CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Consequences of Block-Return on Dynamic In-Plane Behavior of Interlocking Plastic Block Walls

by

Sardar Junaid Asad

A thesis submitted in partial fulfillment for the degree of Master of Science

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Department of Civil Engineering

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I want to dedicate this work to my family, who helped me throughout my education.

CERTIFICATE OF APPROVAL

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(Sardar Junaid Asad)

Abstract

The susceptibility of masonry walls, known as load-bearing masonry walls, to earthquake damage has been demonstrated by past seismic events. Owing to heavy ground motion, the earthquake severely affects the masonry structures. One of the most widely recorded types of structural damage and loss of life, particularly in severe earthquake regions, has been the failure of load bearing wall systems. In addition, the failure of structural components can also pose a danger to life. The biggest contribution to the economic loss caused by an earthquake is damage to structural components.

The economic houses that can resist and monitor the damage due to strong ground movement are required in developing countries. A new construction technique of interlocking plastic block structure for earthquake-resistant houses has been proposed to empower the effective and cost-effective solution for earthquake-resistant houses. Due to its relative movement at the block boundary throughout the time of an earthquake, the interlocking plastic-block system dissipates more energy. The dynamic in-plane behaviour of interlocking plastic block walls that have block-return under snap back and harmonic tests is described in this research. Three walls i.e. solid wall, wall having window opening and wall having door opening, are considered to be the most common configuration in a house structure.

Harmonic loadings of uniform amplitude and various frequencies are used. In order to estimate potential energy dissipation, the response of walls is calculated in terms of acceleration-time and displacement-time under harmonic loading. Energy dissipation power of block-return interlocking plastic-block walls is increased by using rubber band as a vertical reinforcement. In order to predict the behaviour of such structural components, empirical modelling is also suggested. The empirical equation is updated by the addition of the new i-e Block-return factor (Rb) variable with a value of 0.73. The percentage difference is less than 19 % between experimental and empirical values. The experimental and analytical findings agree well with each other. This research will help to clarify the behaviour of plastic-block interlocking systems for further work.

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Abbreviations

IPW	Interlocking Plastic-block Wall with Opening
MPa	Mega Pascal
1D	One Dimensional
OOP	Out-of-Plane
Rb	Return-block
RB	Rubber Band
RB	
SDOF	Single Degree of Freedom Three
3D	Three Dimensional
IP	In-Plane
MDOF	Multiple Degree of Freedom

Symbols

ξ	Damping ratio
Δ	Displacement in millimeter
E	Energy absorbed
E_t	Total energy absorbed
f_n	Fundamental frequency
K	Coefficient having dimensionless value
n	No. of interlocking plastic-blocks
m	No. of blocks along the length of wall in a single layer
a	Base area of interlocking plastic-block
Q	Base-shear
H_z	Unit of frequency
g	Acceleration
$\ddot{u}_g$	Average acceleration at base
$\dot{u}_g$	Average velocity at base
u_g	Average displacement at base
$\ddot{u}_t$	Average acceleration at top of IPWW
$\dot{u}_t$	Averaged velocity at top of IPWW
u_t	Average displacement at top of IPWW

Chapter 1

Introduction

1.1 Background

The vulnerability of masonry walls, classified as load bearing masonry walls, to earthquake damage has been shown by past seismic events. Owing to heavy ground motion, the earthquake severely affects the masonry structures. One of the most commonly recorded forms of structural damage and loss of life, in particular in extreme earthquake regions, has been the failure of load bearing wall systems. [1] researched that nearly 4,50,000 buildings were destroyed, nearly 75,000 people died, nearly 69,000 people were injured, and in the October 2005 earthquake about 2.8 million people were less sheltered. 87,476 and 731 people were killed, 459,76,596 and 11,20,513 people were injured and 852,309 and 19,849 billion economic losses were recorded in the Wenchuan and Ludian earthquakes in China [2]. More than 86,000 causalities, more than 80,000 human casualties and an estimated gross economic loss of $5.2 billion were caused by the October 2005 Azad Kashmir earthquake [3]. Furthermore, the failure of structural elements may also pose a danger to the protection of life. The most substantial contribution to the economic loss caused by an earthquake is the damage to structural components.

The economic houses that can resist and monitor the damage due to strong ground movement are required in developing countries. Many techniques are used in concrete works for the construction of masonry buildings in an effort to mitigate damage in future events.

[4] proposed mortar-free structures (new construction techniques) for earthquake-resistant houses to allow an efficient and cost-effective solution for earthquake-resistant houses.

The weight of CFRC (coconut fibre reinforced concrete) blocks, however, remains a matter of concern. The lighter the structural mass, the lower the force of inertia produced. The lightweight structures in Pakistan are just examples of single storey steel and wooden structures. But the dissipation of energy during an earthquake is still a problem. The ability to dissipate earthquake energy is due to a mortar-free interlocking block system. Lightweight plastic interlocking blocks are one of the best choices for this. In order to decrease inertia forces, it is important to reduce block mass. One of the recently proposed construction techniques for earthquake resistant houses is interlocking block structure. For such kind of structure, few studies with different aspects have been conducted on prototypes using relative approach. Due to their relative movement at the block boundary during the time of an earthquake, plastic interlocking blocks dissipate more energy.

Six degrees of hydraulic shake table freedom are required to produce real earthquake data with different frequencies, but with more operating and maintenance costs, it is very costly. The locally built 1D shake table is used to test the dynamic behaviour of in-plane plastic interlocking block-return walls (solid wall, window opening wall, and door opening wall). Since the 1D shake table is less costly, generating spontaneous excitement as well as periodic motion. It can be used to replicate earthquakes in the laboratory. Locally prepared 1D shake table was therefore used to model earthquake and to analyse the behaviour of small-scale plastic prototype interlocking block return walls (solid wall, window opening wall and door opening wall) under periodic motion.

No research has been done to investigate the action of plastic interlocking block-return walls (solid wall, window opening wall and door opening wall) under cyclic loadings using the locally built low-cost 1D shake table to the best of the author's knowledge.

1.2 Research Motivation and Problem Statement

Earthquake is hazardous activity that cause significant harm. Many people in mountainous regions died during or after an earthquake when buildings collapsed, many of them were homeless. Such damage and loss of human life can be mon-itored if the structures seismic behavior during an earthquake is specifically ob-served, which can help design accordingly. There are such facilities in developed countries, but these amenities are rare in developing countries. For this purpose, interlocking block structures is a possible solution for earthquake resistant hous-ing. However, the greater mass of blocks is a point of concern, because of the resulting larger inertial forces during the earthquake. Confined masonry systems are, on the other hand, slightly un-economical and has same above-mentioned in-ertial forces problem. Therefore, it is the needs of hour to produce cost-effective and reliable solution. [4] has provided an efficient and cost-effective solution, but there is still a need to minimize block mass. Consequently, the problem statement is as follows.

"*Mortar free interlocking block structures have emerged as an innovative construc-tion technique for earthquake resistant housing. These structures have the ability to dissipate the energy during earthquake loading. However, the higher mass of these blocks is still a point of concern. Lighter the mass of block, lower the inertial forces generated during earthquake. For this, light weight interlocking plastic-block is one solution along with fire-resistant paint. For economic and environmental aspects, plastic waste can be recycled for this purpose (note: for the time being, it is outside the scope of this work). For such kind of structure (i.e mortar-free interlocking plastic-block structure), few studies with different aspects have been conducted on prototypes using relative approach. But their dynamic in-plane be-havior is not known. This and previous obtained knowledge can lead to understand the behaviour of complete complex full-scale structure. Consequently, the in-plane behavior of prototype interlocking plastic-block walls with block-return (solid wall, wall having widow opening and wall having door opening) are planned to be inves-tigated under dynamic loading by using locally developed low-cost 1D shake table in this MS research work.*"

1.2.1 Research Questions

How can block-return in the mortar-free interlocking block wall minimize top acceleration and displacement?

Which parameter should the block-return effect be included in the Afzal and Ali (2020) equations?

Which pattern in the block-return wall (among no opening, window opening and door opening) will dissipate more energy?

1.3 Overall Objective of the Research Program and Specific Aim of this MS Thesis

The overall objective of the research programme is to accurately investigate the 3D seismic response of laboratory and field full-scale structures.

The basic objective of this MS research work is to explore the effects of block-return on the dynamic in-plane action of interlocking plastic block walls (solid wall, wall having window opening, wall having door opening) using locally built low-cost 1D shake table in the laboratory It is made locally and significance of such table is to produce harmonic loading.

1.4 Scope of Work and Study Limitation

Three prototype plastic-block interlocking walls (solid wall, window opening wall, door opening wall) with a block-return length of 124 mm (i.e. two block widths) are considered. Fixed base supported with the assistance of base plate and nut bolts. Because of shake table load constraints, mass is not added on the top of walls. Three frequencies are applied to loading (i-e 1.5 Hz, 2.0 Hz and 2.5 Hz). Harmonic loading is chosen to reach the dynamic response (being simple dynamic loading). As a result of the use of a simple 1D shake table, earthquake loadings are not picked. Acceleration-time and displacement-time histories are calculated in terms of response. It is determined by frequency and damping. To evaluate the results based on the[4] approach, analytical equations are used. The wind load is beyond the range. Study restrictions include the use of a basic 1D shake table with just two accelerometers (one at the bottom of shake table and other at the top of wall).

1.4.1 Rationale Behind Variable Selection

The justifications behind specified selections are:

- Because of their regular usage in a home, three patterns of walls (i.e. solid wall, wall having window opening, wall having door opening) are chosen.
- In order to have the wall integrity during harmonic loading, the rubber band is used as vertical reinforcement.
- The 1/10 scale is only applied to elevation measurements as per UBC-97 method A, which depends on the height of the structure.
- Simplified boundary state is known to study only the dynamic wall process (being a cantilever wall above the ground base).

1.5 Research Novelty, Research Significance and Practical Implementation

To the best knowledge of author, no study has been done to examine the consequences of block-return on dynamic in-plane behavior of interlocking plastic block Walls (solid wall, wall having window opening and wall having door opening) using locally developed low-cost 1D shake table.

The research significance is availability of consequences of block-return on dynamic in plane behavior of interlocking plastic block walls with simplified boundary condition. This will help us explain the dynamic behaviour of the whole system.

The previous work of Khan (2019), Sudheer (2020)/Afzal (2020)/Basheer (2020)/S-hazad (2020) have shown favorable results. This work is a step forward in developing interlocking plastic-block structure. The proposed housing technology has the ability to provide underprivileged people with a decent standard of living.

1.6 Methodology

Firstly, all block-return interlocking plastic block walls (solid wall, window opening wall, door opening wall) are built and fitted one by one on the shake table. The purpose of the test is to analyse the wall response at incremental frequencies. Three randomly selected frequencies are applied to start with, keeping in mind the shake table's dynamic loading capability. Two accelerometers are used, one to record ground movement at the shake table and one at the wall top to record the wall reaction. Accelerometers are linked to the computer system to record the information as shown in Annex A.

Within the raw shape, the response of all walls in the in-plane direction in terms of acceleration time is reported. Using seismosignal tools, stored acceleration-time and displacement- time histories are then collected. Base shear (Q) is calculated with the help of displacement vs time-history and acceleration vs time-history of top accelerometer results. The average absorption of energy in one cycle is often measured as the total energy absorbed. To predict the wall response, analytical equations for interlocking plastic-block walls are used.

1.7 Thesis Outline

There are six chapters during this thesis, which are as follows:

The introduction section contains Chapter 1. It includes context, inspiration for research and problem statement, overall purpose and specific objectives, limitations of work and study scope, methodology adopted to conduct the study, and outline of the thesis.

The literature review section is composed of Chapter 2. It consists of history, damage to traditional earthquake masonry structures, modern approach to earthquake-resistant structures, block-return effect and stiffeners on masonry construction, dynamic laboratory prototype structures output and description.

