SEISMIC CAPACITY ENHANCEMENT OF STONE MASONRY BUILDINGS USING HORIZONTAL TIMBER ELEMENTS

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Abstract- Stones and timber are the natural materials found abundantly in the Northern hilly areas of Pakistan and many other countries of the world. Human beings have used them for centuries to make houses for providing shelter against natural and environmental hazards. Bhatar is one such typical construction in which stone masonry walls are divided into panels by providing horizontal timber elements. The timber elements are cross braced at intervals along the length and anchored with orthogonal walls at the corners. Its performance in past earthquakes has been good, which was once again demonstrated in the Kashmir earthquake of October 8, 2005. This study presents the results obtained from shake table test of a reduced scale model of Bhatar construction. The results obtained can be used to evaluate the seismic capacity of these structures

Keywords- Bhatar Construction, Stone Masonry, Seismic Resistance, Shake Table, Timber Bands

1 Introduction

The Northern region of Pakistan; officially called as "Gilgit-Baltistan" and Kashmir is the most beautiful and fascinating region of Pakistan. The world's four famous mountain ranges; the Himalayas, the Karakorams, the Hindukush and the Pamirs meet in this region. Being home to thousands of mountains, the area is rich in stones and timber. The local communities have been using these materials for centuries to construct their houses. Most of the buildings in the region have stones and timber as construction materials in one form or the other even today.

On the other hand, the area is part of seismically one of the most active regions in the world. The Seismic provisions in the Pakistan Building Code [1] categorize most of the region in the high seismic zones (zone 3 and zone 4). The highly vulnerable stone masonry buildings in the presence of high seismic hazard constitute a high seismic risk in the area. This was demonstrated on October 8, 2005, a fatal earthquake of magnitude 7.6 on the Richter scale. The earthquake was one of the biggest disasters in the history of Pakistan. According to Earthquake Reconstruction and Rehabilitation Authority (ERRA) 73,338 people lost their lives, 69,412 experienced serious injuries, and nearly 3.5 million people became homeless [2]. The earthquake destroyed or seriously damaged about 600,000 houses, 796 health units, and 6298 educational buildings in addition to numerous other government buildings and roads [3].

As part of the reconstruction and rehabilitation process after the earthquake, efforts were made by both government and non-government organizations to introduce and encourage such construction practices which could mitigate the seismic risk in future earthquakes. Special emphasis was given to the indigenous traditional construction methods which showed relatively better resistance to past earthquakes [4, 6, 7]. Several research studies were initiated to study and improve the existing conventional building techniques [6-10]. Bhatar; a rubble stone masonry building with horizontal timber elements running along the length of the walls at different heights, was one such construction type. However, most of such efforts were based on experience and engineering judgment, rather than recognized scientific research. This research project is an effort to scientifically investigate the performance of Bhatar construction subject to earthquake excitation. A fully dynamic shake table test of a reduced scale Bhatar model is conducted and the results presented.

2 Research Methodology

2.1 Shake Table Testing and Reduced Scale Modelling:

The core component of the research is the shake table test on a reduced scale model of stone masonry building with horizontal reinforcing elements. The model was constructed based on similitude requirements of distorted model. Two past earthquake time-histories, namely the El Centro 1940 and Kashmir 2005 were used for input excitations.

