Dynamic behaviour of interlocking plastic-block structure using Shake Table

N. Khan, I. Khan & F. Khan
M/s Hidayat Ullah Khan & Brothers, Pakistan

ABSTRACT

Severe damage was caused by the earthquake, primarily to non-engineered structures in rural areas. Structures including roads, bridges, buildings and railroad tracks all suffered catastrophic destruction as a result of strong ground motion. In seismically active areas, the absence of earthquake-resistant structures results in a significant loss of life. To stop losses from future earthquakes, safe and economical earthquake-resistant housing is necessary. A mortar-free interlocking plastic block structure is among the best options for reducing seismic damage. Although several researchers have utilised different interlocking methods, mortar-free interlocking plastic-block structures have not yet been studied. An interlocking plastic block wall prototype is taken into consideration for the research purposes. In this study, a shake table is used to examine how an interlocking plastic-block wall responds to harmonic loading at frequencies of 1.3 Hz, 1.4 Hz, and 1.5 Hz, respectively. To record base excitation, one accelerometer is placed at the bottom of the structure, and the other is attached to the upper block to record the structure's response from the top. Acceleration-time, velocity-time and displacement-time histories are used to predict the structure's behaviour. The response of the structure is recorded in terms of acceleration-time, velocity-time and displacement-time histories. Average energy absorption, base shear (Q)-displacement curves (Δ) and damping of interlocking plastic-block walls are also calculated. This research will be useful in the future to explore the dynamic behaviour of interlocking plastic block structures in more detail.

1 INTRODUCTION

A stronger earthquake produces devastating damage and many fatalities as a result of the collapse of structures like buildings, roads, and bridges. The earthquake has a greater impact on masonry structures. According to Rossetto and Peiris (2009), the 2005 Kashmir earthquake caused full or partial damage to around 45,000 masonry structures. In the Kashmir earthquake, 139,000 people suffered injuries, 80,000 individuals lost their precious lives, and 3.5 million people lost their homes. The Kashmir earthquake caused the deaths of about 20,000 children, most of whom died in schools, and economic damage of over $5.2 billion. Desroches et al. (2011) claim that the 2010 Haiti earthquake resulted in the migration of about one million people, the deaths of 316,000 people, 300,000 injuries, and the destruction of 80 to 90 percent of masonry structures. About 3,000 houses collapsed, 44,000 were hospitalized, 30,000 died, and 12,000 poorly engineered houses were permanently destroyed during the 1999 Izmit earthquake (Reilinger et al. 2000). Pokharel and Goldsworthy

(2017) conducted research on the 2015 Nepal earthquake and found that this earthquake caused 8,969 fatalities and caused 900,000 temples and houses to be partially or completely destroyed.
The majority of the structures in the Kashmir earthquake collapsed owing to poor design, according to a thorough assessment (Maqsood and Schwarz 2008, Subedi and Chhetri 2019). In order to minimise damage in future earthquakes, researchers are working on interlocking blocks. To reduce losses in future earthquakes, particularly in developing nations, it is necessary to construct affordable, secure, and earthquake-resistant housing.

In the last ten years, a few researchers have developed a new technique for earthquake-resistant housing (Ali et al. 2012, Anand et al. 2000, Thanoon et al. 2004). Interlocking concrete blocks have been used to build earthquake-resistant houses, but concrete blocks produce stronger inertia forces due to their heavier weight. Interlocking plastic blocks without mortar are considered for the research because of their low weight. The lighter the structure, the less inertial force is generated during an earthquake. Therefore, investigating interlocking plastic blocks for earthquake-resistant housing is a suitable option. Plastic bag pollution of the environment is a major concern in many nations. Making waste plastic into useful interlocking plastic blocks is a challenge. These plastic bags are recycled to create usable interlocking plastic blocks, interlocking plastic tiles, and interlocking plastic bricks for earthquake-resistant housing, making them environmentally friendly. Although asbestos paint can be used for fire resistance. Asbestos paint can be used to create fire-resistant structures; however, this is outside the scope of the research. In the below section, the latest technology of mortar-free interlocking plastic blocks has been introduced for the most active seismic regions, especially in developing countries. The purpose of this study is to determine the response of an interlocking plastic block wall, the damping ratio, the average energy absorption, and the relationship between the base shear (Q) and displacement curves (Δ).