An experimental system is included in Chapter 3. It includes history, method for constructing interlocking plastic block wall with opening and unreinforced masonry wall with opening, test setup, instrumentation snap back test, application of harmonic loadings using shake table, parameters analysed, empirical equation creation and summary.

Experimental assessment is part of Chapter 4. It contains history, snap-back test results, wall behaviour against harmonic loads, base shear measurement, damping ratio and energy absorption and description.

Chapter 5 contains conversation. It includes context, empirical equation link, study outcome with reference to practical requirements and summary.

The findings and recommendations are included in chapter 6. Right after chapter 6, references are present.

Annexure A has been provided after references.

Chapter 2

Literature Review

2.1 Background

Past seismic events have shown that masonry walls, known as load bearing masonry walls, are vulnerable to earthquake damage. Due to heavy ground movement, earthquakes have a severe impact on the masonry structures. The failure of load bearing wall systems following an earthquake was one of the most commonly recorded types of structural damage in buildings during previous earthquakes, especially in severe earthquake regions. In addition, the failure of structural components can also pose a danger to the quality of life. The biggest contribution to the economic loss caused by an earthquake is damage to structural components. Economic houses are required in the developing countries, which can resist and control damage due to strong ground motion. The literature illustrates many practises used in structural works for the construction of masonry buildings in an attempt to minimise the damage in future events. Vertical and horizontal stiffeners in the various interlocking masonry load bearing walls, for instance. For earthquake resistant houses, a new construction technique of plastic inter-locking block structure has been investigated to empower the successful and cost-effective solution for earthquake resistant houses. Due to their relative movement at the block boundary during the time of an earthquake, plastic interlocking blocks dissipate more energy.

2.2 Effects on Masonry Structure during Earthquake

The demolition of traditional masonry buildings in the form of multiple failures has been documented by several researchers. The Gorkha earthquake in Nepal on April 25, 2015. [6] and performed a recognition analysis. There were around 0.8 million partial or complete collapsed buildings reported. A major seismic event, followed by a large aftershock, hit the entire hilly area of the city, resulting in the collapse of many brick masonry buildings. [1] investigated that nearly 4,50,000 buildings were destroyed, nearly 75,000 people died, nearly 69,000 people were injured, and in the earthquake of October 2005 about 2.8 million people were homeless. 87,476 and 731 people were killed, 459,76,596 and 11,20,513 people were injured and 852.309 and 19.849 billion economic losses were recorded in the Wenchuan and Ludian earthquakes in China[2]. Indonesia's latest earthquake cost more than 1000 homes in 2018. Due to structural flaws, most of the masonry structures collapsed during the earthquake[5]. Several citizens were killed, injured, and homeless before the rescue operation was launched by the governing authorities. Moreover, the world has faced tremendous economic losses as a result of this devastating event[7].

Various brick masonry failures were reported in the form of vertical cracks near the corner, cross cracks from the edges of the openings, plane failure, and gable wall failure and separation of the wall vertically. As shown in Figure 2.1, unreinforced masonry buildings are most prone to in-plane failure. If the relation between the walls and the floors is not sufficiently restrained, due to seismic excitation, the entire wall panel or a substantial portion of the panel is overturned[8]. Bad building methods, poor materials and un-designed structures were the primary reasons behind these brick masonry failures. It had been suggested vertical and horizontal bands for the retrofitting of par- tally damaged masonry buildings.

[9] stated that typical masonry structures had sustained significant damage during the January 2001 Bhuj earthquake. There were zero earthquake-resistant properties in many of the masonry structures, which caused major damage to these buildings. In-plane collapse, cracks under bands, in-plane wall failure leading to

a) b) c)

Figure 2.1: Failure of Masonry Buildings; a,b) Stone Wall Failure, c) Brick Wall Failure [8].

lintel band collapse were more commonly found defects in the masonry schemes. The main cause of these failures was the use of mud mortar or lime mortar, which resulted in poor bond strength. The most common problem was the failure of the brick masonry wall under the lintel beam in the form of cracks and the failure of the lintel band. Since the brick masonry wall with horizontal/vertical bands with corner reinforcement is properly constructed, the shaking of the earthquake is properly resisted. The research showed that while horizontal bands minimise in-plane shear and vertical cracks, they might not be useful in the event of in-plane flexure failure.

Fiorentino et al. (2018)[7] have confirmed that the impact on the district of Amatrice on 24 August 2016 of the two seismic events was exceptionally catastrophic. There were 298 deaths, 386 people were injured, approximately 5000 homeless people and the ancient centre of the city suffered extraordinary devastation. The European Macro-Seismic Scale (EMS-98) clarified the deterioration patterns of structures in the ancient centre of the region, based on an assessment study car-ried out in September 2016. More than 60 percent of the structures examined showing slight or complete breakdown, the degree of damage was found to be exceptionally high. The high degree of harm was caused by the unnecessary inefficiency of the masonry systems due to the insufficient use of materials, the absence of wall connections and the inadequate relationship with walls and floors [10].

Figure 2.2: Masonry Wall Failure; a,b,c) Diagonal Cracks on Wall, d) Separation of Wall, e,f) Vertical and Diagonal Cracks, g,h,i) In-plane Failure [8] and [10].

The study showed that the role of effective engineering assessments in the presence of existing buildings in construction is very important and can not be accomplished by conventional methods alone. [11] investigated the collapse of the masonry structure during the high severity of the Eastern Turkey Anatolian fault line earthquakes. Explanations of failure, updated data on active fault areas, and seismic maps for future studies were also issued. Likewise, during the Gorkha Earthquake of 2015, old masonry buildings sustained major losses. [12] Considere Masonry building damage during the 2008 Wenchuan Earthquake. A major seismic event followed by a large aftershock shot down the entire area, leading to the collapse of many brick masonry buildings. Many people died, several injured and certain were homeless until rescued by the governing authorities. In addition, the planet suffered a major economic loss from this tragedy. Multiple masonry structure failures were recorded in the form of cross-cracks between open-ings, diagonal cracks initiated from openings, in-plane failures. Poor construction techniques, inappropriate use of materials and un-designed construction walls were the main reasons behind these brick masonry failures.

Figure 2.3: Masonry Buildings Failure: a) Gabble Wall Failure, b) Vertical Crack at Corner, c) Separation of Wall [13], [14].

2.3 Recently Proposed Approach for Earthquake Resistant Structure

Ali (2018)[4] examined impact of post-tensioned coconut-fiber ropes in oversight inspired during seismic tremor stacking to interlock mortar-free block structure. It was determined that the suggested inter-locking blocks are suitable for recovering their own location due to arrangement and slanted key shape in blocks a while later, the actuated ground excitation. The lumped mass at the top of the column consisting of inter-locking blocks was 200 kg to mimic a single degree of freedom method. As far as enticed increasing velocities, uplift of blocks, tension in rope and the relative displacement at the top, the dynamic reaction of inter-locking block column was registered. Enticed speeding was found to be increased up to the mid-height of the section and a short time later a smidgen at the top of the segment decreased. Rope stress and the uplift of blocks were found to be very similar. In comparison to experimental findings, 35% difference was seen in predicting the real seismic reaction of the structure, which might agree because of the unpredictability of the inter-locking square segment. [15] For the construction of tremor-safe homes, creative eco-accommodating interlocking blocks created using locally accessible waste materials such as palm oil clinker, palm oil fuel debris, and quarry dust.

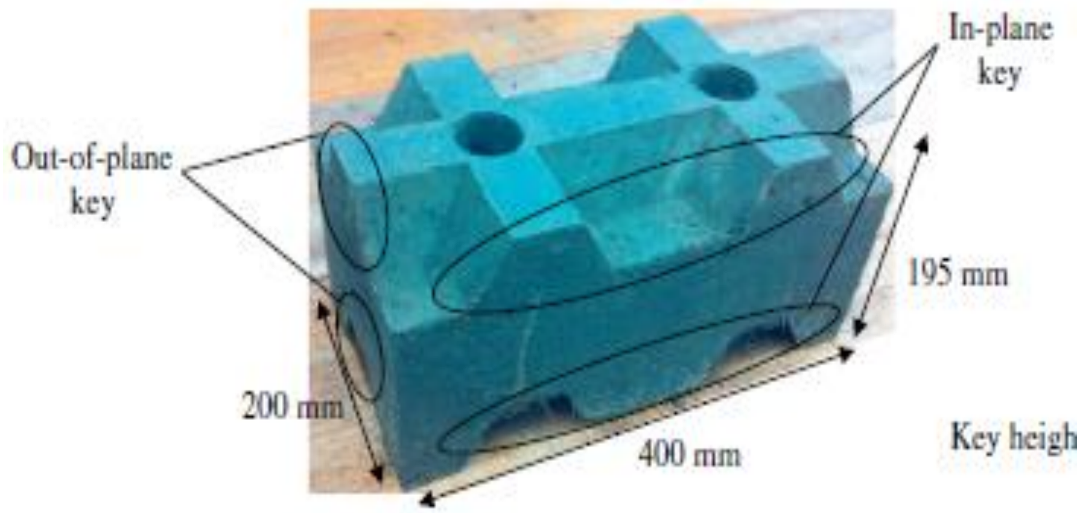


FIGURE 2.4: Interlocking Block of Coconut Fiber Reinforced Concrete (CFRC) [16].

Liu et al (2016)[17] analysed non-interlocking mortar-less block and interlocking mortar less block cyclic behaviour. During the study of cyclic actions, the properties of locking forms, stacking pressure sensations of anxiety and stacking cycles were taken into account. A mechanical model was designed up with the assistance of hysteresis loop technique. Using the Mohr-Coulomb failure system, shear distress modes of the entirety of the examined joints were represented. There was a decrease in the contact coefficients of the entire joints with an increase in the stacking period. The pace of corruption of the touch coefficients has increased with the decrease in the perfection of the interlocking surface. Numerous experts have suggested different compact earth-block interlocking states. Such blocks provide both level and cross-course protection from construction to the wall surface. Expect hydraform interlocking units to provide straight growth and transversely limit one. Despite the fact that these interlocking blocks have different structures, shapes and sizes, their interlocking instrument consists of bulges but is comparable. Owing to the complicated course of action of these obstacles, it was difficult to preserve the exact shape and size of these interlocking squares due to the dirt characteristics and relief con-ditions. Explicit contraction and amazing mud decision, blend plan and excellent healing conditions are required for a plausible strategy. In any event, the use of such devices is inexpensive and inaccessible in developed nations[18]. Another useful arrangement was the review by rearranging the interlocking blocks setup that retained control of the math during the assembly stage. Effective locking of these blocks is the administering part to build a straight and secure block wall that can challenge the supervising powers[19].

Centered on quality perspectives, Jeslin and Padmanaban (2020)[20] looked at traditional blocks and interlocking blocks. For the case interlocking block, the research declared 15% to 30% expansion in mechanical properties. [21] suggested the construction of interlocking brick work with steel fortification for fair lodging in Thailand. Mortar less interlocking block growth has been partly endorsed, but with minimal inspection background, in different countries. The main issue with these blocks is their development, which requires modern devices.

Be that as it may, in the writings, the prominent highlights of the interlocking stone work are remembered throughout. The experts also suggest restricted rearranged and conservative processes of creation. The advantages of these interlocking blocks for the construction of brick work are known to the development companies of developing nations. This new form of interlocking is less complex and does not require mortar sticking motion, accelerating the development time at last. The accessible inter-locking blocks in industry differentiate suit as a fiddle, size and material use in these nations. The interlocking burnt clay brick can be a viable option for traditional bribery because of its improved structural performance and ease of brick masonry construction. Moreover, the introduction of waste marble powder (WMP) into the interlocking of burnt clay bricks will contribute to the economic and sustainable construction of masonry[18].

