DYNAMIC BEHAVIOR OF ADOBE HOUSES IN CENTRAL MEXICO

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ABSTRACT:

Inside the towns of Zacatepec, Coyoacán and Tlayacapan exists adobe houses damaged by earthquakes. In Zacatepec typical adobe house was chosen in order to determine their dynamic behavior experimentally *in situ*. A reproduced model 1:10 was tested on vibration table, reproducing seismic ground motion caused by an earthquake at that period.

KEYWORDS: Adobe houses, Central Mexico, Dynamic Behavior.

1. INTRODUCTION

The study of seismic vulnerability implies the analysis of the seismicity in a region and its effects on the constructions. Inside Mexico there are many constructions of adobe masonry (clay blocks), that depending on their characteristics could be a risk for their inhabitants in an earthquake. Most of these types of houses are located in rural communities where a great number of these houses have been reinforced without suitable work supervision. The present study analyzes real masonry structures built with adobe, located in Santa Maria Zacatepec, Puebla; Tlayacapan, Morelos; and Coyoacán, D.F. The study for the structure of adobe tries to obtain the dominant period of environmental vibration in order to know its dynamic behavior in an earthquake. Records in the original structure and in a built scale model were taken only in Santa María Zacatepec. In this study the dominant period of the site was calculated by mean the Fast Fourier Transform (FFT) from noise records. The dominant periods were considered to determine its vulnerability in order to find the most efficient and economic method to reinforcing adobe structures, using local materials. Also a scale model of the house was built which was tested seismically, to predict the damage level that can appear in the real structure. In this study the dominant period of the site was calculated with spectral ratios H/V and FFT from vibration records.

2. PUEBLA STATE

The adobe is an economical construction material elaborated in many Mexican rural communities. The structures of adobe generally are built by the inhabitants, and the constructive technique depends on the each region or personal criteria. Specifically in Puebla State exists around a hundred thousand

houses of this material (INEGI, 2000). Most of these houses are very old (around a century) and have been damaged due to the degradation of their materials and by seismic events. Evidently its represents risk for their inhabitants. From the damage in constructions caused by the earthquakes, building codes have been elaborated in many cities. Nevertheless, many rural municipalities do not have any regulations and typically adobe houses are built without correct construction techniques. For these reasons, a study of seismic vulnerability was planned to determine the seismic resistance of an adobe structure localized in Puebla State.

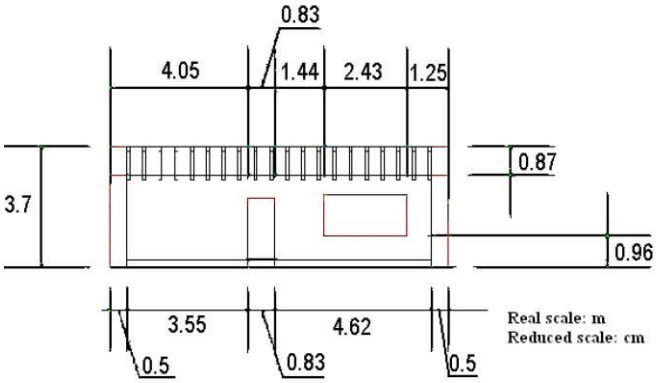


Fig. 1. Sketch of adobe house

Fig. 2. Adobe house, Zacatepec; Puebla.

2.1 Experimental determination of periods

Determination of fundamental frequencies (*fn*) is indispensable for reliable seismic design, because if *fn* of the structure is equal to the one of the ground it generates well known resonance phenomenon.

In order to analyze a representative construction of the existing buildings of adobe a search was made in the municipalities close to Puebla City, Cholula and Huejotzingo. The selected house is located in *Santa Maria Zacatepec* at 15 km from Puebla City. Adobe house dimensions and its configuration are showed in figures 1 and 2.

Environment vibration records were taken with Noise Tester SR04, 24 bit digitizer, SARA equipment. It has three orthogonal channels. We registered on the base and on the roof (fig. 3 and 4). Each record has approximately three minutes.

Fig. 3. Vibration records on the ground.

Fig. 4. Vibration records on the roof.

2.2 Processing records.

We grouped the records in the three orthogonal directions (N-S, E-W, and vertical) and were analyzed separately. Records were divided in five windows, each one with 30 s of duration. Later, from every window we calculate the FFT. Different FFT obtained from different windows from the same record were averaged. From this procedure we obtained the natural period of the adobe structure.

