A THREE COMPONENT SHAKING TABLE STUDY OF THE DYNAMIC RESPONSE OF A SINGLE STORY MASONRY HOUSE

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SUMMARY

Earthquake damage to masonry construction during recent years underscores the need for a better understanding of the seismic response of these structures and the establishment of rational reinforcing requirements. An experimental investigation aimed at determining reinforcing requirements for single-story masonry dwellings in Uniform Building Code Seismic Zone 2 areas of the United States has been conducted at the University of California at Berkeley. During the most recent tests the masonry walls of a house model were simultaneously subjected to two horizontal (in-plane and out-of-plane) as well as to vertical input motions. The earthquake performance of the unreinforced as well as the partially reinforced house model is discussed. The unreinforced house model withstood satisfactorily simulated earthquake motions of moderate intensity; the partially reinforced house model withstood satisfactorily simulated motions of very high intensity.

INTRODUCTION

During the past seven years the U.S. Department of Housing and Urban Development has supported a series of shaking table tests at the Earthquake Engineering Research Center (EERC) of the University of California at Berkeley. The investigation was entitled "Laboratory Studies of the Seismic Behavior of Single Story Masonry Houses in Seismic Zone 2 of the U.S.A.".

The objective of this program has been to evaluate the Department of Housing and Urban Development (HUD) requirements for single story masonry dwellings in seismic Zone 2 areas of the Uniform Building Code, by investigating the earthquake performance of single story masonry house models, constructed with full scale components and subjected to simulated earthquake input produced by the EERC earthquake simulator facility.

In what follows some essential details and results obtained in the most recent shaking table tests will be discussed. Complete data on the test procedures, instrumentation and test results are contained in the project report [1].

During earlier tests four house models were studied, namely House 1, 2, 3 and 4 [2], [3]. In all these tests the direction of the horizontal motion was parallel to two of the walls of the model (in-plane) and perpendicular to the other two walls (out-of-plane). During the present study of House 5, a model essentially the same as the previously tested House 4, was oriented on the shaking table with its axes at 30° to the horizontal direction of table motion,

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so that its walls were simultaneously subjected to in-plane and out-of-plane excitation as well as to vertical input motion. In this way the importance of the combined in-plane and out-of-plane action of earthquake input on the masonry walls was investigated.

TEST PROCEDURES

The test structure consisted of four walls with standard size door and window openings (Fig. 1). The walls were not interconnected at the corners but only at the top level by a wooden roof. Like the earlier models, House 5 was square in plan with 16 ft wall length and 8 ft 8 in. wall height. 12,000 lb weight was added at the top of the roof in order to simulate the load per unit length of prototype loadbearing walls, which were assumed to be three times longer and to support a roof load of 20 lb/sq ft. House 5 was built on a continuous concrete foundation and was transported to the shaking table fully assembled. The foundation block was a rigid system representing stiff-soil site conditions for moderate earthquakes without any soil-structure interaction. The masonry was built of standard hollow concrete blocks with nominal dimensions 6 x 4 x 16 in. laid in running bond with mortar across the shell faces and with mortar joints carefully tooled on both masonry faces. The compressive strength of the mortar was 2,229 psi and the compressive and diagonal tensile strength of the masonry was 2,200 psi and 69 psi, respectively. The simulated input was based on accelerograms recorded at the El Centro 1940, Taft 1952 and Greenville 1980 earthquakes. All simulated earthquake records had one horizontal and the vertical component with no time scaling; the simultaneous action of two horizontal input components on the model masonry walls resulted from the orientation of the walls with respect to the axis of horioznta1 table motion (Fig. 1).

TEST RESULTS

Table 1 lists the tests applied to the unreinforced House 5. After completion of these eight tests, the model was partially reinforced using the reinforcing arrangement shown in Figure 1.