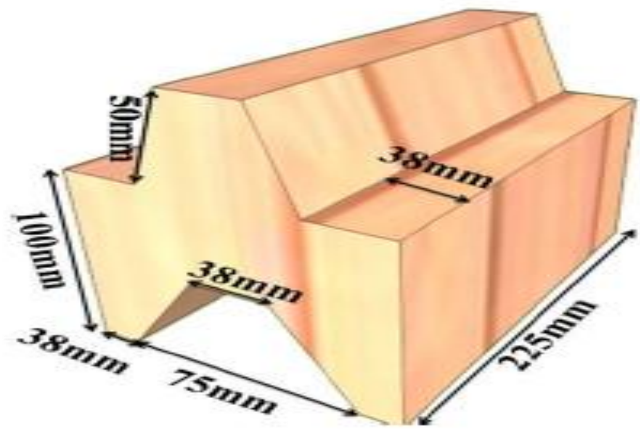


FIGURE 2.5: Interlocking Burnt Clay Brick [18].

2.4 Effect of Block-Return and Stiffeners on Masonry Structures

One of the ancient and commonly adopted building techniques is brick masonry. Additional allies are ample in the supply of brick masonry structural members in ancient buildings. Unreinforced brick masonry buildings are a continuing threat to humanity throughout the world because of their high seismic vulnerability [22]. The main contribution to the economic loss caused by an earthquake is damage to the structural components. These structures were designed with traditional materials and only by taking into account gravity loading [3]. In most cases, these materials are bricks, stones and wood, which are not prone to earthquakes [5]. Most typical unreinforced houses, including concrete block brickwork, conventional brickwork and stone masonry, were totally or partially damaged in the Pakistan earthquake in October 2005[23]. Similarly, during the 2010 Darfield (Christchurch, Nz) Earthquake [13], separation between the roof diaphragms and hence the masonry walls (in the in-plane direction) and damage to masonry pillars at upper levels of unreinforced masonry buildings was observed.

In the laboratory, several re-searchers have researched the seismic efficiency of masonry buildings in the past. In the laboratory studies of the time-scaled Nahnni earthquake in 1985, enormous non-linear activity of unreinforced masonry was observed [24]. Reinforced brick masonry, on the other hand, improves the strength and stiffness of the masonry buildings in the form of concrete stiffness[25]. Not only by laboratory research, but even in the case of true earthquake loading, these phenomena were confirmed. During the laboratory evaluation, the failure modes changed from diagonal tension or shear slip into a diagonal tension and toe mixture-crushing. The integration of reinforcing components into the mortar joints prevented cracking of the structure[26].

In comparison with non-confined walls, confined masonry walls with horizontal stiffeners performed well when subjected to lateral laboratory loading. Compared to unreinforced walls, masonry walls with vertical stiffeners had a major increase in seismic capability in terms of steel ties[27]. The research on earthen wall seismic activity was carried out by Reyes et al.[45] with an opening with horizontal and vertical wood stiffeners. The country of Mexico has a long history of using minimal masonry techniques in its housing construction. It is the nation's foremost common construction activity and is used ex-tensively in the world. Confined masonry is usually practised throughout the country in the sort of engineered and non-engineered construction. Built masonry structures performed substantially better during the 2003 Tecomn earthquake with magnitude 7.6 compared to un-designed brick masonry buildings; the majority of designed masonry buildings were unharmed or sustained only minimal damage[28].

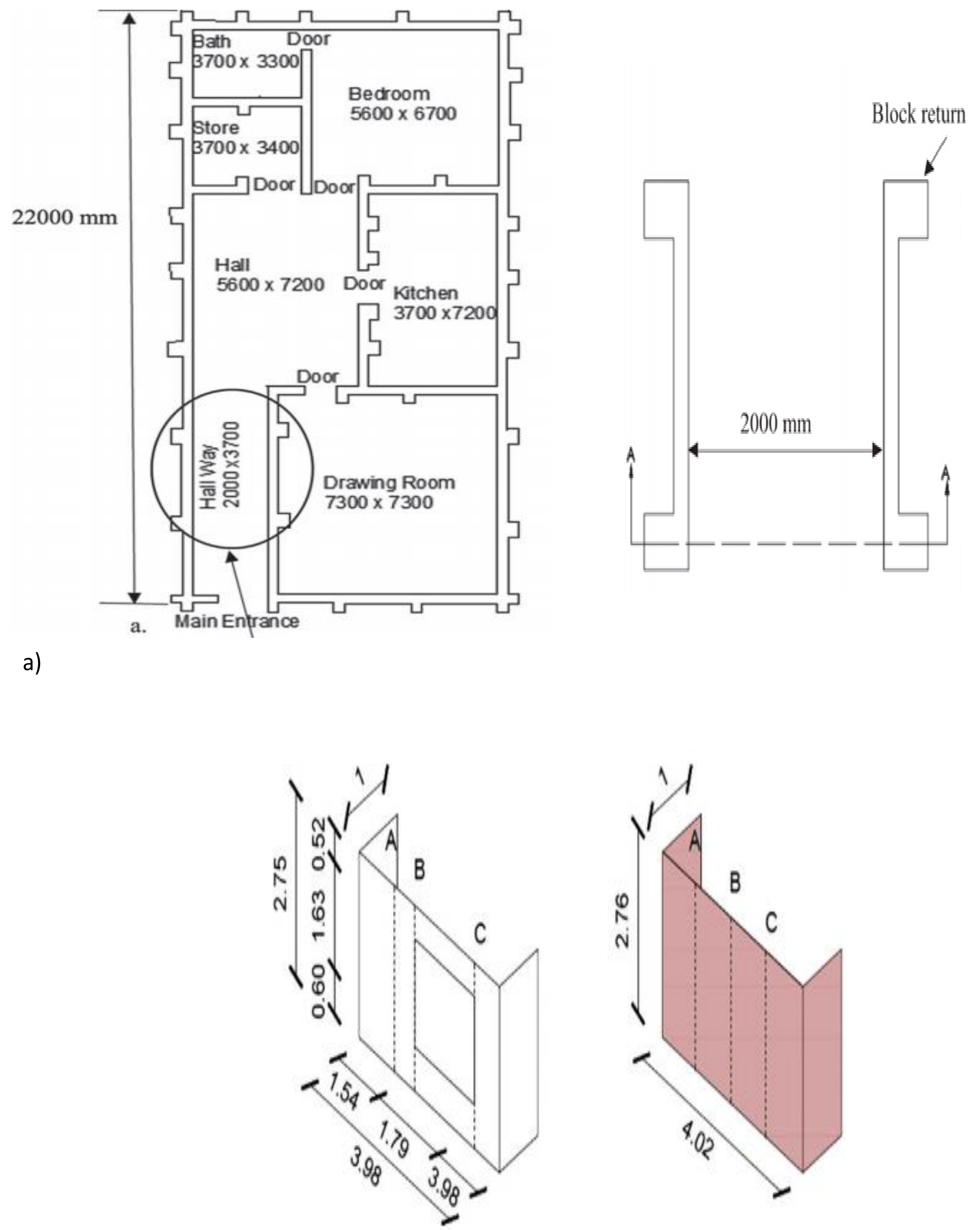


FIGURE 2.6: Wall With Block-return: a) [29], b) [30].

Qamar et al. (2020) [29] conducted a study using natural fibres to enhance lateral resistivity in mortar-free interlocking block-return walls with plaster. In-plane lateral resistance is the key explanation for the failure of the mortar-free interlocking wall framework. In this analysis, increased lateral peak load was noted and further increase was also noted for the reinforced plastered wall system of rice straw and sisal fibre. [30] examined the out-of-plane behaviour of walls with built outer leaves (block-return). They analysed the four single leaves and one full-scale U.R.M cavity walls. Full-scale samples consisting of an OOP panel and two return-block walls were investigated separately, fluctuating in terms of typically encountered boundary conditions and applied overload or absence/presence of openings. Full-scale samples consisting of an OOP panel and two return-block walls were investigated separately, fluctuating in terms of typically encountered boundary conditions and applied overload or absence/presence of openings. In order to evaluate their reliability as disengaged devices for assessing the behavior of all walls exposed to IP two-way twisting excitation, best in class logical procedures depending on the technique for virtual work were applied to evaluate their reliability as disengaged devices for assessing the behavior of all walls exposed to IP two-way twisting excitation.

2.5 Dynamic Performance of Prototype Structures in Lab

In the past, important experiments have been carried out to investigate the behaviour of real-life structures with the assistance of scaled-down laboratory prototypes. In developed countries, the 3-D shake table with six degrees of freedom is used to study the structure's dynamic response to obtain real earthquake data. Emerging countries, on the other hand, lack such a refined and costly 3-D shake table for multiple pieces. However, these countries use a simple 1-D shake table to understand the complex reaction of laboratory prototype structures. The goal behind the production of laboratory prototype structures is to carry out such studies. Several researchers have performed dynamic laboratory testing of small and large-scale designs using the shake table. In these experiments, simplified boundary conditions were introduced for small-scale research. Such studies confirm the conduct of prototype research using the shake table inside the laboratory. Analysis of time history can be a useful technique for evaluating seismic activity of certain prototypes under dynamic loading[31]. The action of full-scale structure under harmonic loading was studied [32], [33], and [34]. [35] The dynamic study of the prototype structure was investigated in the laboratory.

TABLE 2.1: Detail of Different Studies Using Shake Table for Different Testing.

Prototype	**Structure Findings**
Interlocked column of plastic block with and without rubber band [6]	Compared to columns without rubber band, the column with rubber band performed well against harmonic loading
Interlocking campers with plastic block wall with masonry wall [39]	The window interlocking plastic block wall is resistant to harmonic loading while the masonry wall has collapsed during testing.
Score the independent linear damping of inter-story isolated structure output [40]	In order to analyse a 14-story inter-story isolated structure, numeric simulation and shake table real-time hybrid simulation (RTHS) are used. By limiting isolation layer displacements without amplifying accelerations, RILD provides an appealing control alternative.
Ancient Masonry Tower in China [41]	With a macro-modeling approach to further investigate its dynamic behaviour, a nonlinear FEM was developed, the results were compared and well agreed between the tests and the model.
Full-scale corner wall in-plane shake table evaluation, retrofitted with timber elements [42]	Propose a retrofitting technique for both in plane and out of plane directions that improves the strength of the wall. This method consists of symmetrically stalled vertical and horizontal timber elements on each face of the wall to form a confining wood frame, complemented by vertical tensors that precompress the wall.

The effects of degrading mechanisms on masonry dynamic response were studied by Addessi et al. (2019) [36]. During a finite element setting, a non-linear non-local harm plastic material is added and is used to research the out-of-plane behaviour of the tuff-masonry wall, structure response is studied nu- merely under cyclic quasi-static and monotonic loadings and compared with experimental study on shake table. The laboratory shake table test was carried out to analyse the in-plane output of partially grouted, reinforced con-crete masonry walls subjected to simulated seismic loading (zhang et al. [46]). The thesis on the dynamic analysis of the burnt clay brick wall structure in the laboratory was conducted by Singhal and Rai[47]. In order to investigate the effects of window openings on the structural behaviour of historical masonry of the Fatih Mosque, in order to investigate the effects of window openings on the structural behaviour of the mosque, 3D solid and finite elements of mosque models with and without window openings were initially created. Ambient Vibration Research is used to evaluate the experimental dynamic characteristics such as frequency, damping ratio, and mode shapes of the current situation of the mosque, where some window openings were blind. Then, using the experimental dynamic functionality, the finite element model of the current mosque situation is modified. Analyses of the static and seismic time history of the modified finite element model is carried out with and without window openings. Given the displacement and stress propagation of the mosque, structural behaviours with and without window openings were contrasted.

2.6 Summary

Conventional masonry structures are vulnerable to earthquakes. In their construction techniques, contemporary countries have adopted restricted masonry practises. However, up to a certain range, they are also prone to earthquake vibrations. As a brickwork substitution, scholars concentrate on interlocking mortar-free blocks. For these bricks, current literature has implemented a lot of interlocking methods, sizes and shapes. In this respect, a probable solution for earthquake-resilient housing is interlocking block buildings. As always, because of the resultant greater inertial forces during the earthquake, the higher mass of interlocking blocks is a point of concern. Hence, it is important to reduce the mass of the interlocking blocks. The lighter the block mass, the lower the inertial forces produced during the earthquake. Dynamic behaviour of plastic inter-locking block-return walls is known to be dynamic behaviour for that type of construction (i.e. mortar-free interlocking plastic-block structure).