2 EXPERIMENTAL PROCEDURES

2.1 Porotype interlocking plastic-block

Figure 1(a) shows a proposed interlocking plastic block that could be used in actual construction. The suggested interlocking plastic block has a 150 mm x 150 mm base, a 110 mm height, and a 50 mm key height. The proposed block is 2.5 times bigger than the plastic block prototype. Figure 1(b) illustrates the dimensions of the interlocking plastic blocks for research purposes, which have a base area of 60 mm by 60 mm and a total height of 63 mm, including the key height of 13 mm. The weight of each polytype plastic block is 25 g.

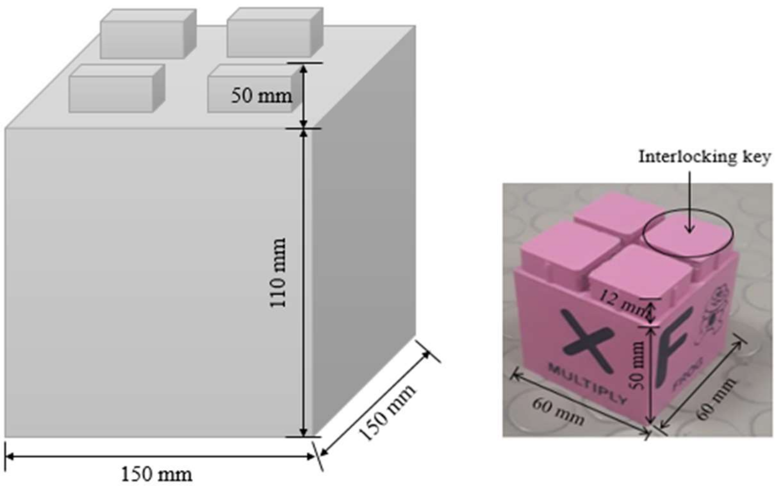


Figure 1: (a) proposed Interlocking plastic-block for construction, and (b) prototype interlocking plastic-block for current study

2.2 Stress-strain curve for interlocking plastic-block

Figure 2 shows the stress-strain of a single and a multiple interlocking plastic block. While a single interlocking plastic block is represented by a full red line, multiple interlocking plastic blocks are shown by a green dotted line. Multiple plastic blocks have been found to have a higher ultimate load than a single plastic block. No failure or yielding was observed in the plastic block's key during the compressive test; however, some little cracks did occur in the bottom portions of the plastic block.

Table 1: Properties of single and multiple interlocking plastic block

Sr. No	No. of blocks	Peak load (kN)	σ (MPa)	ε_0 (-)	E_1 (kN-m)	E_2 (kN-m)	E_t (kN-m)	TTI (-)
1	Single Plastic-block	3.15	0.85	0.015	0.01	0.01	0.02	2.07
2	Multiple Plastic-block	3.67	0.91	0.027	0.02	0.01	0.03	1.67