Observations from the performance of the unreinforced House 5 follow:

a. The first structural crack appeared during test No. 5 (Table 1). This crack was at a horizontal mortar joint near the right bottom corner of loadbearing wall B. The dynamic crack opening during test No. 5 attained the value of 0.060 in. However, the permanent deformations were negligible. The time histories of the base accelerations applied during this test are shown in Figure 2.

b. The dynamic house response after the formation of this first structural crack is dominated by large uplift displacements of wall B at the crack location,inducing large in-plane displacements for wall B and large out-of-plane displacements for wall A1 (Figure 4).

c. Figure 5 depicts the magnified deformed shape of House 5 at the top-of-the-wall level at particular time instants selected to coincide with peak values of the acceleration or displacement response. The arrows depict the measured acceleration values at the top of each wall; the shaking table input acceleration is also plotted with an arrow at the center of the sketch. All plotted accelerations and displacements are horizontal. The displacement and acceleration scales used to plot these measurements also are shown.

Significant out-of-plane displacement response for walls A1 and B1 as well as torsional and distortional response for the house as a whole can be seen in Figure 5.

d. All masonry walls of House 5 have been subjected to a combination of significant in-plane and out-of-plane inertial forces (Table 1) and developed significant in-plane and out-of-plane displacement response (Figures 4 and 5).

e. The first unacceptable damage for unreinforced House 5 occurred during test No. 7 (Table 1) in the form of partial loss of support for the door lintel beam of wall B. The term "unacceptable damage" was defined in this investigation as permanent cracking or sliding displacements in excess of 1/4 in. The performance of unreinforced House 5 during the test program is depicted in Figure 8; the abscissae in this figure represent the sequential test number and the ordinates the test intensity in terms of base accelerations.

Observations on the performance of House 5 after it was partially reinforced were as follows:

a'. The partially reinforced House 5 was subjected to a large number of tests. Table 2 lists a summary of the base motions used for ten of these tests and Figure 3 depicts the time histories of the base accelerations for test No. 5(a). The observed damage of partially reinforced House 5 is well within acceptable levels even for tests of very high intensity (Figure 8).

b'. The large displacement and acceleration response as well as the torsional and distortional response observed during the tests of the unreinforced House 5 after the formation of the first structural crack (Figures 3 and 4) was well controlled by the partial reinforcement (Figures 6 and 7).

c'. A comparison of the earthquake performance of the partially reinforced House 5 and 4, which were essentially the same except that the partial reinforcement of the loadbearing wall A of House 4 was not provided with dowels, shows that House 5 exhibited satisfactory performance, whereas the undowelled partial reinforcement of wall A in House 4 was unable to contain the damage within acceptable levels [3].

CONCLUSIONS

1. The unreinforced House 5 performed satisfactorily with no cracks for simulated earthquake motions with base peak accelerations of 0.25g parallel to walls A,B; 0.15g parallel to walls A1,B1; and 0.22g vertical.

2. After formation of the first structural crack the unreinforced House 5 performed satisfactorily, despite significant in-plane and out-of-plane displacement and acceleration response for the masonry walls and torsional distortional response for the house as a whole; the base peak accelerations were 0.32g, 0.18g and 0.21g, respectively, along the three axes.

3. The first unacceptable damage, in the form of partial loss of support for the door lintel beam, developed in unreinforced House 5 for base peak accelerations of 0.37g, 0.21g and 0.26g, respectively, along the three axes.

4. The simultaneous action of in-plane and out-of-plane inertial forces on all the unreinforced masonry walls of House 5, for moderate to moderately high intensities of simulated earthquake input, did not result in any noticeable increase of the damage of House 5 as compared with the damage of House 4, which was not subjected to this in-plane and out-of-plane coupling. Thus, the assumption made in Reference 4 when interpreting the results of Houses 1 to 4, increasing the expected seismic input by 50 percent for the unreinforced houses in order to account for the coupling effect, is overly conservative.

5. The partially reinforced House 5 earthquake performance was satisfactory throughout a large number of tests, some of them very high intensity simulated earthquake motions; the maximum peak accelerations at the base were 0.87g parallel to walls A,B; 0.50g parallel to walls A1,B1; and 0.56g vertically. The effectiveness in containing damage of partial reinforcement of the shear-resisting elements (when connected to the foundation by dowels) becomes evident by the performance of this model.