Using a basic shake table, this can be done. The behaviour of plastic inter-locking block-return walls was therefore investigated using the locally built low-cost 1D shake table under dynamic loading. No research was performed to the best of the author's knowledge to explore the action of plastic interlocking block-return walls under harmonic loading by using a low-cost 1D shake table locally de-veloped. Therefore, current research would help to explain the behaviour of interlocking plastic-block walls with rubber band block-return for probable application in comparison to harmonic loading.

Chapter 3

Experimental Program

3.1 Background

When talking about the earthquake resistant architecture of buildings, the reaction and response of structures during the earthquake is very important to expect or quantify. Different approaches have been adopted around the world for this determination. The method of assembling plastic interlocking block-return walls, snap back test, harmonic loadings, analysis parameters, development of empirical equations, test setup and instrumentation using locally developed low-cost 1D shake table is described in this study.

The interlocking plastic block for earthquake-resistant house (plan and 3D view of the proposed house is shown in Figure 3.1a and Figure 3.1b respectively) and prototype testing were suggested by Khan and Ali (2019) [38] due to its lighter weight and subsequent lower inertia forces. In earthquake-resistant structures, the function of material weight and the resulting forces of inertia is very crucial. Inertial forces are usually seen as the ability of a system to resist changes caused by any external force (acceleration). The theory is based on Newton's Law of Motion, namely the 1st and 2nd laws. Heavy systems (materials) respond more because of their greater weight compared to lighter systems (materials) in reaction to such external force, thereby creating higher inertial forces.

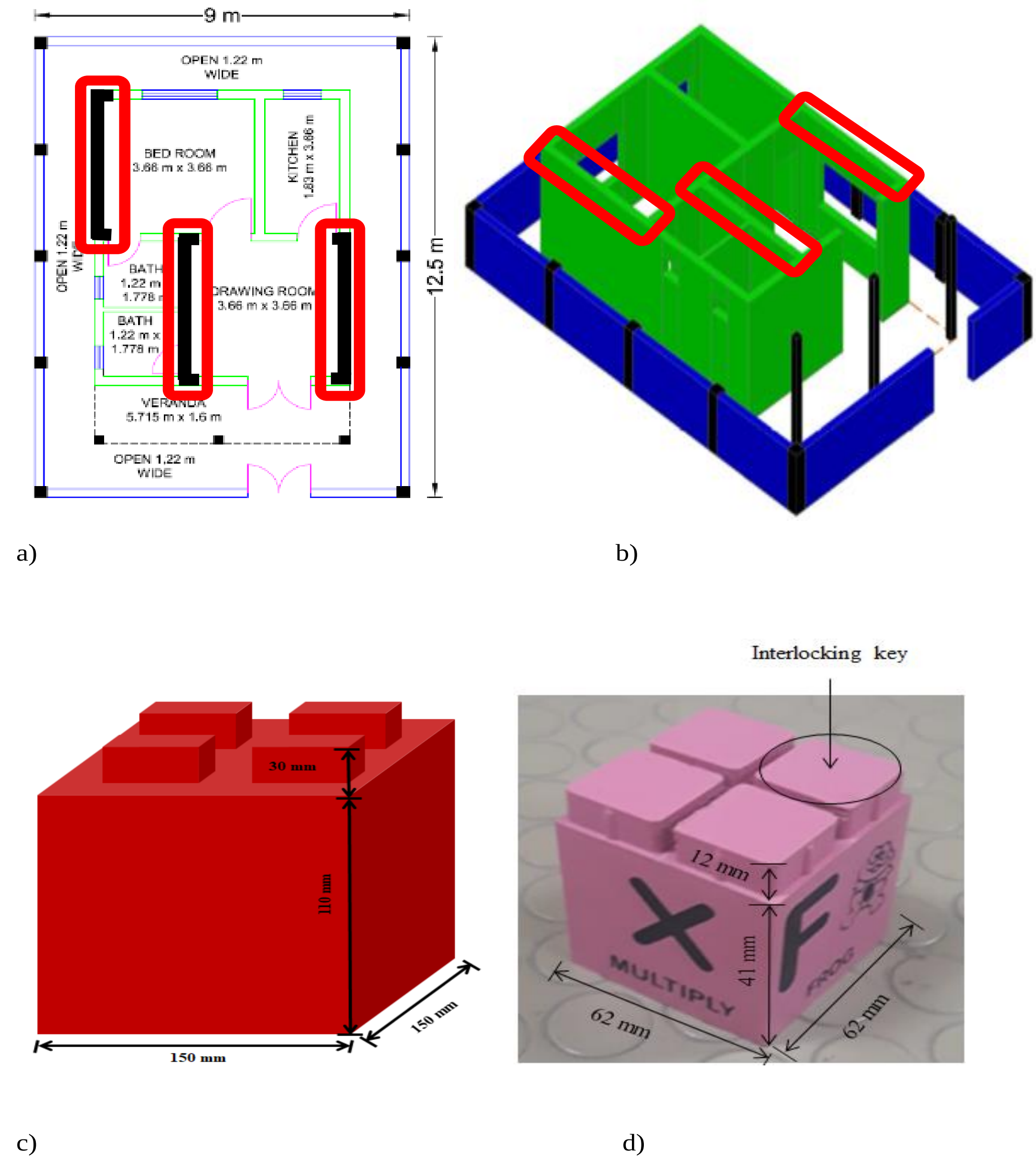
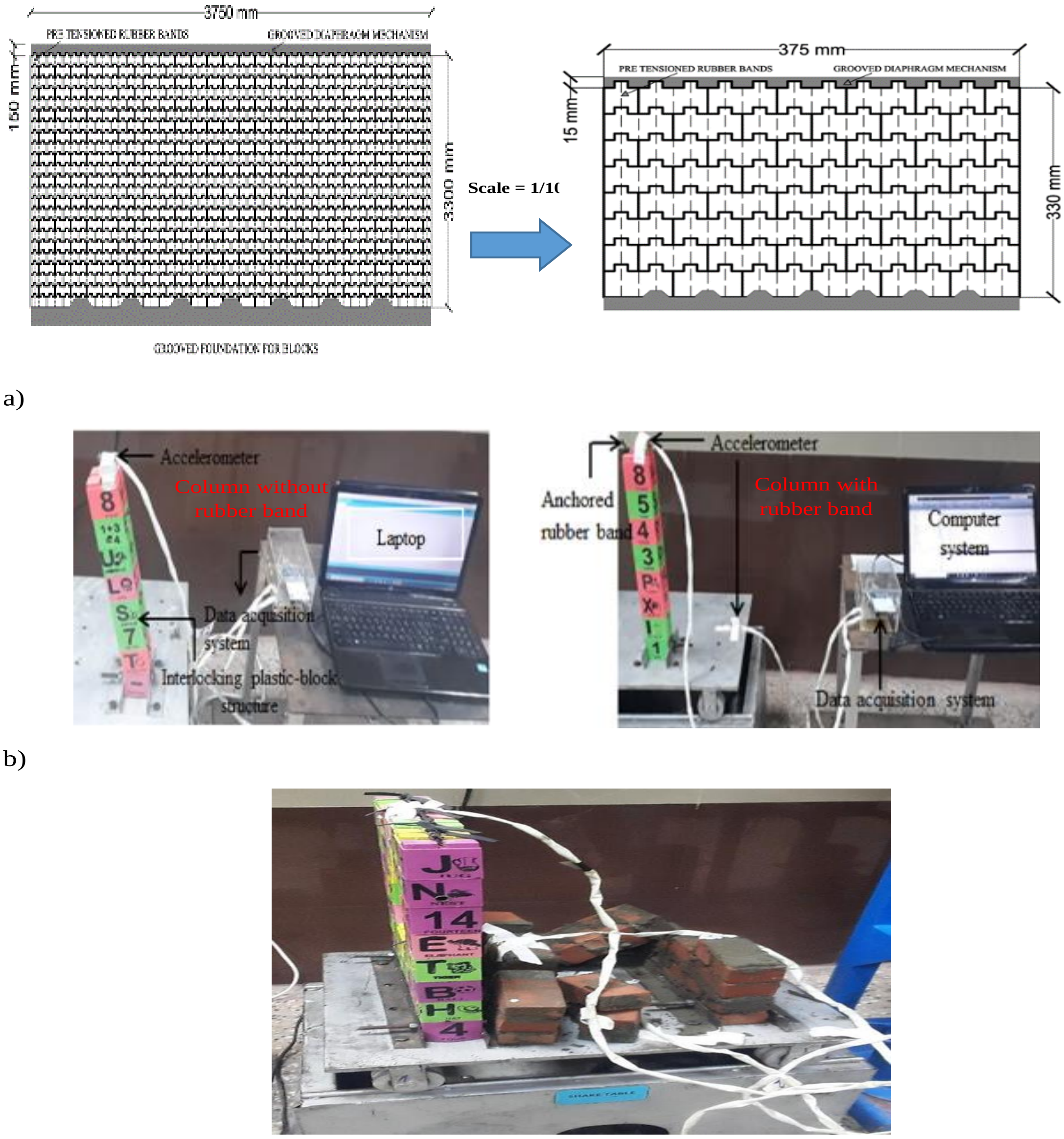


FIGURE 3.1: Proposed Inter-locking Plastic-block House: a) Plan, b) 3D View and Inter-locking Plastic-blocks c) Proposed for Construction and d) Prototype for Current Study.

The proposed interlocking plastic blocks have a base dimension of 150x150 mm and have four keys at the top for the construction of an earthquake resistant housing. The total block height is 140 mm, including the interlocking key height of 30 mm, as shown in figure 3.1. (c). Similarly, the measurements used in the study for prototype construction are 62x62 mm with a height of 53 mm, including the interlocking key height of 12 mm, as shown in figure 3.2. (d). Present research is the continuation of research work [38] and [39].



c)

FIGURE 3.2: Previous Researches; a) Scale Down Technique, b) Column with Rubber Band and column without Rubber Band [38], c) Comparison of Interlocking Plastic Block with Brick Masonry Wall [39].

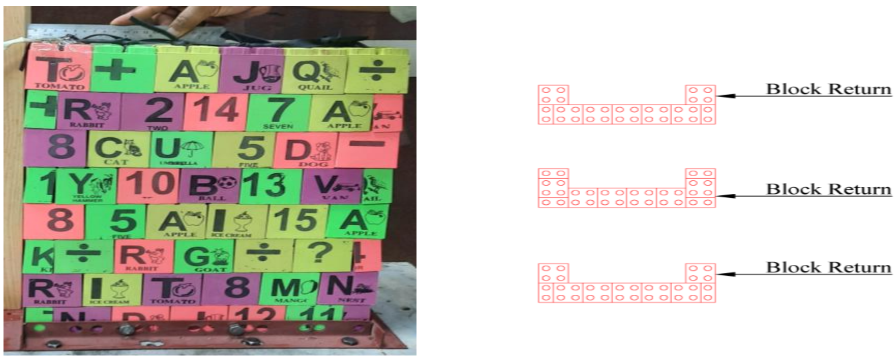
For dynamic research, prototype plastic interlocking block-return walls (solid wall, window opening wall and door opening wall) are considered in this analysis. Prototype testing helps to include criteria rather than theoretical ones for a current or proposed working device. The scaling and construction technique of prototype walls adopted in this research work is based solely on research practices referred to in the literature[40];[41];[42];[43]. The findings of such studies help to explain the behaviour of full-scale systems. The primary goal of the present research is intended to study the dynamic behaviour of block-return structural walls. The structural time period is an important parameter that depends on the height of the structure (UBC-97). That is why the scale-down approach is primarily applied to the elevation dimension of structural walls. It should be noted that the dimensions of the units used in both designs are slightly different (i.e. scaled down wall samples with block return). The elevation measurements of both designs, however, are about the same.

