Evaluation of Fiber Reinforced Polymer Retrofitted House Model under Shake Table Testing

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Seismic retrofitting of masonry structures has attracted the attention of worldwide researchers and many researchers have come out with different retrofitting materials. Use of Fiber Reinforced Polymer (FRP) as retrofitting material has become very popular in the past few decades. High strength to weight ratio and linear elastic behavior are some of inherent advantages of FRP material. In the past, most of the researchers have evaluated the performance of FRP by performing diagonal compression test or cyclic tests on small-scale or full-scale walls whereas some others used out-of-plane load tests but there were almost no detailed study comprising the dynamic behavior of FRP retrofitted house models using dynamic or shake table testing.

Current research work consists of shake table testing of three 1-4 scale house models with wooden truss roof. Out of three house models, one was non-retrofitted (URM) and two were FRP retrofitted house model. In case of two FRP retrofitted house models, one house model was retrofitted with 0.0012 FRP reinforcement ratio whereas other was retrofitted with 0.0006 FRP reinforcement ratio. In both of FRP retrofitted house models, FRP reinforcement was applied only at outer face of the walls. FRP layout and reinforcement ratio was selected based upon previous literature reviews. Response of URM and FRP retrofitted house models was compared in terms of base shear and story displacement hysteresis, story shear and story drift hysteresis, damage levels at different input motions and stiffness degradation. Experimental results have determined that FRP has significantly increased the lateral load resistance of unreinforced masonry structures.

Key Words : *Seismic retrofitting, Fiber Reinforced Polymer, masonry,*

1. Introduction

Dynamic response of masonry structure has been the focus of worldwide researchers for the last two decades. Different researchers tried to determine the response of URM masonry structure analytically and experimentally. In this regards, Earthquake Engineering Research Center, University of California Berkley has conducted shake table tests using four single story house models which were unreinforced and partially reinforced house models to determine their seismic capacity using local masonry construction characteristics [1]. Tomazevic and Klemenc tested two models of three story confined masonry conforming to requirements of Eurocode 8 and proposed a rational method to evaluate the seismic resistance of confined masonry [2]. Benedetti et al. evaluated the response of twelve stone and brick masonry systems and correlated the input base excitation with the damage pattern of the buildings [3]. Dawe and Sean have experimentally determined the seismic behavior of masonry in filled steel frames [4]. Zarnic et al. carried out shaking table test on two 1-4 scale reinforced concrete masonry in filled models and determined the damage pattern of in filled masonry structures [5]. Alcocer et al. did shake table tests on two small scale confined masonry structures using construction practice used in Mexico and evaluated the structural capacity, stiffness, deformation and energy dissipation properties [6]. Hashemi et al. performed shake table test on concrete frames with only one infill wall [7]. Shake table testing of post tensioned masonry walls with opening was done by Wight et al. [8]. Yi-Hsuan et al evaluated the out-of-plane response of infill masonry panels in RC frames through shake table experiment [9]. Kazemi et al. and Stavridis et al. also performed shake table tests with infill RC frames [10,11]. Li huwa et al., evaluated the response of a 1-4 scaled masonry structures strengthened with Basalt Fiber Reinforced Polymer (BFRP) [12]. Moritz and Lothar evaluated the performance of uniaxial glass fiber stripe solution with epoxy resin with fully covered multi axial fiber and cement based mortar system [13].

Sathiparan and Meguro carried out a detailed shaking table study using adobe bricks on 1-4 scaled model of arched and timber roof unreinforced and PP-band retrofitted and proposed PP-band retrofitted techniques [14 to 15]. After going through the past shake table studies, it has been found that there are only few studies [12-15] which deals with strengthening of unreinforced and unconfined masonry structures whereas most of the studies deals with in filled masonry structures [11].

