13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 2861

EXPERIMENTAL STUDY OF RETROFITTING TECHNIQUES FOR ADOBE WALLS

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SUMMARY

In the present work, the experimental test results of five simple and reinforced adobe walls are shown, two of this walls were made with handmade adobe pieces, the other tree walls were constructed with manufactured adobe pieces. For each kind of adobe pieces one wall was tested without reinforcement, as a reference specimen, other one was confined by reinforced concrete elements and the last wall was strengthening with a hexagonal wire mesh. The test were performed to study the hysteretic behavior of this specimens.

INTRODUCTION

Since the civilization beginning the soil to make constructions were used, specially adobe constructions, the technology for this kind of edification have been developed from builders experience and with a few changes along the time. Also some construction defects persist along the time, for example the high variations of the properties of the pieces, defects in the structural configuration system, insufficient protection against weather effects, etc, Hernandez [4].

During the sever natural phenomena like hurricanes, earthquakes or inundation events, the adobe constructions have shown inadequate structural behavior, deterioration and in some cases total collapse, Meli [6].

In the present time, the adobe construction is to rise up again in some places as Spain, France, Germany, Peru, North America, etc. The interest in this construction system is increased for the low

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construction energy consumption, the environment protection reasons, etc. Some countries have enforced adobe construction codes for example "National Construction Code of Peru" and "Adobe Construction Code of New Mexico". In Mexico there aren't special regulations for this kind of constructions, in spite of around 15% of the total house constructions is made with this material Hernandez [5].

The structural security during earthquake events should receive special attention because in Mexico case, a big part of its territory is located on seismic active zones,. For this reasons it is necessary to carry out different studies to develop structural techniques to improve the seismic behavior, developing easy and suitable structural design procedures as well as simple and economical retrofitting techniques for improve seismic behavior of existing constructions.

The use of adobe constructions in Mexico diminished at the beginning of XX century, with the expansion of masonry and reinforced concrete buildings. Actually adobe is employed mainly for poor constructions in rural areas, and it is considerate as a second level material, Vera [7].

According to INEGI (National Institute of Statistics, Geography and Information) statistics in 1970, adobe houses reach 30% of the total constructions in Mexico, this rate decreased to 21% in 1980 and 15% in 1990, and representing 12% at the moment, Millan [2].

Even the use of adobe as a construction material is decreasing, as average in the country, there are a lot of zones were the use of this material is maintained and in some cases increased.

In some states of the country like Querétaro, Quintana Roo, Chiapas, Durango, Guerrero , Oaxaca and Zacatecas the number of adobe constructions have risen. Also in Queretaro and Quintana Roo the edification with this material have risen faster than the average for other materials, which means, that adobe is most popular than other kind of materials.
figuras 1 y 2

