

Seismic performance of rammed earth town halls reinforced with confinement wooden elements

Evaluación del comportamiento sísmico de casas consistoriales de tapia pisada reforzadas con maderas de confinamiento

D. Ruiz ^{1*}, M. Silva *, L. Cerón *, C. López *

* Pontificia Universidad Javeriana, Bogotá. COLOMBIA

Fecha de Recepción: 03/08/2016
Fecha de Aceptación: 01/01/2017
PAG 25-44

Abstract

There are few studies on the behavior of historic structures of adobe and rammed earth in Latin America, which has contributed to the deterioration of these buildings, which are part of our architectural and cultural heritage. Colombia has 90% of its heritage buildings made of earth and most of them are located in high and intermediate seismic risk zones. The town halls of the colonial era (made of adobe or rammed earth) are part of this Colombian architectural heritage and still kept 11 of these houses in the Department of Cundinamarca. This article presents the results of a study conducted by research groups GRIME and Estructuras & Construcción, where the objective was to study a method of rehabilitation of town halls of rammed earth through confinement wooden elements. The research is based on shake table tests on scale models (1:20), with and without reinforcement with confinement wooden elements. The results suggest that the reinforced model had less seismic displacements (69% less than the model without reinforcement) and that the wooden confinement elements diminishes the cracking of the rammed earth walls.

Keywords: Structural reinforcement, wooden elements, rammed earth, adobe, laboratory tests, town halls, shake table tests

Resumen

Existen pocos estudios del comportamiento de estructuras históricas en adobe y tapia pisada en Latinoamérica, lo que ha contribuido al deterioro de estas construcciones, que son patrimonio arquitectónico y cultural. Colombia tiene el 90% de sus edificios patrimoniales en tierra y la mayoría de ellos están ubicadas en zonas riesgo sísmico alto e intermedio. Las casas consistoriales de la época colonial (casas de ayuntamiento hechas en adobe o tapia pisada) son parte de este patrimonio arquitectónico Colombiano y aún se conservan 11 de estas casas en el Departamento de Cundinamarca. Este artículo, presenta los resultados de un estudio desarrollado por los grupos de investigación GRIME y Estructuras & Construcción, donde el objetivo fue estudiar un método de rehabilitación de casas consistoriales de tapia pisada mediante maderas de confinamiento. La investigación se basó en pruebas en mesa vibratoria sobre modelos a escala 1:20, con y sin refuerzo en maderas de confinamiento. Los resultados sugieren que el modelo reforzado tuvo menores desplazamientos sísmicos (69% menos que el modelo sin refuerzo) y que las maderas de confinamiento disminuyeron la fisuración y el agrietamiento de los muros de tapia pisada.

Palabras clave: Reforzamiento estructural, maderas de confinamiento, tapia pisada, adobe, ensayos de laboratorio, casas consistoriales, ensayos de mesa vibratoria

1. Introduction and background

1.1 Earth Construction

Earth is one of the most ancient materials used for the construction of buildings (Yamín et al., 2007); its use dates back to approximately 8000 B.C. During the Spanish Conquest of the Americas, the conquerors introduced the construction with adobe and rammed earth in the main cities of the New Kingdom of Granada, one and two-floor houses were built as government facilities and religious temples (Yamín et al., 2007). Nearly 30 to 50% of the world population currently lives or works in earth buildings, mainly in rural areas (Blondet et al., 2011).

In Colombia, constructions made of earth are an essential part of the cultural patrimony; there are 1118 declared national monuments, from which 90% are made of

earth (López et al., 2007). For this reason, it is important to rehabilitate these buildings to preserve the cultural patrimony and, therefore, seismic rehabilitations and interventions have been performed on earth buildings with patrimonial character in the last decade (López et al., 2007).

One of the techniques used in earth construction is rammed earth, which is made by compacting layers of approximately 100 mm thick with a tool called rammer or tamper. Compacting is made inside a wooden framework, which is made of two wood boards of 2 m long by 1 m high, called "hojas de tapial", and 2 gates providing the wall's width (see Figure 1).

¹ Corresponding author:

Director Departamento de Ingeniería Civil de la Pontificia Universidad Javeriana, Bogotá. Colombia
E-mail: daniel.ruiz@javeriana.edu.co





Figure 1. Rammed earth construction process (Chang et al., 2013)

The floor slab system of rammed earth buildings consists in wood loadbearing beams, which are located between the loadbearing walls. These beams are made of wood logs of 0.15 – 0.20 m diameter or having a rectangular or square section of 0.20 x 0.20. The floor slab tie beams are installed over the loadbearing walls and are a direct support to the loadbearing beams of the floor slab, thereby transmitting the horizontal and vertical loads to the loadbearing walls (AIS, 2004). The roof is usually built with wood logs or sawn elements, forming a truss roof (AIS, 2004).

1.2 Seismic vulnerability of buildings made of earth

Earth buildings (adobe and rammed earth) have construction characteristics that increase their seismic

vulnerability. Furthermore, the age of these buildings and the deterioration of the mechanical properties of their materials are a determining factor in the behavior of rammed earth as a structure. The material's reduced tensile stress that originates a null flexural strength and the diagonal tensile strength of approximately 0.03 MPa, decreases the material's capacity to bear external forces (Yamín et al., 2007). The reason is that earth is a low cemented material, which makes it susceptible to the erosion or disintegration while being constantly in contact with water (Day, 1993). The consequence of this is a tendency of earth buildings to collapse during earthquakes, as in the Cúcuta earthquake (Colombia) in 1875, when the church collapsed (Figure 2).



Figure 2. Collapse of the Cúcuta Church (made of earth) during the 1975 earthquake.
Taken from (Ruiz et al., 2012)

1.3 Seismic rehabilitation techniques in earth constructions (Adobe and Rammed Earth)

Different rehabilitation alternatives have been analyzed to reduce the collapse probability of earth constructions (rammed earth and/or adobe) or allow their dwellers to get out of them (Ruiz et al., 2012). Thus, different types of rehabilitation are proposed: confining wood elements, steel cables, mesh reinforcements, polypropylene bands, installation of tie beams, internal reinforcements with rods, among others (Blondet et al., 2011).

According to tests and researches dealing with the reinforcements previously mentioned, in Colombia, it was concluded that the confining wood elements significantly improve the ultimate displacement and the average shear stress in earth constructions. The reason is that the wood elements generate structural continuity and confinement, thus reducing the possibility of an early failure, increasing the strain capacity in the non-linear range, and the maximum strength of the structural system (Yamín et al., 2007)

The reinforcement with confining wood elements consists in the installation of horizontal and vertical reinforcements, as indicated in Figure 3, considering the separation between the woods and between the edges, in order to increase the flexural strength of the walls and keep the structure unity. Elements should be placed on the inner and outer faces of the wall; the horizontal elements of the walls are fixed with bolts and steel plates, to prevent the walls

from disarticulating and the construction from falling apart (Yamín et al., 2007).

1.4 Town halls

Town halls emerged in the colonial period, with the aim of administrating the cities, and solve legal, administrative and economic problems of the citizens (Uribe et al., 2014). At the beginning of the construction of a city, the first thing was to build residential houses, then the church and, finally, municipal buildings such as town halls (Wyrobisz, 1980).