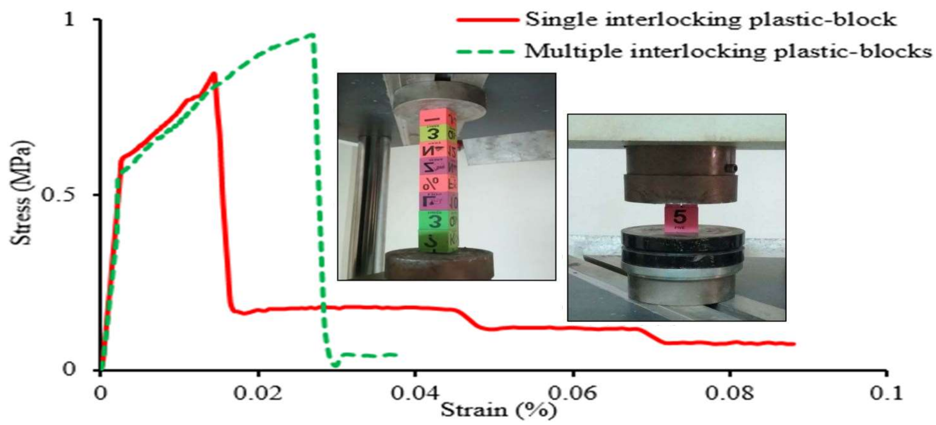


Figure 2: Stress-strain curve for single and multiple interlocking plastic block

The parameters of both single and multiple plastic blocks that were examined, including peak load, compressive strength, strain, toughness index, and total energy absorption, are displayed in Table 1. According to research, 0.02 kN/mm of energy is absorbed by a single interlocking plastic block, but 0.03 kN-mm energy is absorbed in many plastic blocks.

2.3 Mortar-free interlocking plastic-block structure and its instrumentation

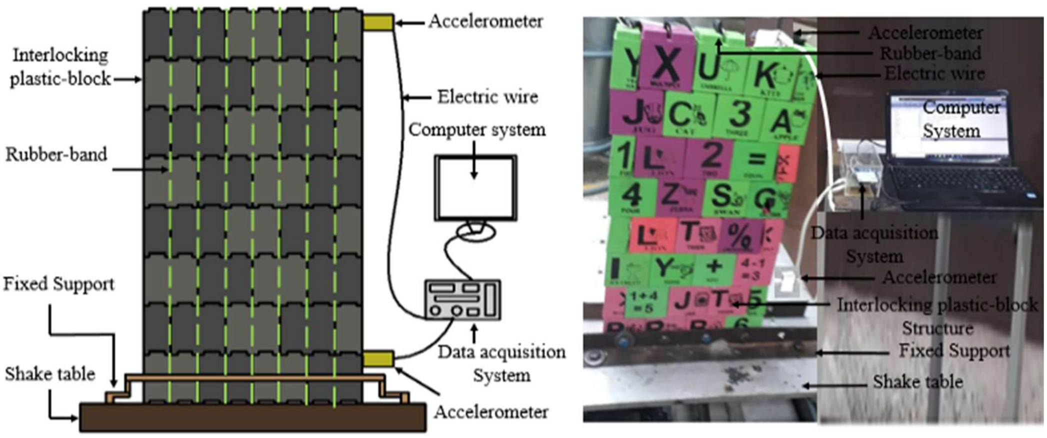


Figure 3: Instrumentation of interlocking wall on shake table, (a) schematic diagram and (b) real test set up

The prototype interlocking plastic-block wall is built with a total of 32 (n=32) plastic blocks. The base area of the wall is 240 mm, and 400 mm is the height (H) of the wall. Rubber bands are used to maintain the structural integrity of the wall because collapse would be expected otherwise. The top of the wall has no mass. The structure has an 800 g overall mass (M). Figure 3 shows the shake table's instrumentation. Two accelerometers are used to record the behavior of a structure under harmonic loading; one is mounted to the shake table's bottom to record the bottom excitation of the structure, and the other is attached to an upper plastic block to record the top behavior of the structure. Structure excitation is recorded in terms of acceleration-time histories.

2.4 Damping and fundamental frequency of structure

The results of the snap-back test on a wall with a rubber band that was displaced from the top mean position by (a) 30 mm and (b) 60 mm are shown in Figure 4. The log-decrement technique is used to calculate the damping ratio (ξ) and fundamental frequency of the wall.