The previous investigations are shown in Figure 3.2. The schematic diagram of the proposed actual wall consisting of interlocking plastic blocks is shown in Figure 3.2 (a). It will have some grooved block mechanism for foundation and roof diaphragm and prototype interlocking plastic block wall scaled down schematic diagram, using 1/10 scale factor. Figure 3.2(b) demonstrates the analysis of the interlocking plastic block column prototype with and without a rubber band [38]. Figure 3.2 (c) shows the change between the plastic interlocking block and the brick masonry wall[39].

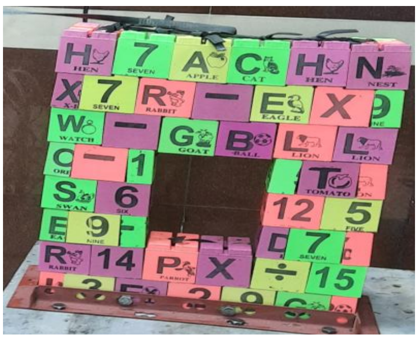
3.2 Construction of Prototype Block-Return Walls

Prototype solid wall interlocking plastic block with block-return and standard first three layers consists of sixty-four plastic interlocking blocks (64), making a total height of 330 mm (H) as shown in Figure 3.3. (a). It's a firm wall with no window or door opening. To provide vertical stiffness in the wall, rubber bands are linked from bottom to top via mid-blocks. With the help of base plates and nut bolts, a fixed base was created. No weight at the top is given. The total mass of the wall (M) is, however, 1.875 Kg. The plastic interlocking block-return wall prototype with window opening consists of 58 plastic interlocking blocks, making a total height (H) of 330 mm as shown in Figure 3.3. (b). It has an opening roughly in the centre in the shape of a window. The area of the opening is 125x125 mm. Wooden lintel is offered as a supportive tool over the window opening. In addition, to provide vertical stiffness in the wall, rubber bands are tied-up from bottom to top through mid-block. A fixed foundation is provided with the aid of base plates and nut bolts.

At the wall top, no mass is applied. The total mass of wall with window opening, however, is 1.715 Kg. It includes 0.056kg weight of wooden lintel as well. Additionally, solid wall has 64 blocks and has 1.875 Kg. Similarly, the plastic interlocking block-return wall having door opening prototype consists of 55 plastic interlocking blocks (55), giving a total height (H) of 330 mm as shown in Figure 3.3. (c). It has a door-style opening on the right side of the wall. The diameter of the opening is 95x250 mm. The Wooden lintel band is supplied above the support mechanism opening. In addition, rubber bands are tied up from bottom to top by mid-blocks to provide the wall with vertical stiffness. With the support base plates and nut bolts, a fixed base is given. At the wall top, no mass is supplied. The total mass of the wall (M), however, is 1,605 Kg.



a)



b)

c)

FIGURE 3.3: Schematic Diagram of Prototype Walls with Block-return with Simplified Boundary Conditions; a) Elevation of Solid Wall and Typical First Three Layers in Plan, b) Elevation of Wall having window opening, c) Elevation of Wall having door opening.

3.3 Test Setup

3.3.1 Snapback Test and Instrumentations

Figure 3.4 (a) demonstrates the snap-back test configuration for the test. At the top of all the interlocking plastic block walls, a wire with a length of 400 mm is connected. An accelerometer is mounted at the top of all the walls to record the wall's reaction. By releasing the attached cable, free vibration from the interlocking plastic-block walls is observed. Wall responses are reported using the accelerometer data in terms of acceleration time history. The method of log decrement is used to measure the late damping ratio (almost) and the simple frequency (fn) of all interlocking plastic block walls with block return.

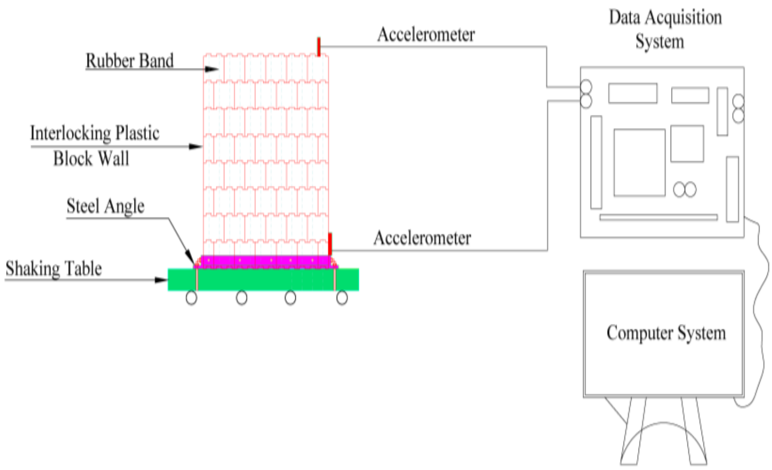
3.3.2 Shake Table Test and Instrumentations

The instrumentation of the shake table tests and proposed harmonic loading are shown in Figure 3.4 (b). Both plastic block-return interlocking walls (solid wall, window opening wall and window opening wall) are placed one-by-one on the shake table using base plates and nut bolt bolt. Two accelerometers are used in total (one is attached to the top of the wall and one is attached to the base of the shake table), repeating this procedure on all the walls. In terms of acceleration-time history, responses from all walls are registered. Then this information is translated using the seismosignal program into velocity-time history and displacement-time history.

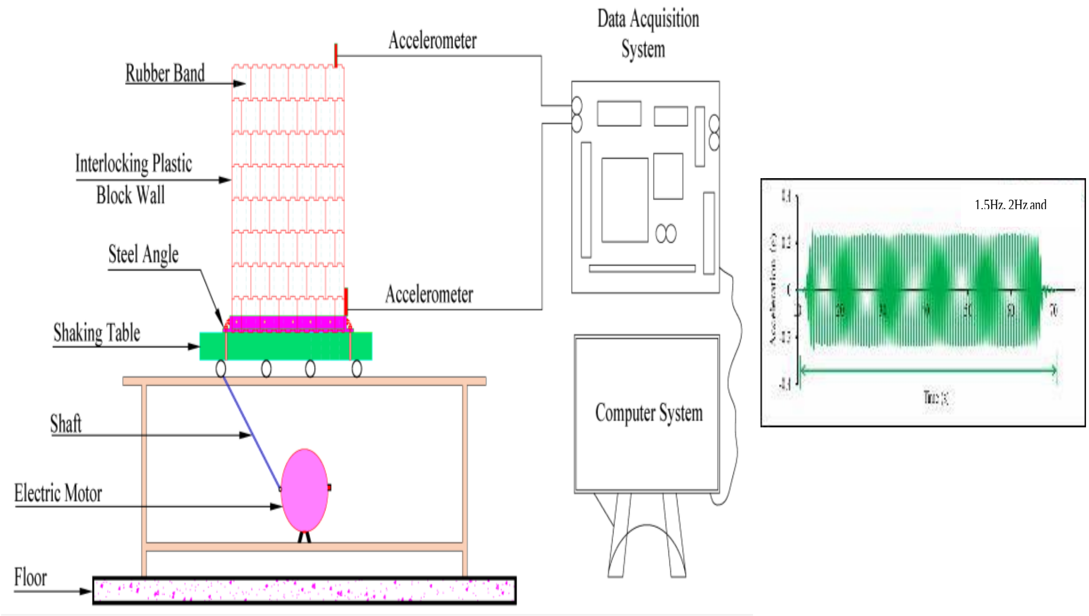
3.4 Loadings

3.4.1 Snapback Test

Both interlocking plastic-block walls with block-return are displaced one-by-one by 50 mm from the top with the aid of attached wire to perform a snap back test.



a)



b)

FIGURE 3.4: Schematic Diagram of Experimental Test: (a) Snap Back Test (b) Proposed Harmonic Loading.

Then, to produce free vibration, the wire was released abruptly. Acceleration-time history data was collected at the top of the wall with the aid of an accelerometer. The damping ratio and basic frequency have been determined with the aid of the log decrement process.

3.4.2 Harmonic Loading Test

The magnitude of the various tests taken into account is given in Table 3.1. Two tests are performed in this study work, i.e., snap back test and harmonic loading test. For various plastic interlocking block-return walls, snap back testing is conducted. For harmonic loading, 1.5 Hz, 2 Hz, and 2.5 Hz frequencies are selected. The amplitude of the interlocking plastic-block walls (solid walls, window opening walls and door opening walls) is 30 mm for harmonic loading. Dynamic loading (simple dynamic loading) is selected for the dynamic response to be tested. As a result of the use of a simple 1D shake table, earthquake loadings are not picked. The acceleration time and displacement time at the top of all walls and the base of the shake table is compared to the dynamic reaction of walls under the influence of harmonic loading. Three test on each solid wall, wall with window opening and wall having door opening under frequencies of 1.2Hz, 2Hz and 2.5Hz have been performed. For plastic interlocking block-return walls with door opening, the acceleration-time history and displacement-time history are supposed to be greater due to the use of rubber band.

Table 3.1: Magnitude of Different Tests Considered.

Test	**Amplitude**	**Solid wall**	**Wall types Wall with window opening**	**Wall with door opening**
Snap back	ug =50 mm	1	1	1
Harmonic	ug = 30 mm (f=1.5 Hz)	1	1	1
	ug = 30 mm (f=2.0 Hz)	1	1	1
	ug = 30 mm (f=2.5 Hz)	1	1	1

3.5 Analyzed Parameters

3.5.1 Analyzed Parameter from Snapback Test

Raw data in terms of acceleration-time history is documented for all plastic interlocking block-return walls (solid wall, wall having window opening and wall having door opening). Some noise has also been documented in acceleration-time history data for the duration of the recording period. To eliminate this noise from the test results, Seismosignal software is used. In addition, the damping ratio (ξ) and the simple frequency (fn) of the plastic interlocking block-return walls are determined using the background of acceleration time. The damping ratio of the plastic interlocking block-return wall with the door opening is estimated to be greater.

3.5.2 Analyzed Parameter from Shake Table

For all block-return walls, harmonic loading with frequencies of 1.5 Hz, 2 Hz, and 2.5 Hz was used (solid wall, wall having window opening and wall with door opening). In terms of acceleration-time history, the response of these walls was documented. Using seismosignal tools, velocity-time history and displacement-time history are determined. Similarly, for both walls, base shear (Q) - displacement curves are also obtained with the aid of acceleration-time history data. Where M is the mass of the respective wall and u is the acceleration at the top of the respective wall, base shear is taken.

3.5.3 Comparison with Empirical Equation

Empirical equations by Khan and Ali (2019) are used to compare the results to explain the complex behaviour of various plastic interlocking block-return walls (solid wall, wall having window opening and wall having door opening). It also measures the percentage difference between experimental and empirical values.

3.6 Summary

The research methods of the research paper are discussed in depth in this chapter. Various interlocking plastic-block return walls (i-e solid wall, window opening wall and door opening wall) are checked under dynamic loads. The test setup and study of snapback and harmonic loading parameters at various frequencies for different block-return walls are also discussed in detail.

Chapter 4

Experimental Findings

4.1 Background

In the last chapter, the snapback and harmonic loading test investigation methods and the parameters examined are discussed in detail. The current chapter illustrates the experimental effects of the data recorded during the experiments. For all walls with block-return, the fundamental frequency (fn) and damping ratio (ξ) are determined by using acceleration-time history. To initially capture the data in raw form, MATLAB software was used and then seismosignal software was used to delete the additional noises. Similarly, histories of displacement time and velocity time were also measured by seismosignal, see Annex A for information.

4.2 Damping Ratio and Fundamental Frequency

The results of the snap back test performed on various plastic interlocking block-return walls are shown in Figure 4.1. (solid wall, wall having window opening and wall having door opening). The top of all the walls is displaced by 50 mm from the average location. The damping ratio (ξ) and fundamental frequency (fn) for plastic interlocking block-return walls were calculated using the log decrement process.

