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Dynamic Performance of Corner-Joints in Mortar-Free Interlocking-Plastic-Block Walls

by

Waseem Akram

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in the

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I want to dedicate this work to my family, who helped me throughout my education. This is likewise a tribute to my best teachers who guided me to go up against the troubles of presence with ingenuity and boldness, and who made me what I am today.



CERTIFICATE OF APPROVAL

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List of Publications

It is certified that following publication(s) have been made out of the research work that has been carried out for this thesis:-

Intended Journal Article

1. W. Akram and M. Ali, “Evaluating corner joints in mortar-free interlocking plastic block walls under dynamic loading”, *Journal of Building Engineering*, 2025.

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3. W. Akram and M. Ali, “Evaluating performance of wall corner joints in mortar-free interlocking block walls under dynamic loading”, in *Proc. 3rd Int. Multidiscip. Conf. Emerging Trends Eng. Technol.*, Benazir Bhutto Shaheed Univ. Technol. Skill Dev., Khairpur Mirs, Sindh, Pakistan, 2025, Paper ID: 61.

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Abstract

Conventional masonry structures, especially those which not engineered are highly susceptible to collapse during strong ground motion. In seismically active regions, particularly in developing countries, the lack of affordable and earthquake-resistant housing poses a serious threat to human life and infrastructure. Several seismic mitigation strategies exist; many are not economically viable for widespread adoption. A common mode of failure in masonry construction is at the corner joints, where the interaction between in-plane and out-of-plane dynamic forces compromises structural integrity especially in structures with degraded mortar strength. The behavior of mortar-free interlocking plastic-block walls under seismic loads, particularly at corner joints, remains under explored. These systems offer potential advantages due to their reduced mass and inertia, making them helpful for low-cost, earthquake-resistant construction. Research reveal that simple low cost shake table testing reveal good results for studying the such kind of behavior. Thus There is need to investigate the behavior of corner joint using simple shake table

Current research focuses on the dynamic behavior of a 1:3 scaled-down corner-joint constructed from interlocking-plastic-blocks. The prototype corner-joint consisted of 280 plastic blocks arranged in 20 layers and was fixed at the base using angle sections to ensure structural stability. To capture the structural response, five accelerometers were installed on specific locations. Two on the top of each orthogonal walls, one at the top of corner- joint, one at the bottom of the corner-joint and one on the base plate to record the base excitation. Snap-back test was performed by displacing the wall in the X-direction using a 400 mm wire and releasing it to evaluate the natural time period, frequency, and damping ratio using the logarithmic decrement method. The study utilized a locally developed low-cost shake table operating at frequencies of 0.8 Hz, 1.1 Hz, and 1.4 Hz to simulate seismic excitation. Acceleration-time history data collected through MATLAB software was processed and refined using SeismoSignal software for noise removal and baseline correction.

Average natural frequency of the interlocking corner-joint was approximately 1.1 Hz, with a damping ratio of up to 5.4 %. Displacement-time history analysis indicate that the out-of-plane wall behavior contributes more significantly to corner deformation than in-plane behavior, with its influence remains to up to 180% depending on the configuration. Energy absorption values were determined from base shear-displacement curves, assuming mass is lumped on the specimen's top. Notably, the wall configuration labeled Sequence B exhibited higher energy absorption with 8.9%, 55%, and 62% than Wall configuration Sequence A at frequencies of 0.8 Hz, 1.1 Hz, and 1.4 Hz respectively. The 34% difference between experimental and empirical results is due to the structure's complexity versus the simplicity of equations. The study can help in understanding corner-joint behavior in mortar-free interlocking block systems. The study demonstrates that corner-joint in mortar-free interlocking- plastic-block wall offers a step towards safe, economical and resilient structure for seismic-resistant housing.

Keywords: Dynamic performance, Mortar-free, Interlocking-plastic -block, Corner-joint.

Contents

Author’s Declaration	iv
Plagiarism Undertaking	v
List of Publications	vi
Acknowledgement	vii
Abstract	viii
List of Figures	xiii
List of Tables	xiv
Abbreviations	xv
Symbols	xvi
1 Introduction	1
1.1 Background	1
1.1.1 Work done till today	2
1.2 Research Motivation and Problem Statement	3
1.2.1 Research Questions	4
1.3 Overall Goal of the Research Program and Specific Aim of this Particular Study	4
1.4 Scope of Work and Study Limitations	4
1.4.1 Rationale Behind the Variable Selection	5
1.5 Brief Methodology	6
1.6 Research Impact on Industry	7
1.6.1 Research Novelty/Uniqueness	7
1.6.2 Research Significance and Benefit	7
1.6.3 Practical Implementation	7
1.6.4 National and Global Impact with Emphasis on SDGs Rele- vance	8
1.6.5 Research Challenges	8

1.6.6	Ethical and Management Considerations Including Risk Management	9
1.6.7	Research Deliverable, Sale and Marketing Potential	9
1.7	Thesis Layout	10
2	Literature Review	11
2.1	Background	11
2.2	Corner Damages in Conventional Masonry Structures	12
2.2.1	Failure in Conventional Masonry Structures	12
2.2.2	Damages in Wall Corner in Conventional Masonry Structures	14
2.3	New Technology Using Mortar-Free Interlocking Masonry	16
2.3.1	Mortar-Free Interlocking Masonry	16
2.3.2	Interlocking Mechanism of Mortar-Free Construction	18
2.4	Dynamic Testing of Corner-Joints in Masonry	22
2.4.1	Joint Strategies for Corner-Joints	22
2.4.2	Testing Techniques	23
2.5	Summary	25
3	Experimental Program	27
3.1	Background	27
3.2	Continuation of Research Program	27
3.3	Construction of Prototype Scaled-down Corner-Joint	31
3.4	Test Setup	33
3.4.1	Snap Back Test Setup and Instrumentation	33
3.4.2	Shake Table Test Setup and Instrumentation	34
3.5	Dynamic Loading	36
3.5.1	Snap Back	36
3.5.2	Harmonic	36
3.6	Parameters Evaluated	38
3.6.1	Parameters Evaluated under Snap Back Loading	38
3.6.2	Parameters Evaluated under Harmonic Loading	38
3.7	Procedure for Empirical Equation Formation	39
3.8	Summary	39
4	Experimental Evaluation	41
4.1	Background	41
4.2	Damping Ratio and Fundamental Frequency	41
4.3	Behavior of Prototype Corner-Joint under Harmonic Loading	44
4.3.1	Behavior in Terms of Acceleration-time and Displacement-time Histories	44
4.3.2	Base Shear(Q)-Displacement(Δ) Curves and Energy Ab- sorption	49
4.4	Summary	52
5	Discussions	53

5.1	Background	53
5.2	Formation of Empirical Equations considering Geometrical Parameters, Structure Behavior and Input Loading Conditions	53
5.3	Outcome of the Research with Respect to Practical implementation	55
5.4	Challenges in Seismic Resilience of Masonry and Remedial Measures	57
5.5	Summary	58
6	Conclusion and Future Work	59
6.1	Conclusions	59
6.2	Future Recommendations	60
	Bibliography	61

List of Figures

2.1	Failures in masonry structures: (a) and (b) out-of-plane damages, (c) and (d) in-plane damages [12], (e) and (f) out-of-plane separation [18, 19], (g) delamination and (h) out-of-plane failure [15]. . . .	13
2.2	Corner failures; a) and b) Avasthi [25], c) and d) Casapulla [26],e) and f) Nayak [22], g) and h) Sarhosis [15].	15
2.3	Mortar free interlocking structure; a) Gul [30] , b) Thamboo[16] . . .	19
2.4	Interlocking blocks; a) [37],b) [38],c) [36] and d) [39]	19
2.5	Interlocking mechanism for blocks; (a) ecofriendly interlocking block with holes and shapes [47], (b) sliding interlocking block [48] , (c) interlocking block with holes to provide reinforcement [49].	21
3.1	Proposed mortar-free interlocking-plastic-block house: a) plan, b) 3D view, c) proposed interlocking-plastic-block and d) real plastic block Khan [5].	28
3.2	Consideration of corner-joint; (a) plan and elevation of house with original corner-joint consideration, (b) scaled-down and simplified boundary conditions and (c) corner-joint with configuration sequence A and B.	30
3.3	Corner-Joint construction details; a) wall configuration sequence A and b) wall configuration sequence B.	32
3.4	Snapback test instrumentation and testing; schematic diagram and real test set up for a) sequence A and b) sequence B.	34
3.5	Shake table instrumentation and testing; schematic diagram and real test set up for a) sequence A and b) sequence B.	35
4.1	\ddot{u} -t from snap back test; a)25mm wall seq.A, b) 50 mm wall seq.B, c)25mm wall seq.B and d) 50 mm wall seq.B.	42
4.2	Fourier amplitude from snap back test : a) wall seq. A with 25 mm , b) Wall Seq. A with 50 mm, c) wall seq. B with 25 mm and d) wall seq. B with 50 mm.	43
4.3	\ddot{u} -time history curve of corner-joint	46
4.4	Δ -time history curve of corner-joint	47
4.5	Q- Δ curves of corner-joint	49

List of Tables

2.1	Prototype model used by researchers in their studies	24
3.1	Snap back loading magnitude	36
3.2	Harmonic loading magnitude	37
4.1	Results from snapback test	43
4.2	Wall's contribution to corner-joint's response	48
4.3	Energy absorption during dynamic loading	50
5.1	Variation in experimental and empirical values for corner-joint of interlocking-plastic-block wall	55
5.2	Comparison with previous researches	56

Abbreviations

1D	One dimensional
3D	Three dimensional
CBM	Confined brick masonry
cm	Centimeter
cm/s	Centi meter per second
CMU	Conventional masonry unit
Hz	Hertz
IPB	Interlocking plastic block
MFI	Mortar free interlocking
mm	Millimeter
MMS	Mortar less masonry system
Nm	Newton meter
PGA	Peak ground acceleration
PT	Post tensioned
RB	Rubber Band
SDOF	Single degree of freedom

Symbols

ζ	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
$Q(N)$	Base-shear
Hz	Unit of frequency
g	Acceleration
\ddot{u}_g	Average acceleration at the base of specimen
\dot{u}_g	Average velocity at the base of specimen
u_g	Average displacement at the base of specimen
\ddot{u}_t	Average acceleration at the top of specimen
\dot{u}_t	Averaged velocity at the top of specimen
u_t	Average displacement at the top of specimen

Chapter 1

Introduction

1.1 Background

Earthquakes severely impact masonry structures, particularly Un-Reinforced Masonry (URM) buildings. The 2005 Kashmir earthquake, for example, caused damage to 45,000 masonry structures, resulting in 80,000 deaths, including 20,000 children, and 5.2 billion dollar in economic losses [1]. Many structures collapsed due to poor design, with out-of-plane (OOP) collapse being a common and damaging failure [2]. Stone and brick masonry buildings, despite their thick walls, often fail during earthquakes due to poor connections, lack of horizontal binding elements, weak wall intersections, and deteriorated mortar. Common failures include corner overturning, horizontal bending, leaf separation, masonry crumbling, and complete collapse, especially in older structures with weak materials and poor workmanship. Corner failures in masonry structures occur due to the combined effects of in-plane and out-of-plane forces, frequently resulting in severe damage that can compromise the usability of the structure.

Researchers have developed earthquake-resistant housing using interlocking concrete blocks that effectively dissipate seismic energy. The slanted keys between these mortar-free blocks allow them to realign after ground motion, offering cost-effective seismic resilience. Hollow concrete block masonry performance is further enhanced by adding RCC confinement, reinforcement, and grouting, which evenly

distributes cracks and reduces damage. Unconfined dry-stacked blocks can also withstand low to moderate seismic actions due to their energy-dissipating sliding and rotational movements. This inter-brick friction and rocking response make interlocking brick walls more seismically resistant than Conventional Masonry Unit (CMU) walls.

The out-of-plane response of masonry structures is key to their seismic vulnerability, affected by material properties, wall quality, structure geometry, and connections. Research shows corner separation is common in older Un-Reinforced Masonry (URM) structures with weak mortar and poor connections. Shake table tests on scaled-down dry-jointed masonry models reveal that corners detach under bi-directional loading. Innovative approaches, like using Interlocking-Plastic-Blocks (IPB) to reduce structural mass, have been tested for stress-strain behavior, energy absorption, and toughness. The use of three dimensional shake tables with six degrees of freedom has been vital in simulating real earthquake conditions and validating prototype structures in labs.

In the developing countries, the economical houses are needed which can resist and control the damages due to strong ground motion. Researchers have explored various mortar less interlocking approaches, but corner-joints in IPB is to yet to be studied. To have the efficient and cost-effective solution for earthquake resistant houses, a new construction technique of IPB structure has been proposed for earthquake resistant houses. Interlocking plastic-blocks structure dissipate more energy due to its relative movement at the interfaces of block during an earthquake.

1.1.1 Work done till today

In an investigation Adnan [3] found that two-block-wide structural elements had better energy absorption and peak load capacities under compressive loads compared to one-block-wide elements, which failed suddenly. Research carried by Sudheer [4] revealed that interlocking plastic-block walls with windows exhibited greater resistance and energy absorption under lateral loads than unreinforced masonry walls. In a study Khan [5] developed empirical equations showing that

interlocking plastic-block structures with rubber bands were stiffer and had less top displacement under harmonic loading. In an investigation Shahzad [6] found that vertical reinforcement using rubber bands increased energy dissipation in interlocking plastic-block walls under harmonic loading. Afzal [7] shown unreinforced brick masonry (URM) solid walls collapsed under loading due to weak mortar-brick bonding. In contrast, the lighter interlocking plastic block solid walls (IPBSW) exhibited better energy dissipation. Aslam [8] interlocking plastic block walls exhibit sufficient compressive strength to support their self-weight and demonstrate improved structural behavior through energy dissipation and crack control.

Study carried by Bashir [9] demonstrated that a wooden diaphragm (elements that transmits structural load to vertical resisting elements like frames or walls) reduced top displacement and enhanced energy dissipation in interlocking plastic-block walls. Anwar [10] studied interlocking plastic-block walls with block-return and diaphragm exhibit superior seismic performance, with higher damping ratios, base shear, and energy dissipation, especially under out-of-plane loading. Research carried by Asad [11] revealed that interlocking plastic-block walls with block-return and rubber band reinforcement effectively dissipated more energy under harmonic loading. OOP walls, walls with opening, corners, junctions are critical locations and studies on IP and OOP behavior of walls have been carried but corner-joint remains unexplored. Current study focuses on to explore the dynamic behavior of corner-joints in mortar-free interlocking-plastic-block walls.

1.2 Research Motivation and Problem Statement

Earthquakes are dangerous events which causes severe damage. During or after an earthquake, many peoples in many countries pass away when buildings collapse, many of them are left homeless. Such damages and loss of human lives can be controlled if earthquake behavior of a structure is precisely studied which can help to design accordingly. For this purpose a cost-effective and efficient solution is needed. A cost-effective solution can be use of mortar less block masonry but it is still too heavy. Using IPBs could be a better option because they are lighter in weight. Thus, the problem statement can be stated as follows:

Mortar-free interlocking block structures have evolved as an innovative construction technique for seismic resistant housing. Such blocks possess the capability to absorb energy but their high mass continues to be a concern, as greater mass leads to higher inertial forces during earthquakes. Reducing block mass can help to mitigate this issue making lightweight interlocking plastic blocks a promising solution. To evaluate the performance of corner-joint in mortar-free IPB, it is essential to study its dynamic behavior. Therefore, the dynamic performance of corner-joint in mortar-free interlocking-plastic-block wall needs to be investigated under dynamic loading.

1.2.1 Research Questions

1. What would be the natural frequency and damping ratio of the corner-joint in mortar-free interlocking-plastic-block walls?
2. How do the in-plane and out-of-plane behaviors of interlocking -plastic-block walls would contribute to the dynamic performance of the corner-joint under dynamic loading?
3. Which of the proposed wall configuration sequence would dissipate more energy under dynamic loading?

1.3 Overall Goal of the Research Program and Specific Aim of this Particular Study

To investigate the 3D seismic response of full scale structure in mortar-free IPB wall in laboratory.

