Behavior of interlocking plastic-block structure under harmonic loading using locally developed low-cost shake table

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Abstract

Earthquake has caused severe damages to non-engineered structures in rural areas of the world. There is a need to develop an economical but safe housing for people of such areas. Interlocking structure is one of the possible solutions. Many interlocking techniques are being investigated by various researchers. But interlocking plastic-block structures are still not explored. To start with, prototype interlocking plastic-blocks are considered for making the mortar-free structure. In this work, behavior of prototype interlocking plastic-block structure is investigated against harmonic loading using locally developed low-cost shake table. Structure consists of vertical eight blocks including bottom block fixed with the shake table. Two accelerometers are used: one is attached at the shake table to record the base excitation and one is attached at the top block to record the structure response. The behavior of structure in terms of acceleration-time, velocity-time and displacement-time histories is recorded. Energy absorption of the structure is determined. Empirical equations are developed keeping in mind the geometry of interlocking blocks, structure height and input loading parameters. This study determines the future directions for exploring the in-depth behavior of interlocking plastic-block structure.

Keywords: Interlocking plastic-block, low cost shake table, Accelerometer, harmonic loading.

1. INTRODUCTION:

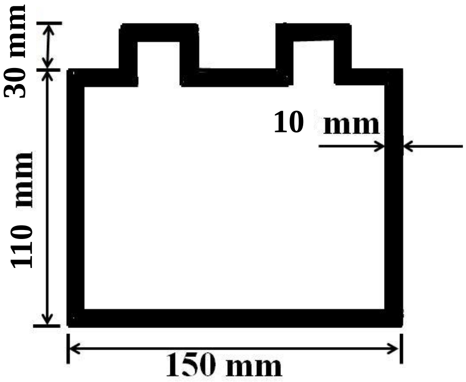
An earthquake is a natural disaster which produces strong ground motion. Primary effects of earthquake cause severe damages, such as collapse of buildings, roads and bridges, which may kill many people. Earthquake badly affects masonry structures. Durring the Kashmir earthquake of 2005, more than 450,000 buildings were partially or fully damaged (Naseer et al. 2010). Ground acceleration is transferred from ground to structure foundation which causes shearing of masonry walls due to inertia. Recently, earthquake in 2018 in Indonesia (Lombok earthquake) damages more than 1000 houses. An effort is required to reduce loses during future earthquake. In seismically active regions, the economical earthquake-resistant housing is desirable particularly for developing counties. During strong ground motions, these regions often suffer a significant loss of life because of lack of such houses. To enable an efficient and cost-effective solution, new construction techniques were investigated by various researchers in last decade (Elvin and Uzoegbo 2011 and Ali at al. 2012). Structures consisted of mortar-free interlocking blocks. Mortar-free blocks used in structure played an important role during strong ground motion. These blocks dissipated more energy during seismic event, because of the relative movement at the block interfaces. (Ali 2013). However, the mass of coconut fibre reinforced concrete blocks is still a point of concern. Lighter the mass of structure, lower the inertia force generated. There is need to reduce mass of block in order to reduce inertia forces. For this, light weight interlocking plastic- block is one solution. An electro hydraulic shake table having six degree of freedom is essential in order to generate real earthquake data. But such a table is very expensive. However, dynamic behavior of structures can also be studied using unidirectional shake table. Darshita and Anoop (2012) conducted study on development of low cost shake table.

During seismic event, interlocking structure can dissipate energy, because of relative movement of block interfaces. Lighter the mass of structure, lower the inertia force generated during the seismic event (Ali et al. 2013). Interlocking plastic-block structure would be light in weight, generating less mass. To the best of author knowledge, no study has been conducting to investigate the behaviour of interlocking plastic-block structure under harmonic loading using locally developed low-cost shake table. The main purpose is to explore the potential of plastic-block in housing. To start with, small-scale interlocking column is considered. For real application, full-scale plastic blocks would be needed along with some mechanism for wall connections with foundation and diaphragm. However, this would be tackled if favourable results are obtained from small-scale testing. Interlocking plastic-block structure is a new kind of structure. Waste plastic can be recycled for useful interlocking plastic-blocks. Also, fire-resistant paints may be needed which is outside the scope of current work. In this study, energy absorption of interlocking plastic-block column is experimentally investigated. Empirical equations are also being developed from the obtained results.

