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An Overview on Recent Developments in Making Efficient Corner Joints in Mortar Free Interlocking Block Walls against Lateral Loading

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Abstract

Unreinforced masonry structures are highly susceptible to earthquakes damages including in-plane and out of plane damages. Confined masonry improves the seismic capacity of the structures. Earthquake resistant strategies for safe housing are partially effective due to economically nonviable. Mortar-free construction claims to be better than unreinforced masonry. The current literature research is to have a comprehensive review of relevant past studies to explore the potential utilization of mortar free interlocking corner joints. This is done by focusing on articles published in highly reputable journals in last one decade. Corner failures in masonry result due to a combination of in-plane and out-of-plane behaviors. Absence of vertical load there is flexural dominant behavior prior to formation of corner. Mortar-free construction allows sliding and rotation in the out-of-plane direction, which significantly reduces structural damage. Scaled down investigation of real corner joint through shake table testing helps to replicate the real structural behavior.

Keywords: mortar free interlocking, corner joints, lateral loading

1. Introduction

Unreinforced masonry (URM) structures are highly vulnerable to earthquakes. URM buildings require comprehensive risk assessment and mitigation for long term serviceability [1]. Out-of-plane (OOP) collapse as a common failure, influenced by factors like wall dimensions and material properties [2]. Weak connections, lack of reinforcement, and poor construction practices contribute to OOP failures [3,4]. The importance of wall connections, often overlooked by traditional methods [5]. Corner failures in URM due to poor connections and deteriorated materials, urging improved design and construction practices to prevent such failures [6, 7]. Vulnerabilities of URM structures through enhanced design, improved construction practices, and risk mitigation strategies is essential prevent out-of-plane collapses and ensure earthquake resilience.

Mortar-less Masonry Systems (MMS) enhance productivity but require reinforcement for seismic and cyclonic forces [8]. MMS these systems perform well under gravity and lateral loads, with block compressive strength crucial for resistance [9]. The potential of Interlocking dry-stacked masonry for affordable housing, was explored for energy dissipation and ability to withstand moderate seismic actions [10]. Reinforced mortar-less systems with slanted keys offer superior seismic performance, while interlocking brick walls outperform conventional CMU walls in seismic resistance, with friction aiding energy dissipation [11]. Reinforced mortar-less masonry systems offer enhanced seismic performance and energy dissipation, making them ideal for affordable and resilient housing solutions.

Interlocking dry-stacked masonry acts as a sustainable and affordable building material with potential for future projects [10]. Out-of-plane response as a key factor in seismic vulnerability, influenced by material properties and wall quality [12]. Corner separation is observed in older structures due to weak mortar and floor connections. Confined masonry and interlocking dry-stacked systems improve seismic resilience [13]. RCC confinement and reinforcement enhances seismic performance by improving energy absorption, reducing damage, and allowing larger displacements with minimal strength loss [14]. Interlocking dry-stacked masonry, when reinforced with RCC confinement, significantly enhances seismic resilience and sustainable construction.

To the best of author's knowledge, Corner Joints in Mortar Free Interlocking Block Walls against Lateral Loading is rarely reported. The aim of this review paper is to explore the potential of Corner Joints in Mortar Free Interlocking Block Walls against Lateral Loading. For this purpose the articles published in reputable journal of the last one decade are reviewed in detail for information related to Corner Joints in Mortar Free Interlocking Block Walls against Lateral Loading. First, the corner damages in conventional masonry structures are discussed. Then, emerging technology mortar free interlocking reinforced masonry structure. Finally, testing of masonry corner joints is explored.

2. Corner Damages in Conventional Masonry Structure

2.1 Failure in Conventional Masonry Structure

Masonry structures are highly vulnerable to earthquakes. Unreinforced masonry (URM) buildings are particularly at risk, emphasizing the need for risk assessment and mitigation [1]. Out-of-plane (OOP) collapse as a common damage type, influenced by factors like wall dimensions, restoring forces, boundary conditions, and material properties [2]. URM is highly susceptible to seismic forces, requires risk assessment and mitigation strategies to prevent both in-plane and out-of-plane failures. It is essential to minimize potential damage and loss of life during earthquakes.