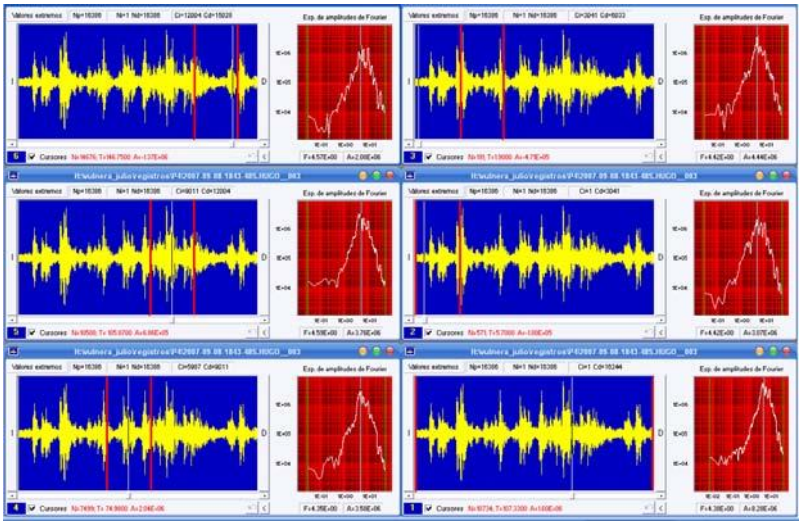
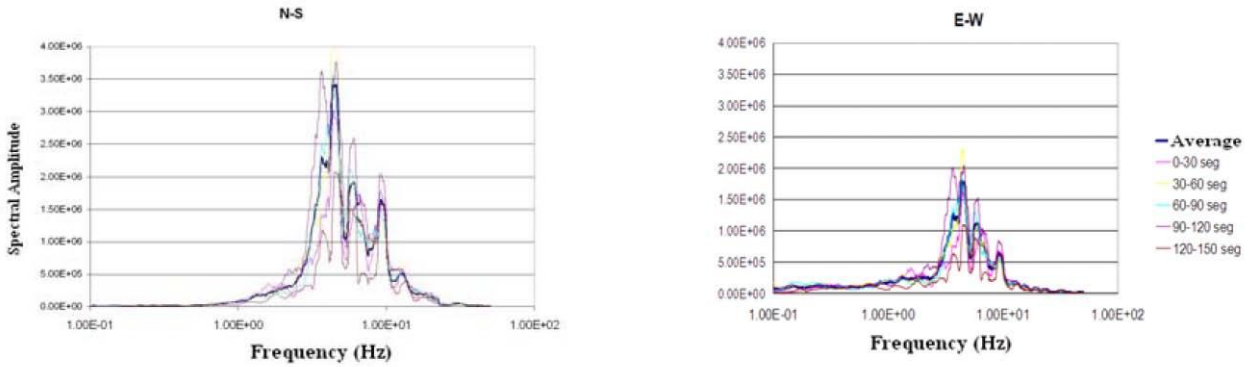


Fig. 5. Noise records and FFT graphics, N-S component.



a) b)

Fig. 6. FFT Average, a) N-S b) E-W.

The *fn* is 4.42 Hertz (fig. 6) both directions (the North-South and the East-West) reason why its natural period is of 0.22 s.

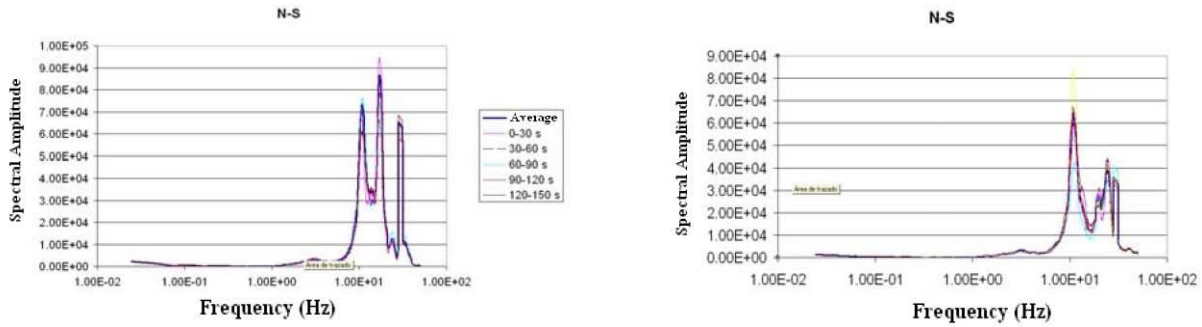
2.3 Determination of the dominant periods in a scale model

In order to know a better way the behavior of a masonry structure of adobe, was taken the decision to construct a model on 1:10 scale from the house. The study of vulnerability was made to the scale model (fig. 1 and 2). The model was damaged with a seismic simulation so that later a method of restoration of the same one is proponed, in addition to predict the possible damage in the real structure.

