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# Timber Frame Houses with Different Insulation Materials - Seismic Analysis

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***Abstract*—The aim of this article is to present results of a dynamic numerical analysis focused on the response of two timber frame building structures exposed to seismic excitations. The first structure was insulated with mineral wool, while the second one with polyurethane foam. Specifications and technology involved in the models' construction are based on the previously conducted experimental study, upon which numerical structural models were proposed. The displacements of selected node were measured and compared between two models during the numerical investigation. The results of the study confirm that using a polyurethan foam leads to much lower displacement values comparing to the case when the mineral wood is applied as an insulation material. Thus, a positive outcome of using polyurethane foam insulation in timber frame structures exposed to seismic excitations is visible.**

***Keywords—numerical analysis; earthquakes; modal analysis; timber houses; mineral wool, polyurethane foam.***

## I. Introduction

When analysing the technology of single-family houses resistant to dynamic loads, including seismic excitations [1-4] it becomes evident that timber is one of the best materials for such structures. Development of different solutions is further escalated with the spread of ecology and energy-efficient related topics, as well as functionality of such structures as building passive houses. Timber frame buildings constructed with accordance to the technological viewpoint are usually quite resistant to dynamic effects, including earthquakes [5]. Timber-derivative boards, like MFP (multifunctional or OSB/3 oriented strand board) are the most often used elements for covering of ceilings, roofs as well as most of walls of the timber frame houses. These boards have very good durability properties, which allow us to stiffen the whole structure and reduce the forces occurring during dynamic excitations [6 - 9]. Data gathered in South America and Japan shows that timber frame houses can often withstand mining shakes and even catastrophic earthquakes with just minor damage [5].

Mining shocks are also dangerous, but in contrast to earthquakes, they can be predictible. All satellite techniques are more or less already used in the measurements necessary for the protection of mining areas. Leveling will not cover the whole area or a given measurement period, the satellite images are archived and always available to determine terrain size. For observation of the mining areas there are minimum five years of observations required. These observations are made by the station's GPS to determine its trend and noise reduction. While satellite gravimetric measurements have so far not been introduced to issues related to the protection of mining areas it can be assumed that satellite gravimetric measurements are only in trial phase. Various measurement methods are being tested to obtain better and better results and resolutions. These are completely innovative studies - just like it was in the case of the GPS technology. It is characterized by turbulent development and it is possible that the further research will develop the topic so that apart from the mining areas, it will be possible to apply measurements to seismic areas[14].

Thermal insulation is extremely important in relation to the timber frame house building technology [10, 11]. Materials used for thermal insulation of such structures may be incompatible with the timber frame or may significantly stiffen it because of their parameters [12]. Testing mechanic parameters of different insulation materials proves their usability for insulation and stiffening purposes. Mineral wool is the most popular insulation material, which does not engage mechanically with the timber frame. Poliurethan foam is another, different kind of insulation material. Due to the closed cell structure and mechanical properties polyurethane foam increases the rigidity of the timber frame elements [12].

The purpose of this article is to present the results of dynamic numerical analysis focused on earthquake-induced response of two timber frame buildings insulated with mineral wool and with polyurethane foam. Both numerical models have identical geometrical properties and differ only in the used thermal insulation material.

## II. Experimental Studies and Numerical Models of Exterior Walls

Two models of exterior walls were constructed using two different insulation materials to verify the behaviour through the experimental study (see [12] for details) Both experimental models were made in the traditional technology of timber houses. One of them was filled with mineral wool and the other with polyurethan foam.

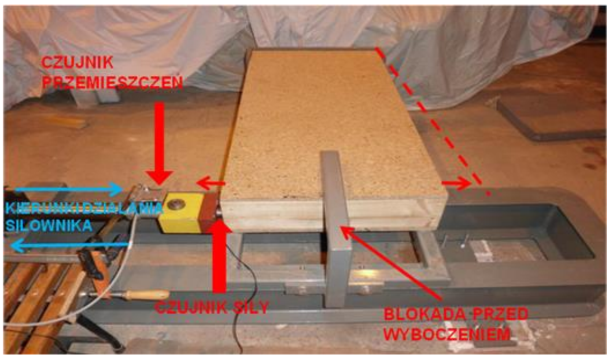



Fig. 1. View of the experiment setup with mounted specimen [13]

A specially designed test setup was used in the experimental study (Fig. 1). The tests were performed for the following excitation frequencies: 0.5 Hz, 1.0 Hz, 2.0 Hz and 5.0 Hz, for various values of displacement. The hysteresis loops were obtained for different displacements for a given frequency excitation. On the basis of the experimental results, numerical models of two wall elements were prepared. The results of numerical analyses were consistent with the results from the experimental study confirming the accuracy of the models created [12].