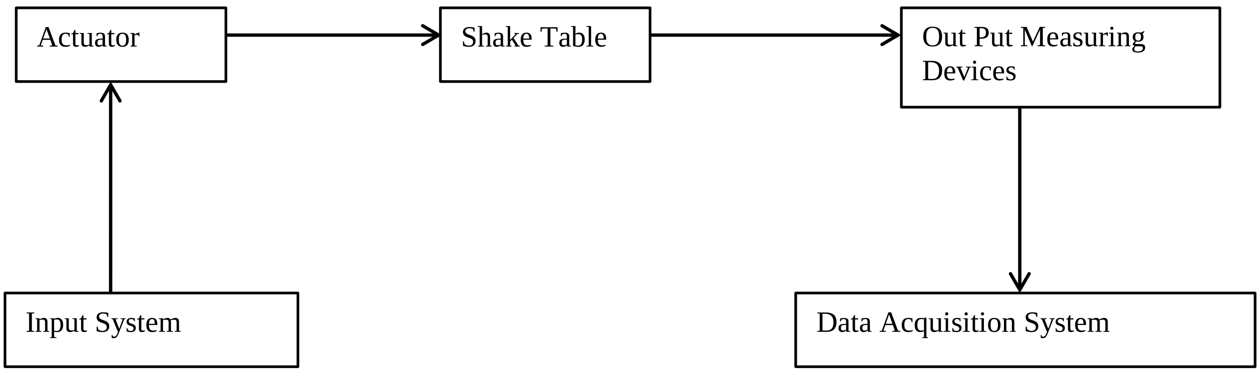

Figure 1. Major components of a shake table testing system

Figure 1 shows the major components and steps involved in a shake table test. Computer hardware and software systems are used to impart the input signals to the actuator. Earthquake records, be they real, artificial, or synthetic, are generally used as input excitations. Hydraulic actuators provide the driving force to shake the table and hence the models. Generally, displacements and accelerations of the model structure are measured as output of the shake table test. The data acquisition system receives electrical signals from transducers and transforms them into information which can be seen on a computer. Signal conditioning is required before the data acquisition system can read the signal which may include processes such as amplification, linearization, filtering, and isolation.

Shake table tests essentially involve subjecting the models to earthquake excitations provided by the actuators, recording the output motions in terms of displacements and accelerations by transducers and recording the output data with the help of a data acquisition system. Ideally the best model would be the structure itself i.e. to test actual structures. However, the construction cost involved in making such models and the limitations of testing facilities imply the use of reduced scale models. These models should satisfy similitude requirements given in Table 1 based on dimensional analysis so that they can be used to predict the response of prototype structures.

Table 1: Scale Factors

Parameter	**Symbol**	**Scale Factor (Cauchy)**	**Scale Factor (Cauchy + Froude)**
Length	L	$L_p/L_M = \lambda$	$L_p/L_M = \lambda$
Modulus of elasticity	E	$E_p/E_M = e = 1$	$E_p/E_M = e = 1$
Specific mass	ρ	$\rho_p/\ \rho_M = \rho = 1$	$\rho_p/\ \rho_M = \rho = \lambda^{-1}$
Area	A	λ^2	λ^2
Mass	m	λ^3	λ^3
Displacement	d	Λ	Λ

Velocity	v	1	$\lambda^{1/2}$
Acceleration	A	λ^{-1}	1
Weight	w	λ^{3}	λ^{2}
Force	F	λ^{2}	λ^{2}
Moment	M	λ^{3}	λ^{3}
Stress	σ	1	1
Strain	ϵ	1	1
Time	t	λ	$\lambda^{1/2}$
Frequency	f	λ^{-1}	$\lambda^{-1/2}$

The model dimensions were based on a prototype room of 15ft x 12ft with 11ft of overall height. Keeping in mind the constraints of testing facilities, i.e. size of the shake table, a scale factor of 3 was selected. Therefore, the overall plane dimensions of the models were 5ft x 4ft with a total height of 44 inches as shown in **Error! Reference source not found.** a nd **Error! Reference source not found.**. All other dimensions of the prototype building are also divided by the scale factor of 3 to obtain the corresponding dimensions of the models.