These town halls had to be located on the main square, where town hall officials got together to hold their meetings; they were scenarios for the most important local events and political decisions. Different government activities took place there, such as offices, town council and hearing assembly halls, clerk offices, files, prisons, and accommodation for the guards.

These constructions were built with the shape of a rectangular parallelogram, the greatest length corresponded to the main façade, with two floors, wooden pillars and corridors; they were characterized by their symmetry both in the floor plan and the façade.

Town halls are part of the Colombian patrimony built with earth; currently, 11 of these town halls remain in Cundinamarca (see Figure 4), which correspond to 39% of the initial total (Uribe et al., 2014).

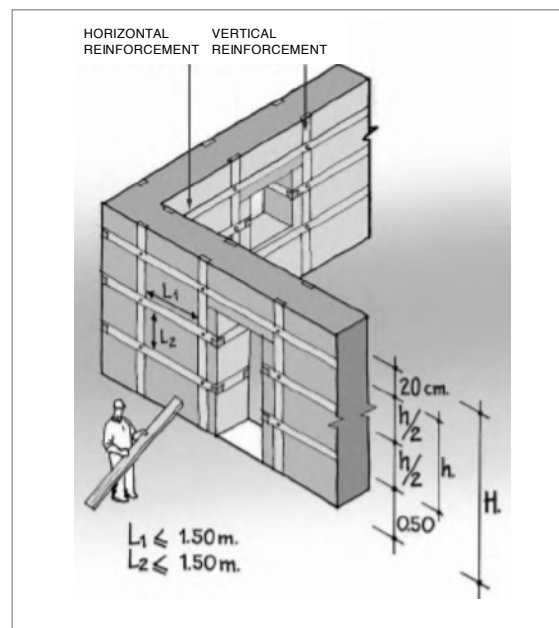


Figure 3. Placement of the confining wood reinforcement (AIS, 2004)



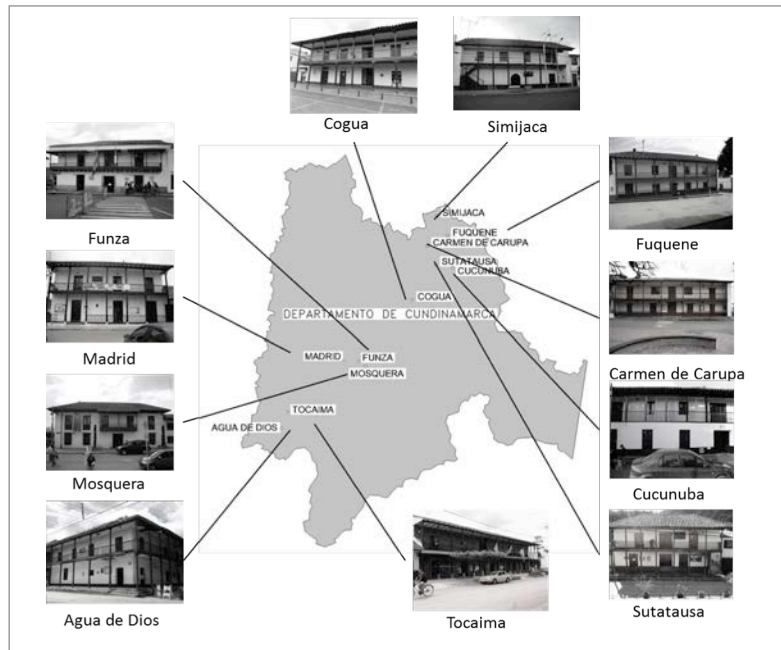


Figure 4. Location of currently existing town halls in Cundinamarca (Uribe et al., 2014)

Town halls have been modified without taking into account the existing typology, and they also lack proper and regular maintenance, which is required for their conservation. These houses are used as the mayor office and some of them have suffered modifications; however, they have kept their main characteristics (Uribe et al., 2014).

1.5 Case study: town hall of Cogua

For this case, the studied town hall is located in Cogua, Cundinamarca, and it was built between 1780 and 1800. It has undergone modifications, but it has kept the wooden pillars in the corridor and the balcony, as well as its symmetry in the façade (see Figure 5). (Uribe et al., 2014).

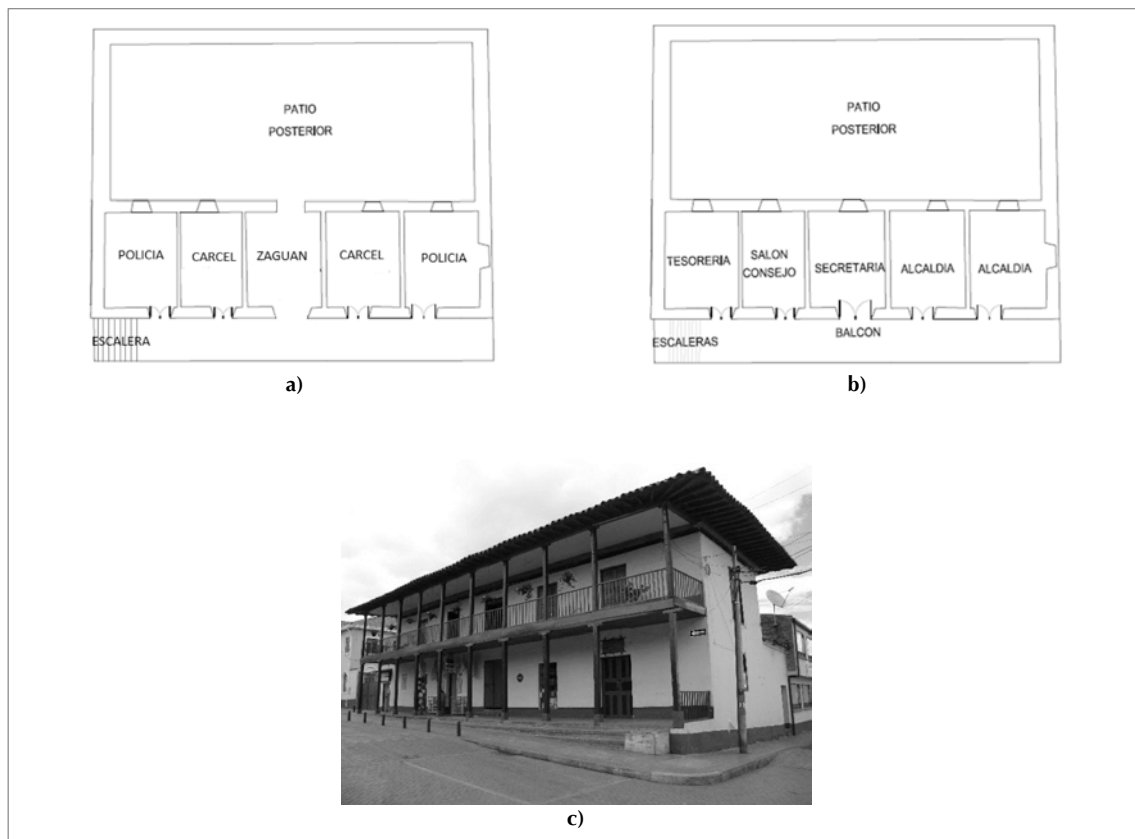


Figure 5. a) Town hall floor plan, first floor; b) Town hall floor plan, second floor; c) Photograph of the town hall of Cogua. Taken from (Uribe et al., 2014)

ENGLISH VERSION.....

