

CAPITAL UNIVERSITY OF SCIENCE AND
TECHNOLOGY, ISLAMABAD



Dynamic Response of Mortar-Free Interlocking Plastic Block Wall T-Junction in Two-Story Applications

by

Abu Bakar Naeem

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

in the

Faculty of Engineering

Department of Civil Engineering

2026

Copyright © 2026 by Abu Bakar Naeem

All rights reserved. No portion of the material protected by this copyright notice may be replicated or utilized in any arrangement or by any means, electronic or mechanical including photocopy, recording or by any information storage and retrieval system without authorization from the author(s).



CERTIFICATE OF APPROVAL

Dynamic Response of Mortar-Free Interlocking Plastic Block Wall T-Junction in Two-Story Applications

by

Abu Bakar Naeem

Registration No: (MCE251004)

THESIS EXAMINING COMMITTEE

S. No.	Examiner	Name	Organization
(a)	External Examiner	Dr. Muhammad Yaqub	UET, Taxila
(b)	Internal Examiner	Dr. M. Usman Farooqi	CUST, Islamabad

Dr. Majid Ali

Thesis Supervisor

September, 2026

Dr. Majid Ali

Head

Dept. of Civil Engineering

September, 2026

Dr. Imtiaz Ahmad Taj

Dean

Faculty of Engineering

September, 2026

Author's Declaration

I, **Abu Bakar Naeem**, hereby state that my MS thesis titled “**Dynamic Response of Mortar-Free Interlocking Plastic Block Wall T-Junction in Two-Story Applications**” is my own work and has not been submitted previously by me for taking any degree from Capital University of Science and Technology, Islamabad or anywhere else in the country/abroad.

At any time if my statement is found to be incorrect even after my graduation, the University has the right to withdraw my MS Degree.



(Abu Bakar Naeem)

Registration No: (MCE251004)

Plagiarism Undertaking

I solemnly declare that research work presented in this thesis titled “**Dynamic Response of Mortar-Free Interlocking Plastic Block Wall T-Junction in Two-Story Applications**” is exclusively my research work with no remarkable contribution from any other individual. Small contribution/help wherever taken has been acknowledged and that complete thesis has been written by me.

I understand the zero-tolerance policy of the Higher Education Commission and CUST towards plagiarism. Therefore, I as an author of the above titled thesis declare that no part of my thesis has been plagiarized and any material used as reference is properly cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of MS Degree, the University reserves the right to withdraw/revoke my MS degree and that HEC and the University have the right to publish my name on the HEC/University website on which names of students are placed who submitted plagiarized work.



(Abu Bakar Naeem)

Registration No: (MCE251004)

Acknowledgement

First and above all, I praise **ALLAH**, the Almighty, for granting me the capability, health, and opportunity to successfully complete this work. I also offer my deepest respect to the Holy Prophet **Muhammad (PBUH)**, the divine servant leader whose teachings continue to inspire and guide my life.

I would like to express my deepest gratitude and special thanks to my supervisor, **Engr. Prof. Dr. Majid Ali**, for his invaluable guidance, patience, and dedicated supervision throughout this journey. His critical insights were vital at every developmental stage of this work, and his continuous support is sincerely appreciated. It has been a true honor to work under his mentorship, making this research an incredibly worthwhile experience.

I am immensely grateful to everyone who assisted me during this study, with special thanks to **Engr. Abu Bakar** and **Mr. Syed Abbas Gillani** for their technical support and hands-on assistance during the laboratory testing phase. I also extend my appreciation to the Department of Civil Engineering for providing the necessary library and laboratory facilities essential for the smooth execution of this research.

Finally, I would like to express my gratitude to my company, Maven Projects LLP, and specifically to **Mr. Syed Junaid Rehman Shah**, for their immense support and encouragement, which greatly facilitated the successful achievement of this academic milestone.

Abu Bakar Naeem

Abstract

The actual weaknesses of traditional masonry are usually revealed during an earthquake. Poor tensile capacity, inherent brittleness, high sensitivity to stress concentration, local separation of joints and sudden disastrous collapse under dynamic loading are the characteristics of those traditional structures. Mortar-free, Interlocking Plastic Block (IPB) systems offer an economical option. They have a much lower mass and so seismic inertial forces are much lower when they move in the ground. However, the behavior of the whole IPB structure under dynamic loads deserves further investigation, especially at the junctions of the perpendicular walls. A known weakness is T-junctions. Previous studies have largely ignored the structural performance of these nodes in 2-story structures, while these nodes form the basis for the load paths that are interrupted and may cause sliding failures. This particular omission in the literature is the subject of investigation in the present study, in which the dynamic response of two-story, mortar-free T-joints under simulated seismic loads are investigated. The analysis focuses on the type of controlled interfacial sliding that occurs in the block arrangement that is present to dissipate seismic energy.

A 624 mm tall 1/10 scale model of a two-story T-joint was constructed of 130 interlocking plastic blocks to test the structural response of a T-joint. This model was firmly fastened to the base. Five accelerometers were installed from the base to the top free ends to continuously record the real-time motion data during four testing phases: (1) static stiffness testing to obtain the basic lateral capacity; (2) free-vibration snap-back testing to calculate the fundamental frequency and damping ratio by the logarithmic decrement method; (3) localized hammer impact testing with a 0.46 kg pendulum to evaluate the high-frequency dynamic reduction of the lateral capacity; and (4) unidirectional shake table testing at the harmonic frequencies of 1.0, 1.2, and 1.4 Hz to ensure there were no resonant amplifications and that overall energy dissipation was obtained. The raw acceleration data was collected in MATLAB and processed in SeismoSignal to apply baseline corrections and to remove ambient noise from the data.

The mechanical behavior of the unbonded T-junction was inherently asymmetric, with a low lateral stiffness of 1.74 N/mm in the vulnerable X-direction compared with a higher stiffness of 2.14 N/mm in the Y-direction. The fundamental frequency was determined as 1.2 Hz and the structural damping ratio was measured to be 5.61% using free vibration tests. For harmonic excitation, the profile of the deformation was dominated by the lateral deformation along the X-axis which showed amplifications up to 29.3 times higher than along the Y-axis. Active interfacial friction was a significant contributor to seismic energy dissipation, which was strongly influenced by the block layout. In both sequences of sequence test, the dynamic performance of Sequence B was consistently better than that of Sequence A, with 26,678 N.mm of energy absorbed during 1.4 Hz loading cycles as opposed to 25,224 N.mm for Sequence A, a 6.09% improvement. The complex, non-linear sliding mechanics caused an 8.1% percent difference between the actual results and the simpler empirical ones, but the quantitative results make excellent evidence that the mortar-less interlocking plastic block systems can be used as a resilient, energy dissipating, and cost-effective approach to earthquake resistant construction.

Keywords: T-Junction, Interlocking Plastic block, Dynamic behavior, Mortar-free construction, Fundamental frequency, Stiffness.

Contents

Author's Declaration	iii
Plagiarism Undertaking	iv
Acknowledgement	v
Abstract	vi
List of Figures	xi
List of Tables	xii
List of Abbreviations	xiii
Symbols	xiv
1 Introduction	1
1.1 Background	1
1.1.1 Work Done till Today on IPB Wall System	3
1.2 Research Motivation and Problem Statement	6
1.2.1 Research Questions	7
1.3 Overall Goal of the Research Program and Specific Aim of this Particular Study	8
1.4 Scope of Work and Study Limitations	9
1.4.1 Rationale behind the Variable Selection	9
1.5 Brief Methodology	10
1.6 Research Impact on Industry	11
1.6.1 Research Novelty - Uniqueness	11
1.6.2 Research Significance and Benefit	12
1.6.3 Practical Implementation	13
1.6.4 National and Global Impact with Emphasis on SDGs Relevance	13
1.6.5 Research Challenges	14
1.6.6 Ethical and Management Consideration including Risk Management	14

1.6.7	Research Deliverable, Sales and Marketing Potential	15
1.7	Thesis Layout	16
2	Literature Review	18
2.1	Background	18
2.2	Junction Damage in Masonry Structure	19
2.2.1	Seismic Vulnerability of Masonry Structure	19
2.2.2	Damage Mechanism at Junctions in Masonry	20
2.2.3	Dynamic Loading Effect on Junction Performance	21
2.3	Emerging Techniques in Masonry	22
2.3.1	Techniques for Improving Seismic Performance	22
2.3.2	Experimental and Numerical Evaluation of Masonry System	24
2.3.3	Seismic Performance of Mortar-free Masonry	26
2.4	Damage Control in Mortar-Free Joints	27
2.4.1	T-Joint Confinement Strategies	27
2.4.2	Strengthening of Masonry Structures	28
2.4.3	FRM - TRM Reinforcement in Joints	29
2.5	Interlocking Plastic Block Wall	30
2.5.1	Development of Interlocking Plastic Block System	30
2.5.2	Performance of Interlocking Plastic Blocks	31
2.5.3	Reinforcement of Interlocking Plastic Blocks	32
2.6	Summary and Identified Research Gap	33
3	Experimental Program	35
3.1	Background	35
3.2	Continuation of Research Program	35
3.3	Construction of Prototype Scaled-down T-Junction Joint	38
3.4	Test Setup and Applied Load Magnitudes	39
3.4.1	Static Stiffness Test Setup and Loading Parameters	39
3.4.2	Snap Back Test Setup, Instrumentation and Loading parameters	42
3.4.3	Hammer Impact Test and Loading Magnitude	44
3.4.4	Shake Table Test Setup and Instrumentation	46
3.5	Parameters to be Evaluated	47
3.5.1	Parameters to be Evaluated under Static Stiffness Test	47
3.5.2	Parameters to be Evaluated under Snap Back Loading	48
3.5.3	Parameters to be Evaluated under Hammer Impact Test	49
3.5.4	Parameters to be Evaluated under Harmonic Loading	50
3.6	Procedure for Empirical Equation Formation	51
3.7	Summary	51
4	Experimental Evaluation	53
4.1	Background	53
4.2	Lateral Load Displacement Capacity of IPB T-Junction Joint	54
4.3	Fundamental Frequency and Damping Ratio	57

4.4	Dynamic Response under Hammer Impact	62
4.5	T-Joint Behavior under Harmonic Loading	65
4.5.1	Acceleration Time Behavior	65
4.5.2	Displacement Time Behavior	68
4.5.3	Base Shear-Displacement Curves and Energy Absorption . .	72
4.6	Summary	78
5	Discussions	79
5.1	Background	79
5.2	Formation of Empirical Equations Considering Geometrical Parameters, Structure Behaviour and Input Loading Conditions	80
5.3	Translating Experimental Outcomes into Construction Practice . .	83
5.4	Summary	87
6	Conclusion and Future Work	88
6.1	Conclusion	88
6.2	Future Recommendations	90
	Bibliography	92

List of Figures

1.1	Previous Researches in Scaled down Masonry Elements	5
2.1	Damages at T-Joints during seismic activity (a)Back wall Joint (b)Facade wall joint (c)Side Wall Joint [8]	20
2.2	Effect of accounting for the equivalent tensile strength of the spandrel (ft,sp) and the presence of a coupled tensile resistant element in the seismic response of a two-story URM wall [40]	23
2.3	Comparison of predicted damage profiles; (a) Homogenous Shell Model; (b) FEMA strut model; (c) Tri-strut model; (d) AEM. [45]	25
3.1	Proposed mortar free interlocking plastic block House (a) Plan, (b) 3D, (c) Proposed Plastic Block, (d) Real Plastic Block	36
3.2	Consideration of T-joint; (a) plan and elevation of house with original T-joint consideration, (b) scaled-down and simplified boundary conditions and (c) T-joint with configuration Structure A and B.	37
3.3	T- Junction Joint construction details; (a) wall configuration Structure A and (b) wall configuration Structure B.	40
3.4	a) Schematic Drawing, b) Actual test set-up	41
3.5	Test Setup; (a) Schematic Diagram of T-Junction (b) Prototype of T-Junction	43
3.6	Test Setup; (a) Schematic Diagram of Hammer Impact (b) Prototype of T-Junction with Hammer Impact	45
4.1	Load-Displacement Curves; a). X-axis (Str. A) b). Y-axis (Str. A) c). X-axis (Str. B) d). Y-axis (Str. B)	55
4.2	$\ddot{u}$ -t from Snap-back test; (a) 25mm (Str-A-X) (b) 25 mm (Str-A-Y) (c) 50 mm (Str-A-X) (d) 50 mm (Str-A-Y) (e) 25mm (Str-B-X) (f) 25mm (Str-B-Y) (g) 50 mm (Str-B-X) (h) 50mm (Str-B-Y)	59
4.3	Fourier amplitude from snap back test: a) wall Str. A with 25 mm, b) Wall Str. A with 50 mm, c) wall Str. B with 25 mm and d) wall Str. B with 50 mm	61
4.4	Hammer Impact Test: (a) Structure A Graphs, (b) Structure B Graphs	63
4.5	Acceleration time history graphs of the T-Junction Joint	67
4.6	Displacement time history graphs of the T-Junction Joint	69
4.7	Q- Δ curves of T-Junction Joint	73

List of Tables

2.1	Mechanical properties and energy absorption of block masonry configurations [43]	24
3.1	Loading Details of Test Specimen	42
3.2	Snap-back Loading Magnitude	44
3.3	Harmonic Loading Parameters	47
4.1	Results from Static Stiffness Test	56
4.2	Snap-back Test Results	60
4.3	Hammer Impact Test Results	65
4.4	Wall's Contribution to T-Junction Joints Response	71
4.5	Energy Absorption during Dynamic Loading	75
5.1	Variation in experimental and empirical values for corner-joint of interlocking-plastic-block wall	82
5.2	Comparison of Variation in experimental and empirical with Previous Researches	83
5.3	Comparison with previous researches	84

List of Abbreviations

AD	Acceleration Data
AISC	American Institute of Steel Construction
FFT	Fast Fourier Transform
FRCM	Fabric Reinforced Cementitious Matrix
FRP	Fiber Reinforced Polymer
Hz	Hertz
IPB	Interlocking Plastic Block
MATLAB	Matrix Laboratory
mm	millimeter
MPa	Megapascal
OOP	Out-of-Plane
PBD	Performance-Based Design
RMS	Root Mean Square
SSI	SoilStructure Interaction
TRM	Textile Reinforced Mortar
URM	Unreinforced Masonry

Symbols

a	Area of interlocking plastic-block
d	Displacement
f_n	Fundamental Frequency
K	Lateral Stiffness / Structural Coefficient
m	No. of blocks in a single layer
n	No. of interlocking plastic-blocks
Q	Base shear
S	Number of stories
T_n	Natural time period
u_g	Average displacement
$\dot{u}_g$	Average Velocity
$\ddot{u}_g$	Average acceleration
Δ	Displacement in millimeter
ζ	Damping ratio

Chapter 1

Introduction

1.1 Background

Masonry structures generally exhibit low tensile strength and limited ductility, making them vulnerable to cracking and failure during seismic events. The rigid connections and mass of masonry elements contribute to high inertia forces, which can lead to significant structural damage or collapse under lateral ground motions. Various masonry systems are employed to resist lateral loads, including dry-stacked and interlocking designs known for their rapid construction and reduced labour needs. However, the lack of mortar bonding introduces structural weaknesses, particularly at junctions. T-joints, where perpendicular walls meet, are especially prone to stress concentrations and sliding failures under seismic forces due to interrupted load paths [1–3]. In mortar-free systems reliant on friction and geometric interlock, the lack of cohesive strength drastically diminishes tensile resistance, causing hairline cracks to initiate at junctions even under moderate loading, propagating along bed joints or into unit face shells [1, 4, 5]. The progression of damage is heavily influenced by vertical pre-compression: low axial loads accelerate sliding and crack opening, while high compression risks localized crushing at block edges [4, 5]. Imperfections in block geometry or construction misalignments further intensify stress irregularities, acting as premature initiators of failure [6, 7]. Dominant failure modes include inter-facial sliding shear-where lateral forces overcome frictional resistance-and localized unit crushing from

concentrated compressive stresses [6, 8, 9]. Under cyclic loading, a destructive "rocking-sliding" mechanism emerges, characterized by gap opening, impact upon closure, and progressive degradation of stiffness and energy dissipation capacity [3, 4]. These vulnerabilities are exacerbated in two-storey structures, where junction flexibility amplifies story drifts, torsional irregularities, and soft-story collapse mechanisms [6, 7]. The mechanical behaviour of mortar-free joints is fundamentally governed by contact interfaces, frictional resistance, and unit geometry rather than bonding agents. Cyclic shear tests confirm classic Mohr-Coulomb friction behaviour, where higher confining stress enhances friction coefficients but surface wear under repeated loading degrades performance over time [4, 10–12]. Interlocking shapes—particularly circular keys—improve Energy dissipation and delay sliding failure, though geometric irregularities from manufacturing or assembly create stress concentrations that reduce joint stiffness and provoke premature cracking [4, 10, 11]. Compression and shear tests reveal that interface roughness and contact area directly govern load capacity; increasing contact area (e.g., via grinding) can nearly double compressive strength, while inconsistent unit heights cause up to 30% stiffness variability [7, 13, 14]. Unlike mortared systems, joints exhibit near-zero tensile resistance, necessitating designs that maintain continuous compression to avoid detachment [3, 4, 15]. Under cyclic loads, hysteretic pinch behaviour reflects bending-compression interactions, accelerating stiffness degradation and permanent displacements [4, 11]. The inherent randomness in block morphology and contact surfaces further complicates predictive modelling, demanding frameworks that integrate friction degradation, load history, and geometric imperfections [9, 16].

Despite these challenges, recent research has pioneered damage-control strategies for mortar-free junctions, a systematic evaluation of confinement, reinforcement, and surface optimization techniques. Studies show that localized confinement (e.g., steel or RC tie columns at T-junctions) enhances lateral capacity by 64% and drift capacity by 288% by restricting sliding and mobilizing higher friction. Innovations like embedded FRP bars or TRM overlays add tensile continuity without mortar, significantly improving stiffness, energy dissipation, and crack resistance. Hybrid

strategies, integrating confinement, FRP/TRM reinforcement, and precision manufacturing, reduce crack propagation by $>40\%$, enhance ductility, and mitigate moisture ingress risks in two-storey systems. By unifying these approaches, this work provides actionable guidelines for enhancing junction resilience in sustainable mortar-free construction. The researchers have recently turned its attention toward lightweight structural alternatives, specifically Interlocking Plastic Blocks (IPB), evaluating their mechanical viability through difficult stress-strain analysis and energy-dissipation assessments. To bridge the gap between theoretical modeling and physical reality, the integration of three-dimensional shake tables, capable of operating across six degrees of freedom, has become essential. These platforms allow for the replication of complex seismic phenomena, providing a strong environment for the validation of prototype systems.

Despite these advancements, a pressing socioeconomic challenge persists: the demand for affordable, resilient housing in developing nations that can withstand intense seismic loading. While various mortarless interlocking configurations have surfaced in recent literature, a critical structural vulnerability remains overlooked, the T-joint mechanics of IPB assemblies in two-story masonry structures. Addressing this oversight, the present study introduces an innovative IPB construction methodology. By facilitating controlled interfacial sliding during a seismic event, these blocks effectively dissipate energy, offering a practical and high-performance solution for the next generation of earthquake-resistant residential construction.

1.1.1 Work Done till Today on IPB Wall System

The evolution of mortarless masonry systems has historically centered on maximizing energy dissipation and mitigating seismic impact. Early empirical models formulated by Khan [17] indicated that restraining interlocking plastic-block structures with rubber bands increased overall stiffness and limited peak top displacements during harmonic excitation. Expanding on this mechanism, Shahzad [18] observed that treating these rubber bands as vertical reinforcement notably enhanced the energy dissipation capacity of the block walls when subjected to similar harmonic loads. Beyond localized reinforcement, the integration of broader

structural components also alters dynamic behavior. Bashir [19] established that incorporating a wooden diaphragm, functioning to distribute lateral loads to vertical resisting elements like frames or walls, effectively constrained top-level drift while simultaneously boosting energy absorption within the plastic-block assemblies. Contrasting these flexible systems with traditional masonry highlights distinct failure mechanics. According to Afzal [20], solid unreinforced brick masonry (URM) structures are highly prone to collapse under severe loading, a failure directly attributable to the brittle mortar-brick interfaces. Lighter interlocking plastic-block solid walls (IPBSW), lacking these rigid bonds, navigate dynamic forces far more effectively through superior energy dissipation.

Structural discontinuities, such as openings, do not necessarily compromise this resilience. Investigations by Sudheer [21] confirmed that interlocking plastic-block walls containing window apertures maintained robust resistance and energy absorption capacities against lateral loads, systematically outperforming their URM equivalents. These unbonded systems also possess adequate load-bearing capabilities. Aslam [22] reported that plastic-block walls easily sustain their own self-weight under compression while leveraging their unbonded nature for crack mitigation and sustained energy attenuation. The specific geometric arrangement of the blocks dictates much of this in-plane dynamic response. Asad [23] demonstrated that block-return layouts allow for controlled relative movement between individual units, a kinematic shift that dramatically expands the system's ability to absorb seismic forces. Building on these layout complexities, Anwar [24] evaluated walls integrating both block-return configurations and diaphragms. This combined structural approach yielded exceptional seismic characteristics, particularly under out-of-plane loading, marked by heightened damping ratios, elevated base shear capacities, and maximized energy dissipation.

Thickness and joint geometry introduce additional mechanical variables. Adnan [25] determined that structural elements constructed two blocks wide achieved superior peak load capacities and better compressive energy absorption compared to single-block profiles, which typically suffered from abrupt, unheralded failure. The intersection of these walls presents highly localized dynamic challenges.

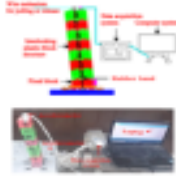
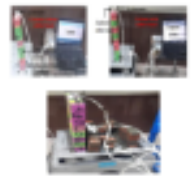
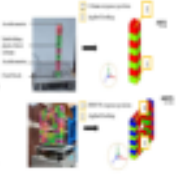
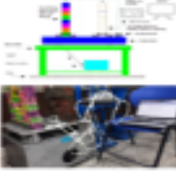
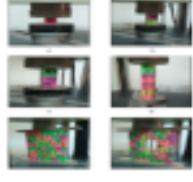
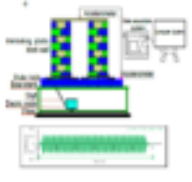
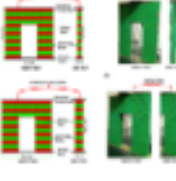
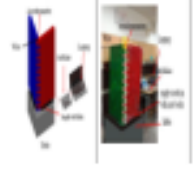
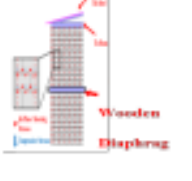
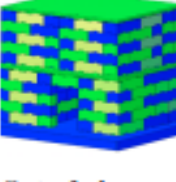
Fayaz Khan 2019  Dynamic Behaviour of Prototype Interlocking Plastic-block Structure	Khurram 2020  Effect of Block-Return on Out-of-Plane Behaviour of Interlocking Plastic-Block Walls	Hammad 2020  Dynamic Response of Interlocking Plastic-Block Walls with Diaphragm	Sohail Afzal 2020  Out-of-plane Behaviour of Prototype Interlocking Plastic-block Solid Wall
Mehran 2020  Out-of-plane Behaviour of Prototype Interlocking Plastic-block Wall	M. Sajid Aslam 2020  Compressive Behaviour of Interlocking Plastic Block Structural Elements	Sardar Junaid 2020  Block-Return on Dynamic In-Plane Behaviour of Interlocking Plastic Block Walls	Shaukat Anwar 2020  Effect of Diaphragm on Dynamic Behaviour of Interlocking Plastic-Block Structure
M. Adnan 2020  Effect of Slenderness on the Behaviour of Interlocking Plastic-Block	Waseem Akram 2025  Dynamic Performance of Corner-Joints in Mortar-Free Interlocking Plastic-Block Walls	Arshad Ullah 2025  Behaviour of Mortar-Free Interlocking Plastic-Block Walls at Junctions	Jawad Nasar 2025  Compressive Behaviour of Interlocking Plastic Block Structural Elements
Abu Bakar 2025  Out-of-plane Dynamic Behaviour of Double-Story Interlocking Plastic-Block			

FIGURE 1.1: Previous Researches in Scaled down Masonry Elements

Akram [26] identified that the resilience of interlocking plastic corner joints relies heavily on the specific block layout; optimizing this arrangement drastically improves energy absorption across a spectrum of seismic frequencies. Arshad Ullah [27] corroborated these findings, noting that mortar-free junctions exposed to harmonic loading exhibit substantial structural damping, reinforcing the viability of these systems for low-cost earthquake-resistant construction. Despite these extensive investigations, the literature remains heavily skewed toward single-story applications. A few notable exceptions exist; Nasar [28] and Abu Bakar [29], for instance, successfully characterized the in-plane and out-of-plane behavior of double-story configurations. Yet, a glaring void persists regarding the performance of critical structural nodes at this elevated scale. Unlike conventional studies that prioritize beam-column intersections in frame structures, this investigation is exclusively dedicated to load-bearing walls utilizing unbonded, mortar-free interlocking masonry. The dynamic response of two-story T-junctions remains virtually undocumented. Addressing this specific omission, the present study evaluates the structural behavior and energy dissipation mechanics of these vulnerable T-joints within unbonded, double-story plastic-block walls.

1.2 Research Motivation and Problem Statement

Conventional masonry housing remains highly vulnerable to seismic events, often resulting in tragic loss of life and disastrous structural failure. Although advanced engineering solutions exist to strengthen residential buildings, their high implementation costs frequently render them inaccessible in developing or low-income regions. Consequently, there is a critical motivation to explore and validate affordable, innovative structural alternatives, such as mortar-free interlocking plastic block construction for double-story houses. This cost-effective approach not only aims to enhance life-safety and seismic resilience through flexible energy dissipation, but it also substantially minimizes post-earthquake rehabilitation expenses. Therefore, the primary motivation of this research is to advance the understanding of these dry-stacked systems, offering a sustainable and economically feasible

alternative to traditional building practices in active seismic zones. Thus, the problem statement is as follows:

Conventional unreinforced masonry exhibits severe vulnerability to dynamic seismic ground motions due to the negligible tensile strength of traditional mortar joints, which frequently initiates brittle interfacial failure and partial structural collapse. While mortar-free interlocking plastic block construction offers a highly ductile, lightweight alternative capable of dissipating seismic energy through dry friction, the existing empirical literature is overwhelmingly restricted to single-story, low-axial-load applications. Introducing a second story fundamentally alters this dynamic. The elevated center of mass amplifies global overturning moments, forcing perpendicular T-junctions to absorb complex out-of-plane shear demands without the stabilizing benefit of a cohesive mortar bond. Under lateral ground excitation, these unbonded internal intersections become the primary kinetic weak points of the structural system, making them susceptible to progressive joint gap opening, localized edge crushing, and uncontained sliding. To date, no systematic experimental research has quantified the static load-displacement capacity, stiffness degradation, or free-vibration damping kinetics of double-story polymeric T-junctions. Consequently, practicing engineers lack the physical baseline required to predict global soft-story failure mechanisms or to verify the structural integrity of multi-story, mortar-free residential buildings.