Key factors in OOP failures, such as the lack of horizontal binding elements and weak wall connections [3]. Several factors contributing to structural damage observed in the field, including the use of heavy earthen roofs, inadequate wall-to-wall and wall-to-roof connections, lack of vertical and horizontal beams, poor workmanship, and insufficient interlocking between layers [4]. Out-of-plane failures in masonry structures result from weak connections, insufficient reinforcement, and poor construction, emphasizing the need for improved design and materials.

2.2 Damages in Wall Corner in Conventional Masonry Structures

Wall connections are very essential in preventing both global and local damage in masonry buildings. However, this issue is often overlooked, and traditional connection methods continue to be used. It is crucial to give special attention to these connections [5]. Corner failures in masonry structures result from a combination of in-plane and out-of-plane behaviors, often rendering structures unusable. These failures are linked to poor connections, low axial loads, weak materials, and inadequate workmanship [6]. Corner failures in masonry structures are primarily caused by inadequate wall connections, poor materials, and substandard construction practices.

Various brick masonry failures, including corner overturning, out-of-plane separation, crumbling, and complete building collapse [7]. Corner separation is common in older URM structures with deteriorated mortar and weak floor connections [13]. Figure 1 shows damages caused due to corner failures in Bhutan and L'Aquila earthquakes. Corner failures in masonry structures result from the combined IP and OOP behaviors of orthogonal walls. Limiting acceleration without vertical loads remains 0.7g in comparison to another study of [16] due to flexural dominant behavior prior to formation of corner. URM are vulnerable to corner failures during earthquakes, particularly in older structures with deteriorated materials and weak connections.

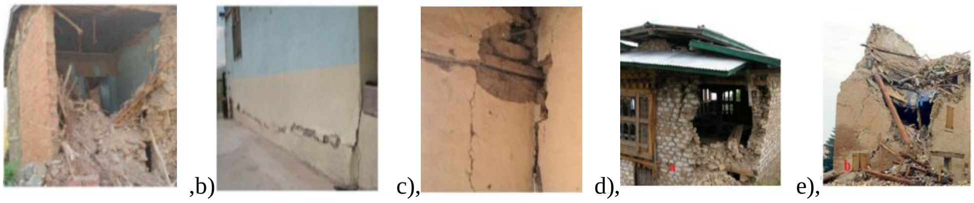


Figure 1. Masonry Failures: a) out of plane, b) in-plane, c) corner [15], d) & e) corner [13]

Figure 1 a) illustrates out-of-plane damage, while 1 b) depicts in-plane damage. 1 c), 1 d) and 1e) highlights the damage at the corners resulting from both in plane and out of plane damages

3. Emerging Strategies Mortar Free Interlocking Reinforced Masonry Structure

3.1 Mortar Free Masonry Structures

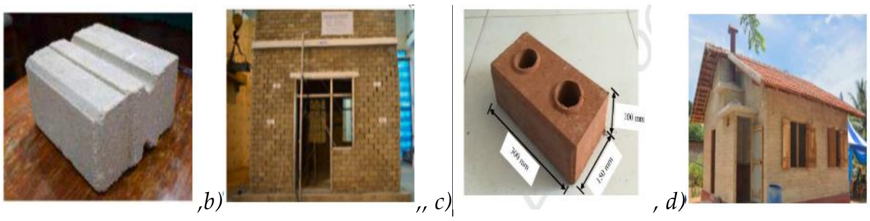
Conventional masonry is labor-intensive, with increasing competition from modern techniques. Mortar-less Masonry Systems (MMS), using interlocking units without mortar, reduce labor reliance and improve productivity. MMS needs additional strengthening to resist out-of-plane flexure and in-plane shear for seismic and cyclonic forces. Mortar-less interlocking structures perform better under gravity and lateral loads, with block compressive strength playing a key role in resistance and failure. MMS offer a promising alternative but still require reinforcement for extreme forces [9]. MMS enhance performance under gravity and lateral loads, their vulnerability to extreme seismic forces requires additional reinforcement to ensure structural integrity.

