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# Understanding The Dynamic Behavior of Junctions in Mortar-free Interlocking Block Walls Through Literature Research

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**Abstract**

This paper presents a comprehensive review of the dynamic behavior of junctions in mortar-free interlocking block walls under harmonic loading, emphasizing their seismic resilience and structural performance. With the rising frequency and intensity of earthquakes, there is a critical need for sustainable and cost-effective construction techniques. Mortar-free interlocking block systems have emerged as a promising solution, offering advantages such as reduced construction time, cost efficiency, and improved environmental sustainability. This study integrates finding from global experimental, numerical and analytical investigations, encompassing shake table tests, finite element modeling, and cyclic loading experiments. It examines critical factors affecting T-junction performance, including interlocking mechanisms, block geometries, material properties, and reinforcement strategies. Research highlight that well-engineered junctions play a pivotal role in enhancing structural integrity and mitigating failure under seismic events. However, certain limitations persist in terms of junction misalignment, inadequate reinforcement, and block displacement under harmonic loading conditions. The review reveals critical gaps in the existing body of research, including the necessity for large-scale experimental investigation, field validation, and optimization of junction design parameters. Future research directions are suggested to address these challenges, aiming to enhance the resilience and reliability of mortar-free interlocking block structures in earthquake-prone zones. This study contributes to advancing construction practices and fostering innovative solutions for sustainable and disaster-resilient infrastructure systems.

**Keywords:** Dynamic Behavior, Interlocking Block Systems, Seismic Resilience.

## 1. Introduction

As the pace of urbanization accelerates and seismic activities become more frequent and severe, the demand for construction systems that integrate resilience and sustainability has become critical. Ali et al. (2013) examined the dynamic performance of mortar-free interlocking block structures reinforced with coconut fibers and ropes, emphasizing their potential for affordable and earthquake-resilient construction in developing regions. Coconut fibers, recognized for their exceptional tensile strength and strain properties, markedly enhance the compressive and flexural strength of concrete [1]. The mortar-less construction technique enables faster, adaptable, and cost-effective construction while reducing cement and other aggregate consumption, thus lowering carbon emissions and mitigating environmental impact. Furthermore, the dry-stack configuration of interlocking blocks proves particularly beneficial for rapid construction, especially in post-disaster scenarios, enabling quick assembly and aiding reconstruction initiatives.

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Mitigating the inconsistencies in the seismic behavior of interlocking block structures remains a key focus in contemporary engineering research. Moshfeghi et al. (2024) conducted tests on shake table to study the out-of-plane behavior of solid masonry walls with timber diaphragms, analyzing seismic response and damage mechanisms across varying reinforcement strategies. Their findings highlight the fundamental influence of reinforcement strategies in augmenting structural resilience during seismic events [2]. In a complimentary study, Rasula and Kumar (2024) utilized finite element analysis (FEA) to evaluate the structural efficiency of different interlocking masonry systems under static loading conditions, concluding that square groove interlocking walls exhibited minimal displacement and optimal stress distribution [3]. Additionally, Ali et al. (2012) examined the behavior of coconut fiber-reinforced concrete (CFRC) interlocking blocks under monotonic loading, reporting enhanced compressive strength capacity in base-layer units relative to alternative configurations [4]. These studies underscore the significant impact of reinforcement strategies and geometric designs and enhancing the dynamic response and structural integrity of interlocking masonry systems, ultimately contributing to their durability, stability, and resilience throughout the life of the structure.

Historical seismic events highlight the vulnerability of traditional masonry construction, highlighting the critical need for innovative design solutions. For instance, the 2005 Kashmir earthquake caused partial or total damage to over 450,000 buildings [5]. Earthquake-induced inertia forces exacerbate shear failures in masonry structures, underscoring the need for improved design and construction methodologies. In response, Ali (2018) proposed a mortar-free interlocking block system capable of effectively dissipating seismic energy [6]. However, the considerable weight of CFRC blocks remains a limitation, as lighter structures produce lower inertia forces. To address this, lightweight interlocking plastic blocks have emerged as a viable alternative. Complementing these innovations, a study conducted by Baran et al. (2010) has demonstrated the efficiency of low-cost, one-dimensional (1D) shake tables for simulating and analyzing the dynamic response of prototype structures in laboratory [7]. These findings underscore the importance of mortar-free interlocking plastic blocks and lightweight plastic materials, which, when paired with cost-effective one dimensional (1D) shake tables, offer efficient energy dissipation and dynamic analysis capabilities during seismic events.