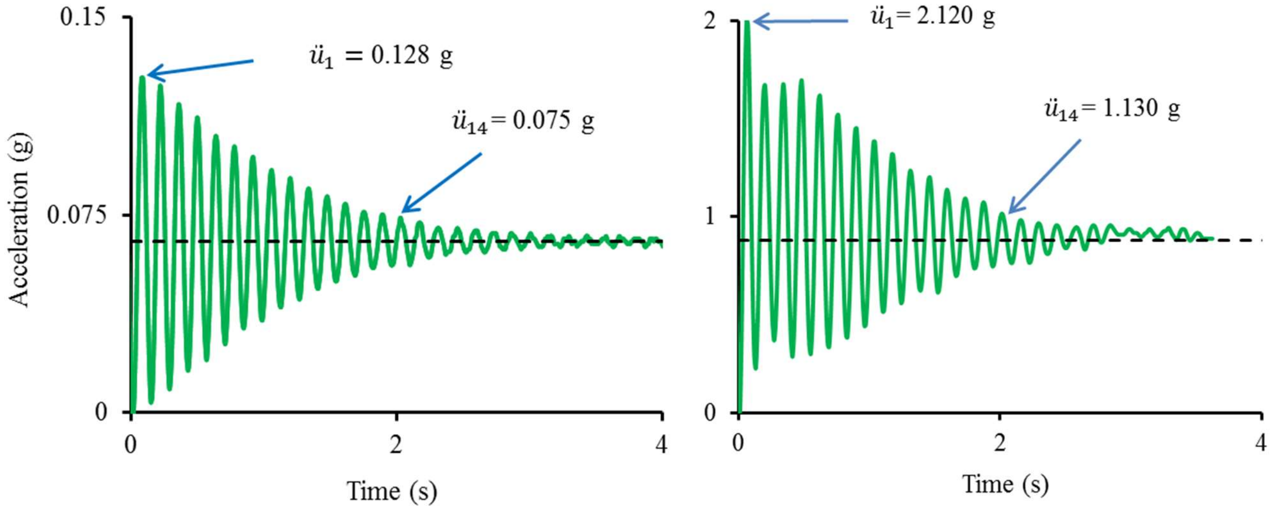


Figure 4: Snap back test results of column with rubber band having displaced top mean position by (a) 30 mm and (b) 60 mm

Table 2 shows the results of the snap-back test performed on an interlocking plastic block wall with a rubber band. A wire is attached to the top of the block for the snap-back test and is used to move the structure's top mean position with amplitudes of 30 and 60 mm. By abruptly releasing a wire, an interlocking plastic block wall's free vibration is noted. Acceleration time histories indicate the free oscillation of a wall made of interlocking plastic blocks. It has been observed that interlocking plastic block wall integrity is enhanced by using rubber bands.

The damping ratios for walls displaced by 30 mm and 60 mm, respectively, are 2.03% and 2.06%. The damping ratio will be higher for a more displaced wall, as mentioned below in Table 2. The computed frequencies are 7.30 Hz and 7.31 Hz, as also indicated in Table 2. The frequency values are the same since a similar structure will have a similar frequency and a damping ratio with slightly different values.

Table 2: Snap-back test results of interlocking plastic block wall

Sr. No	Amplitudes (Hz)	Frequency (Hz)	Damping ratio (%)
1	30 mm	7.30	2.03
2	60 mm	7.31	2.06

3 ANALYSIS AND RESULTS

3.1 Acceleration-time histories

The behaviour of an interlocking plastic-block wall is recorded in terms of acceleration-time histories. The acceleration-time histories between 30 and 50 seconds are shown in Figure 5. Additionally, the average acceleration at the top and bottom of the wall is indicated. The full green line represents base excitation, and the top behaviour of the wall under harmonic loading is shown by the red dashed line.

