
DYNAMIC PROPERTIES IDENTIFICATION FOR A TIMBER FRAMED MASONRY HOUSE

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ABSTRACT

Timber framed masonry houses represent a traditional type of house that can be found in many countries in the world, having small differences in details though. In Romania, this type of house is spread around the Vrancea seismic source, but not limited to that area. Until now, no studies were done on the Romanian timber framed masonry houses in terms of ambient vibration testing and analysis. This paper presents the first study of this kind, conducted on a house with timber frames and masonry infills, which is located in the National Village Museum, namely representing Sarbova area, Timiș County. Ambient vibration tests were done using velocity sensors, and thus determining the modal frequencies, and a simplified analytical study was further conducted leading to similar results as the experiment.

Keywords: dynamic; timber; masonry infills; experiment

REZUMAT

Casele cu schelet din lemn și umplutură din zidărie reprezintă o tipologie tradițională care poate fi găsită în multe țări din lume, însă cu mici diferențe în detaliile constructive. În România, acest tip structural este răspândit în zona de influență a sursei seismice Vrancea, însă nu este limitat la zona respectivă. Până acum, nu au fost realizate studii și analize de vibrații ambientale pe astfel de case. Acest articol prezintă primul studiu de acest fel, realizat pe o casă cu structura din cadre din lemn umplute cu zidărie de cărămidă plină presată, aflată în incinta Muzeului Național al Satului „Dimitrie Gusti”, mai exact casa Sârbova, din județul Timiș. Testele de vibrații au fost efectuate cu senzori de viteze, determinând astfel frecvențele pe ambele direcții. Acestea au fost comparate cu valoarea obținută printr-o analiză simplificată.

Cuvinte-cheie: dinamic; lemn; umplutură din zidărie; experiment

1. INTRODUCTION

There is not much information about the behavior in past earthquakes of traditional buildings with timber frame and masonry infill or other infills in Romania, that's why people generally assume that traditional residential houses behaved well during seismic events.

In other countries, the past earthquakes and experimental studies showed that they have a good deformation capacity as their main characteristic is ductility. Although the

suffer minor to moderate damage, they rarely collapse and thus generated an increased interest among the researchers.

In order to study the seismic behavior of the traditional houses in Romania, a field investigation was done in order to obtain the construction details of such a house. Few regions were selected, located near the Vrancea seismic source and nearby mountain and hill regions in Buzău County, Vrancea county, Dâmbovița County, Prahova County, Argeș County and Vâlcea County. The results

After the static cyclic tests on walls reproduced in the testing laboratory showed a good deformation capacity under lateral load [1], the next step is to investigate the dynamic properties of this typology.

The ambient vibration tests can be used to determine the damage state of a building, if the measurements are done in initial state, and later, on the damage state. In the present study, the studied house was poorly maintained, and presented some light damages due to foundation settlement. Thus, the aim of the tests was to have a better idea on the identification of natural frequencies, vibration mode shapes and equivalent viscous damping [2].

The building that was studied has one floor and it is a residential house, which is exposed in the Village Museum in Bucharest. The house was built in the period 1900-1930 and was dismantled and moved to the museum from its initial location in Sarbova village, Timiș County.

The spaces between these elements are infilled with clay brick masonry (lime mortar),

thus forming the walls of the house, which are also having bracing elements (Figure 3). The doors and windows openings are bordered with lintels (Figure 3). The walls transmit to the foundations the forces by means of a sill plate made of hardwood (Figure 4).