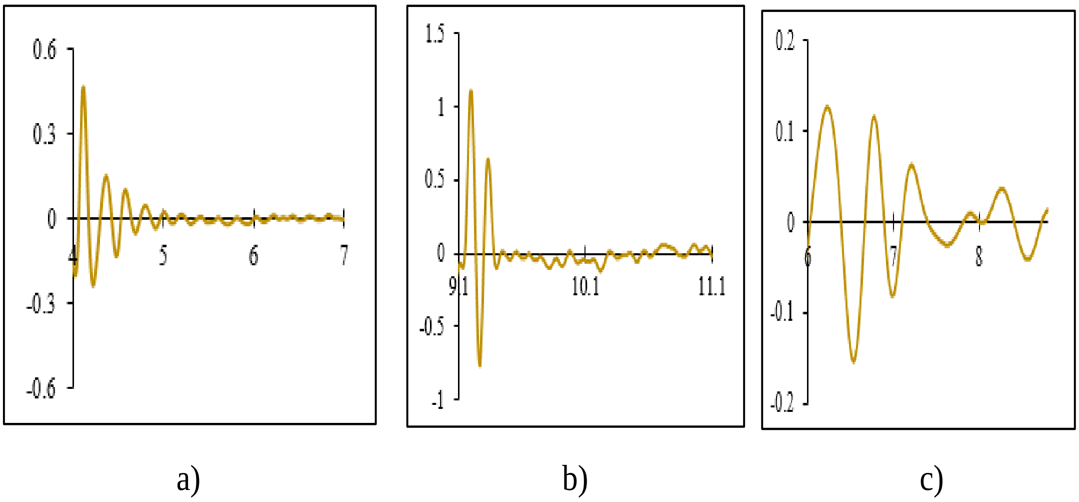


FIGURE 4.1: Results of Snap Back Test Conducted on Interlocking Plastic Block Walls with Block Return, Top of the Walls are Displaced from Mean Position by 50mm; a) Solid Wall, b) Wall with Window Opening, c) Wall with Door Opening.

TABLE 4.1: Snap Back Test Result of Interlocking Plastic Block Walls with Block-return.

Wall types	**Amplitude**	**Frequency (Hz)**	**Damping (%)**
Solid wall	50 mm	3.98	6.72
Wall with window opening	50 mm	5.22	5.77
Wall with door opening	50 mm	2.73	4.93

The snap back test results of various plastic interlocking block-return walls are shown in Table 4.1. (solid wall, wall having window opening and wall having window opening). The structure damping ratio (ξ) for solid walls is 6.72 percent 5.77 percent for window opening walls and 4.93 percent for door opening walls displaced by 50 mm at the top. The measured frequencies are 3.98 Hz, 5.22 Hz and 2.73 Hz for solid walls, window opening walls and window opening walls, respectively. It is noted that the damping value varies somewhat. Compared to other block-return walls, the damping ratio of solid walls with block-return displaced by 50 mm found more damping than that of other block-return walls.

4.3 Response of Prototype Walls against Harmonic Loading

4.3.1 Response in Terms of Acceleration-time and Displacement-time Histories

Plastic interlocking block-return wall (solid wall) response is reported in terms of acceleration time history and displacement time history over the 45s to 50s period, as shown in figure 4.2. (a,b). The purple dash line represents the movement of the shake table or base excitation (applied loading), and the dotted orange dash line represents the reaction at the top of the solid wall block-return interlocking plastic.

In terms of acceleration-time history and displacement-time history, the response of the plastic interlocking block-return wall (wall having window opening) during the 45s to 50s span is reported as shown in figure 4.3. (a,b). The shake table movement or base excitation (applied loading) is represented by the sky blue dash line, and the orange dash dotted line reflects the reaction at the top of the plastic interlocking block-return solid wall.

In terms of acceleration-time history and displacement-time history, the response of plastic interlocking block-return wall (wall having door opening) is reported in the time span of 45s to 50s as shown in figure 4.4. (a,b). The sky blue dash line represents the movement of the shake table or base excitation (applied loading), and the dotted orange dash line represents the reaction at the top of the plastic interlocking block-return solid wall.

In order to analyse the dynamic response of all prototype walls, the acceleration-time history and displacement-time history obtained from analysis of outcome are appropriate. Acceleration-time history is registered and then the acceleration-time history is transformed into displacement-time history as stated earlier using seismosignal software.

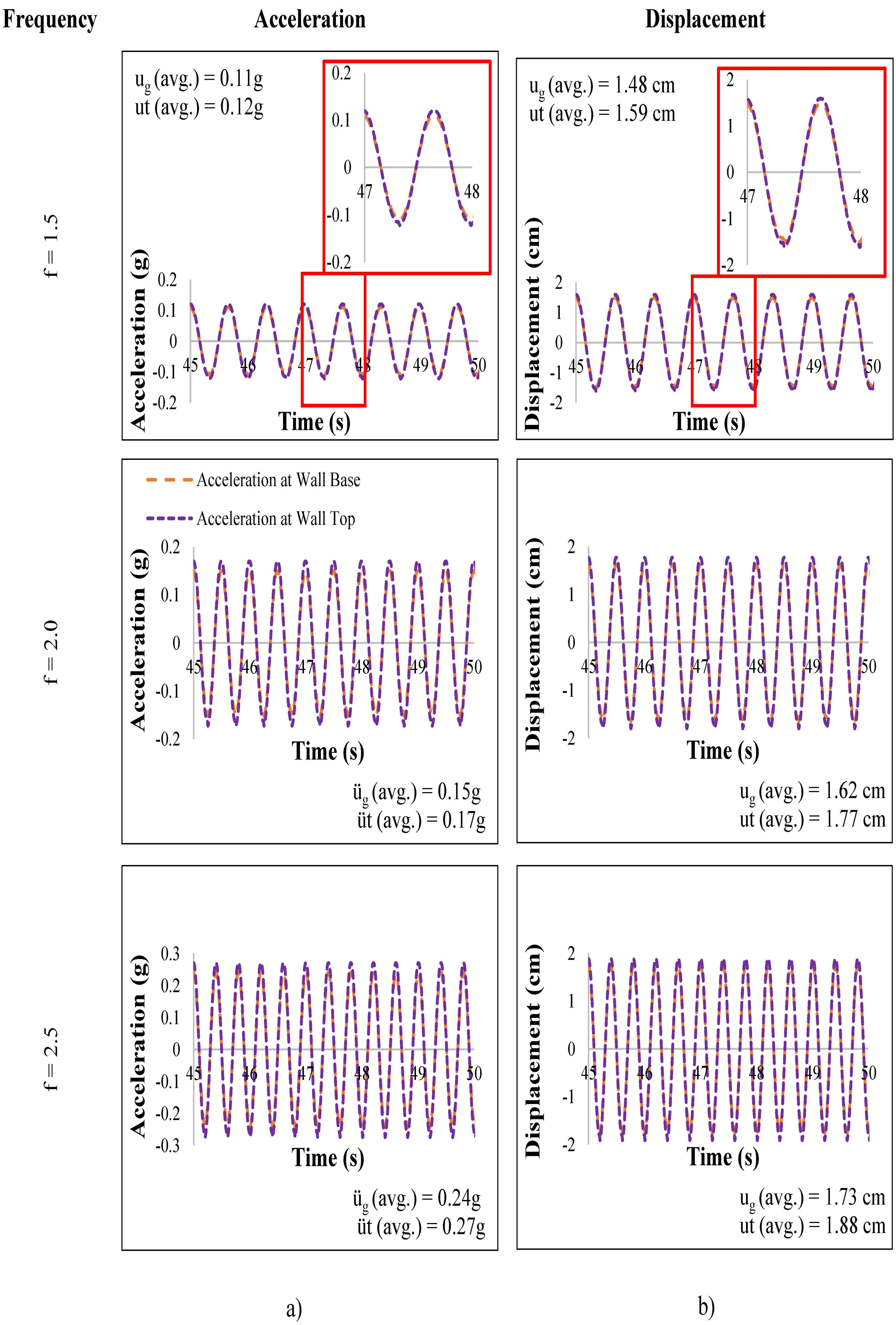


FIGURE 4.2: Response of Solid Wall During Harmonic Loadings of 1.5Hz and 2.0Hz and 2.5Hz Between 45 s and 50s; a) Acceleration-time, b) Displacement-time.

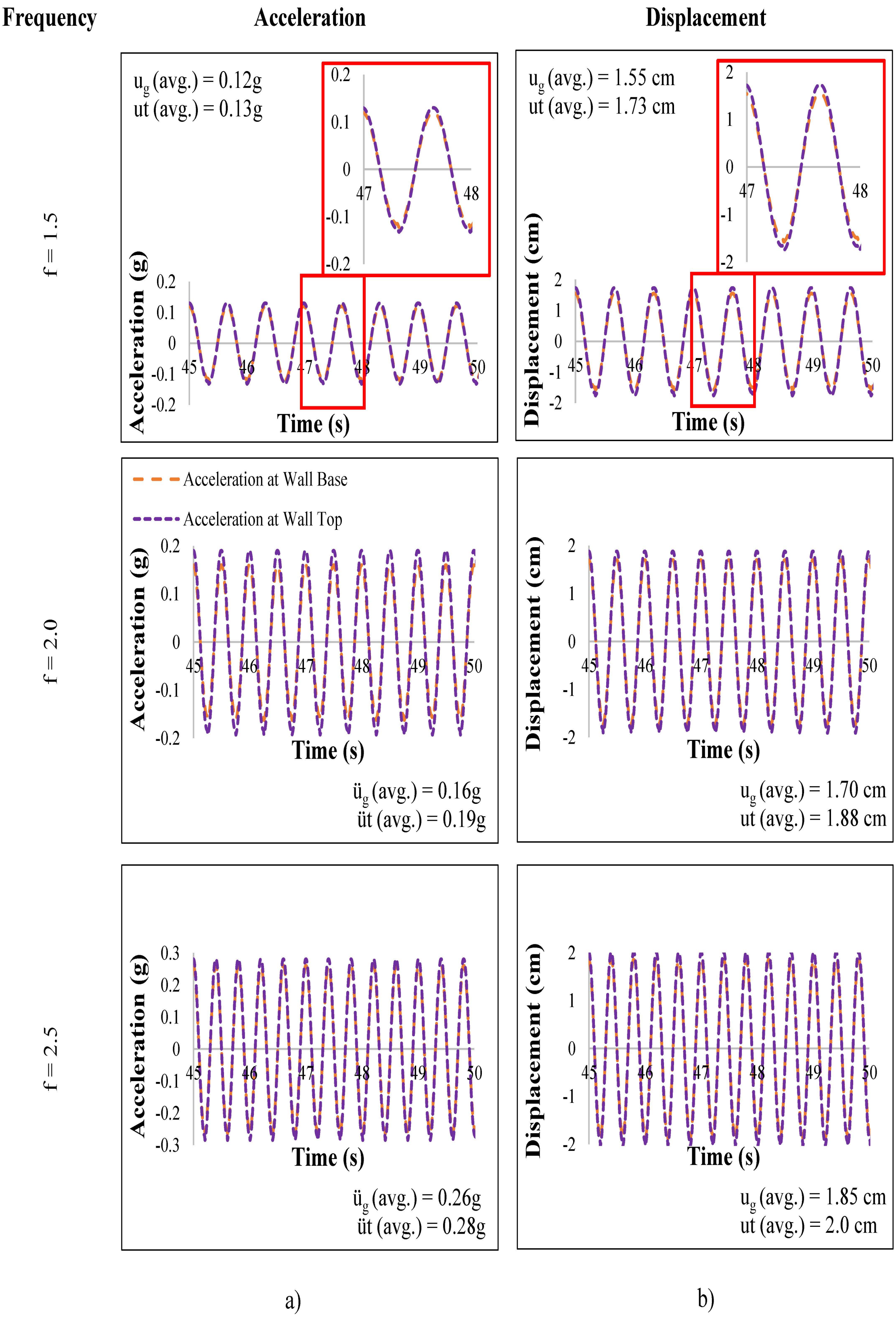


Figure 4.3: Response of Wall having window opening During Harmonic Loadings of 1.5Hz, 2.0Hz and 2.5Hz Between 40 s and 50s; a) Acceleration-time, b) Displacement-time.