Researchers have developed efficient techniques for earthquake-resistant housing using interlocking concrete blocks. Interlocking dry-stacked masonry is an emerging building material with strong potential for future due to its sustainability and affordability in housing [10]. Behavior of reinforced mortar less interlocking brick walls under cyclic loading. The walls, made from a specific type of interlocking bricks with large keys, offer both alignment during construction and enhanced shear resistance [11]. Reinforced mortar-less interlocking dry-stacked masonry with slanted key designs offers strong earthquake resistance and energy dissipation.

3.2 Interlocking Mechanism of Mortar Free Masonry

Mortar free masonry using in interlocking mechanism results in dissipation of seismic energy. Unconfined dry stacked block masonry structures can withstand low to moderate seismic actions, with self-interlocking blocks acting as energy dissipating devices to reduce brittle shear failure[10]. Mortar-free construction enhances energy dissipation during seismic events due to relative block movement [17]. Unconfined dry-stacked block masonry with self-interlocking blocks, adhesive paste, and grout offers enhanced seismic energy dissipation, improved shear capacity, strength, and ductility, making it a resilient and cost-effective earthquake-resistant solution.

Interlocking mechanism of Mortar free masonry results in dissipation of earthquake energy Interlocking brick walls have higher seismic resistance than conventional CMU walls, with inter-brick friction as the key energy dissipation mechanism [18]. Figure 2 shows interlocking masonry structures used in various studies. MFI (Mortar free interlocking) slide and rotate in OOP direction helps in 25% as compared to conventional masonry dissipation of energy. Mortar free construction enhance energy dissipation during a seismic event due to the relative movement at the block interfaces. Mortar-free interlocking construction enhances energy dissipation through relative block movement, significantly reducing seismic damage by allowing sliding and rotation in the out-of-plane direction.



a) ,b) ,, c) , d)

Figure 2. Mortar free Interlocking Unit and Structure; a) & b) [10], c) &d) [8]

It is to be noted from the Fig 2. which depicts the different interlocking units used by the researcher in their studies for safe housing and economic housing.

4. Testing of masonry corner joints

4.1 Strategies for Joints at Corners for Efficient Behavior

Interlocking dry-stacked masonry is a promising building material for sustainable, affordable housing, with potential for future growth. Study emphasized that confinement at corners improves the seismic capacity of these structures [10]. Out-of-plane response as a key factor in seismic vulnerability of masonry, influenced by material properties, wall quality, geometry, and connections [12]. Interlocking dry-stacked masonry with corner confinement improves seismic capacity, while out-of-plane response is influenced by material properties, wall quality, geometry, and connections.

Older unreinforced dry-jointed masonry walls often experience corner separation due to weak mortar and floor connections. Both confined masonry and interlocking dry-stacked masonry offer effective solutions for enhancing seismic resilience [13]. Adding RCC confinement, partial reinforcement, and grouting to hollow concrete block masonry improves seismic performance distributing cracks and reducing damage, allowing for larger displacements with minimal strength loss [14]. Confined masonry, interlocking dry-stacked masonry, and RCC-reinforced hollow blocks enhance seismic resilience by reducing damage and allowing larger displacements with minimal strength loss.

4.2 Testing Techniques to Observe Corner Joint Behavior

A study involved the exploration of structural response of half scale pumice concrete masonry building using shake table tests and FE analysis. Frequency values of pumice decrease up to 23.5% and 19.85% for experimental mode. Both experimental and numerical results show damages occur in the same regions. Shake table and FE analysis provide valuable insights into the seismic behavior of structures, with experimental and numerical results confirming that nonlinear FE models effectively predict damage locations [19]. The study of pumice concrete masonry buildings emphasizes the importance of simulating real-world conditions to identify seismic vulnerabilities.