The specific aim of this MS research work is to investigate the dynamic performance of corner-joints in mortar-free IPB wall using locally manufactured low-cost simple shake table in laboratory.

1.4 Scope of Work and Study Limitations

The research involves constructing a prototype corner-joint in mortar-free interlocking-plastic-block wall composed of specially designed blocks. The wall is built on a

fixed base to simulate realistic structural conditions. During the experiments, three different loading frequencies are applied to assess the dynamic behavior of the corner-joint. The behavior is observed in terms of displacement-time and acceleration-time histories, providing valuable data on how the structure behaves under seismic-like conditions. Snap-back test is also conducted to determine the wall's natural frequency and damping ratio. Based on the collected data, empirical equations have been formulated to characterize the dynamic behavior of the corner joint, thereby contributing to a more comprehensive understanding of its performance.

The study does have some limitations, which include the use of a simple one-dimensional shake table that restricts the testing to uniaxial loading. Additionally, only five accelerometers will be used, one positioned at the bottom and the other at the top of the wall, which limits the scope of data collection. The obtained data from MATLAB is only in the form of acceleration-time history which needs further refining and conversion using siesmosignal software. Furthermore, the study will focus on only three loading frequencies. While these limitations may restrict the range of scenarios tested, they also allow for a focused and controlled investigation, laying the groundwork for future research with more advanced setups and broader testing conditions.

1.4.1 Rationale Behind the Variable Selection

Current research is part of the bigger research program. Corner joint is yet to be studied that's why corner joint is chosen. 1/3 scale is applied on elevation dimensions only due to method A of UBC-97 regarding time-period which depends on structure height. 1350 mm wall length is considered on either side much more than block return. 62 x 62 mm with 50 mm height and 12 mm key. Reason of the selection of interlocking Plastic-Block structural elements for this research study is because the Plastic-Blocks are light weight and absorb more energy as compared to masonry walls [5]. Rubber band is utilized as vertical reinforcement to have the corner joint integrity during harmonic loading. Test in laboratory is a cheap process to investigate the fundamental frequency and maximum failure

acceleration on small-scale prototype structure. Unidirectional loading applied for the study as per availability of the facilities in the lab. Simplified boundary condition is considered to study the dynamic response of corner joint.

1.5 Brief Methodology

A scaled-down corner-joint using scale 1:3 constructed from interlocking-plastic-blocks. The prototype corner-joint consisted of two hundred eighty plastic blocks arranged in twenty layers fixed at the base using angle sections to ensure firmness with the base. To capture the structural response, five accelerometers were installed on specific locations. Two on the top of each orthogonal walls, one at the top of corner- joint, one at the bottom of the corner-joint and one on the base plate to record the base excitation. An Arduino setup was connected to laptop operated through MATLAB software for data acquisition. Snap-back test was performed by displacing the wall in the X-direction using a 400 mm wire and releasing it to record acceleration-time history. This was used for determination of natural time period, frequency, and damping ratio using the logarithmic decrement method.

A locally manufactured one-dimensional shake table capable of running at a frequency of 0.8 Hz, 1.1 Hz, and 1.4 Hz was used to simulate seismic excitation. Acceleration-time history data collected through MATLAB software was processed and refined using SeismoSignal software for noise removal and baseline correction. Base shear is determined from mass of the specimen x acceleration data obtained from accelerometer installed on top of corner-joint Energy absorption is determined from base shear-displacement curves, assuming total mass is lumped on the specimen's top. Average energy dissipation in single loop and total energy absorbed are calculated. To predict the response Empirical equations were formulated by considering the corner joint height, the geometry of the interlocking blocks, and the structural response of the specimen. Experimental and empirical results are compared and the values lie within acceptable percentages.

1.6 Research Impact on Industry

1.6.1 Research Novelty/Uniqueness

Various interlocking techniques have been explored for improving masonry construction, yet limited research has focused on the behavior of corner joints under dynamic loading. Notably, studies using simple 1D (One dimensional) shake tables to evaluate corner joint performance are scarce. As a result, the dynamic response of corner joints constructed with plastic block walls remains largely unexamined, highlighting a gap in current experimental investigations.

1.6.2 Research Significance and Benefit

This study aims to enhance the understanding of corner behavior in mortar-free interlocking construction, addressing a critical aspect of structural performance under dynamic loading. The findings will support the development of more economical and safer housing solutions, particularly in earthquake prone regions.

1.6.3 Practical Implementation

The study supports the development of affordable housing by promoting construction methods that are easy to assemble, cost-effective, and time-efficient. By collaborating with disaster relief organizations, the approach offers a practical solution for rapid deployment in emergency scenarios, contributing to resilient and accessible housing in vulnerable communities. The modular nature of interlocking plastic blocks enables scalability and adaptability to diverse geographic and climatic conditions, making it suitable for both temporary shelters and permanent dwellings. Additionally, the use of lightweight, recyclable materials aligns with sustainable construction practices, reducing the environmental footprint. This approach not only addresses immediate post-disaster housing needs but also advances long-term strategies for inclusive and sustainable urban development.

1.6.4 National and Global Impact with Emphasis on SDGs Relevance

This research enhances disaster resilience by improving safety and reducing infrastructure loss. It also drives innovation in the construction sector, creating job opportunities and supporting economic growth, while enriching the national knowledge base and advancing educational and training initiatives. By introducing modular, low-tech construction techniques, the study fosters inclusive participation from local communities, including unskilled labor, thereby strengthening community engagement in the rebuilding process. Moreover, the findings contribute to policy formulation in disaster risk reduction and urban planning, promoting evidence-based strategies for resilient infrastructure. The integration of such innovative systems into academic curricula can further cultivate a new generation of engineers and planners focused on sustainable and resilient development.

1.6.5 Research Challenges

The study is limited by the use of a 1D shake table and a minimal number of accelerometers, which restricts the scope of dynamic response data. A fixed base was used to simplify boundary conditions, potentially affecting the realism of structural behavior. Additionally, the accelerometer data requires filtering through SeismoSignal, providing only acceleration histories without direct displacement or velocity measurements. These limitations may affect the accuracy of the results, especially in capturing the full spectrum of dynamic responses under complex loading conditions. Future studies could benefit from using multi-directional shake tables and a greater number of sensors to more comprehensively capture the full dynamic behavior of interlocking block systems. Furthermore, the use of advanced numerical simulations alongside experimental data could help validate and extend the findings by providing more detailed insights into displacement and velocity profiles.

1.6.6 Ethical and Management Considerations Including Risk Management

The study emphasizes transparency by reporting all findings and limitations, ensuring ethical integrity. It aims to make the developed technology accessible for affordable housing, while respecting the rights of all collaborators through fair compensation. Compliance with university health and safety regulations is maintained, alongside a structured schedule to ensure timely execution of all activities. Furthermore, the research adheres to ethical guidelines regarding the use of resources, ensuring sustainability in both environmental and economic terms. The collaborative approach fosters a culture of accountability and inclusivity, empowering local communities and stakeholders to actively contribute to the development and implementation of the technology. By ensuring these ethical standards, the study aims to serve as a model for responsible innovation in housing development.

1.6.7 Research Deliverable, Sale and Marketing Potential

The research is tailored for construction companies, affordable housing developers, and disaster relief organizations, highlighting practical benefits such as ease of construction, cost-effectiveness, and reduced building time. It offers a scalable solution for rapid and economical housing, especially in post-disaster and low-income contexts. The modular design and use of IPBs also provide flexibility, enabling adaptation to various environmental conditions and community needs. Moreover, the approach supports local economies by utilizing region-specific materials and labor, promoting self-sufficiency and resilience. This research not only addresses immediate housing shortages but also sets the stage for long-term, sustainable housing solutions, improving quality of life for vulnerable populations. The research is oriented to produce cost effective and safe housing for under privileged people. Creating awareness among construction stake holders about the ease of construction, safety, cost-effectiveness and potential for reducing construction time.

1.7 Thesis Layout

Chapter 1 presents the introduction section, encompassing the background, research motivation, problem statement, overall objective, specific aims, scope of work, study limitations, adopted methodology, and thesis structure.

Chapter 2 provides the literature review, covering background information, observed damages in traditional masonry structures during earthquakes, innovative techniques for seismic resistant design, influence of stiffeners in masonry construction, dynamic behavior of scaled structures under laboratory testing, and a concluding summary.

Chapter 3 outlines the experimental program, detailing the background, construction detail of corner-joint in mortar-free interlocking plastic block wall, test setup, snap back test set up, harmonic loading using shake table, investigated variables, formulation of empirical equations, and summary.

Chapter 4 focuses on experimental analysis, including background, snap-back test results, wall response under harmonic loading, computations of damping ratio, base shear, energy absorption, and a summary.

Chapter 5 comprises the discussion section, which includes background, correlation of empirical equations, interpretation of findings in relation to practical applications, and a summary.

Chapter 6 provides the conclusions and recommendations. References follow Chapter 6, and annexures are provided at the end of the thesis.

Chapter 2

Literature Review

2.1 Background

Severe ground movements caused by seismic actions often result in significant damage to masonry structures. The impact of seismic events varies across affected regions, frequently leading to structural damage and, in extreme cases, loss of human life. In particular, masonry buildings located in both rural and urban seismic zones present a considerable risk to human safety. This is primarily due to the transmission of ground accelerations to the structure's foundation, which induces inertial forces and causes shear failure in masonry walls. Extensive research in the literature highlights the adoption of various construction techniques aimed at enhancing the seismic resistance of masonry buildings. Among these, interlocking block construction has emerged as a promising alternative. However, the high inertial forces associated with the greater mass of conventional masonry blocks remain a significant challenge in seismic performance. This chapter presents a comprehensive review of literature related to the seismic vulnerability of traditional masonry structures, explores innovative approaches for developing earthquake-resistant systems, and discusses the role of stiffeners in improving the structural integrity and dynamic response of prototype masonry constructions under laboratory conditions.

2.2 Corner Damages in Conventional Masonry Structures

2.2.1 Failure in Conventional Masonry Structures

Masonry structures are very susceptible to seismic activity. Strong seismic ground motion can cause extensive damage to infrastructure and lead to loss of life. In-plane (loads acting along the walls length) failure mechanisms, including sliding, shear, flexural, tensile, and crushing, can occur either independently or in combination. In- plane walls can be weaker due to increased length and slenderness. When vertical loads increase, they can cause cracking in walls. In-plane failure is primarily driven by shear forces from lateral seismic loads, leading to shear and flexural cracks. Crushing failure happens when the vertical seismic component surpasses the wall's compressive strength [12]. Unreinforced masonry (URM) buildings are particularly at risk, emphasizing the need for risk assessment and mitigation [13]. Out-of-plane (loads acting perpendicular to the wall surface) collapse as a common damage type, influenced by factors like wall dimensions, restoring forces, boundary conditions, and material properties [14]. Unreinforced masonry is highly susceptible to seismic forces, requires risk assessment and targeted mitigation strategies to prevent both in-plane and out-of-plane failures. It is essential to minimize potential damage and loss of life during earthquakes.

key factors in out of plane failures include lack of horizontal binding elements and weak wall connections [15]. Out-of-plane flexural behavior of conventional masonry is primarily influenced by the tensile bond strength at the mortar contact surface, and can also be affected by the shear bond resistance at the supports. In contrast, the out-of-plane resistance of masonry materials systems is likely much lower than that of conventional masonry due to the absence of mortar joints [16]. Several factors contributing to structural damage observed in the field, including the use of heavy earthen roofs, inadequate connections between walls and roof, absence of vertical and horizontal reinforcement members, substandard workmanship, and poor interlocking between construction layers contribute significantly to

structural vulnerability [17]. Out-of-plane (OOP) failures in masonry structures are influenced by factors such as weak connections, lack of reinforcement, and poor construction practices, highlighting the importance of improving structural integrity through better design and materials.



FIGURE 2.1: Failures in masonry structures: (a) and (b) out-of-plane damages, (c) and (d) in-plane damages [12], (e) and (f) out-of-plane separation [18, 19], (g) delamination and (h) out-of-plane failure [15].

2.2.2 Damages in Wall Corner in Conventional Masonry Structures

A study by Jasiski and Galman [20] revealed the wall connections help in preventing damage at both the global (structural) and local (elemental) levels in masonry buildings. However, this issue is often overlooked, and traditional connection methods continue to be used. It is crucial to give special attention to these connections. Corner damage at inter-wall connections typically results from inadequate connections between structural walls. Structural failure of adobe and stone masonry buildings has been attributed to factors such as substandard materials, deficient construction practices and lack of a proper bond beam [12]. Corner failures in masonry structures result from a combination of in-plane and out-of-plane behaviors, often rendering structures unusable. These failures are linked to poor connections, low axial loads, weak materials, and inadequate workmanship [21].

Unreinforced masonry (URM) walls are the basic load-bearing elements in masonry buildings. During earthquakes, the typical failure mode observed in these structures are corner or junction failures and out-of-plane wall failures [22]. Corner failure is a common occurrence in masonry buildings, particularly evident after seismic events. This type of failure is typically marked by the formation of a masonry wedge, primarily caused by the combined effects of roof thrust and inertial forces. It often involves a rocking-sliding motion along cracks that develop at the intersection of orthogonal walls [23]. A seismic vulnerability assessment shown 17 m high corner stupas (dome like structure used for religious purpose) collapsed while center one sustained during Myanmar earthquake [24]. Corner failures in masonry structures are primarily caused by inadequate wall connections, poor materials, and substandard construction practices.

The study highlights the need for the adoption of improved connection designs, which can mitigate the occurrence of such failures. Moreover, the integration of modern construction materials and techniques could offer significant benefits in enhancing seismic resilience and overall durability of masonry buildings, especially in regions prone to earthquakes. These advancements not only improve structural

integrity but also contribute to the safety of occupants during seismic events. Future research should focus on developing cost-effective solutions that are adaptable to both new constructions and the retrofitting of existing structures.

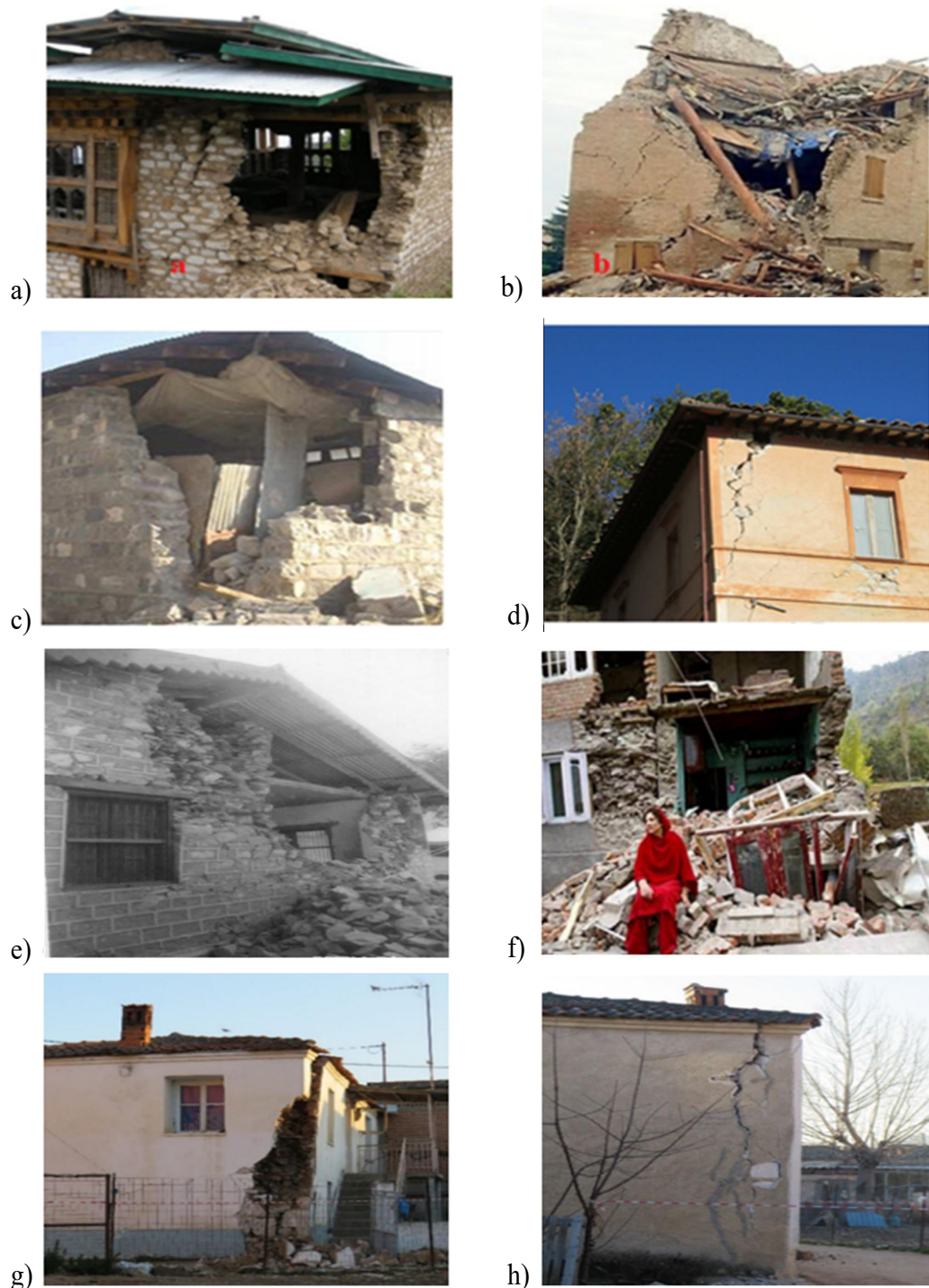


FIGURE 2.2: Corner failures; a) and b) Avasthi [25], c) and d) Casapulla [26], e) and f) Nayak [22], g) and h) Sarhosis [15].

