CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Effect of Block-Return on Out-of-Plane Behavior of Interlocking Plastic-Block Walls under Harmonic Loading

by

Khurram Shahzad

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

in the

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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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Abstract

Past seismic events have demonstrated the vulnerability of masonry walls, classified as load bearing masonry wall, to earthquake damage. Earthquake badly affect the masonry structures due to strong ground motion. The failure of load bearing wall systems has been one of the most widely reported types of structural damages and loss of life, especially in severe earthquake regions. Moreover, the failure of structural components may also represent a threat to life safety. The damages of structural components represents the largest contribution to the economic loss caused by an earthquake.

In the developing countries, the economical houses are needed which can resist and control the damages due to strong ground motion. To empower the efficient and cost-effective solution for earthquake resistant houses, a new construction technique of interlocking plastic-block structure has been proposed for earthquake resistant houses. Interlocking plastic-blocks structure dissipate more energy due to its relative movement at the boundary of block during the period of an earthquake. This study presents the dynamic out-of-plane behavior of interlocking plastic block walls having block-return under snap back and harmonic tests. Three walls (i.e. solid wall, wall with window opening and wall with door opening) are considered as these represent the most common configuration in a house structure.

Harmonic loadings of constant amplitude and varying frequencies are employed. The response of walls are determined in terms of acceleration-time and displacement-time under harmonic loading to estimate the possible energy dissipation. Energy dissipation capacity of interlocking plastic-block walls having block-return is increase by using rubber band as a vertical reinforcement. Empirical modeling is also proposed to predict the behavior of such structural elements. Empirical equation is modified by incorporating the new variable i-e Block-return factor (Rb) with a value of 0.73. Percentage difference between experimental and empirical value is less than 20%. The experimental and empirical results are in good agreement. This study will help to understand the behavior of interlocking plastic-block structures for further work.

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Abbreviations

1 D	One Dimensional
3 D	Three Dimensional
IPWW	Interlocking Plastic-block Wall with Opening
MDOF	Multiple Degree of Freedom
MPa	Mega Pascal
OOP	Out-of-Plane
RB	Rubber Band
SDOF	Single Degree of Freedom
Up	Uplift

Symbols

ξ	Damping ratio
Δ (cm)	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 (KN)	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

Past seismic events have demonstrated the vulnerability of masonry walls, classified as load bearing masonry wall, to earthquake damage. Earthquake badly affect the masonry structures due to strong ground motion. The failure of load bearing wall systems has been one of the most widely reported types of structural damages and loss of life, especially in severe earthquake regions. [1] investigated that almost 4,50,000 buildings were damaged, almost 75000 peoples were died, almost 69000 peoples were injured and about 2.8 million people were shelter less in October, 2005 earthquake. 87,476 and 731 peoples were died, 459,76,596 and 11,20,513 peoples were injured and economic loss of 852.309 and 19.849 billion in wenchuan and ludian earthquake china respectively [2]. The earthquake of Kashmir October, 2005 caused more than 86,000 causalities, more than 80,000 human injuries and an estimated total economic loss of $5.2 billion [3]. Moreover, the failure of structural components can also represent a threat to life safety. The damage of structural components represents the most important contribution to the economic loss caused by an earthquake.

In the developing countries, the economical houses are needed which can resist and control the damages due to strong ground motion. In an effort to mitigate the damages in future events, many practices apply in structural works for the construction of masonry buildings. To empower the efficient and cost-effective solution for earthquake resistant houses, [4] proposed mortar- free structure (a new construction technique) for earthquake resistant houses.

Though, the mass of CFRC (coconut fiber reinforced concrete) blocks is still a point of concern. Lighter the mass of structure, lower the inertia force produced. Single story steel and wooden structures are few examples of the lightweight structures in Pakistan. But, the energy dissipation during earthquake is still a point of concern. A mortar-free interlocking block structure has the capability to dissipate energy of earthquake. For this, lightweight interlocking plastic-block is one of the best option. It is necessary to reduce mass of block in order to reduce inertia forces. Inter- locking block is one possibility to discover a new construction technique of plastic interlocking block structure has been investigated for earthquake resistant houses. Plastic inter-locking blocks dissipate more energy due to its relative movement at the boundary of block during the period of an earthquake.

In order to make actual earthquake data with different frequencies, six degree of freedom hydraulic shake table is required but it's highly expensive with more operational as well as maintenance cost. To evaluate the dynamic behavior of out-of-plane plastic interlocking block-return walls (solid wall, wall with window opening and wall with door opening), locally developed 1D shake table is employed. Because 1D shake table is less-expensive and produce random excitation and also periodic motion. It can be used to get the replication of earthquake in laboratory. Hence, locally prepared 1D shake table was used for the simulation of earthquake and to look at the behavior of small-scaled prototype plastic inter-locking block return walls (solid wall, wall with window opening and wall with door opening) under periodic motion.

To the best knowledge of author, no study has been done to research the behavior of plastic interlocking block-return walls (solid wall, wall with window opening and wall with door opening) under harmonic loading using locally developed low-cost 1D shake table.

1.2 Research Motivation and Problem Statement

Earthquakes are dangerous events, which causes severe damage. During or after an earthquake, many peoples in mounting countries were passed away when buildings collapsed, many of them were left homeless. Such damages and loss of human lives can be control if seismic behavior of structure during an earthquake is precisely studied which can help to design accordingly. Established countries have such amenities but developing countries have lack of these amenities. Shaking-table is one of best facility. To begin with, behavior of plastic interlocking block structure may be studied with locally developed low-cost shake table (operating in one direction). On other hand, confined masonry structures are slight un-economical. The cost-effective and efficient solution is needed. [4] presented an efficient and cost-effective solution, but the block mass still needs to be reduced. Interlocking plastic-block structure can be one possibility with deliberation of fire-resistant paint. For economic, efficient and environmental aspects, plastic waste can be recycled for this purpose (note: for time being, it is outside the scope of this work). Thus, the problem statement is as follow.

During earthquake, Arya et al. (2020) [5] stated that most of the brick masonry buildings were collapsed due to the design deficiencies. Ali (2018) [4] established a mortar-free structure (a new construction technique) for earthquake-resistant houses. A mortar-free interlocking plastic-block structure has the capability to dissipate energy during an earthquake. However, the mass of coconut fiber reinforced concrete blocks is still a point of concern. Lighter the mass of structure, lower the inertia force produced. For this, lightweight interlocking plastic-block is one option towards the solution together with fire-resistant paint. For economical, efficient and environmental aspects, plastic waste can be recycled for this cause (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), dynamic out-of-plane response should be considered. This can be done with simple 1D shake-table. So, the out-of-plane response of interlocking plastic-block walls (solid wall, wall with window opening, wall with door opening) having block-return are wanted to be examined under harmonic loading by using locally developed low-cost 1D shake- table.

1.2.1 Research Questions

How much top acceleration and displacement can be reduced with block-return in mortar-free interlocking block wall?

Which parameter should be included in Afzal and Ali equation for the effect of block-return?

Which pattern (among no opening, window opening and door opening) in wall with block-return 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 program is to precisely investigate the 3D seismic response of full-scale structure in laboratory and field.

The specific aim of this MS research work is to investigate the effect of block-return on out-of-plane behavior of interlocking plastic-block walls (solid wall, wall with window opening, wall with door opening) under harmonic loading using locally developed low-cost 1D shake table in laboratory.

1.4 Scope of Work and Study Limitation

Three prototype interlocking plastic-block walls (solid wall, wall with window opening, wall with door opening) having block-return with a length of 124 mm (i-e two block width) are considered. Fixed base with the help of base plate and nut bolts has provided. Mass is not applied on the top of walls because of load limitations of shake table. Three loadings frequencies are applied (i-e 1.5 Hz, 2.0 Hz and 2.5 Hz). Harmonic loading (being simple dynamic loading) is selected to study the dynamic response. Earthquake loadings are not selected due to the use of simple 1D shake table. Response in terms of acceleration-time, and displacement-time histories are determined. Frequency and damping are determined. Empirical equations are use to compare the results based on [4] approach. Wind load is out of scope. Study limitations include the use of simple 1D shake table, only two accelerometers (one at the bottom of shake table and other at the top of wall).

1.4.1 Rationale Behind Variable Selection

The reason behind certain selections are:

- Three pattern of walls (i-e solid wall, wall with window opening, wall with door opening) are selected because of their frequent use in a house.
- Rubber band is utilized as vertical reinforcement to have the wall integrity during harmonic loading.
- 1/10 scale is applied on elevation dimensions only due to method A of UBC-97 regarding time-period which depends on structure height.
- Simplified boundary condition is considered to study the dynamic mechanism of wall only (being a cantilever wall above base).

1.5 Research Novelty, Research Significance and Practical Implementation

To the best knowledge of author, no study has been done to research the behavior of interlocking plastic-block walls (solid wall, wall with window opening and wall with door opening) having block-return under harmonic loading using locally developed low-cost 1D shake table.

The research significance is availability of out-of-plane dynamic response of different interlocking plastic-block walls having block-return with simplified boundary condition. This will help to understand the complex behavior of complete structure.

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

1.6 Methodology

Firstly, all interlocking plastic block walls with block-return (solid wall, wall with window opening, wall with door opening) are constructed and mounted on shake table one by one. The purpose of testing is to review the response of walls at incremental frequencies. to start with, three randomly selected frequencies are applied, keeping in mind the dynamic loading capacity of the shake table. Two accelerometers are used, one at shake table to record ground motion and one at wall top to record the walls response. Accelerometers are connected to computing system to record the data as shown in annexure A.

Response of all walls in out-of-plane direction in terms of acceleration-time is recorded within the raw form. Then processed acceleration-time and displacement-time histories are obtained using seismosignal software. With the assistance of displacement vs time-history and acceleration vs time-history of top accelerometer data, base shear (Q) is calculated. The averaged energy absorption in one cycle also as total energy absorbed is calculated. Empirical equations for interlocking plastic-block walls are used for predicting the wall response.

1.7 Thesis Outline

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

Chapter 1 comprises of introduction section. It includes background, research motivation and problem statement, overall objective and specific aims, scope of work and study limitations, methodology adopted to conduct the study, and thesis outline.

Chapter 2 comprises the literature review section. It consists of background, damages of conventional masonry structures during earthquake, new approach for earthquake-resistant structures, effect of block-return and stiffeners on masonry construction, dynamic performance of prototype structures in lab and summary.

Chapter 3 comprises of experimental program. It contains background, technique to construct interlocking plastic block wall with opening and unreinforced masonry wall with opening, test setup, snap back test with instrumentation, application of harmonic loadings using shake table, analyzed parameters, development of empirical equations and summary.

Chapter 4 comprises of experimental evaluation. It contains background, results of snap back test, behavior of walls against harmonic loadings, calculation of base shear, damping ratio and energy absorption and summary.

Chapter 5 comprise of dialogue. It contains background, relationship of empir- ical equations, outcome of study with reference to practical requirements and summary.

Chapter 6 comprises of conclusions and recommendations. References are present right after chapter 6.

Annexure A has provided after references.