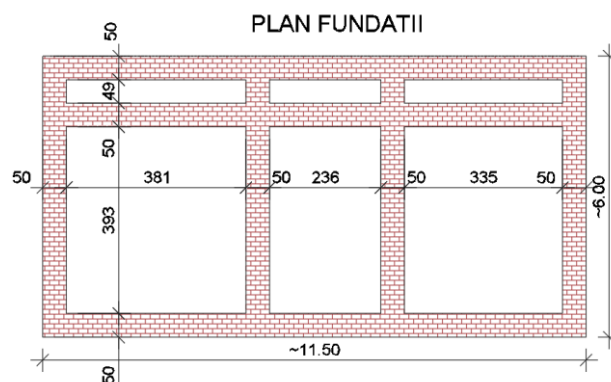


Fig. 1. Plan configuration of the foundations

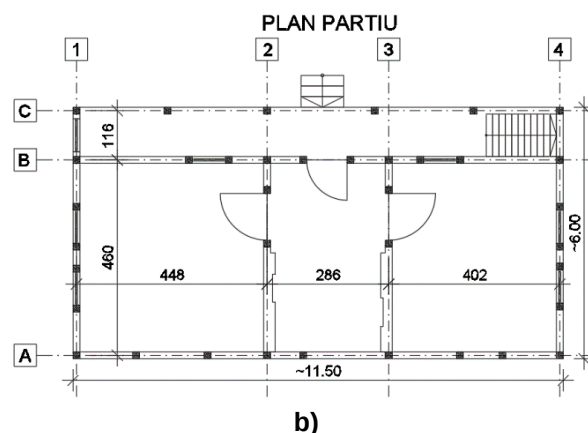
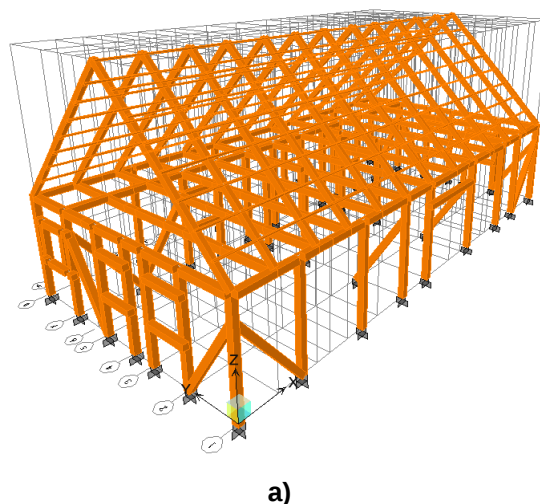


Fig. 2. Spatial (a) and plan (b) configuration of the building

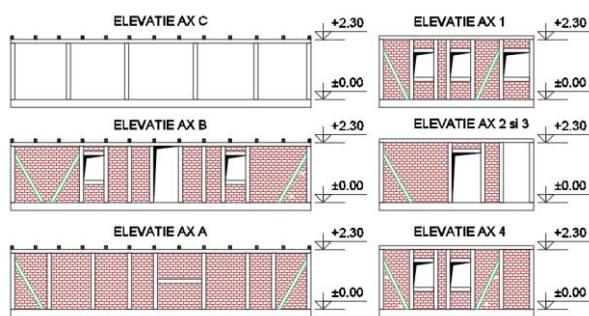


Fig. 3. Elevations of the structural walls

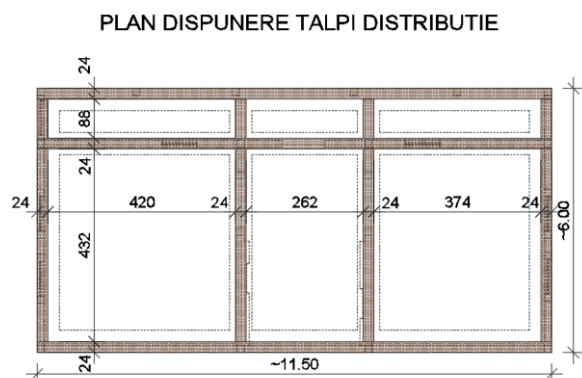


Fig. 4. The sill plate which distributes the walls loads to the foundation

The support structure of the ground floor is made of timber beams, also hardwood, on top of which is applied a flooring made of processed planks (Figure 5). The structure of the floor is made of timber beams, which sit on other contour beams and are visible inside the rooms, the planks being applied only at their upper part, in order to ensure the access to the attic (Figure 6).



Fig. 5. The flooring made of processed planks



Fig. 6. The upper floor

The gable roof with big angles ($\sim 45^\circ$) is made of timber structure with ceramic tiles (Figure 7, Figure 8). The roof timber structure transmits the loads to the structure through axis A (longitudinal wall) and axis C (frame – porch structure), by means of timber beams (Figure 2a).



Fig. 7. Front side of the house



Fig. 8. Front side of the house

The tiles are connected to timber strips, which in turn are connected to the rafters with nails (Figure 9). In the plane of the two slopes of the roof, there are also bracings with a stiffening role for the roof (Figure 10).