Interlocking mechanism and connection between bricks provides different resistances to loadings compared to those of conventional mortar-bonded masonry. The vertical ground motion component also significantly influences damage due to the rocking response [20]. Shake table and finite element (FE) analysis is helpful in assessing the seismic performance and damage distribution in pumice concrete masonry structures. Interlocking mechanism of pumice bricks provides distinct load-resisting behavior compared to conventional mortar-bonded masonry.

Table 1. Prototype model used by researchers in their studies.

Sr.No.	Method and Findings	Test type	Ref.
1	Shake table tests on 1/2 scale URM walls under bi-directional loading show that corner detachments and increased dead load reduce limiting acceleration from 0.55g to 0.52g, with an over-estimation of 31% without vertical loads to [16]	Shake table	[13]

2	Experimental, numerical, and analytical studies on masonry corners show that joint stiffness in full walls can be 2-3 times smaller than in two-block closure tests under horizontal pseudo-static loads.	Tilt-ing Table	[21]
3	Corner confinement in dry-stacked interlocking masonry increases lateral load capacity by 64% and drift capacity by 288%, enhancing seismic performance through improved energy dissipation, displacement ductility, and stiffness.	Shake table	[22]

4. Discussion

The review highlights that corner joints are highly vulnerable under seismic loading due to the combined in-plane and out-of-plane forces. Mortar-free interlocking systems show promising energy dissipation and deformation capacity, especially when confinement is added. However, standardized testing protocols and full-scale validations are still lacking. Future work should focus on optimizing joint geometry and reinforcement strategies for improved seismic resilience.

5. Conclusion

This review paper explores the potential of corner joints in mortar free interlocking block walls against lateral loading as reported in articles published in highly reputable journals. The objective is to consolidate all published information pertaining to mortar free interlocking block walls against lateral loading. Drawing insights from this comprehensive literature research, the following conclusions can be drawn

- Corner failures result from the combined IP and OOP behaviors of orthogonal walls. Limiting acceleration without vertical loads remains 0.7g due to flexural dominant behavior prior to formation of corner.
- Mortar free interlocking provide a sustainable alternative but require additional reinforcement to resist seismic forces. It slides and rotates in OOP direction helps in dissipation 25% more energy as compared to conventional masonry.
- Scaled Shake table testing confirms the seismic efficacy of interlocking block systems. Increased dead load reduce limiting acceleration from 0.55g to 0.52g and confinement in dry-stacked interlocking masonry increases lateral load capacity by 64%.

Corner failures result from combination of in-plane and out-of-plane behaviors. Without vertical loads, flexural dominance limits acceleration to 0.7g. Mortar-free interlocking masonry absorbs 25% more energy than conventional masonry, enhancing sustainability but requiring extra strengthening. Shake table tests confirm the seismic benefits of confinement, which increases lateral capacity by 64%, while increased dead load reduces the limiting acceleration from 0.55g to 0.52g.

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Conflict of Interest. There are no conflicts of interest to declare in relation to this study.

References

1. Losanno, D., Ravichandran, N., & Parisi, F. (2023). Seismic fragility models for base-isolated unreinforced masonry buildings with fibre-reinforced elastomeric isolators. *Earthquake Engineering & Structural Dynamics*, 52(2), 308-334.