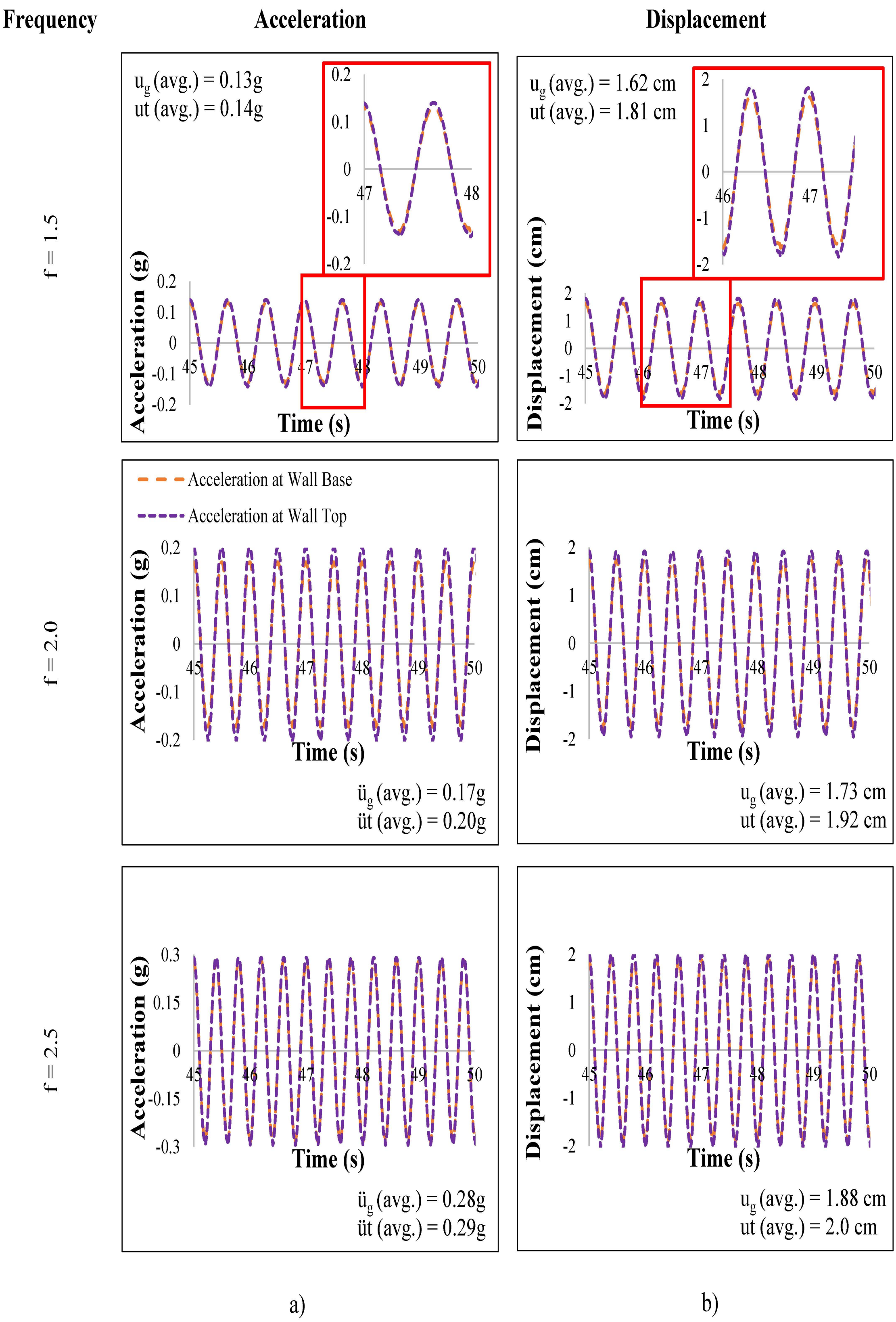


Figure 4.4: Response of Wall having door opening During Harmonic Loading of 1.5Hz, 2.0Hz and 2.5Hz Between 45 s and 50s; a) Acceleration-time, b) Displacement- time

Since the locally low-cost shake table is sufficient to precisely apply dynamic loading, i.e. the constant amplitude of various cycles, the average acceleration and movement of base excitation (i.e. $\ddot{u}_g$ and u_g respectively) is considered as applied loading. The IPWO response is called the average acceleration and displacement at the top of plastic interlocking block-return walls (solid wall, window opening wall and door opening wall) (i.e. $\ddot{u}_g$ and u_g, respectively).

Figures 4.2(a), 4.3(a) and 4.4 show the acceleration time histories of all block-return walls during harmonic loads of 1.5 Hz, 2 Hz and 2.5 Hz between 45s and 50s (a). It is possible to divide structural excitation into three phases: (A) As the structure began vibrating before the steady-state is reached, (B). Structure's steady state response, and (C). Free structure vibration (Ali et al., 2013). For clarification, Fig 4.2, Fig 4.3 and Fig 4.4 display only the portion of steady state result. Normal acceleration is often observed at the base and top of the walls. The acceleration of these walls has been found to increase by rising the shake table frequency. During harmonic loads of 1.5 Hz, 2 Hz and 2.5 Hz between 45s and 50s, displacement time histories of all block-return walls are shown in Figure 4.2(b), Figure 4.3(b) and Figure 4.4. (b). Average displacement is also reported on the ground and on the top of walls. It has been observed that wall displacement is increased by increasing the shake table frequency. Also, at a higher frequency, walls do not collapse during harmonic loading. However, at a higher frequency, the wall can be collapsed. By using ay alternative method such collapse can be prevented.

4.3.2 Energy Absorption And Base Shear (Q) Displacement (Δ) Curve

The total mass of plastic interlocking block-return walls (solid wall having window opening and door opening wall) (M) is presumed to be lumped at the top of walls where its response acceleration time (i.e., $\ddot{u}$t-t) history is registered. (i.e., $\ddot{u}$t-t). The base shear is computed to be M. ut. Figure 4.5 shows the standard base shear (Q) - displacement (Δ) curves of various block-return walls. This is measured according to the work of (Ali et al., 2013).

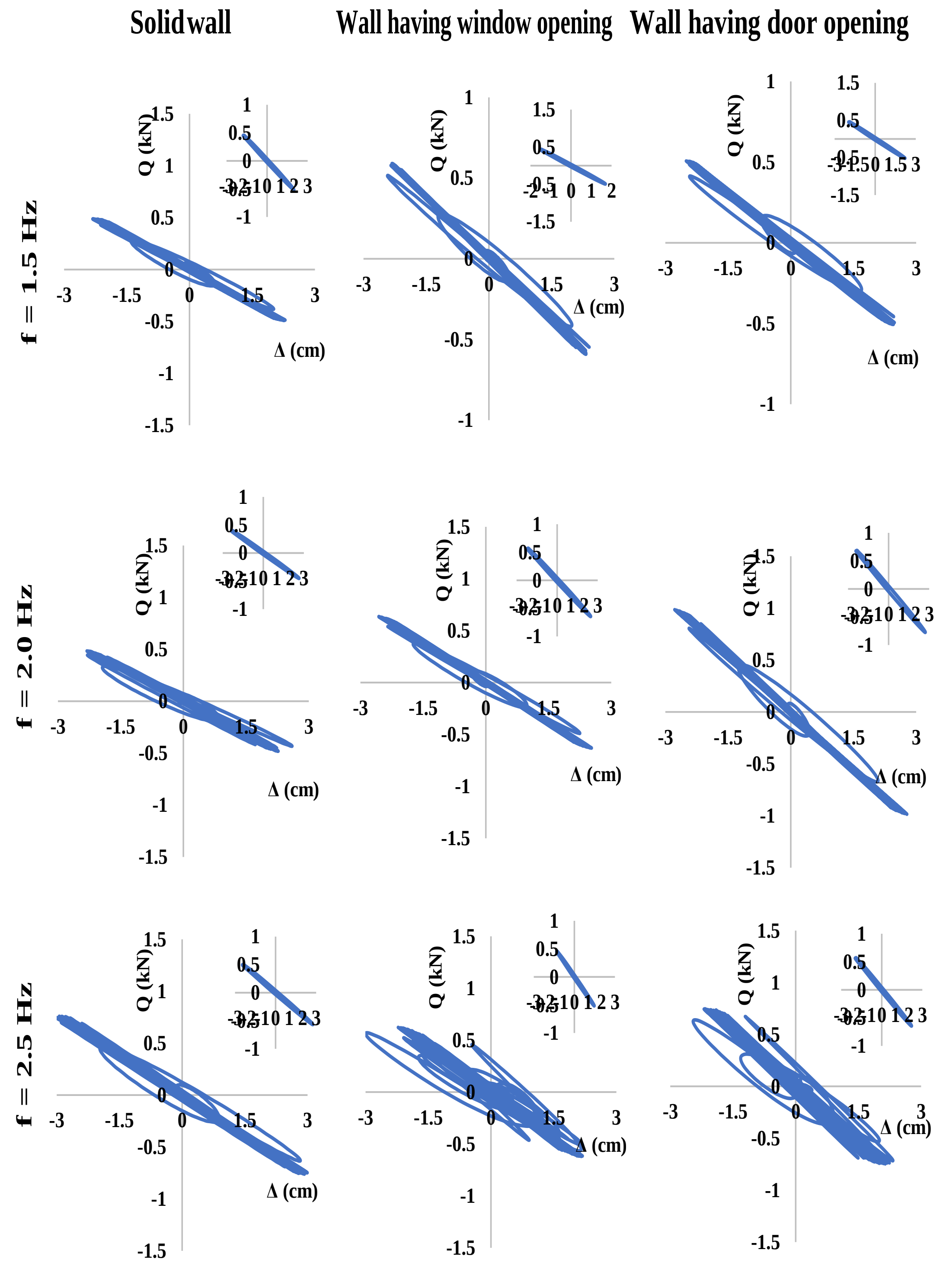


FIGURE 4.5: Base Shear (Q) - Displacement () Curves of Different Interlocking Plastic Block-return Walls (i-e Solid Wall, Wall having window opening and Wall having Door Opening).

The average energy absorption (E) in one cycle and the total energy absorbed are shown in Table 4.2. (ET). The number of harmonic cycles are labelled "N" and the region inside the loop is taken as the absorption of energy (E). Plastic

Table 4.2: Energy Absorption During the Harmonic Loading

			Averaged energy absorbed in one cycle (Nm)				Total energy absorbed (Nm)		
Sr. no	**Amplitude mm**	**Frequency (Hz)**	**Solid wall**	**Wall with window opening**	**Wall with door opening**	**n**	**Solid wall**	**Wall with window opening**	**Wall with door opening**
1	ug = 30	1.5	1.6	1.84	2.8	90	144	165	252
2	ug = 30	2.0	2.88	3.04	3.92	120	345	365	470
3	ug = 30	2.5	3.6	3.84	4.32	150	540	576	648

interlocking block-return walls have been found to dissipate more energy during harmonic loading at 1.5 Hz, 2 Hz and 2.5 Hz frequencies. In disparity to other walls with block-return, it is concluded that greater energy is dissipated in interlock-ing plastic-block walls with block-return having door opening at 2.5 Hz. Due to the relative motion at block interfaces, plastic interlocking block-return walls can absorb more energy in seismic events. Experimentation is carried out by finding that energy dissipation is due to relative block movement or uplift, which will be researched in the future.