Fig. 9. Connection of the timber strips to the rafters



Fig. 10. Stiffeners for the roof

The access to the attic is made by means of stairs made of timber (Figure 11). The access inside the house is made by a porch, which in the past was a resting area. The chimney is made of clay brick masonry (Figure 12), and currently it is not functional.



Fig. 11. Stairs to the attic



Fig. 12. Clay brick chimney

On both interior and exterior, the finishing is made of lime mortar. The timber used to

make the sill plates and the floor beams is hardwood (oak, acacia), while the skeleton of the superstructure and roof is softwood (fir, pine). The connections between the timber elements (posts, sill plates, beams, etc) are cross-halved and with nails (Figure 13, Figure 14, Figure 15), and locally, some staples are used (Figure 16), to ease the mounting of the structure.

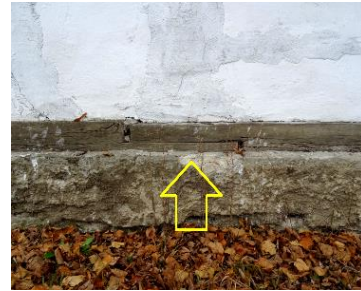


Fig. 13. Cross-halving of the sill plates



Fig. 14. Cross-halving of the roof structure



Fig. 15. Cross-halving of the beams



Fig. 16. Cross-halving of the sill plates at corners

3. STRUCTURAL DESCRIPTION OF THE STUDIED HOUSE

3.1. Test method and instruments

The measurements were done on November 24th 2017, at an ambient temperature of 6°C, and with no wind. The equipment used for ambient vibration measurements consist of an acquisition system (Figure 17) and velocity sensors (Figure 18), made by Buttan Service-Tokyo & Tokyo Soil Research Co., Ltd., Japan. The main characteristics of the acquisition station GEODAS are shown in Table 1.

One direction velocity sensors CR4.5-1 (with main features indicated in Table 2) were used for measurements on the horizontal direction, following the main directions of the building.



Fig. 17. Cross GEODAS acquisition station

Table 1. Characteristics of the acquisition station GEODAS

Name	GEODAS (GEOphysical Data System)
Description	Mobile data acquisition system
Model	GEODAS (with 3 or 12 channels)
Technical characteristics:	
Pre-amplifier	Input impedance 10kΩ Amplification factor 0, 20, 40 dB
Digital analog converter	Resolution: 24 bits Conversion speed: 50 kHz Maximum input voltage: ± 2.5 V
Frequency of sampling	50, 100, 200, 500, 1000, 2000 Hz
Control system	PC COMPAQ Evo N410
Power supply system	DC 12 V (portable battery of 12V)
GPS	Built-in receiver (not used for measurements)
Operating environment	Optimal temperature 10 ~ 45°C; Optimum Humidity 20 ~ 80%
Dimensions / Weight	367 x 342 x 90 mm / aprox. 5 kg



Fig. 18. Cross Velocity sensor CR4.5-1

Table 2. Characteristics of the velocity sensors CR4.5-1

Name	Microtremor sensor
Model	CR4.5-1 H
Number of components	1 vibration component in the horizontal direction (H)
Type of instrument	Mobile velocity seismometer
Sensitivity	1cm/sec = 0.0338 V
Frequency domain	1 ÷ 20 Hz
Fundamental period	1.0 sec.
Dimensions	30 x 30 x 60 mm

For this study, several measurement schemes with 5 sensors (channels) were used (Ch01...Ch05). Four sensors were placed in different positions on the upper floor (above ground floor, beneath the roof) and one sensor was placed on the ground in front of the building. All sensors were connected to one acquisition station (Figure 19), thus ensuring the simultaneous record of the microtremors in all the measurement points. For each measurement scheme, 2 data samples were acquired, with duration of 3 minutes and with a sampling frequency of 100 Hz (sampling interval of 0.01 s).



Fig. 19. Image from the time of the measurements (the acquisition station at the ground floor of the building)

3.2. Scheme 1

The first measurement scheme is shown in Figure 20. The ambient vibration of the building was measured in the transverse direction (the sensors being oriented towards the side of the house with the entrance).