## III. Numerical Models of the Timber Houses – Modal Analysis

A single-storey timber frame building of the following parameters:

- storey height: 2.80 m
- length and width of the building: 12.0 m

was taken into consideration in the numerical analysis (see numerical models at Fig. 2 and Fig. 3). Building’s timber frame was constructed from a conifer timber of C30 class surrounded with OSB3 boards on both sides. Numerical model 1 was created based on the assumption that the structure is insulated with mineral wool, while numerical model 2 was dedicated to building insulated with polyurethan foam. Model of the real structure was created based on numerical models of exterior walls which, in turn, were verified based on experimental study [12].

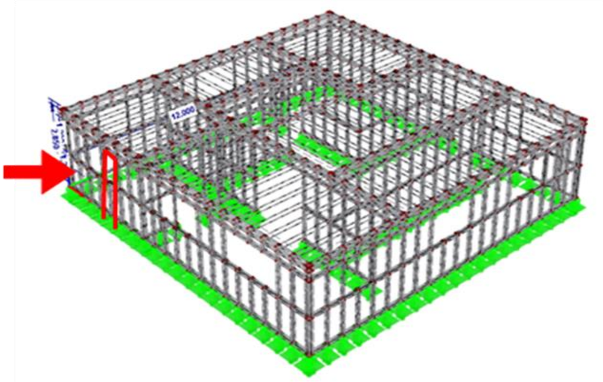


Fig. 2. Numerical model of the building showing a typical wall element

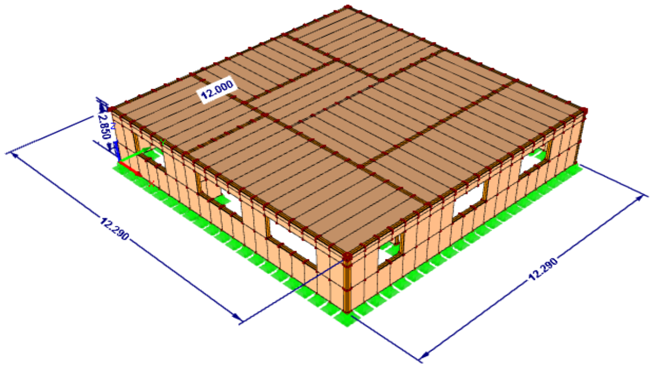



Fig. 3. Full numerical model of timber frame building analyzed [15]

The natural vibrations modes, together with the corresponding frequencies, were obtained as the results of the modal analysis of the timber frame buildings filled with mineral wool and polyurethane foam. The examples of the results in the form of the first natural vibration modes are shown in Fig. 4 and Fig. 5. The values of the first 10 natural frequencies are also summarized in Table I (see [13]).

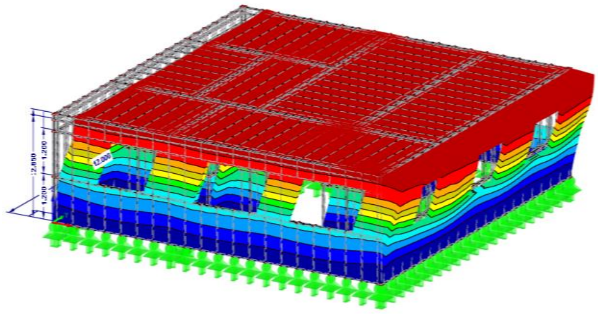


Fig. 4. First natural vibration mode for model with mineral wool [15], first natural frequency: $f = 1.58$ Hz

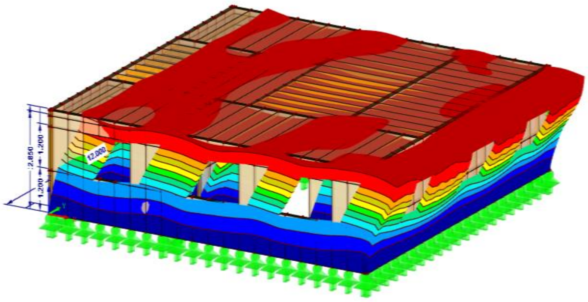


Fig. 5. First natural vibration mode for model with polyurethane foam [14], first natural frequency: $f = 2.72$ Hz