In a Study carried by Camata [27] shown different types of brick masonry failure, including out-of-plane separation, corner overturning, crumbling, and complete building collapse. Corner separation is common in older unreinforced masonry (URM) structures, particularly those with deteriorated mortar and weak floor connections [25]. Figure 2.2 shows examples of damages caused due to corner failures in Bhutan and LAquila earthquakes. Corner failures in masonry structures result from the combined IP and OOP behaviors of orthogonal walls. Limiting acceleration without vertical loads remains 0.7g in comparison to [28]. Poor connections, particularly at wall-to-wall corners, are consistently identified as a primary cause of structural failures in unreinforced masonry (URM) buildings. These failures often result from a combination of poor material quality, inadequate construction practices, and lack of proper bond beams. Both IP and OOP forces contribute to corner damage, which is exacerbated by weak mortar, substandard workmanship, and insufficient axial loads. Unreinforced masonry (URM) walls are extremely susceptible to corner and out-of-plane failures during earthquakes, particularly in older structures with deteriorated materials and weak connections.

2.3 New Technology Using Mortar-Free Interlocking Masonry

2.3.1 Mortar-Free Interlocking Masonry

Conventional masonry construction is labor-intensive and time consuming, facing increasing competition from modern materials and techniques. Mortar less Masonry Systems (MMS), use interlocking or dry-stacked units without mortar, provide an alternative by reduce the reliance on skilled labor and enhance productivity. MMS effectively support load-bearing actions, it requires additional strengthening for out-of-plane flexure and in-plane shear to resist cyclonic and seismic forces [16]. Mortar less interlocking structures perform significantly better in terms of resistance to both gravity and lateral loads. Under gravity loading, compressive strength of the block units plays a key role in determining the overall

resistance and failure mode. MMS offer a promising alternative to traditional masonry by reducing labor requirements and improving productivity, but they still require additional strengthening to resist seismic and cyclonic forces. The effectiveness of MMS is primarily determined by the compressive strength of the block units, which influences their resistance to both gravity and lateral loads [29].

Researchers have developed new techniques for earthquake-resistant housing using interlocking concrete blocks. Interlocking mortar less masonry is an developing construction material with strong potential for future projects, particularly due to its sustainability and affordability in housing [30]. The walls, made from A specialized interlocking brick type featuring enlarged keying mechanisms, offer both alignment during construction and enhanced shear resistance. In-plane cyclic loading was applied to these walls to assess their structural behavior, and the results were compared to conventional masonry walls from existing literature, highlighting The superior ability of interlocking masonry walls to resist seismic forces and absorb seismic energy. Concrete blocks create stronger inertia forces due to their weight [31]. Mortar-free interlocking-block structures can dissipate earthquake energy and return to their original positions after ground motion due to their slanted key design. Interlocking dry-stacked masonry, particularly reinforced mortar-less systems with slanted key designs, shows significant potential for earthquake-resistant housing due to its superior performance in energy dissipation and seismic resistance [32].

MMS reduce labor and enhance productivity while providing strong resistance to gravity and lateral loads. While effective in seismic resistance, MMS require additional strengthening for out-of-plane and in-plane shear. Interlocking concrete blocks with slanted key designs show great potential for sustainable, earthquake-resistant housing, offering improved energy dissipation and resilience. The potential for widespread adoption of MMS in earthquake-resistant housing lies not only in its cost-effectiveness and sustainability but also in its ability to contribute to resilient infrastructure that can withstand the challenges posed by natural disasters. Future studies should focus on refining these systems to ensure they meet the evolving demands of modern construction, while also addressing the specific

needs of communities in regions vulnerable to earthquakes, cyclones, and other environmental stresses.

2.3.2 Interlocking Mechanism of Mortar-Free Construction

Unconfined mortar free block masonry structures, interlocking blocks with self-locking mechanism, are capable of withstanding low to moderate seismic actions acting as energy dissipating devices to reduce brittle shear failure [30]. Mortar-free construction enhances energy dissipation during seismic events due to relative block movement [33]. The application paste for adhesion between blocks significantly enhanced the compressive strength of the masonry prism. In both diagonal and direct shear tests, where the keys for interlocking were directly involved, the presence of adhesive paste and grout was found to enhance the shear capacity. The addition of grout, steel reinforcement and adhesive paste significantly improved both the ductility and strength of the masonry under various loading conditions. Unconfined dry-stacked block masonry, enhanced by self-interlocking blocks, adhesive paste, and grout, effectively dissipates seismic energy, improves shear capacity, and increases strength and ductility, making it a resilient and cost-effective solution for earthquake-resistant construction [34].

Interlocking brick walls have higher seismic resistance than conventional CMU walls, with inter-brick friction as the key energy dissipation mechanism [35]. Because of the interlocking design, the load-bearing behavior of the brick connections differs from that of conventional mortar-jointed masonry. The vertical ground motion component also significantly influences damage due to the rocking response [36]. Figure 2.3 shows interlocking masonry structures used in various studies. MFI (Mortar free interlocking) slide and rotate in OOP direction helps in 25 percent as compared to conventional masonry dissipation of energy. Mortar free construction enhance the relative motion at block interfaces contributes to improved energy dissipation during seismic activity. Interlocking brick walls offer superior seismic resistance compared to conventional CMU walls, with inter-brick

friction serving as the primary energy dissipation mechanism. Mortar-free interlocking construction enhances energy dissipation through relative block movement, significantly reducing seismic damage by allowing sliding and rotation in the out-of-plane direction.

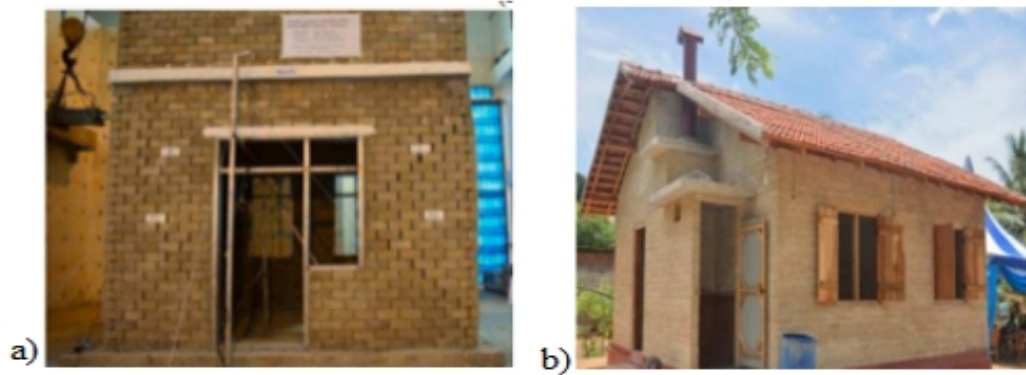


FIGURE 2.3: Mortar free interlocking structure; a) Gul [30] , b) Thamboo[16]

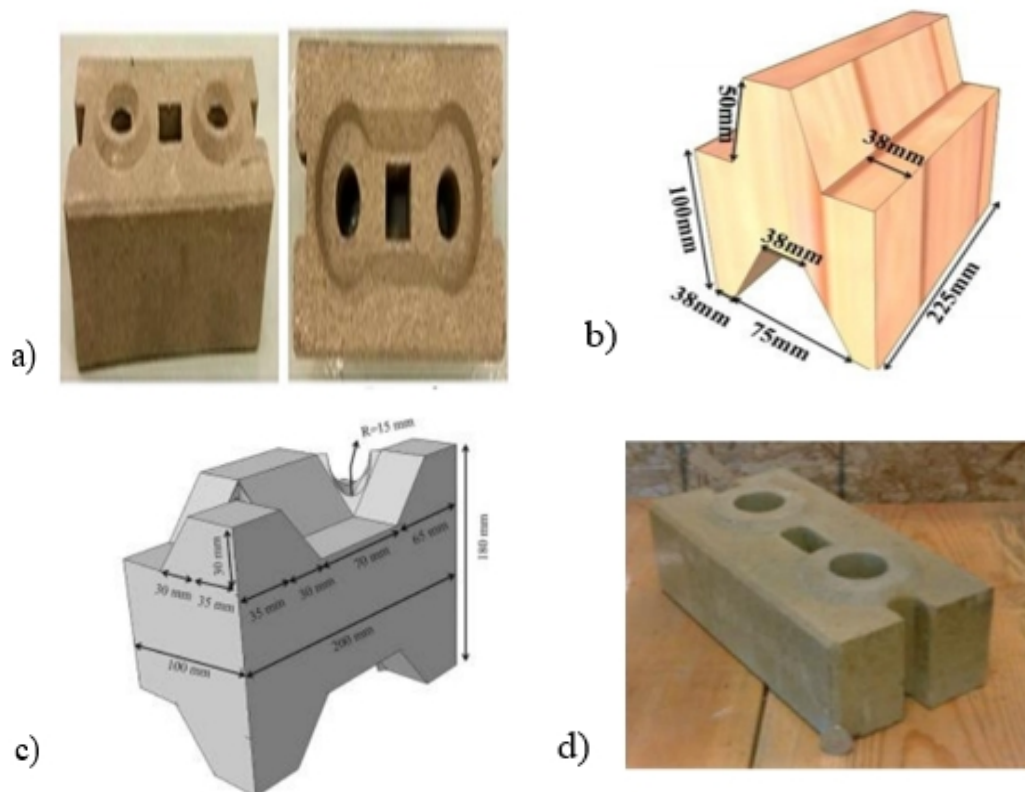


FIGURE 2.4: Interlocking blocks; a) [37], b) [38], c) [36] and d) [39]

Brick masonry, an ancient and widely used construction technique, is highly vulnerable to seismic activity, posing significant risks during earthquakes [40]. Many

buildings constructed with unreinforced brick, stone, and wood materials, which were designed only for gravity loads, suffered extensive damage in events like the 2005 Pakistan earthquake, resulting in significant economic and human losses [41–43]. Importance of interlocking block structure emerges when the objective is to achieve resistance against lateral loading. Lateral loading can act in-plane and out-of-plane depending upon the seismic actions but the behavior to these lateral movements decides the resistive failure mode of the whole structure. Al-fakih [37] carried a validation of the experimental results of [37] through finite element analysis and obtained less than 16% in results. To enhance the seismic performance of confined brick masonry, researchers have suggested incorporating reinforced-concrete (RC) stiffeners.

Typically, the seismic requirement is much lower than the strength provided, even with minimal cross-section dimensions of the stiffeners, concrete strength, and reinforcement bars. Research focused on correlation between the seismic demand and the design of the stiffeners revealed structurally efficient stiffener in Confined Brick Masonry (CBM) meet the required Seismic performance requirements for multiple seismic loading scenarios [44]. A seismic retrofit technique for unreinforced masonry (URM) walls using precast fiber-reinforced cementitious composite (FRCC) panels was developed. The FRCC panels, made with a hybrid fiber mix of steel and nylon fibers (1% volume fraction), were tested on five URM walls under cyclic loading. Key test parameters included shear key types and reinforcement details for the panels.

Results showed significant improvements in load bearing capacity, deformation, stiffness degradation, and energy dissipation for the retrofitted URM walls compared to the control specimen [45]. Corner confinement strategy to improve the seismic performance of mortar less interlocking masonry boosts the capacity to resist lateral forces by 64% and drift capacity by 288 %. Seismic parameters assessed include capacity to resist lateral forces, energy dissipation, deformation capacity, stiffness, and response modification factor [46]. Use of reinforced concrete stiffeners, fiber-reinforced cementitious composite panels, and corner confinement in dry stacked interlocking masonry, have shown significant improvements in the seismic

resilience of masonry structures. These innovations enhance lateral load capacity, energy dissipation, and overall stability, offering effective solutions to mitigate the risks posed by earthquakes to unreinforced masonry buildings. Continued research and implementation of such methods can significantly contribute to safer and more durable construction practices in earthquake-prone regions.

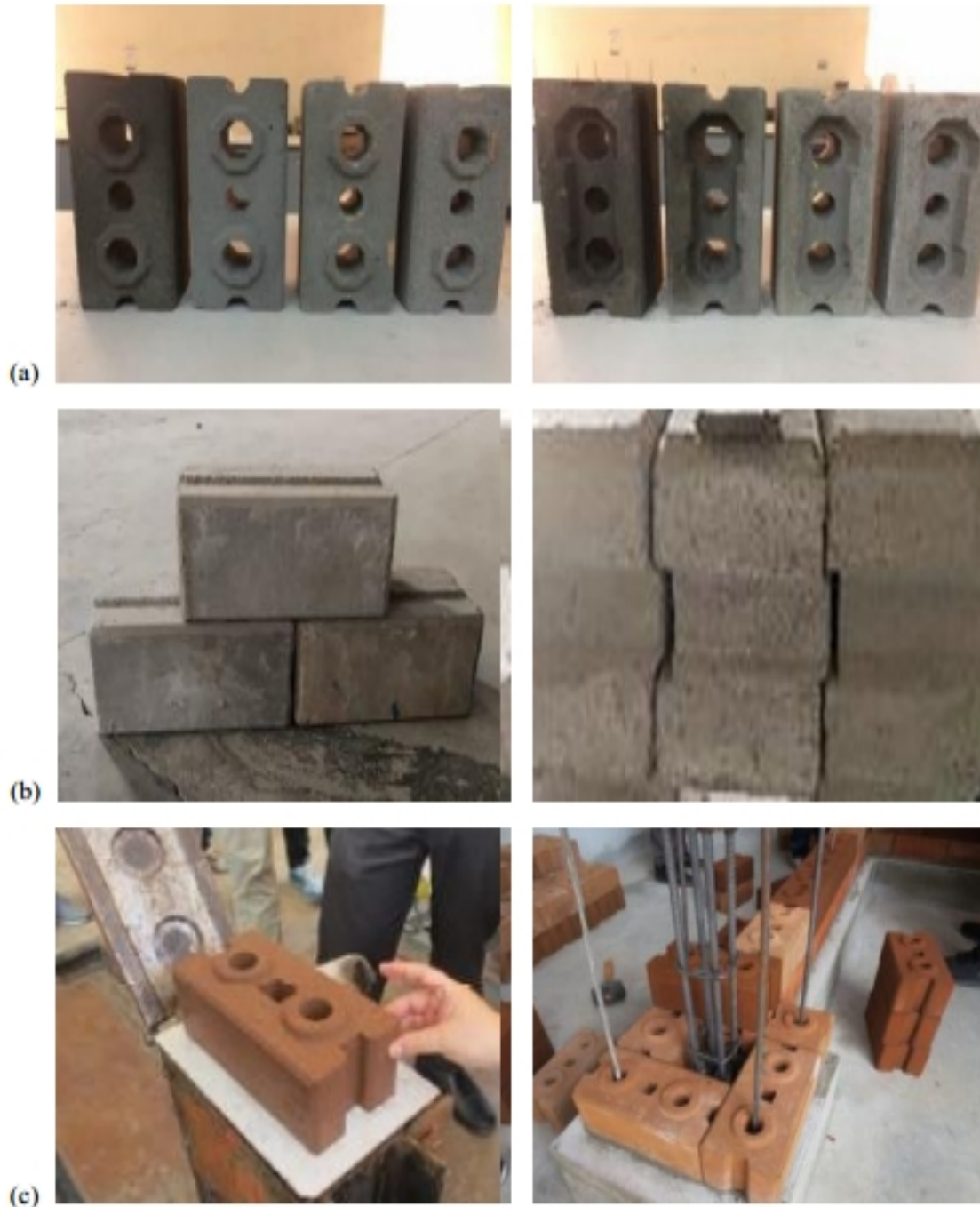


FIGURE 2.5: Interlocking mechanism for blocks; (a) ecofriendly interlocking block with holes and shapes [47], (b) sliding interlocking block [48], (c) interlocking block with holes to provide reinforcement [49].

