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Behavior of traditional timber frames under reverse-cyclic loading

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ABSTRACT: Traditional timber frames in Turkey especially the ones in Safranbolu region consist of several configurations and several infill materials. The configurations include simple frames and braced frames. The infill materials include adobe, stone, brick or wood. Although the frames have a wide variety they do not have specific calculations and design rules. They were designed according to the knowledge and experience of the skilled workers. Therefore, the behaviour depends on workmanship too much. In this study two full scale timber frames of yellow pine and fir were prepared considering the abovementioned discussions. Each frame have the same geometry. They are both 3.3 m high and 3.6 m wide. They do not include any openings. Frames have nailed connections and prepared by the skilled workers. Tests were performed both on bare frames and frames with infills. The yellow pine frame had adobe infill whereas the fir one had wood laths nailed to the timber framing called "şamdolma". Results of the tests revealed that energy is dissipated at the connections especially at the nails on the base. The weakest element in all frames was the nailed connections. Both infills increased the strength.

1 INTRODUCTION

The hybrid construction of the Traditional Ottoman timber frame hımış houses consist of a masonry base story and timber frame upper stories with infill or covering. The masonry base story is generally made of rubble stone masonry or adobe with timber lintels in regular intervals as well as of cut stone or alternating layers of stone and brick (Eldem 1984, Kafesçioğlu 1955). The timber frame upper structures are constructed by using vertical and horizontal elements, and diagonal braces, where the intervals between these timber elements are filled using an infill material, such as brick, timber, adobe or stone (Eldem 1984). The choice of infill material depends on the material availability of the region. The timber frames can also be covered by using laths of different width. An example to these covering methods, which was first appeared in the 18th century, is called bağdadi, where wooden laths were nailed onto the timber frame, and then plaster was applied (Kuban 1995).

The general form and design principles of the Ottoman houses were successfully applied to a vast area (in combination with local housing traditions), such as Balkan countries (except southern Greece and Dalmatian coasts), as well as Syria, Egypt and Iraq, regardless of drastic differences in climate (Kuban 1995, Sözen 2001). Building methods utilized for the construction of a timber Ottoman house has evolved so as to have very simple details, especially in terms of connections. This brings also along the speed and easiness in reconstruction of houses after a devastating fire sweeps them off, as frequently occurred throughout the history, especially in Istanbul (Günay 1998, Kuban 1995).

In many parts of the world, the seismic resistance of timber frame structures, whether they are modern or historic, has been observed and appreciated. After the 1755 Lisbon Earthquake, a new type of

braced half-timber construction called gaiola was developed against seismic risk (Tobriner 2000). D. Eginitis, the director of the Observatory of Athens stated clearly that timber frame structures “resisted the earthquake amazingly” after 1894 Istanbul Earthquake (Şahin Güçhan 2007).
After 1999 Kocaeli and Düzce Earthquakes, the hımış structures had no or little damage. The statistical study conducted after the earthquake is remarkable so as to betray the difference between the numbers of heavily damaged reinforced concrete structures and timber frame ones (Gülhan and Özyörük 2000). Even though the detailed inventory made according to the villages around Düzce gives more scattered information, it still indicates the seismic resistance of timber frame structures (Tobriner 2000).

On the other hand, there are also several post disaster observations reporting poor performance of timber structures. These damages are generally claimed to be based on poor maintenance, biological degradation of timber and improper connections. After 1994 Northridge Earthquake in California in USA, in many multi-story wood frame apartment blocks, the weakest first story was damaged, which then caused the collapse of the whole structure (Rainer and Karacabeyli 2000). Lam et al. (2002) also underlines the loss of life and property occurred due mainly to wooden structures. This situation was attributed to poor quality control, improper nailing, etc.

After 1995 Kobe Earthquake in Japan, the majority of the timber structures constructed before or during 2nd World War were collapsed, however newer timber constructions were perfectly standing. Therefore, one should consider the effect of deterioration and aging as well as bad or insufficient maintenance (Rainer and Karacabeyli 2000).

In this study two full scale timber frames (from Safranbolu (included in the UNESCO World Heritage List since 1994), a district of the city of Karabük, Turkey) of yellow pine and fir were prepared to determine their performance under the reverse-cyclic lateral loads. Each frame was first tested without having infills. After that, frames were repaired, infill materials were placed and tested again to see the effect of infill materials on the behaviour.