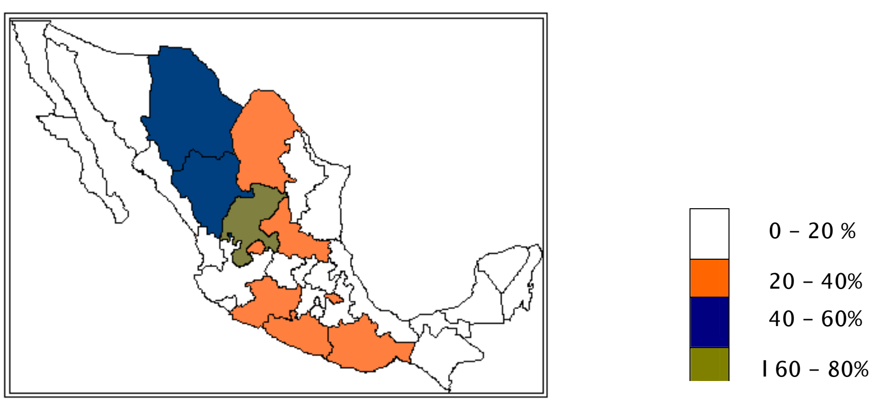

Figure 1. Average of adobe constructions 1990

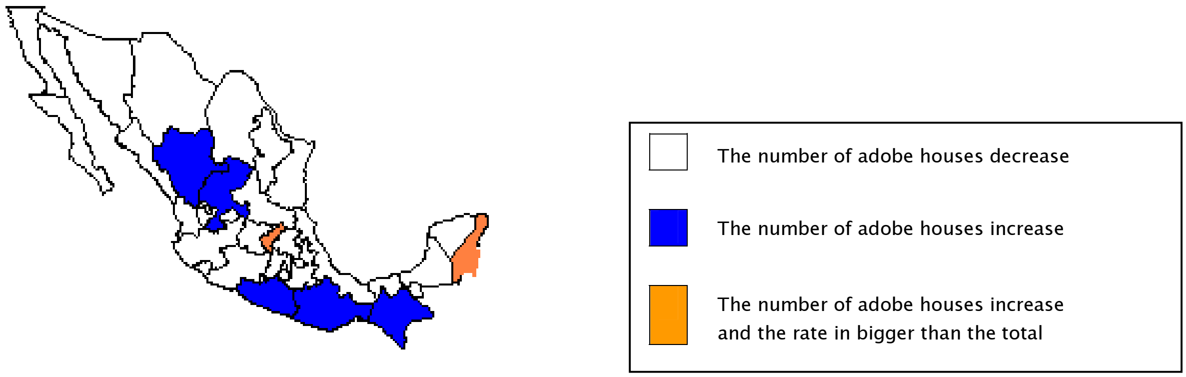

Figure 2. growing rate of adobe construction

The case of Guerrero, Oaxaca and Chiapas is remarkable because they are located in the south of the country, and they have 34.77%, 26.69% and 17.12% respectively of adobe constructions, but in some towns this number reaches 90% of the total.

In figure 3 the earthquake epicenters registered between 1960 and 1993 are presented. The zones mentioned below are located in the highest earthquake activity region in the country.

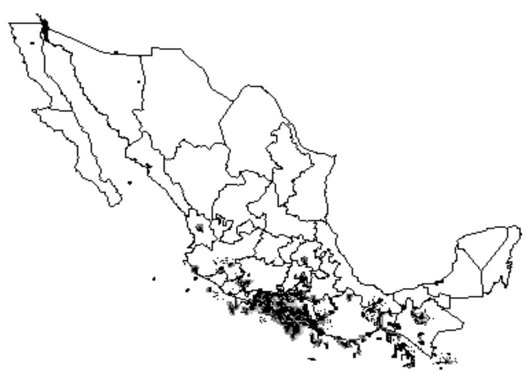

Figure 3. Epicenter location from 1960 to 1993

Summary the states which are more exposed to the seismic activity are using extensively adobe like a constructions materials, and this effect is generally combined with the economic problems..

Objective

The present study was carried out to determinate the efficiency of different kinds of reinforce techniques suitable for adobe walls. This alternatives are focused to be economical and to be accessible to people in rural areas.

As a part of this study, adobe pieces, adobe scale walls and adobe walls were tested. Adobe pieces are classified like handcrafted and industrialized and came from different zones of the State of Mexico. In the case of walls a lateral loads test was performed to five models with different reinforce techniques using handmade and manufactured pieces. The handmade pieces came from Valle de Bravo and industrialized pieces from Metepec.

Table 1. Mechanic Properties of adobe bricks from different zones in Mexico state

ADOBE TYPE	ORIGIN PLACE	MORTAR TYPE	f*m (MPa)	E Prom. MPa	v* , MPa	G Mpa
MANUFACTURED	METEPEC	TYPE I	0.757	494.30		
MANUFACTURED	METEPEC	TYPE II	0.635	490.92	0.076	59.34
MANUFACTURED	METEPEC	TYPE III	0.352	428.21		
MANUFACTURED	METEPEC	TYPE II SAND-SOIL	0.454	491.21		
HANDMADE	VALLE DE BRAVO	TYPE I	0.427	308.51		
HANDMADE	VALLE DE BRAVO	TYPE II	0.390	197.99	0.050	17.46
HANDMADE	VALLE DE BRAVO	TYPE III	0.181	131.36		
HANDMADE	AMATEPEC	TYPE II	0.274	119.00	0.037	11.63
HANDMADE	ORO	TYPE II	0.440	411.47	0.055	20.14
HANDMADE	TEMASCALCINGO	TYPE II	0.369	76.00	0.037	5.97
HANDMADE	SN MIGUEL TOTO	TYPE II	0.448	2,481.51	0.042	13.01

Reinforce Patterns

In this study five adobe walls were constructed. Two of them were built with handcrafted adobe, the first one without reinforce (wall No 1) and the second one (wall No2) with reinforced concrete beams and columns, this elements were located around the wall to confine the adobe elements.