2.4 Dynamic Testing of Corner-Joints in Masonry

2.4.1 Joint Strategies for Corner-Joints

Confined masonry (CM) is a simple, convenient and effective building construction technology in seismic areas [50]. The Post-tensioned metal straps (PTMS) technique enhances axial load-bearing by 80-120%, ductility by 100% , and bond strength by 58%. It increases flexural strength by 22%, bending moment capacity by 69-157 % , and shear strength by 143-182 % , converting brittle shear failures to more ductile bending failures [51]. Infill walls increase capacity to resist lateral forces by 77% but reduce deformation capacity by 42%, with lateral seismic shear demand on restrained columns 1.74 times higher. At PGA 0.8g, infill walls increase the probability of collapse by 35%, while a balanced design reduces this risk to levels similar to bare frame structures [52]. Interlocking dry-stacked masonry is an emerging construction technique with strong potential for future adoption, owing to its sustainable and cost-effective characteristics for affordable housing. Enhancing the seismic capacity of dry-stacked interlocking masonry structures can be effectively achieved through the application of corner confinement [30]. Out-of-plane response as a critical aspect of seismic vulnerability in masonry structures, influenced by factors like material properties, wall quality, structure geometry, and connections [53]. Unreinforced dry-jointed masonry walls under seismic loads, finding prevalent corner separation in older structures with weak mortar and floor connections [25]. Confined masonry and interlocking dry-stacked masonry offer effective solutions for seismic resilience, with confinement at corners enhancing the seismic capacity of these structures.

Using plastic blocks reduces the overall structure's mass, and their prototypes were tested for energy absorption and toughness under compressive loading, revealing effects of slenderness on structural behavior [32]. Significant impact of vertical earthquake components on the crack patterns and collapse of un reinforced masonry walls revealed by [27]. Masonry corner having six half scaled wall specimens were tested, three of which were provided with externally added thin concrete columns. These columns improve the integrity of the masonry structure

under earthquake forces, especially in thin beam-column systems [54]. Adding RCC confinement, partial reinforcement, and grouting to hollow concrete block masonry improves seismic performance distributing cracks and reducing damage, allowing for larger displacements with minimal strength loss [29]. Addition of lightweight materials like plastic blocks and adding reinforcement such as RCC confinement and grouting significantly enhance the seismic performance of masonry structures by improving energy absorption, reducing damage, and allowing for larger displacements with minimal strength loss. Additionally, addressing the effects of vertical earthquake components is crucial for preventing cracking and collapse in unreinforced masonry walls. These enhancements not only improve the structural ductility and integrity but also contribute to greater occupant safety and building resilience. Continued research in material innovation and reinforcement detailing is essential to further optimize the seismic response of modern masonry systems.

2.4.2 Testing Techniques

Significant research has been conducted using scaled-down prototypes in laboratories to evaluate the response of real world structures under seismic loads. Developed countries often use 3-D shake tables with six degrees of freedom to simulate real earthquake data. These prototypes allow researchers to conduct dynamic testing, validating the use of lab-based shake table experiments. 1D testing provides fundamental insights, 2D and 3D or complex shake tables offer greater accuracy for complex loading scenarios involving higher costs and technical demands. However, 1-D shake table can be used to investigate the response of scaled structures with simplified boundary condition in laboratories effectively because of its easy maintenance and operation [55]. Structural response of half scale pumice concrete masonry building using shake table/ambient vibration tests and FE analysis shown that frequency values of pumice decrease up to 23.5 % and 19.85 % for experimental mode. Both experimental and numerical findings reveal that damage is concentrated in the same areas [56]. Dynamic behavior of the prototype model

of the IPB wall having window in comparison with a model of masonry wall without reinforcement having same elevation dimensions. Unidirectional lateral load application and determining base shear, displacement curves to determine energy absorption. Prototype model created by using IPB wall with opening shown more resistance [57]. Table 2.1 shows the parameters studied and prototype models used by researchers in dynamic load testing with shake.

TABLE 2.1: Prototype model used by researchers in their studies

Sr. No.	Method and Findings of the Test	Test Type	Reference
1	Shake table tests on 1/2 scale URM walls under bi-directional dynamic loading show that corner detachments from orthogonal walls and increased dead load reduce the limiting acceleration from 0.55 g to 0.52 g.	Shake Table	Avasthi[25]
2	Experimental, numerical and analytical investigations of masonry corners: Influence of the horizontal pseudo-static load orientation. The actual joint stiffness in a full wall might be smaller (by a factor of 2 to 3) than the one obtained from a joint closure test using only two blocks.	Tilting Table	Colombo[58]
3	Mortar-free interlocking masonry through corner confinement boosts ultimate capacity to resist lateral forces by 64% and drift capacity by 288%. Seismic parameters assessed include capacity to resist lateral forces, energy dissipation, deformation capacity, stiffness, and response modification factor.	Shake Table	Gul[46]
4	An experimental investigation was carried out to assess the in-plane cyclic behavior of full-scale Discrete Structural Interlocking Masonry (DSIM) shear walls, with a focus on evaluating the effectiveness of post-tensioning (PT) as an alternative to conventional grout and reinforcement.	Full-scale Shear Walls	Kohail[59]

Table 2.1 represents the key studies employing prototype models to explore the seismic behavior of unreinforced masonry (URM) systems under various loading conditions. These studies utilize different experimental setups such as shake tables, tilting tables, and full-scale wall testing to assess parameters like joint stiffness, lateral load capacity, energy dissipation, and overall structural performance. The findings offer valuable contributions to dynamic behavior of URM walls, emphasizing the role of corner conditions, load orientation, and innovative reinforcement techniques like post-tensioning and interlocking systems. Additionally, these studies highlight the significant impact of boundary conditions, dead load variations, and confinement strategies on the seismic resilience of masonry structures.

The results reveal the necessity for comprehensive testing that integrates both experimental and numerical methods to accurately predict the behavior of masonry systems during earthquake-induced loads. Furthermore, these investigations contribute to refining design methodologies focusing on strengthening the seismic performance of masonry systems in earthquake hit regions. A better understanding of the interaction between orthogonal walls and the associated failure mechanisms can also inform more effective retrofitting solutions. As seismic design codes continue to evolve, insights from these studies will play a critical role in shaping safer and more resilient built environments.

2.5 Summary

Unreinforced masonry (URM) structures are highly vulnerable to seismic forces, particularly out-of-plane (OOP) forces and corner failures, due to poor connections, weak materials, and inadequate construction practices. While recent developments in mortar-free interlocking (MFI) masonry systems especially those with improved block geometry and grout have shown enhanced seismic performance through energy dissipation, shear strength, and ductility, key structural aspects remain understudied. MFI systems allow relative movement between blocks, reducing seismic damage, and can dissipate up to 25% of energy via sliding and rotation. However, the dynamic behavior of corner-joints where IP and OOP

walls interact has received limited attention, despite being critical to structural stability during earthquakes. This study addresses the gap by investigating the seismic performance of corner-joints in MFI masonry using a simple low-cost shake table.

Chapter 3

Experimental Program

3.1 Background

For the safe design of structures in seismic regions, accurately predicting structural response under earthquake loading is crucial. To achieve this, dynamic testing of prototype structures in laboratory settings is widely practiced across the globe. This chapter emphasizes the construction technique for interlocking corner joints using plastic block walls, the experimental setup, instrumentation for snap-back testing, application of dynamic loads through a shake table, evaluation of key response parameters, and the formation of empirical equations for performance prediction.

3.2 Continuation of Research Program

Khan [5] proposed Interlocking-Plastic-Block (IPB) for earthquake resilient residential structures, with plan and three dimensional view of the proposed house presented in Figures 3.1(a) and 3.1(b). Scaled down testing has demonstrated the systems effectiveness, attributed to its lower mass and the resulting reduction in inertia forces. The weight of the materials and the associated inertial forces play a critical role in the performance of seismic-resistant structures. Inertial force

is typically understood as a system's resistance to changes induced by external forces, such as acceleration. In accordance with Newtons Law of Motion, the Law of Inertia and the Third Law (Action-Reaction principle), systems with greater mass (heavier materials) respond more significantly to external forces due to their increased weight. This results in greater inertia forces when compared to lighter systems.

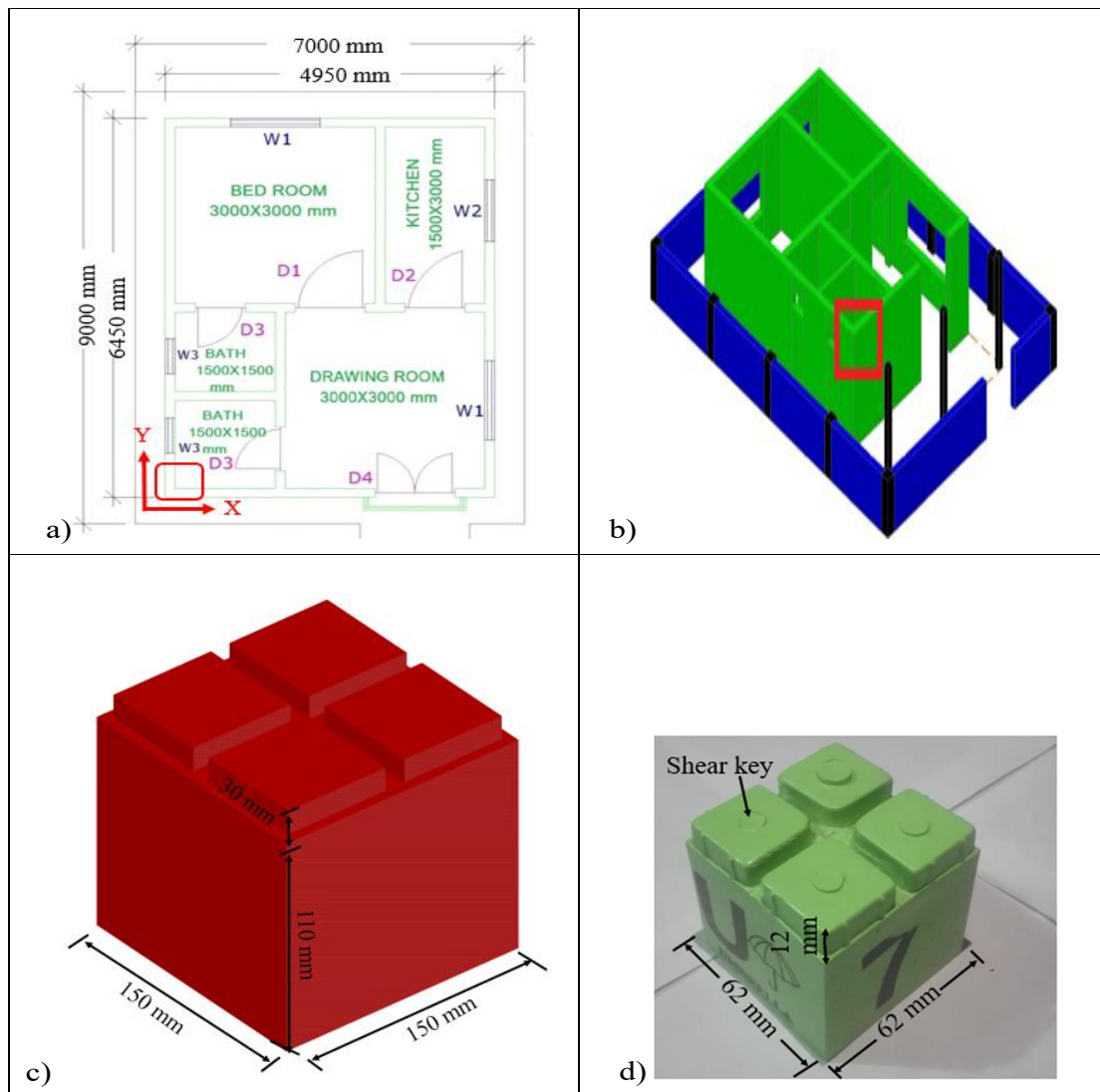


FIGURE 3.1: Proposed mortar-free interlocking-plastic-block house: a) plan, b) 3D view, c) proposed interlocking-plastic-block and d) real plastic block Khan [5].

To facilitate the construction of seismically resilient housing, the proposed IPBs feature a base dimension of 150 mm 150 mm and are designed with four interlocking keys on the top surface as represented in Fig 3.1 (c). The block used for

the experimental work has a height of 62 mm, which includes a 12 mm high interlocking key, as illustrated in Figure 3.1(d). For the scaled down construction, the blocks used in the study had dimensions of 62 mm \times 62 mm, with an overall height of 50 mm, featuring a 12mm interlocking key designed to improve block connectivity, also shown in Figure 3.1(d). This investigation work is extension of a study conducted by Khan [5]. Current study utilizes Square plastic block having 4 keys with vertical joining key and groove interlocking for construction of prototype. In this study, a prototype corner joint constructed from IPB walls is subjected to dynamic testing. The primary aim of the scaled down testing is to establish specifications for a practical, real-world system, rather than relying solely on theoretical models. The scaling and construction techniques for the prototype walls in this research are based entirely on established practices outlined in the literature. The results of these studies contribute to a deeper understanding of the behavior of full-scale structures.

The aim of current research is to study the dynamic behavior of corner-joint. For this, time period of the structure is an important factor that depends on the structure's height according to UBC-97. Therefore, the scale-down approach is mainly used for the elevation dimensions of structural walls. It is important to note that the dimensions of units used in prototype (i.e., scaled down corner-joint in mortar free IPB walls) are slightly different. The Plan and elevation of house with original corner-joint consideration are presented in Figure 3.2(a). Figure 3.2(b) shows scaled-down and simplified boundary conditions of corner-joint. Figure 3.3(c) shows scaled downed corner- joint in mortar free IPB wall with wall configuration Sequence A and B.