Chapter 2

Literature Review

2.1 Background

Past seismic events have demonstrated the vulnerability of masonry walls, classied as load bearing masonry wall, to earthquake damage. Earthquake badly effect on the masonry structures due to strong ground motion. After an earthquake, the failure of load bearing wall systems has been one of the most widely reported types of structural damage in buildings during past earthquakes, especially in severe earthquake regions. Moreover, the failure of structural components may also represent a threat to life safety. The damage of structural components represents the largest contribution to the economic loss caused by an earthquake. In the developing countries, the economical houses are needed which can resist and control the damages due to strong ground motion. In an effort to mitigate the damages in future events, the literature shows many practices apply in structural works for the construction of masonry buildings. For example, vertical and horizontal stiffeners in the different interlocking masonry load bearing walls. To empower the efficient and cost-effective solution for earthquake resistant houses, a new construction technique of plastic inter-locking block structure has been investigated for earthquake resistant houses. Plastic inter-locking blocks dissipate more energy due to its relative movement at the boundary of block during the period of an earthquake.

2.2 Damages of Masonry Structure During Earthquake

Many researches have recorded the destruction of traditional masonry buildings in the form of various failures. After the 25 April 2015, Gorkha earthquake in Nepal. [6] and conducted a reconnaissance study. Some 0.8 million partial or complete collapsed buildings were recorded. A significant seismic event followed by large aftershock hit the entire hilly region of the city, which resulted in the destruction of several buildings made of brick masonry. [1] investigated that almost 4,50,000 buildings were damaged, almost 75000 peoples were died, almost 69000 peoples were injured and about 2.8 million people were shelter less in October, 2005 earthquake. 87,476 and 731 peoples were died, 459,76,596 and 11,20,513 peoples were injured and economic loss of 852.309 and 19.849 billion in wenchuan and ludian earthquake china respectively [2]. Lately earthquake in 2018 in Indonesia costs more than 1000 houses. In earthquake, most of the masonry structures collapsed due to design deficiencies [5]. Several peoples were died, wounded and remained homeless until the governing authorities rescued there operations. Besides that, the country was faced a huge economic loss from this catastrophic [7].

Various brick masonry failures was recorded in the form of vertical cracks near the corner, cross cracks initiated from the edges of the openings, failure of the plane, and failure of the gable wall and separation of the wall vertically. Unreinforced masonry buildings were most vulnerable to out-of-plane failure as shown in figure 2.1. If the connection between the walls and floors is not adequately restrained, the whole wall panel or a significant portion will overturn due to seismic excitation [8]. The main reasons behind these brick masonry failures were poor con- struction practices, poor materials and un-designed structures. For the retrofitting of partially damaged masonry houses, it had proposed that vertical and horizontal bands

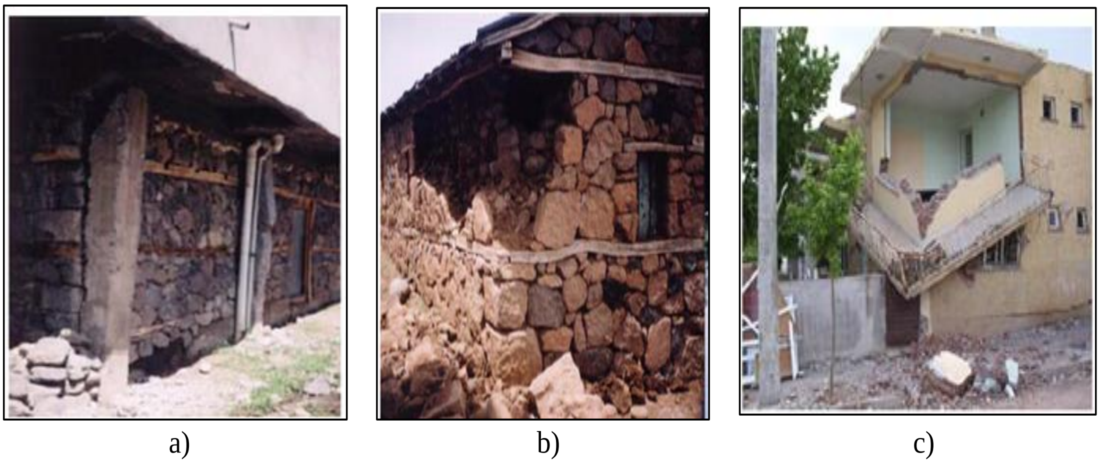


FIGURE 2.1: Failure of Masonry Buildings; a,b) Stone Wall Failure, c) Brick Wall Failure [8].

to be strengthened or supported. [9] reported that during the January 2001 Bhuj earthquake, traditional masonry structures suffered considerable damage. Many of the masonry buildings had zero earthquake-resistant properties, which caused significant damage to these buildings. More frequently observed defects in the masonry systems were out-of-plane collapse, fractures below bands, out-of-plane wall failure leading to lintel band collapse. It was stressed that the primary cause of these failures was the use of mud mortar or lime mortar resulting in weak bond strength. The most common issue was the failure of brick masonry wall in the form of cracks under the lintel beam and the failure of lintel band. Since properly built brick masonry wall with horizontal/vertical bands having corner reinforcement properly resists the shaking of the earthquake. The study indicated that while the horizontal bands decrease the in-plane shear and vertical cracks, they may not be helpful in the event of flexure failure in out-of-plane.

Fiorentino et al. (2018) [7] reported that the effect of the two seismic events on the district of Amatrice on 24 August 2016 was unusually catastrophic. There were 298 fatalities, 386 people were injured, about 5000 homeless people and the city's ancient hub suffered extraordinary destruction. Based on an evaluation report undertaken in September 2016, the European Macro-Seismic Scale (EMS-98) explained the deterioration trends of the systems in the city's ancient center. The level of harm was found to be extremely high with over 60 per cent of the structures investigated showing minor or complete failure. The high degree of damage was caused due the excessive inefficiency of the masonry systems due to improper material usage, the absence of links with the walls and the inappropriate relation 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) Out-of-plane Failure [8] and [10].

The study indicated that the role of successful engineering evaluations in the construction presence of current buildings is very significant, and cannot be achieved by traditional methods alone. [11] investigated the ruin of masonry system during the high-intensity of earthquakes triggered by Eastern Turkey Anatolian fault line. They also provided explanations for failure, updated data on active fault regions and seismic maps for future studies. Likewise, old masonry buildings suffered significant loss during the Gorkha earthquake of 2015. [12] considered damages of masonry buildings during 2008 Wenchuan earthquake. A significant seismic event accompanied by a large aftershock shoot the entire city, resulting in the collapse of several buildings built of brick masonry. Several residents died, were wounded and were homeless until the governing authorities saved their operations. Besides that, the world suffered an immense economic loss from this disaster. Several masonry structures failures in the form of cross-cracks between openings, diagonal cracks initiated from openings, out of plane failures were reported. The key reasons behind these brick masonry failures were bad building methods, improper use of materials and un-designed building walls.

a) b) c)

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

2.3 New Approach for Earthquake Resistant Structure

Ali (2018) [4] analyzed impact of post-tensioned coconut-fiber ropes in overseeing inspire of interlocking mortar-free block structure during seismic tremor stacking. It was accounted for that proposed inter-locking blocks are fit for recovering their own position a while later the actuated ground excitation because of arrangement and slanted key shape in blocks. To emulate single degree of freedom system, lumped mass was 200 kg at top of the column comprised of inter-locking blocks. The dynamic response of inter-locking block column was recorded as far as enticed increasing velocities, uplift of blocks, tension in rope and the relative displacement at top. It was discovered that enticed speeding up was enhanced up to mid-height of the section and a short time later decreased a smidgen at the segment top. Tension in rope and the uplift of blocks were found quite similar. 35% contrast was seen in foreseeing the real seismic reaction of the structure as compared to experimental results, which may agree because of the unpredictability of the inter-locking square segment. [15] developed imaginative eco-accommodating interlocking blocks produced using locally accessible waste materials like palm oil clinker, palm oil fuel debris, and quarry dust for development of tremor safe houses.

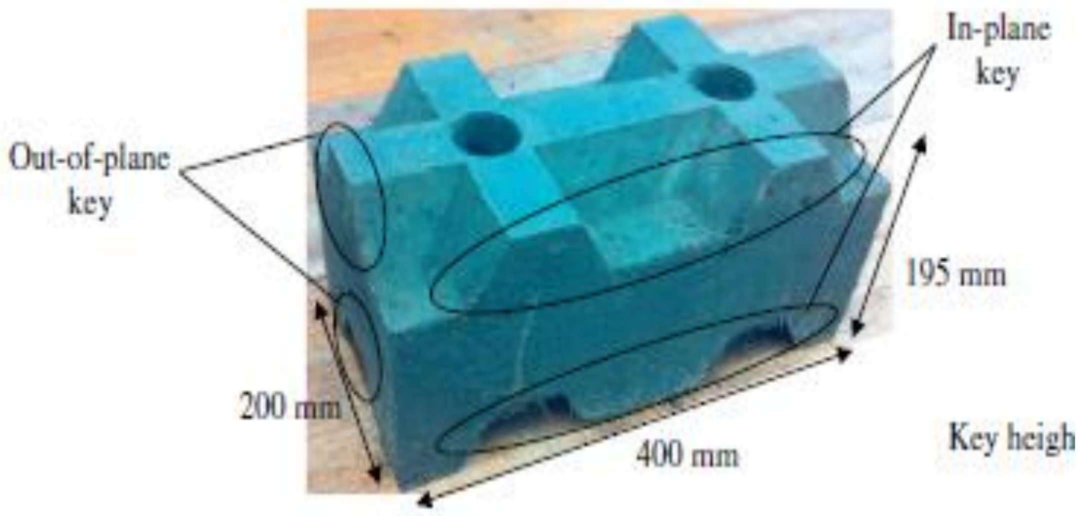


Figure 2.4: Interlocking Block of Coconut Fiber Reinforced Concrete (CFRC) [16].

Liu et al (2016) [17] inspected the cyclic conduct of non-interlocking mortar-less block and interlocking mortar less block. The properties of between locking shapes, stacking pressure feelings of anxiety and stacking cycles were considered during the examination of cyclic conduct. With the assistance of hysteresis loop technique, a mechanical model was built up. Shear distress modes of the entirety of the reviewed joints were portrayed by utilizing Mohr-Coulomb failure technique. With an upsurge in the stacking cycle, there was a decrease in the contact coefficients of the entirety of the joints. With the decrease in the perfection of the interlocking surface, there was an expansion in the corruption pace of the contact coefficients. Numerous specialists have proposed various states of interlocking compacted earth-block . These blocks give protection from the development both in level and cross over course to the wall surface. Expect, hydraform interlocking units give straight development and limits transversely one. Despite the fact that these interlocking blocks have various structures, shapes and sizes however their interlocking instrument is comparative, comprising of bulges. On account of the intricate course of action of these hinders, the dirt attributes and relieving conditions caused trouble in keeping the exact shape and size of these interlocking squares. A plausible strategy needs explicit contraption and amazing mud decision, blend plan and great healing conditions. In any case, use of such device is uneconomical and not accessible in creating nations [18]. The examination proposed another valuable arrangement through rearranging the inter-locking blocks setup keeping control of the math during the assembling stage. The administering component to make straight and stable block wall is successful locking of these blocks which can oppose the overseeing powers [19].

Jeslin and Padmanaban (2020) [20] looked at customary block and interlocking block based on quality perspectives. The examination announced 15%-30% expansion in mechanical properties for the case interlocking block. [21] proposed interlocking brick work development with steel fortification for reasonable lodging in Thailand. Mortar less interlocking block development has been endorsed in part in various nations however with restricted examination history. The essential issue related with these blocks is their creation, which needs modern apparatuses.