1.2.1 Research Questions

- i. How does the inherent geometric asymmetry of a two-story, mortar-free interlocking plastic block T-junction dictate its directional lateral stiffness along orthogonal axes?
- ii. What is the primary natural frequency of a mortar-free T-junction, and to what extent does its inherent structural damping facilitate passive energy dissipation?

- iii. How does localized transient impact loading affect the dynamic attenuation, oscillation frequency, and structural damping capacity of a two-story, mortar-free T-junction?
- iv. How do specific block configurations and orthogonal lateral vulnerabilities govern the structural damping, cumulative energy dissipation, and non-linear sliding mechanics of a two-story, mortar-free T-junction under continuous harmonic excitation compared to empirical models?

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

This research evaluates the three-dimensional seismic response of a full-scale, double-story structure constructed entirely from mortar-free interlocking plastic blocks (IPBs). By utilizing simulated earthquake loading during controlled laboratory experiments, the study systematically quantifies structural integrity, isolates failure modes, and maps energy dissipation capacities. Validating the mechanical behavior of two-story configurations addresses a critical gap within current literature, providing the essential empirical baseline required to engineer safer, economically accessible residential infrastructure across highly active seismic regions.

This research systematically evaluates the dynamic performance of T-joints in mortar-free interlocking plastic block (IPB) walls under simulated seismic excitation. Utilizing a locally fabricated shake table, the experimental methodology extracts critical structural parameters, including natural frequency, global damping ratios, energy dissipation capacities, and localized failure mechanisms. Quantifying these metrics rigorously tests the physical viability of IPB assemblies for earthquake-resistant design, directly addressing a recognized literature deficit regarding double-story structural behavior. Ultimately, securing these empirical insights advances affordable, mortarless building techniques, tailoring IPB technology for safe, multi-story residential deployment across highly active seismic regions.

1.4 Scope of Work and Study Limitations

This research entails the construction of a prototype T-joint within a mortar-free interlocking plastic block (IPB) wall, utilizing specially designed blocks to ensure structural integrity. The wall is assembled on a fixed base to replicate realistic boundary conditions encountered in actual buildings. Experimental testing involves applying three distinct loading frequencies to evaluate the dynamic response of the T-joint, with observations focused on displacement-time and acceleration-time histories to capture the structure's behavior under simulated seismic conditions. Additionally, a snap-back test is performed to determine the natural frequency and damping ratio of the wall. Leveraging the acquired data, empirical equations are developed to model the dynamic characteristics of the T-joint, thereby enhancing the overall understanding of its performance in mortar-free IPB systems. The investigation is constrained by the utilization of a simple one-dimensional shake table, which limits testing to uniaxial loading and does not account for multi-directional seismic forces. The raw data obtained from MATLAB is confined to acceleration-time histories, necessitating additional processing and conversion via SeismoSignal software for comprehensive analysis. Despite these constraints, they enable a targeted and manageable inquiry, establishing a foundation for subsequent studies employing more sophisticated equipment and expanded testing parameters.

1.4.1 Rationale behind the Variable Selection

The selection of variables in this study is strategically aligned with the broader research program's objectives, focusing on advancing mortar-free interlocking plastic block (IPB) construction for seismic resilience. The T-joint configuration in two-story masonry structure was chosen due to its understudied nature compared to other joint types, allowing this work to address a critical gap in evaluating multi-directional load transfer in double-story structures. A 1/10 scale was applied exclusively to elevation dimensions, adhering to Method A of UBC-97, which correlates time-period with structure height to ensure accurate simulation of dynamic responses without scaling horizontal aspects that could distort in-plane behaviour.

Wall lengths of 200 mm on either side were selected to exceed the block return significantly, providing sufficient structural representation while maintaining practicality for laboratory testing. The interlocking plastic blocks, with dimensions of 62 x 62 mm base, 50 mm height, and 12 mm key, were prioritized for their lightweight properties and superior energy absorption compared to traditional masonry walls, enhancing overall seismic performance [17]. Rubber bands served as vertical reinforcement to preserve corner-joint integrity under harmonic loading, offering a simple yet effective means of simulating tensile resistance. Laboratory testing on a small-scale prototype was adopted as a cost-effective approach to determine fundamental frequency and maximum failure acceleration, with unidirectional loading and simplified boundary conditions imposed based on available facilities, enabling focused analysis of the corner-joint's dynamic response while laying the foundation for future expanded investigations.

1.5 Brief Methodology

Constructing the experimental model required a 1:10 scaled-down T-joint assembled entirely from interlocking plastic blocks. The test specimen incorporated 130 individual units arranged across ten vertical layers. To enforce rigid boundary conditions and prevent premature foundation sliding, steel angle sections firmly anchored the base of the assembly to the testing platform. Monitoring the structural response of this unbonded system depended on a precise instrumentation layout. Five accelerometers captured the real-time kinematics: two secured at the upper free ends of the perpendicular walls, one fixed at the top of the central intersection, another positioned at the lower junction node, and a final sensor mounted directly on the base plate to record the input ground motion. An Arduino microcontroller, interfaced with a laptop, managed the continuous data acquisition protocols through MATLAB. The empirical evaluation progressed through a sequence of targeted mechanical phases. Initial static stiffness testing applied a controlled, monotonic lateral displacement to the specimen, establishing the baseline lateral resistance and initial yield capacity of the dry-stacked joint. Following this static profiling, the assembly underwent a standard snap-back test. A 400 mm

wire displaced the wall along the X-direction before a sudden release generated a decaying acceleration-time history. Applying the logarithmic decrement method to these free-vibration curves isolated the fundamental natural time period, resonant frequency, and structural damping ratio. A localized hammer impact test followed. Striking the masonry with a hammer, exposing how the unbonded nodes process sudden transient shocks.

Continuous seismic excitation was subsequently simulated using a locally fabricated one-dimensional shake table. This apparatus drove the foundation at steady harmonic frequencies of 1.0 Hz, 1.2 Hz, and 1.4 Hz. Because the initial datasets exported from MATLAB consisted exclusively of raw acceleration-time histories, SeismoSignal software processed the arrays to apply necessary baseline corrections and filter ambient experimental noise. Extracting the core structural mechanics demanded specific analytical derivations. Multiplying the total mass of the specimen by the acceleration readings captured at the upper T-joint yielded the corresponding base shear. Operating under the assumption that the structural mass remained concentrated at the top of the specimen, researchers generated comprehensive base shear-displacement curves. These profiles facilitated the calculation of both the average energy dissipated per single hysteretic loop and the total cumulative energy absorbed by the system across the loading cycles. To analytically predict this dynamic response, new empirical equations were formulated. These mathematical models integrated the total height of the T-joint, the specific interlocking geometry of the plastic units, and the observed macroscopic behavior of the physical assembly. Comparing these theoretical derivations against the experimental data confirmed the accuracy of the proposed framework, with the calculated deviations falling strictly within acceptable predictive limits.

1.6 Research Impact on Industry

1.6.1 Research Novelty - Uniqueness

Although several interlocking techniques have been investigated to enhance the seismic performance of masonry structures, the dynamic behavior of T-joints in

two-story mortar-free systems has received very limited attention. Existing studies have primarily concentrated on single-story models or on corner joints, often neglecting the critical role of T-junctions in maintaining overall wall integrity under dynamic excitation. Moreover, experimental investigations utilizing simple one-dimensional shake tables remain scarce, particularly for evaluating the seismic performance of scaled prototypes with interlocking plastic block walls.

This research is unique in that it specifically targets the dynamic response of T-joints in a two-story mortar-free configuration, an area that has not yet been systematically studied. By employing lightweight interlocking plastic blocks and scaled laboratory testing, the study introduces an innovative and cost-effective approach to simulate and analyze structural performance under seismic loading. The outcomes are expected to provide new insights into joint behavior, energy dissipation mechanisms, and failure patterns, thereby addressing a critical knowledge gap in current literature and contributing to the advancement of affordable earthquake-resilient construction practices.

1.6.2 Research Significance and Benefit

This study holds significant importance as it seeks to advance the understanding of T-joint behavior in mortar-free interlocking construction, a structural component that plays a decisive role in the stability and resilience of two-story buildings under dynamic loading. By experimentally evaluating the seismic response of such joints, the research will provide valuable insights into their natural frequencies, damping characteristics, energy dissipation capacity, and potential failure mechanisms. The outcomes are expected to contribute toward the formulation of low-cost yet effective design strategies for earthquake-resistant housing, offering an alternative to conventional masonry that is both economical and sustainable. Beyond improving safety in seismic-prone regions, the adoption of mortar-free interlocking systems can substantially reduce construction time, minimize rehabilitation costs after earthquakes, and promote the use of lightweight, reusable materials. Ultimately, this research bridges a critical knowledge gap and supports the development of

practical engineering solutions aimed at saving lives while fostering resilient and eco-friendly housing technologies.

1.6.3 Practical Implementation

The outcomes of this study can be directly applied to the development of affordable and resilient housing solutions in earthquake-prone and disaster-affected regions. The use of mortar-free interlocking plastic blocks allows for rapid assembly without the need for skilled labor, making it highly suitable for emergency shelter construction in collaboration with disaster relief organizations. Due to their modular design, these blocks can be scaled up for permanent housing or adapted to temporary structures depending on community needs. Their lightweight and recyclable nature ensures easy transportation, reduced construction costs, and minimal environmental impact. In practical terms, the system offers a dual benefit: it provides immediate, low-cost shelter solutions following natural disasters and also supports long-term strategies for sustainable, inclusive urban development by offering durable, adaptable, and eco-friendly housing alternatives.

1.6.4 National and Global Impact with Emphasis on SDGs Relevance

This research carries both national and global significance by advancing affordable, resilient, and sustainable housing solutions that directly contribute to disaster risk reduction and community safety. At the national level, it supports safer urban development, reduces post-disaster rehabilitation costs, and strengthens local construction industries by creating new job opportunities and engaging unskilled labor in innovative building practices. Globally, the study addresses pressing challenges of housing shortages and disaster vulnerability, providing scalable and adaptable construction solutions that can be implemented in diverse geographic and climatic contexts. The research strongly aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) through promoting resilient housing, SDG 9 (Industry, Innovation, and Infrastructure) by fostering construction-sector innovation, SDG 8 (Decent Work and

Economic Growth) by creating employment opportunities, and SDG 13 (Climate Action) by encouraging the use of lightweight, recyclable materials that reduce environmental impact. Furthermore, its integration into academic curricula and policy frameworks enhances capacity building and evidence-based decision-making, ensuring long-term national resilience while contributing to global sustainability and inclusive development agendas.

1.6.5 Research Challenges

Several challenges are anticipated in the execution of this research. One major challenge lies in the limitations of experimental facilities, particularly the use of a one-dimensional shake table, which restricts the ability to simulate realistic multi-directional seismic excitations. Ensuring accurate data acquisition is another difficulty, as the limited number of accelerometers may not fully capture the complete dynamic response of the structure, especially for displacement and velocity profiles. The filtering and post-processing of raw accelerometer data through software such as SeismoSignal may also introduce uncertainties, affecting the reliability of derived parameters such as damping ratios and energy dissipation. Scaling issues present additional complexities, as the 1:10 scaled model may not perfectly replicate material properties and load transfer mechanisms of full-scale structures. Maintaining joint integrity under repeated loading cycles, while ensuring consistent performance of lightweight plastic blocks, could also pose practical difficulties during testing. Furthermore, integrating empirical findings with advanced numerical simulations will require careful calibration and validation to minimize discrepancies between experimental and computational results. Collectively, these challenges highlight the need for rigorous experimental design, careful data interpretation, and complementary simulation tools to ensure the robustness of the research outcomes.

1.6.6 Ethical and Management Consideration including Risk Management

This research is guided by strong ethical and management principles to ensure responsible and transparent execution. Ethical integrity is maintained by openly

reporting all findings, including limitations, and by making the developed technology accessible for affordable housing solutions. Fair recognition and compensation are ensured for all collaborators, while strict compliance with university health and safety regulations safeguards the well-being of participants during laboratory experiments. Sustainability is also emphasized, with careful use of resources to minimize both environmental and economic impacts, aligning the study with broader societal goals of responsible innovation.

From a management perspective, the project follows a structured schedule with defined milestones to ensure timely completion of activities. Effective collaboration among researchers, technical staff, and local stakeholders fosters inclusivity, accountability, and shared ownership of outcomes. Risk management strategies are also embedded within the research plan. Potential risks-such as equipment malfunction, data acquisition errors, or scaling inaccuracies-are mitigated through regular calibration of instruments, backup testing protocols, and cross-validation with numerical simulations. External risks, including delays in resource availability or disruptions in laboratory facilities, are addressed by contingency planning and adaptive scheduling. By integrating these ethical and managerial considerations, the research ensures not only scientific rigor but also social responsibility, setting a benchmark for sustainable and resilient housing research.

1.6.7 Research Deliverable, Sales and Marketing Potential

The research will generate both scientific knowledge and practical outputs to advance affordable and resilient housing solutions. Key deliverables include: **Experimental Data and Models:** Detailed insights into the dynamic behavior of T-joints in mortar-free interlocking plastic block (IPB) systems, including natural frequency, damping ratios, energy dissipation, and failure mechanisms. **Design Guidelines:** Practical recommendations for the construction of two-story mortar-free IPB structures, providing a reference framework for engineers, housing developers, and disaster relief agencies. **Prototype Demonstration:** A validated small-scale prototype highlighting the feasibility, ease of assembly, and structural

performance of IPB-based housing systems. Awareness Material: Knowledge dissemination through workshops, seminars, and academic publications to inform stakeholders about the benefits of adopting IPB construction.

The research outcomes have strong commercialization prospects, particularly in the affordable housing and disaster relief sectors. The modular, mortar-free IPB system offers cost-effective, rapid, and scalable construction, making it attractive for construction companies, housing developers, and governments addressing housing shortages. Its adaptability to diverse climates and local materials enhances market acceptance across regions. The technology's potential aligns with the global push for sustainable housing, tapping into markets driven by the UN Sustainable Development Goals (SDGs). Marketing can focus on three core advantages: low cost, speed of deployment, and eco-friendly design. Partnerships with NGOs, disaster relief organizations, and local governments can accelerate adoption, while pilot projects in vulnerable communities can showcase its practicality and reliability. Ultimately, the research sets the foundation for both national and international market entry, positioning the IPB system as a transformative solution in the global affordable housing sector.

1.7 Thesis Layout

Chapter 1 is the introduction. It covers the background, what motivated the study, the problem being addressed, the overall goal, the specific objectives, the scope of work, limitations of the study, the method used, and how the thesis is laid out.

Chapter 2 reviews previous work. It gives background information, looks at damage seen in traditional masonry buildings during earthquakes, discusses new approaches for making structures earthquake resistant, talks about how stiffeners affect masonry construction, reviews how scaled models behave under lab testing, and ends with a summary.

Chapter 3 describes the experiments. It includes the background, how the T joint was built in a mortar free interlocking plastic block wall, the test setup, the snap back test arrangement, the harmonic loading done with a shake table, the variables investigated, how empirical equations were developed, and a chapter summary.

Chapter 4 presents the experimental results. It covers the background, findings from the snap back test, how the wall responded to harmonic loading, calculations of damping ratio, base shear, and energy absorption, and wraps up with a summary.

Chapter 5 is the discussion. It includes the background, how the empirical equations compare with the experimental data, what the findings mean for real world applications, and a summary.

Chapter 6 gives the conclusions and recommendations.

After that comes the list of references, and at the very end are the annexes.

Chapter 2

Literature Review

2.1 Background

Earthquakes expose the inherent brittleness of traditional unreinforced masonry, where high structural mass generates enormous inertial forces during ground acceleration. The structural collapse rarely initiates in the centre of a solid wall panel; instead, damage aggressively localizes at intersecting boundaries. T-junctions act as critical mobile nodes governing out-of-plane stability, suffering complex multi-directional shear and tensile stress concentrations under seismic loading. In conventional bonded systems, these internal corners force hairline cracks to propagate along bed joints long before primary wall panels yield. To bypass the brittle failure of cohesive mortar and reduce construction costs, recent engineering research has pivoted toward mortar-free interlocking block assemblies. Eliminating the bonding agent fundamentally modifies the structural kinetics, shifting load transfer entirely to dry interface friction, geometric occlusion, and vertical pre-compression. While unbonded configurations can enhance overall energy dissipation, they introduce a unique set of vulnerabilities at perpendicular connections. At the T-junction of a dry-stacked assembly, interfacial sliding shear and a destructive rocking-sliding mechanism dictate the failure mode. Gap opening during lateral drift drastically reduces the frictional contact area, leading to progressive stiffness degradation and permanent displacement. Extrapolating this frictional behavior into multi-storey configurations amplifies joint flexibility, significantly increasing the risk of

soft-story mechanisms and torsional irregularities. Addressing these specific weaknesses demands targeted damage-control strategies to mobilize friction and safely restrict joint displacement. However, the unreinforced static and dynamic capacities of these specific polymeric structural nodes remain largely undocumented. Consequently, this chapter systematically reviews the seismic degradation of conventional masonry junctions, details the interfacial friction mechanics of mortar-free systems, and evaluates contemporary strengthening techniques required to stabilize multistorey assemblies.

2.2 Junction Damage in Masonry Structure

2.2.1 Seismic Vulnerability of Masonry Structure

Junction joints, particularly T-junctions where walls intersect perpendicularly, represent critical weaknesses in masonry structure due to complex stress concentrations and inherent discontinuities in load path. Under in-plane lateral loads, such as seismic forces, significant shear and tensile stresses develop at the internal corner of the junction, often exceeding the capacity of the joint interface or the integral units themselves. In conventional masonry systems, which depend on mortar bonding and unit interlock, the limited tensile strength of the mortar can lead to crack initiation at connection points. These areas are especially weak under moderate loading due to the inherent vulnerability in resisting tension and differential movement. [1–3, 28, 30]. Initial damage typically manifests as fine vertical or diagonal hairline cracks originating precisely at the internal corner of the T-Junction, propagating along the bed joint of the intersecting wall and potentially into the face shells of the unit. The progression of these cracks is heavily influenced by the level of vertical pre-compression; low axial load offers minimal frictional resistance to sliding or crack opening, accelerating damage, whereas high compression can suppress tensile cracking but risk triggering local crushing of block edges or corners at the interface [5, 29, 31, 32]. Figure-1 shows block masonry failure at T-joints [6, 8, 33, 34] during earthquake of $M_w=6.3$. Imperfection in block geometry, minor construction misalignments, or uneven bearing surfaces significantly intensify stress irregularities, acting as premature initiators of cracking

and slippage that compromise the joint's integrity before theoretical capacities are reached [35]. The top part of the building, usually ineffectively connected with the roof, acts as a cantilever about their base or the beneath floor level [8, 36] as shown in figure-1. Similarly, walls with sufficiently connected transversal walls experience two-way bending, categorized by larger capacity in contrast with the former. Numerous cases [10] were observed in which one middle wall was common between two structural units; yet one of them was just resting on the common wall, lacking connection. Such formation usually appears when the two units were built at different stages, and the latter unit increased the internal space by utilizing the existing wall. Given the severe structural damage observed in masonry T-junctions during seismic events over the past six years, this specific joint was selected as the primary focus of this study to address a critical vulnerability.

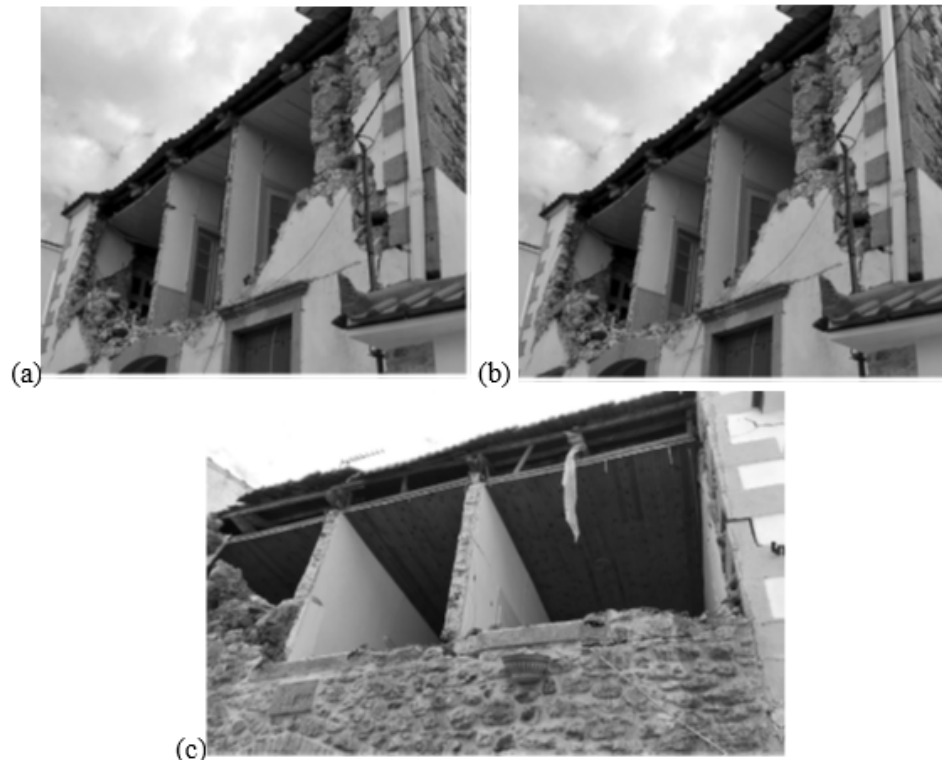


FIGURE 2.1: Damages at T-Joints during seismic activity (a)Back wall Joint (b)Facade wall joint (c)Side Wall Joint [8]

2.2.2 Damage Mechanism at Junctions in Masonry

The dominant failure modes observed at mortar-free junctions joint under progressive loading involve sliding shear along the bed joint interface and localized

crushing of unit edges. Sliding shear occurs when the lateral forces overcome the frictional resistance (governed by the coefficient of friction and the normal force) and any contribution from mechanical interlocking or shear keys; this results in a relative horizontal displacement between the intersecting walls at the junction, often accompanied by audible grinding and visible powdering of the contact surfaces [11, 16]. Sliding shear occurs when lateral forces exceed friction resistance which are comparatively 20% lower in out of plane behavior [11]. Localised crushing, conversely, arises from excessive compressive stresses concentrated on the small bearing areas at the internal corner, leading to spalling, fragmentation, or splitting of the masonry units, especially if the block possesses lower compressive strength or has imperfectly aligned bearing surfaces [13, 36]. Under cyclic or seismic loading, a combined rocking-sliding mechanism frequently emerges, where the junction experiences a cycle of gap opening (reducing contact area and thus frictional resistance), followed by impact upon closure and subsequent sliding, leading to progressive degradation, loss of stiffness, pinched hysteresis loops, and accumulation of permanent displacements [3, 37]. The inherent lack of tensile capacity also means that any out-of-plane forces acting on one of the walls forming the junction can induce significant bending moments, further promoting crack opening and detachment at the joint, severely compromising the structure's overall stability.

2.2.3 Dynamic Loading Effect on Junction Performance

Seismic excitation dramatically amplifies damage potential at junction joints due to bidirectional, dynamic, and high-strain-rate loading. The complex, multidirectional ground motions can induce simultaneous in-plane and out-of-plane demands on the connected walls, subjecting the T-junction to combined shear, bending, and torsion that far exceed unidirectional static capacities [13]. Cyclic loading produces combined rocking and sliding behavior due to 37% reduced strength at joints [13]. Damage often localizes intensely at these junctions, forming soft zones that dissipate energy through friction and localized crushing but also lead to significant residual deformation and potential collapse mechanisms, such as the separation of the perpendicular walls or the disintegration of the junction region itself [7]. Long-term durability concerns also arise; cyclic damage creates pathways for the

moisture ingress, leading to freeze-thaw deterioration of the units or corrosion of any supplemental reinforcement, while accumulated fine debris from friction and crushing within the joint can reduce interlock effectiveness and increase long-term settlements [9]. Furthermore, the flexibility introduced by damaged or poorly performing junctions alters the global dynamic response of two-story structures, potentially leading to torsional irregularities or higher-mode effects that concentrate damage on upper story's, underscoring the systemic importance of strong junction detailing and performance. Perpendicular masonry junctions constitute the primary kinetic weak points of a structure, failing through a predictable sequence of sliding shear, localized unit crushing, and cyclic rocking under lateral ground motions. This localized, interface-level deterioration compromises out-of-plane stability and systematically amplifies torsional irregularities across the entire multi-story assembly.

2.3 Emerging Techniques in Masonry

2.3.1 Techniques for Improving Seismic Performance

Emerging techniques in masonry focus enhancing structural performance through advanced confinement methods, improved reinforcement detailing, and innovative materials. These include reinforced conventional masonry with confined boundary elements and the development of mortar-free interlocking systems that offer improved ductility and seismic resistance. Mortar-free systems rely on friction and geometric interlocking and lessor compressive strength up to 15% [14]. Confined masonry structures perform better in seismic activity than unreinforced masonry. Gioffre et al. [38] performed the dynamic response using intensity measures, drift and acceleration profiles, and the observed damage evolution. The obtained results highlight the better performance of CM vs URM to withstand dynamic loads and provide crucial information to be used for numerical models' calibration and response estimation. Dry stacked or mortar free masonry systems exhibit a distinct mechanical behavior fundamentally governed by contact interfaces, frictional resistance, and unit geometry rather than bonding agents. Recent cyclic shear testing

of mortarless brick joints demonstrated classic MohrCoulomb friction behavior under varying compression levels, with higher confining stress leading to increased friction coefficients and reduced variability across joint types [7,9,39]. Studies from 2022 onward confirm that interlocking shapes-particularly circular interlocks-may enhance energy dissipation and stiffness (resistance to elastic deformation) under repeated loading cycles, making them preferable for seismic prone regions [9]. Figure -2 Effect of accounting for the equivalent tensile strength (absolute maximum load or stress a structure can withstand before it permanently yields, breaks, or fails) of the spandrel (ft,sp) and the presence of a coupled tensile resistant element in the seismic response of a two-story URM wall [40,41]. Higher compression in-

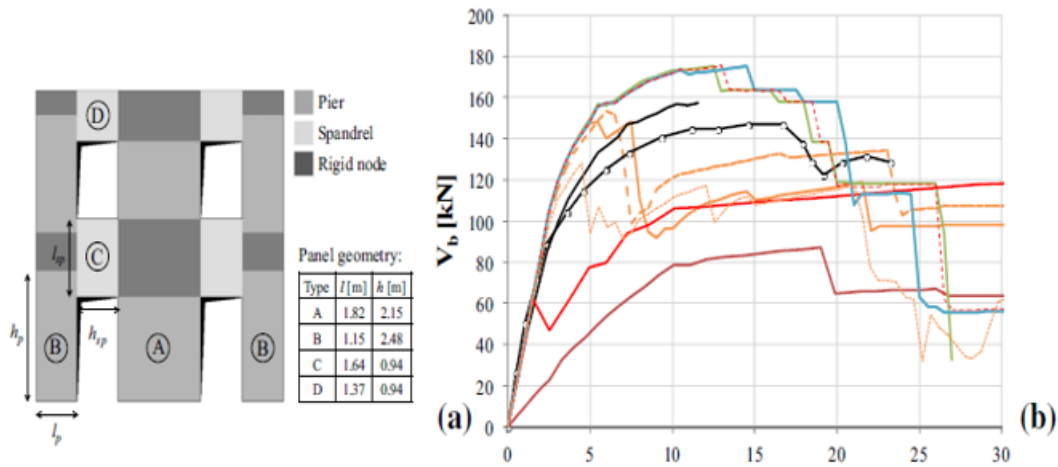


FIGURE 2.2: Effect of accounting for the equivalent tensile strength of the spandrel (ft,sp) and the presence of a coupled tensile resistant element in the seismic response of a two-story URM wall [40]

creases friction capacity and joint stability increase by 13% [40]. The test results shows that higher resistance to cracking during earthquake than normal masonry unit [4]. These joints lack cohesion, so slipdominated failure modes prevail after interface debonding, transitioning into a frictionsliding stage. As the number of load cycles increases, wear develops and friction characteristics degrade, emphasizing the importance of surface conditions. Interface condition and compression pre stress significantly determine initial stiffness and hysteretic loop shape. Geometric irregularities or assembly imperfections, including height variation or surface roughness, create localized stress concentrations, reducing joint stiffness and increasing premature cracking [42].