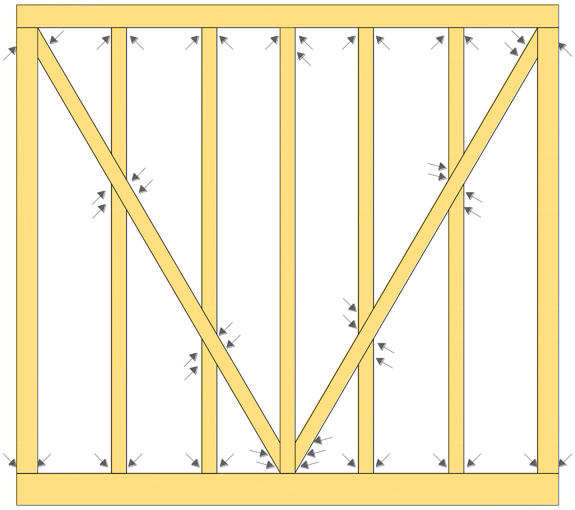
2 TEST PROGRAM

Two test frames were built according to the real examples available in Safranbolu. One of the frames is built from yellow pine and the other from fir. Both frames have the same geometry as shown in Figure 1. They are both 3.3 m high and 3.6 m wide. They do not include any openings. Frames have nailed connections on which the number and orientation of nails are also given in Figure 1.

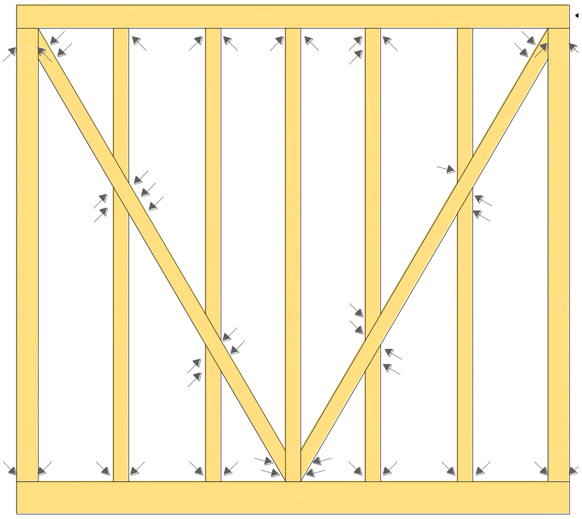
Each frame is tested in-plane under reverse-cycling loading. In the test program the procedure below was followed. The procedure also marked on Figure 2.

1. Frame is placed on a steel base and bolted connection is made between timber and base in order to prevent sliding at the base level
2. Steel frames are placed at middle of the timber frame and both ends and both faces of the timber frame and those frames are tied together with steel bars. They are also connected to the rigid wall prevent any out-of plane behaviour.
3. Roller are placed between steel frames and top of the timber frame to allow the timber frames freely move only in-plane
4. Equivalent vertical slab loads are placed on top of the frame and secured.
5. An hydraulic jack with a load cell on the tip is placed at the top right corner of the frame to give the reverse-cyclic loads.
6. Two horizontal LVDTs - one at the top left corner and the other one at the top right corner - are placed to monitor the lateral deflections under each lateral load cycle.
7. Two LVDTs - one at the bottom left corner and the other one at the bottom right corner - are placed to see the movement at the base. This one used because the final tip deflection will be the difference between top and bottom deflections.
8. Two LVDTs are placed diagonally to see the shear deformations.

9. After placing all the materials and devices the reverse-cyclic load procedure is started. Up to the maximum load level load-controlled procedure is followed. Beyond the maximum load strain-controlled procedure is followed to see the descending part of the curve.