Be that as it may, the notable highlights of the interlocking stone work are all around recognized in the writings. Also, constrained rearranged and conservative creation procedures are proposed by the specialists. The development businesses of created nations are recognizing the advantages of these inter-locking blocks for brick work development. This new interlocking method is less difficult and doesn't require mortar sticking movement, at last accelerating the development time. In these nations, the accessible inter-locking blocks in industry contrast fit as a fiddle, size and material use. Given its improved structural performance and ease of construction, the interlocking burnt clay brick can be a viable option for conventional brick masonry. In addition, the incorporation of waste marble powder (WMP) into the interlocking of burnt clay bricks can lead to economic and sustainable construction of masonry [18].

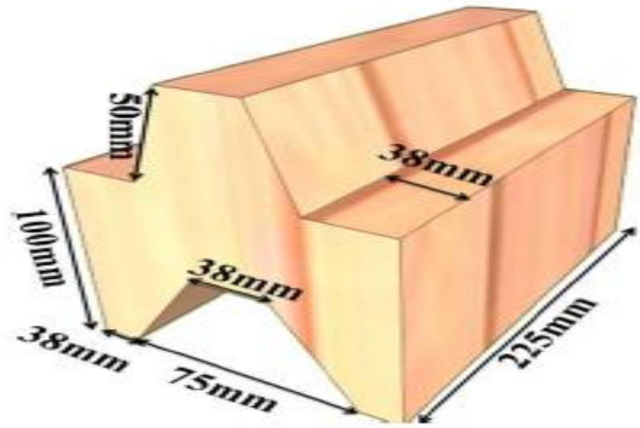


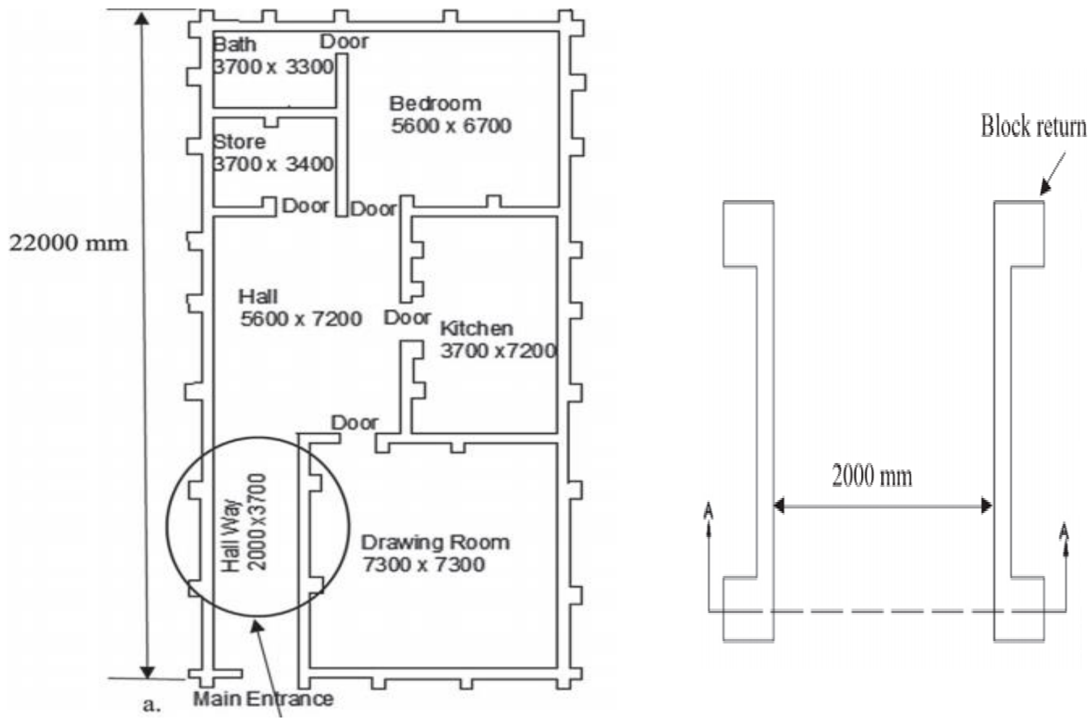
FIGURE 2.5: Interlocking Burnt Clay Brick [18].

2.4 Effect of Block-Return and Stiffeners on Masonry Structures

Brick masonry is one of the ancient and widely implemented construction practice. The supply of brick masonry structural members in ancient buildings is additionally abundant. Throughout the earth, unreinforced brick masonry buildings are continuous threat to mankind, because of their high vulnerability to seismicity

[22]. The damage of structural components represents the largest contribution to the economic loss caused by an earthquake. These structures were constructed with conventional materials and by considering the gravity loading only [3]. These materials in majority of the cases are bricks, stones and wood, which aren't earthquake resistant [5]. In October 2005 earthquake of Pakistan, most of the traditional unreinforced buildings including concrete block brickwork, conventional brickwork and stone masonry were fully or partially damaged [23]. Similarly, separation between the roof diaphragms and therefore the masonry walls (in the out-of-plane direction) and damage to masonry pillars at upper levels of unreinforced masonry buildings were observed within the 2010 Darfield (Christchurch, Nz) Earthquake [13].

Seismic performance of masonry buildings were studied in laboratory by many researchers within the past. Immense non-linear behavior of unreinforced masonry was observed within the laboratory testing under time-scaled Nahnni earthquake 1985 [24]. On contrary, reinforced brick masonry within the sort of concrete stiffeners usage enhanced strength and stiffness of the masonry buildings [25]. These phenomena had been confirmed not only through lab testing but also within the case of real earthquake loading. The failure modes during the laboratory testing changed from diagonal tension or shear slip into a mixture of diagonal tension and toe-crushing. Incorporation of reinforcing elements in mortar joints prevented the structure from cracking [26]. Confined masonry walls with horizontal stiffeners performed well compared to non-confined walls when subjected to lateral loading in laboratory. Masonry walls with vertical stiffeners in terms of steel ties had significant enhancement in seismic capacity as compared with unreinforced walls [27]. Reyes et al. [45] conducted the study on seismic behavior of earthen wall with opening having horizontal and vertical wooden stiffeners. Mexico country features a long record of using confined masonry technique in their housing construction. It's the foremost common construction practice within the country, and is extensively utilized in the country. Confined masonry is typically practiced within the sort of engineered and non-engineered construction everywhere the country. During the 2003 earthquake of Tecomn having magnitude 7.6, designed masonry structures performed significantly well than un-designed brick masonry buildings; majority sizable amount of designed masonry buildings were unharmed or grieved only slight damage [28].



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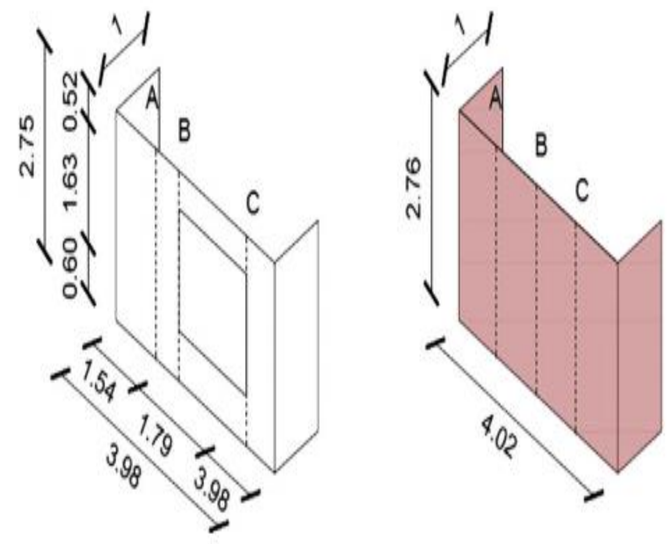


b)

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

Qamar et al. (2020) [29] carried out a study for the improvement of lateral resistance in mortar-free interlocking block-return walls with plaster by using nature fibers. The major reason of the failure of mortar-free interlocking wall system is the out-of-plane lateral resistance. Increase in lateral peak load was noted in this study and further increase also noted for rice straw and sisal fiber reinforced plastered wall system. [30] studied the out of plane behavior of wall with an outer leaf constructed (block-return). They studied the four single leaf and one cavity U.R.M full-scale walls. Separately examined full-scale samples comprising of OOP panel and two return-block walls, fluctuating in terms of normally encountered boundary conditions and applied overburden or the absence/presence of an openings. The samples were subjected to arrangements of incremental input motion till the failures and these outcomes were shows in terms of deformed profiles, mechanisms of failures and displacement-force hysteretic curves. Best in class logical procedures dependent on the technique for virtual work was applied to assess their dependability as disentangled apparatuses for evaluating the conduct of all walls exposed to OOP two-way twisting excitation.

2.5 Dynamic Performance of Prototype Structures in Lab

Significant researches had been conducted within the past to review the behavior of real-life structures with the assistance of scaled down prototypes within the laboratory. 3-D shake table having six degree of freedom is employed in developed countries to research the dynamic response of structure, so as to get real earthquake data. On the opposite hand, emerging countries lack in affording such refined and expensive multipart 3-D shake table. But these countries are using simple 1-D shake table to know the dynamic response of prototype-structures in laboratory. The aim behind development of prototypes structures in laboratory is to conduct such studies. Many researchers have conducted dynamic testing of small and large-scale prototypes within the laboratory using shake table. For little scale testing, simplified boundary conditions had been implemented in these studies. These researches validate the conduction of prototype testing within the lab using shake table. For determination of seismic behavior of those prototypes under dynamic loading, time history analysis may be a useful technique [31]. [32], [33] and [34] studied the behavior of full-scale structure under harmonic loading. [35] studied the dynamic analysis of a prototype structure was conducted in laboratory.

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

Prototype	**Structure Findings**
Interlocking plastic block column with and without rubber band [6]	Column with rubber band performed well against harmonic loadind as compared with column without rubber band
Interlocking plastic block wall campare with masonry wall [39]	Interlocking plastic-block wall having window is withstand against harmonic loading while the masonry wall was collapsed during testing.
Rate independent linear damping performance of inter-story isolated structure [40]	Numerical simulation and shake table real-time hybrid simulation (RTHS) are used to study a 14-story inter-story isolated structure. RILD offers an attractive control alternative by restricting isolation layer displacements without amplifying accelerations.
China ancient masonry tower [41]	A nonlinear FEM was established with macro-modeling approach to further investigation of its dynamic behavior, the results between the tests and the model were compared and agreed well
Out-of-plane shake table test of full-scaled corner wall retrofitted by timber elements [42]	Propose a retrofitting technique that increases the wall strength for both inplane and outofplane directions. This technique consists of vertical and horizontal timber elements symmetrically installed on each face of the wall to form a confining wood frame, supplemented with vertical tensors that precompress the wall.

Addessi et al. (2019) [36] studied the consequences of degrading mechanisms on masonry dynamic response. A non-linear non-local damage plastic material is introduce during a finite element framework and is employed to research the out of plane behavior of tuff-masonry wall, response of structure is studied numerically under cyclic quasi-static and monotonic loadings and compare it with experimental study on shake table. Shake table test in laboratory was conducted to investigate the out-of-plane performance of partially grouted, reinforced concrete masonry walls subjected to simulated seismic loading is investigated (zhang et al. [46]). Singhal and Rai [47] conducted the study on the dynamic analysis of burnt clay brick wall structure in laboratory. [37] investigated the window opening effects on structural behavior of historical masonry Fatih Mosque, so as to research the consequences of the window openings on the structural behavior of the mosque, 3D solid and finite elements models of the mosque with and without window openings were initially developed. The experimental dynamic characteristics like frequency, damping ratio, and mode shapes of the present situation of the mosque, where some windows openings were blind, are determined using Ambient Vibration Testing. Then, the finite element model of the present situation of the mosque is updated using the experimental dynamic characteristics. The static and seismic time history analyses of the updated finite element model with and without window openings were administered. Structural behaviors of the mosque with and without window openings were compared considering displacement and stress propagation's.