2. EXPERIMENTAL PROCEDURES:

2.1 Prototype interlocking plastic-blocks:

The proposed interlocking plastic-blocks for construction and its prototype for current study are shown in Figure 1. The proposed block for real construction has base dimensions of 150 mm x 150 mm with a total height of 140 mm including 30 mm interlocking key height (Figure 1a). The prototype has base dimensions of 62 mm x 62 mm with a total height of 53 mm including 12 mm interlocking key height (Figure 1b). It has a mass of around 25 g.

a. 

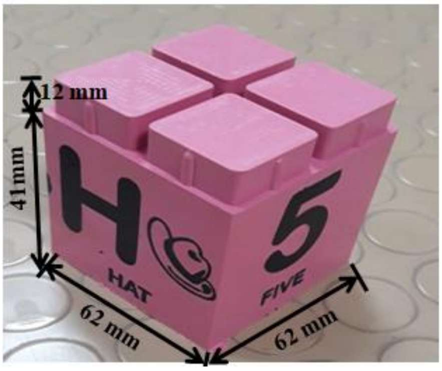
b. 

Figure 1: Interlocking plastic-blocks, a. proposed for construction, and b. prototype for current study

2.2 Locally developed low-cost shake table:

Locally developed low-cost shake table is shown in Figure 2. Simple 1D shake table is prepared by using local human resource and materials. The size of shake table is 600 mm x 450 mm. Shake table can be operated using an electric motor of 1 horse power having variable gear which can control the frequency of applied loading.

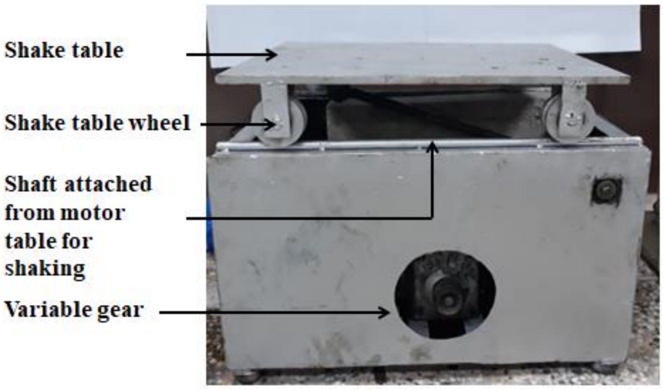


Figure 2: Locally developed low-cost shake table

2.3 Mortar-free interlocking structure on shake table and its instrumentation:

Mortar-free prototype structure consists of eight interlocking plastic-blocks (n=8), making a total height (H) of 340 mm. It is a single block width column having the base area (a) of 62 mm x 62 mm. Uplift up to key height (h) of 12 mm can be availed, otherwise the column collapse is expected. Fixed base is provided. No mass is provided at the column top. However, the total mass of structure (M) is 0.25 Kg. The instrumentation of structure placed on shake table is shown in Figure 3. Schematic diagram is shown in Figure 3a and test set up is shown in Figure 3b. Two accelerometers are used: one at shake table to record ground motion and other at column top to record the structure response. Accelerometers are connected to computer system and data from accelerometers to computer is transferred using two types of software such as arduino and visual studio. Column response in terms of acceleration-time is recorded and velocity-time and displacement-time histories are obtained using software seismosignal.