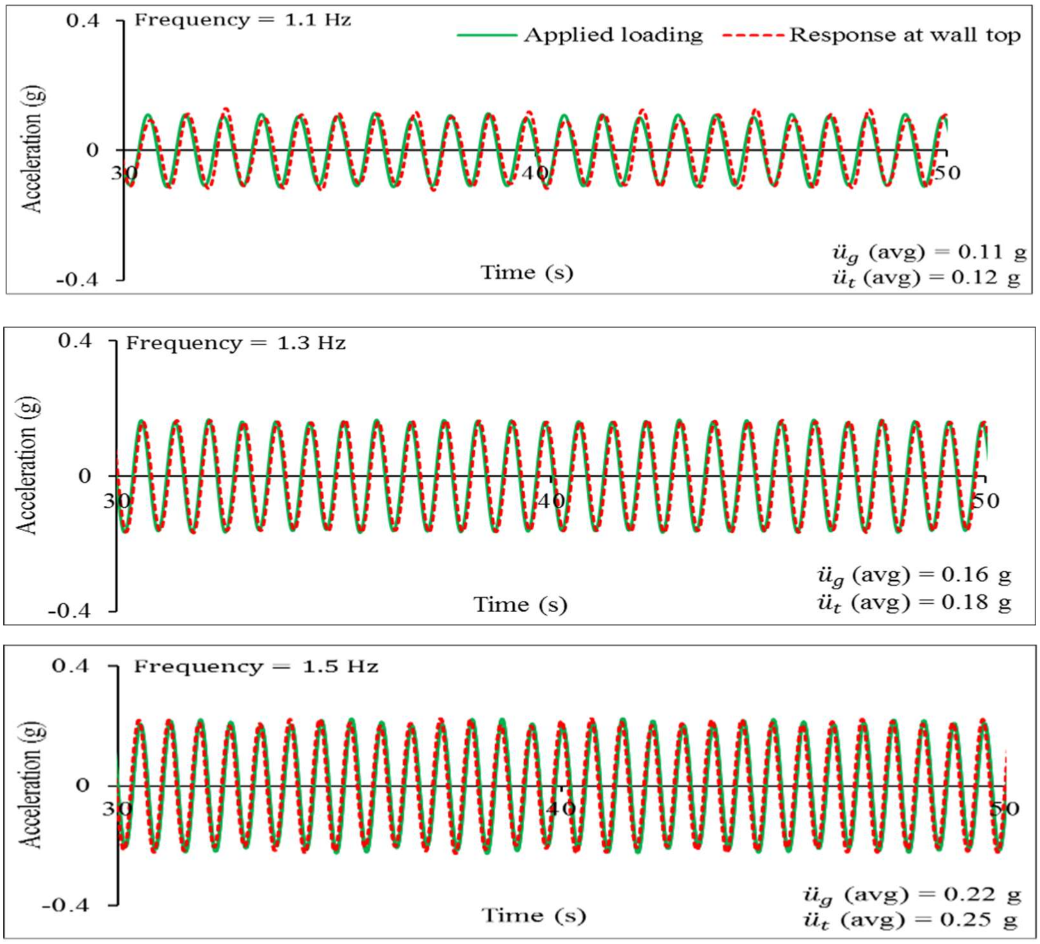
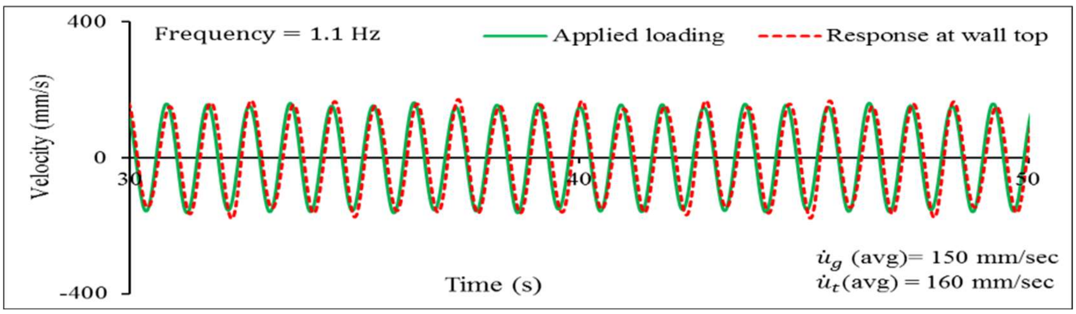


Figure 5: Acceleration-time histories of interlocking plastic block wall during harmonic loadings of 1.1 Hz, 1.3 Hz and 1.5 Hz between 30 s to 50 s

3.2 Velocity-time histories

Acceleration-time histories are converted into velocity-time histories using seismosignal software. The velocity-time histories between 30 and 50 seconds are shown below in Figure 6. A wall's top behaviour under harmonic loading is shown by the red dashed line, whereas the full green line indicates base excitation.