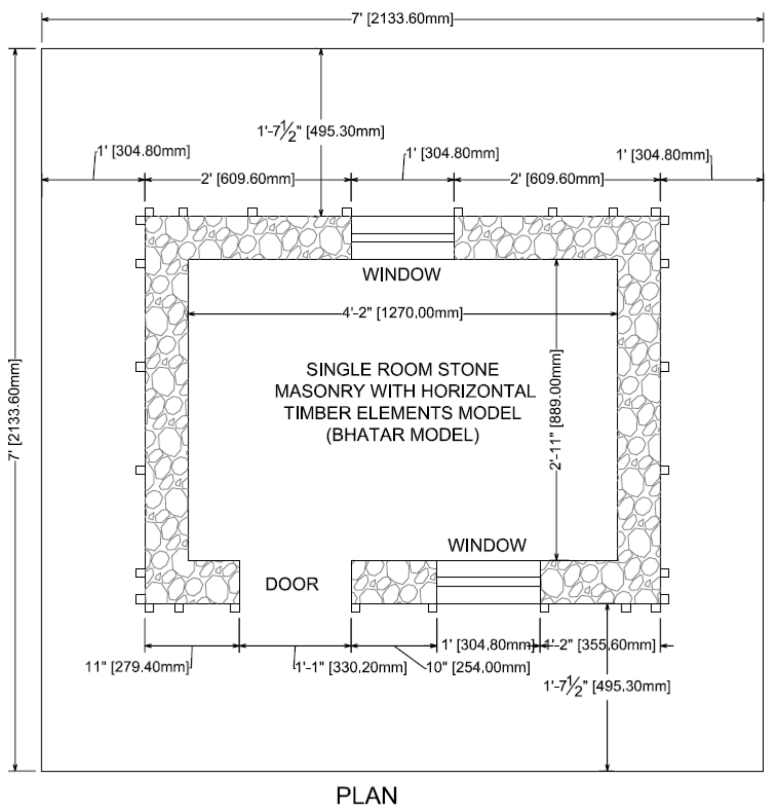

Figure 2. Plan of specimen

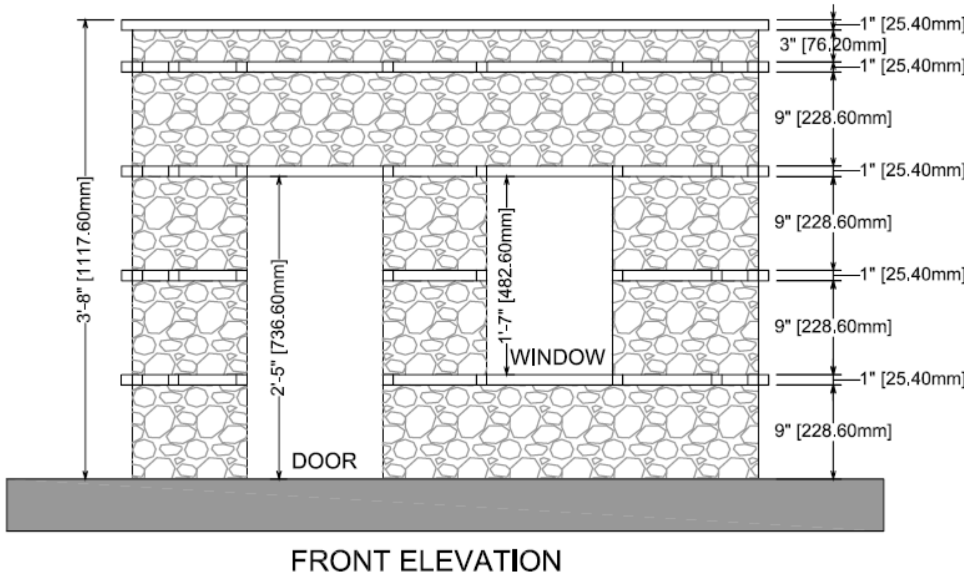

Figure 3. Elevation of specimen

2.2 Construction of the Model

The model was constructed and tested at the Earthquake Engineering Center, University of Engineering and Technology, Peshawar, Pakistan. Major stages of construction are shown in Figure 4Figure 7.

Figure 4. Complete concrete pad being cured

Figure 5. Rectangular skeleton of timber elements

Figure 6. Horizontal Timber elements

Figure 7. Completed Model

2.3 Testing

To capture time rate dependent characteristics of structures or structural components, fully dynamic test methods are employed. There are many methods of dynamic testing currently in use for structures. Linear elastic dynamic tests are conducted when only the structural identification is involved. In such cases, low levels of excitation are generally sufficient, which can be produced by ambient sources such as wind or traffic. Eccentric mass exciters or electrodynamic shakers are used whenever a greater degree of control is required. When complete structural response is sorted, non-linear dynamic test methods such as shake table tests are conducted. As part of this study, fully dynamic shake table tests were performed to study the complete elastic and inelastic response of the structure.