The columns were connected to a bottom beam which had a 0.15 x 0.25 x 2.8 m section, with eight longitudinal bars with 0.0095 m diameter and yield stress equal to 412 MPA. The ties were formed with plain bars of 0.0064 m diameter, yield stress of 248 MPA. and separation of 0.15 m.

The tree other walls were constructed with manufactured adobe bricks one of them (wall No. 3) without reinforced, the other one (wall No 4) was confined with reinforced concrete elements in the similar way as wall number 2. In the last wall (wall No 5) a hexagonal wire steel mash was located along the horizontal joints, also the wall section was increased in the borders for adequate anchor of the mash.

This five elements were tested against lateral reversible forces, looking for evaluate the behavior of handmade and manufactured adobe pieces and to estimate the efficiency of reinforce concrete elements confinement as a retrofitting and reinforce techniques. During this study the maximum lateral capacity, ductility and hysteretic behavior were evaluated .

Model Construction

The five adobe walls were constructed with 2.3 m length and 2.3 m high, in all cases a reinforce concrete beam with 0.45 x 0.2 x 2.8 m of dimension was used to fix the walls. Only the wall No. 5 had a beam with I plant section with flange of 0.45x 0.7 x 0.2 m and web of 0.45 x 0.2 x 1.9m.

In the confined walls the reinforce concrete columns had a 0.15X0.20 m transversal section with six longitudinal steel bars of 0.0095 m diameter and yield stress of fy=412 MPA and ties of steel plain bars of 0.064 m of diameter, yield stress of 248 MPA and separation of 0.15 m the, bottom beams were fixed at the testing slab with 0.025 m diameter steel bars.

The mortar used for joint bricks was made according with the local practice using one part of cement, 2 1/2 parts of soil and 1/4 parts of lime and adding water to adequate workability..

Wall Test
In the top of wall No. 1, 3 and 5 a reinforce concrete beam was constructed for adequate load transmission and to avoid local crushing, this beam had a transversal section of 0.15 X 0.25 with 4 steel bars of 0.0095 m diameter and ties of 0.0064 m diameter at 0.15 m separation. This kind of reinforce was not used in the confined walls.

Load Devise System
A steel frame were used to support the ENERPAC hydraulic jacket with 890 kN push capacity and 427.7 kN pull capacity used for lateral load applications. This Hydraulic jacket was operated with manual pump of high flow.

The lateral load was controlled with digital ENERPAC manometer, DGB model of 69Mpa capacity. For vertical load a hydraulic jackets of 98.1 kN capacity operated with similar pump were used.

Instrumentation System
The instrumentation system was composed with analogic micrometers placed in the faces wall's, in diagonal, horizontal and vertical direction, other four micrometers were located at the wall extreme at different highs, for control the lateral displacement, figure 4 shows the instrumentation scheme of the wall.