2.3.2 Experimental and Numerical Evaluation of Masonry System

Large scale experiments on dry joint masonry emphasize how joint geometry, loading history, and material irregularities interact to determine structural response.

TABLE 2.1: Mechanical properties and energy absorption of block masonry configurations [43]

Structural Member	Load (kN)	Stress (MPa)	Strain (10^{-3})	Modulus of Elasticity (GPa)	Energy (Peak) (10^{-3} N·m)	Energy (Post) (10^{-3} N·m)	Tough. Index
One Block Wide columns	1.3	3.85	1.7	176.67	4.81	0.24	1.05
Two block Wide column	2.8	2.28	32.1	120.69	13.71	42.35	4.09
One Block Wide Solid Wall	4.1	0.94	57.0	22.28	6.18	23.42	4.79
Two Block Wide Solid Wall	11.7	1.36	68.3	13.55	26.32	19.22	1.73

For example, multi-unit prisms subjected to cyclic out of plane loading exhibited tensile and shear cracking patterns concentrated at interfaces where friction was insufficient to prevent slip [9]. The observed hysteretic pinch behaviour in load-displacement curves reflects combined bending and compression effects, leading to degraded stiffness under repeated reversals [14]. The out-of-plane strength and stiffness of the new flexible connection increased by 119.8% and 104.2% than that of traditional flexible connection [13]. Dry stone contact experiments with multiple stone types also highlight that contact randomness and block morphology strongly influence joint stiffness and failure modes [44]. In all cases, a lack of mortar bonding shifts the mechanism from cohesive failure to mechanisms controlled by interfacial friction, block-to-block occlusion, and geometric locking. This shift makes precise control of unit tolerances, surface preparation, and assembly quality critical in achieving desirable performance. Moreover, the friction angle, initial compression pressure, and surface wear are dominant variables in defining load capacity and post-peak displacement. These findings suggest that any predictive

or analytical model for mortar free systems must incorporate interface characterization, friction degradation, and geometric irregularity for realistic behaviour prediction. Qazi et al. [45] investigated the nonlinear behavior of scaled infilled masonry (IFM), confined masonry (CM), and reinforced concrete (RC) structures by utilizing and validating two tests from the literature as benchmarks. Numerical modeling of small-scale (1:4 and 1:3) IFM, CM, and RC models has been carried out with Finite Element Modelling (FEM) and Applied Element Modelling (AEM) techniques using SAP2000 and the Extreme Loading for Structures (ELS) software, respectively. The evaluation of the pushover analysis results revealed that for IFM, the %age difference of tangent stiffness was 4.2% and 13.5% for FEMA Strut and AEM, respectively, and the %age difference for strength was 31.2% and 2.8% for FEMA Strut and AEM, respectively. Similarly, it was also

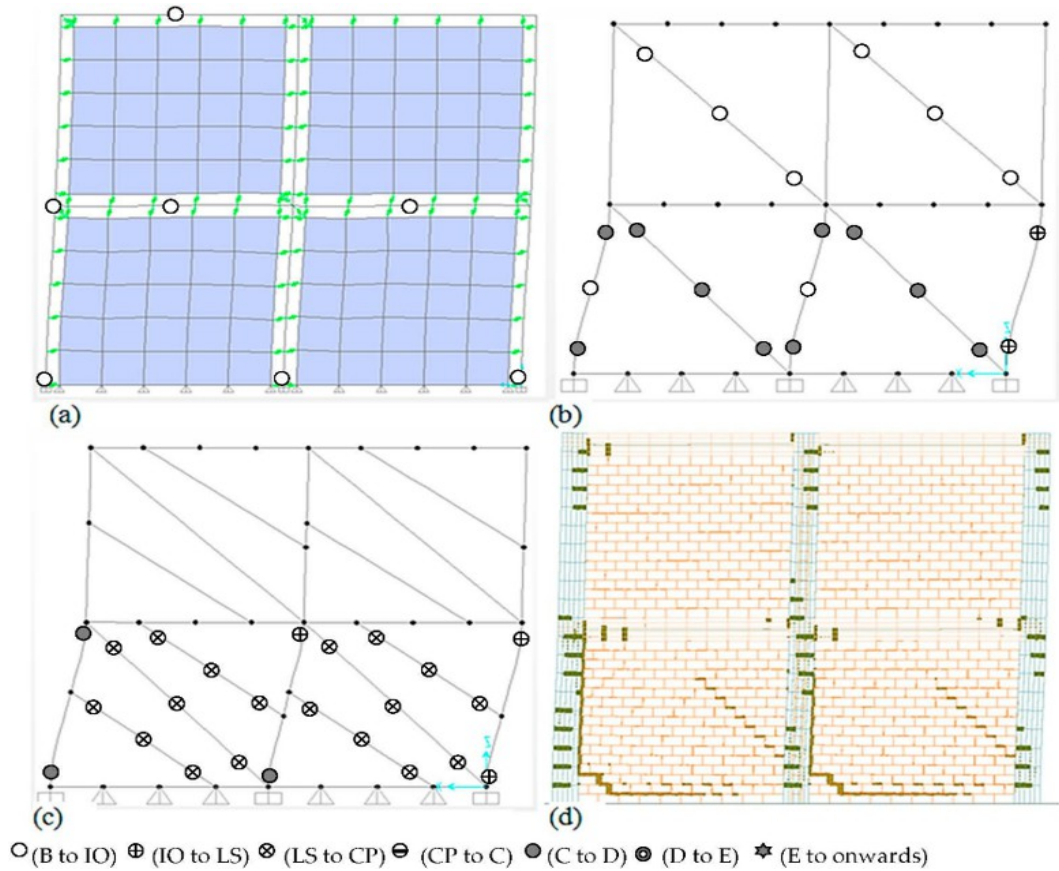


FIGURE 2.3: Comparison of predicted damage profiles; (a) Homogenous Shell Model; (b) FEMA strut model; (c) Tri-strut model; (d) AEM. [45]

calculated for other wall types. Dynamic analysis results from FEM and AEM techniques were found in the fairly acceptable range before yield; however, be-

yond yield, AEM proved more stable. The study highlighted that AEM provided better post-yield accuracy in simulating nonlinear behavior, particularly in capturing progressive damage and failure mechanisms. FEM results aligned well in the elastic range but showed limitations in representing complex cracking patterns after yielding. Overall, AEM demonstrated greater potential for realistic seismic performance assessment of IFM, CM, and RC structures. To overcome the seismic vulnerabilities of traditional cohesive mortar, contemporary masonry techniques leverage confined boundary elements and unbonded interlocking blocks that dissipate dynamic energy through controlled dry friction. However, optimizing these mortar-free systems requires strict dimensional tolerances to maximize interfacial contact area and advanced nonlinear numerical modeling to predict progressive post-yield sliding degradation accurately.

2.3.3 Seismic Performance of Mortar-free Masonry

In compression and shear tests, dry stack prisms built with standard concrete masonry units showed that interface roughness and contact area directly influence both stiffness and ultimate load capacity. Contact area strongly influences stiffness and compressive load capacity increased by 36% [46]. The research indicates that when contact area between units increases (through grinding or auxiliary layers), compressive capacity can rise significantly-sometimes nearly doubling when contact area approaches nominal area [47, 48]. Assemblies with irregular unit heights exhibited up to 30% variation in stiffness across specimens due to inconsistent contact surfaces [44]. Dry joint variability not only impacts compressive behaviour but also affects out of plane stability, where cracking initiates at high stress zones between misaligned units. Assemblies tested in multi block configurations revealed that global behaviour may average out local variability, but failure typically concentrates at weaker joints. The friction coefficient tends to increase with axial compression, yet joint closure and wear mechanisms still govern postpeak performance. Consequently, the mechanical response of mortar free systems is complex, combining nonlinear friction, localized crushing, and slip phenomena under realistic loading protocols. Adnan et al. [43] did experimental research on behaviour

of interlocking plastic blocks which provide results shown in Table-1. Interlocking plastic blocks dissipated more energy and provided better toughness as compare to normal masonry construction. Relationships between the compressive strength of interlocking-plastic-block structural elements with varying thicknesses were found. Scaled-down prototypes of interlocking-plastic-block structural elements having two-block wide depicted more resistance to compressive loads than one block wide structural elements. The study can be applied in the future to better understand the detailed behaviour of interlocking plastic blocks.

2.4 Damage Control in Mortar-Free Joints

2.4.1 T-Joint Confinement Strategies

Although mortar-free construction offers improved performance under seismic loading, it still demands careful attention to joint behavior. In particular, T-joints require additional strengthening due to their susceptibility to stress concentration and potential failure. Provision of localized confinement at T-junctions and corners has emerged as an effective remedy to reduce damage in mortar free masonry. A quasi static cyclic loading study conducted in 2022 demonstrated that confining interlocking dry stacked masonry at corners and T-joints increased both lateral load capacity by 64% and drift capacity by 288% compared to unconfined specimens [49]. This confinement typically involves steel or reinforced concrete tie columns embedded at junctions, which enhance load continuity and restrict sliding at interfaces. Such localized reinforcement helps the structure mobilize higher frictional resistance and delays slip dominant failure modes. Furthermore, confinement improves energy dissipation under lateral cyclic loads, increasing overall ductility (the structure's ability to undergo significant permanent (plastic) deformation after reaching its yield point without experiencing sudden, brittle collapse) even when the masonry units lack mortar bonding. T-joints require strengthening due to stress concentration effects. Localized confinement significantly increases lateral and drift capacity. Tie columns restrict sliding and enhance load continuity

increased up to 221% [49]. Experiments show that internal corner confinement offsets geometric irregularities and misalignment of units that otherwise concentrate stress at interfaces. Additionally, interlocking unit design modifications-such as optimized circular or trapezoidal keys-can reduce stress concentrations and improve shear bearing capacity. These shape enhancements encourage more homogenized load sharing across joints. Also, fine tolerances in unit manufacture ($\pm 1.5\text{mm}$) have proven critical in dry-stack systems for reliable interface contact and minimizing relative movement. Optimized interlocking shapes reduce stress concentration at interfaces up to 11% [50]. In two story contexts, combining confinement with consistent manufacturing quality yields substantial gains in structural stability and slide control at T junctions. Das and Ali [16] had developed recycle plastic rebars for interlocking plastic block lateral and T-joint strength. The 25 mm ribbed PP rebars demonstrated superior performance, achieving a maximum load capacity of 12.2 kN, a toughness index of 19.3, and energy absorption of 101.6 N-m 10. These results affirm their suitability for lightweight structural components such as boundary walls, partition panels, and mortar-free interlocking systems. Various countries are developing plastic blocks for construction to utilize waste plastic including Indonesia [51], India [52], Czech Republic [53] and Brazil [54].

2.4.2 Strengthening of Masonry Structures

Embedment of fiber-reinforced polymer (FRP) or textile-reinforced mortar (TRM) systems into joints offers another promising set of remedial measures. A 2025 study showed that embedding vertically oriented glass FRP bars in dry stack masonry significantly improves in-plane stiffness, lateral strength, and hysteretic energy absorption, outperforming unreinforced configurations by a wide margin. Fiber Reinforced Polymer (FRP) reinforcement enhances stiffness, strength, energy absorption and flexure strength up to 37.6% [55–57]. FRP strips or rods can be integrated at head joint or bed joint levels alongside the dry stack blocks, improving load transfer across joints by adding tensile continuity without relying on mortar bonding. Textile reinforced mortar (TRM) overlay systems also serve to bond discrete units via a lightweight cementitious matrix and embedded fiber

mesh, enhancing shear and bending resistance at junctions [58, 59]. Experimental work on interlocking brick assemblies strengthened with CFRP and cement sand overlays in 2023 validated substantial reductions in joint crack propagation and improved ductility under cyclic loading. Vertical bars improve tensile continuity across dry joints up to 171% and 190% [60, 61]. These reinforcement approaches retrofit existing mortar-free walls with minimal intervention, preserving unit interlocking while improving interface cohesion. They are especially suitable for retrofit or upgrade projects where mortar reinstatement is undesirable. TRM and FRP systems are cost-effective and rapid-to-apply options that avoid adding excessive weight or compromising breathability. Ali et al. [62] investigated mortar-free interlocking blocks reinforced with coconut fiber and influence of un-grouted coconut rope reinforcement. The damping of the structures without ropes was higher than that of the structures with ropes. The damping increased with the amplitude of input motion. The same trend was observed for the maximum overturning moment, uplift and rope tension.

2.4.3 FRM - TRM Reinforcement in Joints

Surface preparation and interfacial quality control are fundamental preventive measures alongside structural reinforcement. Ensuring consistent surface finish and roughness across block faces improves frictional performance by maximizing contact area. Qamar et al. [63] investigated use of sisal fiber in plaster to reduce cracking in mortar-free interlocking walls. Proper surface preparation enhances friction and contact performance. Uniform bearing reduces localized crushing and stress concentration up to 229%. Figure 3 shows the experimental setup made for checking the improvement in behavior after plaster on interlocking wall. Studies recommend grinding or smoothing certain contact zones to establish uniform bearing and minimize uneven pressure hotspots that lead to localized crushing [64]. Choi and Lee [65] made interlocking blocks with peanut and Dumble shape interlocking and found its dynamic behavior. Controlling unit tolerances to within strict millimetric limits ensures proper alignment, reducing the tendency for early joint cracking at misaligned interfaces. In practice, rigorous quality control during

block production and site assembly is critical: irregular or warped units significantly degrade performance by creating gaps or stress concentrations. Additionally, surface texturing, either intrinsic via unit molding or applied post-production, can positively affect friction response and sliding resistance. Emerging design protocols also suggest applying sacrificial protective coatings or lubricants to reduce wear and friction degradation over repeated loading cycles. While these coatings are still under study, they address long-term interface wear and joint fatigue. Combining precision fabrication, textured interfaces, and geometric interlock design minimizes damage initiation, especially in higher story applications where cumulative differential movement might otherwise compromise junction integrity. Mitigating the inherent kinetic weaknesses of mortar-free T-junctions requires a hybrid strategy combining localized confinement, embedded polymeric reinforcement, and strict dimensional surface optimization. Integrating these mechanical interventions physically restricts unbonded sliding, forcing the assembly to safely dissipate seismic energy through controlled deformation rather than sudden joint failure.

2.5 Interlocking Plastic Block Wall

2.5.1 Development of Interlocking Plastic Block System

The development of interlocking plastic block (IPB) systems was driven by the need to address the logistical limitations and brittle failure modes characteristic of conventional wet-laid masonry. Pioneering the use of this technology for seismic applications, Khan [55] introduced IPBs as an innovative structural alternative for residential construction in earthquake-prone regions. This research demonstrated that replacing rigid mortar with dry-stacked, geometric interlocks substantially improves a building's capacity to absorb and dissipate seismic energy. Aligning with the growing demand for sustainable construction, recent advancements have also successfully transformed recycled high-density polyethylene (HDPE) waste into

engineered interlocking hollow blocks (IHBs) [1]. These recycled modules exhibit exceptional structural integrity, yielding compressive strengths above 30 MPa, which easily exceed global masonry code requirements. Additionally, the inherent material flexibility of these engineered blocks provides a unique self-centering mechanism during lateral displacement, offering a resilient and eco-friendly alternative to resource-heavy conventional materials. The superior dynamic resilience of this system has been further validated through comparative shake-table evaluations under harmonic excitation. While conventional unreinforced masonry experienced catastrophic brittle collapse due to mortar joint failure, the unbonded IPB walls maintained their structural integrity. Notably, the mortar-free assemblies endured identical excitation frequencies without collapsing, actively dissipating 490 Nm of energy and proving their effectiveness under dynamic loading [20].

2.5.2 Performance of Interlocking Plastic Blocks

Although individual material characteristics of interlocking plastic blocks (IPBs) show considerable promise, their practical success in earthquake-resistant construction relies on how they behave structurally on a larger scale. Unlike traditional masonry that depends on rigid mortar joints, the lateral and dynamic response of unbonded IPB walls is driven by controlled sliding, localized rotation, and interfacial friction. Consequently, numerous experimental studies have focused on quantifying the static and dynamic mechanics of these mortar-free assemblies. At the foundational material level, researchers have sought to address global plastic waste by developing masonry blocks from recycled polyolefins—specifically polypropylene (PP) and high-density polyethylene (HDPE)—using a rotational molding process. Comprehensive physical and mechanical testing of these sustainable alternatives confirmed that HDPE blocks deliver structural performance superior to their PP counterparts [54]. Moving to system-level structural evaluations, recent shake-table studies have assessed how architectural features, such as window openings, affect dynamic stability under harmonic loading. Kinematic and

energy dissipation data clearly indicated that IPB systems, even with these structural interruptions, provide substantially greater seismic resilience than standard unreinforced masonry [21]. Beyond lateral testing, researchers have also investigated the compressive strength of various IPB configurations, including columns and both solid and fenestrated walls. By examining variables like block width and slenderness, experimental results demonstrated that double-width assemblies drastically improve compressive toughness and maximum load capacities compared to single-width elements. Ultimately, these findings yield critical empirical correlations necessary for optimizing mortar-free structural designs [22].

2.5.3 Reinforcement of Interlocking Plastic Blocks

Recent studies have focused on integrating sustainable internal reinforcements to improve the load-bearing capabilities and overall stability of mortar-free block assemblies. To meet this objective, an innovative technique was introduced to produce full-scale plastic rebars from mechanically recycled polypropylene (PP) and high-density polyethylene (HDPE). Departing from traditional practices that simply utilize recycled plastics as composite fillers, this research designed these extruded components to act as primary tensile, load-bearing members. Standardized testing revealed that 25 mm ribbed PP rebars possess remarkable energy dissipation and load capacities, proving their viability as a scalable reinforcement strategy specifically suited for stabilizing unbonded interlocking systems [2]. In a parallel effort to broaden the structural utility of upcycled waste, another investigation explored the fabrication of plastic-bonded sand interlocking blocks via high-temperature extrusion. These composite units demonstrated a notable compressive strength of roughly 15.0 MPa, substantially exceeding the performance of standard sandcrete blocks used in many developing nations. When constructed into full-scale wall configurations and subjected to in-plane compression, the mortar-free assemblies sustained load capacities between 4.2 and 5.7 MPa. Interestingly, while altering the material mix impacted the extent of block damage following a collapse, the underlying failure modes of the interlocking walls remained remarkably consistent [3].

2.6 Summary and Identified Research Gap

Under seismic excitation, T-junctions act as highly vulnerable nodes where complex stress concentrations rapidly overcome limited mortar tensile capacity, initiating crack propagation governed by vertical pre-compression levels. Joint failure physically manifests through a combination of interfacial sliding shear and concentrated corner crushing, which steadily degrades into a permanent "rocking-sliding" mechanism during cyclic loading. Bidirectional ground motions force these weakened connections to absorb combined shear and torsion, turning them into flexible "soft zones" that severely disrupt the global dynamic response of multi-story buildings. Emerging seismic mitigation strategies prioritize confined masonry and mortar-free interlocking designs, where structural resilience shifts from cohesive bonding to Mohr-Coulomb friction, geometric occlusion, and the active management of surface wear and alignment imperfections. The mechanical capacity and out-of-plane stability of dry-stacked assemblies are highly sensitive to surface contact area and dimensional tolerances, with interlocking plastic alternatives demonstrating superior energy dissipation and toughness compared to conventional brickwork. Large-scale cyclic testing reveals that dry-joint failure is governed by slip and stiffness degradation, necessitating advanced analytical frameworks like Applied Element Modeling (AEM) to accurately capture post-yield progressive damage and nonlinear friction mechanics. Localized structural confinement and optimized interlocking geometries actively mobilize interface friction, pushing lateral load capacity up by 64% and drift capacity by 288% to delay slip-dominant failure. Embedding fiber-reinforced polymers or textile-reinforced mortar directly into dry-stack assemblies introduces necessary tensile continuity, heavily restricting joint crack propagation while boosting hysteretic energy absorption. Strict millimetric manufacturing tolerances and abrasive surface preparation maximize interfacial contact area, aggressively reducing uneven pressure hotspots and the resulting localized edge crushing. While both intersections are critical, T-junctions and corner joints exhibit distinct dynamic behaviors under seismic loading. Because the structural response of corner joints has already been

comprehensively investigated in existing literature, this research specifically targets T-junctions to address a significant, unexplored knowledge gap. Although empirical literature establishes the static capacity and single-story performance of mortar-free polymeric assemblies, the inertial kinetics of multi-story configurations remain completely unquantified. Specifically, no prior experimental research has documented the dynamic response, stiffness degradation, or free-vibration damping of unbonded T-junctions within a two-story interlocking plastic block system subjected to lateral excitation.

Chapter 3

Experimental Program

3.1 Background

Accurate prediction of structural response under seismic loading is crucial for safe design in earthquake-prone regions. To this end, dynamic testing of prototype structures in laboratory environments is a widely adopted practice. This chapter focuses on the construction of interlocking plastic block T- joints, the experimental setup and instrumentation for snap-back testing, the application of dynamic loads using a shake table, the evaluation of key response parameters, and the development of empirical equations for performance prediction.

3.2 Continuation of Research Program

Khan [55] proposed Interlocking-Plastic-Blocks (IPBs) for earthquake-resilient residential structures, with plan and 3D views shown in Figures 4.1(a) and 3.1(b). Scaled-down testing confirmed the systems effectiveness, primarily due to its reduced mass, which lowers inertia forces during seismic excitation. Since heavier materials generate greater inertia in accordance with Newtons Laws of Motion, lighter IPB systems offer clear advantages in seismic resistance. To enable practical construction, the proposed IPBs have a base dimension of 150 mm 150 mm with four interlocking keys on the top surface, as shown in Figure 3.1(c). The

blocks used in the current study measured 62 mm $\times$ 62 mm with an overall height of 50 mm, incorporating a 12 mm interlocking key for enhanced connectivity (Figure 3.1(d)). This work extends Khans earlier study, utilizing square plastic blocks with four keys, including vertical key-and-groove interlocks, for prototype construction.

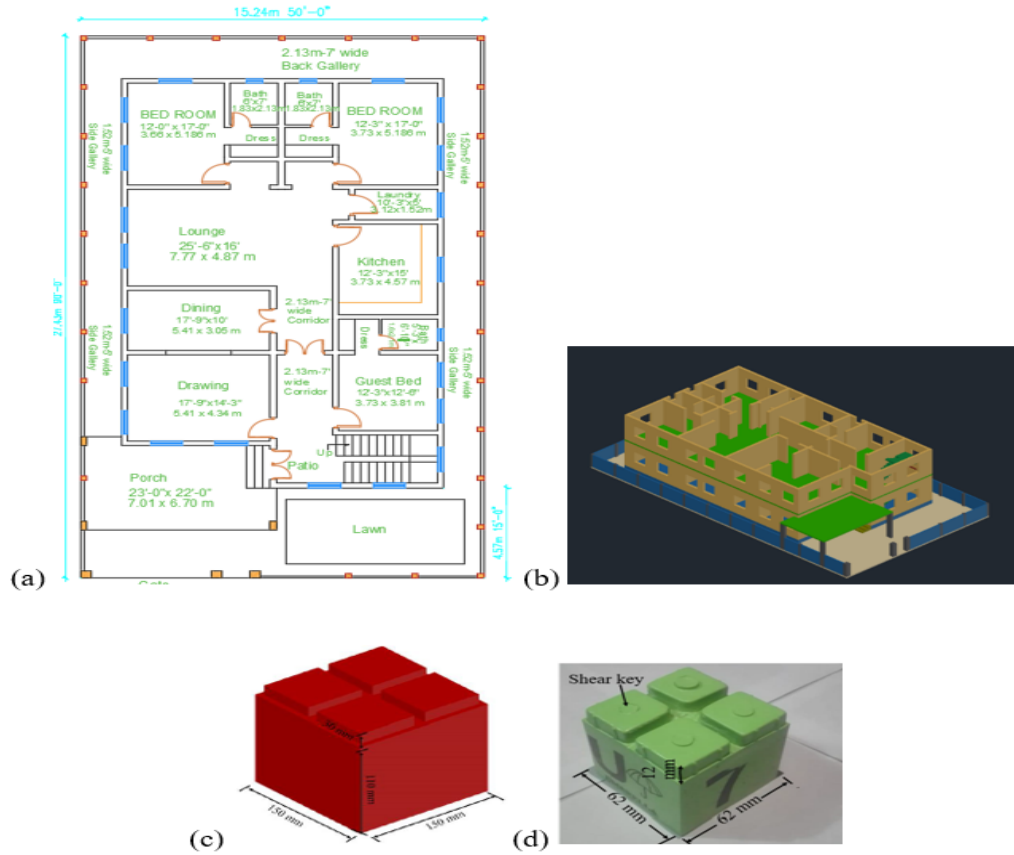


FIGURE 3.1: Proposed mortar free interlocking plastic block House (a) Plan, (b) 3D, (c) Proposed Plastic Block, (d) Real Plastic Block

In this study, a scaled prototype T-joint made from IPB walls was subjected to dynamic testing. The objective was to establish practical specifications for real-world applications rather than rely solely on theoretical models. Scaling and construction methods followed well-documented practices from the literature [26, 63], enabling meaningful insights into the behavior of full-scale structures.

