COMPONENTS INTERACTION IN TIMBER FRAMED MASONRY STRUCTURES SUBJECTED TO LATERAL FORCES

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ABSTRACT

Structures with timber framed masonry represent a special typology that is frequently found in Europe and other countries of the world. They are traditional buildings, non-engineered, which showed an unexpected redundancy during earthquakes where reinforced concrete buildings (improperly constructed) collapsed. In the paper, aspects regarding the interaction between timber elements and masonry are mainly addressed, that were observed both in experimental studies, but also in the in situ seismic behavior of this type of structure during important earthquakes.

Keywords: masonry; timber, interaction; earthquake

REZUMAT

Structurile cu schelet din lemn şi umplutură din zidărie reprezintă o tipologie aparte, care este des întâlnită atât în Europa, cât şi în alte ţări din lume. Ele sunt case tradiționale, construite fără cunoştințe inginereşti, dar care au dat dovadă de o redundanță neaşteptată în timpul cutremurelor, acolo unde clădiri din beton armat (executate neadecvat) s-au prăbuşit. În articol sunt abordate in principal aspecte legate de conlucrarea dintre lemn şi zidărie, observate prin studii experimentale, dar şi prin comportarea acestui tip structural în timpul unor cutremure importante.

Cuvinte cheie: zidărie; lemn; interacțiune; seism

1. INTRODUCTION

Timber framed masonry structures represent a traditional type of building that is usually non-engineered and built with no special workmanship, according to local building culture. Nevertheless, there are some examples that were enforced by law as earthquake resistant structures, like the *pombaline* buildings in Portugal, or *casa baraccata* in Calabria region (2).

However, in other countries, even though they were built only based on the aesthetic trends in those times, they withstood strong earthquakes, in which other modern (poorly executed) building types suffered a total collapse (Fig. 1) (4, 5).

Fig. 1. *Gingerbread* houses in Haiti, after the 2010 earthquake (6)

2. SEISMIC BEHAVIOR OF TIMBERED MASONRY BUILDINGS

The structure of these buildings is composed of two different materials. One is the timber, that carries the horizontal forces (seism or wind), and the other one is the masonry, that mainly carries the gravity loads, but it also dissipates energy through joints sliding after the mortar cracks. It is interesting to observe how the timber elements and masonry work together, both in experimental studies (1), and the earthquake behavior of this type of structure.

The contribution of each component for this case (timber, masonry), when the whole structure is subjected to lateral forces, was observed in experimental tests carried out within REABEPA program at Instituto Superior Tecnico (1). The tests showed that stiffness in the approximately linear segments (load between 0 kN and ca. 10 kN) was 3 times higher for the masonry wall (Fig. 3), than for the timber frame (Fig. 2).

Fig. 2. Timber frames – TF (left) and masonry walls – MW (right) (1)

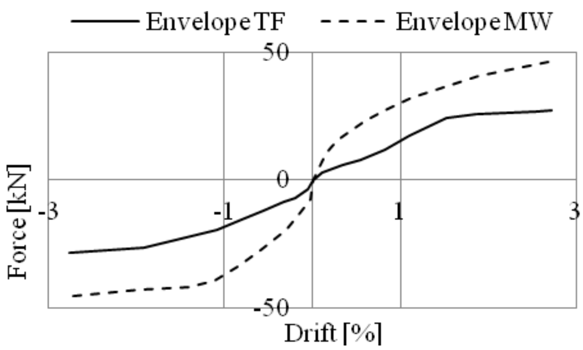

Fig. 3. Force – relative displacement diagrams (envelope) for timber frame, respectively, masonry wall

The seismic behavior of these buildings was also observed in strong earthquakes. Though the system seems weak, this might be exactly the main advantage, because the timber flexibility allows for large deformations; moreover, the buildings being usually two storeys high, they are light, but stiff, because of the masonry infill.