6. The importance of the roof-to-walls connections used in this study must be underlined. This type of connection, typical of standard construction practice, withstood a large number of simulated earthquake motions of moderate to very high intensity without signs of any significant distress. Loss of support for the roof from the failure of these connections would have been extremely detrimental to the overall earthquake performance of the test structure.

REFERENCES

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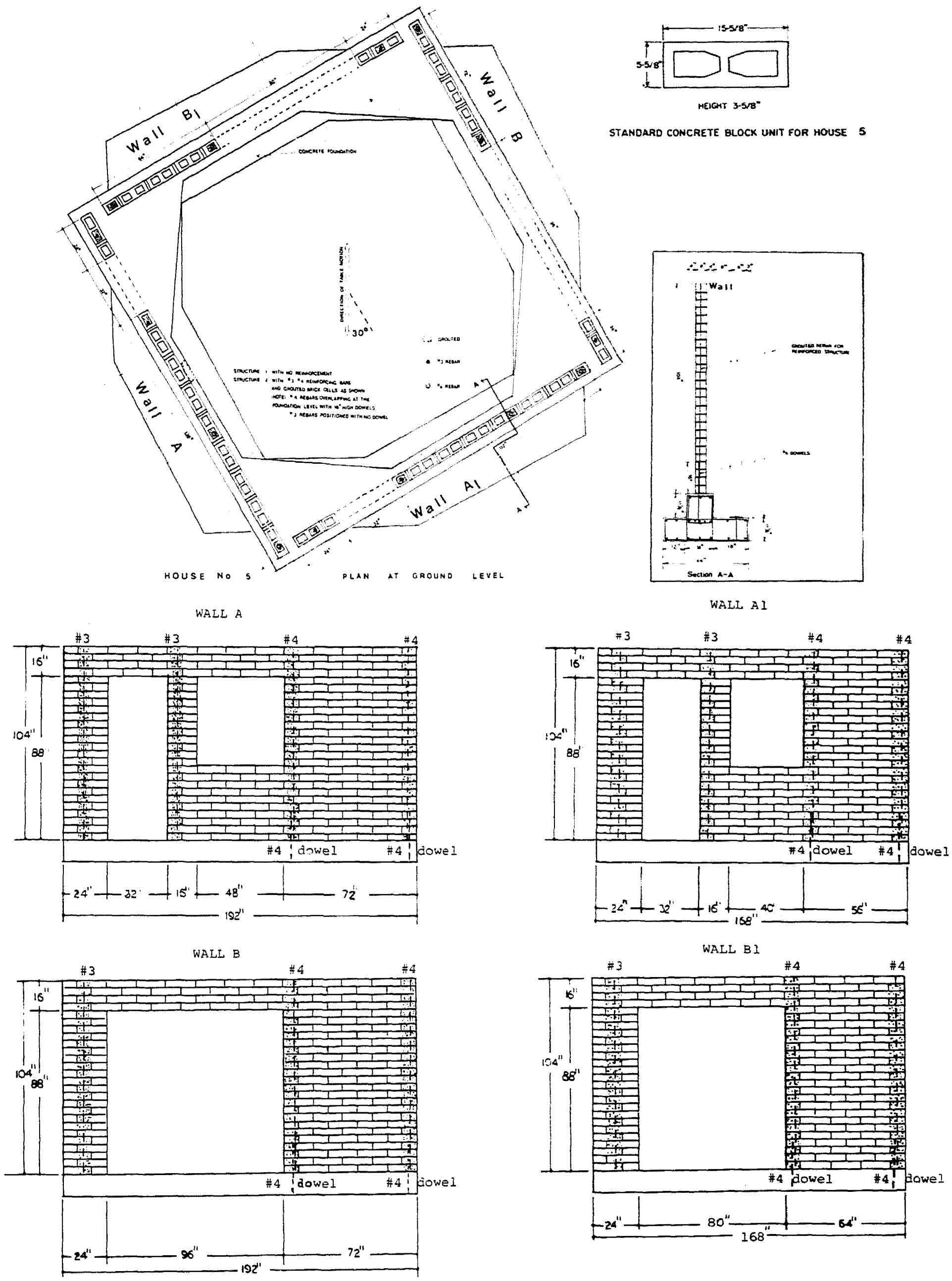