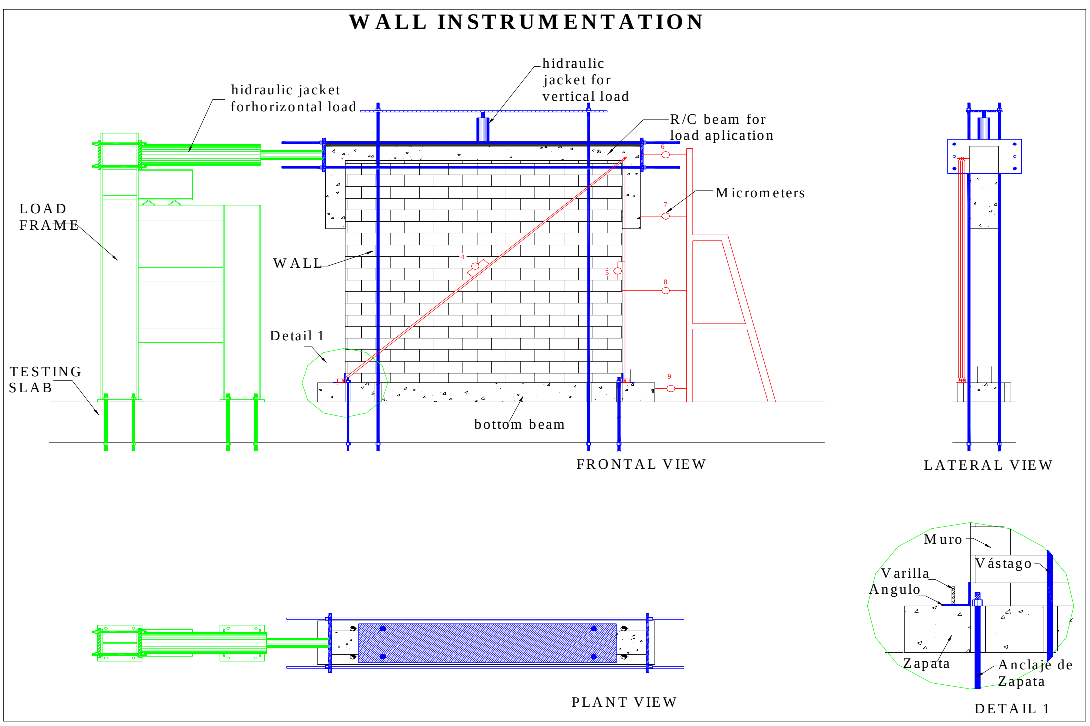

Figure 4.- Instrumented wall

Test Development
For the wall test, lateral and vertical loads were applied. The vertical load was constant during the test and was used for emulate the common gravitational actions in rural houses used in Mexico, the horizontal load emulate the seismic effects and change in magnitude and direction along the test forming push and pull cycles. The tests were controlled by displacement increase making tree cycles for each displacement.

The damage level in each element was reported as a function of cracking, pattern. Figure 5 shows the final cracking pattern of each wall.

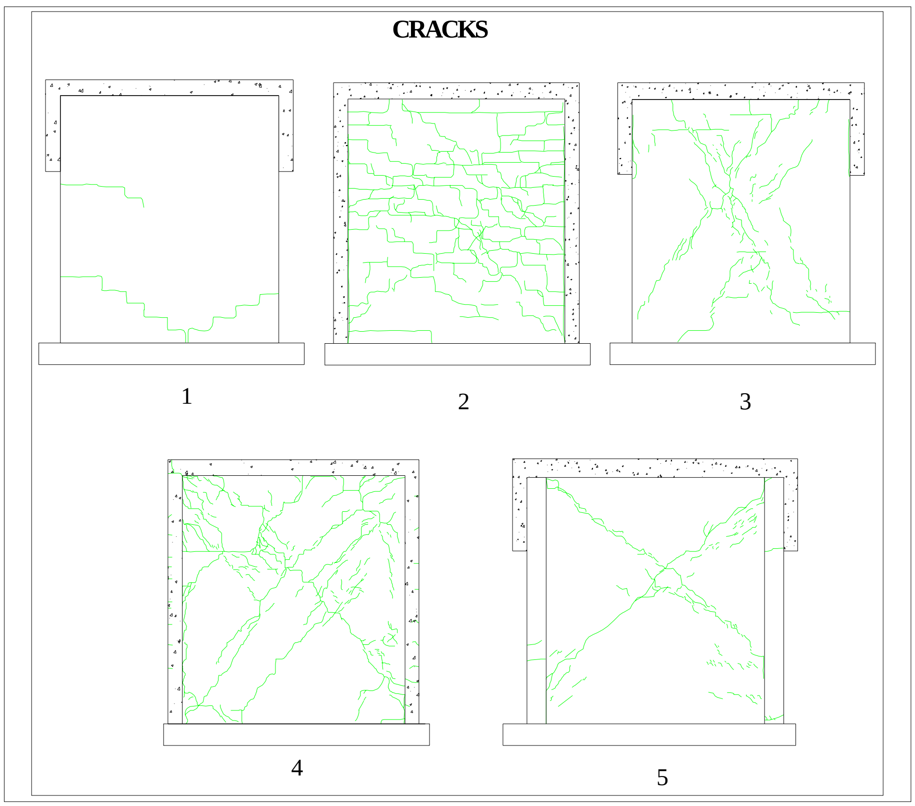

Figure 5.- Walls Cracking Patterns.