Corner-joint is fixed with plate by use of steel angle section. Walls length of 1350 mm and height of 3000 mm are considered for corner-joint for this study. Length of the wall considered in this research is more than the block-return length. Scaled-down length is 450 mm and height of 1000 mm considered. To simulate the real world scenario fixity is ensured at bottom. Corner under consideration is shown the plan of the house. Current research focuses on studying the behavior of corner-joint in x-direction only with an assumption that due to law of symmetry the

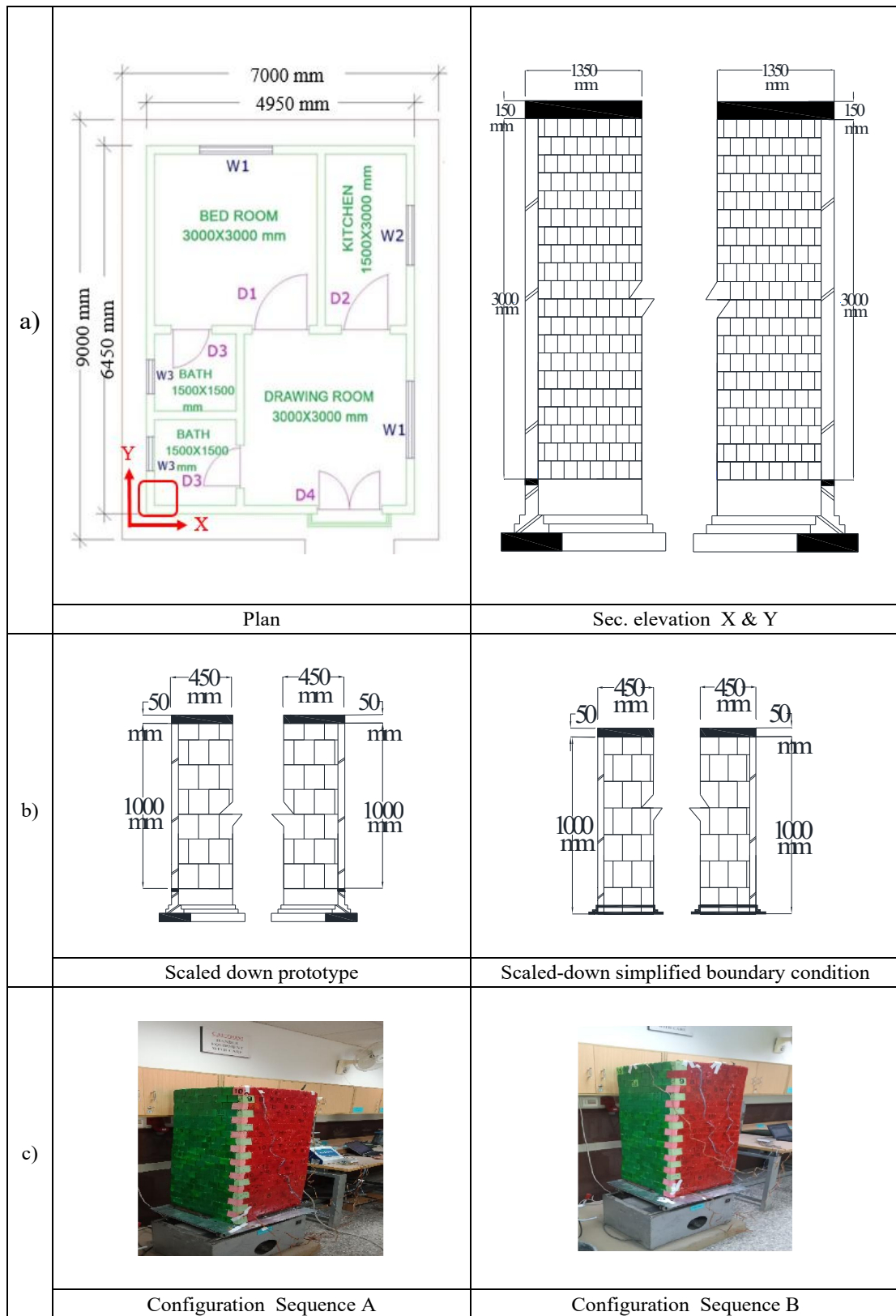


FIGURE 3.2: Consideration of corner-joint; (a) plan and elevation of house with original corner-joint consideration, (b) scaled-down and simplified boundary conditions and (c) corner-joint with configuration sequence A and B.

behavior of the corner-joint in y-direction also would remain same.

3.3 Construction of Prototype Scaled-down Corner-Joint

The prototype corner-joint of the IPB wall is created by using 280 plastic blocks ($n = 280$), with a total height (H) of 1000 mm, as shown in Figure 3.3. The wall configuration is built in two sequences. Sequence A is designed such that the out-of-plane behavior of Wall 1 starts from the corner, while Sequence B arranges the walls so that the out-of-plane behavior of Wall 2 begins from the corner edges. The wall consists of 20 layers in total. To enhance the vertical stiffness of the wall, rubber bands are tied vertically from the bottom to the top through the middle of the blocks. 5 stiffeners are used in the form of rubber band 2 in each wall and 1 in the corner-joint where the orthogonal walls meet.

The structure is fixed at the base with the shake table to ensure uniform excitation. No additional mass is placed at corner-joint's top. The mass of the corner-joint itself is 6.45 kg. To further support the stability of the corner joint and prevent collapse, five stiffeners in the form of rubber bands are strategically placed at different points: one at the joint and four others across the walls, with two rubber bands placed in each of the two walls. This setup is to replicate real-world conditions. Two wall configurations are used for testing.

The corner-joint in IPB wall is laterally fixed to a shake table using nut bolts and angle sections, allowing for replication fo real world scenario and controlled testing under dynamic conditions. Corner joint is tested in only one direction (X-direction). Testing in Y- direction is out of scope of this research and assumed to be same as that of X- direction due to law of symmetry. The results of this investigation are expected to contribute valuable insights into the seismic resilience and structural integrity of interlocking block wall systems, aiding in the development of more robust and safer construction practices for such materials.

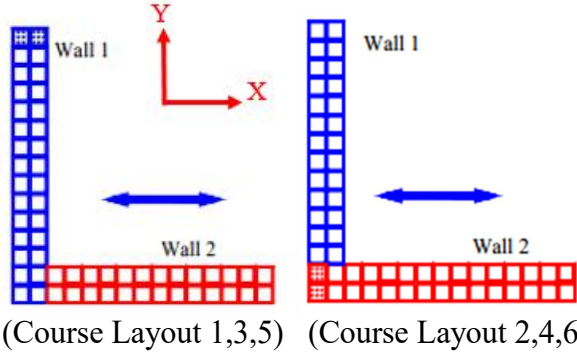

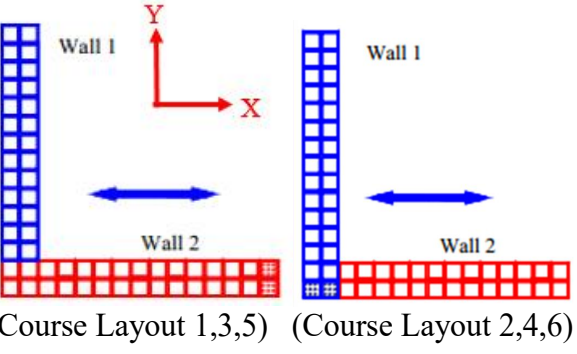

<p>a)</p>	<p>Schema- tic diagram of Corner -Joint</p>		<p>Wall Configuration Sequence A</p>
	<p>Real Corner -Joint</p>		
<p>b)</p>	<p>Schema- tic diagram of Corner -Joint</p>		<p>Wall Configuration Sequence B</p>
	<p>Real Corner -Joint</p>		

FIGURE 3.3: Corner-Joint construction details; a) wall configuration sequence A and b) wall configuration sequence B.

3.4 Test Setup

3.4.1 Snap Back Test Setup and Instrumentation

The Snapback test setup is illustrated in Figure 3.4. The Fig 3.4 a) shows both the schematic and actual test setup for sequence A, while b) presents the schematic and real test setup for sequence B. A 400 mm long wire is fixed to the top of the corner-joint in IPB wall to initiate free vibration. To monitor the dynamic behavior of the corner-joint, an accelerometer is installed at the top of the structure. The free vibration behavior of the corner joint is observed by displacing the wall via the wire and then releasing it, allowing the system to oscillate freely. Corner-joint made of IPB wall was displaced twice one for 25 mm and then for 50 mm.

Test is performed for both wall configuration sequence Sequence A and Sequence B. Both are subjected to a pull in X-direction. Behavior in Y-direction is assumed to be same due to law of symmetry. Behavior in Y direction is out of the scope of the current research. The response of the corner joint, constructed from interlocking plastic-block walls, is recorded as an acceleration time history utilizing the data obtained from the accelerometer. Then using the logarithmic decrement method, damping ratio (ζ) and the fundamental frequency (f_n) of the system are determined. For this purpose the number of cycles and their maximum acceleration values (amplitudes) are also determined. ζ is calculated from the formula for the corner joint.

$$\zeta = \frac{1}{2\pi N} \ln \left(\frac{x_0}{x_1} \right) \times 100 \quad (3.1)$$

Where x_0 and x_1 represent the acceleration values of first and last cycle. N represents the number of cycle. Fundamental frequency represents the natural vibration frequency of a structure. If it is too close to the dominant frequency of an earthquake, resonance can occur, amplifying structural vibrations and increasing the risk of failure. A well-designed seismic-proof structure should have a fundamental frequency that avoids resonance with typical seismic excitations.

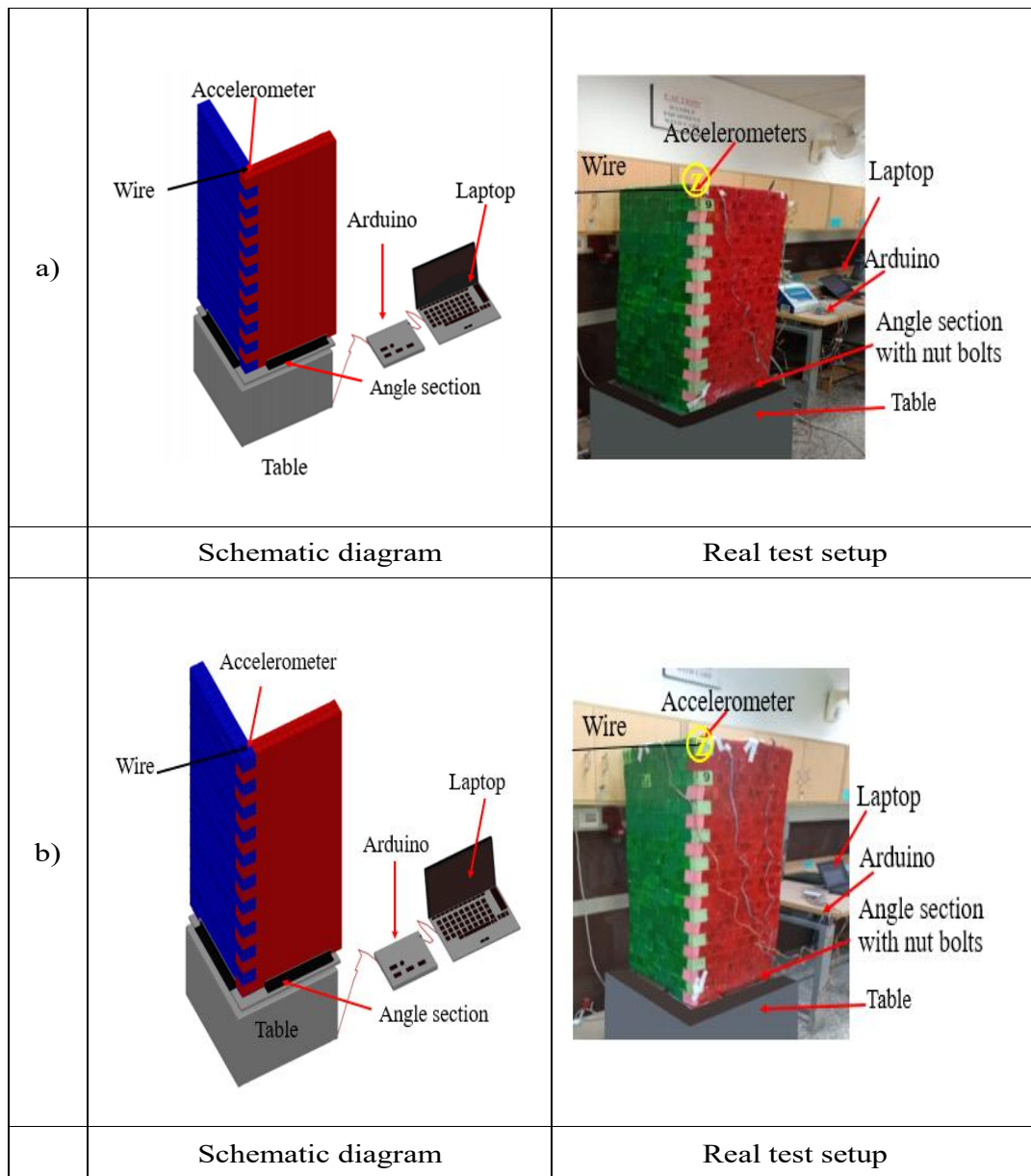


FIGURE 3.4: Snapback test instrumentation and testing; schematic diagram and real test set up for a) sequence A and b) sequence B.

3.4.2 Shake Table Test Setup and Instrumentation

Note from the Figure 3.5 that represents instrumentation for shake table testing: a) schematic diagram and b) experimental test setup. The corner joint, constructed from interlocking plastic-block walls, is assembled on shake table by means of angle section and nut-and-bolt connections. A total of five accelerometers are utilized in the setup. Two accelerometers are attached at the top of each wall to monitor their contribution to joint behavior and potential failure. Two additional

accelerometers are placed at the top and bottom of the corner joint to capture relative motion and deformation. The fifth accelerometer is mounted at the base of the shake table to record the input ground excitations. Behavior of corner-joint is captured based on acceleration-time history. The data is then processed to obtain the velocity-time and displacement-time histories utilizing the SeismoSignal software.

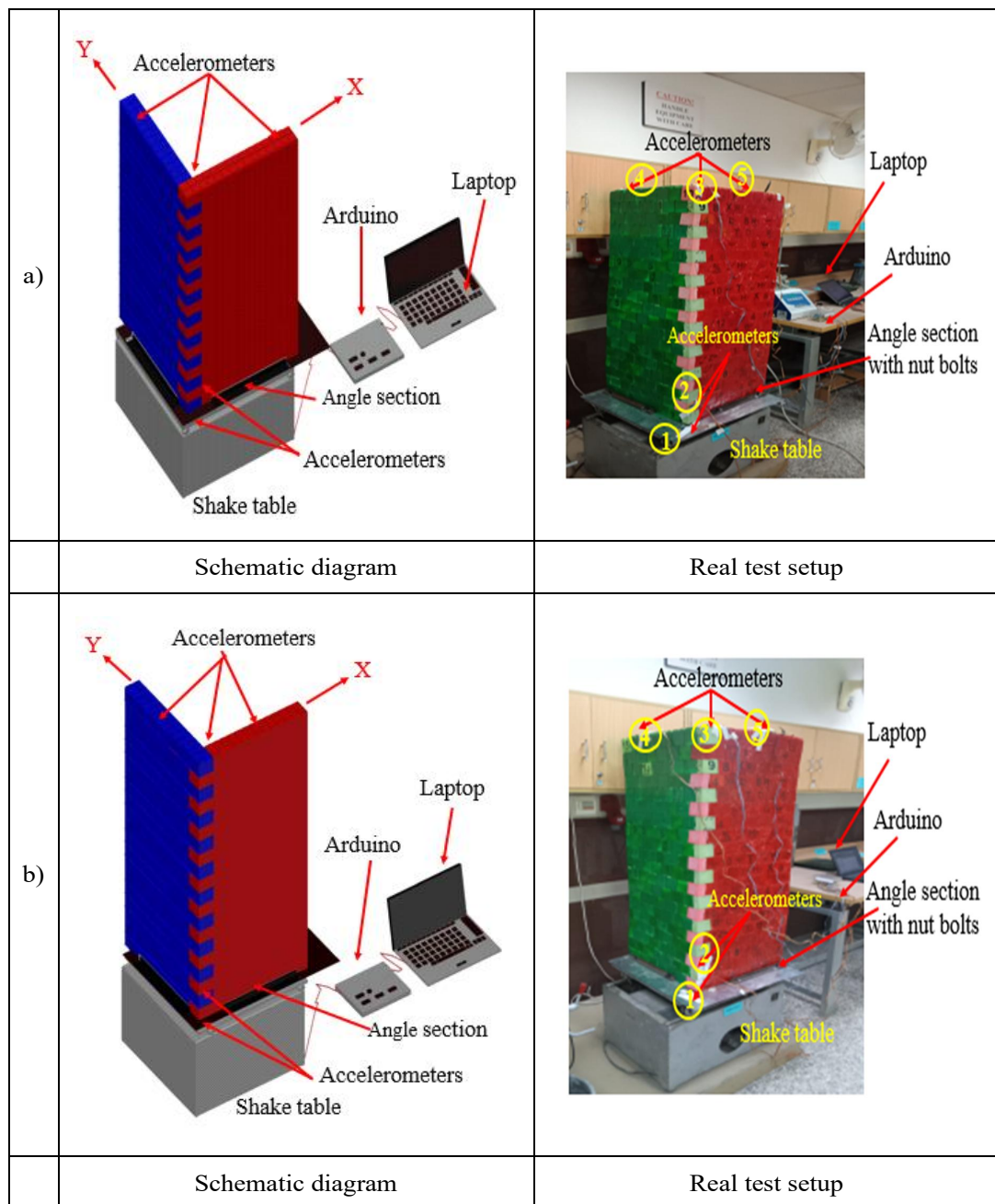


FIGURE 3.5: Shake table instrumentation and testing; schematic diagram and real test set up for a) sequence A and b) sequence B.