4.4 Improvement in Empirical Equations and Comparison with Experimental Results

Khan (2019) developed empirical equations integrating inter-locking block geometry, column height, column response, and parameters for input loading. In order to predict the reaction of plastic in-terlocking block-return walls (solid wall, window opening wall and door opening wall), following empirical equations are developed by adding more new variable variables.

$$\ddot{u}_t = \frac{\left(\frac{a}{h^2}\right)}{n} \mathrm{R}_b R_s K^{\left(1+\frac{2n}{100}\right)} \ddot{u}\mathrm{g} \text{........4.1}$$

$$u_t = \frac{\left(\frac{a}{h^2}\right)}{n} \mathrm{R}_b R_s K^{\left(1+\frac{2n}{100}\right)} ug \text{ ....4.2}$$

Where $\ddot{u}_g$, and ug are averaged ground acceleration, and displacement, respectively. $\ddot{u}_t$ $\ddot{u}_t$ u$_t$ are response top acceleration and top displacement, respectively. a, h, n, and Rs are wall surface area, key height, number of block layers in wall, reduction factor due to increase stiffness respectively. Their corresponding values are 30752 mm2, 12 mm, 8 and Rs, respectively, 0.12 for solid wall, 0.13 for window wall and 0.135 for door wall). Rb and K have a dimensionless coefficient of 0.73 and 0.45 respectively. Responses of walls in case of the block return, Rb, are lesser than where it is not used. By adding return block stiffens of the wall can be increased and consequently it reduces the responses. Comparisons of experimental and empirical values for wall response are shown in Table 4.3. It can be found that experimental values comply well with empirical values. The gap is the maximum percentage is less than or equal to 19% . Owing to the complex features of interlocking assemblies, the percentage difference between experimental and empirical results is relatively high for wall structures. As Ali (2018), in predicting the structure response that could be related to the dynamic behaviour of the structure versus the simple empirical method, the percentage difference was up to 35%. However, this can also help to systematically explain the actions of the mortar-free interlocking method.

TABLE 4.3: Comparison of Experimental and Empirical Values of Wall Response at Top.

Wall type	**f (Hz)**	**Wall response**	**Experimental values**	**Empirical values**	**Percentage difference**
Solid wall	2.5	Acceleration (g)	0.273	0.25	4.0%
		Displacement (cm)	1.887	1.97	5.0%
Wall having window	2.5	Acceleration (g)	0.288	0.29	11.0%
		Displacement (cm)	2.00	2.28	14.0%
Wall having door	2.5	Acceleration (g)	0.29	0.3	8.0%
		Displacement (cm)	2.00	2.4	19.0%

4.5 Summary

The experimental results from data collected during research are outlined in this chapter. The experiment was conducted twice to carry out a rigorous study. For all walls having block-return, the fundamental frequency (fn) and damping ratio (ξ) have being determined by using acceleration-time history. To filter the data, MATLAB software was initially used and then seismosignal software was used to remove the additional noises. Seismosignal also measured the background of displacement-time and velocity-time. In this chapter there is a graphical representation of acceleration-time, displacement-time histories, base shear curves.

Chapter 5

Discussion on Practical Implementation

5.1 Background

In previous chapter, experimental results are revealing. These results included the effect of block return on in-plane behaviour of the different walls. However, in this chapter results are compared with different previous studies for the practical use of the inter locking plastic blocks. Furthermore, the last chapter explains in depth the graphical representation of acceleration-time history, displacement time history, and base shear-displacement. Noteworthy, energy absorption is observed in the inter-locking plastic-block wall with open door, where block-return is greater than other block-return walls. Experimental results, on the other hand, are contrasted with observational results, and the object of comparing results is to verify the percentage difference. In this chapter, the link between experimental and empirical values is formed to predict the behaviour of block-return interlocking plastic-block walls. Moreover, the percentage difference between empirical and experimental values is seen. This can be helpful for the understanding of actual behaviour of block return in full scale structure.

5.2 Comparison of Current Study with Previous Studies

The findings of the current analysis have been compared to previous research programme reports. Acceleration time and displacement time results have been computed between solid straight wall and solid wall with block return, and the percentage difference is less than 4.6 percent. Acceleration-time and displacement-time results for window opening wall (without block-return) and block-returning window opening wall have been compared and the percentage difference is less than 10.1%. The value of the reduction factor due to increased stiffness (Rs) is 0.13 by applying the empirical equations of the current Sudheer study[39] and the percentage difference is observed as 18 percent.

TABLE 5.1: Comparison with Previous Studies

Parameter	**f (Hz)**		**Solid wall**		**Wall with window opening**		
		w/o block-return	with block-return	%diff.	w/o block-return	with block-return	%diff.
		Afzal and Ali	Current work		Sudheer and Ali	Current work	
$\ddot{u}_t/\ddot{u}_g$	1.5	1.07	1.09	1.8	1.05	1.08	2.7
	2	1.04	1.13	7.9	1.06	1.18	10.1
	2.5	1.06	1.12	5.3	1.15	1.07	6.9
u_t/u_g	1.5	1.125	1.07	4.6	1.13	1.11	1.8
	2	1.14	1.09	4.58	1.12	1.10	1.8
	2.5	1.10	1.08	1.85	1.17	1.08	7.6

5.3 Outcome of Research Work With-respect-to Practical Needs

The application of cyclic loadings using a locally built 1D shake table is capable of generating a certain amount of accurate harmonic loading. The seismic reaction of the structure under observation can therefore be determined. This is because the harmonic loading applied is taken as the base ground motion and the structural element's action is evaluated with regard to it. Alternatively, the perceived reaction of various interlocking block-return plastic-block walls is approximately the same as defined in the literature. The different block-return walls studied showed positive potential in the form of structural stability and absorption of energy. The block-return wall should therefore be studied in conjunction with other components. In a supplement to the, by using interlocking plastic blocks for earthquake resistant structures, the opposing effect of earthquakes can be minimized.

5.4 Summary

In this chapter, the findings of research work are ex-clarified with respect to the functional requirements. The locally-developed 1D shake table with fixed amplitude and variable frequencies is not significantly accurate. However, it is capable of precisely generating harmonic loading to some degree. In order to investigate the seismic reaction of the structural elements under observation. Compared to that of masonry wall, interlocking plastic block wall with block return is more convenient for earthquake-resistant construction. Ductility of the structure is enhanced by using rubber band which is clearly shown in results. Compared to other block-return walls, the plastic block wall having door opening with block-return dissipates more energy. The analytical equations have improved with the inclusion of a new factor Rs with a value of 0.12 for solid wall, 0.13 for window opening wall and 0.135 for door opening wall due to block return. Owing to the limitations of the shake table and human errors, experimental values are less precise, whereas empirical values are more precise compared to experimental values to verify the percentage difference in values with respect to experimental values. In difference to experimental values, empirical values are dimensionally correct. Owing to the shake table limitations and human error, experimental values are less reliable.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

For earthquake-prone regions, several earthquake-resistant building techniques are available in the literature. Those, however, are uneconomical. Developing countries can not afford such methods to reduce the damage caused by earthquakes. Dynamic behaviour of the plastic interlocking block-return walls in this pilot study (solid wall, wall having window opening and wall having door opening). Prototypes of all walls are checked to determine the response and their dynamic characteristics under different harmonic loads. In order to research the dynamic response, harmonic loading (being a simple dynamic load) is selected. As a result of the use of a simple 1D shake table, earthquake loadings are not picked. Because of the shake table's load limitations, mass was not added to the top of the walls. Although it was impractical to perform a test without any top mass. The object of the test is to analyse the behaviour of various interlocking plastic-block walls with simplified boundary condition patterns. The harmonic tests were found to be more successful in identifying the fundamental frequencies of the structure compared to the snap-back test. It is possible to draw the following conclusions from this research paper:

- The snap-back test calculations show that damping ratio (ξ) is decreasing with respect to size of opening. It is lowest in case of wall having door.

- Variation in response for all the three wall patterns, solid wall, wall having window opening and wall having door opening, against different frequencies, 1.5Hz, 2Hz and 2.5Hz have been observed.

  – In case of solid wall, on all frequencies to be considered 1.5Hz, 2Hz responses were less.

  – In case of wall with door opening, on all frequencies to be considered 1.5Hz, 2Hz responses were more as compared to solid wall.

- Energy dissipation in case of in-plan responses is less as compared to out of plan. The only reason is the less deformation in the said case.

- By integrating the new variable i-e Block- return factor (Rb) variable with a value of 0.733, the empirical equation is updated for calculations of responses.

  – Empirical outcomes obtained from Khan and Ali (2019) approach are in strong agreement with the experimental findings of the present work.

In comparison to harmonic loading, the prototype plastic interlocking block-return walls (solid wall, window opening wall and door opening wall) generally made a remarkable sound. The proposed housing technology has the potential to provide vulnerable people with a decent living standard.

6.2 Recommendations

In this research program, dynamic in-plan behavior of interlocking plastic blocks has been studied. Following are certain areas which were not in the scope of the above research but they must be studied.

- Foundation of interlocking plastic blocks should be investigated in future researches.

- Numerical approach, finite element modeling, must be investigated properly by using commercial available software. It can help both researchers and industry for the practical use of such blocks.

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Annexure A

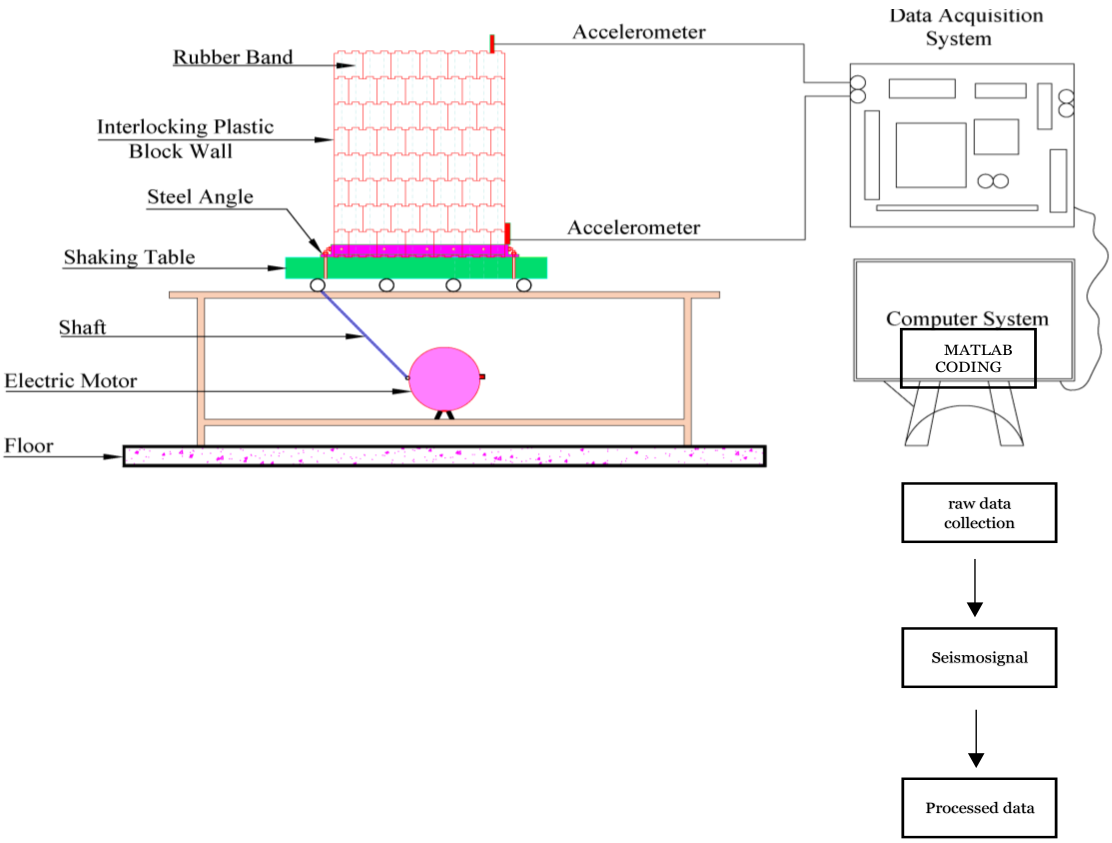

FIGURE A.1: Data Gathering Mechanism