a) Yellow pine



a) Fir

Figure 1. Test frames and number and locations of nails

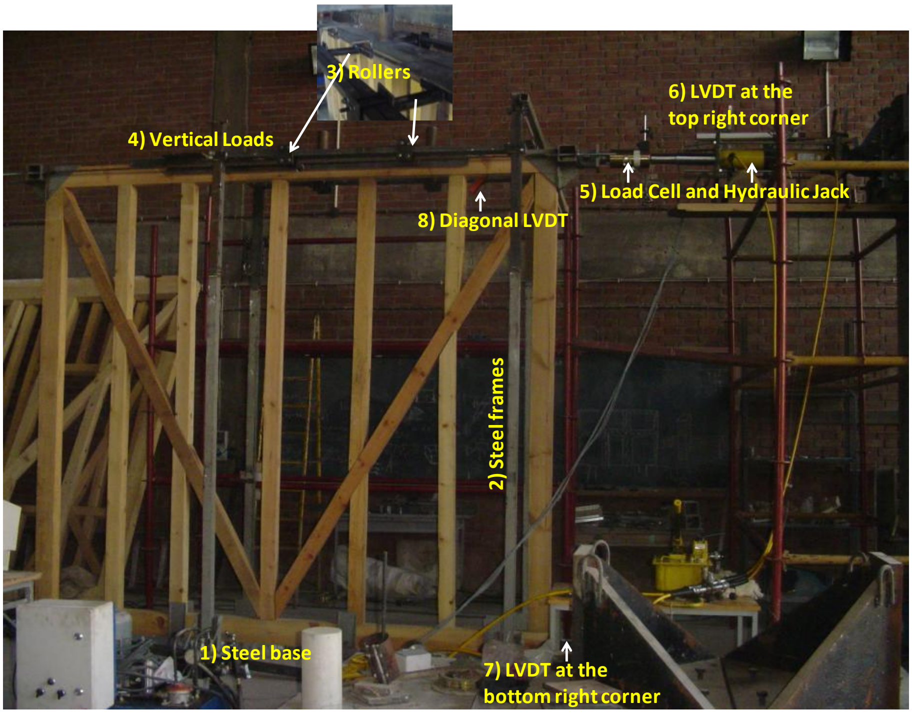


Figure 2. Timber frame in the test setup and details of the test setup

Frames are first tested without having any infill to see the reference behaviours and the difference in the behaviour of yellow pine and fir. The load-deflection behaviours are recorded via data acquisition system.

3 RESULTS AND DISCUSSION

Bare frame tests were first performed to record the reference behaviours. Envelope curves of these tests are given for both frames in Figure 3. As it is seen both frames showed almost the same behaviour - same maximum load and same displacement which indicates that material either yellow pine or fir is not important in such structures because behaviour depends on the quality of the connections. Since frame elements were connected each other by means of nails, flexible connections, which allow both transverse displacement and rotation, were created. From the failure pictures given in Figure 3 it is clear that failures were due to the nail slippage at the critical locations. Since nails slipped off, the connection was lost at those regions and frame became unstable due to the lack of determinacy.

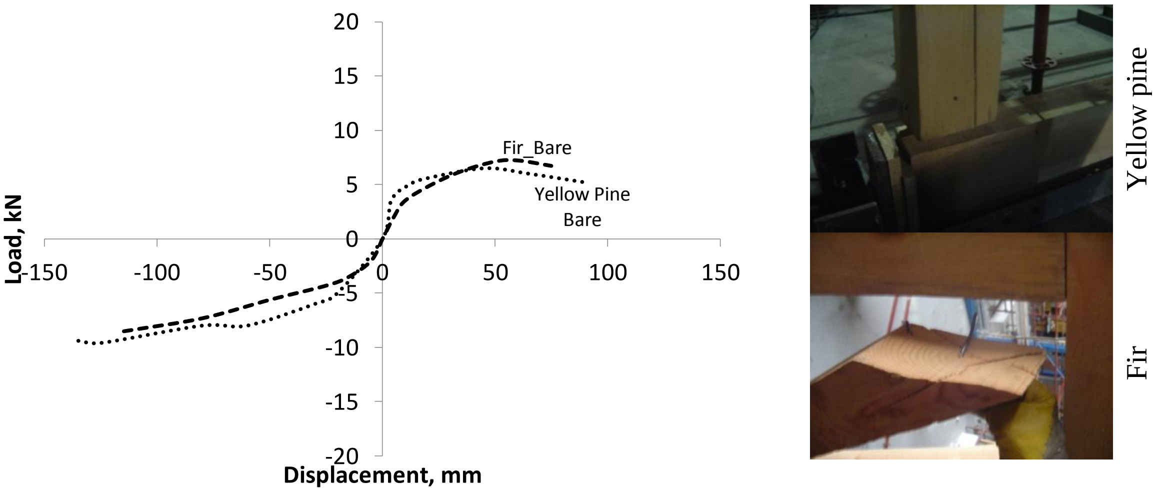


Figure 3. Load-displacement curves and failures of bare frames

After bare frame tests, connections of both frames were repaired by local construction workers and yellow pine frame was infilled with adobe whereas fir frame was covered by wood whose technique is called "şamdolma" (Figure 4). In "şamdolma" technique wide laths were nailed at both faces of the frame. After the adobe infill and wood covering both frames were plastered by a special mud made from sand, lime and water (Figure 4).