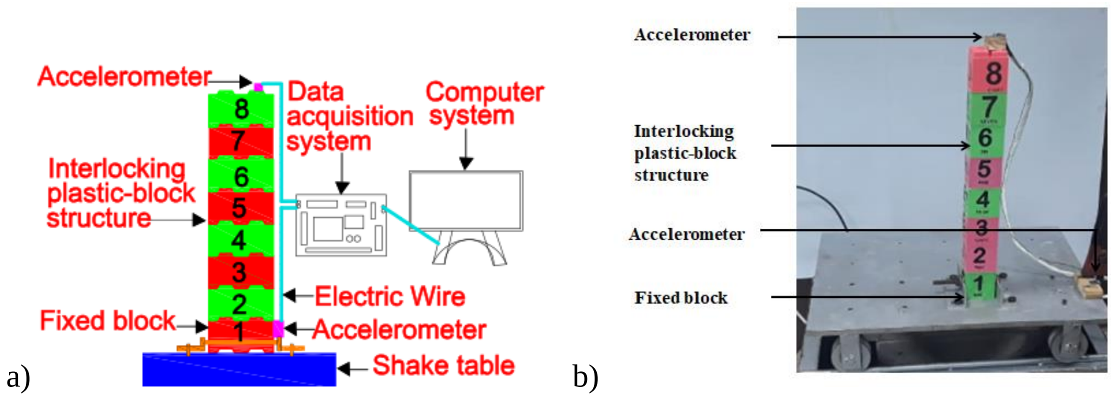


Figure 3: Instrumentation of interlocking structure on shake table, a. schematic diagram, and b. test set up

2.4 Testing:

Prototype interlocking plastic-block structure was tested on shake under harmonic loading with amplitude of around ±3 cm and frequency of 2.83 Hz (i.e. time period 't' of 0.35 s or rotation of 170 rpm).

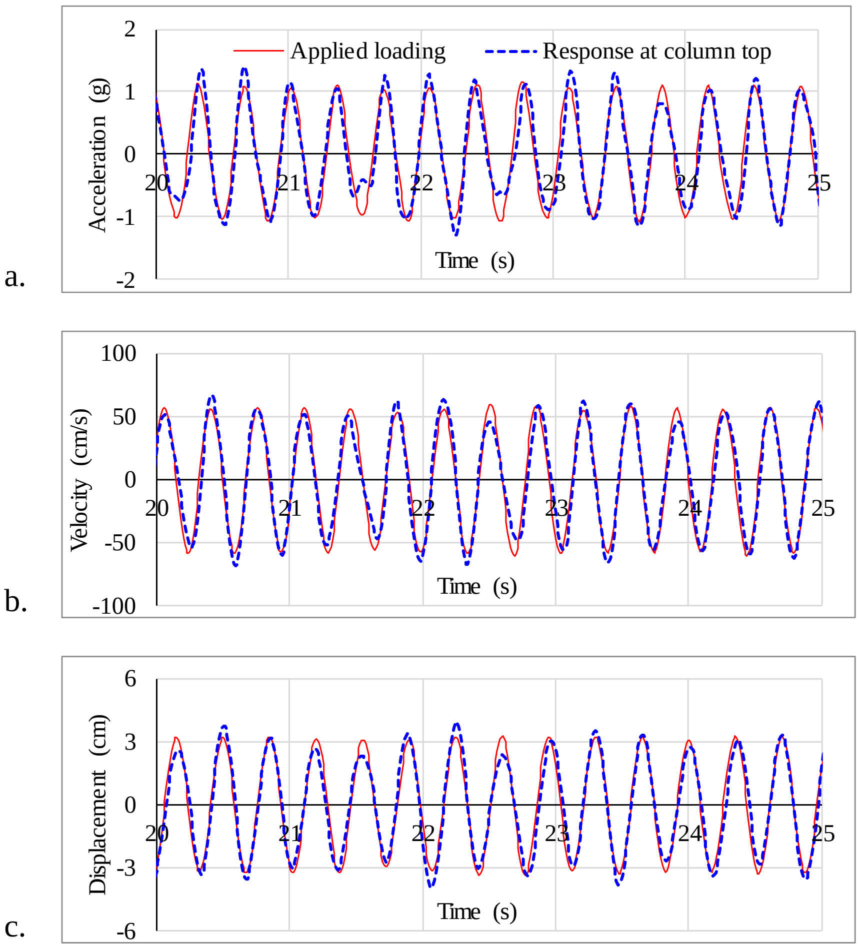


Figure 4: Response of interlocking structure for intermediate 5 seconds, a. acceleration – time history, b. velocity – time history and c. displacement – time history

3. RESULTS:

3.1 Acceleration – time, velocity – time, and displacement - time histories:

The response of interlocking plastic-block structure i.e. acceleration – time history, velocity – time history and displacement – time history during the period from 20 s to 25 s are shown in Figure 4. The blue dash line shows response at top of structure while red full line shows applied loading. These histories are acceptable to large extent to study the dynamic response of column structure. As described earlier, acceleration-time history was recorded with the help of accelerometer and then it was being converted to velocity- time and displacement-time histories using software seismosignal.