The Stone Masonry Models were tested in Earthquake Engineering Centre of the Department of Civil Engineering, University of Engineering & Technology (UET), Peshawar, Pakistan. The seismic simulator consists mainly of 1.5 m x 1.5 m (5 x 5 ft), 2.5-inch-thick aluminum table and an actuator as shown in Figure 8. The table has a grid of holes at 20 cm x 20 cm to attach the model/pad to the table.

Figure 8. Shake table at UET Peshawar

3 Results

3.1 Data Processing

The data obtained was processed using Seismosignal software as shown in Figure 9. Appropriate filtering and baseline corrections were applied to each data set.

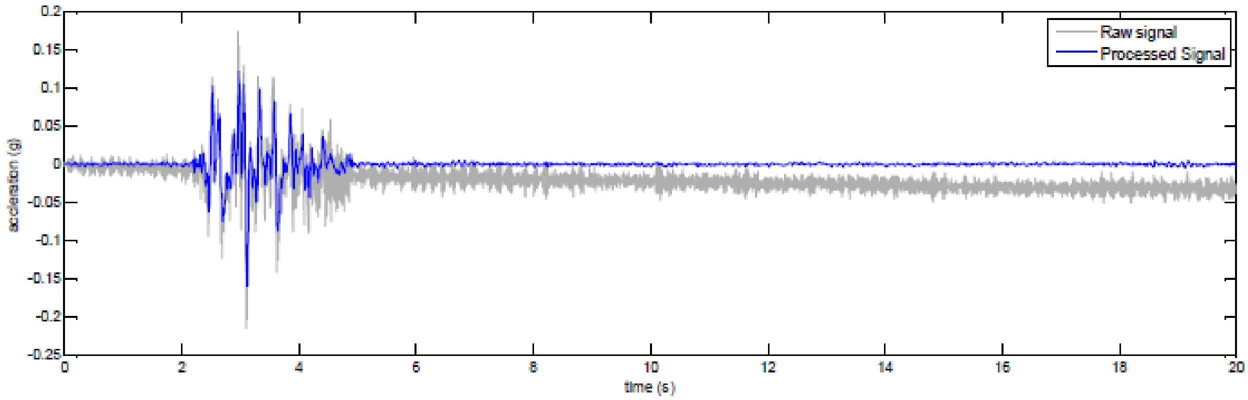

Figure 9. Raw and filtered data

3.2 Amplification

Acceleration amplification is calculated by dividing the acceleration at the top over the acceleration at the base. The graph is shown in Figure 10. The variation is nonlinear with irregular increase and decrease at the different runs.

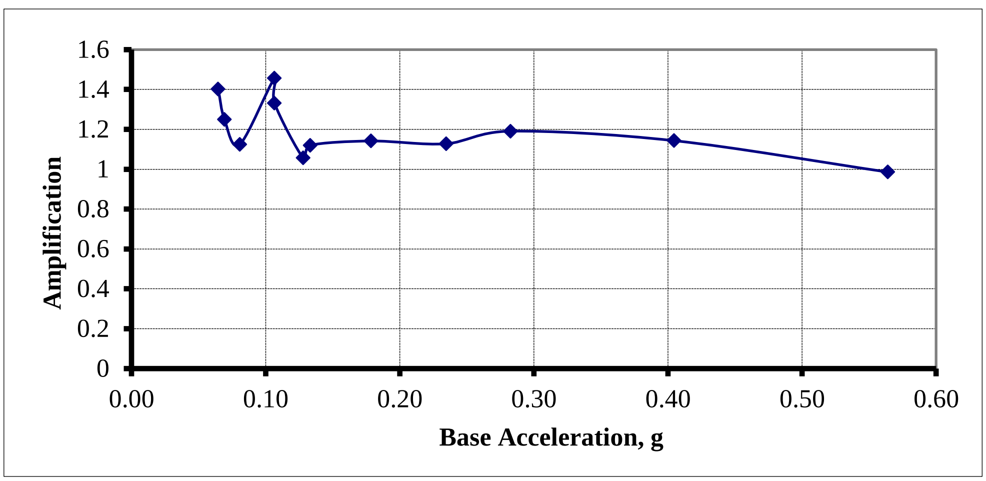

Figure 10. Acceleration amplification

3.3 Demand vs Actual Acceleration

Input acceleration given to the system is not exactly transferred to the model. Figure 11 shows input demand and acceleration recorded at the base of the shake table.