(1) Research objectives

Current research work consists of shake table testing of three 1-4 scale house models with wooden truss roof. Out of three house models, one was non-retrofitted (URM) and two were FRP retrofitted house model. In case of two FRP retrofitted house models, one house model was retrofitted with 0.0012 FRP rein-forcement ratio whereas other was retro-fitted with 0.0006 FRP reinforcement ratio. In both of FRP retro-fitted house models, FRP reinforcement was applied only at outer face of the walls. FRP layout and rein-forcement ratio was selected based upon previous literature reviews. Response of URM and FRP retrofitted house models was compared in terms of base shear and story displacement hysteresis, story shear and story drift hysteresis, damage levels at different input motions and stiffness degradation. Experimental results have determined that FRP has significantly increased the lateral load resistance of unreinforced masonry structures.

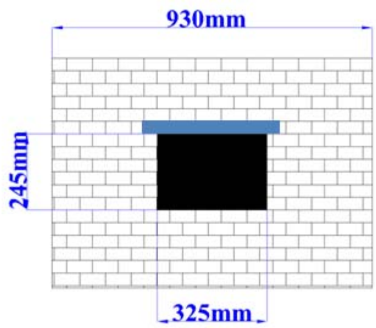
2. EXPERIMENTAL PROGRAM

Shaking table experimental plan consist of shake table test on three 1-4 scaled brick masonry house models with timber roof. Out of three houses, one was non-retrofitted; one was retrofitted with FRP reinforcement ration of 0.0006 and one was retrofitted with FRP reinforcement ration of 0.0012. PP-band retrofitted, four FRP retrofitted and one FRP+PP-band retrofitted.

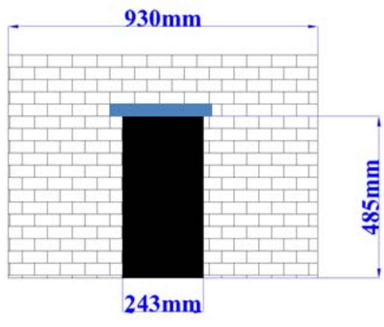
(1) Construction of model houses

Each house model consists of 930mm×930mm×50mm with a door opening of 243mm×485mm and a window opening of 325mm×245mm. **Figure 1** shows the door side view, window side view and details of walls. Size of the brick unit is 75mm×50mm×38mm which is same as that of bricks units used in diagonal compression test, out-of-plane load tests. Cement, lime and sand mortar with weight mixed proportion of cement140g: lime1110g: sand2800g with cement/water ratio of 0.4 is used. Mortar mix was specially designed to practically simulate the mechanical properties of mortar used for masonry construction in most of developing countries even though the construction materials used were those available in Japan. Two wooden lintels were also placed at the top of door and window openings as shown in **Fig.1(a)** and **(b)**. All house models were constructed using same constituent material under and cured for 28 days under similar environment conditions.

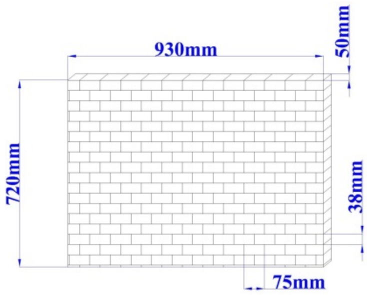
After curing the samples, a wooden truss roof was attached to the house with the help of specially cast bricks with connecting dowels coming out of them as shown in **Fig.2**. These bricks with dowels were laid in the same mortar mix as that of other bricks to keep the same conditions throughout the model. First seven days water was sprinkled over the houses and cured for total of 28 days. All of the house models were surface finished using the eight mixed proportion of cement140g: lime1110g: sand2800g with cement/water ratio of 0.14.