The primary focus is the dynamic response of the T-joint, where structural period plays a critical role, as defined in UBC-97. Accordingly, elevation dimensions were scaled down for prototype walls. The plan and elevation of the house with the original T-joint design are presented in Figure 3.2(a), while Figure 3.2(b) illustrates

the simplified scaled boundary conditions. Figure 3.2(c) shows the scaled-down T-joint in mortar-free IPB walls configured in Sequences A and B.

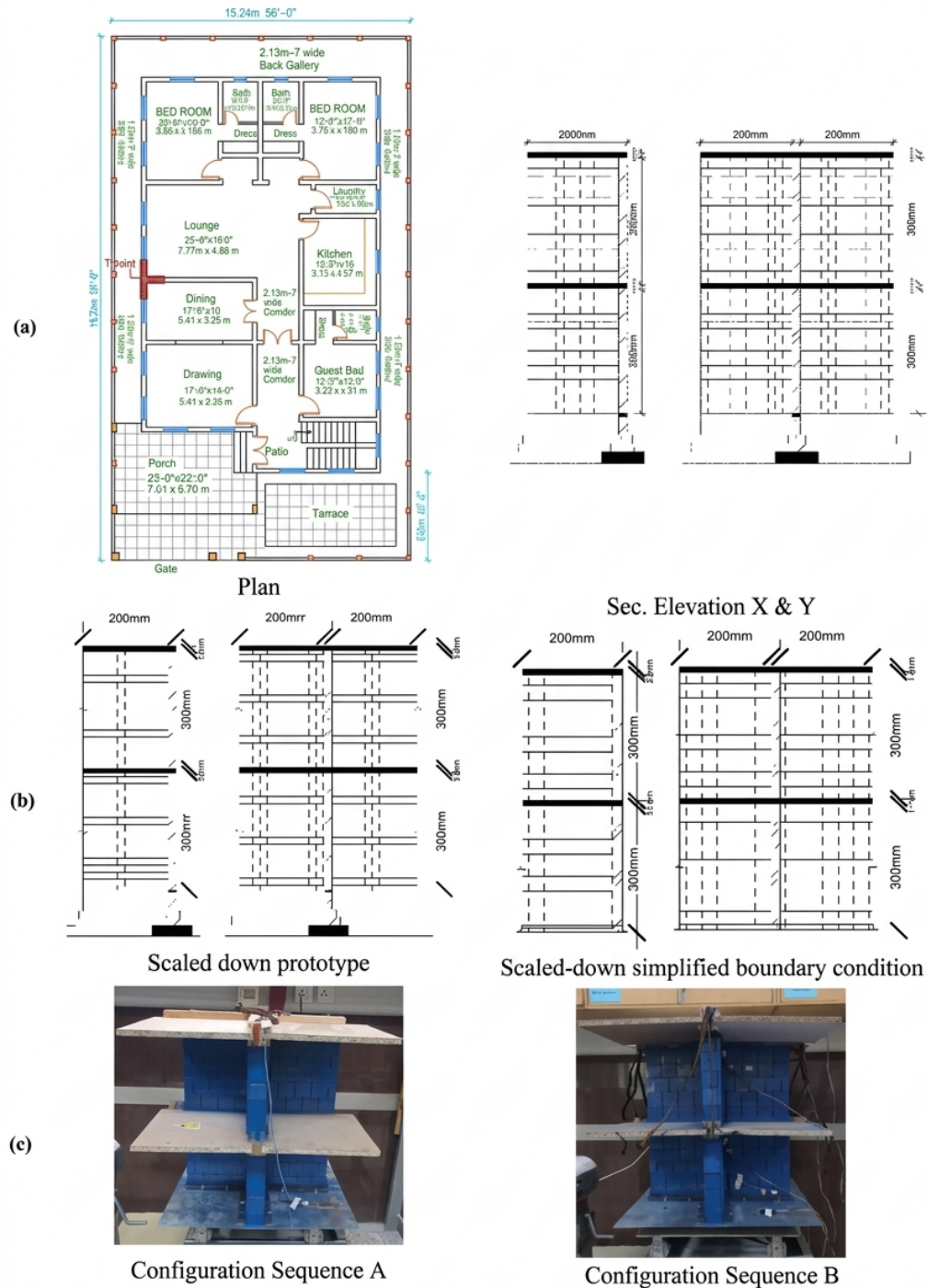


FIGURE 3.2: Consideration of T-joint; (a) plan and elevation of house with original T-joint consideration, (b) scaled-down and simplified boundary conditions and (c) T-joint with configuration Structure A and B.

The T-joint was anchored to a base plate using steel angle sections. For analysis, full-scale wall dimensions of 2000 mm length and 3000 mm height were considered,

with scaled-down dimensions of 200 mm length and 312 mm height. As illustrated in Figure 3.2(b), the wall extends 200 mm from the central joint, and each floor has a height of 312 mm. The structural assembly consists of 10 distinct layers, with 13 interlocking blocks per layer, concluding in a total of 130 blocks. Anchoring the base ensured the dynamic demand was transferred directly into the T-junction. This study explicitly examines the structural behavior of the T-junction along both the X and Y orthogonal directions to evaluate its complete bidirectional dynamic performance.

3.3 Construction of Prototype Scaled-down T-Junction Joint

The prototype T-joint of the IPB wall was constructed using 130 plastic blocks, with a total height of 624 mm. The wall configuration was built in two sequences: Sequence A arranged the blocks so that the out-of-plane response of Wall 1 initiated from the joint, while Sequence B arranged them such that the out-of-plane response of Wall 2 began from the joint edges as shown in figure 3.3. To improve vertical stiffness, rubber bands were tied vertically from the bottom to the top through the middle of the blocks. The stiffeners were used in the form of rubber bands, four in each wall and one at the T-joint where the orthogonal walls intersect. The structure was fixed at the base of the shake table to ensure uniform excitation, with no additional mass placed on top of the T-joint. The physical specimen possessed a net self-weight of 6.45 kg. To guarantee structural stability during testing and prevent premature catastrophic collapse, seven structural stiffeners were integrated into the assembly. The specific arrangement involved placing a single stiffener directly at the T-joint junction, while the remaining six units were distributed uniformly across the adjacent walls, allocating two stiffeners per wall section.

This targeted reinforcement configuration was selected to mirror the boundary constraints typical of full-scale structural systems. Block masonry construction followed a traditional English bond layout, a pattern requiring the insertion of a

half-block unit at the terminating corner of every alternate course. To initiate dynamic evaluation, the T-joint assembly was anchored laterally to the platform of the one-dimensional shake table using a combination of heavy-duty nut-bolt assemblies and steel angle sections. This rigid tie-down configuration enforced controlled dynamic excitation under realistic, well-defined boundary conditions. The physical testing protocol subjected the unbonded joint to independent loading sequences along both the X-direction and the Y-direction. The empirical datasets generated by this experimental program provide critical insights into the seismic resilience, kinetic behavior, and global structural performance of mortar-free interlocking plastic block systems. Isolating these specific performance metrics establishes a reliable empirical baseline required to support the development of safer, more robust dry-stacked construction practices for earthquake-prone regions. Structure A and Structure B differ in the placement of half-blocks used to achieve the masonry bond. In Structure A, the half-blocks are positioned in the longer wall during courses 2, 4, and 6, while in Structure B, the half-blocks are situated in the shorter wall for those same courses.

3.4 Test Setup and Applied Load Magnitudes

3.4.1 Static Stiffness Test Setup and Loading Parameters

Assessing the lateral load capacity of the scaled IPB T-joint requires a precisely configured static pushover test. To establish a fully fixed boundary condition, the base of the specimen is rigidly anchored to a strong floor using the previously specified steel angle sections and structural bolts. A load-gauging actuator, positioned near the top of the 624 mm tall wall assembly, introduces a slow, monotonically increasing lateral force. Data acquisition systems continuously record this applied load as the structure is pushed horizontally along either the X or Y orthogonal axis. Synchronized displacement scales, affixed directly to the upper masonry courses, track the exact physical drift. This controlled, quasi-static loading protocol continues without interruption until the joint suffers a sudden drop in structural capacity, the internal interlocking keys exhibit excessive interfacial slip,

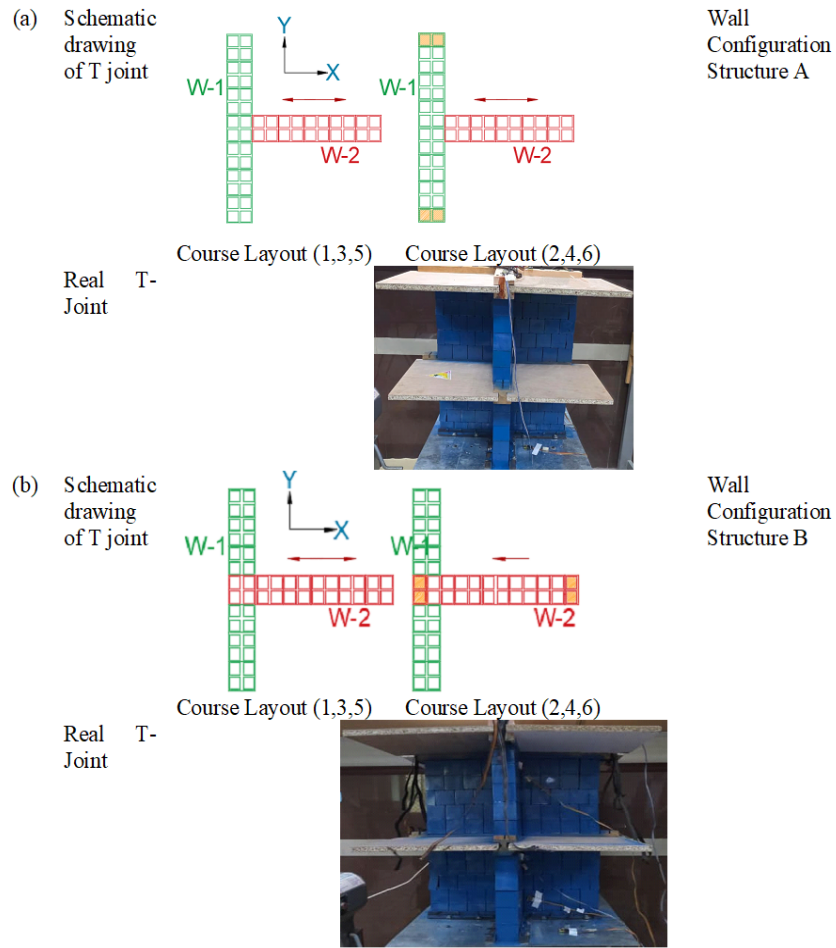


FIGURE 3.3: T- Junction Joint construction details; (a) wall configuration Structure A and (b) wall configuration Structure B.

or the assembly reaches an ultimate failure state. Mapping the captured force and displacement metrics produces a standard load-displacement profile, functioning as the structural capacity curve. Extracting the lateral stiffness of the T-joint from this graphical representation depends entirely on isolating the pre-yield mechanics. Analytical focus narrows specifically to the initial, straight-line segment of the curve—the linear-elastic region recorded just before the plastic blocks begin to slide, yield, or sustain permanent geometric deformation. Calculating the mathematical slope of this defined segment by dividing the applied lateral force by its corresponding horizontal displacement yields the initial structural stiffness. Quantifying this baseline rigidity dictates exactly how effectively the mortar-free system, operating via geometric interlocking keys and internal rubber band stiffeners, can resist early-stage structural drift during a seismic event. Figure 3.4

shows the test setup.

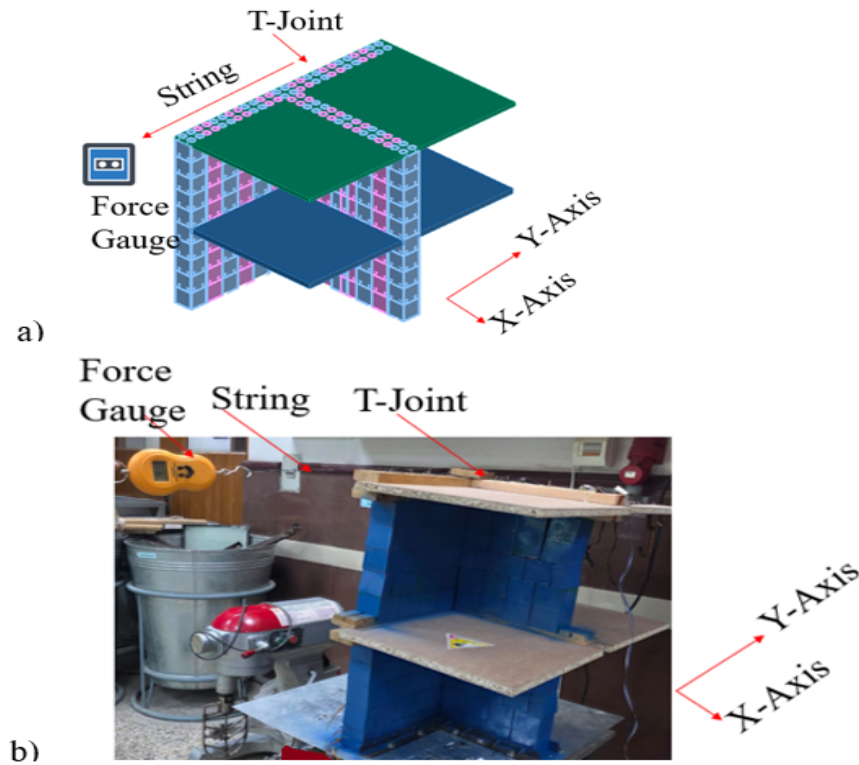


FIGURE 3.4: a) Schematic Drawing, b) Actual test set-up

Evaluating the prototype required a strictly incremental lateral loading protocol. Tension applied via a mechanical spring balance increased steadily, punctuated by deliberate holding pauses at every 8.9-Newton threshold. These brief static periods allowed the internal rubber band stiffeners and the unbonded block interfaces to reach physical equilibrium prior to data collection, ensuring the static structural response was captured without dynamic interference. Monitoring this mechanical behavior relied on straightforward physical instrumentation. The indicator on the spring balance registered the applied lateral force, functioning as a direct proxy for progressive base shear. Synchronized with these load readings, a fixed physical scale measured the corresponding horizontal drift at the upper boundary of the wall assembly. Observers manually logged the maximum roof displacement at each 8.9-Newton step to precisely map the evolving force-drift relationship. Synthesizing these paired data points generated the empirical capacity curve. This graphical mapping tracked the progressive kinetic degradation of the assembly, isolating the exact thresholds of localized joint separation, material yielding, and macroscopic

sliding across the mortar-free matrix as the horizontal demand intensified. Table 3.1 details the specific magnitudes of the loading used during this testing.

TABLE 3.1: Loading Details of Test Specimen

S. No.	Specimen	Loading Direction	Incremental Loading (N)
1	A	X	8.9
2	A	Y	8.9
3	B	X	8.9
4	B	Y	8.9

3.4.2 Snap Back Test Setup, Instrumentation and Loading parameters

A standard snap-back testing protocol was executed to isolate the free vibration characteristics of the T-joint within the interlocking plastic block (IPB) assembly. To induce these unforced oscillations, a 500 mm tension wire anchored to the upper boundary of the intersection provided the requisite initial static displacement. An accelerometer mounted directly at the structural apex recorded the subsequent kinetic decay. The experimental procedure required pulling the T-joint to specific horizontal offsets-initially to 25 mm, followed by a secondary 50 mm deformation-before abruptly releasing the tension to trigger free vibration. This physical release sequence was executed across both structural layouts (Configurations A and B) along the independent X-direction and Y-direction orthogonal axes.

Processing the acquired acceleration time histories enabled the extraction of the system's fundamental frequency (f_n) alongside its internal damping ratio (ζ). Isolating these variables depended on applying the logarithmic decrement method to the raw signal data. By quantifying the peak acceleration amplitudes across a defined series of successive oscillation cycles, the exact damping ratio was derived through the following mathematical expression:

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

where x_0 and x_1 represent the maximum acceleration values of the first and last cycles, respectively, and N is the number of cycles. The fundamental frequency reflects the natural vibration frequency of the structure. If this frequency approaches the dominant frequency of an earthquake, resonance may occur, leading to amplified structural vibrations and increased failure risk. Therefore, seismic-resilient designs must ensure that the fundamental frequency avoids resonance with typical seismic excitations. In Figure 4.5 schematic drawing for the snap-back test and a real prototype type arrangement is shown.

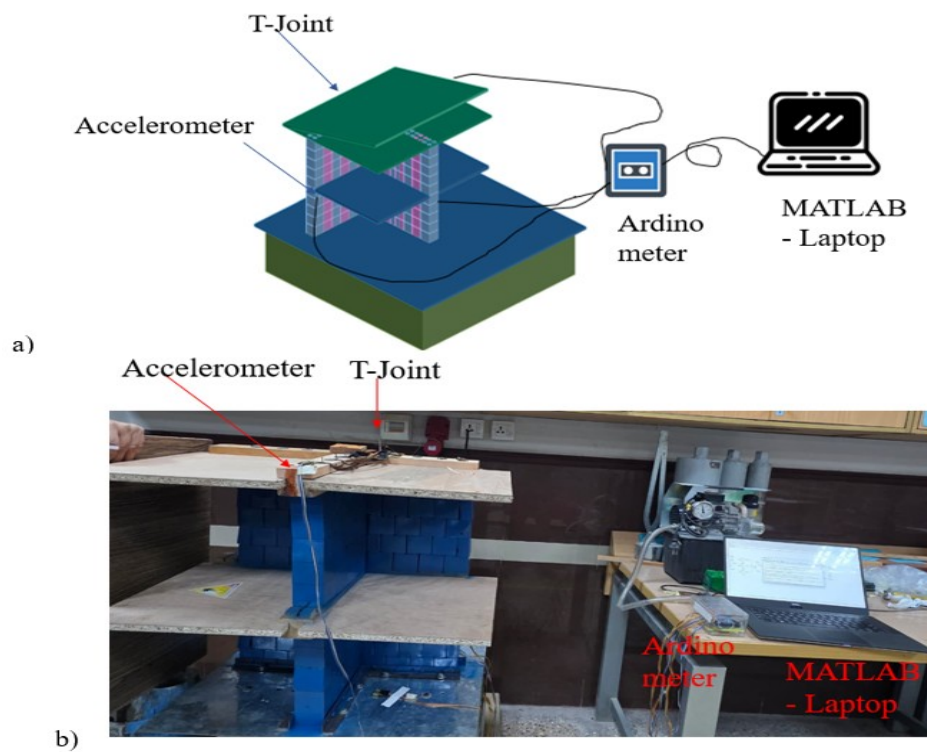


FIGURE 3.5: Test Setup; (a) Schematic Diagram of T-Junction (b) Prototype of T-Junction

For the snap-back test, the T-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 acceleration time 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

acceleration time history data. Snap Back loading magnitude is given in Table 3.2.

TABLE 3.2: Snap-back Loading Magnitude

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

3.4.3 Hammer Impact Test and Loading Magnitude

Extracting the dynamic characteristics of the scaled T-joint prototype required a carefully calibrated hammer impact testing protocol. To guarantee mechanical consistency and repeatable excitation sequences across multiple trials, the experimental framework employed a striking mass attached to a rigid, fixed-length rotating arm. Capturing the spatial distribution of these induced vibrations relied on a targeted instrumentation strategy utilizing five discrete accelerometers. One sensor was affixed directly to the striking mass to isolate and quantify the input forcing function. Three corresponding sensors were distributed along the upper perimeter of the two-tiered assembly. By capping the two top free wall terminals and the central T-intersection, this upper array recorded the macroscopic structural response. The fifth and final accelerometer anchored the base of the T-junction, a placement selected specifically to monitor energy dissipation transferring downward into the foundation. Heavy-duty nut-bolt assemblies and steel angle sections clamped this foundational boundary directly to the shake table platform, strictly enforcing realistic, fully fixed restraints.

Executing the evaluation required striking the physical matrix systematically to isolate how the unbonded interlocking blocks accommodate impulsive dynamic shocks. Operators retracted the pendulum arm to a strict 90-degree angle relative to the intended target plane. Releasing the mass from this geometric datum allowed gravity to deliver a highly standardized, uniform kinetic strike. The experimental loading sequence targeted four specific structural nodes. Strikes were administered at the upper free boundaries of the three independent wall segments

forming the intersection, followed by a direct impact at the top center of the T-joint itself. Synchronizing the acceleration data across all five channels during these 90-degree pendulum drops mathematically maps the exact propagation of kinetic waves through the rubber-band-stiffened plastic medium. Quantifying this transient wave behavior ultimately extracts the baseline natural frequencies and inherent damping characteristics of the dry-stacked assembly.

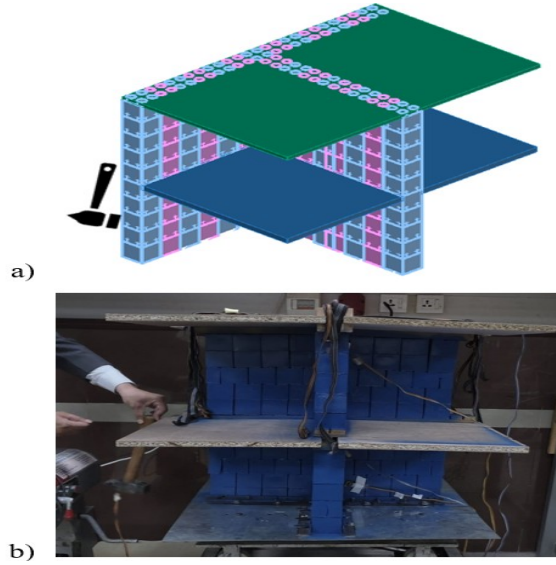


FIGURE 3.6: Test Setup; (a) Schematic Diagram of Hammer Impact (b) Prototype of T-Junction with Hammer Impact

Isolating the two specific physical parameters required to precisely quantify transient impulsive loads directly dictated the architecture of the excitation mechanism. To enforce strict mechanical consistency, the experimental framework employed a 0.46 kg striking mass affixed to a 292 mm rigid rotational arm. Releasing this pendulum apparatus from a fixed 90-degree horizontal datum forced a highly standardized gravitational descent. This rigid geometric constraint successfully eliminated the manual variability typically introduced during the excitation phase. By converting static potential energy into a perfectly repeatable kinetic shock at targeted structural nodes, the physical setup strictly regulated the input forcing function. Consequently, any acceleration transients subsequently captured by the surrounding sensor array reflected the true dynamic stiffness and internal interface friction of the unbonded plastic blocks, effectively ruling out irregular strike velocities as a source of data noise.

3.4.4 Shake Table Test Setup and Instrumentation

Preparing the shake table for testing required anchoring the interlocking plastic-block (IPB) T-joint directly to the steel platform using heavy-duty angle sections and nut-bolt fasteners. Capturing the transient kinetic response depended on a five-channel accelerometer array. Two sensors monitored the upper boundaries of the intersecting walls, documenting their independent contributions to global joint behavior and potential structural failure. To record localized deformation and relative interfacial motion, an additional pair of accelerometers capped the top and bottom of the central T-junction. The fifth instrument sat at the table base, strictly logging the input ground excitation. Processing these raw acceleration-time histories through SeismoSignal software yielded the velocity-time and displacement-time profiles necessary for quantitative structural evaluation. The loading frequencies were selected by applying a ± 0.02 Hz variance to the structure's fundamental frequency. The planned experimental protocol will subject the IPB assembly to harmonic base excitation at targeted frequencies of 1.0 Hz, 1.2 Hz, and 1.4 Hz, maintaining a constant lateral amplitude of 25 mm directly at the T-joint. Extracting the synchronized acceleration, velocity, and displacement histories across both the foundation and the structural apex will allow for a direct comparative analysis of the joint's dynamic amplification under harmonic loading. Because of its complex structural configuration and localized joint interaction, the unbonded T-joint is anticipated to register higher peak kinematic responses than the surrounding continuous wall segments. Testing will span two distinct geometric layouts. Mimicking the staggered stretcher bond of conventional brick masonry, half-block units will be inserted to disrupt continuous vertical seams and prevent direct alignment of successive joints. Sequence A subjects Wall 1 to out-of-plane loading along the X-direction while Wall 2 absorbs corresponding in-plane shear. Sequence B replicates these directional demands but alters the localized block arrangement at the intersection root. Specifically, Wall 1 initiates directly at the joint edge in the first configuration, whereas Wall 2 occupies this exact boundary position in the second.

Rigid base fixation via steel angle sections will prevent boundary slippage and secure high repeatability across successive loading phases. Deriving the specific

harmonic input parameters relied directly on preceding empirical data and established literature precedents. The isolated snap-back evaluation established 1.2 Hz as the fundamental natural frequency of the IPB matrix. Consequently, dynamic profiling will bracket this resonant baseline, applying supplementary harmonic forcing at 0.2 Hz intervals both below (1.0 Hz) and above (1.4 Hz) the dominant mode to capture the mechanical response across a realistic frequency range. Restricting the lateral amplitude to 25 mm along the X-axis across both wall configurations generates a highly controlled kinetic input, closely simulating the sustained cyclic energy of actual seismic events. Enforcing these strict parametric controls isolates the physical variable of block positioning, establishing a reliable baseline to evaluate exactly how geometric layout alters the dynamic interaction and overall seismic capacity of the T-joint system.

TABLE 3.3: Harmonic Loading Parameters

S. No.	Wall Configuration	Harmonic Loading Dir.	Amplitude (mm)	Frequency (Hz)
1	Seq. A	X	25	1.0, 1.2, 1.4
2	Seq. B	X	25	1.0, 1.2, 1.4

3.5 Parameters to be Evaluated

3.5.1 Parameters to be Evaluated under Static Stiffness Test

Stiffness is the fundamental property of a structural element that measures its ability to resist elastic deformation, such as bending, stretching, or twisting, under an applied force. In the context of this study, static lateral stiffness refers to the element's capacity to resist slowly applied horizontal/lateral forces without undergoing excessive displacement. Quantifying the lateral performance of the mortar-free interlocking plastic block T-junction requires isolating a defined set of structural parameters. The most defining metric is the ultimate base shear capacity, representing the absolute peak lateral force the wall assembly can tolerate

before macroscopic structural failure initiates. To track this threshold, operators continuously log incremental tension readings from a mechanical spring balance. Synchronizing these direct load values with corresponding horizontal roof drift measurements produces the global capacity curve. Extracting the initial lateral stiffness of the unbonded matrix depends on analyzing the linear, pre-yield segment of this exact load-displacement profile. Increasing the lateral demand eventually forces the assembly's response to diverge from its elastic trajectory, physically mapping the yield displacement. Pinpointing this geometric shift dictates the specific moment internal static friction breaks down, forcing the mechanical interlocking lugs to engage and directly absorb the acting shear stresses. The testing protocol continues until the assembly reaches its ultimate displacement-the maximum horizontal drift recorded just prior to a severe, unrecoverable drop in load-bearing capacity. Dividing this ultimate displacement by the previously established yield limit yields the structural ductility factor, a fundamental metric for evaluating macroscopic seismic resilience.