The walls are 600, 700 and 800 mm thick and it has square columns of 150 mm located on the main façade of the town hall, in the first and second floor, on pedestals of 300 mm high and square section of 200 mm (Uribe et al., 2014).

The walls have a wood tie beam in the floor slab and the roof; however, there is no information available in relation to the beams (Uribe et al., 2014).

The ceiling is suspended from the floor slab and roof beams; it is made of chusque (type of bamboo) and earth, and it is lime-coated; it has multiple cracks. The roof is made of wood elements (truss roof), the finish is made with canes, earth and clay tile; the roof presents a high level of deformation and decomposition (Uribe et al., 2014).

2. Methodology: laboratory tests

The study methodology consisted in:

- Physical-mechanical characterization of the materials: soil and wood.

- Mechanical characterization of reinforced walls through diagonal tension tests.
- Reinforced and unreinforced model construction of the town hall of Cagua, at a scale of 1:20 (see Figure 6).
- Shake table test for built models (reinforced and unreinforced with confining wood elements), prior instrumentation of the models.
- Interpretation of the results: cracking levels and comparison of the displacements of the walls reinforced and unreinforced with confining wood elements.

2.1 Soil characterization

The soil used for the construction of the models was subjected to lab tests to determine aggregate grading, plasticity index, liquid limit, plastic limit, among others contributing to the interpretation of the material's behavior. The results corresponding to the aforementioned tests are shown in Tables 1 and 2.

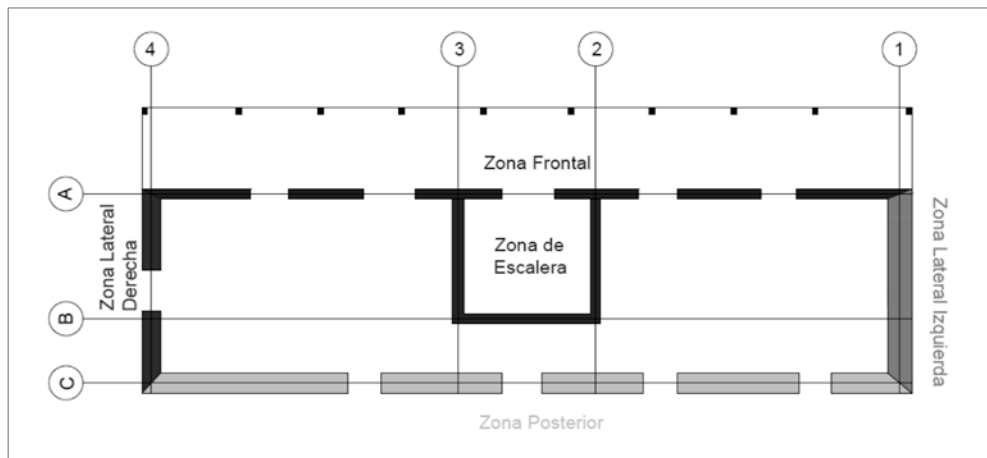


Figure 6. Wall drawing of the scale model

Table 1. Physical characteristics of the soil

Specific Gravity (g/cm^3)	Liquid Limit	Plastic Limit	Plasticity Index	USCS Classification	Humidity Content
1.68	23	13	10	SP	1%

Table 2. Soil aggregate grading

Aggregate Grading		
Passing Sieve No. 200	Passing Sieve No. 40	Passing Sieve No. 4
1%	30%	66%



Based on the Unified Soil Classification System (USCS), the material was classified as poorly graded sand (SP). This type of soil does not fulfill the requirements described for earth construction, since it has a low content of fine aggregates. Therefore, clay was added to produce the cohesion that the material required. The used material was formed by 5 parts of material passing sieve No. 10, 1 part of clay, 1 part of lime, one layer of fique fiber on top of the mixture, and water to obtain the required consistency.

Rocks are the main material of the foundation and can be angular, rounded or a combination of both; the foundation contains sand material, to fill the voids, besides limestone as cementitious material (AIS, 2004). The cementation material for the scale models was 2 parts of granular material (passing

sieve No. 4 and retaining sieve No. 10), ½ part of sand, ½ part of lime and water to obtain the required consistency.

2.2 Characterization of the confining wood

The wood, for the reinforcement elements of the town hall models, was tested as described in Table 3. Cedar was chosen, according to the recommendations of (Ruiz et al., 2014).

The longitudinal compressive tests were conducted on three specimens made of cedar to determine the wood's resistance. Figure 7 presents the assembly and Figure 8 shows the failure patterns (mainly by shear).

Table 4 presents the main results of the compressive tests.

Table 3. Characterization tests of reinforcement wood

Test	Standard
Compression in longitudinal fibers	ASTM D143-09 (ASTM 2009)
Tension in longitudinal fibers	ASTM D143-09 (ASTM 2009)



Figure 7. Assembly of specimens under compression on the universal machine

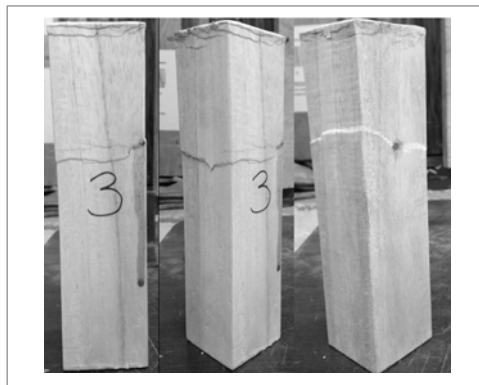


Figure 8. Type of failure in specimen 3

Table 4. Results of the longitudinal compression test in wood elements

	Stress to the proportional limit (MPa)	Strength (MPa)	Elastic Modulus (MPa)
Specimen 1	27.3	30	9763
Specimen 2	26.6	33	9823
Specimen 3	30.1	34	9510

It is important to note that the wood used also showed good ductility capacity to unit strain (compression), since it presented a 4% deformation after achieving its maximum load.

Additionally, three wood tensile strength tests were

performed, according to the reference technical standards. Figure 9 shows the assembly and Figure 10 presents the failure of the specimens.

Table 5 shows the mechanical parameters determined from the tensile strength tests.

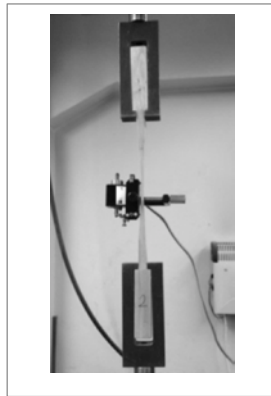


Figure 9. Assembly of wood specimens subjected to tensile test on the universal testing machine

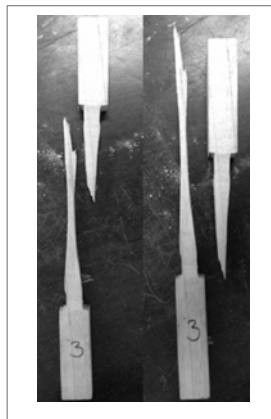


Figure 10. Failure of specimen 3 subjected to stress tests

Table 5. Results of the longitudinal tensile strength tests on wood

	Stress to the proportionality limit (MPa)	Maximum Stress (MPa)	Elastic Modulus (MPa)
Specimen 1	96.1	102	9885
Specimen 3	74.9	92	9518



Unlike the compression test, the unit strain in the inelastic range of the wood subjected to tensile loads is limited and reached 0.27%.