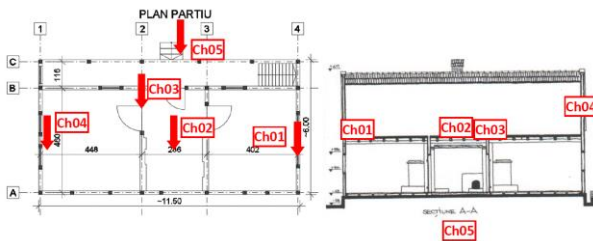


Fig. 20. Image Scheme 1 - sensors layout (transverse direction)

The sensors were placed on the attic floor in the following positions: Ch01 next to the lateral left (from the entrance) (Figure 21a), Ch02 central next to the chimney (Figure 21c), Ch03 towards the edge of the entrance of the slab (Figure 21c), and Ch04 directly on the window of the lateral right masonry wall (Figure 21b). Sensor Ch05 was placed on the ground, outside the building.

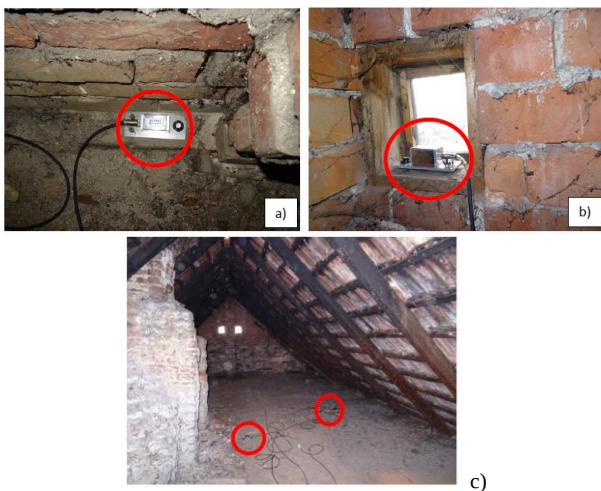


Fig. 21. Sensor locations in Scheme 1

In Figure 22 a) and b) there are presented the Fourier amplitude spectra of the signals recorded during the two measurements in Scheme 1, transverse direction.

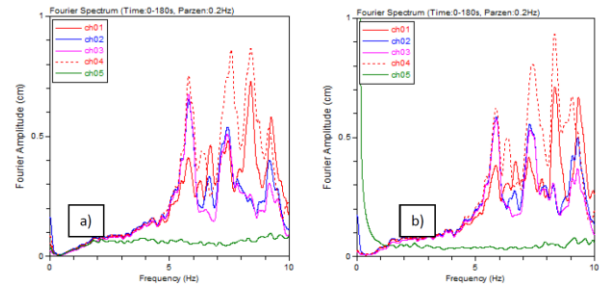


Fig. 22. Fourier amplitude spectra of velocity records for Scheme 1, transverse direction, Measurement 1 (a) and Measurement 2 (b)

3.3. Scheme 2

The second measurement scheme is shown in Figure 23. This time the building ambient vibrations on the longitudinal direction were recorded (the sensors were oriented perpendicular to the entrance).

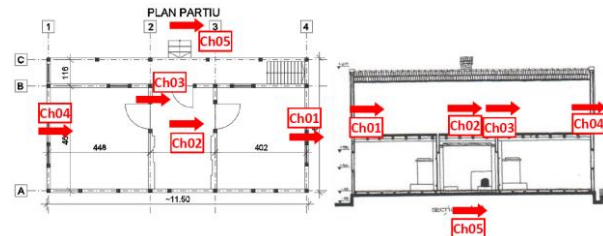


Fig. 23. Scheme 2 - sensors layout (longitudinal direction)

The sensors were placed on the floor slab as follows: Ch01 near the masonry wall, Ch02 central next to the chimney, Ch03 towards the edge of the floor in the direction of the entrance, and Ch04 near the masonry wall (on the floor). Sensor Ch05 was placed on the ground.

The Fourier amplitude spectra of the signals recorded during the two measurements in Scheme 2 (the longitudinal direction) are presented in Figure 24 a) and b).

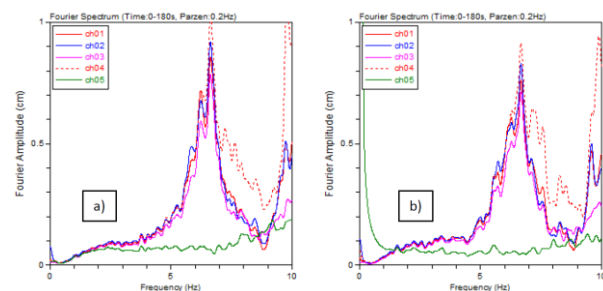


Fig. 24. Fourier amplitude spectra of velocity records for Scheme 2, longitudinal direction, Measurement 1 (a) and Measurement 2 (b)

3.4. Scheme 3

Scheme 3 is shown in Figure 25. Simultaneously, the ambient vibrations of the building were recorded in the transverse and longitudinal directions (with sensors oriented towards the entrance and, respectively, on the perpendicular direction).