3.5 Dynamic Loading

3.5.1 Snap Back

For the snap-back test, the corner-joint in mortar-free IPB wall was laterally displaced by 25 mm and 50 mm at the top using an connected wire. The wire was abruptly freed to initiate free vibration. The resulting response was captured as accelerationtime history data using an accelerometer mounted at the top of the wall. Both wall configuration Seq. A and Seq. B are tested in X-direction. Response in Y-direction would be same due to law of symmetry which currently out of scope. Using the logarithmic decrement method, both the damping ratio and the fundamental frequency of the corner-joint in mortar-free IPB wall were determined from the accelerationtime history data. Snap Back loading magnitude is given in Table 3.1.

TABLE 3.1: Snap back loading magnitude

Sr. No.	Specimen	Loading Dir.	Amplitude (mm)
1	A	X	25, 50
2	B	X	25, 50

3.5.2 Harmonic

Table 3.2 presents the harmonic magnitudes corresponding to the six tests conducted as part of this study. Harmonic excitations are applied at frequencies of 0.8 Hz, 1.1 Hz, and 1.4 Hz, with an amplitude of 25 mm at the corner-joint of the IPB wall. The accelerationtime history, velocitytime history, and displacement-time history recorded at the top and at the base of the shake table are analyzed in comparison to the dynamic behavior of the corner-joint under harmonic loading. It is anticipated that the corner-joint of the IPB wall will exhibit higher acceleration, velocity, and displacement responses due to its structural configuration and joint behavior. Table 3.1 shows the arrangement of plastic blocks for different IP

and OOP behavior of walls. 1/2 plastic block is provided to avoid the successive joint coming over one another just like in stretcher bond in normal brick masonry. Total of 2 combinations are shown. In wall configuration Sequence A wall 1 is experiencing out of plane loading (x- direction) and wall 2 in-plane(x direction). In wall configuration sequence B wall 1 is experiencing out-of-plane loading (x-direction) and wall 2 in-plane(x-direction).The only difference is the arrangement and start of walls. In wall configuration Sequence A, Wall 1 starts from the edge of the joint, whereas in Sequence B, Wall 2 starts from the edge of the joint. In Sequence A, the corner-joint is rigidly fixed to the shake table using a steel angle iron section to ensure stability and repeatability during testing. The harmonic loading parameters presented in Table 4 are based on experimental observations and established literature. Specifically, the dominant frequency of 1.1 Hz, highlighted in bold, was identified through a snap-back test conducted on the system, indicating the natural frequency corresponding to the primary dynamic response mode. Khan [5] carried study on column, Afzal [7] on solid wall, Sudheer and Ali [57] on wall with opening using frequency difference of 0.2, 0.5, 0.5 Hz, respectively. For current investigation fundamental frequency (f_n) is determined from Snapback test approximately 1.1 Hz and 0.3 Hz is selected for one upper and lower frequency. The applied harmonic loading amplitude of 25 mm in the X-direction for both Wall Configurations (Seq. A and Seq. B) reflects a controlled input consistent with experimental protocols designed to simulate realistic dynamic excitation scenarios. Additionally, the test setup ensures consistency in boundary conditions and loading application, enabling a reliable comparison between both configurations. These parameters are crucial for assessing the impact of initial wall positioning on dynamic interaction and overall seismic response. Table 3.2 summarizes the harmonic loading magnitude considered for the testing.

TABLE 3.2: Harmonic loading magnitude

Sr. No.	Wall Config.	Harmonic Loading Dir.	Amplitude (mm)	Frequency (Hz)
1	Seq. A	X	25	0.8, 1.1 , 1.4
2	Seq. B	X	25	0.8, 1.1 , 1.4

3.6 Parameters Evaluated

3.6.1 Parameters Evaluated under Snap Back Loading

For the corner joint in the mortar-free interlocking plastic-block wall, the raw data was initially recorded in terms of acceleration-time history. During the recording process, some noise was inadvertently captured within the acceleration data. To enhance the quality of the recorded data, using the SeismoSignal software noise was removed. Specifically, a bandwidth filter was applied within the software to eliminate unwanted signal components and improve the clarity of the acceleration time history, while MATLAB was used in the initial stages to eliminate excessive noise from the recorded data, ensuring greater accuracy. Furthermore, the fundamental frequency (f_n) and damping ratio (ζ) for the corner joint in the mortar-free interlocking plastic-block wall were calculated from the acceleration-time history as per working of [60, 61].

These values are critical for understanding the dynamic behavior of the system, as the damping ratio provides insights into the energy dissipation characteristics, and the fundamental frequency is crucial for assessing the resonance conditions. The processed data and derived parameters contribute significantly to the accurate modeling and evaluation of the system's seismic response, allowing for more precise design and performance predictions. Additionally, the filtering and analysis techniques employed ensure that the results are both reliable and representative of the actual behavior of the corner-joint under dynamic loading.

3.6.2 Parameters Evaluated under Harmonic Loading

Dynamic loading utilizing frequencies of 0.8 Hz, 1.1 Hz, and 1.4 Hz was applied to the corner joint, and the structural response was recorded in terms of acceleration-time history. Subsequently, velocity-time and displacement-time histories were derived using Seimosignal software through numerical integration. Additionally,

acceleration-time data facilitated the development of base shear (Q) versus displacement curves, where base shear was computed as $Q=Mx\ddot{u}_t$, with M representing the top acceleration of the corresponding wall. These parameters were essential in characterizing the dynamic stiffness and energy dissipation capacity of the corner joint, providing a comparative basis for evaluating performance under varying excitation frequencies.

3.7 Procedure for Empirical Equation Formation

For understanding the dynamic response of the corner-joint in mortar-free interlocking plastic-block walls, empirical equations are developed considering the IPB's geometry, size of the block, height of the structure, and input loading parameters as per the study of Khan [5]. The percentage difference between the experimental and empirical values is also calculated to assess the accuracy of the developed model. To minimize the discrepancy between the experimental and empirical results, a value of $K=1.14$ is applied. This adjustment improves the reliability of the empirical equations, ensuring that they closely align with real-world behavior. The refined model provides a more accurate prediction of the structural performance, offering valuable insights into the behavior of IPB walls under dynamic loads, which can be instrumental in optimizing the design of such systems for enhanced seismic resilience.

3.8 Summary

This chapter details the experimental methodologies and testing procedures adopted in the study. The study focuses on testing a prototype corner joint made from interlocking plastic blocks under dynamic loading conditions. The behavior of the corner-joint to be examined and compared with results derived from empirical equations. Detailed descriptions of the test setup and the instrumentation used are provided, highlighting the equipment and methods employed to carry out the experiments. Additionally, the parameters evaluated during testing are discussed,

offering insight into the factors considered in assessing the performance of the corner joint. Special attention is given to the dynamic response characteristics, including displacement, acceleration, and failure modes observed during testing. This chapter serves as a comprehensive guide to understanding the experimental approach and the reliability of the results obtained, forming a critical foundation for validating analytical and numerical models developed later in the study.

Chapter 4

Experimental Evaluation

4.1 Background

In the last chapter, investigatory methods of snapback and dynamic loading test and analyzed parameters are discussed in detail. Current chapter explains the experimental findings from the data recorded during testing. Fundamental frequency (f_n) and damping ratio (ζ) are calculated for corner joint 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. Acceleration-time and displacement time histories also drawn from the data obtained from seismosignal. Energy absorption is also calculated for each loading frequency.

4.2 Damping Ratio and Fundamental Frequency

Fundamental frequency represents the natural vibration frequency of a structure. If it is too close to the dominant frequency of an earthquake, resonance can occur, amplifying structural vibrations and increasing the risk of failure. A well-designed seismic-proof structure should have a fundamental frequency that avoids resonance with typical seismic excitations. Figure 4.1 shows the results obtained from the snapback tests conducted on corner joint made of IPB wall. Top of corner-joint using chord was displaced from its mean position by 25 mm and 50 mm. Utilizing

the log decrement method, fundamental frequency (f_n) and damping ratio (ζ) for corner joint of IPW were determined.

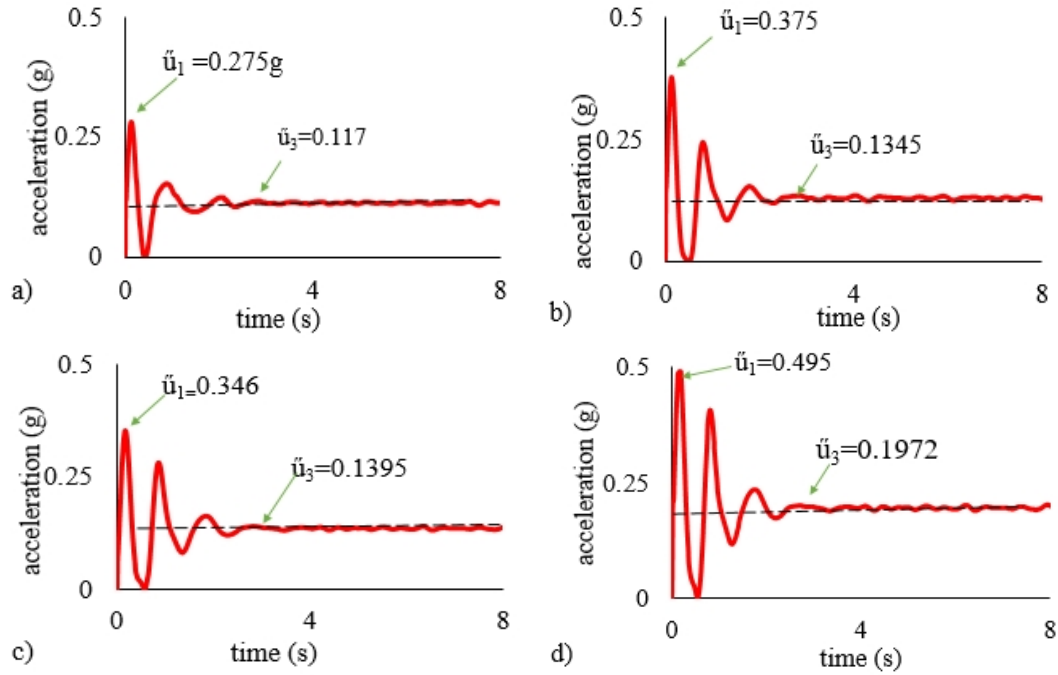


FIGURE 4.1: \ddot{u} -t from snap back test; a) 25mm wall seq. A, b) 50 mm wall seq. B, c) 25mm wall seq. B and d) 50 mm wall seq. B.

Results of the snap back test are shown in table in 4.1. It is to be noted that amplitude of the structure rapidly decreases showing the greater damping capacity when corner- joint displaced from its mean position. Damping quantifies how quickly vibrations decay after excitation. Higher damping ratios indicate better energy dissipation, reducing oscillations and preventing excessive structural damage. Seismic-resistant designs incorporate materials and connections that enhance damping to minimize prolonged shaking and structural fatigue. By analyzing these parameters, engineers can optimize building design to ensure stability, reduce damage, and improve overall earthquake resilience. For wall configuration Seq. A damping for the corner joint displaced 25 mm remained 4.5 percent and for the 50 mm corner joint displaced found 5.4 percent. Frequency for the corner joint displaced 25 mm found 1.1 Hz and for the 50 mm corner joint displaced found 1.11 Hz. Similarly, wall configuration Seq. B damping for the corner joint displaced 25 mm remained 4.8 percent and for the 50 mm corner joint displaced found 4.9 percent. Frequency for the corner joint displaced 25 mm found 1.14 Hz and for

the 50 mm corner joint displaced found 1.13 Hz. A slight variation in damping

TABLE 4.1: Results from snapback test

Wall Configuration	Amplitude (mm)	Freq. (Hz)	Damping (%)
Seq. A	25	1.10	4.5
-	50	1.11	5.4
Seq. B	25	1.13	4.8
-	50	1.14	4.9

can be justified by considering material properties, structural behavior, and energy dissipation mechanisms. Current investigation focuses on the product and element and its material properties are beyond the scope of this research. Factors such as nonlinear material response, joint friction, and boundary conditions can lead to small changes in damping under different loading conditions. Additionally, in real-world structures, damping is influenced by amplitude-dependent effects, where energy dissipation mechanisms (such as internal friction, air resistance, and connection flexibility) vary slightly with motion intensity. Around 20% damping can be expected in real structures.

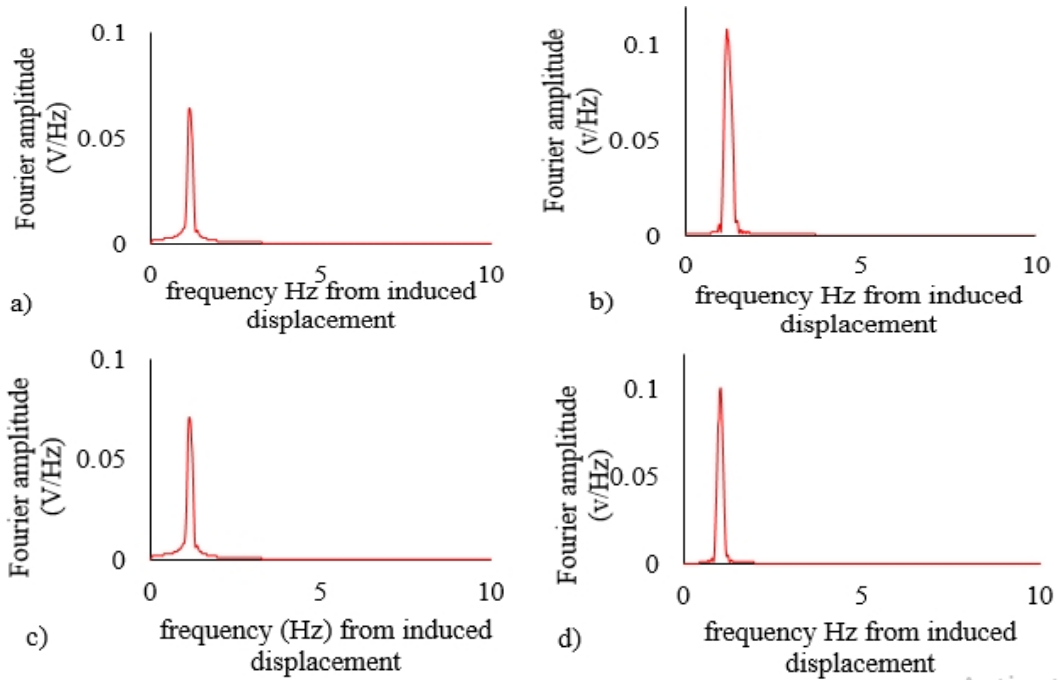


FIGURE 4.2: Fourier amplitude from snap back test : a) wall seq. A with 25 mm , b) Wall Seq. A with 50 mm, c) wall seq. B with 25 mm and d) wall seq. B with 50 mm.

Figure 4.2 shows the Fourier amplitude from snapback test performed for 25 mm and 50 mm, it stays around 1.1 Hz for both wall sequence.

4.3 Behavior of Prototype Corner-Joint under Harmonic Loading

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

Behavior of corner-joint made of IPB wall captured based on of acceleration time history and displacement time history during the time period of 40 s to 45 s as presented in Figure 4.3 and Figure 4.4 Red solid line depicts the base excitation taken as (applied loading), the green dotted line depicts the response at the base of the corner joint of IPB. Blue line represents the top of corner joint. Purple dotted line presents the out-of-plane movement of wall 1. Brown line represents the in-plane movement of wall 2. The experimentally obtained acceleration-time and displacement-time histories are suitable for analyzing the dynamic response of the prototype corner joint. By utilizing the seismosignal software the data of acceleration-time history is then processed into displacement time histories.