## 2. Failure Mechanism at Unreinforced Masonry Wall Junctions

Interlocking block systems are gaining popularity in seismic resistant-construction due to their structural efficiency, enhanced energy dissipation capabilities, and suitability for rapid, modular assembly. These systems employ various block types, including compressed earth, concrete, and stabilized soil blocks, which interlock without the utilization of mortar. Anand and Ramamurthy (2000) highlighted that interlocking block masonry is more efficient and has greater flexural capacity than conventional mortar-bedded masonry, depending on block design and applied loads [8]. In a related study, Nayak and Dutta (2016) investigated cost-effective strengthening techniques for unreinforced masonry (URM) structures, concluding that the incorporation of horizontal dowel bars, polypropylene bands, and steel wire mesh significantly enhanced the strength of the structure at critical junctions [9]. These methods are particularly suitable for low-cost seismic reinforcement in developing countries. The February 2023 Kahramanmaraş earthquakes revealed that many masonry structures failed at wall junctions due to weak connections and inadequate reinforcement. Poor construction practices and lack of interlocking at these junctions led to out-of-plane failures, worsening the overall collapse during significant ground motions [10]. Which is shown in figure 1.

Lan et al. (2023) introduced an interlocking compressed-earth block (ICEB) composite wall, combining stabilized ICEBs with reinforced concrete core columns and lateral strengthening strips. Testing nine scaled walls under low-frequency cyclic loading, they examined failure modes, hysteretic behavior, stiffness degradation, and energy dissipation. The core columns and strengthening strips significantly improved seismic performance [11]. Figure 2 shows junction failure in unreinforced masonry structures during the 2005 Kashmir earthquake, where the lack of reinforcement at junctions caused out-of-plane wall collapses, making masonry structures vulnerable even during minor seismic events


(**a**) (**b**)

**Figure 1.** Damages occurred in adobe structures with various wall materials: adobe-rubble stone and adobe-briquette [10].

Shi et al. (2021) performed an extensive study on the compressive behavior of interlocking bricks with large shear keys, finding that the number of blocks greatly improves compressive strength. Factors like surface roughness and material strength influenced stress distribution and failure patterns, aiding in the design of mortar-less structures [12].

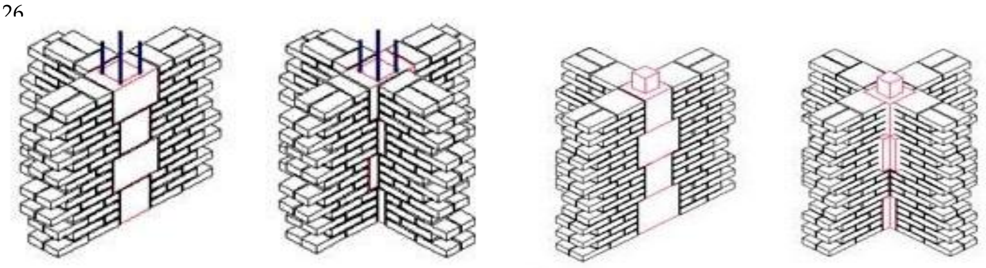
(**a**) (**b**)

**Figure 2.** Junction failure during Kashmir Earthquake [9].

Xie et al. (2023) analyzed reinforced mortar-less interlocking brick walls under cyclic loading, showing strong deformation capacity and strength retention post-cracking. Numerical models confirmed that interlocking blocks outperform traditional masonry in energy dissipation and displacement control during earthquakes. Shake table tests revealed that dowel bars, bands, mesh, and interlocking blocks improved structural integrity and energy dissipation, offering a low-cost seismic strengthening solution, with models confirming better performance than traditional masonry [13]. Finite element analysis of the Jama Masjid, a masonry heritage building in Aligarh, revealed that critical stress concentrations occur at the dome-wall junctions, wall-roof junctions, and minarets, with stresses exceeding permissible limits under earthquake loading in both X and Z directions [14]. A damage survey of moderate Indian earthquakes in the Eastern Himalayas and plains regions identified the absence of proper connections at masonry junctions as the principal cause of structural failure in unreinforced masonry walls [15].

## 3. Interlocking Block Mechanism for Wall Junctions

Baneshi et al. (2023) explored the in-plane behavior of interlocking blocks using adhesive paste, grout, and steel rebar, finding that adhesive paste significantly improved compressive strength compared to mortar, with further gains when combined with grout and rebar, enhancing both strength and ductility [16]. These techniques also mitigated the blocks' brittleness, improving performance under extreme loads. Moshfeghi et al. (2024) studied the out-of-plane (OOP) collapse in masonry during earthquakes, highlighting the role of wall dimensions, vertical loads, boundary conditions, and material properties. Shake table tests demonstrated that reinforcement methods such as carbon strips and helical bars improved wall strength and minimized damage [2]. Guojue et al. (2017) examined on the seismic vulnerability of rural masonry buildings in China, where the absence of reinforced concrete columns and beams was common. They proposed the utilization of precast concrete interlocking blocks, as a cost-effective alternative, which showed superior seismic performance through both experimental testing and modeling [17]. Figure. 3 illustrates these fabricated columns at various wall intersections.