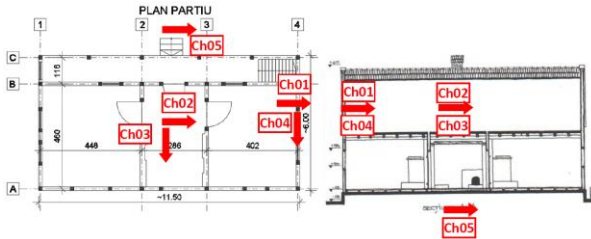


Fig. 25. Scheme 3 - sensors layout

The sensors were placed on the attic floor as follows: Ch01 (longitudinal) and Ch04 (transverse) near the masonry wall (Figure 26), Ch02 (longitudinal) and Ch03 (transverse) near the chimney (Figure 27). Sensor Ch05 (longitudinal) was placed on the ground.



Fig. 26. Sensors for channels Ch01 and Ch04 - Scheme 3



Fig. 27. Sensors for the Ch02 and Ch03 channels - Scheme 3

In Figure 28 are shown the Fourier amplitude spectra of the signals recorded during the two measurements in Scheme 3.

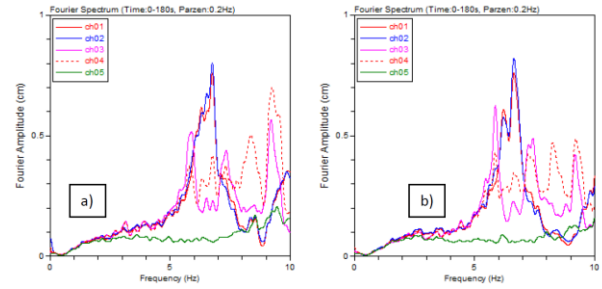


Fig. 28. Fourier amplitude spectra of velocity records for Scheme 3, longitudinal and transverse direction, Measurement 1 (a) and Measurement 2 (b)

3.5. Scheme 4

Scheme 4 is shown in Figure 29. The ambient vibrations of the building were recorded in the longitudinal direction (direction perpendicular to the entrance).

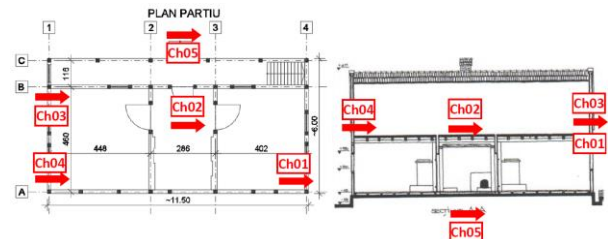


Fig. 29. Scheme 4 - sensors layout (longitudinal direction)

The sensors were placed on the attic slab such as Ch01, Ch03 and Ch04 as far as possible along the corners of the slab beside the masonry side walls, Ch02 central near the chimney, to the edge of the slab, and Ch05 on the ground. Figure 30 shows the Fourier amplitude spectra of the signals recorded during the two measurements in Scheme 4.

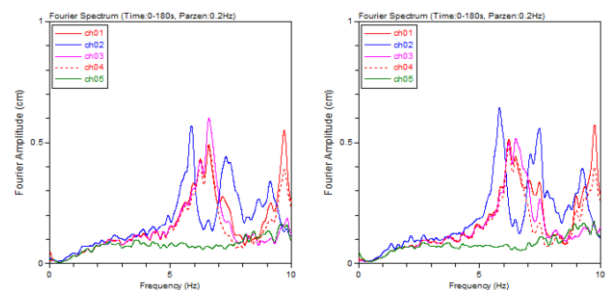


Fig. 30. Fourier amplitude spectra of velocity records for Scheme 4, Longitudinal Direction, Measurement 1 (a) and Measurement 2 (b)

3.6. Scheme 5

Measurement scheme 5 is shown in Figure 31. The building ambient vibrations were recorded in the transverse direction (entrance direction).