Even though the experimental program could not reproduce exactly the real behavior, the unexpected redundancy of this structural system was proved by the damages observed after various earthquakes (Izmit 1999 (4) or Lefkas 2003 (7)). Another confirmation is the fact that after 1755 Lisbon earthquake, the government of that time enforced by law the construction of *pombaline* buildings, that had timber framed masonry structures. The same was done by the Italian government after the Calabria earthquake in 1783. More recent evidence is given by the fact that, after Pakistan 2005 Kashmir earthquake, a reconstruction solution is actually the use of this system (Fig. 4).

Moreover, after the Haiti 2010 earthquake the *gingerbread* houses (Fig. 1) did not collapse even though they were severely damaged, unlike the poorly executed RC structures.

Fig. 4. Housing reconstruction in earthquake affected areas in Pakistan (9)

Romania is located in a seismic prone area, and here timber framed masonry houses can be found, as well. Fig. 5 shows a house in Buzau County, where this type of structure was most probably chosen precisely for its seismic resistance properties, as the area is very close to the Vrancea source. The specific of the local construction practice consists in the use of only one diagonal, as compared to timbered masonry in other countries, where generally two diagonals are used. It should be noted that the house is symmetrical, even if it is a non-engineered building, and it may not have two diagonals in the same frame. However, there are diagonal timber elements for both directions, so that when one is in compression the other one is in tension. Thus, during an earthquake, diagonals are able to carry horizontal forces in both directions.

Fig. 5. Traditional house in Buzau County

3. OBSERVED INTERACTION OF STRUCTURAL COMPONENTS

For timber masonry infilled frames, at low levels of in-plane force, the frame and the infill panel will act in a fully composite fashion, as a structural wall with boundary elements. As lateral deformations increase, the behavior becomes more complex, as a result of the frame attempting to deform in a flexural mode, while the panel attempts to deform in a shear mode. The result is the separation between frame and panel at the corners on the tension diagonal and the development of a diagonal compression strut on the compression diagonal. The separation may occur at 50 to 70% of the ideal lateral shear capacity of the infill for concrete frames, and at very much lower loads for steel frames (8).

The separation of the masonry from the timber frame is similar to the steel frame situation, as it was observed during the experimental program. Separation occurred very early in the loading process, starting at the inferior masonry triangles in early loading cycles and ending, at failure load, with the separation of the superior triangle adjacent to the middle horizontal timber element (Fig. 6).

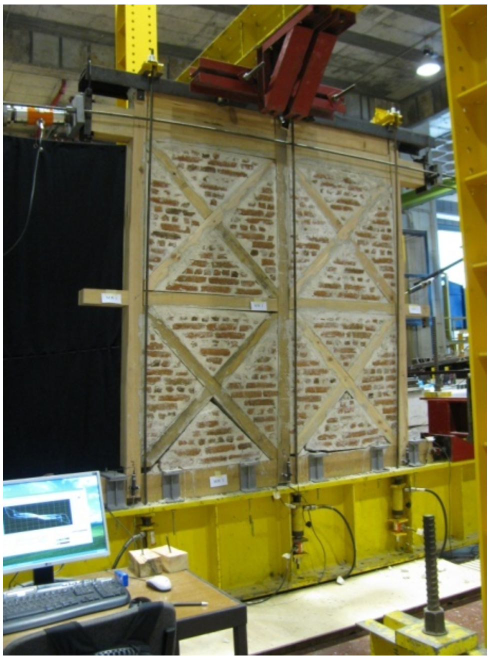

Fig. 6. Crack opening in lateral loading

A very important factor is the strength of the mortar. For the traditional houses presented before, and which were built hundreds of years ago, lime mortar, which is very weak, was used. As a consequence, the mortar fails first, and not the masonry, thus dissipating energy when experiencing earthquakes through sliding of bricks. The masonry used for these tests consists of ceramic debris and of cement-lime-sand mortar with a volume ratio of 1:2:6. Although ancient mortars were only composed of lime and sand, cement was added in these cases to ensure a faster cure (lime mortars need several months or years to cure through the carbonation process) (3).

