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EFFECT OF THE INTERIOR MASONRY WALLS IN THE SEISMIC BEHAVIOR OF CONCRETE HOUSES – AN EXPERIMENTAL STUDY

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ABSTRACT:

The 1990 Census of Puerto Rico reported that 75.20 percent of the residential houses were built using a combination of concrete walls and concrete roof. A large number of these houses are constructed with reinforced concrete walls oriented primarily in one direction (strong direction), and masonry walls constructed perpendicular to the concrete walls (weak direction). In the weak direction, the masonry walls bounded by the R/C walls are the only system available to resist the inertial loads. Until now, the in-plane capacity of these masonry walls has not been clearly established, nor the lateral capacity of residential houses in the weak direction. This paper, presents the results obtained from carrying out experimental tests to full scale model of the residential houses tested in the weak direction. The experimental results showed that the lateral strength in the weak direction of a typical house increased 7 times while the lateral stiffness increased 177 times by adding unreinforced or reinforced masonry wall between the concrete walls. If unreinforced masonry walls are used, the failure mechanism will be governed by crushing of the masonry walls at the corner and the punching shear failure of the R/C walls. When reinforced masonry panels connected to the wall-slab frame were used, the collapse mechanism was governed by the failure of the last row of the concrete block wall and the punching shear failure of the R/C walls.

KEYWORDS:

Infill walls, Masonry walls, Reinforced concrete, Cyclic loading

1. INTRODUCTION

Puerto Rico, by its geological conditions, is vulnerable to seismic events. The Island is located in the limit between the North America and the Caribbean plates. Throughout the years, several strong earthquakes have shaken Puerto Rico since the beginning of its colonization (1670, 1787, 1867 and 1918). Since the last strong earthquake occurred (1918), 90 years have passed and thus currently there is a high risk that a severe shaking may occur.

The collapse of structures and the loss of human lives during an earthquake increase when the structural system used to withstand the seismic loads have not been designed following an appropriate design philosophy. The 1990 Census of Puerto Rico reported that 75.20 percent of the residential houses were built using a combination of concrete walls and concrete roof. A large number of these houses are constructed with reinforced concrete walls oriented primarily in one direction. This orientation will be referred in this work as the strong direction. After the R/C walls and the slabs are finished, masonry walls are constructed perpendicular to the concrete walls. For this work, the masonry wall direction will be referred as the weak direction. In the strong direction, the reinforced concrete walls provide adequate structural capacity for resisting the inertial loads generated during a seismic event. In the weak direction, the masonry walls are the only system available to resist the inertial loads in addition to the reinforced concrete walls and roof acting as frames in their weak direction.

Until now, the in-plane capacity of these masonry walls has not been clearly established, nor the lateral capacity of residential houses in the weak direction. Since the only reliable way to obtain the capacity of these structures in their weak direction is by performing experimental tests, this research is focused in carrying out experimental tests to full scale model of the residential houses and determining their structural capacity in the weak direction when subjected to cyclic lateral loading.

2. RESEARCH OBJECTIVES

The response of infilled frames subjected to in-plane lateral loading has been investigated by various researchers (Stafford 1967, Klinger 1977, Abrams and Paulson 1991, Mehrabi et al. 1996, Lee and Woo 2002) during the last decades. The results of these investigations revealed that the failure mechanisms are governed by the relative strength and stiffness of the infill with respect to the surrounding elements. However, all these investigations were carried out on infill bounded by steel or reinforced concrete frames composed by beams and columns. The behavior of infill panels surrounded by reinforced concrete walls acting in their weak direction has not been studied. In Puerto Rico houses, the infill panels surrounded by reinforced concrete walls are the only structural component to resists the earthquakes in the weak direction of the house. Therefore, determining the capacity of these types of infill panels is of fundamental importance for assessing the earthquake risk of the Puerto Rico houses.