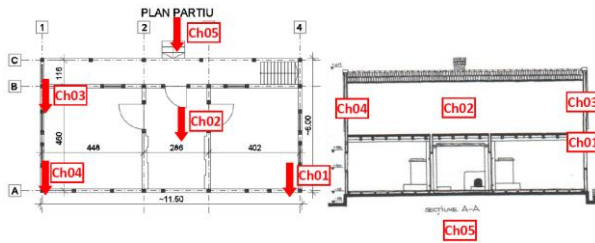


Fig. 31. Scheme 5 - sensors layout (transverse direction)

The sensors were placed on the attic slab as follows: Ch01, Ch03 and Ch04 as far as possible to the corners of the slab beside the lateral masonry walls, Ch02 central near the chimney, to the edge of the slab, and Ch05 on the ground.

In Figure 32 the Fourier amplitude spectra of the signals recorded during the two measurements in Scheme 5 are presented.

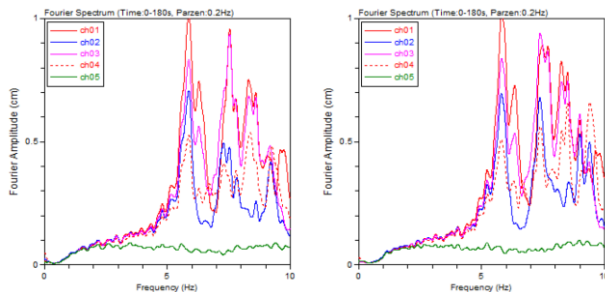


Fig. 32. Fourier amplitude spectra of velocity records for Scheme 5, Transverse Direction, Measurement 1 (a) and Measurement 2 (b)

3.7. Scheme 6

The measurement scheme 6 is shown in Figure 33. Simultaneously, the ambient vibrations of the building were recorded in the transverse and longitudinal direction (sensors oriented towards the entrance and, respectively, perpendicular to the entrance direction).

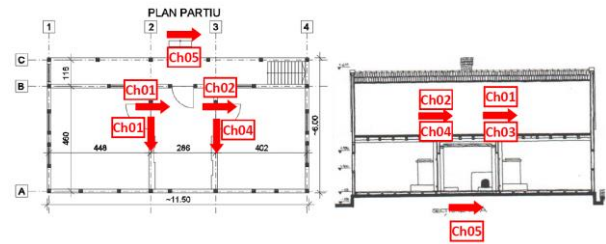


Fig. 33. Scheme 6 - sensors layout

The sensors were placed on the attic floor as follows: Ch01 (transverse) and Ch03 (longitudinal), and Ch02 (longitudinal) and Ch04 (transverse). Ch05 (longitudinal) was placed on the ground (longitudinal).

In Figure 34 are presented the Fourier amplitude spectra of the signals recorded during the two measurements in Scheme 6, in longitudinal and transverse directions.

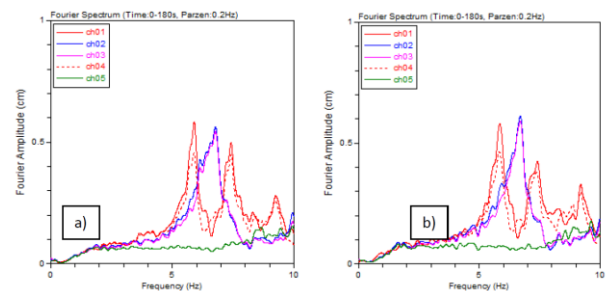


Fig. 33. Fourier amplitude spectra of velocity records for Scheme 6, Longitudinal and Transverse Directions, Measurement 1 (a) and Measurement 2 (b)

4. AMBIENT VIBRATION TEST RESULTS

Ambient vibration recordings with different sensor layout schemes and their analysis indicate, as expected, a different (transverse vs. longitudinal) directional response. The directional stability of the main spectral peaks highlighted in the different measurement schemes was observed. Generally, the spectra for the longitudinal direction are clearer than the spectra for the transverse direction.

In Table 3 are presented the frequencies corresponding to the main spectral peaks identified for each measurement scheme in part on the transverse and longitudinal directions of the building. Using their

averaged values, the corresponding average periods were obtained.