2.6 Summary

Conventional masonry buildings are susceptible to earthquake. Contemporary countries have implemented the confined masonry practice in their building construction methods. Nevertheless, they are also susceptible to earthquake vibration up to some range. Scholars are concentrating on interlocking mortar-free blocks as brickwork replacement. Existing literatures has introduced a lot of interlocking techniques, sizes and shapes for these blocks. In this respect, interlocking block constructions is a probable solution for earthquake resilient housing. However, the greater mass of interlocking blocks is a point of concern, because of the resulting greater inertial forces during the earthquake. Therefore, the mass of the interlocking blocks needs to be reduced. Lighter the mass of block, lesser the inertial forces generated during earthquake. For that type of construction (i.e mortar-free interlocking plastic-block structure), dynamic behavior of plastic interlocking block-return walls considered. This can be done with simple shake table. Therefore, the behavior of plastic inter-locking block-return walls investigated by using locally developed low-cost 1D shake table under dynamic loading. To the best knowledge of author, no study has been conducted to explore the behavior of plastic interlocking block-return walls under harmonic loading by using locally developed 1D low-cost shake table. Hence, current research will helps to understand the behavior of interlocking plastic-block walls having block-return with rubber band for probable application in contradiction to harmonic loadings.

Chapter 3

Experimental Program

3.1 Background

While talking about the earthquake resistant design of buildings, it is very essential to expect or calculate the response and reaction of structures during the earthquake. For this specific determination, different techniques had been adopt all over the world. This research define the method of assembling the plastic inter-locking block-return walls, snap back test, harmonic loadings, analysis parameters, development of empirical equations, test setup and instrumentations by using locally-developed low-cost 1D shake table.

Khan and Ali (2019) [38] proposed the interlocking plastic-block for earthquake resistant house (plan and 3D view of proposed house is shown in figure 3.1a and figure 3.1b respectively) and prototype testing, due to its lighter weight and resulting lesser inertia forces. The role of materials weight and resulting inertia forces is very crucial in earthquake resistant structures. Inertial forces are generally taken as a system's ability to resist changes caused by some external force (acceleration). The concept is based on Newtons Laws of Motion, including the 1^{st} and 2^{nd} Law. In response to such external force, heavy systems (materials) responds more due to their greater weight in comparison with lighter systems (materials), thus causing greater inertial forces.

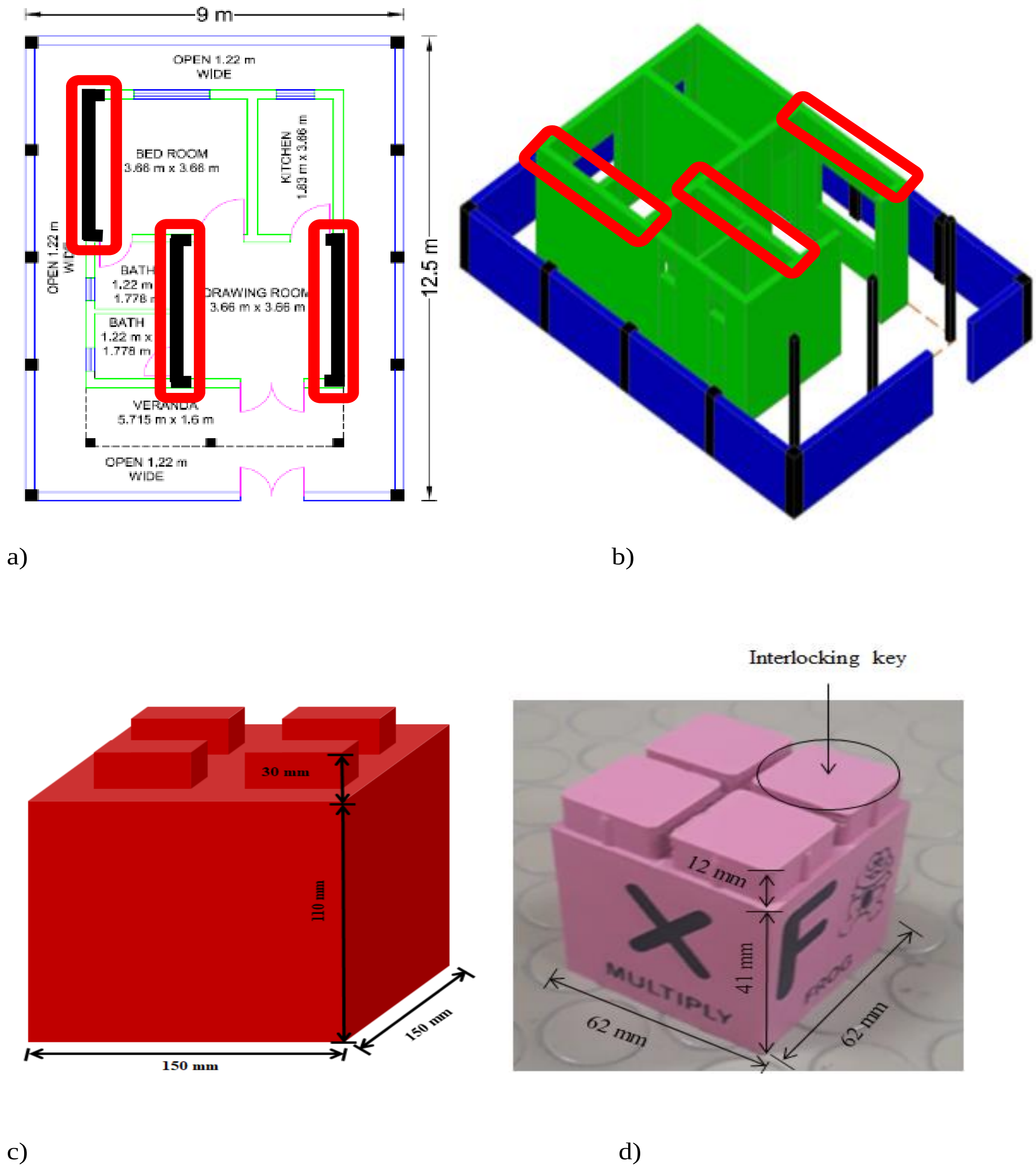


FIGURE 3.1: Proposed Inter-locking Plastic-block House: a) Plan, b) 3D View and Inter-locking Plastic-blocks c) Proposed for Construction and d) Prototype for Current Study.

For construction of earthquake resistant housing, the proposed interlocking plastic blocks have base dimension of 150x150 mm and having four keys at the top. Total height of block is 140 mm including the 30 mm height of interlocking key as shown in figure 3.1 (c). Similarly, for prototype construction, the used dimensions in the study was 62x62mm with a height of 53 mm including the 12 mm height of interlocking key as shown in figure 3.2 (d). Current research work is continuation of [38] and [39] research work.

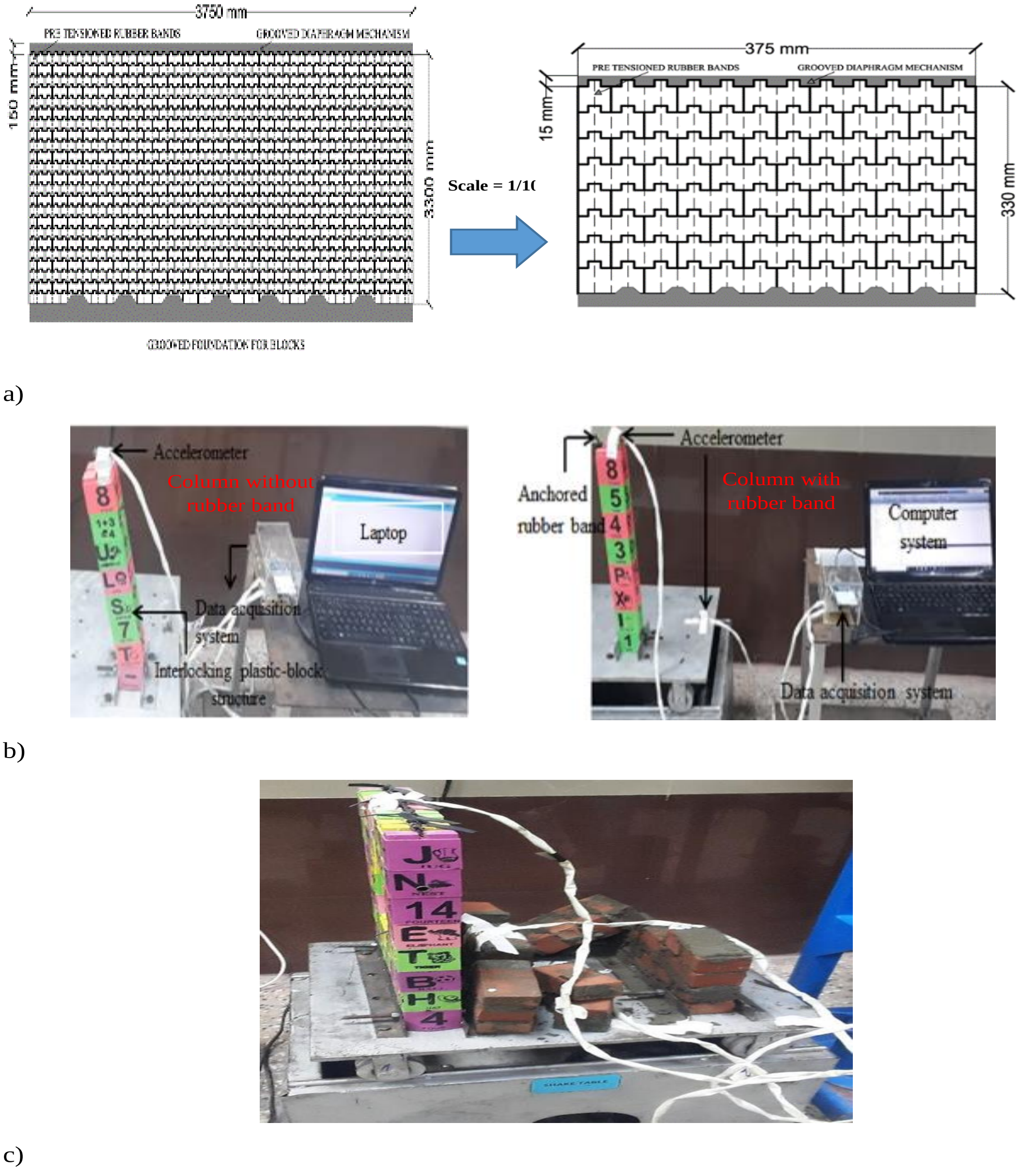


FIGURE 3.2: Previous Researches; a) Scale Down Technique, b) Column with Rubber Band and column without Rubber Band [38], c) Comparison of Interlocking Plastic Block with Brick Masonry Wall [39].