The tests results were plotted in the hysteretic loops. Figure 6 shows the histerectic loops as a function of lateral load and story drift for each wall. Additionally the first and last cycle were plotted in figure 7 looking for remark wall deterioration. Finally the enveloped of the hysteretic behavior for each wall is presented in figure 8.

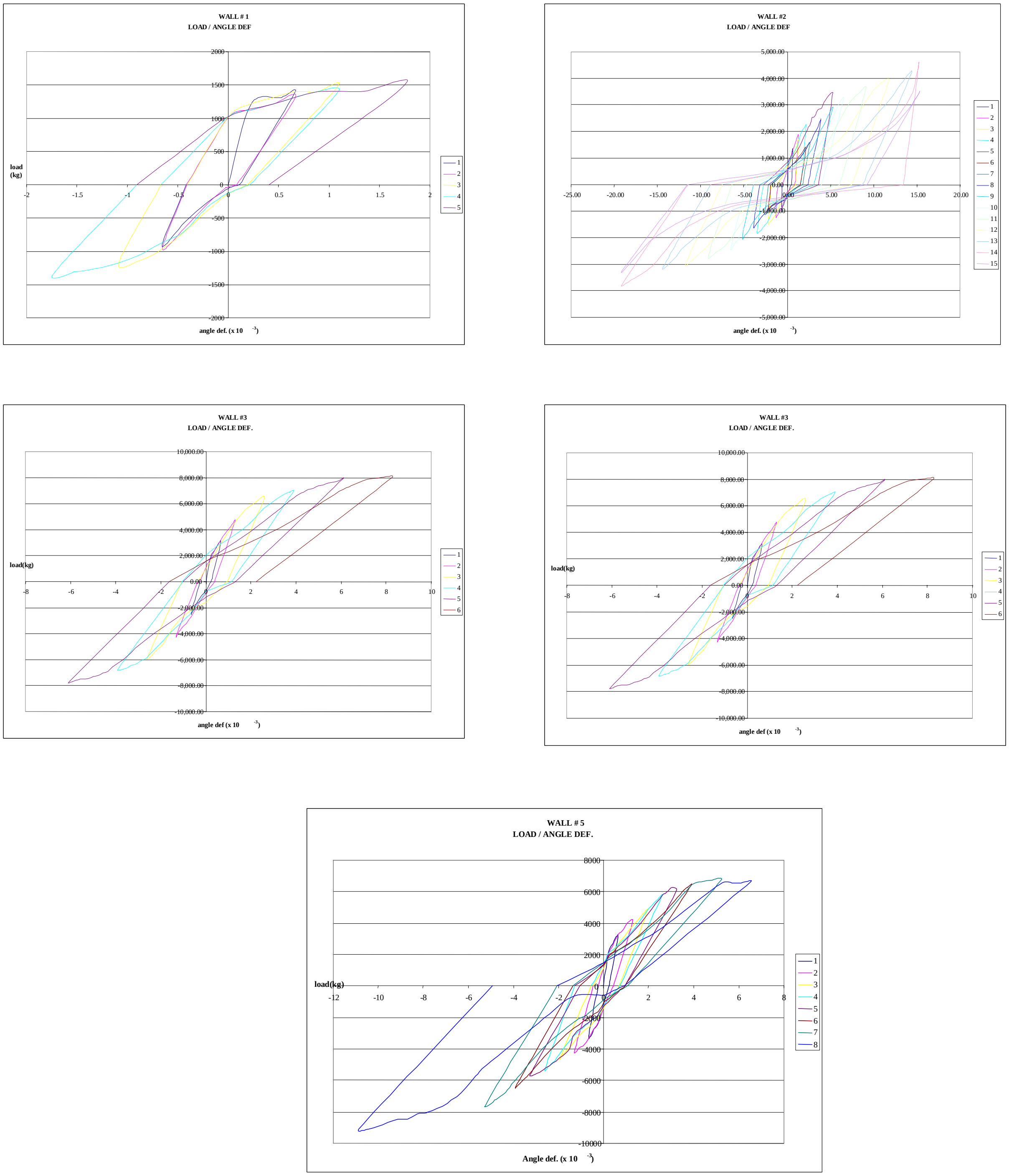

Figure 6.- Hysteretical Curves Lateral Load–Angle Deformation

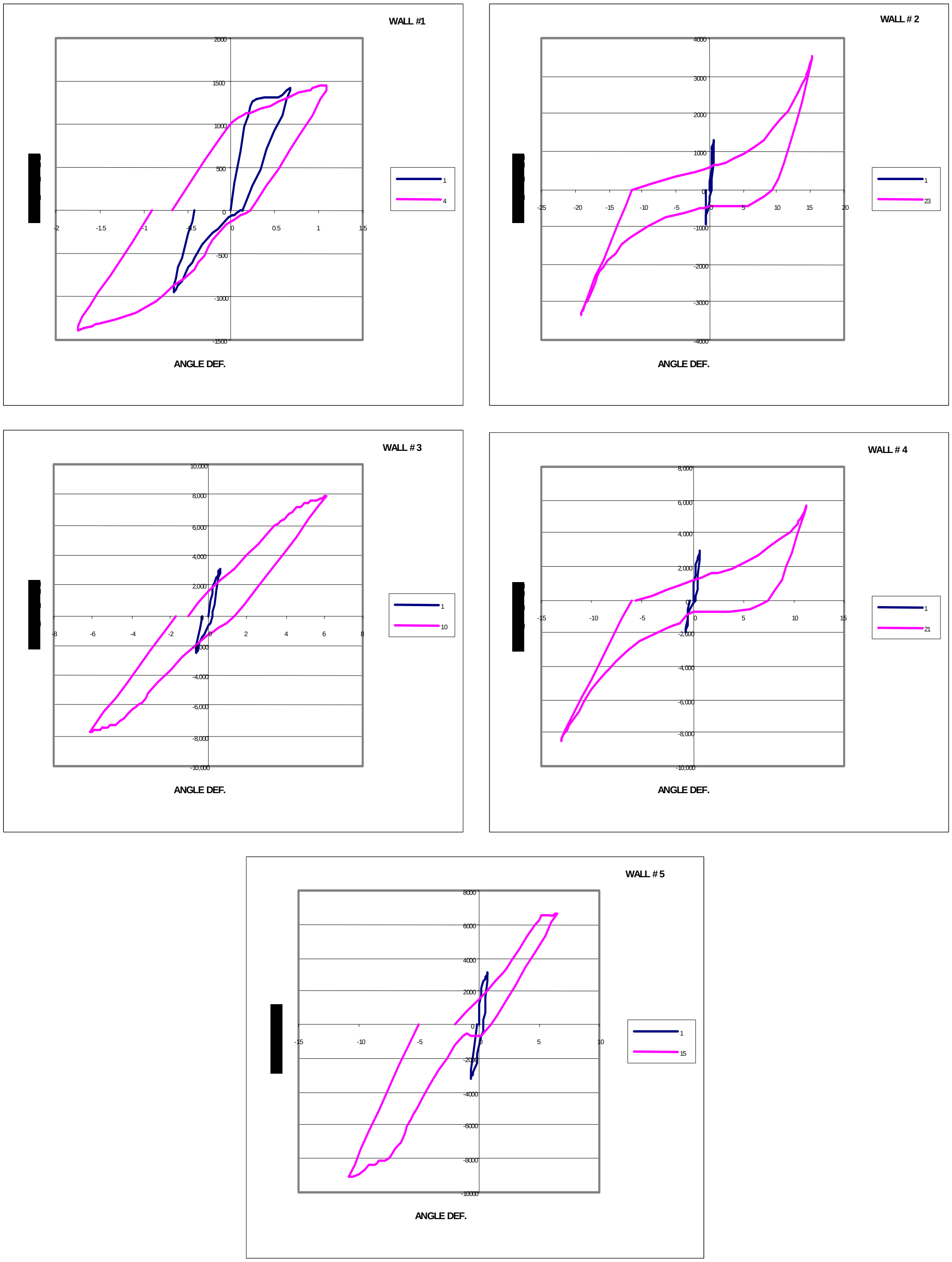

Figure 7.- Hysteretical Curves, First And Last Cycle

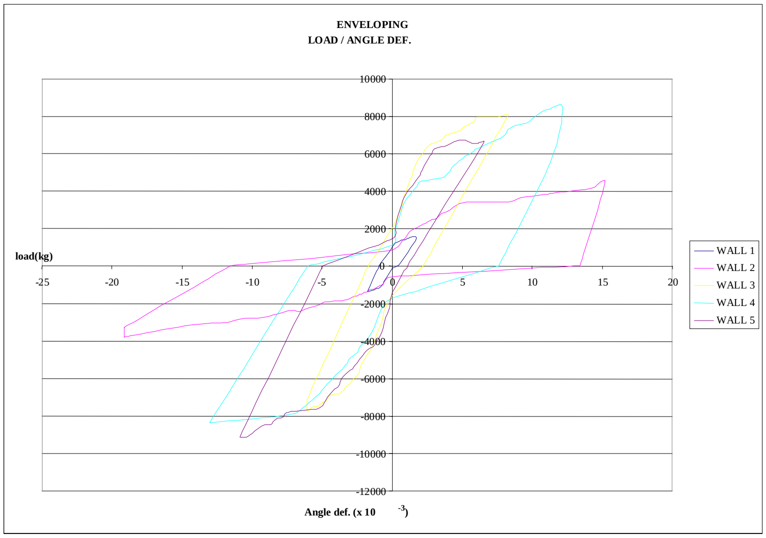

Figure 8.- Response Envelopings

Stiffness Degradation