2.3 Diagonal tensile strength of walls

Before implementing the reinforcement alternative with confining wood elements, diagonal tensile tests were conducted. This test is typically used for the characterization of masonry under seismic loads. Therefore, four specimen

walls were built at scale 1:20 with the dimensions of a town hall scale wall measuring 150 mm x 150 mm x 20 mm. Two of these walls specimens had confining wood reinforcements and two did not. Walls were made with the earth previously described. Once the drying process was over (1 month) and with the wood reinforcement already installed, the walls were tested by the diagonal tensile test, according to the ASTM E519 standard (ASTM 2010) (see Figure 11 and 12).

All walls specimens had a crack in one of the diagonals (see Figure 13).

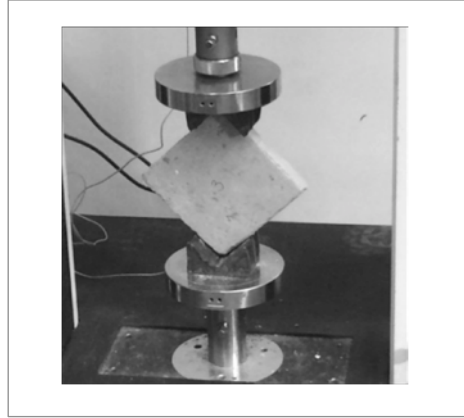


Figure 11. Assembly of the unreinforced wall test specimen

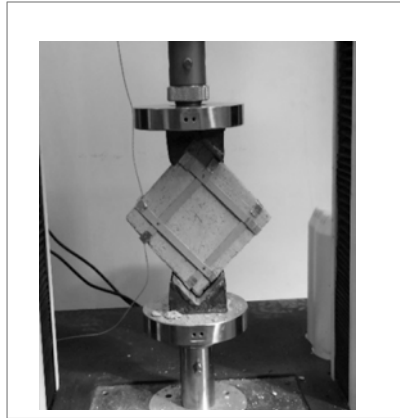


Figure 12. Failure of the reinforced and unreinforced wall test specimens

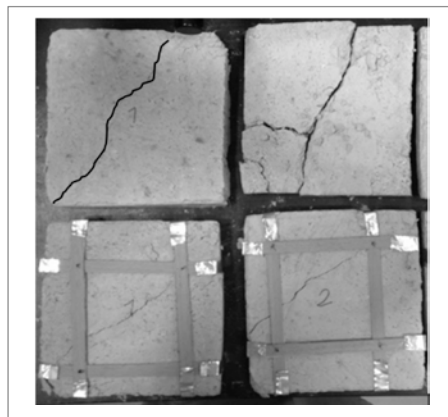


Figure 13. Cracks in the reinforced specimen walls caused by diagonal tensile stress

ENGLISH VERSION.....

These diagonal tensile tests showed ductility capacity to unit strain of walls reinforced with confining wood. This is shown in Figure 14, in the records of shear stress vs. unit strain. Unlike the unreinforced wall, reinforced walls kept their unity once the test was over.

2.4 Construction of scale town house models

The foundation consisted in strip footings made of compacted filling, conforming a framework of different

thicknesses, under the main walls of the building. The same foundation was used for unreinforced and reinforced models (see Figure 15), and the material described in the soil characterization paragraph was used.

Afterwards, the framework of the first floor was assembled, covered with plastic film to avoid adhering to the material, and tied between the edges to prevent thickness differences in the walls. The material was compacted in layers of approximately 5 cm (see Figure 16).

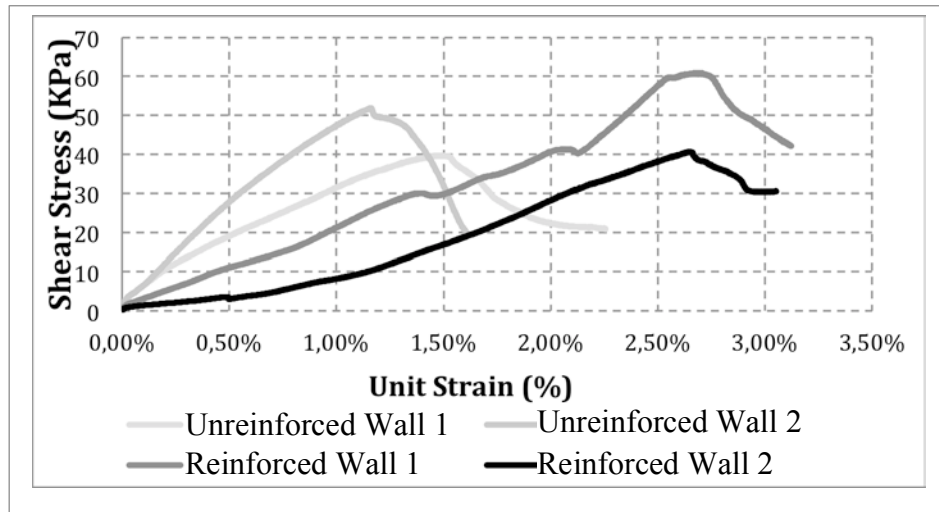


Figure 14. Shear stress vs. unit strain of wall specimens subjected to diagonal tensile stress



Figure 15. Foundation of the structure



Figure 16. Walls' compacting process

Once the walls of the first floor were finished, the wood beams of the floor slab system were placed in order to continue with the adjustment of the framework of the second floor and repeat the compacting process of the walls.

One week after finishing the compaction, the formwork was removed (see Figure 17) and then the walls, joists and columns were painted (see Figure 18).

The construction of the walls of the model reinforced with confining wood elements follows the same steps as the unreinforced model.

The reinforcement with confining wood was made with cedar plywood of 1 cm wide and 1 mm thick (at real scale it would be 20 cm wide and 20 mm thick).

The reinforcement was placed according to the drawing of Figure 3. Based on the scale of 1:20, woods were separated by 75 mm from each other (1500 mm at real scale), at 30 mm from the corners and 25 mm from the cementation (see Figure 19). Likewise, the reinforcement was placed at 20 mm from the floor slab and the roof. In the joints between vertical and horizontal reinforcements, a copper wire was used; corresponding to steel bolts at real scale, and a knot was made on both ends to ensure that walls were confined. In the same way, to guarantee that the reinforcement worked, it was put together with brass sheets (steel plates at real scale) in the inner and outer corners, as well as between doors and windows, that would ensure this union (see Figure 20).



Figure 17. Opening process of doors and windows



Figure 18. Unreinforced model before the failure



Figura 19. Placing of the reinforcement wood



Figure 20. Union of corners, doors and windows

Finally, woods were painted to get a better visibility of their behavior during the earthquake simulation test (see Figure 21). Reinforced and unreinforced models were subjected to loads on the roof and the floor slab to simulate the seismic mass (see Figure 22).