(a) Window (Front) Side



(b) Door (Back) Side



(c) Left and Right End Side

Fig. 1 Different Views of non-retrofitted masonry (URM) masonry house

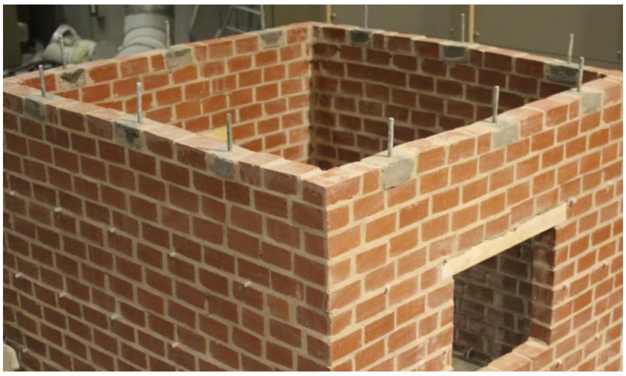


Fig 2. Connecting bricks for roof truss at the top most layer

(1) FRP Retrofitted model houses

In case of FRP retrofitted house model the reinforcement ratio of FRP was selected after going through the previous test studies and literature reviews. Based upon the tension test results of different FRP materials [16], GFRP is found to be the most suitable type of FRP as it is of lowest cost among CFRP, AFRP and GFRP with satisfactory structural performance. GFRP fabric thickness of 0.5mm is used for this study. Before applying the FRP, brick surface was cleaned with the help of cloth and brush after that FRP was applied on the brick surface with the help of Bond E-250 epoxy. **Figure 3(a) and (b)** shows the FRP-0.0012 and FRP-0.0006 retrofitted house models. In both of the house models

In case of FRP-0.0012 retrofitted model FRP reinforcement ratio was 0.0012. The layout of FRP-0.0012 retrofitted house models is shown in **Fig. 3(a)**. In this case, width of FRP 40mm is kept constant and spacing of FRP was 400as shown in **Fig. 3(a)** but FRP was applied at only outer faces of walls.

In case of FRP-0.0016 retrofitted model FRP reinforcement ratio was reduced around 50% of 0.0012 which resulted in FRP reinforcement ratio of 0.0006. The layout of FRP-0.0016 retrofitted house models is shown in **Fig.3(b)**.. In this case, width of FRP was reduced from 40mm to 20mm whereas spacing was kept same as that of FRP-0.0012 as shown in Figure **3(b)** but FRP was applied only at outer faces of walls.

(a) FRP-0.0012 retrofitted house model

(b) FRP-0.0012 retrofitted house model

Fig.3 FRP retrofitted house models

3. RESULTS

(1) Experimental Setup

The test specimen wee fixed on a shaking table with dimensions 1.5 m by 1.5 m. The Shaking table system at Institute of Industrial Science, The University of Tokyo is capable of controlling six degrees of freedom and operating in frequencies ranging from 0.1 to 50 Hz. It has a maximum displacement of ±100mm and maximum weight of the specimens is 2 tons. In this experiment shaking table system controlling limited to one direction shaking for simplicity of motion. To assess the global and local behavior, specimens were instrumented to measure accelerations and displacements.

(2) Loading Sequence

Simple easy-to-use sinusoidal motions of frequencies ranging from 2Hz to 35 Hz and amplitudes ranging from 0.05g to 1.4g were applied to obtain the dynamic response of the structures. This simple input motion was applied because of its adequacy for later use in the numerical modelling. The numbers given in the **Table 1** shows the loading sequence followed for tests on all types of house models. General trend of loading was from high frequency to low frequency and from lower amplitude to higher amplitude. Higher frequencies motions were skipped towards the end of the runs.

Table 1 Loading sequence for shake table tests

Amplitude	Frequency (Hz)							
	2	**5**	**10**	**15**	**20**	**25**	**30**	**35**
1.2g	53	52						
1.0g		51						
0.8g	50	49	43	40	37	34	31	28
0.6g	48	45	42	39	36	33	30	27
0.4g	47	44	41	38	35	32	29	26
0.2g	46	25	24	23	22	21	20	19
0.1g	18	17	16	15	14	13	12	11
0.05g	10	09	08	07	06	05	04	03
Sweep	01,02							

(3) Test Results

Performance of the house models were assessed based on the damage level of the buildings at different levels of shaking. Performances were evaluated in reference to five levels of performances: light structural damage, moderate structural damage, heavy structural damage, partially collapse, and collapse. Table 6-5 shows different damage categories according to European Macroseismic Scale 1998[17].

