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TRADITIONAL BUILDINGS WITH TIMBER FRAME AND VARIOUS INFILLS IN ROMANIA

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ABSTRACT: The Romanian territory has an important seismic potential in Europe, with the Vrancea source. The most destructive seismic events that occurred in Romania in the 20th century (November 10, 1940 and March 4, 1977) have revealed a high level of seismic vulnerability of the built environment. An important part of this built environment is represented by historical buildings, including the traditional ones (timber frame and infills from various materials as brick, stone, adobe, etc.). The investigations after seismic events from November 10, 1940 and March 4, 1977, revealed that the traditional buildings did not suffer any or important damages, thus showed their particular seismic behavior.

Also, both the experience after similar seismic events from other countries as Turkey, Haiti, China, etc. and research studies from countries like Portugal, France and Japan, revealed an unexpected good behavior of such of buildings.

Therefore, in this paper the results of the investigations done on traditional buildings from Romania are presented, regarding their various constructive systems.

KEYWORDS: traditional, timber, masonry, earth and straw, wattle and daub

1. INTRODUCTION

The present paper has as goal the investigation on traditional buildings with various structural types, such as timber frame and infill masonry, which have proven over the time to be an earthquake resistant structure and with a remarkable architectural potential. Many countries in the world have structures with timber skeleton and masonry infill or other kind of infills, representing valuable heritage.

In some countries, timber framed walls are visible and were built most for aesthetical and architectural purposes (i.e. Germany, France, Czech Republic, etc.), while in others countries, they also have an earthquake resistance contribution (i.e. Portugal, Italy, Turkey, etc.) [1]. Timber framed masonry (TFM) system is also being presently used as reconstruction solution of areas that were destroyed by major earthquakes (i.e. Portugal, Pakistan) [1].

In all countries where these type of buildings are found, they were built without being based on any design regulation, but there are some situations (i.e. Turkey), where even if they date since 15th century, it was observed how people adapted their houses to local seismicity and made the structure as earthquake resistant as possible. Their behavior under earthquakes could be seen after some strong events as Kocaeli 1999, Kashmir 2005 or Haiti 2010. In the Izmir seismic event it was noticed that even if their damage state was advanced, at least they still stood up, while other types of structures fell [2]. In some situations, buildings with timbered masonry showed few damages (minor cracks, plaster falls, etc.), while poorly executed reinforced concrete structures near them collapsed or showed extensive damage [3].

Experimental studies were carried out for different configurations [4, 5, 6, 7, 8]. The common result was confirmation of the excellent behavior of in plane masonry infilled timber frames under cyclic loading, which is characterized by a significant deformability because of the timber's confinement for the masonry infills.

2. MOTIVATION

In Romania in the last years the studies on earthquakes produced an increase in the awareness of the population and authorities. For example, the most seismic exposed cities from Romania are Bucharest and Iasi. In Bucharest, according to seismic code P100-1/1992 the a_g (maxim expected seismic ground acceleration) was 0.20g and today, according to code P100-1/2013 a_g is 0.30g (50% increasing) and for Iasi city, it was also 0.20g and increased to 0.25g (25% increase).

After the two major earthquakes that occurred in Romania on 10 November 1940 and 4 March 1977, there is not much information about traditional buildings with timber frame and masonry infill or other infills which suffered complete collapse or major damages. So people

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generally assume that traditional residential houses behaved well during seismic events.

Today, more owners want to build such traditional houses with infilled timber frame structure, because they are easy to build, relatively cheap, ecologic, aesthetic and, the most important, as the recent studies have shown, they have a satisfactory seismic resistance and especially a high ductility, aspect also revealed by the past seismic events. In this moment, in Romania, for these type of structures there is no specific design method specified in the national Code P100-1/2013, and also no evaluation procedures for this existent type of building.

In Romania there are places where the buildings with infilled timber frame structure are inspired by the German "Fachwerk" traditional buildings, as there are in Sinaia city and its surroundings (Fig. 1).

Figure 1: *Old(left) and new (right)"Fachwerk" architecture in Sinaia city, Romania [1]*

Also, there are other places, in rural areas, where people build this type of structure due to the local tradition of the area, such as Buzau county area.

It is surprising how people without engineering knowledge started to build their houses using this system due to its earthquake resistance and how it became a traditional type in many villages from Romania (Fig. 2).

Figure 2: *Traditional infilled timber frame house from Buzau county [4]*

It is obvious that traditional is actually the result of the adaptation of tens or hundreds of years to local seismic culture [9].