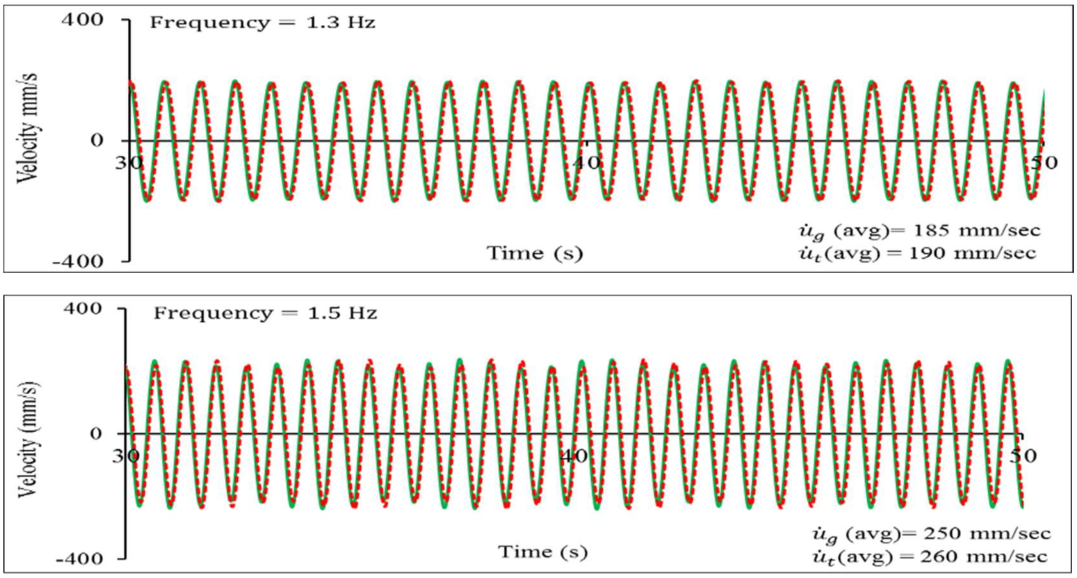


Figure 6: Velocity-time histories of interlocking plastic-block wall during harmonic loadings of 1.1 Hz, 1.3 Hz and 1.5 Hz between 30 s to 50 s

3.3 Displacement-time histories

Similar to above, seismosignal software transforms velocity-time histories into displacement-time histories. Figure 7 shows the displacement-time histories between 30 and 50 seconds. The entire green line represents base excitation, and the top behaviour of the wall under harmonic loading is shown by the red dashed line.