Fig. 1. structure 2 : PARTIALLY REINFORCED HOUSE 5
(structure 1 : unreinforced house 5 as above without reinforcement)

TABLE 1. PEAK VALUES OF TABLE-BASE ACCELERATION FOR UNREINFORCED HUD-HOUSE No. 5

Test No.	E.Q. Motion	Peak Hor. Table Acc. (g)	Peak Ver. Table Acc. (g)	Peak Hor. Acc. at base // to walls A and B (g)	Peak Hor. Acc. at base // to walls A1 and B1 (g)
1)	EL CENTRO	-.131/.120	-.057/.052	0.113	0.066
2)	EL CENTRO	-.215/.191	-.113/.107	0.186	0.108
3)	EL CENTRO	-.292/.269	-.217/.164	0.253	0.146
4)	TAFT	-.205/.264	-.132/.110	0.229	0.132
5)	EL CENTRO*	-.363/.331	-.211/.199	0.314	0.182
6)	TAFT	-.295/.366	-.400/.209	0.317	0.183
7)	EL CENTRO*	-.427/.340	-.263/.264	0.370	0.214
8)	TAFT	-.330/.427	-.439/.232	0.368	0.213

* The intensity of the earthquake motion for these tests is approximately the same as the intensity of the original ground shaking

// denotes parallel

TABLE 2. PEAK VALUES OF THE TABLE ACCELERATION FOR PARTIALLY REINFORCED HUD-HOUSE No. 5

Test No. (s)	E. Q. Motion	Peak Hor. Table Accelerat. (g)	Peak Ver. Table Accelerat. (g)	Hor. Acc. at base parallel to walls A and B (g)	Hor. Acc. at base parallel to walls A1 and B1 (g)
1)	EL CENTRO	-.519/.408	-.364/.346	0.450	0.260
2)	TAFT	-.426/.543	-.319/.258	0.470	.272
3)	EL CENTRO	-.662/.486	-.419/.490	0.573	0.331
4)	TAFT	-.586/.768	-.414/.356	0.665	0.384
5)	EL CENTRO	-.895/.558	-.450/.520	0.775	0.448
6)	TAFT	-.766/1.01	-.567/.462	0.872	0.504
7)	TAFT	-.766/1.03	-.567/.462	0.890	0.514
8)	GREENVILLE	-.656/.322	-.192/.231	0.568	0.328
9)	TAFT	-.580/.758	-.420/.360	0.656	0.379
10)	EL CENTRO	-.969/.604	-.412/.476	0.839	0.485