Fig. 7. Recording noise on the Scale model.

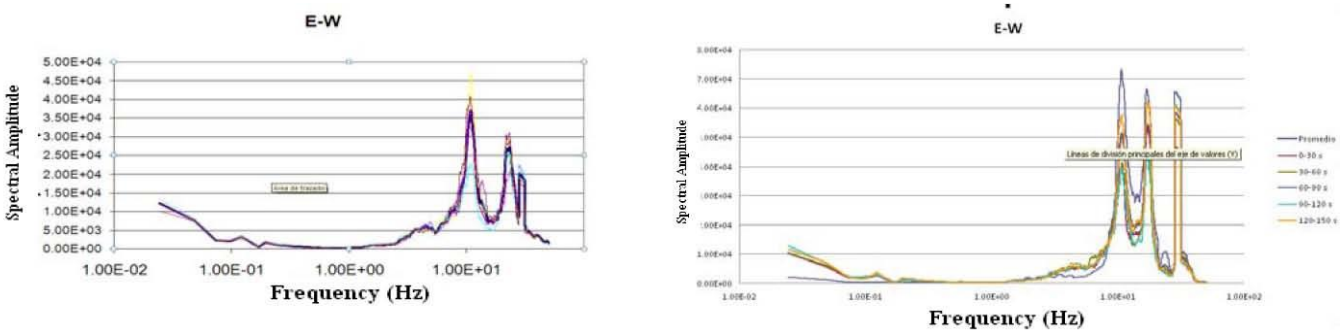
2.4 Simplified Seismic Test.

The seismic event was simulated on rollers in order to observe the damages that it would generate in the structure. Also environmental vibration registries were taken in the scale model (fig. 7) before and after the simulation to be able to observe in both cases the dominant periods with the same method previously seen.



a) b)

Fig. 8. FFT Average, N-S component, a) before the test b) after the test.



a) b)

Fig. 9. FFT Average, E-W component, a) before the test b) after the test.

The *fn* before the test was 10.9 Hertz (fig. 8 and 9) both directions (the East-West North-South and) reason why its natural period is of 0.09s, and after the test *fn* is of 17.1 Hertz in both directions reason why its period after the test is of 0.056 s.

3. ADOBE HOUSES IN TLAYACAPAN, MORELOS STATE

Adobe is currently still used in Mexico, especially people with limited resources. The town of Tlayacapan is located in the northwestern of Morelos State (Fig. 10). This municipality has houses built with brick, cement and many with adobe and tile. The place situated on soils composed of limestone, andesites, conglomerates, basalt, ash and volcanic soils (Tapia, 1991). There are many adobe houses and chapels and highlight their cracking due to their antiquity.

The self-building allows for great concern over the danger of any collapse in adobe dwellings in Tlayacapan. The adobe houses have cracking that remains in time. The serious damage to homes, occur without a good foundation. It

is partially or completely buried under the ground surface, is designed for sustaining and anchoring the superstructure and transmits loads directly to ground through the main architectural elements of the building.