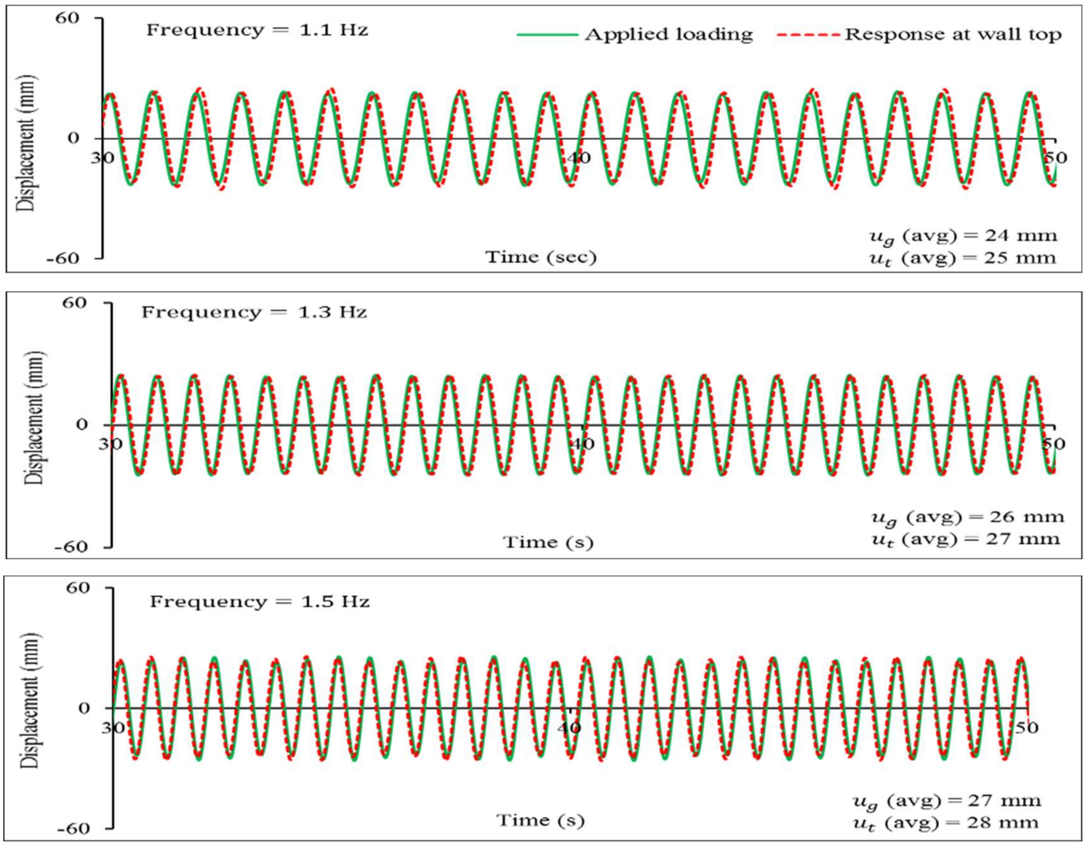


Figure 7: Displacement-time histories of interlocking plastic block wall during harmonic loadings of 1.1 Hz, 1.3 Hz and 1.5 Hz between 30 s to 50 s

3.4 Base-Shear (Q)- displacement curves (∆) and energy dissipation

Base shear displacement curves with an enlarged single typical loop are shown in Figure 8. Assume the total mass of the structure at the top of the wall. To calculate the base shear (M), multiply the structure's mass by the acceleration. By using Ali et al. (2018) techniques, base shear is calculated. A single loop area is used to calculate energy dissipation. The larger the loop area, the greater the energy absorption.

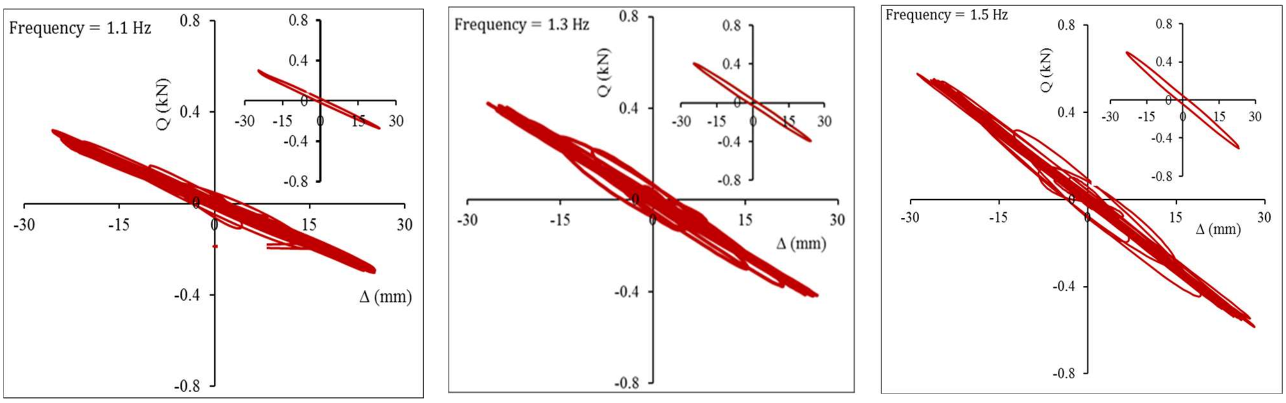


Figure 8: Base shear (Q)- displacement (∆) curves with enlarge single typical loop

The total and average energy absorption for three different harmonic loadings is shown below in Table 3. It is found that interlocking plastic-block structures have good energy absorption capacity under dynamic loading because of the relative moments of the blocks.

