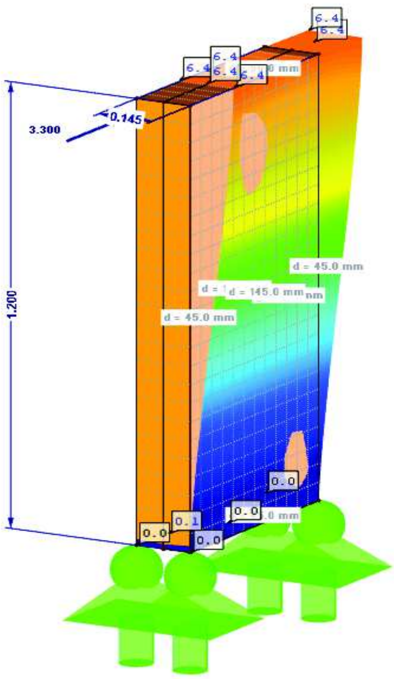
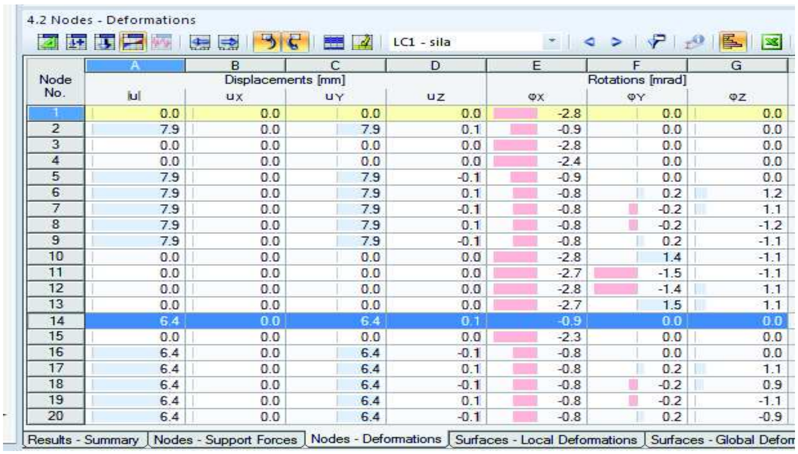


Figure 9. Deformation of the numerical model



4.2 Nodes - Deformations

LC1 - sila

Node No.	A	B	C	D	E	F	G
	Displacements [mm]				Rotations [mrad]		
	|u|	uX	uY	uZ	φX	φY	φZ
1	0.0	0.0	0.0	0.0	-2.8	0.0	0.0
2	7.9	0.0	7.9	0.1	-0.9	0.0	0.0
3	0.0	0.0	0.0	0.0	-2.8	0.0	0.0
4	0.0	0.0	0.0	0.0	-2.4	0.0	0.0
5	7.9	0.0	7.9	-0.1	-0.9	0.0	0.0
6	7.9	0.0	7.9	0.1	-0.8	0.2	1.2
7	7.9	0.0	7.9	-0.1	-0.8	-0.2	1.1
8	7.9	0.0	7.9	0.1	-0.8	-0.2	-1.2
9	7.9	0.0	7.9	-0.1	-0.8	0.2	-1.1
10	0.0	0.0	0.0	0.0	-2.8	1.4	-1.1
11	0.0	0.0	0.0	0.0	-2.7	-1.5	-1.1
12	0.0	0.0	0.0	0.0	-2.8	-1.4	1.1
13	0.0	0.0	0.0	0.0	-2.7	1.5	1.1
14	6.4	0.0	6.4	0.1	-0.9	0.0	0.0
15	0.0	0.0	0.0	0.0	-2.3	0.0	0.0
16	6.4	0.0	6.4	-0.1	-0.8	0.0	0.0
17	6.4	0.0	6.4	0.1	-0.8	0.2	1.1
18	6.4	0.0	6.4	-0.1	-0.8	-0.2	0.9
19	6.4	0.0	6.4	0.1	-0.8	-0.2	-1.1
20	6.4	0.0	6.4	-0.1	-0.8	0.2	-0.9

Results - Summary | Nodes - Support Forces | Nodes - Deformations | Surfaces - Local Deformations | Surfaces - Global Defor

Figure 10. Results of the numerical analysis indicating the same displacement value as during experimental test

6. Conclusions

Based on the results of the comparison between the experimental tests and the numerical analyses, the numerical model has been verified to be correct. On this basis, it can be concluded that not only the material properties and characteristics but also the support conditions have been properly modelled. Therefore, the numerical model can be used in further analyses so as to investigate the behaviour of the whole building (see Fig. 11) under dynamic loads, including seismic and paraseismic excitations. Using such a numerical model, it will be possible to evaluate the improvement in resistance against dynamic loads for the case when PU foam is used instead of mineral wool.

Figure 11. Numerical model of the whole wood-frame house

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