3. TEST SPECIMENS

The behavior of the structural and non-structural elements of the residential houses was experimentally investigated using six different specimens. The results of three of the six specimens are partially presented here. Further information about the tests and their analytical modeling, can be found in Velez (2007). The construction details used in the specimens were based on the result of a survey. The survey consisted of obtaining construction drawings of residential houses and visiting construction projects. During the survey study, special attention was given to the connections between the footing and the roof with the reinforced concrete wall or with the masonry wall. Also, the amount of horizontal and vertical reinforcement of the concrete and masonry walls was noted.

3.1 Specimen 1-Control Model

The first specimen was a typical reinforced concrete one-story wall-slab frame with two bays. This specimen was set as control model to obtain information about the overall lateral capacity of the slab-wall interaction. The dimensions of the structural elements, steel reinforcement patterns, and connection details between the footing and the roof with reinforced concrete wall for this specimen are shown in Figure 1. This specimen has a width of4 feet -1.5 inches. The concrete in this and the other five specimens had a specified compressive strength of 3,000 psi.

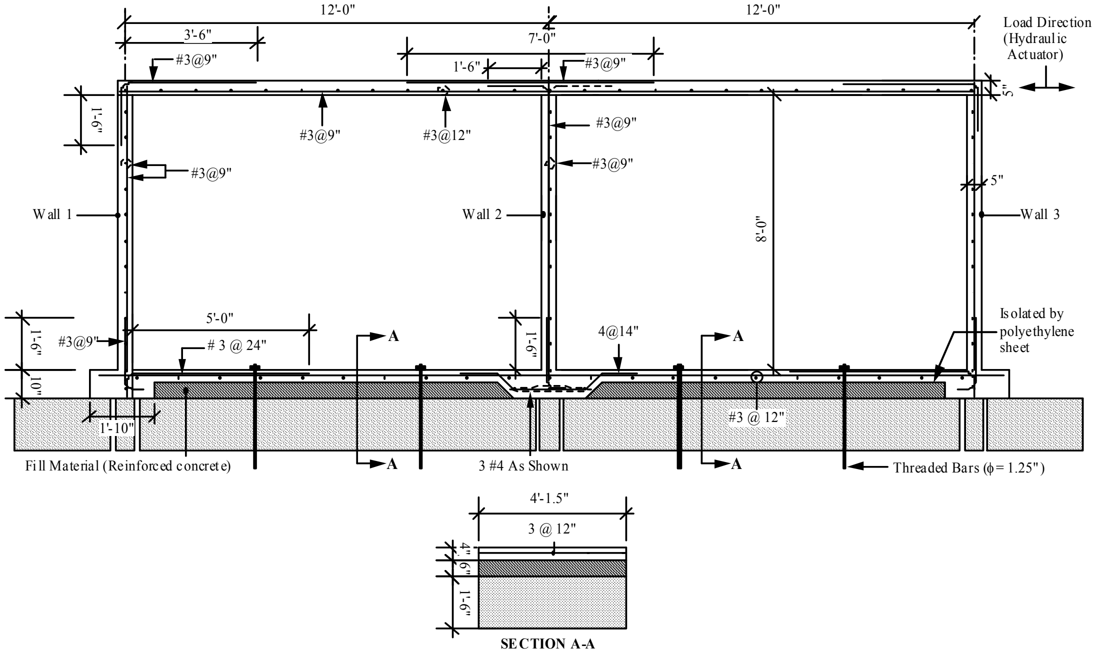

Figure 1 Details of dimensions, reinforcement and foundation for Specimen 1-Control Model.

3.2 Specimen 2-Unreinforced Masonry Wall

The second specimen illustrated in Figure 2, was constructed in the same fashion as the control model, with the difference that the specimen strip was 6 feet -1.50 inches wide and one bay was infilled with an unreinforced concrete block wall. The purpose of this specimen was to obtain the capacity of the system with an un-reinforced infill panel bounded by slab and wall elements.