(**a**) (**b**)

**Figure 3.** Fabricated columns at T-junctions in various wall intersection scenarios [17].

Xie et al. (2024) investigated mortar-free interlocking brick walls under quasi-static in-plane cyclic loading using a detailed numerical model. Their study demonstrated that while these walls exhibit high energy dissipation and deformation capacity, their performance is influenced by reinforcement placement and design factors. The numerical simulations provided equations to predict the walls' resistance to cyclic loading, revealing differences from traditional masonry structures [18]. Tang et al. (2014) evaluated the residual compressive and shear strengths of coconut fiber reinforced concrete (CFRC) interlocking blocks. Their experimental study found that CFRC blocks had improved residual strengths after dynamic loading, with compressive and in-plane shear strengths increasing by up to 3.2% and 5.7%, respectively, underscoring the advantages of CFRC in earthquake-prone regions [19]. Unreinforced masonry (URM) walls can be significantly strengthened using interlocking masonry units, with ductile units showing improved ductility and strength compared to conventional URM walls [19]. The interlocking block technique also enhances construction efficiency by eliminating the necessity for mortar, allowing faster wall assembly with less skilled labor, while providing structural flexibility for configurations like buttresses and T-junctions [20].

## 4. Junction Performance in Mortar-free Interlocking Block Construction

The performance of junctions in mortar-less interlocking block construction is a critical factor in ensuring structural stability and safety, particularly when subjected to dynamic loading conditions commonly associated with seismic events. Baneshi et al. (2023) conducted a comprehensive experimental investigation on interlocking masonry blocks that were produced using 3D-printed molds. The study included various block shapes, such as trapezoidal, Lego, cross, and checkered configurations, alongside a standard control block. Their results demonstrated that the shape of the block significantly influences performance under different loading scenerios [16]. This study emphasizes the importance of optimizing block shape to enhance junction performance under dynamic forces.

**Table 1.** Summary of Seismic Performance Studies on Various Masonry and Block Structures

| Block Type | Methodology | Key Findings | Gaps Identified | Ref. |
|---|---|---|---|---|
| **Coconut Fiber Reinforced Concrete Blocks** | Monotonic Loading Tests | High compressive and shear capacity; cost-effective for earthquake-resistant construction. | Limited to CFRC blocks; no large-scale field testing. | [4] |
| **Solid Masonry Walls** | Shake Table Tests | Improved out-of-plane behavior with reinforcement techniques. | Restricted to small-scale masonry walls; no studies on long-term durability. | [2] |
| **Mortar-less Interlocking Brick Walls** | Cyclic Loading Tests and Numerical Models | Strong energy dissipation and deformation capacity in reinforced walls. | Lacks varied reinforcement strategies; requires more field validation. | [13] |
| **Interlocking Compressed Earth Blocks** | Cyclic Loading Tests | Critical role of core columns in seismic performance enhancement. | Concentrated on cyclic loading; lacks full-scale real-world testing. | [11] |
| **Unreinforced Masonry (URM) Walls** | Shake Table Tests, Experimental Studies | Polypropylene bands and steel wire mesh effectively enhanced the seismic performance of URM structures at low cost. | Limited to small-scale testing; needs broader quantified benefit and field validation. | [9] |

This study indicates that the performance of junctions in mortar-free interlocking block walls under harmonic loading depends on the design of the interlocking mechanism and construction precision, as stability relies on mechanical interlock rather than mortar. Misalignment or weak mechanisms create vulnerabilities, compromising structural integrity. A review of seismic performance studies Table 1 highlights the importance of junction integrity for resilience and identifies research gaps in the seismic behavior of interlocking blocks at junctions under dynamic loading. Experimental investigations show that enhancing junction performance involves advanced designs, improved construction, and reinforcements like steel bars or fibers to distribute loads, reduce block displacement, and boost resilience against seismic forces, although the effectiveness of these methods varies with different conditions and block systems.

## 5. Conclusions

The dynamic behavior of mortar-less interlocking block walls, particularly at junctions, is crucial in determining the overall stability and seismic performance of these structures. While such systems provide significant advantages in terms of sustainability, cost-efficiency, and ease of construction, junctions remain a critical aspect that requires further research and optimization.

- Junctions represent the most structurally vulnerable points in mortar-free interlocking block walls when subjected to dynamic loading.
- The primary failure mechanism at unreinforced junctions involves the loss of inter-block friction, which leads to structural instability.
- The stability of junctions under harmonic loading is highly dependent on well-designed interlocking mechanisms.

Therefore, further research is neccessary to develop more effective interlocking mechanisms and construction practices that enhance the performance of these junctions under dynamic loading conditions.

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