Where

D0: No damage, D1: Light structural damage, D2: Moderate structural, D3: Heavy structural damage, D4: Partially collapse and D5: Collapse

Table 2 shows the performances of non-retrofitted (URM) house model with different JMA intensities. Partial collapse of the non-retrofitted building was occurred at the Run-41(0.4g and 10Hz) at intensity JMA~4 and total collapse at the Run-44(0.4g and 5Hz) at intensity JMA 5-.

Table 2 Performance of URM house model

Acceleration (g)	**Frequency (Hz)**							
	2	5	10	15	20	25	30	**35**
1.2								
1.0								
0.8			D5	D3	D3	D2	D2	D2
0.6			D4	D3	D3	D2	D2	D2
0.4		D5	D4	D3	D3	D2	D2	D2
0.2		D2	D2	D2	D2	D1	D1	D1
0.1	D1	D1	D1	D1	D1	D1	D1	D1
0.05	D0	D0	D0	D0	D0	D0	D0	D0

Table 3 shows the performances of FRP-0.0012 retrofitted house models. FRP-0.0012 retrofitted house model has also shown similar behaviour until Run-52(1.2g and 5Hz) JMA 6+ but at last run of 1.2g and 2Hz some of the bricks shown small bed joint cracks. These cracks were observed only under those bricks which were connecting roof with walls. 3 shows the performance of FRP-0.0012 retrofitted house model.

Table 3 Performance of FRP-0.0012 house model

Acceleration (g)	**Frequency (Hz)**							
	2	**5**	**10**	**15**	**20**	**25**	**30**	**35**
1.2	D1	D0						
1.0	D0	D0						
0.8	D0	D0	D0	D0	D0	D0	D0	D0
0.6	D0	D0	D0	D0	D0	D0	D0	D0
0.4	D0	D0	D0	D0	D0	D0	D0	D0
0.2	D0	D0	D0	D0	D0	D0	D0	D0
0.1	D0	D0	D0	D0	D0	D0	D0	D0
0.05	D0	D0	D0	D0	D0	D0	D0	D0

Table 4 shows the performances of FRP-0.0016 house model with different JMA intensities. FRP-0.0016 has shown no damage until Run-26(0.4g and 35Hz). Extensive damage (D3) was observed at Run-40(0.8g and 15Hz). Partial collapse of the non-retrofitted building was occurred at the Run-42 (0.6g and 10Hz) at intensity JMA~4 and total collapse at Run-45(0.6g and 5Hz) at intensity JMA 5-

Table 4 Performance of FRP-0.0016 house model

Acceleration (g)	Frequency (Hz)							
	2	5	10	15	20	25	30	35
1.2								
1.0								
0.8			D4	D3	D2	D2	D2	D1
0.6		D5	D4	D2	D2	D2	D2	D1
0.4		D4	D3	D2	D2	D2	D2	D1
0.2		D0	D0	D0	D0	D0	D0	D0
0.1	D0	D0	D0	D0	D0	D0	D0	D0
0.05	D0	D0	D0	D0	D0	D0	D0	D0

3. CONCLUSIONS

Current research work has given an insight of different retrofitting methods using dynamic testing. After going through the shake table experimentation of URM, FRP-0.0012 and FRP-0.0016 retrofitted house models it has been found that URM is highly vulnerable against earthquake motions and they can hardly withstand a severe ground motion even for small input motions URM may not remain serviceable. FRP-0.0012 has also shown good behavior although it has shown some inelastic behavior at very higher input motions but overall structural performance was more than satisfactory. This conclusion has given a breakthrough in the FRP field as most of the researchers encourage not using FRP on one face but their finding was once again based upon diagonal compression test studies. FRP applied in the form of vertical strips just act like a strong shear link in between the masonry units and act like a shear wall in concrete buildings by providing higher lateral stiffness to whole structure. In case of FRP-0.0006, quantity of FRP was reduced from 0.0012 to 0.0006keeping the same layout of applying FRP only at outer face. FRP-0.0006 with very small quantity of FRP has not served satisfactory and could hardly stood an input motion greater than URM.

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