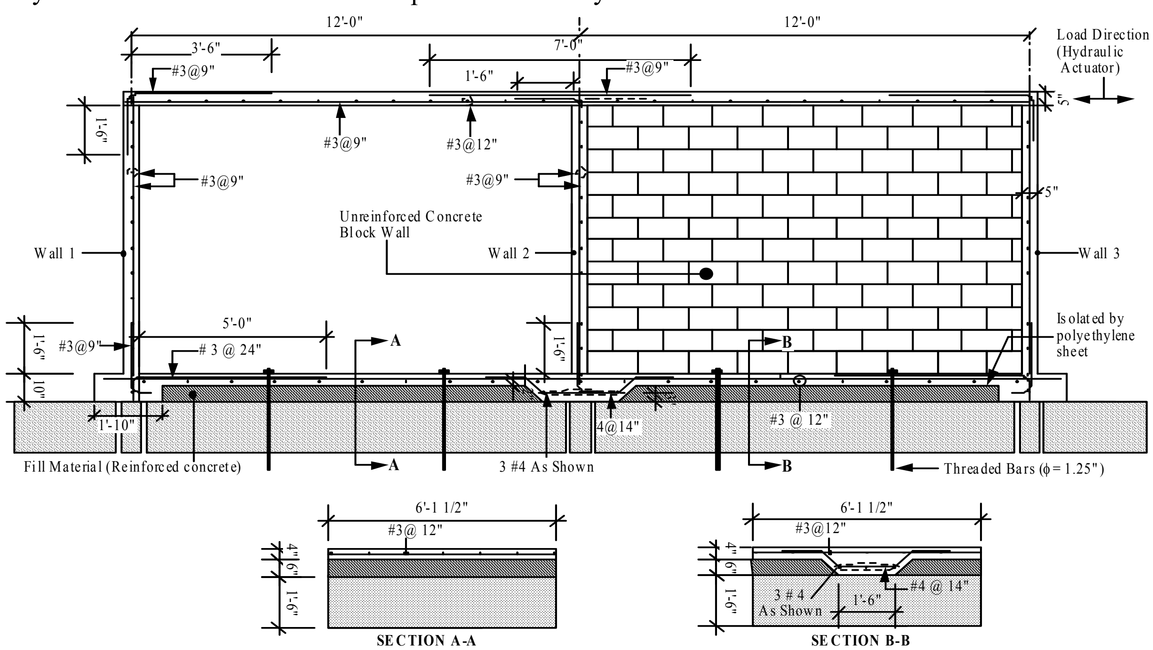

Figure 2 Details of dimensions, reinforcement and foundation for Specimen 2

3.3 Specimen 3-Reinforced Masonry Wall

Details of the dimensions, reinforcement, and foundation for specimen number 3 are shown in Figure 3. In general, the Specimen 3 was built following a construction process similar to that used in the second specimen, with the difference that the masonry wall was connected to the surrounding elements and was reinforced in the vertical and horizontal directions.