The stiffness degradation between each cycle was defined with pick to pick stiffness as

K = lateral force/ lateral drift

The results of lateral stiffness degradation are plotted in figure 9.

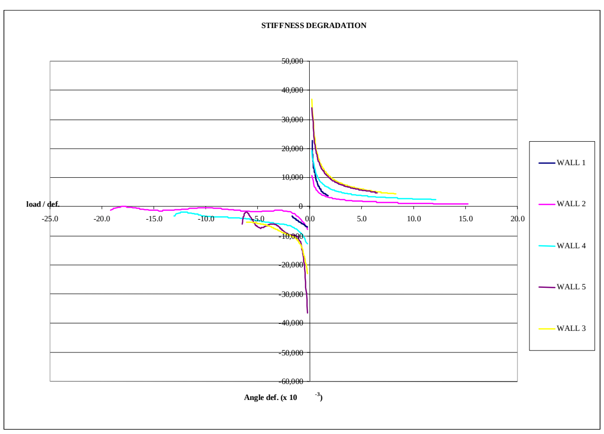

Figure 9.- Stiffness Degradation.

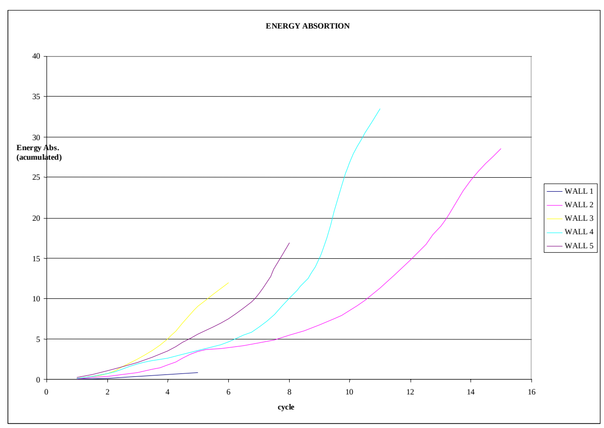

Figure 10.- Dissipated Energy.