No design or calculation was made during the repair and infilling. Details and design depend on the skills of the local construction workers. Both frames are tested under reverse-cyclic loading to see the difference in the behaviour when compared to the bare frames. The other comparison is made to see the effect of adobe infill and wood covering on the behaviour.

Results are illustrated in Figure 5. It is seen that if the frames are filled with adobe or they have şamdolma technique, their behaviour enhance considerably. Load carrying capacity is increased without any decrease in displacement capacity. The adobe infill and wood covering increases the lateral load strength of a timber frame, by an order of 1.81 and 2.19 times, respectively. The values are the average of push and pull cycles of lateral loads because behaviour under pushing load is different from the pulling load.

The frame with adobe infill showed no immediate decrease in strength, however there is sharp decrease in şamdolma in both loading ways. This can be attributed to the stiffness increase which is great in adobe infill. Adobe infill and wood covering also increases stiffness, in the order of 2.2 and 4.0 times, respectively.

From the Figure 5, it is seen that energy dissipation capacity significantly increases with infill or covering. Since strength increases without any reduction in displacement capacity, energy is dissipated more as compared to the bare frames. Energy dissipation capacity increased 2.1 times in adobe infill yellow pine frame and 2.5 times in fir frame with wood covering.

Yellow pine frame with adobe infill | Fir frame with wide lath coverings

Figure 4. Frames with infill and coverings

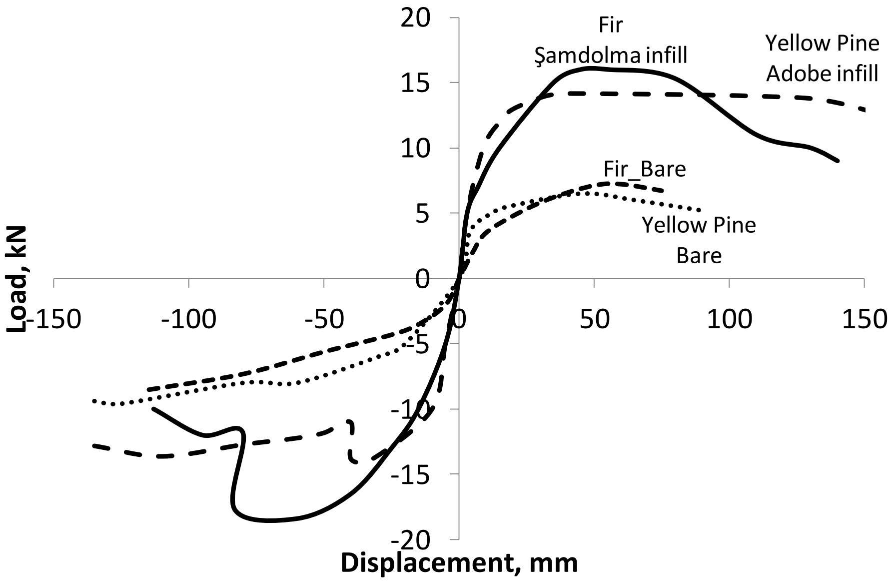


Figure 5. Load-displacement curves

4 CONCLUSIONS

The following conclusions can be drawn from the results of this experimental present study:

- Connections are the vulnerable parts of such structures. In both bare frame tests, it is seen that connection failure governs the structural failure. The type of the wood material is not effective in behaviour and does not play any significant role in the failure. Both yellow pine and fir frames showed almost the same load and displacement capacity.

- The adobe infill and wood covering increases the lateral load strength of a timber frame, by an order of 1.81 and 2.19 times, respectively. The values are the average of push and pull cycles of lateral loads because behaviour under pushing load is different from the pulling load.

- Adobe infill and wood covering also increases stiffness, in the order of 2.2 and 4.0 times, respectively.

- Energy dissipation capacity increased 2.1 times in adobe infill yellow pine frame and 2.5 times in fir frame with wood covering. Since strength increases without any reduction in displacement capacity, energy is dissipated more as compared to the bare frames.

Workmanship is an important point to be considered because since they do not perform any calculations and follow a unique design rule, the quality of the work changes from one frame to the other. This can be clearly seen from the nail numbers and nail applications

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