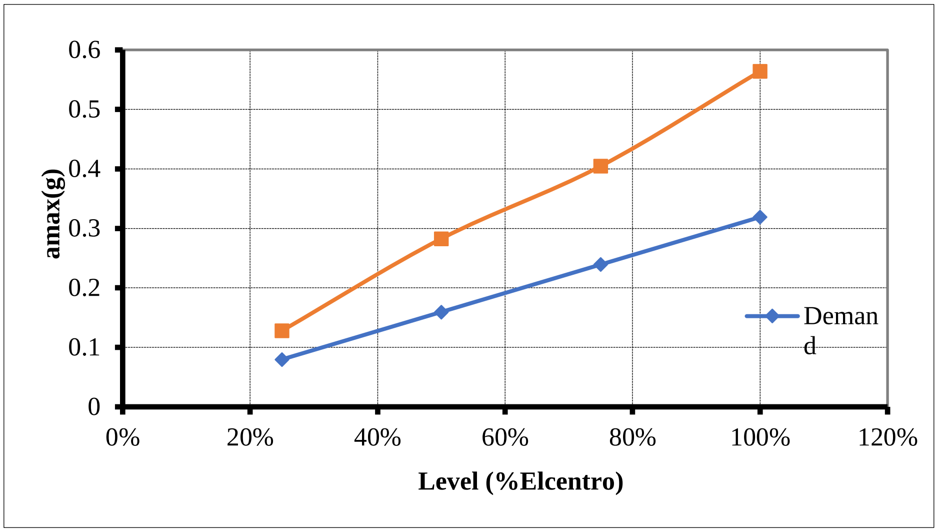

Figure 11. Level (% Elcentro)

3.4 Seismic Capacity Curve

The seismic capacity curve is shown in Figure 12. The maximum base share coefficient of 0.55 was observed against a story drift ratio of 0.068. The specimen experienced severe damage at the end of the test as shown in Figure 13.

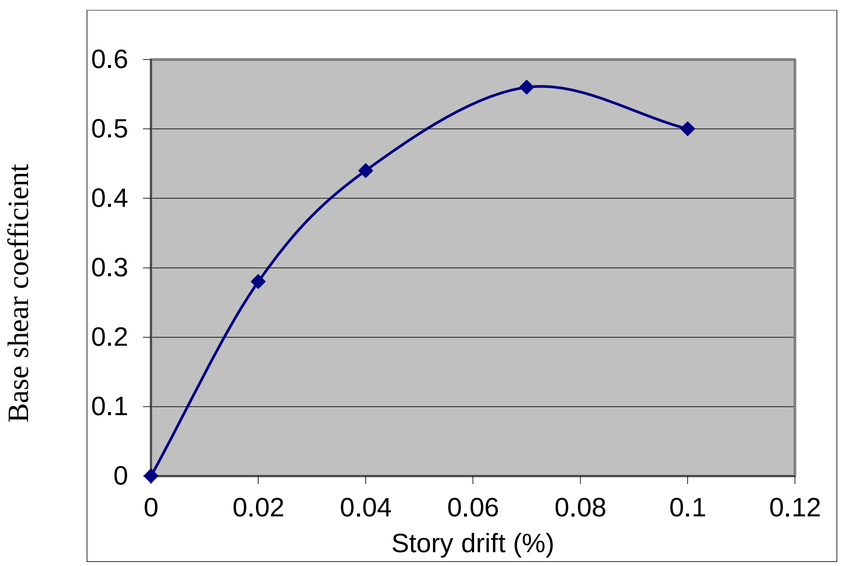

Figure 12. Seismic capacity curve

Figure 13. Damages at the end of the test

4 Practical Implementation

The results of this study will help in understanding and quantifying the seismic response of Bhatar construction.

5 Conclusion

The following conclusion can be derived from the data obtained from the shake table tests performed.

1. Model with timber horizontal bands collapsed at PGA 0.5g.
2. The governing failure criteria is observed to be falling of stones.
3. The models showed good response in comparison to models with no horizontal elements [9].

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