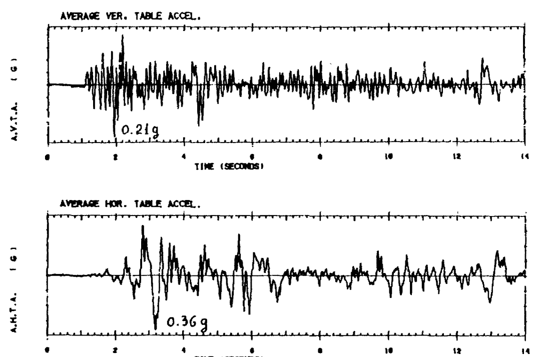

Fig. 2. UNREINFORCED HUD-HOUSE 5 , EL CENTRO H=0.36G V=0.21G ACCELERATIONS AT BASE LEVEL

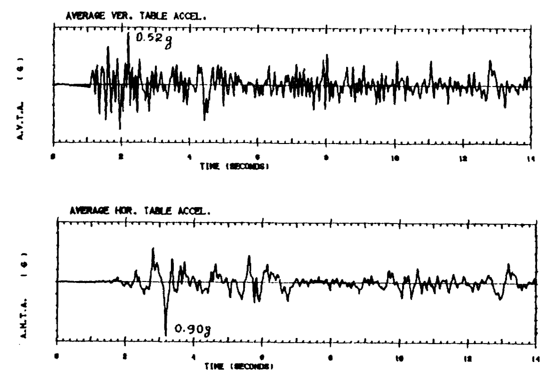

Fig. 3. REINFORCED HUD-HOUSE 5 , EL CENTRO H=0.90G V=0.52G ACCELERATIONS AT BASE LEVEL

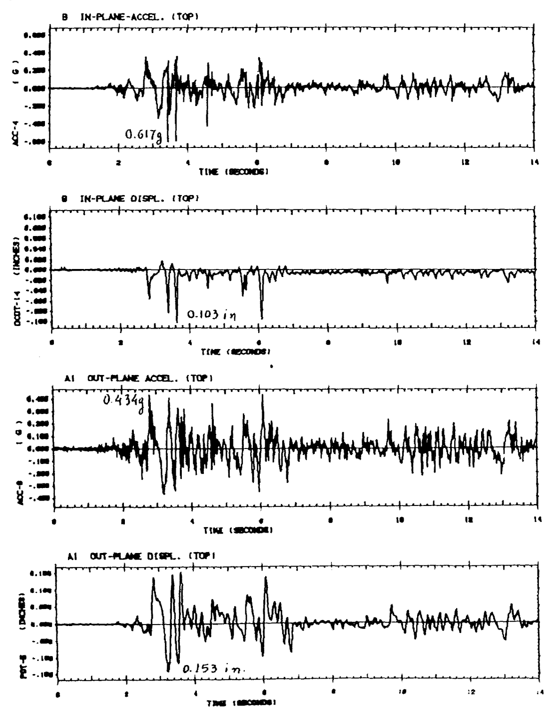

Fig. 4. UNREINFORCED HUD-HOUSE 5 , EL CENTRO H=0.36G V=0.21G
DISPLACEMENTS AND ACCELERATIONS

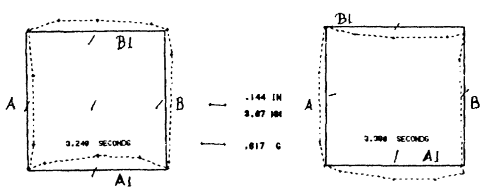

Fig. 5. UNREINFORCED HUD-HOUSE 5 , EL CENTRO H=0.36G V=0.21G
(HOR. DISPL. AND ACCEL. AT THE TOP OF THE HOUSE-WALLS LEVEL.

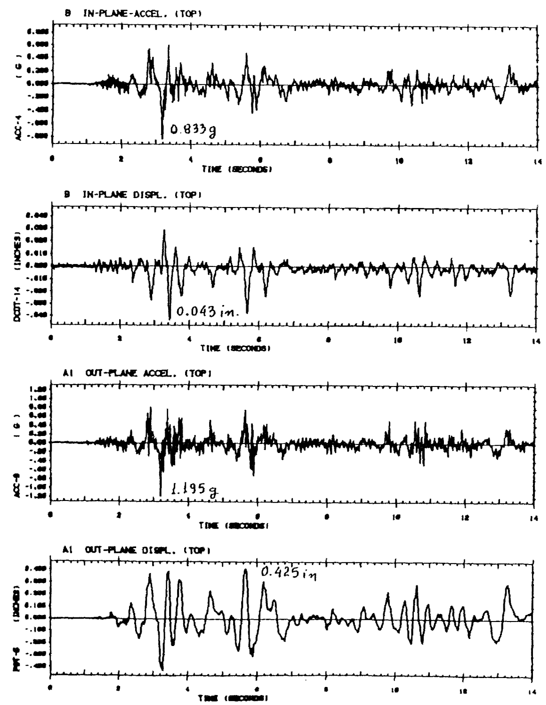

Fig. 6. REINFORCED HUD-HOUSE 5 , EL CENTRO H=0.90G V=0.52G
DISPLACEMENTS AND ACCELERATIONS

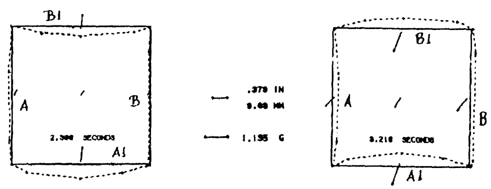

Fig. 7. REINFORCED HUD-HOUSE 5 , EL CENTRO H=0.90G V=0.52G
(HOR. DISPL. AND ACCEL. AT THE TOP OF THE HOUSE-WALLS LEVEL)