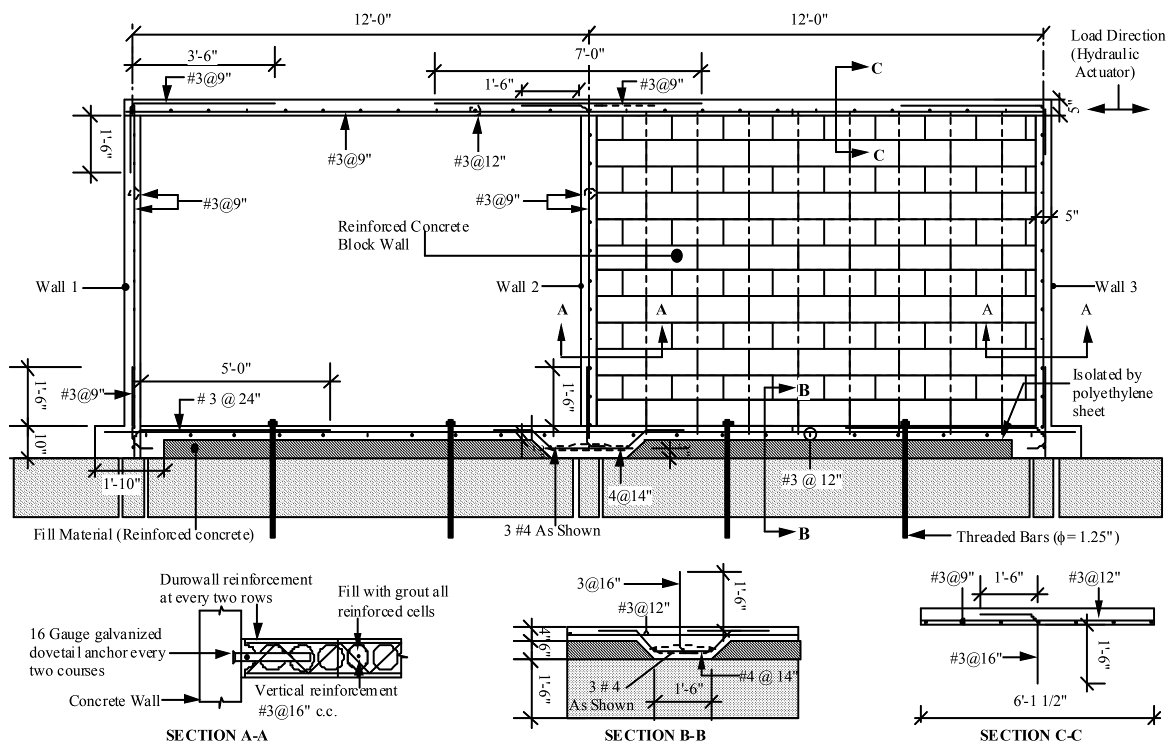

Figure 3: Details of dimensions, reinforcement and foundation for Specimen 3

4. TEST RESULTS

The six full-scale specimens of the slice of a typical house were aligned in the East-West direction. This means, when the specimen goes toward East (pulled), the sign convention adopted for the lateral displacement and lateral load are positives. On the other hand, when the specimen was loaded in the other direction, toward the West (pushed), the lateral displacement and the lateral load are negative.

For each test, figures (a), and (b) are presented. Figures (a) illustrate the lateral capacity of the specimen in term of its effective self weight (denoted W_{eff} which is the weight excited in the dynamic analysis), and figures (b) illustrate the failure mechanism observed during the test.

4.1 Specimen 1-control model

The control model was a typical reinforced concrete wall slab frame with one single-story and two bays. The experimental results of this specimen revealed information of the overall lateral capacity of the slab-wall interaction. The pinching of hysteretic loops was due to opening and closing of concrete wall cracks. Figure 4(a) shows the ratio between lateral load applied to the specimen and its effective weight (W_{eff}). The specimen effective weight was calculated taking into account the roof slab weight plus the tributary weight of the upper part of three reinforced concrete walls. The specimen had the capacity of resisting a lateral load of 43 percent of its W_{eff}. The specimen exhibits a ductile behavior, where five plastic hinges developed in the three reinforced concrete walls. The deformed shape and the failure pattern of the control model, such as flexural cracks at the roof slab joints, are shown in Figure 4(b).