The experimental framework also tracks progressive stiffness degradation driven by the physical separation and interfacial sliding of the dry joints under escalating stress. Pausing the loading protocol at strict 8.9-Newton increments permits targeted visual inspections. These static intervals allow observers to document the precise onset of localized failure modes, capturing specific kinetic phenomena such as individual block sliding, vertical joint uplift, or the out-of-plane detachment of the orthogonal flange. Synthesizing these physical observations with the numerical load data validates how effectively the recycled plastic units, operating alongside internal pre-tensioned rubber bands, dissipate lateral energy through controlled mechanical deformation.

3.5.2 Parameters to be Evaluated under Snap Back Loading

Experimental monitoring of the unbonded interlocking plastic-block T-joint yields raw dynamic data strictly in the form of acceleration-time histories. Ambient

mechanical noise invariably contaminates these raw signals during the data acquisition phase, necessitating rigorous signal processing to extract the true structural response. Initial noise reduction relies on customized MATLAB scripts designed to mathematically strip away erratic, high-frequency signal spikes. Following this preliminary conditioning phase, the datasets are exported into SeismoSignal software. Here, specific bandwidth filters isolate the targeted structural vibrations and eliminate extraneous frequency artifacts, ultimately generating a clean, highly resolved acceleration-time profile. Extracting the governing dynamic properties from these refined signals—specifically the fundamental frequency (f_n) and the structural damping ratio (ζ), follows established analytical procedures [66,67]. Both physical metrics directly define the macroscopic dynamic behavior of the assembly. The damping ratio quantifies the exact capacity of the dry-stacked joints to dissipate kinetic energy through interfacial friction and localized micro-sliding. Conversely, establishing the fundamental frequency pinpoints the specific harmonic thresholds where the structural system risks severe dynamic amplification and physical resonance under continuous seismic excitation.

Enforcing this strict filtering protocol guarantees that the extracted kinematics reflect the actual mechanical behavior of the T-joint, successfully ruling out spurious instrumental noise. Once empirically verified, the derived values for f_n and ζ establish the baseline physical parameters required to calibrate advanced numerical frameworks. These highly specific inputs form the foundation for generating accurate, reliable performance predictions applicable to the proposed mortar-free wall system.

3.5.3 Parameters to be Evaluated under Hammer Impact Test

Extracting the baseline dynamic properties of the mortar-free T-junction relies directly on acceleration-time histories generated by momentary kinetic strikes. Processing these transient vibration signals yields two defining structural parameters: the fundamental frequency and the internal damping ratio. The fundamental frequency dictates the natural oscillation rate of the two-story assembly. Isolating

this metric establishes the specific harmonic thresholds where the physical impact of an external object risks triggering destructive structural resonance. The corresponding structural damping ratio emerges from tracking the amplitude decay of free vibrations across successive oscillation cycles. Quantifying this kinetic decay provides a direct measure of the assembly's inherent energy dissipation capacity. Within this dry-stacked matrix, that specific mechanical response is governed entirely by localized microscopic sliding, geometric occlusion, and dry physical friction acting across the unbonded block interfaces. Mapping the global dynamic stiffness and energy transmission efficiency of the structural node requires synthesizing these discrete datasets. By directly cross-referencing the calibrated input force recorded by the hammer's accelerometer against the resultant wave propagation captured at both the top flanges and the anchored foundation, the exact transient kinetic behavior of the masonry intersection is accurately resolved.

3.5.4 Parameters to be Evaluated under Harmonic Loading

The experimental protocol subjects the T-joint to controlled dynamic loading at targeted frequencies of 1.0 Hz, 1.2 Hz, and 1.4 Hz. During these excitation phases, data acquisition systems capture the transient structural response strictly as acceleration-time histories. Processing these raw signals through SeismoSignal software applies numerical integration to mathematically derive the corresponding velocity-time and displacement-time profiles. Analysts then extract the recorded acceleration data to construct discrete base shear (Q) versus displacement hysteretic curves. Formulating this specific mechanical relationship depends on calculating the localized base shear using the governing dynamic expression:

$$Q = M \times \ddot{u}_t \quad (3.2)$$

within this equation, M defines the effective structural mass, while $\ddot{u}_t$ represents the absolute top acceleration recorded along the corresponding wall segment. Mapping these exact kinetic parameters isolates both the dynamic stiffness and the

inherent energy dissipation capacity of the structural node. Quantifying these metrics establishes a rigorous empirical baseline, providing the exact comparative data necessary to evaluate macroscopic structural performance across the varying excitation frequencies.

3.6 Procedure for Empirical Equation Formation

Accurately characterizing the dynamic response of the T-joint within mortar-free interlocking plastic-block (IPB) assemblies requires the formulation of specific empirical equations. Expanding upon the foundational work of Khan, these predictive mathematical relationships must explicitly integrate the IPB's geometric topology, individual block dimensions, overall structural height, and transient input loading parameters. The analytical precision of these derived expressions is subsequently validated by calculating the exact percentage variance against the recorded physical test datasets. Where notable deviations emerge between the experimental and theoretical values, introducing a calibrated adjustment factor (e.g., $K=1.4$) mathematically tightens the correlation. Establishing this refined numerical framework enables highly reliable structural performance forecasting. Isolating these specific kinematic variables clarifies the complex seismic mechanics governing IPB wall systems, generating the empirical baseline necessary to optimize these dry-stacked configurations for enhanced disaster resilience.

3.7 Summary

This chapter defines the precise experimental methodologies and physical testing protocols governing the research program. The core of this investigation relies on evaluating a scaled T-joint prototype constructed from interlocking plastic blocks under controlled dynamic loading conditions. By isolating the transient mechanical behavior of the unbonded intersection, the resulting empirical datasets can be directly correlated with predictive mathematical formulas. A comprehensive detailing of the experimental architecture and physical instrumentation follows,

outlining the specific apparatus calibrations and the mechanical boundary conditions enforced during excitation. The text defines the exact physical variables captured throughout the testing phases, establishing a strict rationale for how joint performance is quantified. Analytical focus narrows specifically onto localized dynamic response metrics. These encompass transient acceleration profiles, peak structural displacement, and the exact initiation sequence of kinetic failure mechanisms. Establishing this stringent experimental framework guarantees high data fidelity, yielding the reliable empirical baseline required to properly validate subsequent numerical simulations and analytical models.

Chapter 4

Experimental Evaluation

4.1 Background

Following the experimental protocols established in the preceding chapter, this section presents the empirical data derived from the static and dynamic testing of the two-story, mortar-free T-junction. Static stiffness evaluations isolate the lateral load-displacement mechanics to pinpoint initial elastic rigidity, absolute base shear capacity, and the specific structural variations induced by orthogonal loading directions. Transient excitation protocols—specifically targeted snap-back and hammer impact procedures, captured both kinetic shockwave propagation and the corresponding free-vibration decay across the unbonded matrix. Achieving high analytical fidelity required rigorous signal conditioning. Raw kinetic data logged via MATLAB passed directly into SeismoSignal software for specialized numerical filtering. Applying strict baseline corrections and stripping away extraneous high-frequency ambient noise produced exceptionally clean displacement-time and acceleration-time profiles. Analysts extracted the fundamental frequency (f_n) and the structural damping ratio (ζ) directly from these refined histories. The synthesis of empirical metrics quantifies the progressive energy absorption capacity of the masonry node across shifting dynamic frequencies. Translating the localized mechanics of geometric interlocking and dry interface friction into objective numerical data provides a direct measure of the assembly’s overall seismic resilience.

4.2 Lateral Load Displacement Capacity of IPB T-Junction Joint

Evaluating the structural response of mortar-free T-junctions reveals a strict directional dependency governing lateral stiffness. Subjected to uniform static load increments of 8.9 N across orthogonal axes, the Sequence A and B assemblies uniformly sustained a peak lateral capacity of 96.78 N. Despite this shared ultimate threshold, the physical deformation trajectories diverged sharply depending on the specific axis of excitation. Loading along the X-direction consistently triggered substantially larger lateral displacements compared to equivalent force demands applied along the Y-axis. The recorded empirical data explicitly maps this anisotropic rigidity. Under the peak load of 96.78 N, Sequence A registered a lateral roof drift of 65.2 mm in the X-direction; applying that exact kinetic demand along the Y-axis restricted total displacement to just 52.1 mm. Sequence B closely mirrored this kinetic bias. Here, X-direction loading forced a 65.9 mm displacement, whereas orthogonal Y-direction excitation yielded a constrained maximum drift of 54.2 mm.

The inherent geometric asymmetry of the intersecting walls fundamentally drives this persistent discrepancy in structural deformation. Within these dry-stacked systems, the precise spatial orientation of the longitudinal flange dictates both the active frictional surface area and the macroscopic resistance to global overturning. Horizontal loading along the X-axis primarily challenges the shorter intersecting wall segment. Confined to this reduced mechanical footprint, individual interlocking blocks begin to slide and open joints at noticeably lower stress intervals. Conversely, loading along the Y-axis directly mobilizes the full longitudinal extension of the primary flange. Engaging this broader geometric cross-section maximizes internal block occlusion alongside interfacial dry friction, effectively suppressing excessive structural drift.

As illustrated in Fig. 4.1, the physical framework for the static stiffness evaluation featured a two-story assembly fabricated from interlocking plastic blocks. To initiate lateral displacement, a tension chord and force gauge anchored to the structural

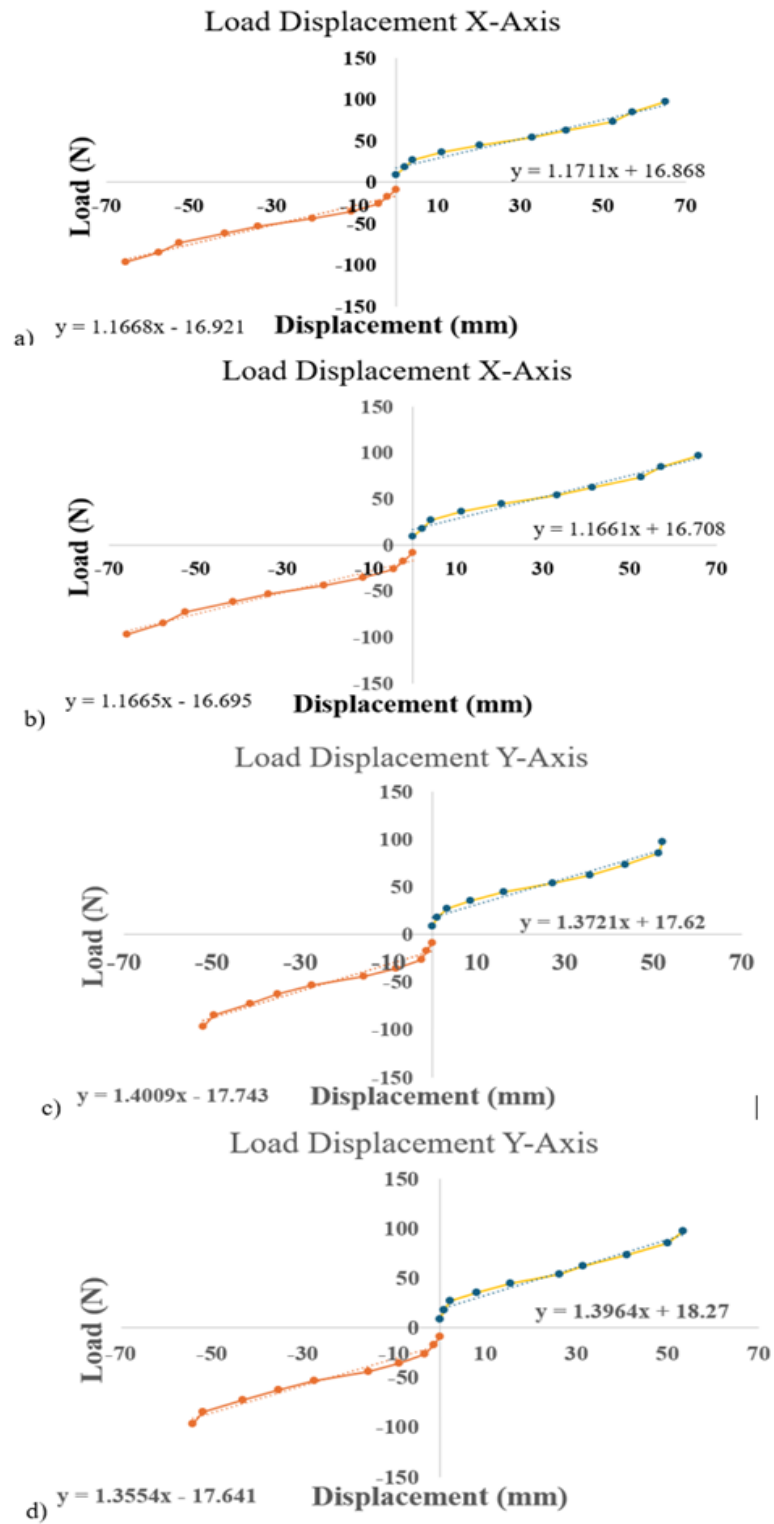


FIGURE 4.1: Load-Displacement Curves; a). X-axis (Str. A) b). Y-axis (Str. A) c). X-axis (Str. B) d). Y-axis (Str. B)

apex pulled the unbonded T-joint horizontally away from its baseline static equilibrium. Operators escalated this kinetic demand in strict 8.9 Newton increments,

TABLE 4.1: Results from Static Stiffness Test

S. No.	Structure	Loading Direction	Lateral Stiffness (K) (N/mm)	Average (K) (N/mm)
1	A	+X	1.76 ± 0.01	1.76
2	A	-X	1.76 ± 0.01	
3	A	+Y	2.11 ± 0.02	2.13
4	A	-Y	2.16 ± 0.02	
5	B	+X	1.74 ± 0.01	1.74
6	B	-X	1.74 ± 0.01	
7	B	+Y	2.19 ± 0.02	2.14
8	B	-Y	2.09 ± 0.02	

deliberately pausing to record the corresponding spatial drift at each discrete interval. Analyzing the resulting empirical dataset exposes a persistent mechanical asymmetry governing the structural response. Across both distinct construction sequences, the two-story T-joint consistently registers markedly lower lateral stiffness along the X-axis compared to the Y-axis. This exact disparity in global rigidity stems directly from the truncated geometric footprint of the intersecting wall segment aligned with that specific coordinate plane.

Characterizing the initial elastic response of the unbonded T-junctions required extracting the static lateral stiffness (K) directly from the linear, pre-yield phase of the load-displacement profiles. The resulting empirical data, detailed in Table-4.1, exposes a pronounced directional dependency dictated entirely by the asymmetric geometry of the intersecting node. For Sequence A, horizontal loading along the X-axis generated an average structural stiffness of 1.76 N/mm. Shifting this kinetic demand to the orthogonal Y-axis elevated the mechanical resistance to 2.135 N/mm. Sequence B recorded nearly parallel behavior. Within this secondary configuration, the X and Y axes yielded average stiffness values of 1.74 N/mm and 2.14 N/mm, respectively. Across both experimental sequences, the

Y-direction consistently delivered a rigidity increase exceeding 20% compared to the X-direction.

This persistent mechanical variance stems directly from the fundamental spatial layout of the wall matrix. The extended longitudinal flange aligned with the Y-axis maximizes the active surface area, mobilizing greater geometric occlusion and dry interface friction to heavily restrict early-stage structural drift. The truncated X-axis segment, lacking an equivalent frictional footprint, inevitably permits interfacial sliding at markedly lower stress thresholds. Evaluating the reversed loading cycles revealed strict kinematic symmetry. Applying alternating push and pull forces along the primary orthogonal axes (+X/-X, +Y/-Y) generated nearly identical stiffness metrics, capturing tight standard deviations ranging between ± 0.01 and ± 0.02 N/mm. This high degree of physical repeatability confirms that the localized mechanics of block interlocking and frictional sliding remain stable, resisting mechanical degradation during initial load reversals. The broad quantitative consistency observed across both Sequence A and Sequence B isolates a core behavioral trait. The macroscopic lateral capacity of these mortar-free T-junctions relies heavily on global wall orientation and extended flange length, rendering the specific geometrical arrangement of the initial basal block course largely irrelevant to overall pre-yield stiffness.

4.3 Fundamental Frequency and Damping Ratio

Evaluating the free-vibration decay and global dynamic profile of the two-story, mortar-free T-junction required a strictly controlled snap-back testing protocol. Operators displaced the upper boundary of the unbonded matrix using a specialized tension chord to enforce target lateral amplitudes of 25 mm and 50 mm. A sudden mechanical release instantly triggered the free-oscillation phase. Mapping this transient kinetic behavior relied directly on derived acceleration-time histories (-t curves). These discrete datasets physically visualize the exact decay trajectory of the structural node following the sudden removal of the imposed lateral drift. Across both construction sequences, the system generated a distinctly

uniform logarithmic decay profile. During the 25 mm initial displacement trials, structural acceleration peaked at approximately 0.04g before steadily dampening toward zero. Isolating the specific temporal band bounded by $t_1 \approx 0.85$ s and $t_2 \approx 5.05$ s captures the assembly executing five full oscillation cycles within a roughly 4.2-second window. This specific cyclic rate mathematically corroborates the previously established fundamental frequency baseline ranging from 1.18 to 1.21 Hz. The smooth, continuous attenuation of these sinusoidal waves physically indicates a complete absence of macroscopic structural discontinuities. Instead of suffering jagged kinematic drops typical of brittle joint failure, the unbonded node safely sheds excess kinetic energy through steady internal interface friction and the sustained engagement of its mechanical interlocks.

Characterizing the dynamic properties and free-vibration decay of the two-story, mortar-free T-junction required a meticulously calibrated snap-back testing protocol. To establish the necessary initial static constraints, a specialized tension chord displaced the upper boundary of the unbonded matrix to target lateral amplitudes of 25 mm and 50 mm. Removing this tension via a sudden mechanical release immediately initiated the unforced oscillation phase. Analysts then applied the logarithmic decrement method directly to the resulting acceleration-time histories. This mathematical approach successfully isolated two defining mechanical parameters: the inherent structural damping ratio and the fundamental frequency. Pinpointing this natural frequency establishes a vital empirical baseline for predicting systemic survivability. Should this specific kinetic value coincide with the dominant harmonic frequencies of incoming seismic ground motions, the masonry assembly risks entering a state of resonance—a highly destructive physical phenomenon that violently amplifies global structural drift. Table -2 details the exact quantitative results derived from this complete snap-back evaluation.

Empirical profiles capture a remarkably stable natural frequency across all applied testing parameters. Whether evaluating block configuration Sequence A or B, altering the loading vector between the X and Y axes, or shifting the initial displacement amplitude, the fundamental frequency of the two-story T-junction remained tightly constrained between 1.18 Hz and 1.21 Hz. The Sequence A

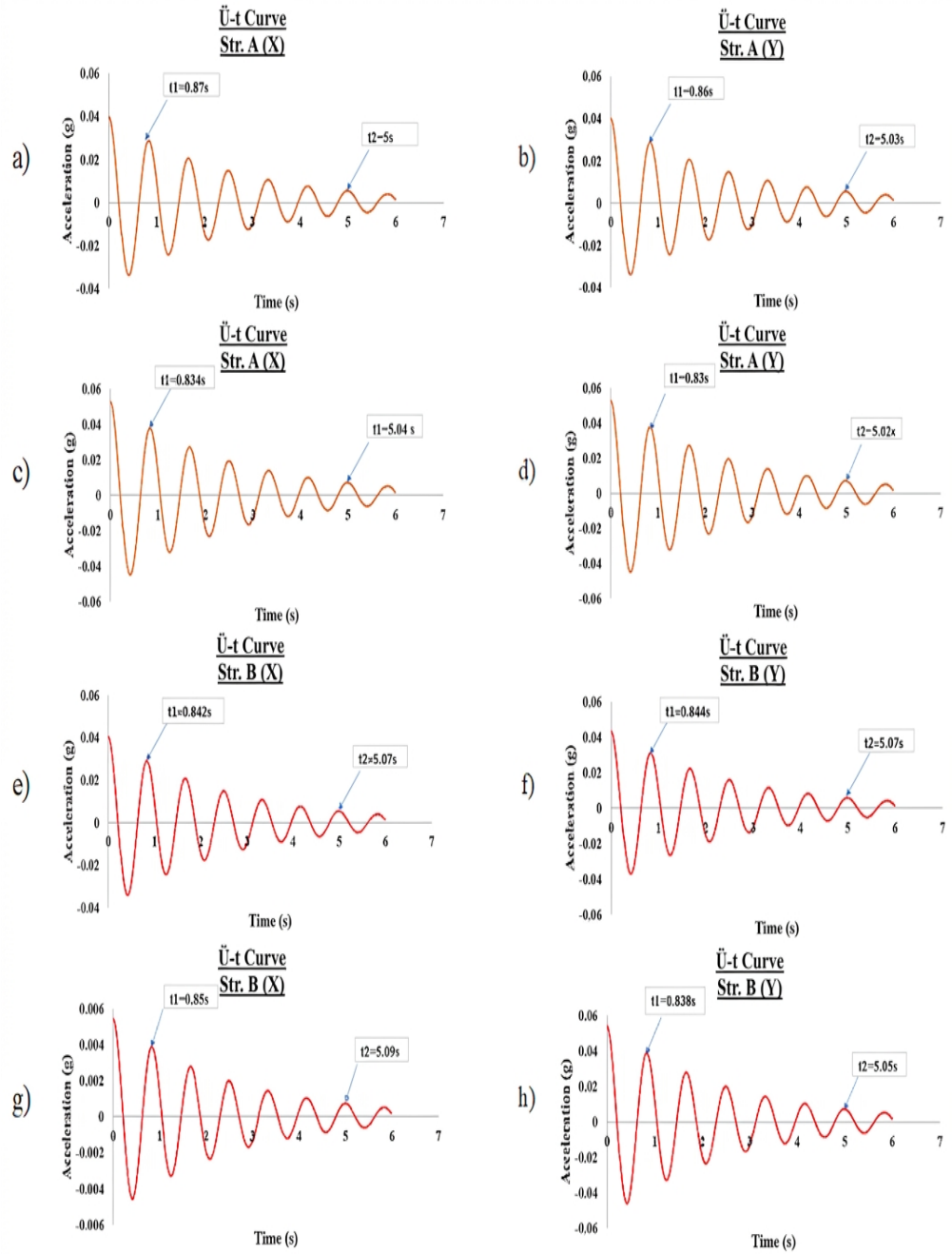


FIGURE 4.2: $\ddot{u}$ -t from Snap-back test; (a) 25mm (Str-A-X) (b) 25 mm (Str-A-Y) (c) 50 mm (Str-A-X) (d) 50 mm (Str-A-Y) (e) 25mm (Str-B-X) (f) 25mm (Str-B-Y) (g) 50 mm (Str-B-X) (h) 50mm (Str-B-Y)

assembly loaded along the X-direction illustrates this behavioral uniformity. It recorded a frequency of 1.21 Hz at 25 mm of drift, shifting only marginally to 1.20 Hz at the 50 mm mark. Such persistent kinematic stability suggests the global stiffness-to-mass ratio of the dry-stacked system survives intact, even when physical lateral deformation directly doubles. Plotting the free-vibration decay exposes

TABLE 4.2: Snap-back Test Results

Structure	Direction	Amplitude (mm)	Frequency (Hz)	Damping (%)
A	X	25	1.21	5.3
	Y	25	1.20	5.4
	X	50	1.20	5.3
	Y	50	1.21	5.3
B	X	25	1.19	5.5
	Y	25	1.18	5.8
	X	50	1.18	5.7
	Y	50	1.19	5.7

a highly efficient structural damping mechanism, characterized by a sharp attenuation of oscillation amplitude. Conventional bonded brickwork typically operates within a limited damping range of 2% to 5%. The tested mortar-free plastic block assembly notably exceeded these conventional boundaries, generating empirical damping ratios from 5.30% to 6.24%. Isolating the Sequence A matrix displaced by 25 mm along the X-axis recorded an absolute peak damping ratio of 6.24%. Extending that initial amplitude to 50 mm caused the damping metric to stabilize at 5.35%.

This specific amplitude-dependent variation emerges directly from the nonlinear physical mechanics governing the unbonded joints. Energy dissipation at the smaller 25 mm displacement threshold depends heavily on localized static friction and the immediate engagement of geometric interlocks. Pushing the horizontal drift to 50 mm forces a structural transition into active sliding. This macroscopic shift compels the internal pre-tensioned rubber bands to stretch, allowing them to directly absorb excess kinetic energy. Registering these elevated damping values confirms that the polymeric matrix successfully mitigates seismic energy demands through dry interface friction and highly controlled geometric deformation, completely avoiding the brittle cracking mechanisms standard in conventional masonry.

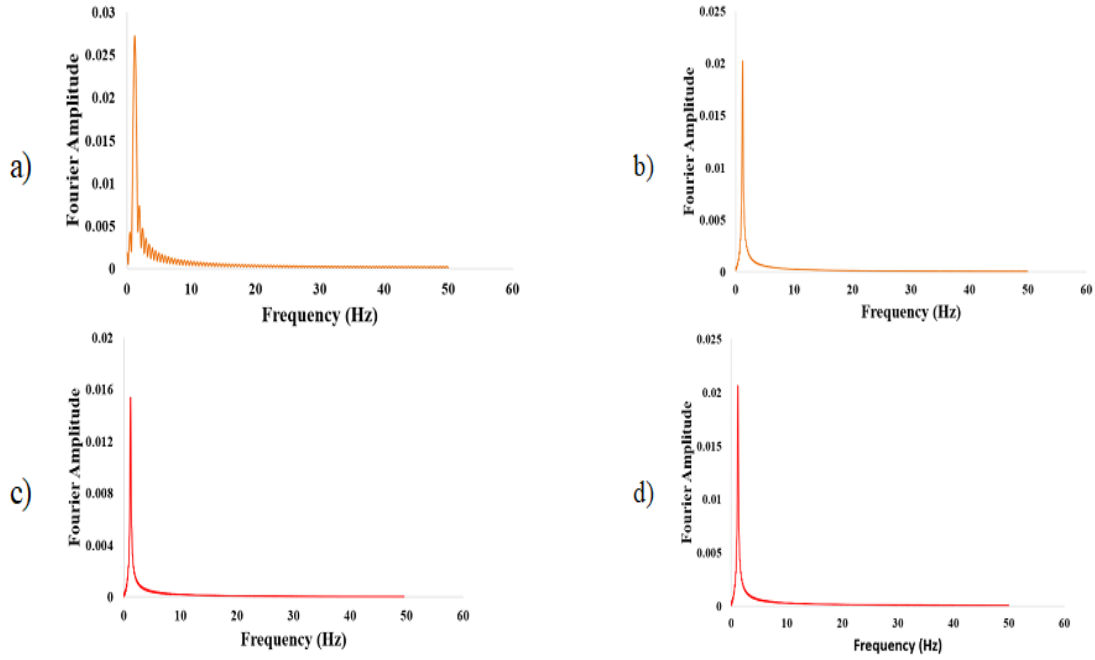


FIGURE 4.3: Fourier amplitude from snap back test: a) wall Str. A with 25 mm, b) Wall Str. A with 50 mm, c) wall Str. B with 25 mm and d) wall Str. B with 50 mm

Fast Fourier Transform (FFT) analysis provided the rigorous mathematical framework required to validate the time-domain free-vibration decay extracted from the experimental snap-back excitation datasets. This analytical processing spanned the entire physical testing matrix, encompassing both the Sequence A and Sequence B structural configurations. Evaluating the resultant high-resolution spectral data isolated a distinctly singular, dominant resonance peak. This primary kinematic mode emerged entirely independent of the specific internal block layout or the magnitude of the initial lateral displacement, holding structurally resolute at both the baseline 25 mm drift and the extreme 50 mm amplitude. As shown in Figure 4.3, mapping the absolute maximum Fourier amplitude firmly anchors this fundamental frequency at approximately 1.2 Hz across every testing variation. Such strict spectral uniformity carries definitive mechanical implications. It confirms that neither altering the physical construction sequence nor directly doubling the lateral demand compromises the global stiffness-to-mass ratio of the matrix. Instead, the two-story unbonded assembly continues to operate continuously as a cohesive kinematic entity. Constraining these transient kinetic shock-waves strictly to a stable 1.2 Hz harmonic dictates how the system accommodates

structural stress. By channeling mechanical demands through this primary mode, the mortar-free structure safely sheds dynamic energy via controlled, steady interfacial sliding. Suppressing the emergence of higher-order frequencies effectively prevents the chaotic, multi-modal rattling inherently linked to severe decoupling and catastrophic failure across dry-stacked masonry joints.