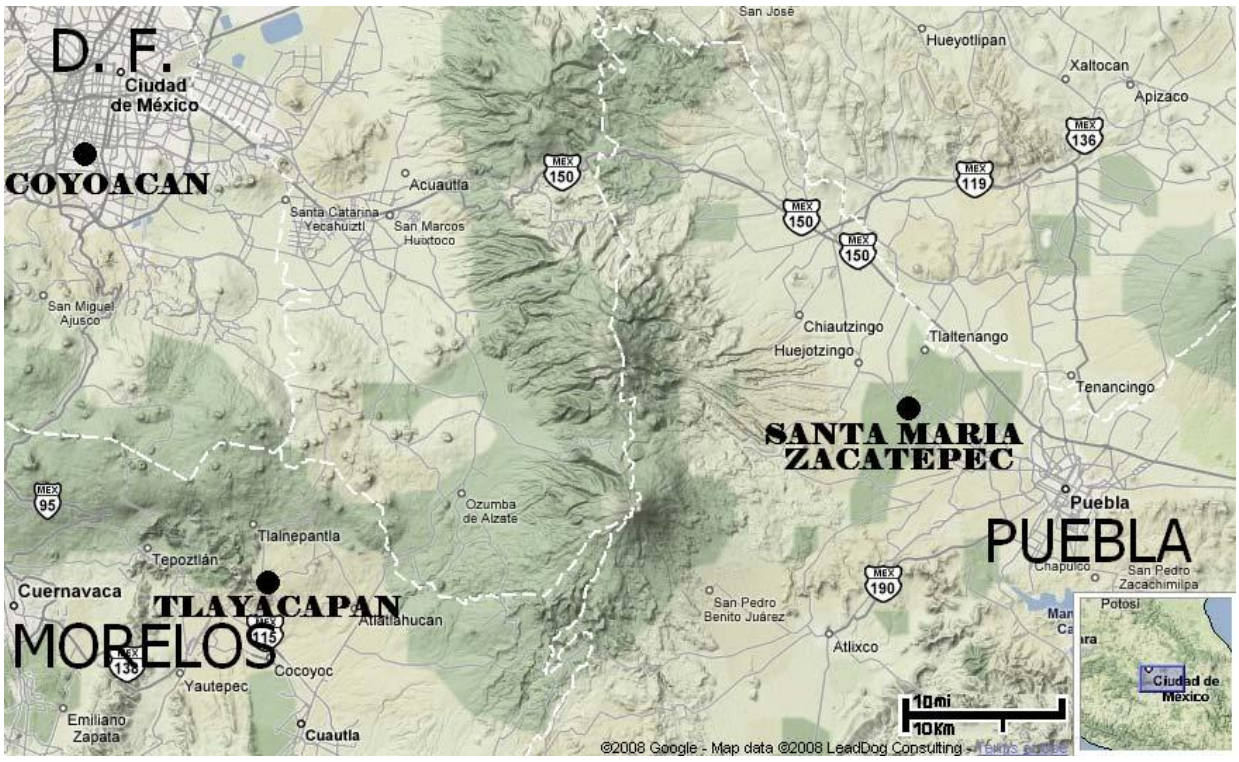


Figure 10.- Location (in black circle) of Santa Maria Zacatepec (Puebla), Tlayacapan (Morelos), and Coyoacán (Distrito Federal). At the bottom center is Popocatepetl Volcano.

3.1 Adobe Blocks

The adobe is formed filled with mud by hand into wooden molds; it is 20% clay and 80% sand, with water flowing form a mass that can be emptied into molds on the floor. When drying the mixture takes the form of the mold is exposed to the sun so that water will evaporate and dry after being removed from the mold. After the sun gets another 30 days for the bloc is harder.

The common measures of this brick are 38 x 38 x 38 cm or 40 x 20 x 10 cm. Some of the features Adobe is a litmus test, sound and no echo, also controls the temperature of the house. We must take into account that in Tlayacapan houses are made of adobe in the economic and because its soil lends itself to do.

3.2 Adobe Houses

Moreover analyze the form of construction in the town of Tlayacapan, we find about 50% with adobe houses of which most homes already have constructive reinforcements for not harmed in any major earthquakes or fails by overload at the important elements of construction, however there is a percentage of homes without lintels, frames in window and doors, columns, beams supporting the roof, like light roofs with serious danger to the population.

In Tlayacapan, we found a house with two vertical cracks (Fig. 11) and have no columns, beams and frames in window and door and reflecting self- building. A house with a wall of stone in its base of 0.5m to 1m thick, the adobe blocks with a long between 45 and 50 cm, which gives them good stability to adobe walls, roofs with tiles or sheets (prior coverage insulating material) and wooden beams (figure 12).

Figure 11.- Adobe house in Tlayacapan, presents vertical Figure 12.-Another adobe house with reinforcements. Cracking, there are not beams or columns. A short wall with frames on doors and windows and in its base of stones in base is not sufficient, in supports the house with stones about 50 cm high. The roof is with tiles on foot. Its roof is laminate.