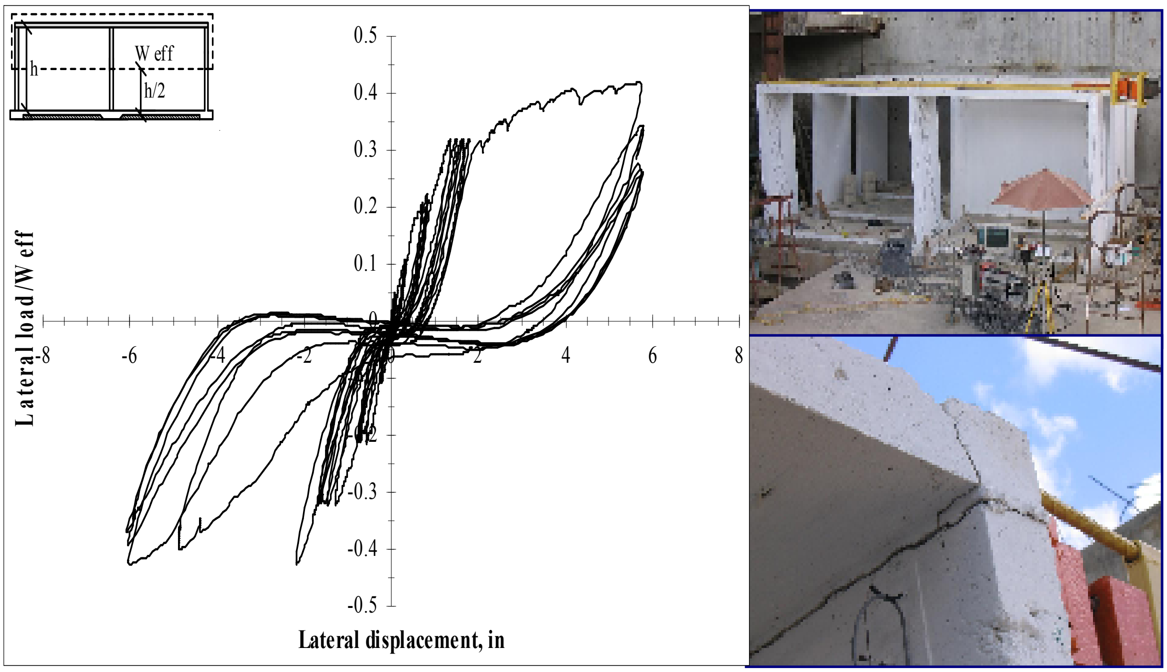

Figure 4 (a) Lateral load normalized with respect to the W_{eff} , (b) Failure patterns.

4.2 Specimen 2-Unreinforced Masonry Wall

Specimen 2 was a typical reinforced concrete wall slab frame with one bay infilled with an unreinforced concrete block wall. Figure 5(a) shows the unsymmetrical load-displacement curve of the second specimen. The unsymmetrical behavior was mainly due to the effect of the specimen self weight. When the vertical component of the diagonal strut developed in the infill panel exceeds the tributary specimen self weight acting on the interior and exterior concrete walls, the specimen started to uplift. The uplift of the foundation of the wall 3 (exterior wall) started at a lateral load of -12.50 kips in the push direction, while the uplift of the foundation of wall 2 (interior wall) was observed at 20.0 kip in the pull direction.

The curve illustrated in Figure 5(a) was normalized by effective weight (W_{eff}) of Specimen 2. For this specimen, its effective weight included the weight of the roof slab plus the tributary weight of the upper part of three reinforced concrete walls and masonry wall. For lateral load lesser than $0.66W_{eff}$, the specimen showed a linear behavior. The maximum lateral resistances were $1.73W_{eff}$ in the negative direction and $1.93W_{eff}$ in the positive direction.

The failure pattern of second specimen was governed by the punching shear failure of the interior and exterior concrete walls, and the corner crushing of the infill panel. The corner crushing of the masonry wall and punching shear failure of the interior reinforced concrete walls are shown in Figure 5(b).