As low-cost locally developed shake table is able to impose harmonic excitation precisely i.e., using uniform amplitude of cycles, the averaged acceleration and displacement of base excitation (i.e. \ddot{u}_b , \dot{u}_b , u_b respectively) is taken applied loading. The values of acceleration and displacement at the top of corner-joint of IPB wall (i.e. \ddot{u}_t , \dot{u}_t , u_t respectively) is taken as its behavior. Figure 4.3 presents the acceleration-time histories of the corner joint subjected to harmonic loadings at frequencies of 0.8 Hz, 1.1 Hz, and 1.4 Hz within the time interval of 40 to 45 seconds. The structural excitation can be characterized into three phases: (A) the initial phase, where the structure begins vibrating until it reaches steady-state; (B) the steady-state response; and (C) the free vibration phase following the removal of external excitation [61].

For better comprehension, only some part of steady state behavior is presented in Figures 4.3 and 4.4. Average acceleration values at both the base and top of the corner-joint are presented. It has been observed that the acceleration is increased by rising the frequency of shake table upon application of the second harmonic loading i.e., 1.1 Hz, the corner-joint in mortar free IPB wall oscillated vigorously and have undergone excessive deformation as shown in Figure 4.2(b). The top of corner in the form of wedge tends to separate in harmony with some previous researches that flexural dominance in absence of vertical load in term of slab load. The observed damage was cumulative, involving the influence of prior frequency excitations. Displacement time histories of the corner joint during dynamic loadings at 0.8 Hz, 1.1 Hz, and 1.4 Hz recorded between 40 s and 45 s are presented in Figure 4.3.

To examine the behavior at the base, the displacement time history for this same time interval is also presented. The average displacements at both the ground level and the top of the corner are presented. It was observed that the displacement of the walls increased with the rising frequency of the shake table input. Locally manufactured shake table can only apply precise dynamic loading. There is slight variations in amplitudes observed across the cycles. The averaged acceleration, velocity and displacement of base movement (\ddot{u}_b , \dot{u}_b , u_b , respectively) is considered as applied loading. After the application of the first and second dynamic loadings, specifically at 0.8 Hz and 1.1 Hz, the interlocking plastic-block wall underwent sudden excessive deformations.

This behavior was clearly captured in the data and is depicted in Figure 4.4. The observed increase in displacement is a critical finding, as it indicates that under dynamic loading at these frequencies, the interlocking plastic-block system might not be fully able to resist the forces acting on it. This could be due to the specific characteristics of the interlocking mechanism or the material properties of the blocks, which may not be optimized for these particular loading conditions. The displacement behavior suggests that the wall becomes less stable under these dynamic frequencies, resulting in excessive movements that could lead to potential damage or failure in real-world scenarios, such as during an earthquake. In addition to the out-of-plane displacement, it was noted that the in-plane contribution of the

wall was reduced under the dynamic loading at 1.1 Hz. This reduction indicates that the wall’s ability to resist forces in the plane of the wall (parallel to its surface) weakened when exposed to this loading frequency. The wall may have experienced sliding or shifting in the in-plane direction, which contributed to a reduction in its overall resistance to horizontal forces. This is a crucial observation because the walls in-plane stiffness is an important factor in its ability to resist lateral forces, which are often a key cause of damage during seismic events.

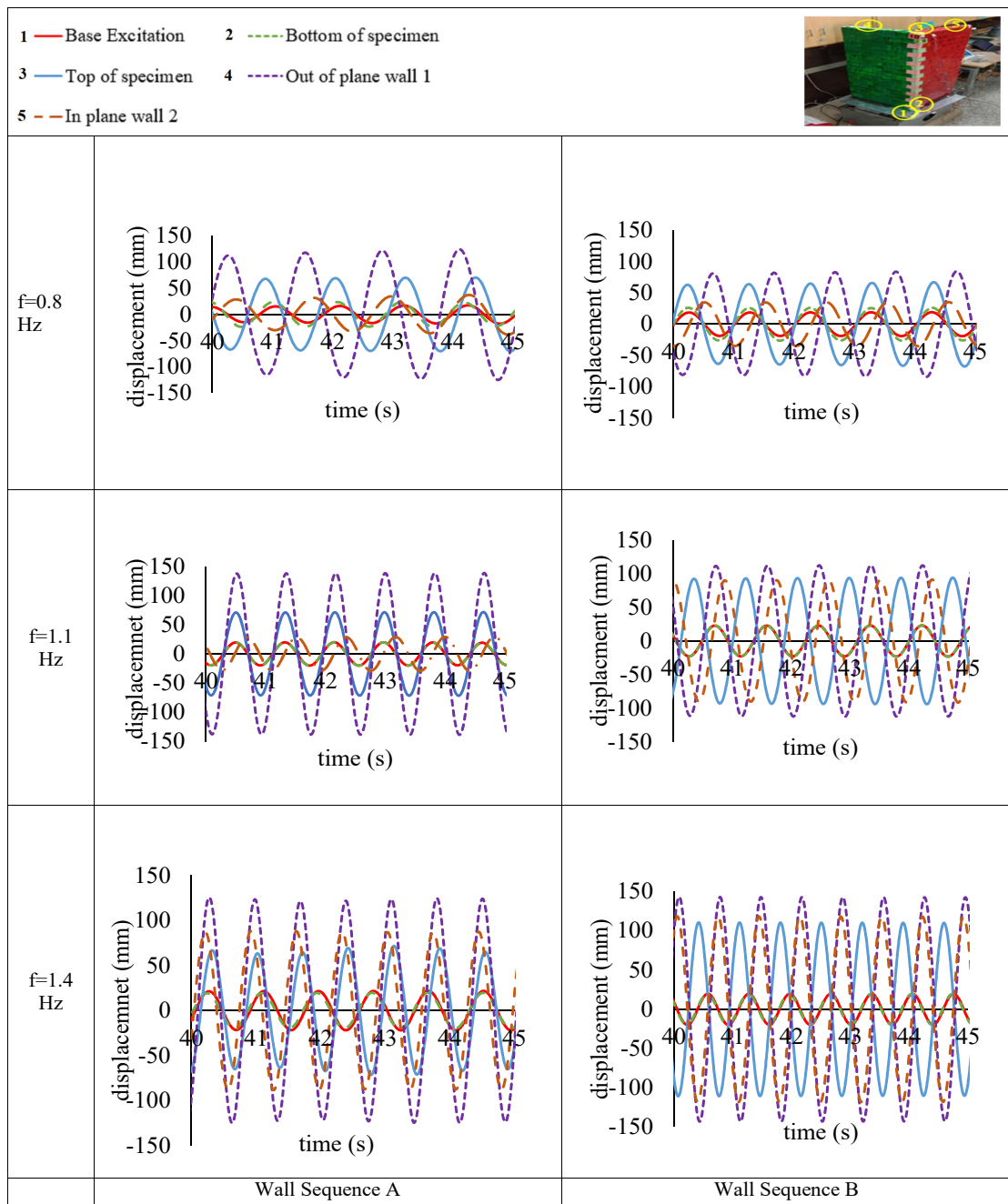


FIGURE 4.3: \dot{u} -time history curve of corner-joint

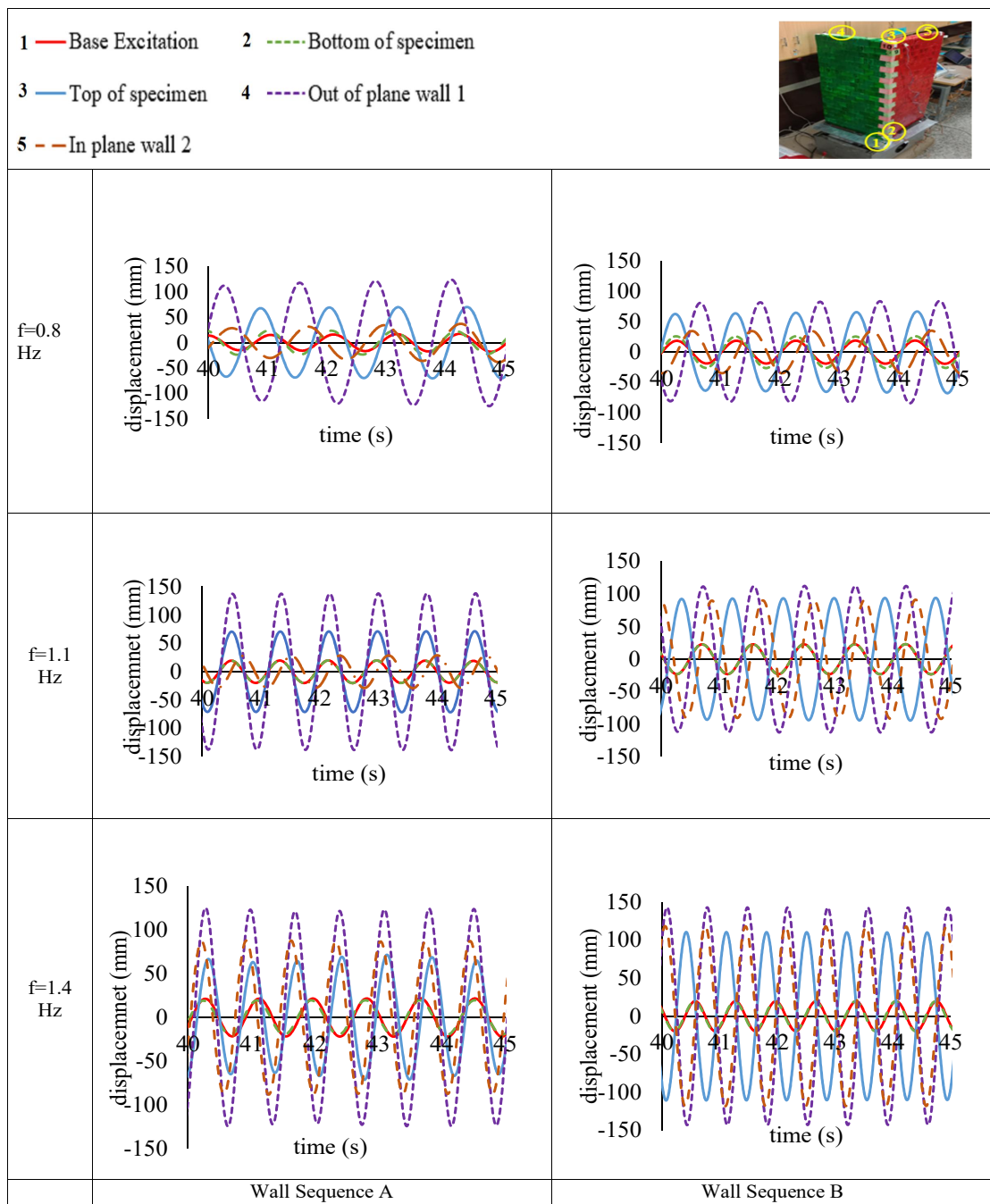


FIGURE 4.4: Δ -time history curve of corner-joint

Despite these observations of excessive deformations and a reduction in in-plane resistance at certain frequencies, the data supports the idea that construction using interlocking-plastic-block remains an effective option for earthquake-resistant housing schemes. While the wall may experience some vulnerability to excessive deformation under certain dynamic loading conditions, its inherent energy absorption capabilities, especially at higher frequencies, offer potential benefits.

The interlocking mechanism itself can absorb and dissipate energy, making it a valuable feature for mitigating the effects of seismic forces.

This suggests that with further design improvements, such as enhancing the interlocking system or modifying the material properties, the performance of interlocking plastic-block walls could be significantly improved. Even though the wall exhibited excessive deformation at 0.8 Hz and 1.1 Hz, it still shows promise for providing a flexible, resilient, and energy-absorbing structure in earthquake-prone regions. Thus, despite some challenges observed at specific frequencies, interlocking plastic-block construction could offer a potential solution for creating safer and more effective earthquake-resistant housing.

TABLE 4.2: Wall's contribution to corner-joint's response

Wall Config.	Freq. (Hz)	OOP (mm)	IP(mm)	% contribution
Seq. A	0.8	73	26	180.4
-	1.1	137	60	128.3
-	1.4	123	81	51.8
Seq. B	0.8	79	32	149.3
-	1.1	114	91	25.1
-	1.4	158	115	37.3

Table 4.2 represents the wall's contribution to corner behavior. In Sequence A, Wall 1 under out-of-plane OOP loading exhibited displacements of 73 mm, 137 mm, and 123 mm at 0.8 Hz, 1.1 Hz, and 1.4 Hz, respectively significantly higher than Wall 2 under IP loading, which showed 26 mm, 26.5 mm, and 81 mm. Similarly, in Sequence B, OOP loaded Wall 1 showed displacements of 79 mm, 114 mm, and 158 mm, compared to 32 mm, 91 mm, and 115 mm for IP loaded Wall 2. These results indicate the contribution of OOP wall remains up to 180% to the corner behavior. The higher displacement values suggest that the OOP wall's flexibility and energy dissipation capacity play a critical role in the joint's seismic response.

4.3.2 Base Shear(Q)-Displacement(Δ) Curves and Energy Absorption

For the calculation of energy absorbed during dynamic loading, it is assumed that the total mass of the IPB corner-joint (M) is concentrated at the top of the corner joint. Its behavior based on acceleration time (i.e., \ddot{u}_t) history is captured. Base shear is determined as $M \cdot \ddot{u}_t$. Base shear (Q)-displacement(Δ) curves are presented in Figure 4.5.

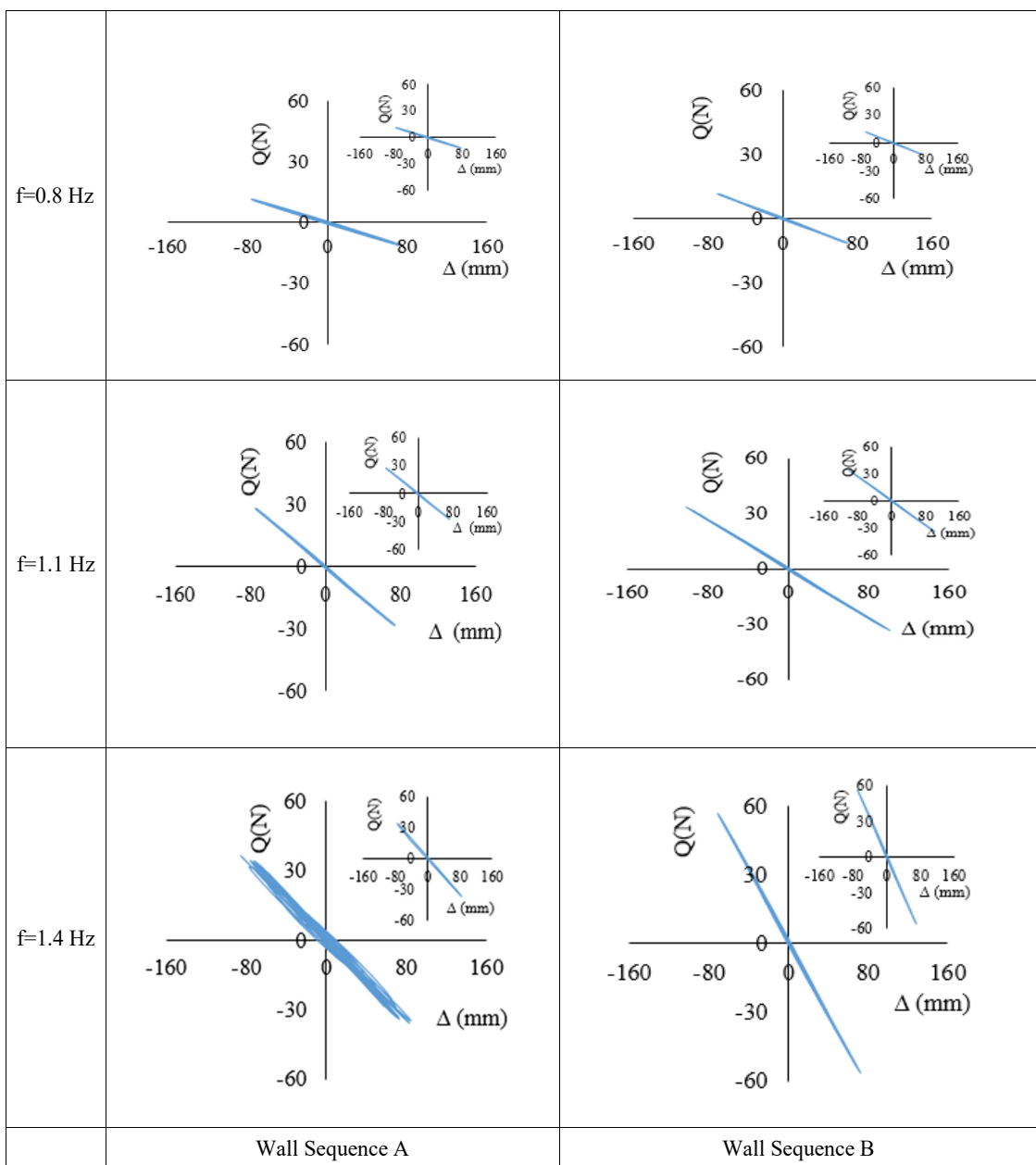


FIGURE 4.5: Q- Δ curves of corner-joint

This is calculated as per working of [61]. Base shear is drawn on Y- axis and displacement on X-axis. Area within hysteresis loops is the energy absorbed by the specimen subjected to harmonic loading. Results for the energy absorption are shown in Table 4.4. including total number of hysteresis loops, average energy absorbed in a single loop and equivalent damping. Equivalent damping ratio is calculated as per formula.

$$\zeta = \frac{E}{2\bar{\Delta}Q_{\max}\Delta_{\max}} \quad (4.1)$$

Equivalent damping is calculated as working of per of [62]. Where is E is energy absorbed in a cycle, Q_{\max} and Δ_{\max} is max shear and displacement in a single loop. Energy absorption for different loading frequencies are shown in Figure 4.5. Energy absorption increases with rise in frequency of loading.