Bricks strength is not really important as even in this situation, when using debris bricks, they did not failed in neither shear nor tension.

It was observed that the timber diagonals do not work in tension, when they actually detach from the joint (Fig. 7). When they are compressed, they usually come back to the initial position, without experiencing out of plane behavior. This can be explained by the presence of masonry, as in previous tests with only pure timber frame, there was a significant out of plane behavior of timber diagonals.

Fig. 7. Diagonal timber element detaching from left inferior joint

Masonry mainly increases the stiffness of the panel, as it can be seen in Fig. 3. It is interesting how the whole element behaves when subjected to lateral force, as only the inferior masonry panels suffer shear failure, the other ones remaining almost intact (Fig. 8).

Fig. 8. Separation of masonry from timber frame when subjected to shear stress

4. ATTEMPTS TO INCREASE INTERACTION BETWEEN STRUCTURE COMPONENTS

As this type of building is quite largely spread and the system is still used nowadays, either because it is known to be seismic resistant or because its aesthetical value, some interesting aspects regarding the increasing of interaction between elements should be pointed out, as observed in Haiti's *gingerbread* houses (Fig. 9).

As it can be seen in Fig. 9, within the masonry layers there are some barbed wires embedded in the mortar joints. As simple as the idea is, as useful it was proved to be. This kind of practices is encouraged, using local, easy to get materials for masonry reinforcement. For this particular example, the barbed wire is appropriate since it is galvanized, easy to be laid in the mortar joints of the masonry and it is widely used in local agriculture (8).

Fig. 9. Barbed wire used as reinforcement for masonry (6)

For this construction type, rebar reinforcement cannot be used, as it would imply its anchorage in the timber frame. This is not a reliable solution, as it means the weakening of the timber section and, additionally, the use of lime mortar favors the corrosion of steel.

Another example of interaction increase attempt is the case of *pombaline* buildings. Fig. 10 shows how nails were used on the timber elements and embedded in mortar when masonry was built for the experimental program on simple module (St. Andrew's cross) of *pombaline* buildings within REABEPA project.

Fig. 10. Increasing the bond between materials by the use of iron nails (3)

5. CONCLUSIONS

The structural capacity of these type of structure when subjected to lateral forces is difficult to be predicted by calculation, as it involves three materials (timber, bricks, mortar) and each of them behave differently.

The building's design codes of Romania do not provide information related to timber framed masonry structures. It is difficult to apply the timber structures design code or the masonry code for this particular case.

Thus, considering that it is still built nowadays, the importance of experimental studies on this structural type is obvious. Moreover, being a traditional non-engineered construction, often preferred by people in seismic prone areas in Romania because of both earthquake resistance and economic reasons, the subject deserves more attention in terms of theoretical and experimental research.

Even if the timber has actually a limited interaction with the masonry, it is clear that they "help" each other. The timber carries the horizontal forces (seism or wind), while the masonry carries mainly the gravity loads, also dissipating energy through joints sliding after mortar cracking.

It was observed during experimental tests that the timber diagonals do not work in tension, when they actually detach from the joint. However, when they are compressed they usually come back to their initial position, without experiencing out of plane behavior.

Local seismic culture has a clear and important influence, as it was observed, for example, in Romania, where timber framed masonry houses do not have diagonals in the same frame, being separate. However diagonal timber elements exist for both directions, so when one is in compression, the other one is in tension, such that during an earthquake they can carry horizontal forces in both directions.

Looking at the *gingerbread* houses in Haiti or *pombaline* buildings in Portugal, it is clear that increasing the interaction between the structure components is possible, using local, easy to get materials, as barbed wire or nails. Even if the technologies have advanced greatly nowadays, there is still to be learned from the past construction practices and, in many other situations, the simplest ideas prove to be sometimes the most useful and handy.

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