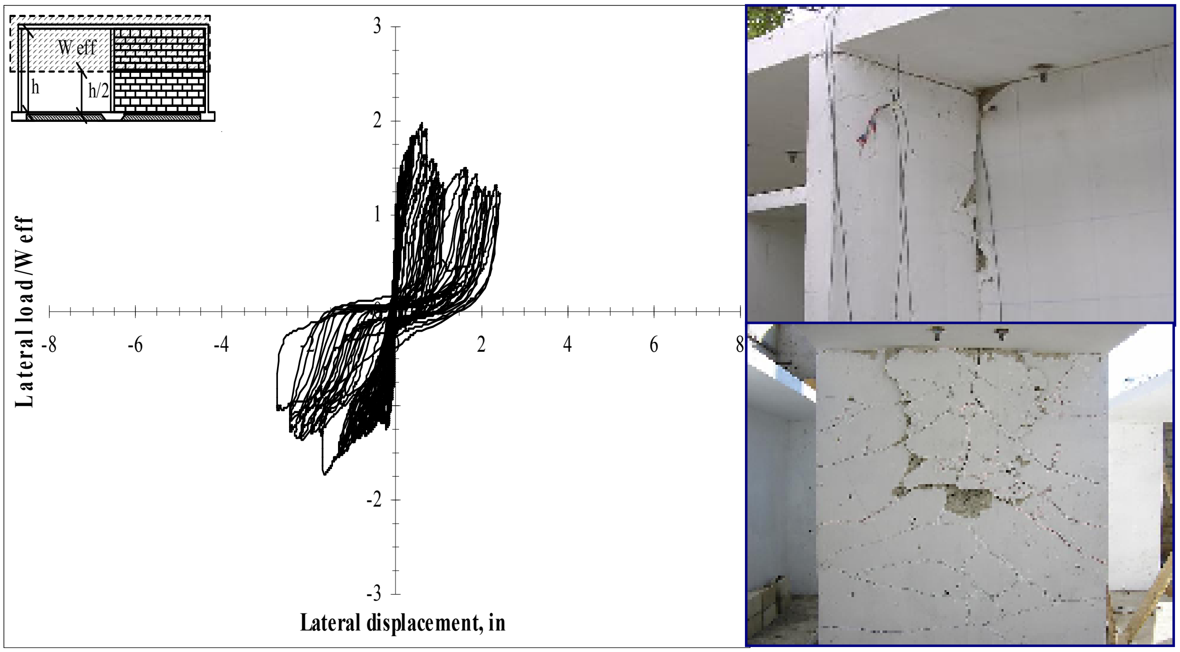

Figure 5 (a) Lateral load normalized with respect to the W_{eff} (b) Failure patterns.

4.3 Specimen 3-Reinforced masonry wall

Specimen 3 was built following construction process similar to that used in Specimen 2, with the difference that the masonry wall was reinforced in the vertical and horizontal directions with No. 3 bars spaced each 16 inches and dur-o-wall type truss placed each two rows of blocks, respectively. The infill panel was connected to the floor and roof slab using hooked bars and to the R/C walls via metal ties, commonly called dove tail. The maximum resistance of this infill panel was governed by the punching shear failure of the interior wall accompanied by the failure of the last row of concrete blocks at 41.40 kips and 1.20 inches of displacement. Once the punching shear failure of central wall happened, the roof slab started to move relative to masonry wall, failing concrete blocks. The concrete block closer to the exterior reinforced concrete wall failed by crushing mode, while other blocks failed due to connection between the roof slab and the masonry wall, which was made using No. 3 hooked bars. After the maximum load capacity was reached, a severe strength and stiffness degradation were observed in the following load cycles.

For the third specimen, the overall lateral capacity in terms of W_{eff} is shown Figure 6(a). For lateral load smaller than W_{eff}, the system showed stable hysteretic loops without strength and stiffness degradation. The specimen resisted lateral loads in the order of $2.45W_{eff}$ and $-2.04W_{eff}$, in the pull and push directions, respectively. Figure 6(b) shows the crack pattern of the specimen observed during the test. At the end of test a contact zone of 27 inches between the interior wall and masonry wall was observed, while for the exterior wall the contact zone was 14 inches.