Due to technical features (satisfactory seismic resistance and high ductility) and practical benefits (easy to build, economic, etc.), the traditional infilled timber framed buildings can be one alternative to conventional and modern type of buildings (RC frame, walls or confined masonry structures, etc.) for all kinds of owners (rich and poor).

Thus, this fact is also confirmed by the actual use of this structure type by regular people that, despite of their lack of engineering knowledge, adopted it because they saw that neighbors having same type of house didn't have problems in the past earthquakes (from personal communication with villagers during field investigation).

This situation is found at least in Romania, where engineering studies regarding behavior of infilled timber frames only recently started and so far no design procedure was issued with this subject.

Due to this reason, in Technical University of Civil Engineering Bucharest, a research project was started, to test an evaluation method currently under development and to experimentally study seismic resistance of traditional residential buildings, in order to validate the evaluation method.

In this paper, the first part of the project is presented, consisting of field investigation and proposal of test specimens for the next step of the project.

3. FIELD INVESTIGATIONS

Two geographic areas from Romania, that are significantly exposed to earthquake (Viperesti from Buzau county with a_g = 0.40g and Sinaia from Brasov county with a_g = 0.30g) (Fig.3), were chosen for the field investigation. Traditional buildings, similar to those from other countries where they have been previously studied (i.e. Portugal, Japan, Turkey, Italy, etc.) [1, 2, 10], were found and observed.

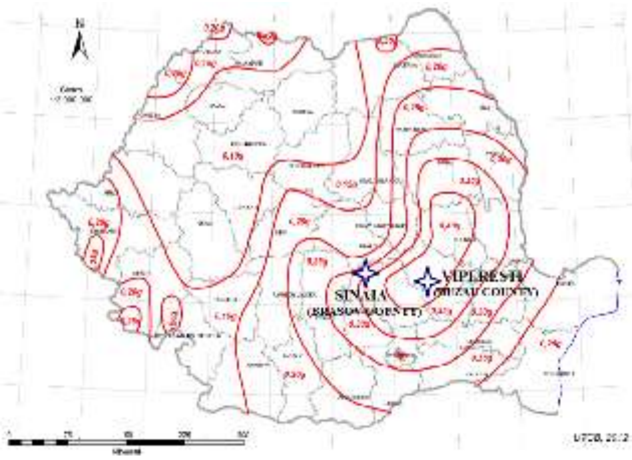

Figure 3: *Romanian zonation of pick ground seismic accelerations a_g (according to national seismic code P100-1/2013)*

3.1 Investigation methodology

In order to obtain the necessary information for the study of Romanian traditional buildings, the field investigations consisted in the following steps:

– request of the help of local authority (mayor, mayor counsellors, city hall employer, etc.);

– the representative areas from each village of Viperesti commune and Sinaia city were selected, where representative traditional houses (the old and new ones) could be found, and they were identified and marked on the map (Fig. 4), with the help of the mayor and his counselors, as building C_1, C_2, …, C_n, etc.

Figure 4: *Example of buildings' marking investigated on field*

– for each house three technical investigation data sheets were filled in: first containing information about the owner, the type of structure, structural description and particular features [11]; the second containing information about nonstructural and structural damages caused by earthquake and/or other actions (differential settlement ground, variations of humidity and temperature, biologic attack) [11] and the third containing general information about the Viperesti and Sinaia areas (natural environment, socio-economical profile, the culture, financial and materials resources, etc.) [12];

– it was discussed with the authorities and local inhabitants about the history of the built environment and other important technical information (access to the materials, the tradition artisans, the tradition of the structural systems and the reasons they chosen the structure type, etc.);

– a photo survey was done for each house;

– it was discussed with the owners about history of the house:

- when the house was built (period/year);
- with who they built it (local artisans as: quarries, carpenters, masons, etc.);
- how they have purchase the materials (wood, clay, stone, brick, etc.);
- the manner that they built (technological phases and materials used);

– based on which criteria they selected the structural system they built (tradition, easy to build, economic and ecologic, seismic resistant, etc.);

– the damages after earthquakes or other natural / anthropic causes they observed;

– other particular information.

3.2 Field investigation in Viperesti area

3.2.1 Generalities

Viperesti is an area located in West of Buzau county and it consists of the following villages: Viperesti, Tronari, Ursoaia, Palici, Rusavat and Muscel (Fig. 5);

Figure 5: *Geographical location of Viperesti area*

[on Google maps]

From geographically point of view, Viperesti area is located on the base of *Carpathians* Mountains and valley of Buzau river; also it has 233 m altitude and an area of 66 km^2. Viperesti has a population consisting of around 3.500 inhabitants.