4. ADOBE HOUSES IN COYOACAN, DISTRITO FEDERAL

We identify the techniques and materials used in various buildings (Minke Gernot, 2001; Meli, 1998), specifically rocks and mud, in the historic center of Coyoacán, south of Mexico City (Fig. 10), some damage. We sought information about buildings constructed with rocks and mud in the Historic Center of Coyoacán (INAH, 2002).

4.1 Adobe Buildings

With the investigation has been able to appreciate that the construction of adobe houses and walls located in the Historic Center of Coyoacán counted as one of its most important structural elements, a wall of rocks between 50cm and 1m of height in its base.

The adobe house showed in Fig 13(a) have a good state of preservation, as well as the presence of wall in its base and frames to doors and windows made of stone, also shows coverage and flattened in good condition in the façade

(a) (b) (c) (d)

Figure 13.- Adobe houses in Coyoacán D.F.. (a) The first photo shows a good coverage of cement in its façade. (b) The facade neglected, without frames in its door. These houses have a wall in its base with stones near 1 m. (c) It is a fence made of adobe without columns, only a short wall of stones in its base. (d) Shows a diagonal crack in its interior as in its exterior. in the room with adobe walls (church “La Conchita”).

The house in the Fig 13(b) is in a state of neglect, but not manifests a state conservation severely damaged from its facade. Like the previous houses presenting stone at the base of their walls. It is appreciated that the construction of adobe walls is reinforced by a column of brick to be located between two orthogonal adobe walls. Despite the damage to the flattened, the structure of the exterior walls of the house shows no significant damage as mud cracks.

In the Fig 13(c) a wall of stone at the base, however a lack of columns at one end of the wall, just where the property ends on the street. It has in certain places in the top of the wall, coverage for the rain. Some parts of the wall are leaning. At the base of the walls there is a minor than 50cm high of stones. The case of fences made of adobe, not showed the existence of a column that shared the wall of stone and adobe.

In the Fig 13(d) presents a room damaged by a diagonal crack of tension in the adobe wall viewed in its interior as in its exterior (Church "La Conchita"), because of the slight sinking of its sacristy.

5. RECOMEDATIONS

It is recommended training in construction techniques and reinforcement, to safeguard the life of any inhabitant before the earthquake. It is vitally important, to create awareness in people who build on sites with seismic risks to which they can confront their buildings, as well as offer training in handling techniques reinforcement structural, to reduce the damage that buildings may suffer thereby achieving the greatest possible safety of users of the building.

Buildings of adobe since the earliest constructions and today are made of a way to make more resilient and efficient. To have a well document in hand capable of giving sufficient information to prevent further damage or even a single disaster in the future.

6. CONCLUSIONS

The study of Seismic Vulnerability determines the resistance of the structures and is of great help for the detection of vulnerable sections to earthquakes which on having been reinforced in a suitable way can avoid both the cracking and the collapse of the walls. The repair and the reinforcement in a structure can be vital in a seismic event for what it is necessary to do a study of vulnerability to the houses, especially to adobe houses due to the fact that they are ancient structures that have been, in the major one of the cases, repaired without having the suitable supervision.

The methodology to determine the dynamic response of adobe structure is simple if all the factors that affect in the vibrating period of the structure are taken in mind. In base to the effects in the scale model it is possible to determine a scale factor in a real structure and therefore quantify the damages in a given event.

We found dynamic response of a simple adobe structure in Santa Maria Zacatepec in Central Mexico, experimentally in situ. From a model of adobe house made of in laboratory in a reduced scale 1:10, was determined its dynamic behavior as determined due to earthquake of important magnitude. This scaled model was tested in a vibration table, reproducing seismic ground motion caused by an earthquake. We calculated the period vibration of the typical adobe house and from scale model.

Inside of Coyoacan, the adobe houses presenting stone at the base of their walls. It is appreciated that the construction of adobe walls is reinforced by a column of brick to be located between two orthogonal adobe walls. Despite the damage of the facade, the structure of exterior walls of the house shows no significant damage as mud cracks. In Tlayacapan, adobe house presents vertical crack, there are no beams or columns, short wall of stones in base is not sufficient, in supports the house on foot. The roof normally is laminate or with tiles. Damage can be repaired with established techniques for reinforcing in a fast and economic way with materials from the same region and applying appropriate construction techniques.

7. ACKNOWLEDGMENTS

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