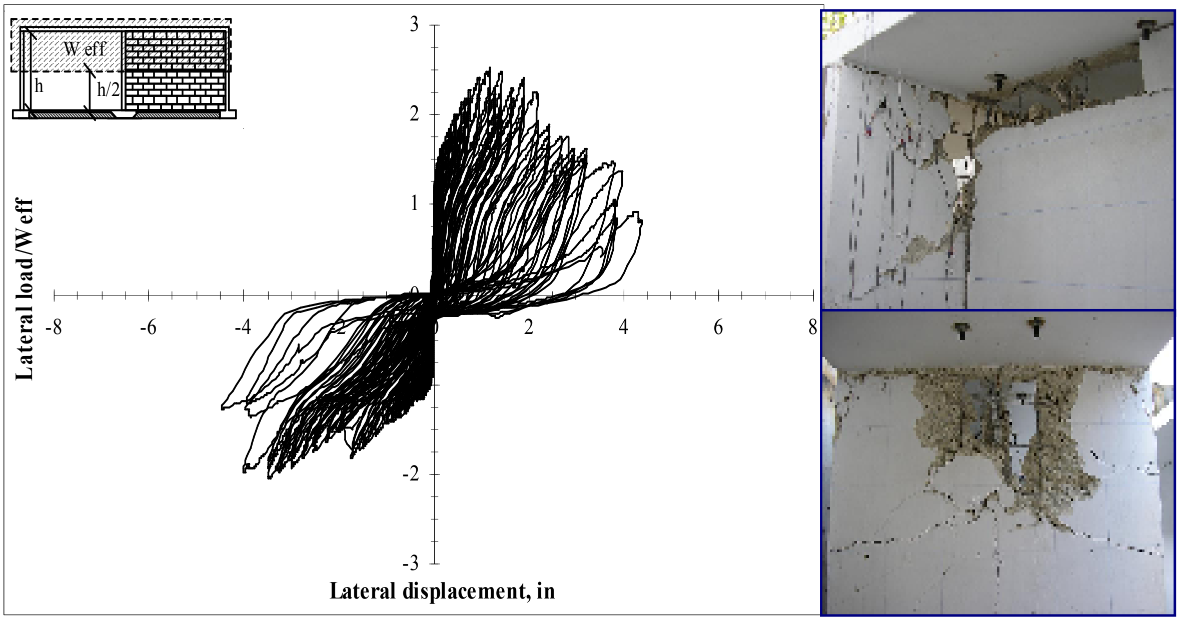

Figure 6(a) Lateral load normalized with respect to the W_{eff} (b) Failure patterns.

5. CONCLUSIONS

Six full-scale specimens were constructed and experimentally investigated in order to establish the lateral behavior and find the different failure modes of the house components. The experimental results of three of these specimens are reported here-in In these specimens the behavior of various parameters were investigated, among them were wall-slab frame behavior, infilled frame behavior, un-reinforced and reinforced solid masonry panels. The following conclusions and findings are drawn based on the experimental results:

Wall-slab frame vs. In filled Masonry Panel. The wall-slab frame exhibited a ductile behavior, with plastic hinges developed at the bottom and top of the reinforced concrete walls. During the test it was observed that the steel reinforcement details used in the joints between the roof slab and the exterior R/C walls did not allow for the development of the full reversal moments, which is generated by the cyclic lateral loadings. When an unreinforced or reinforced solid panel is added to the system, the lateral strength increased 7 times while the lateral stiffness increased 177 times. In both cases, the inclusion of the infill panels significantly improved the lateral strength, the lateral stiffness and the energy dissipation of the specimens.

Unreinforced vs. Reinforced Masonry Panel. The maximum resistance of the wall-slab frame with an unreinforced solid panel was governed by the masonry corner crushing and punching shear failure of the reinforced concrete walls which was caused by the internal strut action developed in the unreinforced infill panel. When the infill panel was reinforced and connected to the wall-slab frame, the collapse mechanism was governed by failure of the last row of the concrete block wall and the punching shear failure of the R/C walls. The failure of the last row of concrete blocks was produced by the hooked bars, which were used to connect the roof and floor slab to the reinforced masonry wall. The experimental results showed that by adding reinforcement to a masonry panel, it is possible to increase the lateral capacity of the system between 17 and 27 percent, depending of the load direction. The lateral stiffness of a system with reinforced masonry panel was 10 percent greater than the same panel but without reinforcement.

6. ACKNOWLEDGEMENTS

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