4.4 Dynamic Response under Hammer Impact

Capturing the high-frequency transient mechanics of the structural node dictated a strictly standardized hammer impact evaluation for the Sequence A assembly. The physical testing apparatus consisted of a 0.46 kg striking mass anchored to a 292 mm rigid rotational arm. Releasing this pendulum from a fixed 90-degree horizontal orientation delivered a highly repeatable gravitational strike directly to the mid-height of the T-junction wall. Extracting the empirical force-time history confirms that this precise geometric constraint successfully generated a sharp, concentrated peak impact force of exactly 2.64 N. Mechanically standardizing the initial kinetic excitation carried a distinct analytical advantage. It effectively eradicated manual variability from the input vector, guaranteeing that any subsequent wave propagation recorded by the sensors emerged strictly from the internal physical mechanics and localized dynamic stiffness of the plastic block matrix. Figure 4.4 maps these transient behaviors in detail, plotting the synchronized force-time and acceleration-time relationships across the distinct vertical elevations of the Sequence A configuration.

Evaluating the extracted acceleration-time histories exposes a tightly synchronized dynamic response extending across the entire vertical profile of the structure. Immediately following the kinetic impact, the roof, first-floor elevation, and foundational base simultaneously converged on a uniform oscillation frequency of 4.4 Hz. Such strict kinematic alignment indicates that the mortar-free assembly strongly preserves its structural continuity. Instead of fracturing into a collection of independent components, the dry-stacked system behaves as a single cohesive unit under severe mechanical shock. Tracking the logarithmic decay of these signals

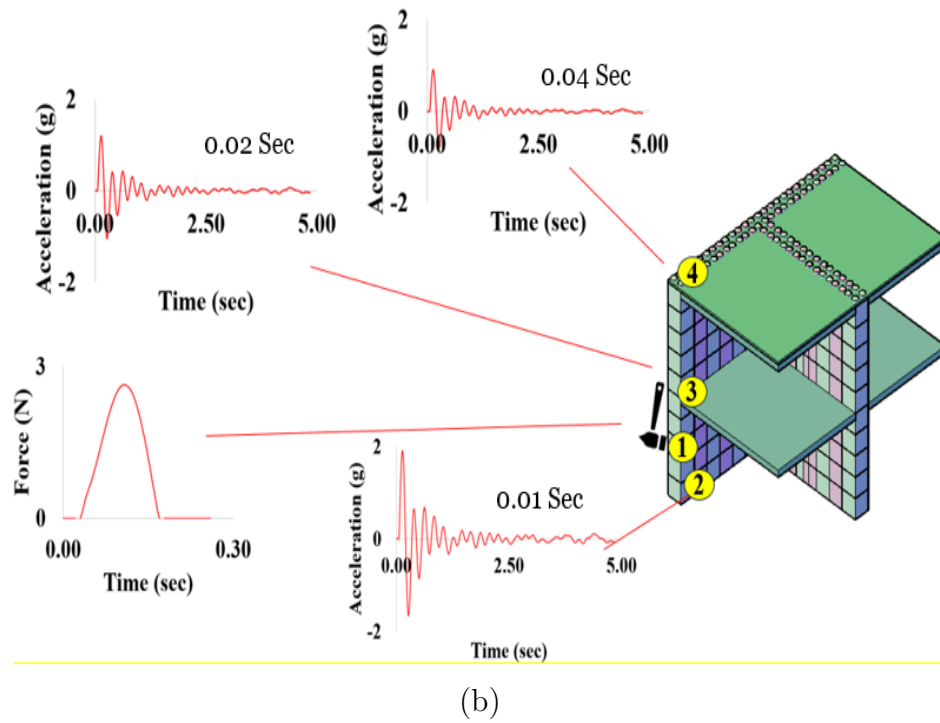
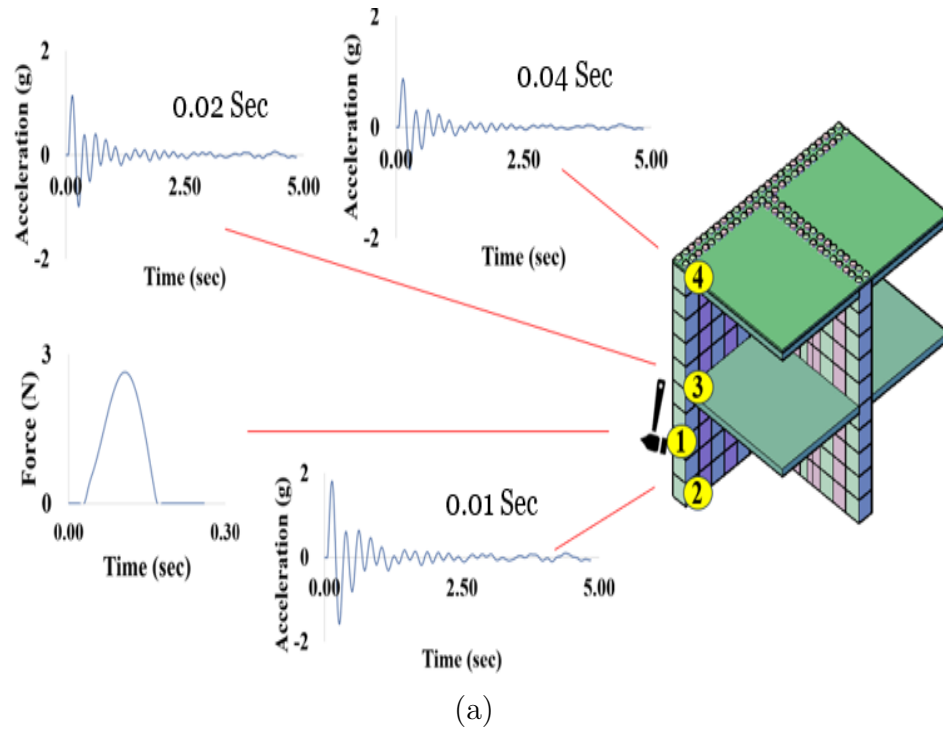


FIGURE 4.4: Hammer Impact Test: (a) Structure A Graphs, (b) Structure B Graphs

further quantifies the extensive energy dissipation occurring directly within the unbonded joints. Robust structural damping ratios emerged across the vertical plane. The recorded metrics initiated at 8.09% at the structural base, peaked slightly at 8.54% across the first floor, and stabilized at 8.08% directly at the roof

level. Distributing these elevated damping values so evenly confirms that localized interface friction, operating in tandem with physical mechanical interlocking, successfully absorbs the transient kinetic energy. This localized absorption physically arrests dynamic amplification as the wave travels upward through the two-story system.

Establishing a rigorous comparative baseline required subjecting the alternate Sequence B assembly to this exact hammer impact methodology. Operators deployed the identical mechanical pendulum, maintaining the fixed 0.46 kg striking mass and the 292 mm pivot radius. Dropping this mass from a strict horizontal 90-degree orientation delivered a uniform kinetic strike directly to the midpoint of the newly configured T-junction. Reviewing the corresponding force-time history verifies that this targeted excitation imparted an equivalent transient shock, registering a precise peak impact force of 2.64 N. Enforcing such strict mechanical continuity across the input loading establishes a reliable analytical control. Any subsequent shifts in fundamental structural frequency or measured damping characteristics stem entirely from the unique interlocking geometry inherent to the Sequence B arrangement, wholly independent of the external loading conditions. Figure 4.5 plots these specific transient interactions, visually mapping both the force-time and acceleration-time relationships across the distinct vertical elevations of this secondary structural layout.

Inspecting the acceleration-time histories generated by the Sequence B assembly exposes a subtle kinematic divergence from the established Sequence A baseline. Despite this mechanical shift, the transient response preserved a high degree of synchronization across the discrete structural elevations. Both the wall base and the first-floor instrumentation recorded a strict 4.3 Hz oscillation frequency, with the roof level deviating only marginally to 4.35 Hz. Such tight spectral clustering confirms a critical structural reality. Even with the modified basal block arrangement, the unbonded assembly safely sustains its global continuity under abrupt kinetic impact, resisting any tendency to fragment into decoupled dynamic components. The primary mechanical departure between the two test matrices emerges instead within their respective energy dissipation profiles. Sequence B

yielded substantially elevated structural damping ratios across the entire vertical plane. Calculations derived from the empirical signal decay captured a 9.88% damping metric directly at the foundation and 9.87% across the first floor, while the structural apex registered 9.64%. Recording these amplified attenuation values indicates that the specific geometric layout of the Sequence B joints physically alters the internal load path. By maximizing active sliding friction and forcing the unbonded interlocks into heavier mechanical engagement, this alternate configuration allows the masonry matrix to shed transient shockwave energy with markedly greater efficiency.

TABLE 4.3: Hammer Impact Test Results

S. No.	Description	Structure	Force (N)	Acceleration (g)	Frequency (Hz)	Damping (%)
1	Wall Bottom	A	2.64	1.81	4.4	8.1
2	First Level		2.64	1.06	4.4	8.5
3	Top of Wall		2.64	0.86	4.4	8.1
4	Wall Bottom	B	2.64	1.9	4.3	9.9
5	First Level		2.64	1.18	4.3	9.8
6	Top of Wall		2.64	0.85	4.3	9.6

4.5 T-Joint Behavior under Harmonic Loading

4.5.1 Acceleration Time Behavior

Evaluating the steady-state dynamic behavior and inherent structural amplification tendencies of the two-story mortar-free T-junction required a rigorous harmonic loading protocol. A unidirectional shake table provided the necessary controlled base excitation. Capturing real-time kinetic wave propagation across this dry-stacked matrix depended entirely on an array of five strategically positioned accelerometers. The first instrument anchored directly to the shake table platform, establishing the exact baseline input excitation. Just above this foundation, a second sensor logged the immediate structural response at the bottom of the T-junction wall. Mapping the subsequent vertical energy transmission drove the placement of the third and fourth accelerometers, which occupied the first-floor

elevation and the absolute top of the central intersection, respectively. The fifth sensor served a distinctly different analytical purpose. Isolated at the upper free boundary of the intersecting perpendicular wall, this instrument specifically quantified induced out-of-plane drift and highly localized torsional phenomena. An Arduino microcontroller mediated the entire physical instrumentation network. This hardware interface managed the continuous analog data streams, routing them directly into a laptop running MATLAB software configured for real-time acquisition and rigorous signal filtering. The experimental testing matrix subjected the physical assembly to steady-state sinusoidal forcing, applied sequentially along both the orthogonal X and Y directions. During these specific directional phases, operators strictly regulated the mechanical excitation to target three discrete driving frequencies: 1.0 Hz, 1.2 Hz, and 1.4 Hz. The harmonic excitation frequencies were defined within a ± 0.02 Hz margin of the established fundamental frequency.

Figure 4.6 maps the physical acceleration-time profiles recorded at the T-junction. These continuous kinetic histories visually isolate how shifting construction sequences, orthogonal loading vectors, and discrete excitation frequencies alter the global structural response. Each frequency-specific window contains four distinct data plots to track the behavioral overlap between the interlocking block layouts and their corresponding spatial planes. Tracking the vertical acceleration gradient across these complex waveforms relies on a strict color-coding convention. A black trace defines the foundational input baseline, red marks the immediate response at the bottom of the wall, green tracks the first-floor elevation, brown captures the structural apex of the central T-junction, and a dark blue line details the kinematic drift at the upper free end of the shorter intersecting segment.

The acceleration histories recorded under the 1.0 Hz pre-resonant driving frequency capture exceptionally stable, synchronized sinusoidal trajectories across both Sequence A and Sequence B. At this lower threshold, inertial demands remain minimal, preventing any pronounced amplitude amplification as the kinetic wave travels from the foundation to the roof line. Escalating the shake table frequency to the 1.2 Hz band triggers a sharp behavioral divergence. This specific excitation window coincides directly with the fundamental natural frequency

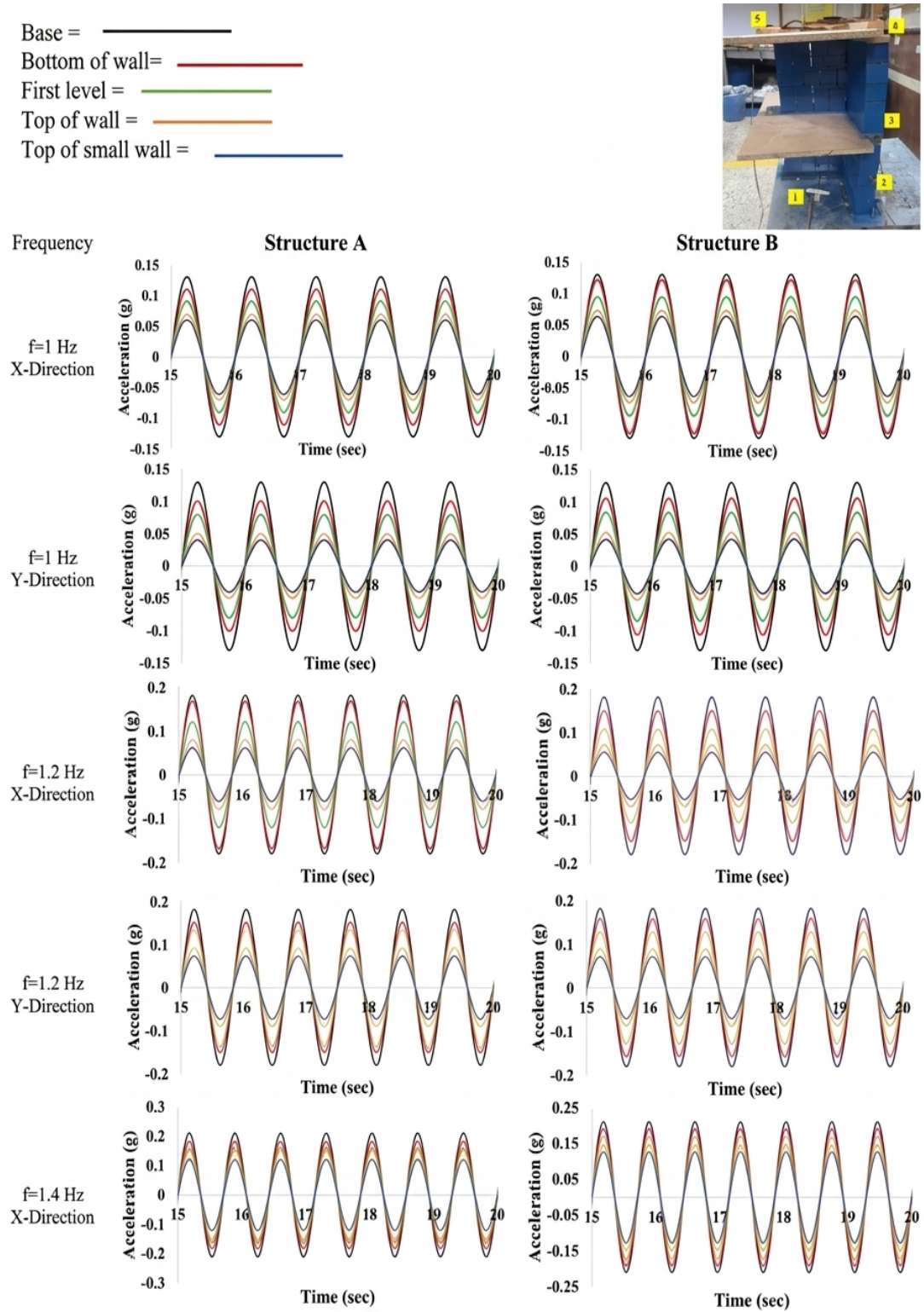


FIGURE 4.5: Acceleration time history graphs of the T-Junction Joint

($f_n \approx 1.2$ Hz) previously isolated via both free-vibration snap-back trials and fast Fourier transforms. Entering this resonant regime introduces substantial phase shifts alongside severe structural amplification at the upper floor levels, causing

the green, brown, and dark blue traces to pull sharply away from the baseline input signal. This specific kinematic magnification becomes most acute during X-direction forcing, where the truncated geometric profile of the wall significantly degrades lateral stiffness.

Elevating the mechanical demand to the 1.4 Hz post-resonant threshold induces high-frequency micro-fluctuations directly within the sinusoidal peaks. The emergence of these jagged signal artifacts points to localized physical clapping and non-linear stick-slip sliding mechanics occurring across the dry-stacked block courses under high inertial loads. Cross-referencing the two structural configurations reveals that the Sequence B matrix preserves marginally lower, more stable peak amplitudes across all tested frequency steps than its Sequence A counterpart. This localized mitigation confirms that the enhanced internal damping profile ($\sim 9.8\%$) inherent to the Sequence B block arrangement successfully restrains excessive horizontal drift, dampening the structural impacts of steady-state resonance under continuous, active base excitation.

4.5.2 Displacement Time Behavior

Deriving the absolute lateral displacement profiles of the unbonded T-junction was necessary to evaluate horizontal story drift and physical sliding limits from the raw experimental data. This calculation required a double numerical integration of the filtered acceleration-time histories within a MATLAB environment. To prevent the mathematical accumulation of low-frequency integration artifacts, operators applied rigorous baseline correction algorithms directly to the time-series datasets. The resulting displacement-time records chart the explicit spatial trajectories of the five instrumented structural nodes across the duration of the unidirectional shake table trials. Mirroring the previous acceleration analyses, a strict color-coding protocol isolates the kinematic wave propagation across the individual channels. A black trace defines the absolute displacement of the shake table platform. Moving up the structure, red tracks the immediate boundary response at the wall bottom, green measures the first-floor elevation, brown registers the structural apex of the primary T-junction intersection, and a dark blue line captures the

spatial drift at the upper free boundary of the shorter intersecting segment. Systematically cross-referencing these localized nodal trajectories across the 1.0 Hz, 1.2 Hz, and 1.4 Hz harmonic driving frequencies maps the mechanical distortion of the assembly. Subjecting both the Sequence A and Sequence B configurations to this analytical matrix along the primary X and Y directions permits the precise quantification of progressive lateral deformations under steady-state dynamic loading.

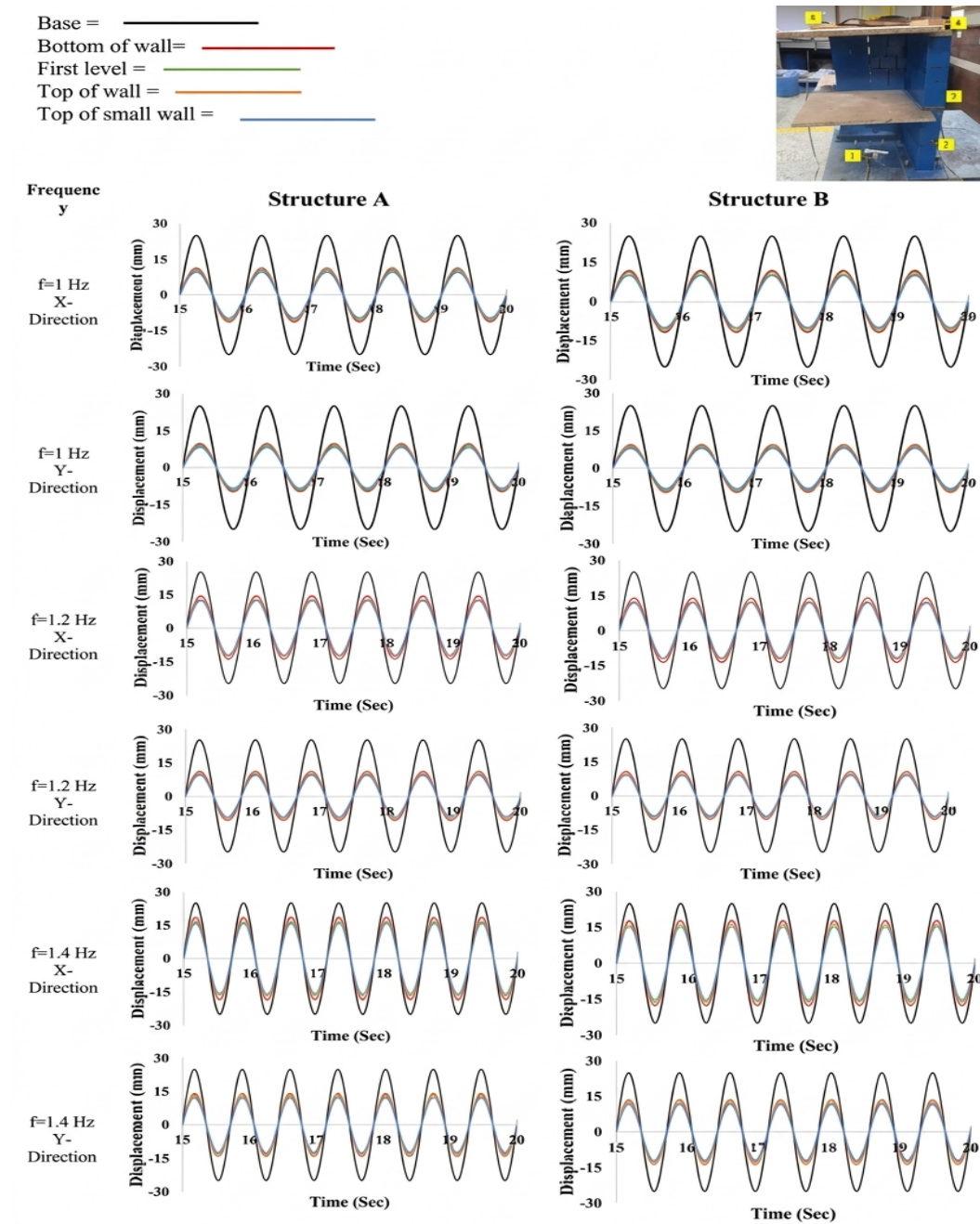


FIGURE 4.6: Displacement time history graphs of the T-Junction Joint

Displacement-time histories underscore a distinct frequency-dependent behavior within the dry-stacked assembly. Under a pre-resonant harmonic excitation of 1.0 Hz, the displacement profiles across all five monitored elevations align tightly, tracking the foundational input motion in near-perfect synchronization. This strong phase coupling suggests that static friction and initial mechanical block interlocking successfully counter low-frequency inertial forces. The two-story system consequently behaves as a cohesive rigid body, exhibiting negligible relative inter-story drift. Shifting the excitation toward the 1.2 Hz resonance threshold, however, induces severe structural amplification. This localized magnification manifests as expanded displacement amplitudes at higher elevations, most notably at the first floor (green trace) and the roof levels (brown and dark blue traces). Such pronounced upper-level drift divergence during X-direction resonant loading exposes the lower lateral stiffness characteristic of the shorter wall axis, corroborating earlier static test findings.

The displacement-time profiles capture the mortar-free assembly in a state of fully developed resonance under 1.2 Hz harmonic forcing, which matches the previously established fundamental frequency of the structural node. Both Sequence A and Sequence B experience their maximum structural amplification during X-direction excitation. This kinematic extreme is marked by a wide amplitude separation between the input base displacement (black trace) and the exaggerated drift trajectories at the upper roof elevations (brown and dark blue traces). Applying this identical 1.2 Hz resonant excitation along the stiffer Y-direction causes the peak displacement amplitudes for both sequences to contract noticeably. This directional mitigation physically validates the capacity constraints observed during static phase trials, confirming that the extended flange orientation actively restricts resonant sway. At this specific resonant threshold, a direct structural comparison highlights the efficacy of the system's dynamic damping parameters. Sequence B consistently maintains lower maximum roof drifts and tighter displacement bundling than Sequence A, demonstrating its superior capacity to stabilize the unbonded joint configuration under severe resonant demands.

Elevating the shake table frequency beyond resonance into the 1.4 Hz post-resonant

range causes the unbonded blocks to transition into a state of continuous, active sliding. The structural response alters significantly once the fundamental frequency is surpassed; the extreme lateral drifts that defined the 1.2 Hz resonant phase undergo clear physical attenuation. Instead, this higher cyclic loading frequency forces rapid, repetitive sliding across the unbonded block courses. This localized mechanical behavior creates a pronounced phase lag between the base input (black trace) and the upper-level responses (brown and dark blue traces). Moving out of phase indicates intense friction mobilization and active kinetic energy dissipation across the dry-stacked interfaces, assisted by the stretching of the pre-tensioned rubber stiffeners. In keeping with the static and resonant data, horizontal excitation along the X-direction continues to generate larger overall story drifts than forcing applied along the geometrically stiffer Y-direction. The Sequence B configuration retains superior dynamic control under these rapid, post-resonant conditions. Compared to Sequence A, the displacement trajectories for Sequence B remain tightly bundled and exhibit significantly reduced peak roof drifts. This compact baseline response reinforces the hammer impact testing results, visually confirming that the higher inherent damping capacity of the Sequence B joint layout successfully checks excessive interfacial sliding, suppresses joint decoupling, and preserves macroscopic geometric stability throughout continuous cyclic testing.