2.5 Instrumentation

The test instrumentation of the model consisted in three LVDT-type deformimeters and two uniaxial accelerometers. The LVDTs were placed on the upper area of

the walls in order to record the displacements perpendicular to their planes. One of the accelerometers recorded the motions in the longitudinal direction of the model, while the other recorded the accelerations in the cross-section direction of the town hall. This process took into account that the model was located at 45 degrees in relation to the direction of the motion with the aim of simultaneously generating flexural and shear stresses in the walls. The exact location of the LVDTs and accelerometers is shown in Figure 23.

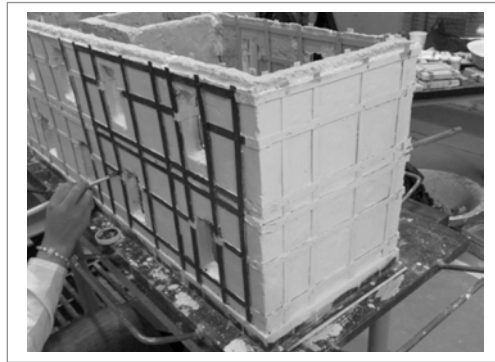


Figure 21. Painting process of the confining wood elements



Figure 22. Reinforced model with loads before the earthquake

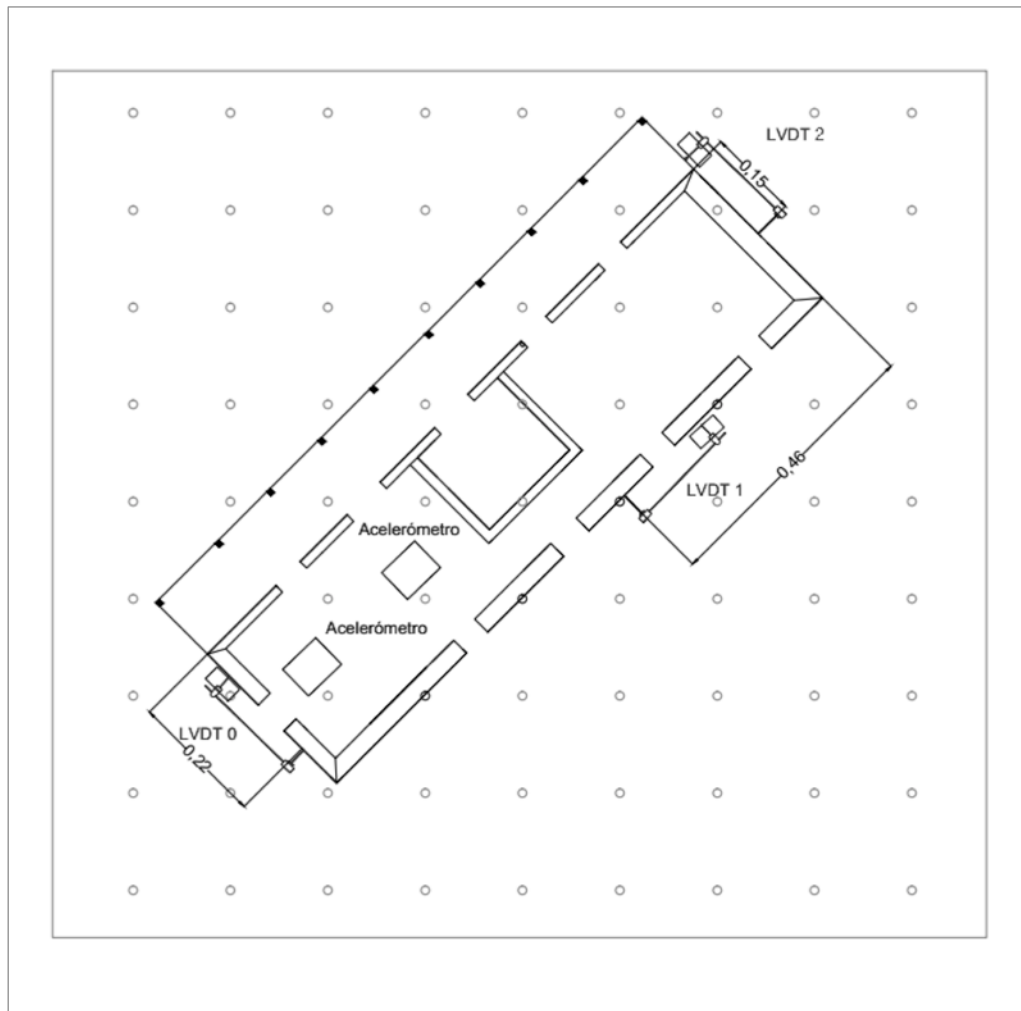


Figura 23. Location of the instrumentation

2.6 Shake table testing

Dynamic tests were conducted in the shake table of the Laboratory of Tests and Trials of the Pontificia Universidad Javeriana of Colombia, whose dimensions are 1.5 m x 1.5 m with a capacity for models up to 20 kN and a maximum displacement of ± 125 mm. The system is driven by a hydraulic actuator with a dynamic load capacity of 100 kN.

Regarding the assembly of the models, both reinforced and unreinforced, they were located at an angle of 45° in relation to the displacement direction of the ground, with the aim of guaranteeing that the generated inertial force would act on the longitudinal and cross-section direction of the structure and that the orthogonal effect was considered.

Models were subjected to the Tauramena earthquake (see Figures 24 and 25) recorded in 1995 (Rosal Station, Colombia), which is a characteristic signal that could take place in Bogota during an earthquake, with source in the frontal fault of the Eastern Mountain Range of Colombia (Ruiz et al., 2014; Yamín et al., 2003).

In order to consider the scale model, it was necessary to modify the time scale of the input signal, to maintain the similarity dynamic force of excitation (Yamín et al., 2003). Therefore, Figure 25 shows the displacement record against the time used in the shake table, which is significantly shorter than the real signal, but generates acceleration levels that are in accordance with the scale model, as established in (Harris and Sabnis, 1999).