2. Moshfeghi, A., Smyrou, E., Arslan, O., & Bal, I. E. (2024, August). Out-of-plane shake table tests on solid masonry walls with timber floors. In *Structures* (Vol. 66, p. 106815). Elsevier.
3. Sarhosis, V., Giarlelis, C., Karakostas, C., Smyrou, E., Bal, I. E., Valkaniotis, S., & Ganas, A. (2022). Observations from the March 2021 Thessaly Earthquakes: an earthquake engineering perspective for masonry structures. *Bulletin of Earthquake Engineering*, 20(10), 5483-5515.
4. Işık, E., Avcil, F., Büyüksaraç, A., İzol, R., Arslan, M. H., Aksoylu, C., ... & Ulutaş, H. (2023). Structural damages in masonry buildings in Adıyaman during the Kahramanmaraş (Turkiye) earthquakes (Mw 7.7 and Mw 7.6) on 06 February 2023. *Engineering Failure Analysis*, 151, 107405.
5. R. Jasi´ nski, I. Galman, Testing joints between walls made of AAC masonry units, *Buildings* 10 (4) (2020) 69.
6. Mercimek, Ö. (2023). Seismic failure modes of masonry structures exposed to Kahramanmaraş earthquakes (Mw 7.7 and 7.6) on February 6, 2023. *Engineering Failure Analysis*, 151, 107422
7. Camata, G., Di Primio, A., Sepe, V., & Cantagallo, C. (2023). The effect of the vertical component of the earthquake on a regular masonry wall. *Applied Sciences*, 13(4), 2459.
8. Thamboo JA, Zahra T, Dhanasekar R. Development of design methodology for mortarless masonry system:Case study–a resettlement housing colony. *Journal of Building Engineering*. 2020;27:100973.
9. Ahmed, S., & Ali, M. An Overview on Gravity Load Carrying Capacity and Lateral Load Resistance of Interlocking Block Structures, *ICEANS 2022, Konya, Turkey*.
10. Gul, A.; Alam, B.; Shahzada, K. Seismic performance evaluation of unconfined dry stacked block masonry structure. *Eng. Struct*.2022, 265, 114529.
11. Xie, G., Zhang, X., Hao, H., Shi, T., Cui, L., & Thomas, J. (2023). Behaviour of reinforced mortarless interlocking brick wall under cyclic loading. *Engineering Structures*, 283, 115890.
12. Vlachakis, G., Cervera, M., Barbat, G. B., & Saloustros, S. (2019). Out-of-plane seismic response and failure mechanism of masonry structures using finite elements with enhanced strain accuracy. *Engineering Failure Analysis*, 97, 534-555.
13. Avasthi, R., Bansal, N., & Rai, D. C. (2023). Behavior of unreinforced dry-jointed masonry walls at corners under lateral loads. *Earthquake Spectra*, 39(1), 100-125
14. Ahmed, A., Sadiq, A., & Shahzada, K. (2022). Confined hollow concrete block masonry buildings: An experimental approach for vulnerability assessment. *Composites and Advanced Materials*, 31, 26349833221091290
15. Yön, B. (2021). Identification of failure mechanisms in existing unreinforced masonry buildings in rural areas after April 4, 2019 earthquake in Turkey. *Journal of Building Engineering*, 43, 102586.
16. Casapulla, C., Giresini, L., Argiento, L. U., & Maione, A. (2019). Nonlinear static and dynamic analysis of rocking masonry corners using rigid macro-block modeling. *International Journal of Structural Stability and Dynamics*, 19(11), 1950137.
17. Ali, M. Gultom, RJ. Chouw, N., (2012). Capacity of innovative interlocking blocks under monotonic loading, *Construction and Building Materials*, Vol 37, pp 812- 821
18. Xie, G., Zhang, X., Hao, H., Bi, K., & Lin, Y. (2022). Response of reinforced mortar-less interlocking brick wall under seismic loading. *Bulletin of Earthquake Engineering*, 20(11), 6129-6165.
19. Kaya, A., Roudane, B., Adanur, S., Sunca, F., Genç, A. F., Gunaydin, M., & Altunişik, A. C. (2024). Structural response of half-scale pumice concrete masonry building: shake table/ambient vibration tests and FE analysis. *Meccanica*, 59(7), 1159-1190.
20. T. Shi, X. Zhang, H. Hao, G. Xie, Experimental and numerical studies of the shear resistance capacities of interlocking blocks, *Journal of Building Engineering*, 44 (2021) 103230.
21. Colombo, C., Savalle, N., Mehrotra, A., Funari, M. F., & Lourenço, P. B. (2022). Experimental, numerical and analytical investigations of masonry corners: Influence of the horizontal pseudo-static load orientation. *Construction and Building Materials*, 344, 127969.
22. Gul, A., Alam, B., Khan, I. U., Shah, S. A. A., Khan, S. W., & Shahzada, K. (2023). Improving seismic capacity of dry stacked interlocking masonry structure through confinement at corners. *Soil Dynamics and Earthquake Engineering*, 165, 107710.