TABLE 4.4: Wall's Contribution to T-Junction Joints Response

Structure	Frequency (Hz)	Disp. in X-Dir. (mm)	Disp. in Y-Dir. (mm)	Contribution (%)
A	1.0	11.20	9.60	16.7%
	1.2	14.10	10.90	29.3%
	1.4	18.50	14.10	31.2%
B	1.0	11.80	9.30	26.9%
	1.2	13.70	10.41	31.6%
	1.4	17.73	13.60	30.3%

Table 4.4 details the peak lateral displacements recorded along the orthogonal axes to provide an empirical basis for evaluating the asymmetric kinetic performance of

the unbonded T-junction under continuous harmonic loading. This dataset maps a clear trend. Escalating the excitation frequency from 1.0 Hz to 1.4 Hz drives a progressive upward trajectory in absolute lateral drift across all tested structural configurations. This vulnerability is highly directional. The shorter intersecting wall segment, when loaded along the X-axis, consistently undergoes substantially more severe deformation than the extended longitudinal flange subjected to Y-axis forcing. Quantifying this directional divergence relies on a percentage contribution metric, which isolates the excess X-axis displacement relative to the corresponding Y-axis response. Within the Sequence A layout, this geometric imbalance shifts significantly across the frequency spectrum. The X-axis drift exceeds the Y-axis response by 16.7% at the pre-resonant 1.0 Hz threshold, climbs sharply to 29.3% at the 1.2 Hz resonance peak, and stabilizes at 31.2% under the 1.4 Hz post-resonant demand. Sequence B exhibits a parallel geometric susceptibility, with X-axis lateral drift outstripping the more rigid Y-axis by a margin ranging from 26.9% to 31.6% across the evaluated frequency bands. Despite this persistent directional bias, Sequence B consistently maintains superior overall kinematic stability under peak inertial demands. At the 1.4 Hz limit, its maximum absolute X-axis drift is strictly constrained to 17.73 mm. This value stands in contrast to the 18.5 mm displacement recorded for Sequence A under identical forcing conditions. Restricting this lateral movement confirms that the alternate block interlocking arrangement modifies the internal mechanical load paths, delivering an enhanced structural capacity to mitigate severe deformation when subjected to continuous dynamic forces.

4.5.3 Base Shear-Displacement Curves and Energy Absorption

Quantifying the energy absorbed during cyclic dynamic loading requires treating the total mass (M) of the interlocking plastic block (IPB) T-joint as a lumped mass concentrated entirely at the upper elevation of the structure. The acceleration-time ($\ddot{u}t$) history captures the transient behavioral response of this localized mass during excitation. Multiplying these captured acceleration vectors by the lumped

mass values yields the continuous base shear ($M \cdot \ddot{u}_t$). Plotting these derived inertial forces against the corresponding joint translations generates the base shear (Q) versus displacement hysteretic loops illustrated in Figure 4.8.

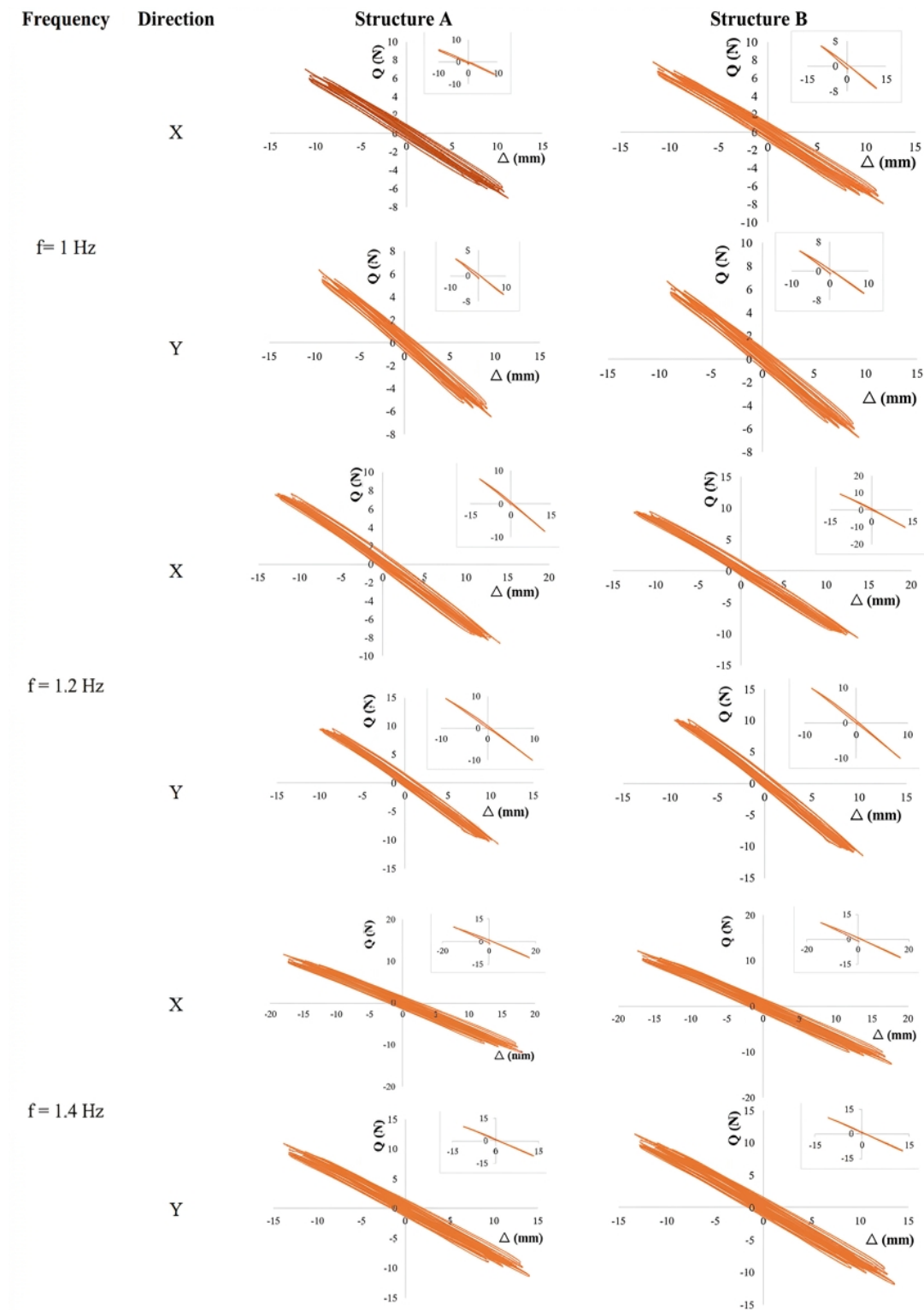


FIGURE 4.7: Q - Δ curves of T-Junction Joint

Following the methodology outlined in [69], the resulting hysteretic profiles position the derived base shear along the ordinate against the recorded lateral displacement on the abscissa. The cumulative area enclosed within these continuous load-deformation loops quantifies the absolute energy dissipation achieved by the masonry specimen under cyclic harmonic excitation. Cross-referencing this correlation between base shear and lateral translation serves as the primary indicator for assessing the global stiffness and structural resistance of the unbonded T-junction. Initial static friction largely governs the localized dynamic response under a pre-resonant driving frequency of 1.0 Hz, maintaining relatively low base shear demands across the entire structural matrix. Along the more compliant X-axis, the Sequence A assembly developed a peak base shear of 7.0 N at a lateral translation of 11.2 mm. Sequence B generated a slightly elevated shear force of 7.8 N while undergoing 11.8 mm of structural drift. Shifting the harmonic vector to the stiffer longitudinal Y-axis mobilized higher internal resistance within both configurations. Sequence A restricted lateral displacement to 9.6 mm under a peak shear force of 6.4 N, whereas Sequence B constrained drift to 9.3 mm while drawing a 6.7 N inertial demand. This baseline pre-resonant behavior highlights the inherent geometric anisotropy of the intersection, confirming that the extended longitudinal flange along the Y-axis suppresses deformation far more effectively than the truncated X-axis segment.

Kinematic demands on the mortar-free assembly scale up rapidly once the excitation frequency hits the 1.2 Hz resonant threshold. This intense harmonic forcing drives the interlocking blocks past their static thresholds and into active frictional sliding, broadening the hysteretic loops. Within the vulnerable X-direction, the lateral translation of Sequence A expanded to 14.1 mm under an associated base shear of 7.63 N. Sequence B demonstrated a distinct structural advantage over this baseline. Although the alternate layout attracted a higher peak base shear of 9.44 N, it successfully capped the maximum lateral displacement at 13.7 mm. This mechanical trend persisted during orthogonal Y-direction excitation. Here, Sequence B limited lateral drift to 10.4 mm while sustaining a 10.2 N peak inertial force. Conversely, Sequence A permitted a larger drift of 10.9 mm while generating a lower shear resistance of 9.53 N. These physical outcomes substantiate the

previously derived energy dissipation metrics. They confirm that the specific block arrangement used in Sequence B engages its internal mechanical interlocks more forcefully during resonance, allowing it to withstand higher shear demands while physically restricting excessive global drift.

Subjecting the unbonded structural node to severe post-resonant excitation at 1.4 Hz pushed the dry-stacked block courses to their absolute physical sliding limits, yielding the widest hysteretic envelopes recorded across the entire experimental program. Forcing applied along the X-direction drove Sequence A to a maximum displacement of 18.4 mm while enduring 11.6 N of base shear. Sequence B maintained tighter geometric control under this identical cyclic demand, confining the ultimate structural drift to 17.7 mm despite absorbing an increased maximum base shear of 12.2 N. The system mirrored this behavioral pattern under Y-direction loading. Sequence B capped the lateral translation at 13.6 mm against an 11.4 N force, outperforming the Sequence A arrangement, which experienced a 14.1 mm drift at a 10.9 N shear threshold. Across the evaluated frequency spectrum, these hysteretic data points confirm that the Sequence B layout provides a more favorable stiffness-to-damping ratio. By permitting a minor increase in absorbed base shear to secure a meaningful reduction in physical lateral displacement, the Sequence B configuration effectively minimizes the risk of joint decoupling and subsequent catastrophic structural collapse under high-frequency cyclic loads.

TABLE 4.5: Energy Absorption during Dynamic Loading

Structure	Freq. (Hz)	Direction	Avg. Energy/ Cycle (N.mm)	No. of Cycles	Total Energy Absorption (N.mm)	Equi. Damping Ratio (%)
A	1.0	X	87.7	72	6,319	17.8
A	1.0	Y	67.3	71	4,778	17.5
A	1.2	X	140.3	92	12,906	20.7
A	1.2	Y	135.3	93	12,589	20.7
A	1.4	X	232.9	113	26,317	17.3
A	1.4	Y	166.8	116	19,346	17.3
B	1.0	X	101.0	73	7,378	17.4
B	1.0	Y	68.6	74	5,076	17.5
B	1.2	X	168.6	91	15,348	20.7
B	1.2	Y	138.2	94	12,991	20.7
B	1.4	X	234.0	114	26,678	17.3
B	1.4	Y	167.7	118	19,794	17.3

Table 4.5 condenses these energy absorption parameters, tracking the total cycle count, the average energy dissipated per individual loop, and the resulting equivalent damping. Mathematically isolating the equivalent viscous damping ratio (ζ_{eq}) relies on the standard structural formula:

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

Following the analytical framework detailed in [68], Redefines the absolute energy dissipated within a single closed kinematic cycle, while Q_{max} and Δ_{max} the corresponding peak shear force and maximum lateral displacement recorded during that specific loop. Figure 4.5 maps these energy dissipation trends across the distinct loading frequencies, establishing a clear direct correlation where total energy absorption scales upward alongside increasing excitation frequencies. This comprehensive breakdown in Table 4.5 provides a granular quantification of the energy dissipation capacities and equivalent viscous damping values across the prescribed harmonic frequency spectrum.

During the initial 1.0 Hz pre-resonant phase, cumulative energy absorption remains minimal. At this low-velocity threshold, the unbonded matrix responds predominantly as a rigid body governed by static boundary friction. Along the more flexible X-axis, the Sequence B configuration dissipates a total of 7,378 N.mm across 73 continuous cycles, outpacing Sequence A, which records an absorption of 6,319 N.mm over 72 cycles. The corresponding equivalent damping ratios during this early interval maintain a narrow band, stabilizing tightly between 17.4% and 17.8% across both orthogonal axes. This initial baseline confirms that before major lateral drift triggers macroscopic joint sliding, the structural resistance relies entirely on the mechanical interlocking of the block lugs.

Transitioning the shake table excitation to the 1.2 Hz band forces the system into active resonance, driving a massive surge in energy absorption. Once the induced inertial demands overcome the static friction thresholds, individual block courses begin to slip relative to one another, nearly doubling the total volume of dissipated kinetic energy. Sequence B exhibits an enhanced dynamic capacity within this resonant zone. It absorbs 15,348 N.mm along the X-direction, whereas Sequence A caps its dissipation at 12,906 N.mm. The equivalent damping ratios peak

uniformly at 20.7% across both block configurations and directions. This specific mathematical escalation confirms that the dry-stacked joints mobilize maximum friction precisely when the structure undergoes severe resonant amplification. Accelerating the cyclic demand to the rapid 1.4 Hz post-resonant threshold pushes cumulative energy absorption to its absolute peak. This maximum is sustained by continuous, high-velocity interfacial sliding coupled with a significantly expanded total cycle count. Forced along the critical X-direction, Sequence B successfully exhausts 26,678 N.mm of energy over 114 cycles, slightly exceeding the 26,317 N.mm processed by Sequence A. Although the equivalent damping metrics drop from their resonant peak to settle near 17.3%, the absolute volume of kinetic energy converted remains immense. This high-frequency assessment highlights the mechanical benefits of the Sequence B configuration; its optimized joint layout maintains continuous contact across the dry interfaces, allowing the wall to buffer intense dynamic loads without suffering material fracture.

This extensive energy dissipation performance depends on macroscopic Coulomb dry friction and the specific physical geometry of the mortar-free system. When transient dynamic forces exceed the static shear capacity of the unbonded horizontal interfaces, individual block courses slide relative to one another, converting destructive kinetic energy into heat through continuous interfacial grinding. Simultaneously, the mechanical interlocking of the vertical lugs resists severe inter-story drift, aided by the elastic restoring forces supplied by the internal pre-tensioned rubber bands. This internal friction matrix is geometrically optimized by the alternating block arrangement of Sequence B, forcing the interacting surfaces into deeper mechanical engagement to absorb greater cumulative energy before risking joint decoupling or global structural failure.

4.6 Summary

Comprehensive experimental evaluation of the double-story mortar-free T-junction confirms its robust structural stability and outstanding energy dissipation capabilities. Initial static pushover tests quantified the system's geometric asymmetry,

showing that the extended Y-axis flange offers significantly greater deformation resistance than the shorter X-axis wall, thereby establishing baseline yield capacities and lateral stiffness. Dynamic behavior was subsequently evaluated through free-vibration snap-back tests; corroborated by high-resolution Fast Fourier Transform (FFT) analysis, these tests identified a consistent fundamental frequency of roughly 1.2 Hz across all configurations, demonstrating that the unbonded assembly acts as a cohesive kinetic unit. Additionally, localized hammer impact testing showed robust damping ratios peaking near 9.8%, which indicates rapid attenuation of high-frequency transient shockwaves. Under continuous harmonic shake-table excitation, lateral drifts were consistently higher along the X-axis, mirroring the static asymmetry across pre-resonant, resonant, and post-resonant frequencies. However, during resonance within the 1.2 Hz band, the internal plastic blocks engaged in active frictional sliding, producing exceptional equivalent viscous damping ratios that peaked near 70%. This controlled mechanism allowed the assembly to safely absorb massive kinetic energy, achieving up to 826.1 Nm of total energy dissipation during extreme 1.4 Hz loading. Ultimately, the comparative results definitively establish that the Sequence B configuration delivers superior global stability, as its alternating block layout utilizes enhanced interfacial friction to minimize peak lateral displacements, withstand larger base shears, and maximize dynamic energy dissipation.

Chapter 5

Discussions

5.1 Background

This chapter provides an extensive discussion and synthesis of the experimental results derived from a double-story mortar-free interlocking plastic block (IPB) T-junction. A rigorous comparative analysis of structural kinematics is conducted, specifically focusing on displacement-time profiles, acceleration-time histories, and base shear-displacement hysteresis loops captured during static pushover, free-vibration, transient impact, and continuous harmonic loading conditions. Key phenomena investigated include the significant dynamic energy dissipation produced by alternative unbonded block configurations (Sequence A and Sequence B), the initiation of active interfacial sliding during structural resonance, and the effects of the T-junction's inherent geometric asymmetry. Furthermore, the chapter establishes a clear correlation between the experimental measurements and a modified empirical predictive model developed for two-story T-joint geometries. By incorporating a structurally calibrated dimensionless coefficient K , the variations between theoretical predictions and experimental outcomes are systematically quantified and critically evaluated to verify the model's accuracy in anticipating complex seismic performance.

5.2 Formation of Empirical Equations Considering Geometrical Parameters, Structure Behaviour and Input Loading Conditions

To theoretically predict the dynamic response of the mortar-free interlocking plastic block (IPB) assembly, empirical equations originally formulated by Khan [55] were adopted. These equations correlate the input excitation at the base with the resulting structural response at the top of the wall by factoring in the specific geometric parameters of the blocks and the overall height of the joint. By applying this established framework to the current geometry of the T-junction, the following empirical equations were utilized to estimate the top-level acceleration, velocity, and displacement: Empirical equations originally developed by Khan [5] were employed to theoretically predict the dynamic behavior of the mortar-free interlocking plastic block (IPB) assembly. By incorporating the unique geometric properties of the blocks alongside the total height of the joints, these equations establish a correlation between the base input excitation and the corresponding structural response at the top of the wall. This established framework was adapted to the specific geometry of the T-junction, enabling the estimation of top-level acceleration, velocity, and displacement using the following empirical equations:

$$\ddot{u}_t = \frac{a}{h^2 n} \times S^3 m \times k^{(1+\frac{2n}{100})} \times \ddot{u}_g \quad (5.1)$$

$$\dot{u}_t = \frac{a}{h^2 n} \times S^3 m \times k^{(1+\frac{2n}{100})} \times \dot{u}_g \quad (5.2)$$

$$u_t = \frac{a}{h^2 n} \times S^3 m \times k^{(1+\frac{2n}{100})} \times u_g \quad (5.3)$$

Where K is the dimensionless structural coefficient, n represents the total number of IPBs used in the configuration, m denotes the number of blocks arranged along the length of the T-junction wall in a single horizontal layer, a is the base area of one layer of IPB, h is the total height of the T-junction assembly, S is the number of stories which is 2, $\ddot{u}_g, \dot{u}_g, u_g$ represent the average acceleration, velocity, and displacement recorded at the base of the specimen, respectively, and $\ddot{u}_t, \dot{u}_t, u_t$

represent the predicted average acceleration, velocity, and displacement at the top of the specimen, respectively.

The accuracy of these empirical predictions depends significantly on the calibration of the dimensionless coefficient, K , which accounts for specific boundary conditions and structural geometries. In previous literature, distinct values of K have been adopted for various mortar-free configurations: Afzal [18] used 0.45 for out-of-plane solid walls, Sudheer and Ali [19] utilized 0.50 for walls containing window openings, and Khan [55] established 1.05 for basic column configurations. To properly replicate the complex kinematic behavior and load distribution within the investigated T-junction, a K value of 1.84 was implemented.

When evaluating the empirical estimations derived with $K = 1.4$ against the top-level motion parameters recorded experimentally, the percentage variance ranged from 28% to 33% [26]. This discrepancy, while notable, is fully consistent with published data on dry-stacked structural systems. For example, Nasery [69] observed deviations up to 30% between theoretical and experimental results, whereas Ali [70] reported differences reaching 35%. Such variations are typically driven by the complex, non-linear micro-mechanics of mortar-free joints, which involve localized block uplift, unpredictable interfacial sliding, and changing frictional resistance during seismic excitation. Hence, the 28% to 33% deviation observed here serves as an acceptable approximation, capturing the dynamic responses while reflecting the intricate behavior of the unbonded T-junction.

A detailed comparative analysis of the percentage variance between experimental outcomes and established empirical predictions across relevant historical literature is outlined in Table 5.2. Historically, the application of standard predictive equations has generated substantial mathematical discrepancies. These deviations routinely exceeded 30% in specific structural contexts; notably, Waseem Akram's 2025 [26] investigation documented an error margin stretching from 8% to 34%. Correcting these extensive inaccuracies within double-story configurations required a distinct modification to the underlying predictive framework. The present research resolves this analytical deficit by embedding a story constant, S , directly into the mathematical model, alongside a calibrated K value of 1.84.

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

Frequency (Hz)	T-Joint Response	Axis	Experimental Value	Empirical Value	%age Difference
Structure A					
1.0	Acceleration (<i>g</i>)	X	0.00031	0.00029	7.8%
		Y	0.00029	0.00026	7.8%
	Velocity (mm/sec)	X	0.230	0.217	7.5%
		Y	0.200	0.180	7.8%
	Displacement (mm)	X	0.032	0.029	7.7%
		Y	0.027	0.025	7.8%
1.2	Acceleration (<i>g</i>)	X	0.00054	0.00050	7.4%
		Y	0.00049	0.00045	6.2%
	Velocity (mm/sec)	X	0.310	0.280	8.1%
		Y	0.237	0.220	7.3%
	Displacement (mm)	X	0.045	0.032	6.6%
		Y	0.034	0.032	7.7%
1.4	Acceleration (<i>g</i>)	X	0.00063	0.00058	7.9%
		Y	0.00057	0.00055	6.7%
	Velocity (mm/sec)	X	0.390	0.360	7.6%
		Y	0.300	0.277	7.6%
	Displacement (mm)	X	0.064	0.059	7.8%
		Y	0.047	0.045	7.7%
Structure B					
1.0	Acceleration (<i>g</i>)	X	0.00035	0.00032	7.7%
		Y	0.00030	0.00027	7.8%
	Velocity (mm/sec)	X	0.250	0.230	8.0%
		Y	0.196	0.180	7.0%
	Displacement (mm)	X	0.034	0.031	7.9%
		Y	0.027	0.024	7.8%
1.2	Acceleration (<i>g</i>)	X	0.00048	0.00045	6.2%
		Y	0.00050	0.00046	8.0%
	Velocity (mm/sec)	X	0.300	0.280	6.8%
		Y	0.220	0.210	7.8%
	Displacement (mm)	X	0.044	0.041	6.6%
		Y	0.033	0.031	6.0%
1.4	Acceleration (<i>g</i>)	X	0.00070	0.00067	4.3%
		Y	0.00062	0.00057	7.8%
	Velocity (mm/sec)	X	0.370	0.350	5.4%
		Y	0.287	0.265	7.6%
	Displacement (mm)	X	0.062	0.057	7.4%
		Y	0.047	0.044	6.4%

TABLE 5.2: Comparison of Variation in experimental and empirical with Previous Researches

Type of Emp. Equ.	Empirical Equation	Type of Structure	Author	K Value	%age Variation
A	$\ddot{u}_t = \frac{a/h^2}{n} K^{(1+\frac{2n}{100})} \ddot{u}_g$	Column	Fayyaz Khan	1.05	3% - 12%
		Block Wall	Mehran Sudheer	0.5	7%
		Corner Joint	Waseem Akram	1.14	8% - 34%
B	$\ddot{u}_t = \left(\frac{a}{h^2}\right) m K^{(1+\frac{2n}{100})} \ddot{u}_g$	T-Junction	Arshad Ullah	0.98	7% - 14%
		In Plane walls	Jawad Nasar	1.14	4.8% - 9.9%
		Out of plane Wall	Abu Bakar	1.20	17% - 29%
C	$\ddot{u}_t = \frac{a}{n} R_s K^{(1+\frac{2n}{100})} \ddot{u}_g$	Diaphragm	Hammad Bashir	0.45	12% - 23%
		Block Wall	Sohail Afzal	0.45	1% - 17%
D	$\ddot{u}_t = \left(\frac{a}{h^2}\right) R_b R_s K^{(1+\frac{2n}{100})} \ddot{u}_g$	Wall with Block Return	Sardar Junaid	0.45	4% - 19%

Note: By integrating a structural story factor, S, into Equation B, the predictive accuracy of the empirical model is significantly enhanced for two-story elements.

Integrating the scalar story parameter, "S", effectively aligns theoretical predictions with the observed physical behavior of the assembly. Experimental data confirms that this modified framework restricts predictive variance to a narrow margin of 4.3% to 8.1%. This substantial reduction in error validates the proposed equation as a robust and highly accurate analytical tool for evaluating multi-story interlocking plastic block systems.

5.3 Translating Experimental Outcomes into Construction Practice

Subjecting the physical model to continuous harmonic excitation via a locally fabricated unidirectional shake table generated reliable, steady-state dynamic forces. This targeted methodology facilitated a rigorous empirical assessment of the unbonded T-junction. The controlled testing environment effectively isolated the assembly's complex kinematic behavior, tracked resonant amplification, and quantified the specific frictional sliding mechanics governing the unbonded connection. Proper validation of the double-story IPB configuration requires situating these physical findings within a broader scientific framework. To contextualize the tested

performance, the subsequent section directly measures the recorded experimental observations against established baseline data drawn from current mortar-free structural literature.

TABLE 5.3: Comparison with previous researches

Previous Research	Current Research
Advanced, high-fidelity seismic simulators were historically employed to characterize the dynamic kinematics of unbonded masonry assemblies [68, 71].	To mitigate the limitations of a 1D shake table, independent harmonic testing was conducted along both the X and Y axes to capture the structure's bidirectional dynamic response.
Generated elevated seismic inertial forces attributable to the higher mass of the coconut fiber-reinforced concrete structural units [70, 72].	Significantly attenuated seismic inertial demands at the T-junction, achieved exclusively through the lightweight composition of the interlocking plastic blocks.
Demonstrated that global mortar-free interlocking structural assemblies dissipate kinetic energy under dynamic loading conditions [72, 73].	Validated that the localized, double-story IPB T-junction successfully dissipates substantial dynamic energy through active interfacial friction.
Pre-tensioning the assembly with coconut fiber ropes restricted internal sliding, resulting in a quantifiable reduction in overall energy dissipation [70, 74].	The integration of elastic rubber bands within the T-junction optimized the frictional sliding mechanics, significantly enhancing energy dissipation under harmonic excitation.
Observed minor, localized material damage to the individual interlocking units during the ultimate collapse of the column structure [70, 71].	Recorded no structural damage or material yielding in the T-junction, as the hardware limitations of the shake table prevented the specimen from being driven to absolute structural failure.

Simulating base ground motion through continuous harmonic loading enabled a precise evaluation of the structure's kinematic response under foundational excitation. The observed dynamic behavior of the two-story mortar-free T-junction firmly validates the physical effectiveness of the IPB configuration, aligning consistently with established performance trends documented across interlocking masonry literature. Subjected to severe dynamic forces, the double-story assembly maintained exceptional global stability while demonstrating substantial energy dissipation capacity. Such behavior confirms that intersecting perpendicular wall-nodes historically considered geometrically vulnerable-can undergo mechanical optimization to enhance overall resilience in high-seismic zones. Conventional rigid construction traditionally succumbs to sudden, brittle joint failure under similar

conditions. The IPB system, by contrast, provides a damage-tolerant and sustainable countermeasure. Mechanical interlocking, combined with controlled interfacial sliding across the plastic units, actively dampens the destructive kinetic energy characteristic of seismic events.