3.2.2 Brief history of Viperesti area

In Rusavat village the traces of the first dwellings from Viperesti area were found; the existence of Viperesti and Muscel villages were first documented since 1534. Also Ursoaia village it was mentioned from 1733 [13].

Archival documents reveal the existence in Viperesti area of a quarry sand, gravel and earth for bricks, since 1920, as the main resource of materials for constructions.

Near Viperesti area, there is Berca commune with an old tradition of bricks manufacture. In 1970 was found the first and modern bricks factory in the area. Today, the bricks factory from Berca commune is one of the most important brick maker from South-East of Romania. The clay for bricks is obtained from Berca quarries.

3.2.3 Structural typologies found in Viperesti area

After the field investigations three main structural systems were found as below:

- type 1: timber frame and brick masonry infill (Fig. 6 and Fig. 7);

Figure 6: *Building with timber and brick masonry infill structure, built in around 1925 with unreinforced masonry, and reconstructed after November 10th, 1940 major earthquake with timber frames and infills– main façade*

Figure 7: *Building with timber and brick masonry infill structure, from Viperesti commune, Romania, built in around 1925 with unreinforced masonry, and reconstructed after November 10th, 1940 major earthquake with timber frames and infills – backyard façade*

- type 2: timber frame and earth (clay) with straw infill (Fig. 8 and Fig. 9);

Figure 8: *Building with timber and earth with straw infill structure, from Viperesti commune, Romania, built in around 1930-1940 – main façade*

Figure 9: *Building with timber and earth with straw infill structure, from Viperesti commune, Romania, built in around 1930-1940 –infill detail*

- type 3: timber frame and wattle & daub infill (Fig. 10 and Fig. 11).

Figure 10: *Building with timber and wattle and daub infill structure, from Viperesti commune, Romania, built in around 1910-1920 – main façade*

Figure 11: Building with timber and wattle and daub infill structure, from Viperesti commune, Romania, built in around 1910-1920 – detail infill

3.2.4 Structural description of each typology

Foundations for all three typologies of traditional buildings

The old traditional buildings have stone foundations (generally damp river rock). These type of foundations are made by massive stones (laid up one over the other), generally without any mortar or lime or/and cement/clay mortar (Fig. 12). The new houses have concrete foundations.

Figure 12: *Stone foundation specific for the traditional buildings, the old ones*

Structural walls

For type 1, the walls are made of timber skeleton composed of horizontal elements (superior stringers with around 15x15÷20x20 cm cross section, which have a confining role to connect the walls and inferior stringers with same cross section, to distribute the load to the foundations), vertical elements (timber columns with cross section varying from 12x12 to 20x20 cm), timber bracings with around 10x10÷15x15 cm cross section and brick masonry infill (Fig.13);

For types 2 and 3 the timber skeleton structure is similar as it is described above for type 1 structure, the difference is that the infill for type 2 consists of earth and straw (Fig. 14) and for type 3, the infill is made of wattle and daub (Fig. 15).

The wood used for structural elements is generally pinewood, oak and locust/ acacia tree, etc., and the earth (clay) used for infills is obtained from local quarries.

Roof structure and covering

The structure of the roof is made of pinewood and the roof covering is made by timber shingle and ceramic tile.

The daub

The daub is generally done by earth and straw mortar or lime and/or cement mortar.

Figure 13: *Description of the type 1 structure – main specific structural elements*

Figure 14: *Description of the type 2 structure – main specific structural elements*

Figure 15: *Description of the type 3 structure – main specific structural elements*

3.2.5 Important general field observations

The wood used is harvested in a certain period of the year (February), when the humidity inside the trees is the lowest, and after that it is left to dry almost 2 months.

The clay used for brick and mortar is a special one with good plasticity and workability. The clay mortar is generally mixed with straw.

The timber elements are bound with nails and/or clamps and various types of cross-halving and/or mortise-tenon connections (Fig.16 and Fig.17).

Figure 16: *Clamps used for timber elements connections*

Figure 17: *Nails and cross-halving for timber elements connection*

3.3 Field investigation in Sinaia area

Sinaia city is famous for its heritage buildings. The Peles Castle (Fig. 18) dates since 1914 when its construction was finished. For building the castle, workers from Germany and Austria were enrolled, to be able to achieve the Fachwerk architecture that was designed by the architect.

Figure 18: *Peles castle, Sinaia city*

The castle is made of unreinforced masonry at the first floor, and the upper storeys are made of timber and brick masonry infill. At the time of the construction, Romania didn't have a seismic design code, so the reason this structural system was chosen is more likely to be due to architectural reasons.