TABLE 4.3: Energy absorption during dynamic loading

Wall Config.	Freq. (Hz)	Avg. Energy per Cycle (Nm)	No. of Cycles	Total Energy Absorption (Nm)	Equiv. Damping Ratio (%)
Seq. A	0.8	1.08	72	78.03	19.6
–	1.11	2.71	91	247	20.5
–	1.4	3.78	112	424	19.7
Seq. B	0.8	1.11	76	85.48	21.8
–	1.11	4.29	89	382	20.0
–	1.4	5.97	115	687	23.4

The data presented in Table 4.3 offers a comprehensive insight into the energy absorption behavior of the corner joint in an interlocking plastic-block wall system under dynamic loading conditions. In this study, energy absorption (E) is defined as the energy dissipated during a single cycle of loading, while the total energy absorbed (ET) corresponds to the cumulative energy dissipated over multiple cycles of harmonic excitation. A notable outcome of the analysis is the frequency-dependent variation in energy dissipation, underscoring the influence of excitation frequency on the dynamic performance of the corner joint. Specifically, at a higher frequency of 1.4 Hz, the corner joint demonstrates a significantly enhanced energy dissipation capacity compared to lower frequencies of 0.8 Hz and 1.1 Hz.

This trend indicates that frequency plays a vital role in modulating the structural damping characteristics and the mechanical response of the interlocking block system. Quantitatively, the corner joint absorbs 8.03 times more energy at 1.4 Hz than at 0.8 Hz in wall sequence B, and 5.42 times more energy under the same frequency comparison in wall sequence A. This substantial increase in energy dissipation at higher frequencies may be attributed to increased cyclic deformation, enhanced internal friction between interlocking units, and frequent relative movements among the plastic blocks. These mechanical interactions become more prominent at elevated loading rates, thereby facilitating higher energy loss through frictional damping and material hysteresis. Moreover, for Wall Sequence B, 8.9% more energy dissipation was observed when comparing to Wall Sequence A at 0.8 Hz.

Similarly Wall Sequence B, 55% more energy dissipation was observed when comparing to Wall Sequence A at 1.1 Hz. And Wall Sequence B, 62% more energy dissipation was observed when comparing to Wall Sequence A at 1.4 Hz with reinforcing the hypothesis that even modest increases in excitation frequency can produce measurable gains in energy absorption. The implication of these findings is significant for structural design and performance assessment, particularly in the context of seismic or impact loading where high-frequency excitations are common. The enhanced energy dissipation observed at 1.4 Hz indicates a potential for

these interlocking systems to serve as effective energy-absorbing components in dynamic environments. Engineers and designers can leverage this behavior to improve the resilience of non-mortared wall systems, especially in low-rise or modular construction where lightweight and flexible connections are advantageous. Furthermore, the frequency-sensitive nature of the corner joint highlights the importance of dynamic characterization in structural testing protocols, suggesting that conventional static tests may not fully capture the behavior of innovative systems like interlocking plastic-block walls. Future research could explore the long-term durability and cyclic degradation of such joints under repeated high-frequency loading to better inform performance-based design approaches.

4.4 Summary

In this chapter, a detailed experimental evaluation of the captured dynamic behavior's data is discussed, providing valuable insights into the behavior of the corner-joint under seismic loading. Seismoignal software was employed to process the data of acceleration-time history, converting it into velocity-time and displacement-time histories for further analysis. These time histories are graphically represented, illustrating the dynamic behavior of the structure. Additionally, base shear-displacement graphs drawn and energy absorption is calculated showing detailed view of the structural performance under harmonic loading conditions. The findings reveal that, when subjected to dynamic loading near the system's natural frequency, the corner joint experiences significant deformation. However, this deformation does not lead to complete structural failure, indicating that the joint's design allows for considerable flexibility and energy dissipation. This behavior is attributed to the relative movement between the corner joint and the base, which facilitates the absorption of seismic energy without compromising the integrity of the overall structure. Such movement effectively mitigates the risk of catastrophic failure by distributing the forces more evenly across the structure. These results underscore the importance of corner joint design in ensuring the resilience of mortar-free interlocking block systems under dynamic loading conditions, particularly in earthquake-prone areas.

Chapter 5

Discussions

5.1 Background

In the final chapter, a detailed discussion is presented on the results of accelerationtime history, velocitytime history, displacementtime history, and base sheardisplacement relationships. Notably, substantial energy absorption was observed at the corner joints of the interlocking plastic-block wall system. This chapter also establishes a correlation between the experimental results and the empirically derived values to estimate the behavior of the IPB corner-joint. Furthermore, the percentage differences between the empirical and experimental values are quantified and analyzed.

5.2 Formation of Empirical Equations considering Geometrical Parameters, Structure Behavior and Input Loading Conditions

Empirical equation developed by Khan [5] using the geometry of interlocking blocks, corner joint height, its response and other input loading parameters. Following empirical equations are developed for predicting the response of corner joint

of interlocking plastic-block wall by incorporating further new variable:

$$\ddot{u}_t = \frac{a}{h^2 n} \times m \times k^{(1+\frac{2n}{100})} \times \ddot{u}_g \quad (5.1)$$

$$\dot{u}_t = \frac{a}{h^2 n} \times m \times k^{(1+\frac{2n}{100})} \times \dot{u}_g \quad (5.2)$$

$$u_t = \frac{a}{h^2 n} \times m \times k^{(1+\frac{2n}{100})} \times u_g \quad (5.3)$$

Where K is dimensionless Coefficient, n denotes Number of IPB, m Number of blocks arranged along the length of corner-joint wall in one layer, a represents base area of IPB, \ddot{u}_g is average acceleration at base of specimen, \dot{u}_g average velocity at base of specimen, u_g average displacement at base of specimen, \ddot{u}_t is average acceleration at top of specimen, \dot{u}_t is averaged velocity at top of specimen and u_t is average displacement at top of specimen. Their respective values are 62 mm x 62 mm, 12 mm, 280 and 14. K is coefficient having dimensionless value of 1.14.

To assess the dynamic response, motion parameters are recorded both at the base and at corner-joint's top. Table 5.1 represents the comparison of experimental and empirical values of corner joint of IPB wall's response. Different Values of K are being used in past researches i.e Khan [5] used 1.05, Afzal [7] used 0.45 and Sudheer and Ali [57] used 0.5 for columns, OOP solid wall and OOP wall with window, respectively, keeping in mind the geometries and loadings of specimen. For current scenario of the corner joint, the value of K is taken as 1.14 which resulted minimum difference of -34% to 30%. The percentage difference in experimental and empirical values is high but that can be attributed to complex behavior of the structure.

In a study by Nasery [63] reported differences in experimental and empirical values upto 30%. Ali [64] reported a percentage difference of up to 35% between experimental and empirical values, acknowledging the complex behavior of mortar-free interlocking columns with multiple uplift mechanisms, and aiming to provide an approximate estimation of the induced accelerations. Thus, the current research having variation from -34% to 30% due to involving the complex nature of structure can help in understanding the behavior of corner-joint in mortar-free IPB wall.

TABLE 5.1: Variation in experimental and empirical values for corner-joint of interlocking-plastic-block wall

Freq. (Hz)	Joint response	Experimental values	Empirical values	Percentage difference
Seq. A				
0.8	Acceleration (g)	0.152	0.20	-34
–	Velocity (mm/s)	295.4	396	-34
–	Displacement (mm)	59.0	79	-34
1.11	Acceleration (g)	0.335	0.363	-12
–	Velocity (mm/s)	504	545	-8
–	Displacement (mm)	73	79	-9
1.4	Acceleration (g)	0.495	0.585	-22
–	Velocity (mm/s)	553	694	- 26
–	Displacement (mm)	63	79	-26
Seq. B				
0.8	Acceleration (g)	0.185	0.2	-10
–	Velocity (mm/s)	361	396	-10
–	Displacement (mm)	72	79	-10
1.11	Acceleration (g)	0.46	0.4	14
–	Velocity (mm/s)	621	545	12
–	Displacement (mm)	90	79	15
1.4	Acceleration (g)	0.82	0.57	30
–	Velocity (mm/s)	923	694	25
–	Displacement (mm)	105	79	25

5.3 Outcome of the Research with Respect to Practical implementation

The application of harmonic loading using a locally manufactured shake table is capable of generating reasonably accurate harmonic motion, allowing for the study of the dynamic behavior of the structure under observation.

TABLE 5.2: Comparison with previous researches

Previous Researches	Current Research
A complex shake table was employed to assess the dynamic behavior of the mortar-free interlocking structure [59].	Simple 1D shake table is used to evaluate dynamic behavior of corner-joint in IPB wall.
The coconut fiber-reinforced concrete blocks generated greater inertial forces due to their higher weight [64].	Less inertial force is generated in corner-joint due to its lightweight interlocking unit.
Energy is dissipated in mortar-free interlocking structure during dynamic loadings [61].	Corner-joint in mortar-free IPB wall also dissipates energy.
Pre-tensioning the structure with coconut fiber ropes resulted in lower energy dissipation in comparison to the configuration without ropes [64].	The addition of rubber bands to the corner-joint in IPB wall enhanced energy dissipation during harmonic loading.
During collapse of column, slight damage was observed in interlocking block [64].	No damage could be introduced in specimen due to shake table's limitation.

This is so because the applied harmonic loading is taken as the base ground motion, and the structural response is evaluated relative to it. The observed behavior of the corner joint in the mortar-free interlocking plastic-block wall aligns closely with findings reported in prior studies, further validating its effectiveness. The corner joint demonstrated promising performance in terms of structural stability and energy dissipation under dynamic loading conditions. This indicates that such joints can play a vital role in enhancing the resilience of structures, especially in seismic regions. By incorporating interlocking plastic blocks, the adverse effects of earthquakes can be mitigated, offering a sustainable and damage-tolerant alternative to conventional construction methods.

Table 5.2 presents a comparative summary of findings from previous research and

the current study, revealing a consistent trend in energy dissipation patterns observed across mortar-free systems. This reinforces the growing consensus on the viability of interlocking block technologies in earthquake-resistant construction practices. Furthermore, the use of these systems shows great potential in reducing overall construction costs and minimizing the need for heavy reinforcement, which makes them not only more cost-effective but also more environmentally sustainable. As the demand for resilient infrastructure increases globally, these findings suggest that the adoption of mortar-free interlocking block systems could significantly contribute to safer, more durable buildings in earthquake-prone regions.

Moreover, these systems align with performance-based design philosophies, which emphasize controlled damage and energy dissipation rather than complete rigidity. Their modular nature facilitates ease of construction, repair, and scalability, particularly valuable in resource-constrained settings. The integration of such innovative materials and systems could thus mark a paradigm shift in sustainable seismic design, bridging the gap between affordability, resilience, and ease of deployment.

5.4 Challenges in Seismic Resilience of Masonry and Remedial Measures

Reduced mass results in lower inertial forces during earthquakes, making it an effective seismic design strategy. As per UBC 1997, base shear is directly proportional to the building weight, expressed by:

$$V = \frac{C_v \times I}{RT} \times W \quad (5.4)$$

Therefore, reducing the mass of a structure significantly decreases seismic demand. The use of mortar-free interlocking-plastic-blocks offers a lightweight alternative with efficient energy dissipation, particularly at corner-joints. Their dry assembly system enhances construction speed, reusability, and reduces dependency on

skilled labor. This makes them suitable for large-scale, earthquake-resistant structures in seismic prone zones. Applications of such systems have been explored in recent studies, including [65].

5.5 Summary

This chapter presents the outcomes of the study, emphasizing practical implementation and the formulation of an empirical equation. The empirical equation was formulated to validate the experimental results, ensuring consistency between theoretical predictions and observed behavior. The discrepancy between experimental and empirical values can be attributed to the complexity of the structure involved in the testing, coupled with the use of a simplified empirical equation. Harmonic loading was applied using a locally developed shake table which is cost-effective, demonstrated limitations in maintaining a consistent amplitude across varying frequencies. Although there were limitations, the shake table successfully generated consistent harmonic loading adequate for assessing the structure's dynamic response. These results enabled a meaningful assessment of the structural behavior under dynamic conditions. The empirical equation further supported and reinforced the experimental findings, providing additional reliability to the study. Ultimately, the integration of experimental and analytical approaches enhances the practical applicability of the research, offering valuable insights for real-world applications.

Chapter 6

Conclusion and Future Work

6.1 Conclusions

This study examines the dynamic behavior of a 1:3 scaled interlocking plastic-block corner-joint. The test model consisted of 280 plastic blocks arranged in 20 layers and fixed at the base using angle sections. Five accelerometers were used to record structural response: two on each wall top, two at the corner, and one at the base. A snap-back test was also conducted to determine the natural frequency, time period, and damping ratio using the logarithmic decrement method. Study conducted using a locally manufactured one-dimensional shake table operating at 0.8 Hz, 1.1 Hz, and 1.4 Hz. Data from MATLAB was refined using SeismoSignal for noise filtering and baseline correction. Based on this research, the following conclusions can be made:

- The average fundamental frequency is approximately 1.1 Hz, and the damping ratio for the corner-joint remains up to 5.4%.
- The response of the prototype corner joint was recorded in terms of acceleration time and displacement time histories.
 - The OOP wall contributes more significantly to corner behavior, with displacements reaching up to 180% of those observed under IP harmonic loading.

- Wall Sequence B absorbs 8.9%, 55%, and 62% more energy than Wall Sequence A at frequencies of 0.8 Hz, 1.1 Hz, and 1.4 Hz, respectively.
- The percentage difference of up to 34% between the experimental and empirical values in predicting the structural response can be attributed to the complex nature of the structure compared to the simplicity of the developed approach. However, the research can help in understanding the behavior of corner-joints in mortar-free interlocking block systems.
- The corner-joint in mortar-free interlocking-plastic-block wall helps in energy dissipation highlighting its potential for earthquake-resistant construction.

The lightweight corner-joint in mortar-free interlocking-plastic-block walls enhances energy dissipation under harmonic loading, promoting structural safety. This sustainable housing innovation offers an affordable and resilient solution for vulnerable communities in earthquake, ensuring a decent standard of living.

6.2 Future Recommendations

Following may be considered to further explore the behavior of interlocking plastic block structure.

- Optimizing Corner Configurations for Balanced Seismic Response in Interlocking Block Structures.
- Optimization of Empirical Modeling Techniques for Predicting Corner-Joint Dynamics in Modular Wall Systems.

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