Energy Disipation Capacity

The energy dissipation capacity showing during the test development was calculated as the area inside the hysteretic loops in the lateral load - displacement curve. Figure 10 shows the energy dissipation capacity.

Tests Results

During the test, it was observed that the first cracks initiate with small levels of lateral distortion, even for reinforced walls, after that the lateral stiffness decrease significantly, for the non reinforced walls the lateral resistance was sustained only for small increases in lateral distortion and this lateral capacity was sustained for significant increases in the lateral distortion, for the reinforced walls.

In the next section brief description of the observed behavior of the walls during the tests is presented.

In the wall No. 1 the first cracks appear with the first lateral load cycle, this cracks rapidly propagated during the next cycles. The main cracks appeared in horizontal direction in both ends of the wall due to tension stress caused for the bending moment in the wall plane.

The total damage in the wall was limited, comparatively with the other walls, mainly because the lateral movement of the wall was concentrated in the initial cracks. This cracks propagated rapidly depending the direction of the lateral load, generating a bending failure associated with a fast resistance and stiffness deterioration.

In the wall No. 2 as well as in the other walls, the cracking begins with the first load cycles, however in this case the lateral resistance keeps up an incremental tendency in the subsequent load cycles, even for high lateral story drift in the order of 0.012. The final lateral resistance of this element was increased significantly respect to the non reinforced wall, however the mayor contribution of the confined elements in the global behavior of the wall was the important increase on the ductility and also in the amount of energy dissipation capacity, both of them really important building properties on seismic zones

In the first step of the test, the cracking begins mainly in the principal diagonal of the element due to the diagonal tension by shear stress and it was observed the cracking propagation with the subsequences loading curves. The yielding in the longitudinal reinforce of the columns begins at the 0.012 drift, this phenomena was associate with a big amount in the wall damage and rapidly lateral resistance reduction.

The wall No. 3 presents a diagonal tension failure, the wall behavior was substantially better than wall No. 1 (made with handmade adobes). mainly in lateral ductility and lateral resistance, however, the global behavior still be fragile. In this wall the initial cracking starts in the 3rd lateral load cycle and it appeared in diagonal direction, from this moment the cracking propagates quickly with the consequent stiffness and lateral capacity reduction.

In the wall No. 4, the global behavior was similar as wall No. 2, but a bigger lateral capacity and ductility was observed. The cracking pattern begins in the second lateral load cycle and propagates rapidly in the wall faces. With the 0.01 drift a separation between columns and wall was detected, when this crack covered the most part of the column-wall intersection, the lateral capacity decreased.

The initial behavior of wall No. 5 was similar as the wall No. 3 (non reinforced wall) but the lateral capacity was sustained on small amount in the cracks opening. Due to the contribution of steel mash acting along the horizontal joints, however, the contribution of the steel reinforce was very limited because of it is small steel area ratio. The cracking pattern of this wall was like the wall No. 3.

Conclusions

During this study an important improvement between the industrialized adobe walls and hand made adobe walls was observed.

The use of reinforced concrete elements to wall confinement has not important influence on lateral capacity, however, its very significant in the element ductility and energy absorption capacity. This technique could be a useful method to reinforce and retrofit adobe constructions.

In the case of hexagonal wire mesh located in the longitudinal joint, the steel ratio used has not important effect on the global performance, but it is possible that the behavior could be improved adding a superior steel amount. Table No. 2 shows the main tests results obtained.

Table 2.- Walls Lateral Loads Tests Results .

Wall	Structuration	Adobe type	Failure pattern	Young Modulus MPa	Cracking Stress MPa	Stress Max MPa	Load Max KN	Stiffness Max KN/m	Total Energy absorved
1	Simple	Handmade	Flexural	66.9	0.014	0.019	14.66	23137	0.87
2	Confined	Handmade	Shear	54.1	0.013	0.056	43.99	18333	28.56
3	Simple	Industrialized	Shear	129.6	0.092	0.121	83.41	39932	11.98
4	Confined	Industrialized	Shear	129.6	0.087	0.128	83.50	36664	33.50
5	Int. reinforce.	Industrialized	Shear	149.1	0.081	0.137	89.23	44759	16.95

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