In this study, prototype plastic interlocking block-return walls (Solid wall, wall with window opening and wall with door opening) are considered for dynamic testing. Prototype testing serve to provide specifications for a real or proposed working system rather than a theoretical one. Prototype walls scaling and construction technique adopted in this research work is purely based on research practices mentioned in literature [40]; [41]; [42]; [43]. Outcome of such studies help to understand the behavior of full-scale structures. The primary purpose of current research is to study the dynamic behavior of structural walls with block-return. For this, structural time-period is an important parameter, which depends on the structure height (UBC-97). That is why; scale down technique is applied mainly on elevation dimension of structural walls. It may be noted that the dimensions of units used in all prototypes (i.e., scaled down walls samples with block return) are slightly different. However, the elevation dimensions in both prototypes are approximately the same.

Figure 3.2 shows the previous researches. Figure 3.2 (a) shows schematic diagram of proposed real wall made up of interlocking plastic blocks. It will have some grooved block mechanism for foundation and roof diaphragm and scaled downed schematic diagram of prototype interlocking plastic block wall, using 1/10 scale factor. Fig 3.2 (b) shows the study of prototype interlocking plastic block column with and without rubber band by [38]. Figure 3.2 (c) shows the comparison of interlocking plastic block with brick masonry wall by [39].

3.2 Construction of Prototype Block-Return Walls

Prototype interlocking plastic block solid wall with block-return and typical first three layers consists of sixty-four interlocking plastic blocks (64), making a total height (H) of 330 mm) as shown in figure 3.3 (a). It is a firm wall with no opening i-e no window or no door. Rubber bands are tied-up from bottom to top through mid of blocks to provide vertical stiffness in the wall. Fixed base with the help of base plates and nut bolts was provided. No mass is provided at top. However, the total mass of wall (M) is 1.875 Kg. Prototype interlocking plastic block-return wall with window opening consists of fifty-eight inter- locking plastic blocks (58), making a total height (H) of 330 mm as shown in figure 3.3 (b). It is having an opening in form of window approximately in the middle. The dimensions of opening are 125x125 mm. Wooden lintel is provided over the window opening as a supporting tool. In addition, rubber bands are tied-up from bottom to top through mid of blocks to provide vertical stiffness in the wall. Fixed base with the help of base plates and nut bolts is provided. No mass is provided at the wall top. However, the total mass of wall (M) is 1.715 Kg. Similarly, Prototype interlocking plastic block-return wall with door opening consists of fifty-five interlocking plastic blocks (55), making a total height (H) of 330 mm as shown in figure 3.3 (c). It is having an opening in form of door at right side of wall. The dimensions of opening are 95x250 mm. Wooden lintel band is provided above the opening for support mechanism. In addition, rubber bands are tied-up from bottom to top through mid of blocks to provide vertical stiffness in the wall. Fixed base with the help base plates and nut bolts is provided. No mass is provided at the wall top. However, the total mass of wall (M) is 1.605 Kg.

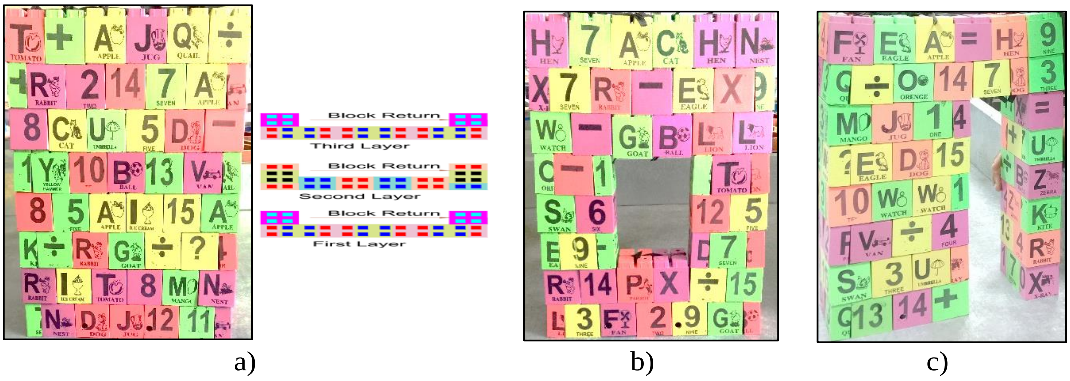


FIGURE 3.3: Schematic Diagram of Prototype Walls with Block-return with Simplified Boundary Conditions; a) Elevation of Solid Wall and Typical First Three Layers in Plan, b) Elevation of Wall with Window Opening, c) Elevation of Wall with Door Opening.

3.3 Test Setup

3.3.1 Snapback Test and Instrumentations

Figure 3.4 (a) shows the test setup of snap-back test. A wire having length of 400 mm is attached at the top of all interlocking plastic-block walls. To record the response of the wall, an accelerometer is attached at the top of all the walls. Free vibration of the interlocking plastic-block walls are observed by freeing the attached wire. Response of the walls are recorded in terms of acceleration-time history using the accelerometer data. Log decrement method is used to calculate the damping ratio (ξ) and fundamental frequency (fn) of the all interlocking plastic-block walls having block-return.

3.3.2 Shake Table Test and Instrumentations

Figure 3.4 (b) shows the instrumentation of shake table testing and proposed harmonic loading. All the plastic interlocking block-return walls (solid wall, wall with window opening and wall with window opening) are mounted on the shake table one-by-one using base plates and nut bolt. Total two accelerometers are used (one is attached at the top of the wall and one is attached at the base of the shake table), repeat this method with all walls. Response of all walls are recorded in terms of acceleration-time history. Then this data is converted into velocity-time history and displacement-time history using the seismosignal software.

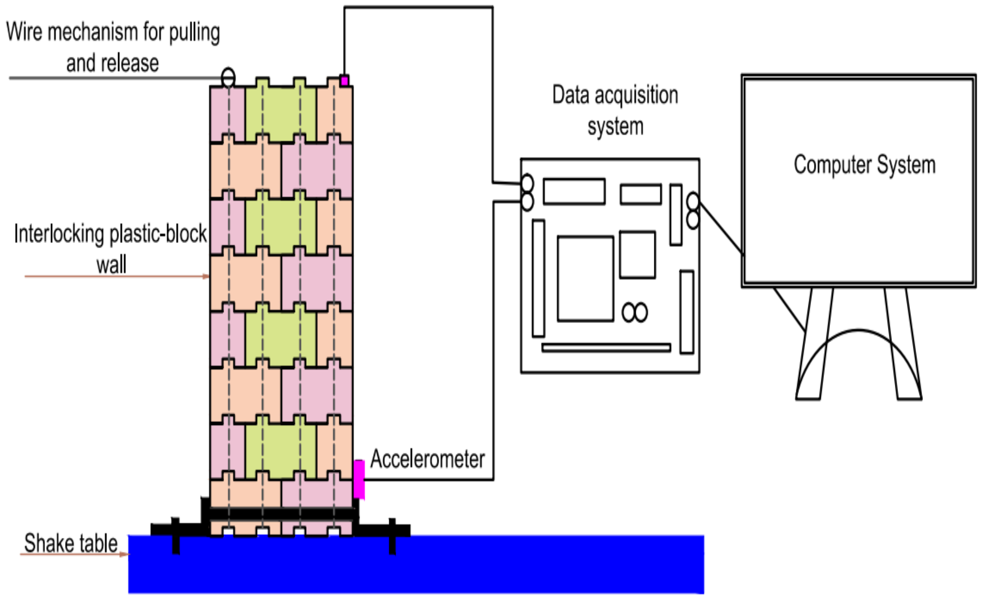
3.4 Loadings

3.4.1 Snapback Test

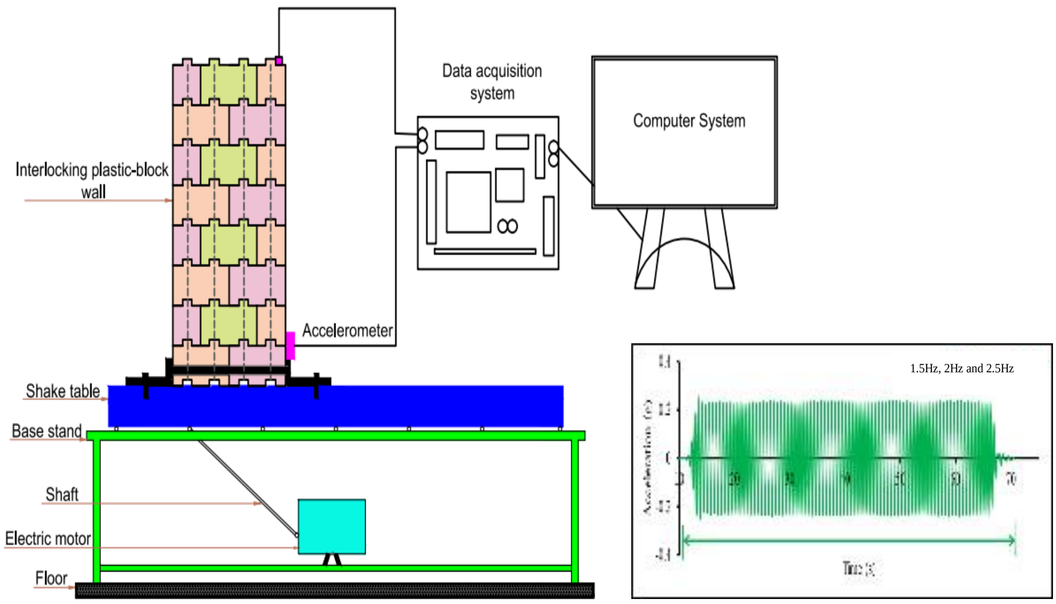
To perform snap back test, all interlocking plastic-block walls having block-return were displaced by 50 mm from the top with the help of attached wire one-by-one. Then, the wire was suddenly released to produce free vibration. Acceleration-time history data was recorded with the help of accelerometer attached at the top of the wall. With the help of log decrement method, damping ratio and fundamental frequency has calculated.

3.4.2 Harmonic Loading Test

Magnitude of different tests considered are given in Table 3.1. In this research work, two tests are performed i.e., snap back test and harmonic loading test.



a)



b)

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

Snap back test is performed for different plastic interlocking block-return walls. For harmonic loading, frequencies of 1.5 Hz, 2 Hz, and 2.5 Hz are considered. For harmonic loading, the amplitude of interlocking plastic-block walls (solid wall, wall with window opening and wall with door opening) is taken as 30 mm. Harmonic loading (being simple dynamic loading) is selected to study the dynamic response. Earthquake loadings are not selected due to the use of simple 1D shake table. Acceleration-time history, and displacement-time history at the top of all walls and base of shake table is compared to evaluate the dynamic response of walls under the influence of harmonic loading. It is predicted that the acceleration-time history, and displacement-time history will be greater for the case of plastic interlocking block-return walls with door opening.

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

For all plastic interlocking block-return walls (solid wall, wall with window opening and wall with door opening), raw data is recorded in terms of acceleration-time history. For the duration of the recording period, some noise was also recorded in acceleration- time history data. Seismosignal software was used to remove this noise from test data. Bandwidth filter of seismosignal software was used to remove undesired data (see annexure A for detail). Furthermore, damping ratio (ξ) and fundamental frequency (fn) of the plastic interlocking block-return walls was calculated by using the acceleration-time history. It is predicted that the damping ratio of the plastic interlocking block-return wall having door opening was greater.