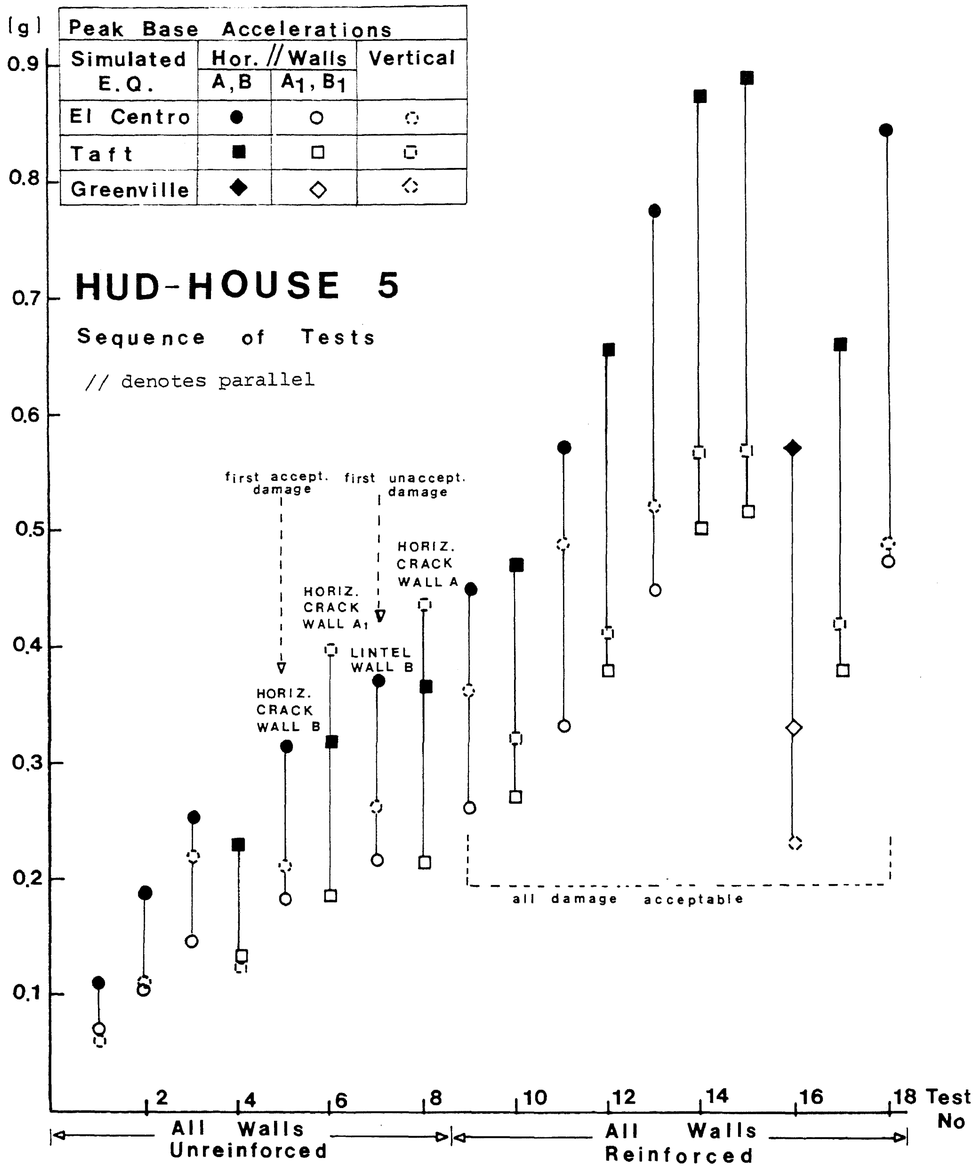

Fig. 8. Sequence of tests for unreinforced and partially reinforced House 5.