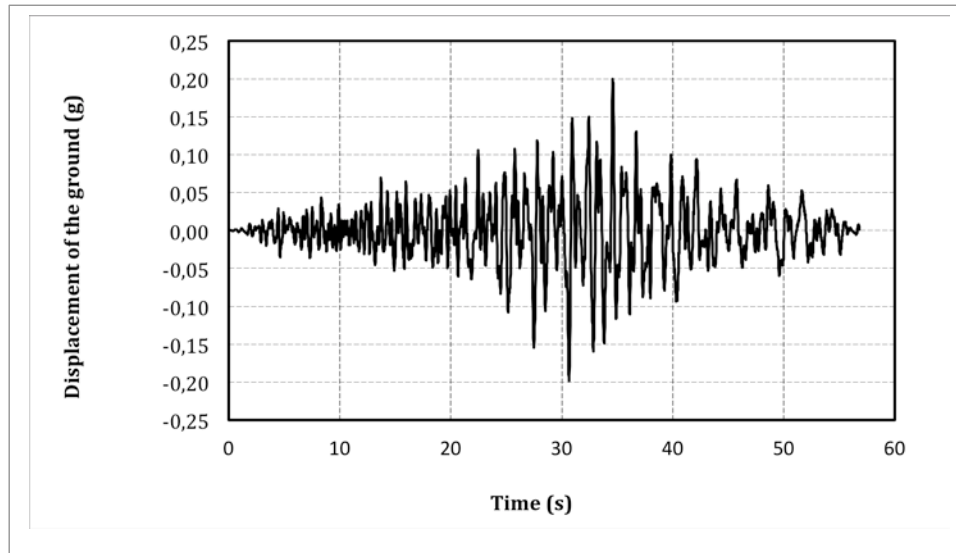


Figure 24. Earthquake signal of Tauramena

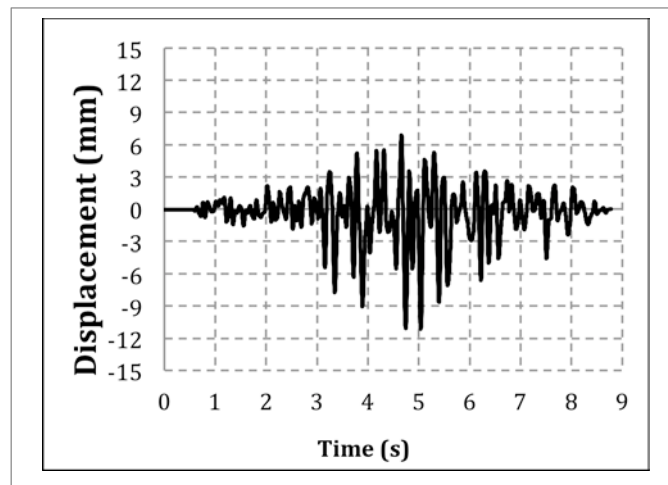


Figure 25. Displacement of the ground for the Tauramena earthquake used in the tests

3. Results and discussion

3.1 Unreinforced scale model

After subjecting the unreinforced model to the motions of the shake table, the town hall presented cracking on the left lateral area, in the union of the axis 1 – C on the second floor, starting in the roof (see Figure 26), and reaching the first floor. Additionally, a sequence of cracks was evidenced in the union of axis A and 1, which generated independent

vibrations from one wall to the other, producing the collapse of most of the wall, as shown in Figure 27.

On the right lateral area, the edge of the axis C – 4 cracked in the second floor and cracking was evidenced in the window opening of the second floor, crossing the wall horizontally as far as axis A, as shown in Figure 28.





Figure 26. Cracking on the left lateral area after the seismic activity

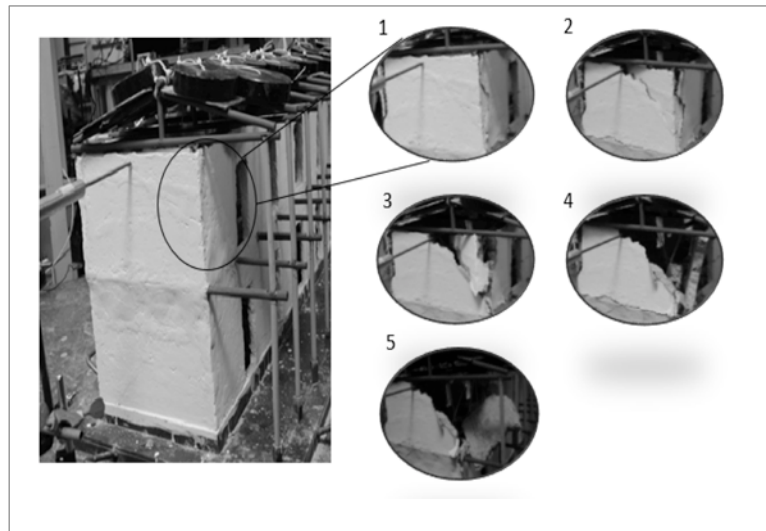


Figure 27. Collapse sequence on the left lateral area



Figure 28. Cracking on the right lateral area after the seismic activity

ENGLISH VERSION.....

In the back, on the second floor, vertical cracks between axis 3 and 4 of axis C and horizontal cracks between axis 2 and 3 of axis C, were detected. At the same time, cracks in the window openings were observed between axis 1 and 2 of axis C, and a vertical crack was generated on the first floor in the union of axis 1 – C, from the floor slab to where the foundation starts (see Figure 29).

In the front, cracking of the door opening occurred on the second floor between axis 1 and 2 of axis A. Moreover, the wall of the left upper side collapsed in the union of axis A – 1 and between axis A – 4. A crack was generated from the roof to the floor slab (see Figure 30).

In the stairway area, the walls of axis 2 and 3 collapsed, thereby destroying the floor slab (see Figure 31).



Figure 29. Cracking produced in the back by the seismic activity

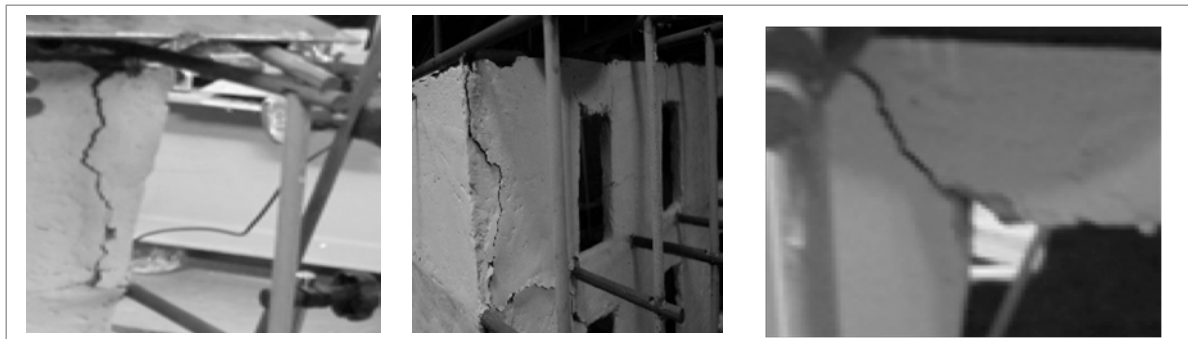


Figure 30. Cracking produced in the front by the seismic activity



Figure 31. Collapse of the stairways on the second floor

According to the experimental seismic tests, the deficiencies of the structures made of rammed earth make them very vulnerable. Since they do not have a rigid diaphragm and the walls show vibrations independent from each other. When walls crack on their lateral ends, the walls do not work together and each wall absorbs the earthquake independently (Yamín et al., 2007), generating stress concentrations on the upper side of the connection between orthogonal walls, thereby making the walls to vibrate freely perpendicular to their planes.

Some of the failures are produced by lack of connections between the walls of the structure, which tend to separate due to the cracks going from the corners or stress concentration points to the openings of doors or windows (Yamín et al., 2003).

3.2 Reinforced scale model

This model presented less cracks in all faces. Moreover, there were no partial or total collapses of any of the walls.

On the left lateral area, a crack was observed on the second floor on the border of the corner between axes 4 - C (see Figure 32).

On the right lateral area, in the lower side of the wall between axes 1 - C, a diagonal crack was observed (see Figure 33).

In the back, three cracks were generated: one in the corner between axes C - 4, another in the upper side of the window opening located between axes 4 and 3 over axis C, and the third between the edges of the windows located in axes 3 and 4, crossing the floor slab (see Figure 34).