3.5.2 Analyzed Parameter from Shake Table

Harmonic loading having frequencies of 1.5 Hz, 2 Hz, and 2.5 Hz was applied to all block-return walls (solid wall, wall with window opening and wall with door opening). Response of these walls in terms of acceleration-time history was recorded. Velocity-time history and displacement-time history was calculated by using the seismosignal software. Similarly, with the help of acceleration-time history data, base shear (Q) - displacement curves were also obtained for both walls. Base shear is taken where M is the mass of respective wall and $\ddot{u}_t$ is the acceleration at the top of respective wall.

3.5.3 Comparison with Empirical Equation

For understanding the dynamic behavior of different plastic interlocking block-return walls (solid wall, wall with window opening and wall with door opening), empirical equations by Khan and Ali (2019) are used to compare the results. The percentage difference between the experimental and empirical values is also calculated.

3.6 Summary

In this chapter, investigational methods of the research work are discussed in detail. Under the harmonic loading, different interlocking plastic-block return walls (i-e solid wall, wall with window opening and wall with door opening) are tested. Test setup and analyzed parameters from snapback and harmonic loading at different frequencies for different walls having block-return are also discussed in detail.

Chapter 4

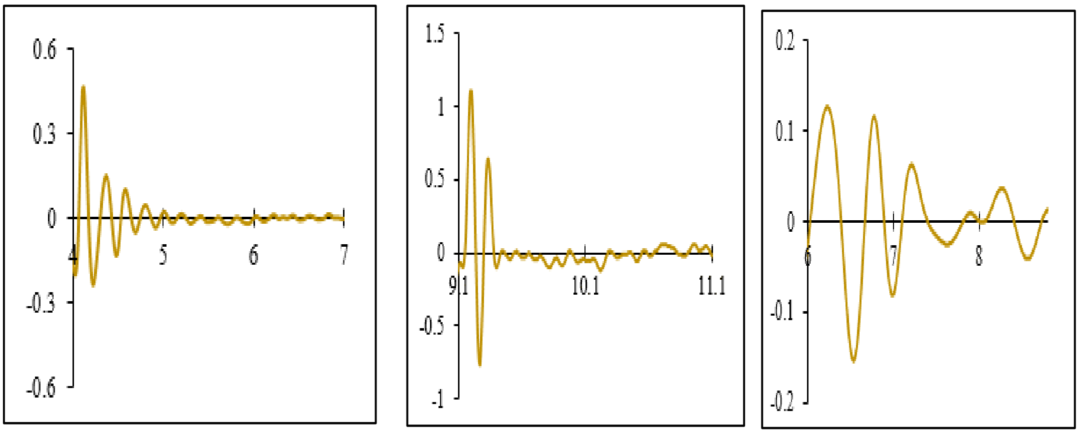
Experimental Findings

4.1 Background

In the last chapter, investigational methods of snapback and harmonic loading test and analyzed parameters are discussed in detail. Current chapter enlighten the experimental findings from tha data recorded during testing. Fundamental frequency (fn) and damping ratio (ξ) are calculated for all the walls having block-return by using acceleration-time history. Initially MATLAB software is used to collect the data in raw form and then seismosignal software was used to remove the extra noises. Likewise, displacement-time and velocity-time history was also calculated by seismosignal, see annexure A for details.

4.2 Damping Ratio and Fundamental Frequency

Figure 4.1 depicts the results of snap back test conducted on different plastic interlocking block-return walls (solid wall, wall with window opening and wall with door opening). The top of all the walls are displaced from mean position by 50 mm. By using log decrement method, damping ratio (ξ) and fundamental frequency (fn) for plastic interlocking block-return walls were calculated.



a) b) c)

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	3.8	6.4
Wall with window opening	50 mm	5	5.5
Wall with door opening	50 mm	2.6	4.7

Table 4.1 lists the snap back test result of different plastic interlocking block- return walls (solid wall, wall with window opening and wall with window opening). The damping ratio (ξ) of structure is 6.4% for solid wall 5.5% for wall with window opening and 4.7% for wall with door opening at top displaced by 50 mm. The frequency calculated is 3.8 Hz, 10 Hz and 2.6 Hz for solid wall, wall with window opening and wall with window opening respectively. It is observed that there is some difference between damping value. The damping ratio of solid wall having block-return displaced by 50 mm found more damping as compared to 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

Response of plastic interlocking block-return wall (solid wall) are recorded in terms of acceleration-time history and displacement-time history during the time-period of 40s to 45s as shown in fig 4.2 (a,b). The sky blue dash line represents the shake table movement or base excitation (applied loading), and the orange dash dotted line represent the response at the top of the plastic interlocking block-return solid wall.

Response of plastic interlocking block-return wall (wall with window opening) are recorded in terms of acceleration-time history and displacement-time history during the time-period of 40s to 45s as shown in fig 4.3 (a,b). The sky blue dash line represents the shake table movement or base excitation (applied loading), and the orange dash dotted line represent the response at the top of the plastic interlocking block-return solid wall.

Response of plastic interlocking block-return wall (wall with door opening) are recorded in terms of acceleration-time history and displacement-time history during the time-period of 40s to 45s as shown in fig 4.4 (a,b). The sky blue dash line represents the shake table movement or base excitation (applied loading), and the orange dash dotted line represent the response at the top of the plastic interlocking block-return solid wall.

The acceleration-time history and displacement-time history obtained from analysis of result are acceptable to investigate the dynamic response of all prototype walls. Acceleration-time history is recorded and then by using seismosignal software the acceleration-time history is converted into displacement-time histories as described earlier.

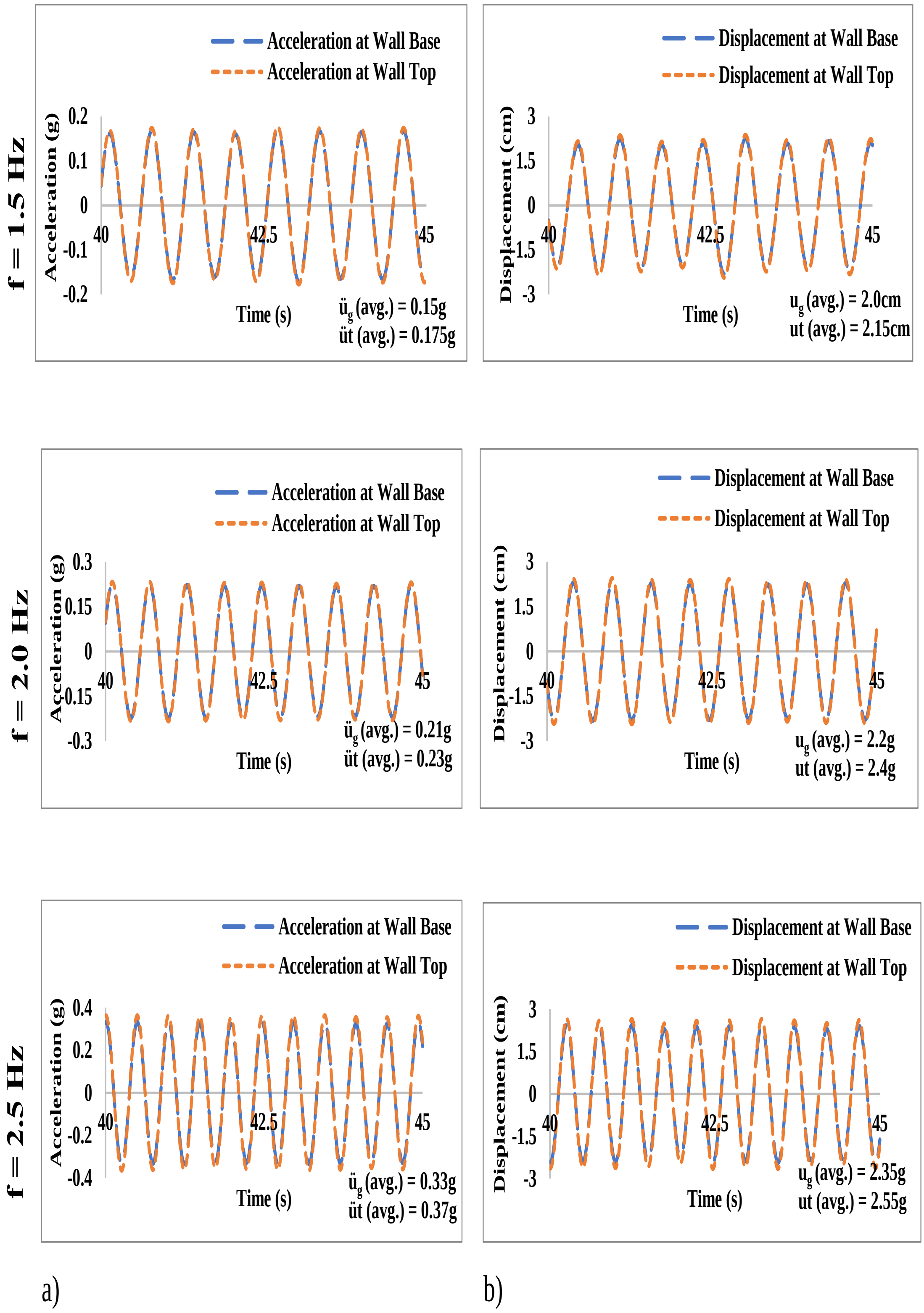


Figure 4.2: Response of Solid Wall During Harmonic Loadings of 1.1Hz and 1.3Hz Between 40 s and 50s; a) Acceleration-time, b) Displacement-time.