Since the locally developed shake table is only able to apply precise harmonic loading (i.e. a little variation exists in amplitude of different cycles), the averaged acceleration, velocity and displacement of base motion (i.e. $\ddot{u}_g, \dot{u}_g, and\ u_g$, respectively) is taken as applied loading. These are 1 g, 55 cm/s and 3.2 cm, respectively. Similarly, the averaged acceleration, velocity and displacement at column top (i.e. $\ddot{u}_t, \dot{u}_t, and\ u_t$, respectively) is taken as column response. These are 1.3 g, 60 cm/s and 3.6 cm, respectively. It may be noted that the amplitude of each cycle is considered for taking the average of any particular parameter.

3.2 Base shear – displacement curves and energy absorption:

Total mass of structure (M) is assumed to be lumped at column top where its response acceleration-time (i.e $\ddot{u}_t$-t) history is recorded. Base shear is calculated as M. $\ddot{u}_t$." Typical base shear – displacement curves for a single cycle are shown in Figure 5. This is calculated as per working of Ali et al. (2013). Table 1 shows the averaged energy absorption in one cycle as well as total energy absorbed. Area within the loop is taken as energy absorption. In seismic event, interlocking plastic-block structure can absorb more energy, because of the relative movement at block interfaces. Energy conservation generally applies to uplift and rocking behaviors, it is typically the rocking impacts that could lead to energy absorption, but rocking/uplift "works" because it reduces secant stiffness of structure and hence detune the effect of earthquakes. It may be noted that this is a pilot study in which shake table is prepared with local resources and local materials (claimed to be Pakistan's first ever shake table with local resources and local materials, capable of applying harmonic loading with fixed amplitude and variable frequencies). Experimentation is being done with observation that energy dissipation is because of relative movement or uplift of block which will be studied in future.

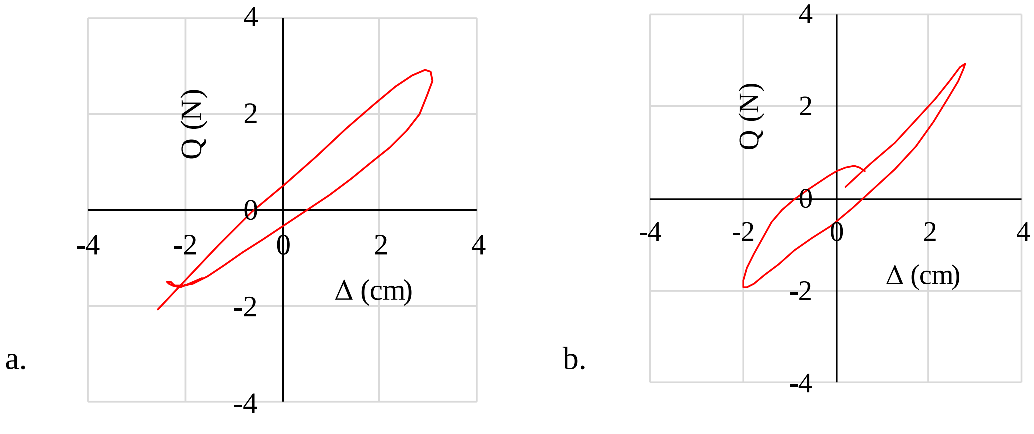


Figure 5: Typical force displacement curves, a. maximum loop area in positive direction, and b. maximum loop area in negative direction

Table 1: Energy absorption during the harmonic loading

Structure	**Averaged energy absorbed in one cycle (Nm)**	**Total energy absorbed (Nm)**
Eight-blocks column	0.32	22