TABLE I. NATURAL FREQUENCIES FOR 10 NATURAL VIBRATION MODES [13]

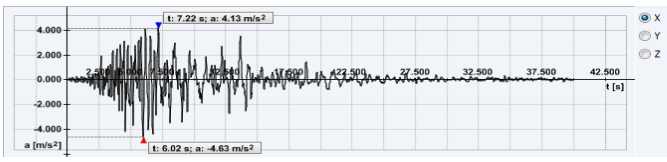
| Model filled with mineral wool (Hz) | Model filled with polyurethane foam (Hz) |
|---|---|
| 1.58 | 2.68 |
| 1.65 | 2.88 |
| 2.11 | 3.73 |
| 5.17 | 4.97 |
| 5.34 | 5.93 |
| 5.38 | 6.56 |
| 5.45 | 6.73 |
| 5.48 | 7.17 |
| 5.53 | 7.38 |
| 5.62 | 7.73 |

The results of modal analysis of both models show that the timber frame model insulated with polyurethane foam displays larger stiffness.

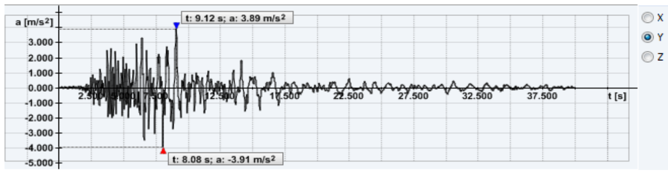
## IV. NUMERICAL ANALYSIS OF THE RESPONSE OF THE BUILDING UNDER SEISMIC EXCITATION

The next stage of the study was devoted to the numerical analysis focused on structural behaviour under seismic excitation. During the analysis, both models were subjected to the Loma Prieta earthquake of October 17th 1989 (see Fig. 6) acting in all three directions simultaneously. Due to limitation of the space, only the examples of the results are shown in paper. Fig. 7 presents visualisation of extreme displacements for model with mineral wool. The displacement time histories in all three directions for node no. 1 of this model are shown in Fig. 8. The corresponding results for the model with polyurethane foam are presented in Fig. 9 and Fig. 10. The detailed comparison between the peak displacements at node no. 1 for both models in all three directions is shown in Tables II - IV.

X direction



*Y* direction



*Z* direction

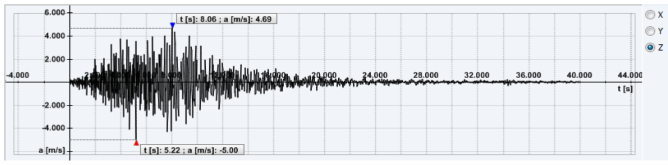


Fig. 6. Acceleration time histories of the Loma Prieta earthquake

NODE NO. 1

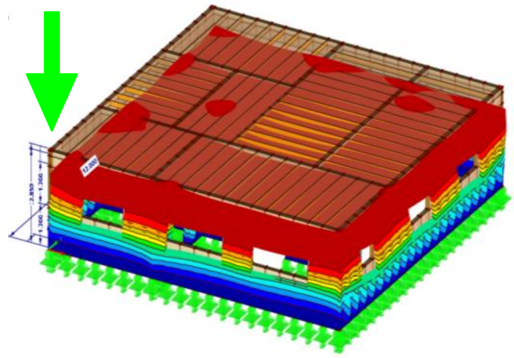
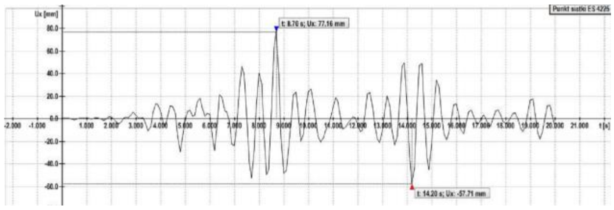
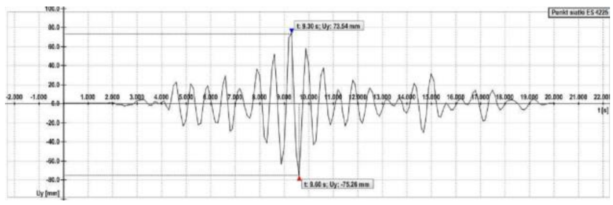