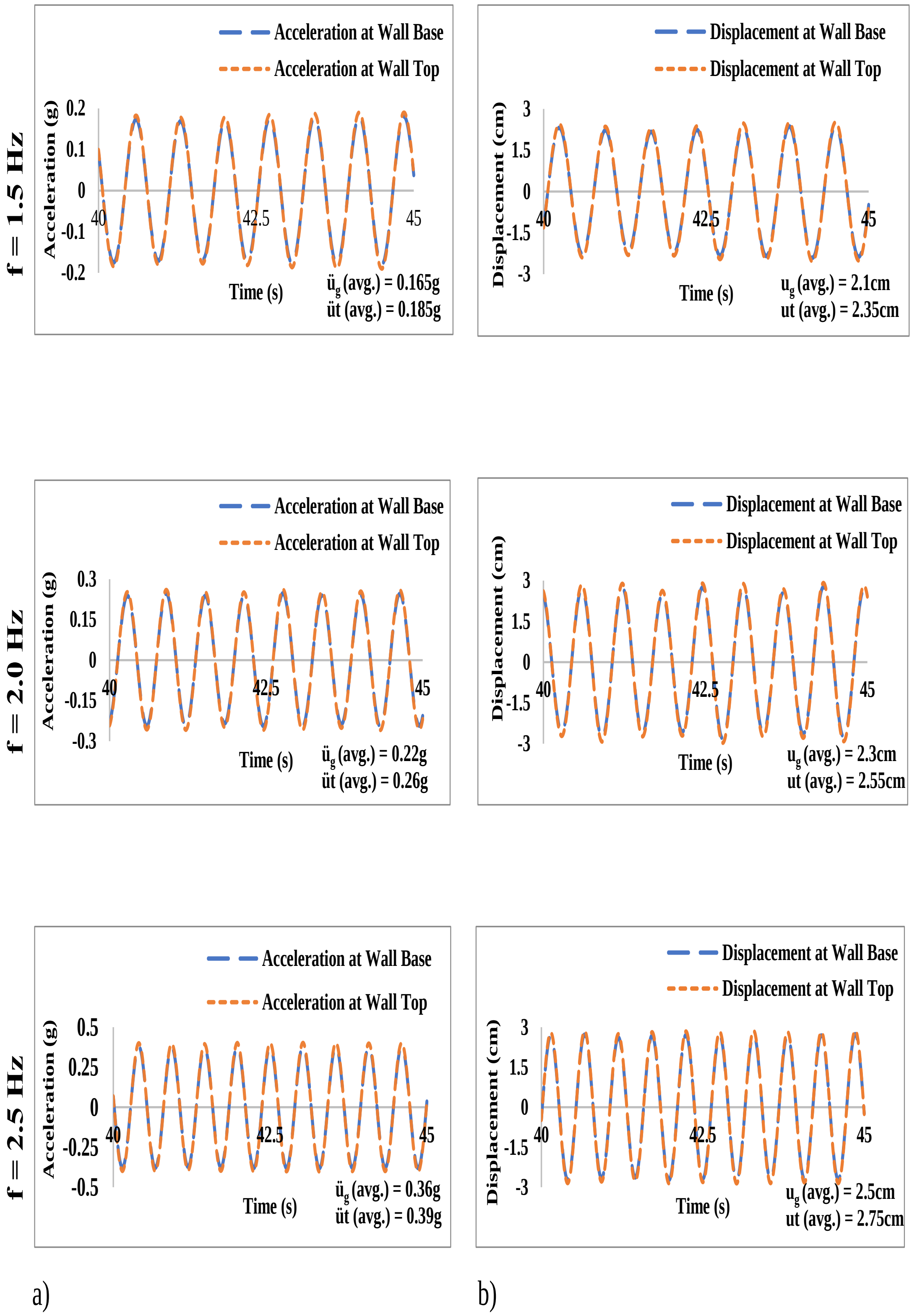


FIGURE 4.3: Response of Wall with Window Opening During Harmonic Loadings of 1.1Hz and 1.3Hz Between 40 s and 50s; a) Acceleration-time, b) Displacement-time.

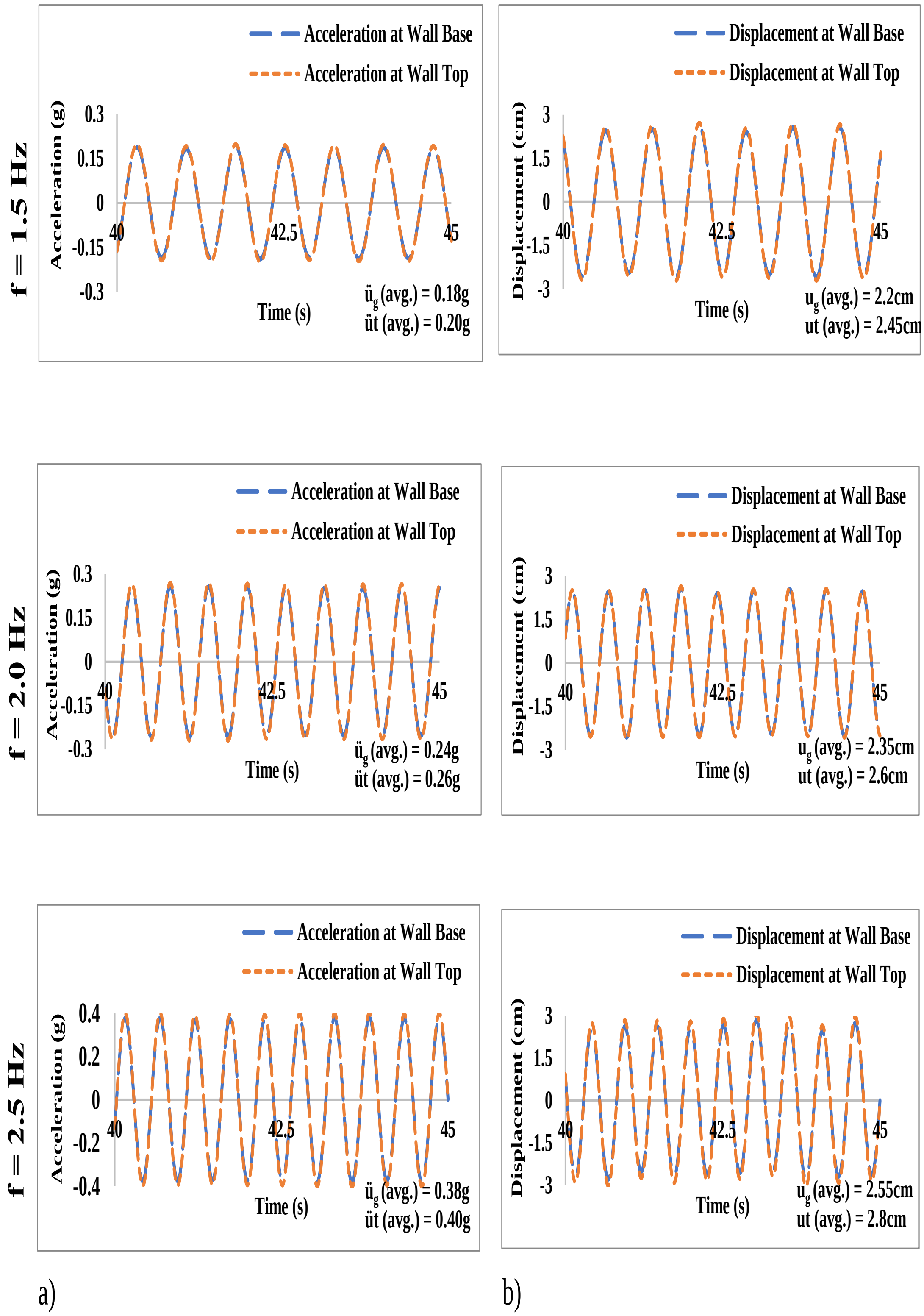


FIGURE 4.4: Response of Wall with Door Opening During Harmonic Loading of 1.1Hz and 1.3Hz Between 40 s and 50s; a) Acceleration-time, b) Displacement-time.

Since the locally low-cost shake table is good enough to apply harmonic loading precisely i.e., constant amplitude of different cycles, the averaged acceleration and displacement of base excitation (i.e. $\ddot{u}_g$ and ug respectively) is considered applied loading. The averaged acceleration and displacement at the top of plastic interlocking block-return walls (solid wall, wall with window opening and wall with door opening) (i.e. $\ddot{u}_t$ and ut respectively) is considered as IPWW response.

Acceleration-time histories of all block-return walls during harmonic loadings of 1.5 Hz, 2 Hz and 2.5 Hz between 40s to 45s are shown in fig 4.2 (a), 4.3 (a) and 4.4 (a). The structure excitation can be classified into three phase: A. when the structure started its vibration until it attained the steady-state, B. steady state response of the structure, and C. free vibration of the structure (Ali et al., 2013). For clarity, only the portion of steady state response is shown in fig 4.2, fig 4.3 and fig 4.4. Averaged acceleration at base and top of walls are also mentioned. It has been noticed that the acceleration of these band is increased by increasing the frequency of shake table. Displacement-time histories of all block-return walls during harmonic loadings of 1.5 Hz, 2 Hz and 2.5 Hz between 40s and 45s are shown in fig 4.2 (b), fig 4.3 (b) and fig 4.4 (b). Averaged displacement at ground and top of walls is also mentioned. It has been noticed that the displacement of walls are increased by increasing the frequency of shake table. Walls are not been collapsed during harmonic loading even at a higher frequency. But wall may collapse at a higher frequency. This needs to be avoided by some mechanism to make structure resistant.

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

It is assumed that the total mass of plastic interlocking block-return walls wall,(solid wall with window opening and wall with door opening) (M) is lumped at walls 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 (Q) - displacement (Δ) curves of different block-return walls are shown in Fig 4.5. This is calculated as per working of (Ali et al., 2013).

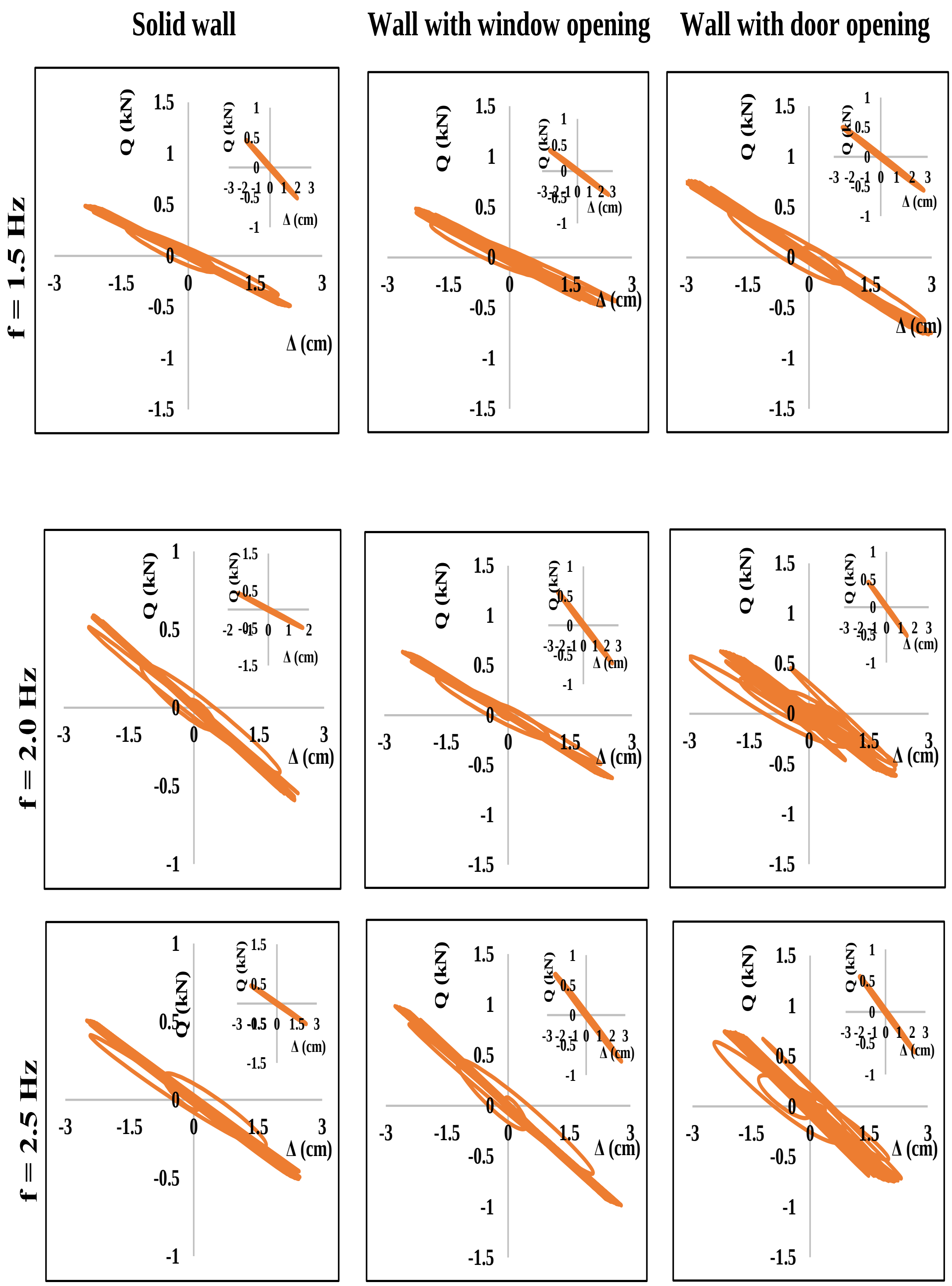


FIGURE 4.5: Base Shear (Q) - Displacement (Δ) Curves of Different Interlocking Plastic Block-return Walls (i-e Solid Wall, Wall with Window Opening and Wall with Door Opening).