3.3 Development of empirical equations:

Empirical equations are being developed keeping in mind the geometry of interlocking blocks, column height, column response and input loading parameters. The purpose of such empirical modelling from obtained experimental results is to get an idea about how the structure response is related to structure parameters? This may lead to better understanding of such type of structures (simple walls and 3D house). Following empirical equations are developed for predicting the column response:

$$\ddot{u}_t = \frac{a/h^2}{n} K^{(1+\frac{2n}{100})} \ddot{u}_g \ldots\ldots\ldots \text{Eq (1)}$$

$$\dot{u}_t = \frac{a/h^2}{n} K^{(1+\frac{2n}{100})} \dot{u}_g \ldots\ldots\ldots \text{Eq (2)}$$

$$u_t = \frac{a/h^2}{n} K^{(1+\frac{n}{100})} u_g \ldots\ldots\ldots \text{Eq (3)}$$

$$E = \frac{a/h^2}{n} \frac{1.05\, K\, H^2 M}{t^2} \frac{u_t}{u_g} \ldots\ldots\ldots \text{Eq (4)}$$

Where $\ddot{u}_g, \dot{u}_g, and\ u_g$ are averaged ground acceleration, velocity and displacement, respectively. Their corresponding values are 1 g, 55 cm/s and 3.2 cm, respectively. $\ddot{u}_t, \dot{u}_t, and\ u_t$ are response acceleration, velocity and displacement, respectively. A, h, n, H, M, and t are block base area, key height, number of blocks, total column height, total mass of structure and input loading period, respectively. Their corresponding values are 62 mm x 62 mm, 12 mm, 8, 41 mm * 8 + 12 mm = 340 mm, 0.20 Kg and 0.35 s, respectively. K is coefficient having dimensionless value of 0.45.

In Table 2, comparison of experimental and empirical values of column response is shown. It can be noted that experimental values are in good agreement with empirical values. The percentage difference is less than 5%.

Table 2: Comparison of experimental and empirical values of column response at top

Column response	**Experimental values**	**Empirical values**	**Percentage difference**
Acceleration (g)	1.3	1.3	0.3%
Velocity (cm/s)	60	62.6	4.4%
Displacement (cm)	3.6	3.65	1.3%
Energy absorbed (Nm)	0.32	0.33	1.4%

4. DISCUSSIONS:

Locally developed low-cost shake table is not so much accurate with respect to applying harmonic loadings with different frequencies and fixed amplitude. However, it is able to produce precise harmonic loading to some extent so that the dynamic behavior of structure can be studied. This is so because the applied harmonic loading is taken as the base ground motion and the response of structure is studied with respect to it. On the other hand, the observed behavior of interlocking plastic-block structure is more or less same as that reported in other researches (Ali et al. 2013 and Elvin and Uzeogbo 2011). The studied column structure has shown the positive potential in order of structure stability and energy absorption. So, it should be explored in detail for wall structure.

5. CONCLUSIONS:

Following conclusions can be drawn from the conducted study:

- Locally developed low-cost shake table is good enough to study the dynamic behavior.
- Column response (averaged acceleration, velocity and displacement) is increased a little bit at its top compared to applied loading at foundation.
- Energy absorption (22 Nm) is due to interlocking plastic-block uplifts during applied harmonic loading.
- Experimental values of column response are in good agreement with empirical values.

The above outcome is favourable indicating the exploration of its in-depth behavior. Next step should be the dynamic behavior of interlocking plastic-block wall. Numerical modelling on mechanism of energy dissipation and influence of reducing the mass on it is planned in parallel research.

ACKNOWLEDGEMENTS:

The authors would like to thank every person/department who helped thorough out the research work, particularly EE department, ORIC and Engr. Dr. Munir Ahmed.

REFERENCES:

Ali, M. Briet, R. Chouw, N., (2013). Dynamic response of mortar-free interlocking structures, Construction and Building Materials, Vol 42, pp 168-169.

Ali, M. Gultom, RJ. Chouw, N., (2012). Capacity of innovative interlocking blocks under monotonic loading, Construction and Building Materials, Vol 37, pp 812-821.

Darshita, T. and Anoop, P. (2012). Development and instrumentation of low-cost shake table. International Journal of Science and Research, pp. 1310-1312.

Elvin, A. and Uzoegbo, H.C., (2011) Response of a full-scale dry-stack masonry structure subject to experimentally applied earthquake loading, Journal of the South African Institution of Civil Engineers, Vol 53, pp 22 -32.

Naseer, A., Khan, A. N., Hussain, Z., & Ali, Q. (2010). Observed seismic behavior of buildings in northern Pakistan during the 2005 Kashmir earthquake. Earthquake Spectra, Vol 26 No 2, pp 425-449.