Table 3. The peak frequencies corresponding to the main spectral peaks identified

Peak frequency	f_{1T} (Hz)	f_{2T} (Hz)	f_{3T} (Hz)	f_{1L} (Hz)	f_{2L} (Hz)
Scheme 1	5.89	7.30	9.31	-	-
Scheme 2	-	-	-	6.65	9.76
Scheme 3	5.84	7.28	9.21	6.70	9.85
Scheme 4	5.84	7.45	9.39		
Scheme 5	-	-	-	6.54	9.61
Schema 6	5.87	7.40	9.21	6.73	9.78
Average frequency (Hz)	5.86	7.36	9.28	6.66	9.75
Average period (s)	0.17	0.14	0.11	0.15	0.10

The first vibration periods identified from ambient vibration tests are: 0.17 seconds for the transverse direction and 0.15 seconds for the longitudinal direction. These results characterize the building vibration with small amplitudes (elastic behavior).

5. DISCUSSION

The results agree well with the value resulting from the simplified calculation given in P100-1:2013, Annex B, p. 279:

$$T_1 = C_t H^{3/4} = 0.05 \cdot 4^{3/4} = 0.14s \quad (1)$$

where:

C_t = coefficient depending on the structure type, chosen as 0.05 (other structures than steel and concrete);

H = building height, in m, measured from the foundation level or the upper edge of the infrastructure which considered rigid. It was chosen 4 m, as found in the field investigation.

It should be noted that the actual state of the house is poor, with partial detachment of the infills from the timber (the building will be part of a museum repairing program).

Another results comparison was made with the Chinese ChuanDou houses, after the

Lushan earthquake [3] and they agree for house type C, in China, for which the structural system is similar to the Romanian one (Figure 35). Details of the houses differ in terms of connections and shape of the infill, but the overall structure with the simple principles of timber framed masonry such as flexibility of timber frame stiffened by the masonry infill panels is similar. Typologies can be compared, as they both represent timber framed masonry houses. The state of the house C when the measurements were done was that it has sustained minor to moderate damage in the infills during the Lushan earthquake. This is comparable with the state of the house studied in this paper, which presented many cracks at the interface between the infills and the timber frame (Figure 36). These cracks appear to be cause only from the foundation settlement of the house (Figure 37). The timber frame did not show damage, though.

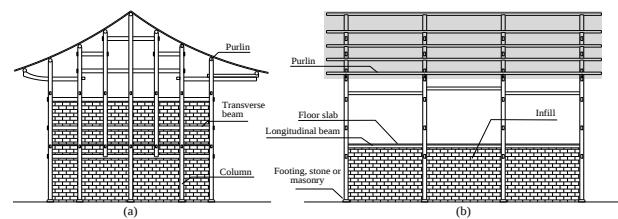


Figure 35. Structural configuration of Chuandou timber houses with infills: (a) transverse elevation and (b) longitudinal elevation [3]

Table 4. Identified dynamic characteristics of typical timber houses [3]

House		Fundamental period, T_0 (s)			
		Run 1	Run 2	Run 3	Average
C	x	0.08	0.08	0.12	0.09
	y	0.12	0.12	0.12	0.12



Fig. 36. Masonry infill separation cracks visible inside the house



Fig. 37. Cracks on the exterior of the house

6. CONCLUSIONS

This paper presents the identification of the dynamic characteristics for a timber framed masonry house, part of the National Village Museum “Dimitrie Gusti” in Bucharest, based on ambient vibration tests. The house is part of one popular typology found in Romania also in seismic areas (Vrancea) and it was for the first time to study the dynamic properties of such an example. Previous experiments were conducted on this type of house in Romania and the results of static tests under lateral load were satisfactory in terms of earthquake resistance [1]. As found all over the world, this type of house has increased deformation capacity and during moderate to strong earthquakes they rarely collapse, thus saving people’s lives.

The results of the ambient vibration tests were compared with the simplified equation for fundamental period given in the Romanian national seismic design code, and also with other existing literature studies. They all agree well.

Further steps involve using the results found in the hereby study to make numerical modeling more accurate, a necessary step due to the fact that the interaction between the two materials (timber and masonry), which are not homogenous, nor isotropic, can be quite difficult.

ACKNOWLEDGMENTS

This study was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS – UEFISCDI, project number PN-III-P2-2.1-PED-2016-1073.

The authors also thank the National Village Museum “Dimitrie Gusti” in Bucharest for the kind support and openness to the present study.

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