Fig. 7. Visualisation of extreme displacements for model with mineral wool

Displacement of node no. 1 in *X* direction



Displacement of node no. 1 in *Y* direction



Displacement of node no. 1 in *Z* direction

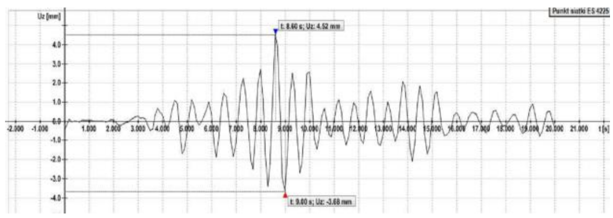


Fig. 8. Displacement time histories for model with mineral wool

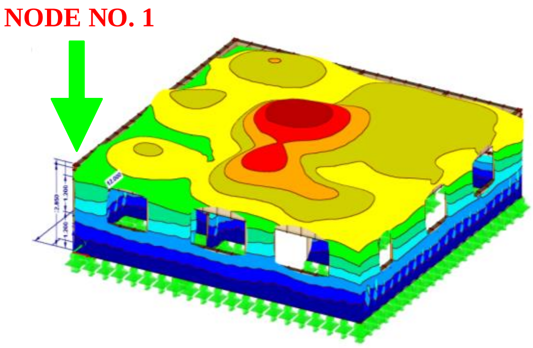
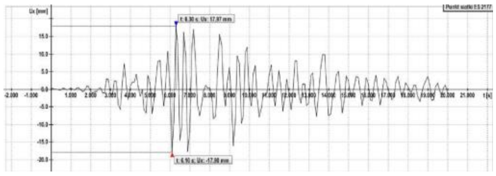
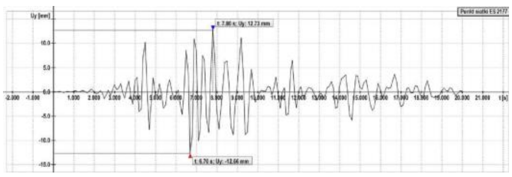



Fig. 9. Visualisation of extreme displacements for model with polyurethane foam.

Displacement of node no. 1 in *X* direction



Displacement of node no. 1 in *Y* direction



Displacement of node no. 1 in *Z* direction

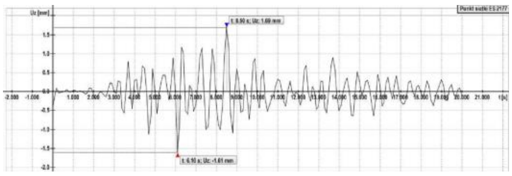


Fig. 10. Displacement time histories for model with polyurethane foam

TABLE II. PEAK DISPLACEMENS AT NODE NO. 1 – *X* DIRECTION

| **Model with mineral wool [mm]** | **Model with polyurethane foam [mm]** | **Reduction (%)** |
|---|---|---|
| 77.16 mm | 17.97 mm | 76.7 |

TABLE III. PEAK DISPLACEMENS AT NODE NO. 1 – *Y* DIRECTION

| **Model with mineral wool [mm]** | **Model with polyurethane foam [mm]** | **Reduction (%)** |
|---|---|---|
| 73.54 mm | 12.73 mm | 82.7 |

TABLE IV. PEAK DISPLACEMENS AT NODE NO. 1 – *Z* DIRECTION

| **Model with mineral wool [mm]** | **Model with polyurethane foam [mm]** | **Reduction (%)** |
|---|---|---|
| 4.52 mm | 1.69 mm | 62.6 |

## V. CONCLUSIONS

The dynamic numerical analysis focused on the response of timber frame house under seismic excitation has been presented in this paper. The results of the study confirm that using a polyurethan foam leads to much lower displacement values comparing to the case when the mineral wood is applied as an insulation material. The reductions of peak values for node no.1 is as large as 76.7 %, 82.7 % and 62.6 % for *x*, *y* and *z* direction, respectively. It is especially important considering the fact that the reduction in displacements is directly related to the reduction in damage of structures exposed to dynamic loads (see also [13]). Therefore, based on the results, a positive outcome of using polyurethane foam insulation instead of mineral wool in timber frame structures exposed to seismic excitations is clearly visible.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