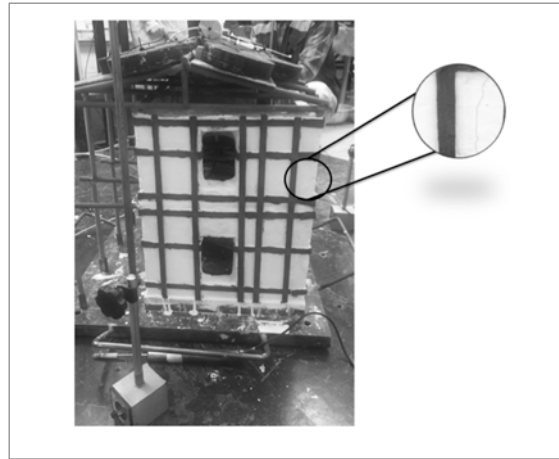


Figure 32. Left lateral side of the reinforced model

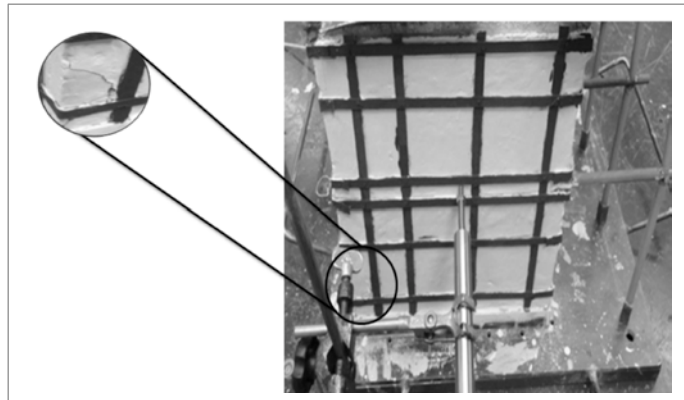


Figure 33. Right lateral side of the reinforced model

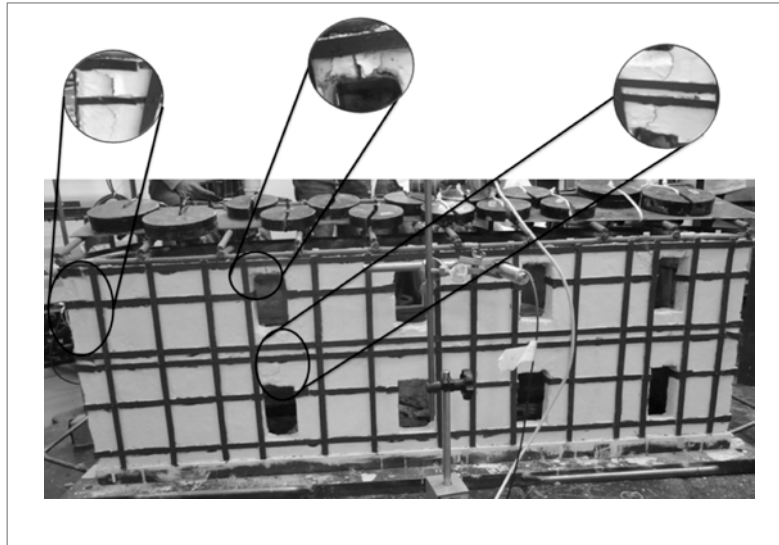


Figure 34. Back of the reinforced model

It should be highlighted that the use of confining wood elements prevented the formation of cracks in this model, considering that only 5 cracks were observed that did not compromise the stability of the walls.

3.3 Effect and influence of seismic reinforcement on walls displacements

The (relative) displacements (with regard to the ground movement) were obtained from the measurements of the LVDTs during the earthquake ground motion, for the reinforced and unreinforced models. Figure 23 shows the numbering and location of the LVDTs.

At the roof level, the LVDT 0 located in the right lateral wall registered a maximum displacement of 7.06 mm in the unreinforced model, and 2.40 mm in the reinforced model (see Figure 35). The unreinforced model registered a permanent displacement of 1.40 mm at the end of the seismic test, unlike the reinforced model where no permanent

displacements were registered. Moreover, the decrease of the displacement records for the reinforced model, compared with the unreinforced model, should be highlighted.

The LVDT 1 located in the back wall registered a maximum displacement of 21.15 mm in the unreinforced model, and 9.47 mm in the reinforced model (see Figure 36). The unreinforced model registered a permanent displacement of 4.90 mm at the end of the seismic test. A decrease of the displacement records for the reinforced model can also be observed with regard to the unreinforced model.

In the left lateral wall, where the LVDT 2 is located, a maximum displacement of 13.94 mm was registered in the unreinforced model, and a displacement of 4.40 mm in the reinforced model (see Figure 37). The unreinforced model registered a permanent displacement of 4.47 mm at the end of the seismic test. There is also a reduced displacement record in the reinforced model, compared with the unreinforced model.

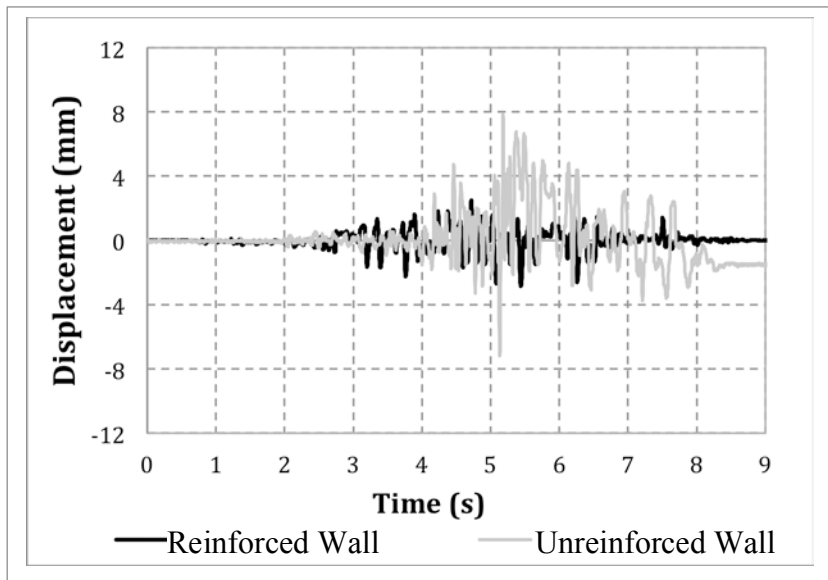


Figure 35. Displacements measured by LVDT 0 in reinforced and reinforced models for the roof

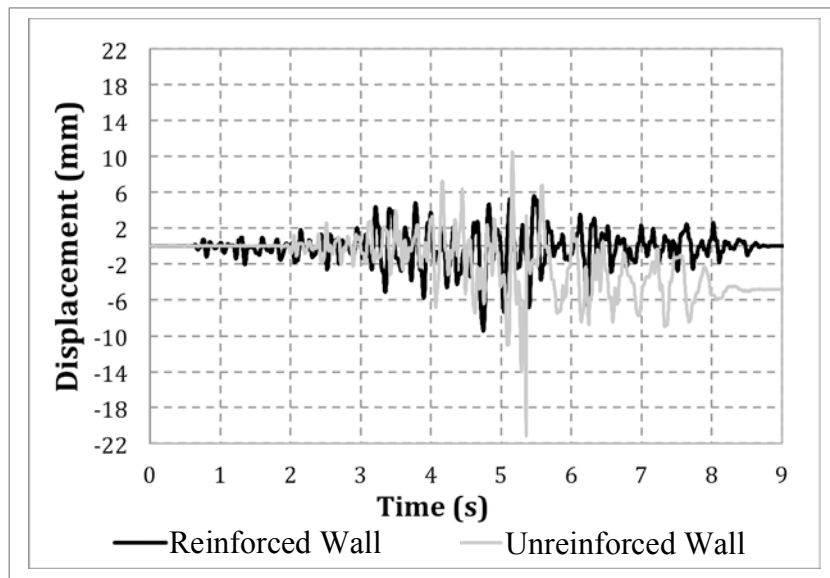


Figure 36. Displacements measured by LVDT 1 in reinforced and reinforced models for the roof