Also, exterior construction details, like overlapping a column along the story height (Fig. 19) indicates that the seismic resistance was not the primary importance when it was built the castle.

Figure 19: *Overlapping of columns along the height of the upper story*

After finishing the castle's construction, the workers remained to live in the area, this explaining the specific architecture that can still be seen nowadays (Fig. 20) [personal communication], although new houses are made of other materials. The workmanship with corresponding construction details got lost in time and the current seismic design code does not allow construction of this type of house anymore, due to lack of design method for such a building.

Figure 20: *Residential house in Sinaia city, having Fachwerk architecture*

4. PROPOSED TEST SPECIMENS

Based on the field investigations, it was decided to test two specimens from each structural type identified. The test specimens will have the dimensions as in Fig. 21, Fig. 22 and Fig.23.

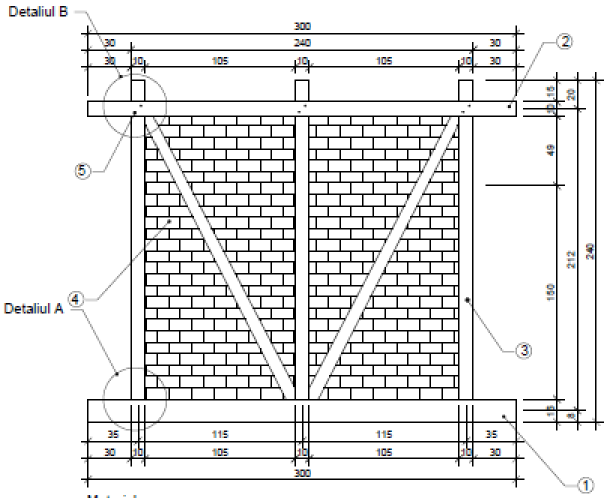

Figure 21: *Specimen S1 (from type 1)- timber and brick masonry infill structure: 1 – inferior stringer; 2- superior stringer; 3 – column; 4 – masonry infill; 5 – iron nails and cross – halving connections of timber elements (columns and stringers)*

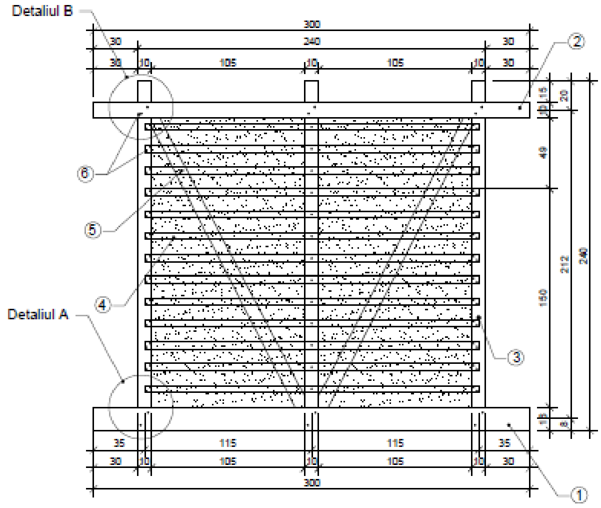

Figure 22: *Specimen S2 (from type 2) - timber and earth with straw infill structure: 1 – inferior stringer; 2- superior stringer; 3 – column; 4 – timber strips; 5 –earth and straw infill; 6 - iron nails connections of strips and cross – halving connections of timber elements (columns and stringers)*

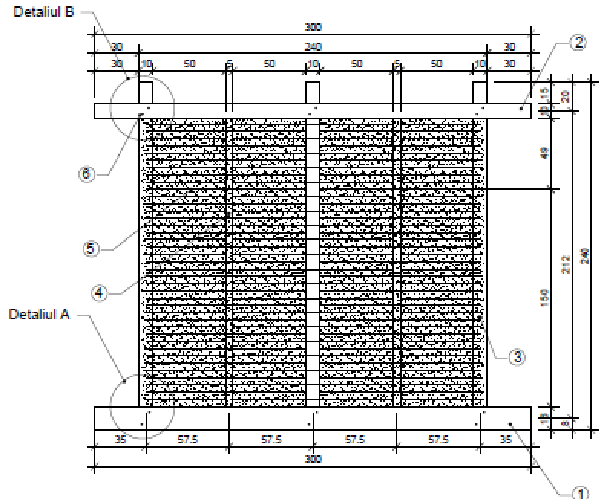

Figure 23: *Specimen S3 (from type 3) - timber and wattle&daub infill structure: 1 – inferior stringer; 2- superior stringer; 3 – column; 4 – wattles; 5 – daub (earth and straw infill role); 6 – iron nails and cross – halving connections of timber elements (columns and stringers)*