Table 3: Energy dissipation during harmonic loading

Sr. No	Amplitude	Frequency (Hz)	Average energy absorbed in one cycle (Nm)	Total numbers of cycle (n)	Total energy Absorbed (Nm)
1	$u_{g\,=}$ 30 mm	1.1	1.0	56	56
2	$u_{g\,=}$ 30 mm	1.3	2.5	70	175
3	$u_{g\,=}$ 30 mm	1.5	3.6	89	320

4 CONCLUSION

People with low incomes in society have been severely impacted by rising worldwide inflation. All individuals need safe and economical places to live, which is a serious problem. Plastic interlocking blocks can be used to build a structure that is both economical and earthquake-resistant. Interlocking plastic blocks are simple to assemble and do not require skilled workers during construction.

An accurate harmonic loading with a predetermined amplitude can be provided via a two-dimensional (2D) shaking table in order to evaluate the dynamic behaviour of an interlocking plastic block wall. Applied harmonic loading is taken as the base ground motion, and with respect to it, the behaviour of the interlocking plastic block wall is studied thoroughly. The following conclusion can be drawn from the conducted research work:

- In current research work it has been found that plastic blocks are brittle while they should be ductile by nature.
- Interlocking plastic blocks are an economical and safe solution to reduce losses in future earthquakes because of their light weight.

- The wall response (averaged acceleration, velocity and displacement) is increased a little bit at its top compared to the applied loading at the foundation.
- A significant amount of energy is dissipated (320 N-m) in the interlocking plastic block wall when the blocks are uplifted or the block interfaces move relative to one another.

5 FUTURE SCOPE

The next step is to explore the dynamic behaviour of an interlocking plastic block column along with its diaphragm. There is a need for further research to investigate (in a numerical sense) the mechanism of energy dissipation, namely the relative movement or uplifts of blocks. There is also a need to categorise interlocking block structures according to seismic demand; it is necessary to develop construction guidelines based on an in-depth study of the materials required for block manufacturing and interlocking mechanisms.

6 CONFLICT OF INTEREST

The authors confirm that there are no conflicts of interest in this article's content.

7 ACKNOWLEDGEMENT

The author would like to thank everyone who helped with the research, especially ORIC, the Electrical Engineering Department, for providing the data acquisition system (accelerometers) and training on how to record data using an accelerometer.

8 REFERENCES

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

Ali, M. (2018). Role of post-tensioned coconut-fibre ropes in mortar-free interlocking concrete construction during seismic loadings. KSCE Journal of Civil Engineering, 22(4), 1336-1343.

Anand, K. B., & Ramamurthy, K. (2000). Development and performance evaluation of interlocking-block masonry. Journal of Architectural Engineering, 6(2), 45-51.

DesRoches, R., Comerio, M., Eberhard, M., Mooney, W., & Rix, G. J. (2011). Overview of the 2010 Haiti earthquake. Earthquake Spectra, 27(S1), S1-S21.

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.

Khan, F. and Ali, M., (2018). Behavior of interlocking plastic-block structure under harmonic loading using locally developed low-cost shake table. In Proceedings of Annual Australian Earthquake Engineering Society Conference, Perth, Western Australia (p. 51).

Maqsood, S. T., & Schwarz, J. (2008). Analysis of building damage during the 8 October 2005 earthquake in Pakistan. Seismological Research Letters, 79(2), 163-177.

Rossetto, T., & Peiris, N. (2009). Observations of damage due to the Kashmir earthquake of October 8, 2005 and study of current seismic provisions for buildings in Pakistan. Bulletin of Earthquake Engineering, 7(3), 681-699.

Subedi, S., & Chhetri, M. B. P. (2019). Impacts of the 2015 Gorkha Earthquake: Lessons Learnt from Nepal. In Earthquakes-Impact, Community Vulnerability and Resilience.

Thanoon WA, Jaafar MS, Kadir MRA, Ali ABA, Trikha DN and Najm AMS. (2004). Development of an innovative interlocking load bearing hollow block system in Malaysia.