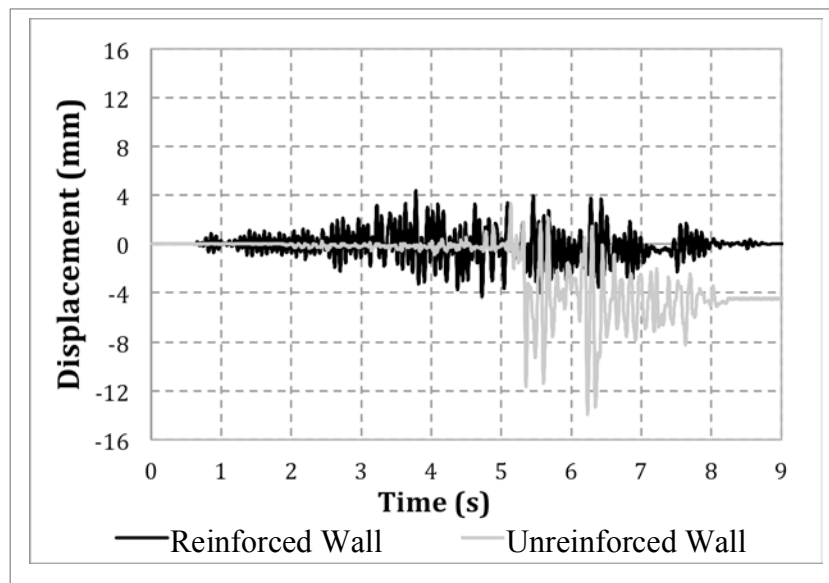


Figure 37. Displacements measured by LVDT 2 in reinforced and reinforced models for the roof

4. Conclusions

- The use of confining wood elements as a reinforcement alternative evidenced an improvement in the two-floor town hall, because the wood made the walls to work together and increased the energy dissipation capacity of the structure
- When comparing the reinforced and unreinforced models (see Table 6), a better seismic performance in the reinforced model with confining wood elements was observed, while the unreinforced model presented several collapses, due to the tensile, flexural and shear stresses.
- In terms of relative maximum displacements (see Table 7), the confining woods reduced the displacements of the walls up to 69% for the same analyzed earthquake.
- As the efficiency of the confining wood elements was demonstrated, they can be used as rehabilitation technique in town halls built with rammed earth, with the aim of preserving the historical and cultural patrimony of Colombia.

Table 6. Comparative chart of reinforced and unreinforced models

	Fissure	Cracks	Collapses
Unreinforced	8	9	1
Reinforced	6	0	0

Table 7. Relative displacements of the roof

Wall	Maximum Displacement without Reinforcement (mm)	Maximum Displacement with Reinforcement (mm)	Decrease
Right Lateral	7.06	2.40	66%
Back	21.15	9.47	55%
Left Lateral	13.94	4.40	68%



5. Acknowledgements

The research described in this paper was financed by the Department of Civil Engineer, the Department of Architecture and the Research Vice-Rector of the Pontificia Universidad Javeriana of Colombia. All tests were carried out

in the Laboratory of Tests and Trials of the Department of Civil Engineer of the same University. The project was developed by the research groups Estructuras y Construcción, and GRIME.

6. References

- AIS (2004)**, Manual para la rehabilitación de viviendas construidas en adobe y tapia pisada. Asociación Colombiana de Ingeniería Sísmica.
- ASTM (2009)**, "Standard test methods for small clear specimens of timber." D143, West Conshohocken, PA.
- ASTM (2010)**, "Standard test method for diagonal tension (Shear) in masonry assemblages." E519, West Conshohocken, PA.
- Blondet M., Vargas J., Tarque N. and Iwaki C. (2011)**, Construcción sismorresistente en tierra: la gran experiencia contemporánea de la Pontificia Universidad Católica del Perú. *Informes de la Construcción*, 63(523): 41-50, doi: <http://dx.doi.org/10.3989/ic.10.017>.
- Chang G., Fiori C. and Schexnayder C. (2013)**, Rammed Earth: Construction Lessons from Experience. *Pract. Period. Struct. Des. Constr.* 18, 149-154. doi:10.1061/(ASCE)SC.1943-5576.0000152
- Day R. (1993)**, Performance of Historic Adobe Structure. *J. Perform. Constr. Facil.* 7, 164-169. doi:10.1061/(ASCE)0887-3828(1993)7:3(164)
- Harris H., Sabnis G. (1999)**, *Structural Modeling and Experimental Techniques*, Second Edition. CRC Press.
- López C., Ruiz D., Jerez S., Quiroga P. and Uribe J. (2007)**, Rehabilitación sísmica de muros de adobe de edificaciones monumentales mediante tensores de acero. *Revista Apuntes*, 20(2): 304-317.
- Ruiz D., López C., Unigarro S. and Domínguez M. (2014)**, Seismic Rehabilitation of Sixteenth- and Seventeenth-Century Rammed Earth-Built Churches in the Andean Highlands: Field and Laboratory Study. *Journal of Performance of Constructed Facilities*, 29(6): 04014144-1 - 04014144-17, doi: [http://dx.doi.org/10.1061/\(ASCE\)CF.1943-5509.0000605](http://dx.doi.org/10.1061/(ASCE)CF.1943-5509.0000605).
- Ruiz D., López Pérez C. and Rivera J.C. (2012)**, Propuesta de normativa para la rehabilitación sísmica de edificaciones patrimoniales. *Apunt. Rev. Estud. Sobre Patrim. Cult. - J. Cult. Herit. Stud.* 25, 226-239.
- Uribe. C., Lopez C. and Ruiz D. (2014)**, Casas consistoriales en Cundinamarca. Estudio de caso de la casa del municipio de Cogua. *Revista Apuntes*, 27(1), 124-141. <http://dx.doi.org/10.11144/Javeriana.APC27-1.ccce>
- Wyrobisz A. (1980)**, La ordenanza de Felipe II del año 1573 y la construcción de ciudades coloniales españolas en america. *Estud. Latinoam.* 7, 11-34.
- Yamin L., Rodríguez A., Fonseca L., Phillips C. and Reyes J. (2003)**, Comportamiento sísmico y alternativas de rehabilitación de edificaciones en adobe y tapia pisada con base en modelos a escala reducida Ensayados en mesa vibratoria. *Revista de Ingeniería*, 18, 175-190.
- Yamin L., Phillips C., Reyes J. and Ruiz D. (2007)**, Estudios de vulnerabilidad sísmica, rehabilitación y refuerzo de casas en adobe y tapia pisada. *Revista Apuntes*, 20(2): 286-303.