4.1 Technical description of specimens

Timber skeleton for S1 and S2 specimens is composed by vertical (columns), horizontal (stringers) and bracing timber elements (pinewood) with 12x10 cm cross section (generally). Specimen S1 has masonry infill (bricks 24x11.5x6.3 cm and lime & cement mortar). Specimen S2 has earth and straw infill and specimen S3 has wattle and daub infill (huzel or willow wattles).

The maximum in-plane dimension of specimens it is 300 x 240 cm, and the scale was slightly reduced so they can fit into the reaction frame.

The connection will be mortise-tenon type with nails for the bottom ones and for the upper ones cross – halving type with nails will be used (Fig. 24). The brick will be traditional one, made from the special clay from

Viperesti area quarries. The bracing will have an angle of 45°.

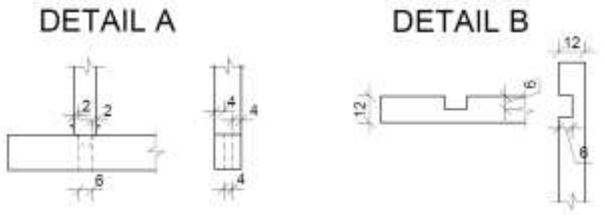

Figure 24: *Mortise-tenon and cross halving connections*

4.2 Test setup description

Tests will be conducted on a reaction frame in a static cyclic regime. Test setup is shown in Fig. 25. The CUREE Caltech loading protocol [14] developed for timber frames will be used (Fig. 26). The choice of the protocol is made considering that residual deformation has a significant influence on timber frames and also to be able to compare the test results with the previous experiments.

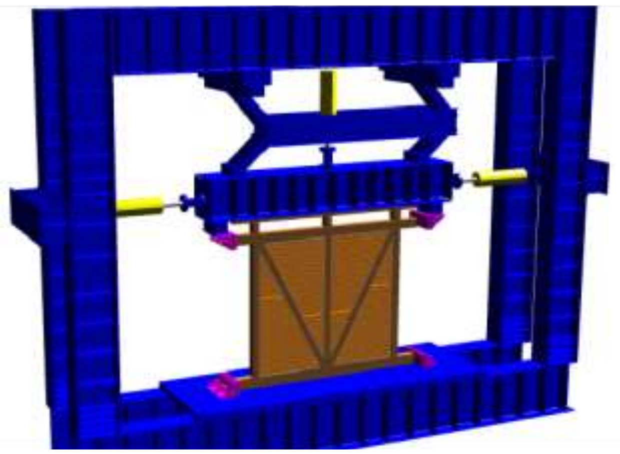

Figure 25: *Test setup for all the wall types*

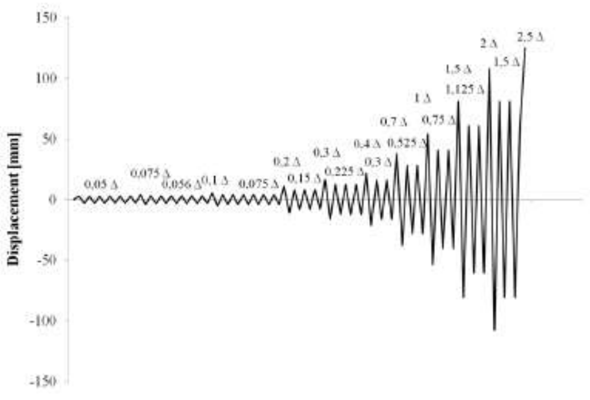

Figure 26: *Proposed loading protocol [10, 14]*

Axial load will be applied at the top of the wall, with the amount corresponding as much as possible to the real situation, representing the roof's weight.

5. CONCLUSIONS

As it was observed in other countries, after important earthquakes, most of the infilled timber frames are resilient enough so they protect the lives of their inhabitants. For this reason, the field investigation is of tremendous importance in Romania, being one of the most seismic affected countries in Europe. The field investigation aimed at finding the characteristics of the specific infilled timber frames in Romania and further be the base of an experimental and analytical study.

Another finding in this field investigation was the confirmation that the reason of choosing the structural system of Peles castle and surrounding residential houses with timber frames and clay brick masonry infills was not for seismic reasons, but architectural.

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