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	2.0	2.3	3.5	90	180	207	315
2	ug = 30	2.0	3.6	3.8	4.9	120	432	456	588
3	ug = 30	2.5	4.5	4.8	5.4	150	675	720	810

Table 4.2 shows the averaged energy absorption (E) in one cycle as well as total energy absorbed (ET). Number of harmonic cycles are denoted by "N" and area within the loop is taken as energy absorption (E). It has been noticed that plastic interlocking block-return walls dissipates more energy during harmonic loading with frequencies 1.5 Hz, 2 Hz and 2.5 Hz. It is concluded that greater energy is dissipated in interlocking plastic-block wall with block-return having door opening at 2.5 Hz as comparison with other walls having block-return. In seismic event, plastic interlocking block-return walls can absorb more energy, because of the relative movement at block interfaces. Experimentation is performed with observation that energy dissipation is because of relative movement or uplift of block, which will be studied in future.

4.4 Improvement in Empirical Equations and Comparison with Experimental Results

Khan (2019) developed empirical equations incorporating the geometry of interlocking blocks, column height, column response and input loading parameters. Following empirical equations are developed for predicting the response of plastic in- terlocking block-return walls (solid wall, wall with window opening and wall with door opening) by incorporating further new variable.

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

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

Where $\ddot{u}_g$, and ug are averaged ground acceleration, and displacement, respectively. $\ddot{u}_t$ ut 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 mm^2, 12 mm, 8 and Rs is 0.12 for solid wall, 0.13 for wall with window and 0.135 for wall with door respectively) respectively. Rb and K is coefficient having dimensionless value of 0.73 and 0.45 respectively. In Table 4.3, comparison of experimental and empirical values of wall response is shown. It can be noted that experimental values are good agreement with empirical values. The maximum percentage difference is less than or equal to 17%. The percentage difference between experimental and empirical result is relatively large for wall structures due to dynamic characteristics of interlocking assembly. As Ali (2018) percentage difference was up to 35% in predicting the structure response which could be attributed towards the complex behavior of the structure versus the simple empirical approach. But still, this can help in understanding the behavior of mortar-free interlocking structure in a systematic manner.

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)	0.375±0.005	0.306	19.0%
		Displacement (cm)	2.60±0.05	2.67	-3.0%
Wall with window	2.5	Acceleration (g)	0.395±0.003	0.361	9.0%
		Displacement (cm)	2.825±0.075	3.08	-9.0%
Wall with door	2.5	Acceleration (g)	0.405±0.005	0.396	2.0%
		Displacement (cm)	2.825±0.025	3.32	-18.0%

4.5 Summary

This chapter enlighten the experimental findings from tha data recorded during testing. Experiment has performed two times to make the robust analysis. Fundamental frequency (fn) and damping ratio (ξ) are calculated for all the walls having block-return by using acceleration-time history. Initially MATLAB software is used to filter the data and then seismosignal software was used to remove the extra noises. Likewise, displacement-time and velocity-time history was also calculated by seismosignal. Graphical representation of acceleration-time, displacement-time histories, base shear curves are shown in this chapter. Interlocking plastic-block wall with door opening having block-return dessipate more energy as compared to other walls.

Chapter 5

Discussion on Practical Implementation

5.1 Background

In the last chapter, graphical representation of acceleration-time history, displacement time history and base shear-displacement are described in detail. Notable, energy absorption is observed in interlocking plastic-block wall with door opening having block-return is greater as compared to other wall with block-return. On the other hand, experimental results are compared with empirical results, the purpose of comparison of results is to check the percentage difference. In this chapter, relationship between experimental and empirical values are developed to predict the behavior of interlocking plastic-block walls having block-return. In addition to that, percentage difference between empirical and experimental values are presented.

5.2 Comparison of Current Study with Previous Studies

Results of current study has compared with previous studies of research program. Results of acceleration-time and displacement-time of solid straight wall and solid wall with block-return has compared and the percentage difference is less than 4.6%. Results of acceleration-time and displacement-time of wall with window opening (without block-return) and wall with window opening having block-return has compared and the percentage difference is less than 10.1%. By applying the empirical equations of current study on Sudheer [39] results with the value of reduction factor due to increase stiffness (R_s) is 0.13, and the percentage difference is observed as 18%.

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	1.06	0.94	1.05	1.1	4.5
	2	1.04	1.075	3.2	1.06	1.18	10.1
	2.5	1.06	1.08	1.85	1.15	1.08	6.4
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	1.14	2.63

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

Application of harmonic loading using locally-developed 1D shake table is capable to produce precise harmonic loading to some amount. So that, the seismic response of structure under observation can be calculated. This is because, the applied harmonic loading is taken as the base ground motion and behavior of the structural element is examined with respect to it. Alternatively, the perceived response of different interlocking plastic-block walls having block-return is approximately same as described in the literature. The studied different block-return wall has displayed positive potential in the form of structural stability and energy-absorption. So, it should be examined the block-return wall connect with other elements. Moreover, the opposing impact of earthquake can be reduced by using interlocking plastic-block for earthquake resistant buildings.

5.4 Summary

In this chapter, outcome of research work with-respect-to practical needs are explained. Locally-developed 1D shake table is not considerable exact with-respect-to fixed amplitude and variable frequencies. But, it is capable to produce harmonic loading precisely to some magnitude. So that the seismic response of structural el- ements under the observation can be investigated. Interlocking plastic-block wall having block-return is more convenient for earthquake resistant structure as compared to that of masonry wall. Plastic-block wall with door opening having block-return dissipate more energy as compared to other block-return wall. Due to block-return, the empirical equations has improved by adding new factor Rs with the value of 0.12 for solid wall, 0.13 for wall with window opening and 0.135 for wall with door opening. Experimental values are less-accurate because of the limitations of shake table and the human errors while, empirical values are more accurate as compared to that of experimental values is to check the percentage difference of values with respect to experimental values. Empirical values are dimensionally accurate as compare to experimental values. Experimental values are less accurate due to shake table limitations and human error.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

Many earthquake resistant construction techniques are available in literature for earthquake prone areas. But those are uneconomical. Developing countries cannot afford such techniques to lessen the earthquake damages. In this pilot study, dynamic behavior plastic interlocking block-return walls (solid wall, wall with win- dow opening and wall with door opening). Prototypes of all walls are tested under different harmonic loading to determine the response and their dynamic characteristics. Harmonic loading (being simple dynamic loading) is selected to study the dynamic response. Earthquake loadings are not selected due to the use of simple 1D shake table. Mass was not applied on the top of the walls because of the load limitations of shake table. Although without any top mass, it was unrealistic to conduct a test. The purpose of testing is only to examine behavior of different pattern of interlocking plastic-block walls with simplified boundary condition. For finding the fundamental frequencies of the structure, the harmonic tests were found more accurate compared to snap back test. Following conclusions can be drawn from this research work:

- Fundamental frequency (fn) and damping ratio (ξ) was determined by snap-back test.

- Response of different interlocking plastic-block walls having block-return in term of acceleraton-time and displacement-time histories are recorded.

  – Three frequencies (i-e1.5Hz, 2Hz and 2.5Hz) for harmonic loading are considered.

  – Base shear (Q) and energy absorption of all the walls are determined.

  – Energy dissipation capacity of interlocking plastic-block walls having block-return is increased by using rubber band as a vertical reinforcement.

- Empirical equation is modified by incorporating the new variable i-e Block-return factor (Rb) with a value of 0.73.

  – Percentage difference between experimental and empirical value is less than 20%.

  – Empirical results obtained from khan and Ali (2019) are in good agreement as compared with experimental results of the current work.

On overall basis, prototype plastic interlocking block-return walls (solid wall, wall with window opening and wall with door opening) performed remarkably sound in contradiction to harmonic loading. The proposed housing technology has the potential to provide respectable living standard for underprivileged people.

6.2 Recommendations

In the research program, next study should be the in-plane and out-of-plane dynamic response of interlocking plastic-block wall having block-return attached with diaphragm.

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Annexure A

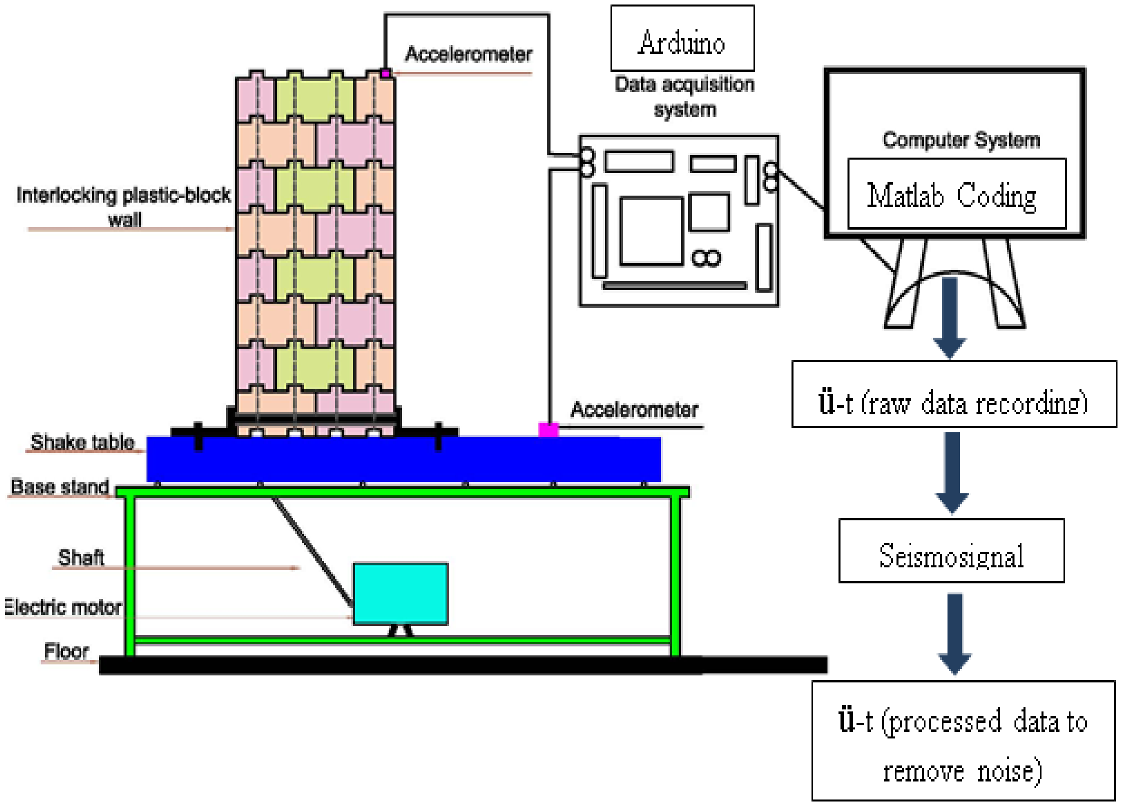

Figure A.1: Data Gathering Mechanism