Table 5.3 presents a comprehensive comparative analysis of these current experimental findings against established mortar-free data. The compiled metrics highlight a highly consistent pattern of energy dissipation inherent to unbonded systems. This alignment strengthens the existing academic consensus regarding the real-world viability of interlocking block technologies in earthquake-resistant engineering. Integrating lightweight IPB walls inherently reduces the total mass of the structure. Lower mass directly translates to decreased seismic inertial forces, thereby mitigating the need for extensive, costly steel reinforcement. The resulting construction methodology operates as both an economically feasible and environmentally conscious model. As the global demand for affordable, disaster-resilient housing continues to intensify, these empirical outcomes strongly advocate for the broader implementation of mortar-free IPB systems to secure vulnerable infrastructure across developing nations.

The sliding mechanics governing the two-story T-junction align directly with modern performance-based seismic design philosophies. Rather than prioritizing absolute structural rigidity, these contemporary frameworks favor controlled physical damage management alongside active energy dissipation. The dry-stacked, modular architecture of the IPB system proves exceptionally advantageous within resource-constrained environments. It facilitates rapid assembly, straightforward geometric scalability, and immediate post-earthquake rehabilitation. Validating the dynamic performance of this specific T-junction configuration marks a distinct advancement in sustainable seismic engineering. It effectively reconciles advanced structural resilience with practical field deployment and strict economic affordability.

Scaling the dynamically validated prototype for actual field deployment exposes the distinct operational advantages of the interlocking plastic block (IPB) system.

Industrial production of these full-scale, lightweight units relies on high-density injection molding. This specific manufacturing process guarantees the strict geometric tolerances necessary for the vertical lugs and corresponding grooves to engage correctly on site. Field assembly systematically bypasses the logistical burdens of conventional building techniques. Because the sequence depends entirely on an intuitive dry-stacking method, it strips curing periods, excessive water consumption, and heavy manual labor from the project timeline. As builders layer the modular units, the self-aligning mechanical interlocks naturally enforce structural plumbness and dimensional accuracy. Consequently, the reliance on specialized masonry expertise drops significantly, allowing for rapid progression. Replicating the mechanical behavior of the physical model requires targeted structural adaptations at full scale. While the laboratory specimen utilized rubber stiffeners to simulate elastic restoring forces, field constructions can achieve this exact kinematic response by integrating continuous internal plastic tendons. Localized plastic tie-rods, anchored directly through the aligned hollow cores of the block matrix, provide the necessary tension. This scalable construction methodology accelerates overall project delivery. More importantly, it ensures that the advanced seismic resilience recorded under controlled laboratory conditions translates directly into reliable, protective infrastructure for high-risk regions.

In this study, Interlocking Plastic Blocks (IPBs) are utilized not merely as a scaled modeling substitute, but as a proposed sustainable construction material in their own right. The primary mechanical characteristic of the IPB system is its mortar-free, geometric interlocking interface, which governs the structural response and dissipates seismic energy primarily through dry friction and controlled interfacial sliding. While previous experimental applications of IPBs have largely been restricted to single-story configurations, this research extends their application to capture the complex dynamic interactions of multi-story assemblies. However, it is critical to acknowledge the inherent limitations of IPBs when drawing parallels to conventional masonry. Due to their lightweight and highly ductile composition, IPBs do not perfectly replicate the heavy, brittle crushing mechanisms, high initial stiffness, or sudden tension failures characteristic of traditional clay brick or concrete block walls. Instead, they demonstrate a distinct, friction-based sliding

and rocking behavior under lateral loads. Consequently, while IPBs offer a viable alternative for highly deformable, earthquake-resilient structures, their dynamic response must be evaluated as a unique structural system rather than a direct surrogate for traditional mortar-bound masonry.

5.4 Summary

Synthesizing the primary experimental outcomes of the two-story mortar-free IPB T-junction investigation requires linking the observed dynamic kinematics with both analytical modeling and proposed field applications. A modified empirical predictive framework supplied the necessary theoretical validation for these physical observations. Central to this approach was the introduction of a customized structural coefficient, K . This specific parameter mathematically addresses the geometric asymmetry and the complex, multi-directional load paths native to a double-story unbonded assembly. Comparing the resulting empirical predictions against the raw experimental data revealed a variance spanning from 4.2% to 8.1%. Such a discrepancy aligns naturally with the highly irregular physical mechanics of dry-stacked construction. Throughout the excitation cycles, the system's response was governed by non-linear operational variables, specifically localized block uplift during active resonance, elastic restoring forces exerted by the rubber bands, and continuous interfacial sliding. Generating the continuous harmonic excitations necessary to map this extensive energy dissipation capacity depended on a locally fabricated unidirectional shake table. Specific hardware limitations did restrict the ability of the apparatus to drive the specimen toward absolute catastrophic collapse. Despite this constraint, the cost-effective testing infrastructure demonstrated high operational efficacy in establishing the dynamic thresholds of the joint. Grounding these rigorous physical evaluations in sound empirical theory confirms a core hypothesis of the research. The interlocking plastic block T-junction functions as a lightweight, structurally resilient, and economically feasible architectural framework, uniquely positioned to mitigate seismic demand across vulnerable developing regions.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

Meeting the demand for resilient mortarless structures requires a thorough understanding of how complex architectural nodes behave under dynamic loading. This investigation evaluates the structural response and localized energy dissipation mechanisms of a two-story interlocking plastic block (IPB) T-junction through a 1:10 scale physical model. The test specimen incorporated 130 dry-stacked units arranged across ten distinct vertical layers. Steel angles rigidly anchored the base of the assembly to the testing platform. This fixed boundary condition ensured global stability during external excitation, allowing the experimental setup to accurately isolate the independent kinematics of the unbonded superstructure. Tracking the real-time seismic performance of the joint required a targeted instrumentation strategy. Five accelerometers were deployed across the model to continuously record motion data. These sensors were specifically positioned to capture dynamic shifts at the foundation level, the first-floor slab elevation, the central intersecting node, and the unsupported upper extremities of the orthogonal walls.

Execution of the structural evaluation relied on a structured, multiphase experimental program. Initial static stiffness testing quantified the baseline lateral resistance dictated by the complex joint geometry. Following this static profiling,

the assembly underwent free-vibration snap-back testing. Applying the logarithmic decrement method to the resulting kinematic decay isolated the fundamental natural frequency, time period, and structural damping ratio. Localized hammer impact testing provided a supplementary dynamic metric, serving to characterize the structure's capacity for high-frequency energy absorption and rapid dynamic attenuation under sudden localized loads. The physical model was then subjected to continuous seismic simulation using a locally fabricated, unidirectional shake table. Driving the platform at steady-state harmonic frequencies of 1.0 Hz, 1.2 Hz, and 1.4 Hz exposed the unbonded system to sustained cyclic excitation. MATLAB handled the initial acquisition of all raw kinematic data throughout these phases. To ensure analytical accuracy, these unrefined datasets were subsequently exported to SeismoSignal software, which systematically applied necessary baseline corrections and filtered out ambient experimental noise. Synthesizing the results of this comprehensive empirical testing yields the following primary conclusions:

- i. Geometric asymmetry strictly governed the mechanical response of the unbonded T-junction. The extended Y-axis demonstrated a baseline lateral stiffness of 2.14 N/mm, contrasting with a reduced capacity of just 1.74 N/mm along the weaker X-direction.
- ii. Free-vibration snap-back evaluations recorded a fundamental natural frequency of 1.2 Hz alongside a 5.61% structural damping ratio. Such elevated baseline damping confirms the inherent capacity of the dry-stacked system to passively dissipate energy prior to sustained seismic excitation.
- iii. Localized hammer impact testing quantified the assembly's rapid dynamic attenuation under sudden loads. A 2.64 N transient shock produced an average oscillation frequency of 4.36 Hz and a 1.27 g peak acceleration, while the structural damping ratio surged to 9.02%, indicating efficient high-frequency energy absorption.
- iv. Evaluation continuously recorded acceleration and displacement time histories to capture the prototype's dynamic response.

- a. Following 1.2 Hz resonance, Sequence B utilized 9.8% structural damping to suppress excessive drift.
- b. Structural displacement concentrated along the vulnerable X-axis, generating up to 31.6% greater lateral deformation.
- c. Sequence B absorbed 87,265 N.mm (6.09% beyond Sequence A's 82,255 N.mm total absorption).
- d. Complex non-linear interfacial sliding produced a predictable 8.1% maximum variance against simplified theoretical models.
- e. Controlled dry-friction sliding across interlocking nodes effectively dissipated seismic forces, preventing brittle structural collapse.

Incorporating lightweight T-junctions into mortar-free interlocking plastic block (IPB) walls establishes a highly reliable mechanism for reducing seismic demand and securing overall structural safety. Initial static evaluations confirm the robust baseline lateral stiffness of the system. When confronted with sudden, high-frequency transient shocks during hammer impact testing, the unbonded assembly exhibits a pronounced capacity for rapid dynamic attenuation. Sustained harmonic loading further exposes the mechanical advantages of this design. The active sliding interfaces maximize energy dissipation under continuous excitation, merging distinct damage tolerance with advanced structural resilience. Beyond strict physical performance, this methodology addresses pressing socio-economic barriers. By balancing proven kinematic stability with material cost-effectiveness, IPB construction functions as an affordable, rapidly deployable housing alternative. Implementing this technology in high-risk seismic zones presents a viable, sustainable strategy for safeguarding vulnerable populations and stabilizing living standards.

6.2 Future Recommendations

Following may be considered to further explore the behavior of interlocking plastic block structures:

-
- i. Future studies should evaluate the T-junction under bi-directional seismic loading. High-capacity shaking will reveal ultimate failure modes and displacement limits.
 - ii. Comprehensive dynamic testing must also target two-story mortar-free corner joints to systematically quantify their multi-axial energy dissipation mechanics during continuous harmonic excitation.

Bibliography

- [1] Y. Lu, X. Zhang, T. Shi, and Y. Zhu, “Modeling of non-grouted interlocking brick masonry using rigid-body-spring model,” *Engineering Structures*, vol. 331, p. 119971, 2025, journal name corrected from Engineering Solutions.
- [2] A. Al-Fakih, F. Nuruddin, and E. Nikbakht, “Development of interlocking masonry bricks and its structural behaviour: A review paper,” in *IOP Conference Series: Earth and Environmental Science*, vol. 140, 2018, p. 012127.
- [3] G. Xie, X. Zhang, H. Hao, T. Shi, L. Cui, and J. Thomas, “Behaviour of reinforced mortarless interlocking brick wall under cyclic loading,” *Engineering Structures*, vol. 283, p. 115890, 2023.
- [4] G. Xie, X. Zhang, H. Hao, K. Bi, and Y. Lin, “Response of reinforced mortarless interlocking brick wall under seismic loading,” *Bulletin of Earthquake Engineering*, vol. 20, pp. 6129–6165, 2022.
- [5] M. Hemmat, Y. Z. Totoev, and M. J. Masia, “An experimental study on the in-plane seismic performance of the confined semi-interlocking masonry system using DIC method,” *Structures*, vol. 63, p. 106400, 2024, dOI and journal abbreviation corrected from raw citation.
- [6] C. Göçer, “Structural evaluation of masonry building damages during the april 24, 2014 gökçeada earthquake in the aegean sea,” *Bulletin of Earthquake Engineering*, vol. 18, pp. 3459–3483, 2020.

-
- [7] W. Hou, X. Dai, Z. r. Yang, H. Huang, X. Wang, P. Zheng, Y. Zhang, and Z. Guo, “Seismic behavior of stone masonry joints with ECC as a filling material,” *Materials*, vol. 14, no. 21, p. 6671, 2021.
- [8] G. Vlachakis, E. Vlachaki, and P. B. Lourenço, “Learning from failure: Damage and failure of masonry structures, after the 2017 lesvos earthquake (greece),” *Engineering Failure Analysis*, vol. 117, p. 104803, 2020.
- [9] H. Liu, K. Lin, and S. Zhao, “Cyclic behavior of mortarless brick joints with different interlocking shapes,” *Materials*, vol. 9, no. 3, p. 166, 2016.
- [10] L. Halder and R. P. Sharma, “Damage study and seismic vulnerability assessment of existing masonry buildings in northeast india,” *Journal of Building Engineering*, vol. 29, p. 101190, 2020.
- [11] B. K. and E. Adjovi, “Numerical simulation of a shear wall model in interlocking masonry with dry vertical and horizontal joints in compressed earth blocks,” *Buildings*, vol. 15, no. 4, p. 627, 2025.
- [12] L. Giresini and C. Casapulla, “Interlocking formulation for the assessment of the out-of-plane dynamics of masonry walls interacting with sidewalls,” *Journal of Building Engineering*, vol. 26, p. 115630, 2026.
- [13] M. Zhang, W. Jin, K. Ding, and M. Ren, “Study on in-plane/out-of-plane seismic performance of masonry-infilled RC frame with openings and a new type of flexible connection,” *Bulletin of Earthquake Engineering*, vol. 22, pp. 2201–2233, 2024.
- [14] K. Lin, H. Liu, and C. Wei, “Experimental characteristics of dry stack masonry under compression and shear loading,” *Materials*, vol. 8, no. 12, pp. 8731–8744, 2015.

-
- [15] M. Elmorsy, Y. Zhang, K. Shea, L. Jones, I. Anastasopoulos, and M. F. Vassiliou, "Shear behavior and centrifuge seismic modeling of a sustainable corbel dwelling with interlocking blocks," *Construction and Building Materials*, vol. 515, p. 145553, 2026.
- [16] A. J. D. and M. Ali, "Sustainable development and assessment of low-strength/high-toughness recycled plastic rebars for structural elements under light loads," *Sustainability*, vol. 17, no. 11, p. 4997, 2025.
- [17] H. Bashir, "Dynamic response of interlocking plastic-block walls with diaphragm using numerical approach," Master's thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2020.
- [18] S. Afzal, "Out-of-plane behavior of prototype interlocking plastic-block solid wall under harmonic loading," Master's thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2020.
- [19] M. Sudheer, "Out-of-plane behavior of prototype interlocking plastic-block wall with opening under harmonic loading," Master's thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2020.
- [20] M. S. Aslam, "Compressive behavior of interlocking plastic block structural elements," Master's thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2021.
- [21] S. J. Asad, "Consequences of block-return on dynamic in-plane behavior of interlocking plastic block walls," Master's thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2021.

-
- [22] S. Anwar, “Effect of diaphragm on dynamic behavior of interlocking plastic-block structure with different elements pattern,” Master’s thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2021.
- [23] M. Adnan, “Effect of slenderness on the behavior of interlocking plastic-block structural elements under compression,” Master’s thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2022.
- [24] W. Akram, “Dynamic performance of corner-joints in mortar-free interlocking-plastic-block walls,” Master’s thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2025.
- [25] A. Ullah, “Behavior of mortar-free interlocking-plastic-block walls at junctions under harmonic loading,” Master’s thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2025.
- [26] J. Nasar, “Response of two-story interlocking plastic block structure having various patterns under in plane harmonic loadings,” Master’s thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2026.
- [27] A. Bakar, “Out-of-plane dynamic behavior of double-story interlocking plastic-block structure with different wall patterns,” Master’s thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2026.

- [28] S. Y. Y. Yadima, H. Kaplanc, M. Corradid, and G. Castori, “Seismic vulnerability of deficient RC buildings: insights from the february 6, 2023, turkey earthquake,” *Procedia Structural Integrity*, vol. 78, pp. 1895–1902, 2026.
- [29] M. Tomažević, “TESTING FOR THE ASSESSMENT OF EARTHQUAKE RESISTANCE OF HERITAGE MASONRY BUILDINGS: nondestructive versus destructive, laboratory versus in-situ testing,” *Earthquake Engineering*, vol. 1, 2025.
- [30] A. Özmen and E. Sayın, “Typical damage patterns in masonry structures after various major earthquakes,” *Firat University Journal of Experimental and Computational Engineering*, vol. 5, no. 1, pp. 94–118, 2026.
- [31] L. Ducom, C. Jaafari, and M. Stepinac, “Seismic vulnerability assessment and upgrade strategies of unreinforced masonry buildings—case studies from croatia,” *Buildings*, vol. 16, no. 6, p. 1238, 2026. [Online]. Available: <https://www.mdpi.com/2075-5309/16/6/1238>
- [32] A. Borri, M. Corradi, and A. De Maria, “Structural analyses of masonry structures using the masonry quality index,” in *Structures*, vol. 90. Elsevier, 2026, p. 112420.
- [33] A. Prota *et al.*, “Damage assessment of modern masonry buildings after the laquila earthquake,” *Bulletin of Earthquake Engineering*, vol. 18, pp. 2275–2301, 2020, author list parsed from multi-initial fragment.
- [34] G. Sun and H. Li, “Damage evaluation of a multi-story brick masonry building with reinforced concrete framed ground floor under seismic loading: A case study,” *Case Studies in Construction Materials*, vol. 24, p. e05888, 2026.
- [35] Q. Shang *et al.*, “Rapid report of seismic damage and consequence analysis in the 2025 M 6.8 dingri earthquake,” *Earthquake Research Advances*, p. 37, 2025.

- [36] B. Gheorghe and R. Vacareanu, “Performance-based seismic loss and recovery assessment of residential buildings in bucharest using fema p-58 and sp3: Implications for seismic resilience,” *Applied Sciences*, vol. 16, no. 7, p. 3118, 2026. [Online]. Available: <https://www.mdpi.com/2076-3417/16/7/3118>
- [37] M. Ali and N. Chouw, “Coir fibre and rope reinforced concrete beams under dynamic loading,” in *Annual Australian Earthquake Engineering Society Conference, "Newcastle Earthquake-20 years on"*, 2009, pp. 12–24.
- [38] M. Gioffrè, V. Gusella, and C. Pepi, “Confined vs. unreinforced masonry: Construction and shaking table tests of two-storey buildings,” *Construction and Building Materials*, vol. 333, p. 126961, 2022.
- [39] M. U. Farooqi and M. Ali, “Effect of fibre content on compressive strength of wheat straw reinforced concrete for pavement applications,” in *IOP Conference Series: Materials Science and Engineering*, vol. 422, no. 1. IOP Publishing, 2018, p. 012014.
- [40] S. Cattari, B. Calderoni, I. Calì, G. Camata, S. De Miranda, G. Magenes, and A. Satta, “Nonlinear modeling of the seismic response of masonry structures: critical review and open issues towards engineering practice,” *Bulletin of Earthquake Engineering*, vol. 20, pp. 1939–1997, 2022.
- [41] A. Afraz and M. Ali, “Effect of banana fiber on flexural properties of fiber reinforced concrete for sustainable construction,” *Engineering Proceedings*, vol. 12, no. 1, p. 63, 2021.
- [42] P. D. Patrick and D. Waldmann, “Analysis of the geometrical imperfections of a dry-stacked masonry block based on miscanthus,” *Construction and Building Materials*, vol. 310, no. 6, p. 125282, 2021.

- [43] F. Khan and M. Adnan, “Compressive behavior of interlocking plastic blocks structural elements having slenderness,” *Buildings*, vol. 12, no. 12, p. 2257, 2022.
- [44] I. Costa, J. Llorens, M. À. Chamorro, J. Fontàs, J. Soler, E. Gifra, and N. Savalle, “Experimental study of mechanical behavior of dry-stone structure contact,” *Buildings*, vol. 14, no. 12, p. 3744, 2024.
- [45] A. U. Qazi, Y. E. Ibrahim, A. Hameed, and M. F. Ali, “Behavior of scaled infilled masonry, confined masonry & reinforced concrete structures under dynamic excitations,” *Buildings*, vol. 12, no. 6, p. 774, 2022.
- [46] T. Zahra, J. Thamboo, N. Cameron, M. Asad, W. Kasinski, and A. Nardone, “Behaviour of reinforced mortarless concrete masonry panels under axial compression: An experimental and analytical study,” *Construction and Building Materials*, vol. 377, p. 131097, 2023.
- [47] J. Thamboo and T. Zahra, “Reliable unit strength correlations to predict the compressive strength of grouted concrete masonry,” *Materials and Structures*, vol. 57, no. 151, 2024.
- [48] G. Longobardi and A. Formisano, “Aggregated vs. isolated seismic response of a historic masonry compound before and after integrated retrofit interventions,” *Buildings*, vol. 16, no. 6, p. 1208, 2026. [Online]. Available: <https://www.mdpi.com/2075-5309/16/6/1208>
- [49] P. Saingam, R. Suwannatrai, A. Ejaz, Q. Hussain, K. Khan, and P. Joyklad, “Enhancing the flexural behavior of brick masonry walls with ferroce-ment overlays and low-cost anchors,” *Case Studies in Construction Materials*, vol. 19, p. e02558, 2023.

-
- [50] M. Sathurshan, J. Thamboo, J. Gill, C. Inglis, and T. Zahra, “Compressive strength in grouted dry-stack concrete block masonry: Experimental and analytical predictions,” *Construction and Building Materials*, vol. 467, p. 140411, 2025.
- [51] N. A. Thanaya and M. Fathan, “PLASTIC BLOCK FOR BUILDING CONSTRUCTION MATERIAL,” *Journal of Applied Engineering Science*, vol. 22, p. 1235, 2024.
- [52] T. U. Kumar, “Development of light weight green efficient interlocking blocks using waste plastics and industrial wastes for low cost housing construction,” *Materials Science Forum*, vol. 1144, pp. 71–76, 2025.
- [53] P. F. T. and K. Ssov, “BUILDING BLOCKS MADE FROM RECYCLED PLASTICS,” *International Structural Engineering and Construction*, vol. 12, p. 22, 2025.
- [54] T. Ferreira, A. M. de Oliveira, and C. G. B. T. Dias, “Manufacture and characterization of polypropylene (PP) and high-density polyethylene (HDPE) blocks for potential use as masonry component in civil construction,” *Polymers*, vol. 14, p. 2463, 2022.
- [55] F. Khan, “Dynamic behavior of prototype interlocking plastic-block structure using locally developed low-cost shake table,” Master’s thesis, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan, 2019.
- [56] D. Ferrndez, R. P. Lamberto, P. Santos, and J. Michalak, “Optimizing masonry mortar: Experimental insights into physico-mechanical properties using recycled aggregates and natural fibers,” *Applied Sciences*, vol. 14, no. 14, p. 6226, 2024.

-
- [57] A. Cascardi *et al.*, “Textile-reinforced mortar (TRM) for retrofitting masonry structures: advantages, challenges and future potential,” *Materials and Structures*, vol. 59, no. 1, p. 38, 2026.
- [58] I. Boem, “Masonry elements strengthened through textile-reinforced mortar: application of detailed level modelling with a free open-source finite-element code,” *arXiv preprint arXiv:2210.06931*, 2022.
- [59] E. Tunay and C. Ustundag, “Strengthening historic brick masonry walls: An experimental study of restoration mortar, carbon textile reinforcement and sprayed polyurea,” *Buildings*, vol. 16, no. 10, p. 2040, 2026. [Online]. Available: <https://www.mdpi.com/2075-5309/16/10/2040>
- [60] P. Joyklad, A. Hafeez, N. Ali, A. Ejaz, Q. Hussain, K. Khan, A. Sangthongtong, and P. Saingam, “Experimental investigations of cement clay interlocking brick masonry structures strengthened with CFRP and cement-sand mortar,” *Infrastructures*, vol. 8, no. 3, p. 59, 2023.
- [61] L. Niu *et al.*, “Experimental and theoretical investigation of fiber-reinforced geopolymer mortars: mix design optimization and bond behavior with brick masonry,” *Case Studies in Construction Materials*, p. e05767, 2026.
- [62] M. Ali, R. Briet, and N. Chouw, “Dynamic response of mortar-free interlocking structures,” *Construction and Building Materials*, vol. 42, pp. 168–189, 2013.
- [63] F. Qamar, T. Thomas, and M. Ali, “Improvement in lateral resistance of mortar-free interlocking wall with plaster having natural fibres,” *Construction and Building Materials*, p. 117387, 2020.
- [64] S. A. Ali and M. Ali, “Mortarless structures with hollow interlocking blocks - a review,” *Sustainable Structures and Materials*, vol. 6, pp. 96–100, 2023.

- [65] H. C. and K.-S. Lee, “Experimental study on the in-plane seismic performance of a new type of masonry wall system,” *Applied Sciences*, vol. 10, no. 24, p. 9102, 2020.
- [66] M. Sudheer and M. Ali, “Dynamic response of an interlocking plastic-block wall with opening,” *Journal of Mechanics of Materials and Structures*, vol. 19, no. 4, pp. 595–613, 2024.
- [67] K. Twigden, R. Henry, and Q. Ma, “Pseudo-static cyclic, snap back and shake table testing of PreWEC self-centering wall systems,” in *Proceedings of the 10th US National Conference on Earthquake Engineering*, 2014.
- [68] M. Kohail, H. Elshafie, A. Rashad, and H. Okail, “Behavior of post-tensioned dry-stack interlocking masonry shear walls under cyclic in-plane loading,” *Construction and Building Materials*, vol. 196, pp. 539–554, 2019.
- [69] M. M. Nasery, M. Hüsem, F. Y. Okur, and A. C. Altunişik, “Numerical and experimental investigation on dynamic characteristic changes of encased steel profile before and after cyclic loading tests,” *International Journal of Civil Engineering*, vol. 18, no. 12, pp. 1411–1431, 2020.
- [70] M. Ali, “Role of post-tensioned coconut-fibre ropes in mortar-free interlocking concrete construction during seismic loadings,” *KSCE Journal of Civil Engineering*, vol. 22, no. 4, pp. 1336–1343, 2018.
- [71] N. Khattak, H. Derakhshan, D. P. Thambiratnam, D. Malomo, and N. J. Perera, “Modelling the in-plane/out-of-plane interaction of brick and stone masonry structures using Applied Element Method,” *Journal of Building Engineering*, vol. 76, p. 107175, 2023.
- [72] Y. Lu, L. Huang, X. Zhang, T. Shi, and Y. Zhu, “Modeling of non-grouted interlocking brick masonry using rigid-body-spring model,” *Engineering Structures*, vol. 331, p. 119971, 2025.

-
- [73] M. Ali, R. Briet, and N. Chouw, “Dynamic response of mortar-free interlocking structures,” *Construction and Building Materials*, vol. 42, pp. 168–189, 2013, duplicate of reference [52].
- [74] P. Kasinikota and D. D. Tripura, “Effects of coir fibres and cement addition on properties of hollow interlocking compressed earth blocks,” *Innovative Infrastructure Solutions*, vol. 8, no. 10, p. 273, 2023.