Sustainable Structures and Materials, *Vol. 6, No. 1, (2023) 96-100*
DOI: https://doi.org/10.26392/SSM.2023.06.01.096

Mortarless Structures with Hollow Interlocking Blocks – A Review

Shehryar Ahmed[1], Majid Ali*[1]

[1]Dept. of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan
*Corresponding author/ E-mail: majid.ali@cust.edu.pk

(Received April 04, 2023, Revised May 20, 2023, Accepted June 4, 2023)

ABSTRACT. *Cost-effectiveness of structures mostly rely on reduction of building materials. Additionally, the construction time also contributes to economic aspect. Both material and time consumption take part in making conventional construction expensive. Potential of mortarless construction in local regions of Pakistan has not been reported in literature. Thus, the aim of this literature research is to have a comprehensive review of literature about the potential of mortarless construction in local regions. This is accomplished by focusing on articles published in highly reputable journals in last one decade. Pakistan is currently facing an issue of housing demand due to 2.4% annual population growth. Mortarless construction being one of the vibrant techniques has its own pros and cons. Mechanism of interlocking commonly depends on the block shape, applicable restraints and interfacial angles. Interlocking blocks with lugs and keys have the ability to use their topology in maintaining the structural integrity. The peripheral boundary of a block is responsible for maintaining the structural stability by dissipating frictional forces at contact surfaces. Boundary constraints like lintels and tensioned ropes provide additional integrity to whole structure. The interfacial angle between interlocked surfaces determines the resistance of block removal against lateral loading. Local regions in Asia and particularly Pakistan face economic limitations in construction. Practical implementation of mortarless interlocking structures can be economically beneficial provided sufficient robustness for stability*.

Keywords: Interlocking structures, hollow blocks, block geometry, mortarless structures, earthquake-resistant structures

1. INTRODUCTION

Resilience and cost-effectiveness have always been the prime focus of construction industry. Masonry construction behaves linearly elastic under low stresses but transforms into non-linear elastic after formation of cracks (1). Concept of topological interlocking is dependent on blocks having keys and grooves that result from segmentation of monolithic structure and provide a restraining mechanism by neighboring elements. The dissipation of energy at block peripheries contributes towards structural stability more than a similar monolithic structure. The initiation of fracture is resisted by block unit and it does not propagate beyond the peripheral boundary of a single block. Consequently, the joined faces of blocks provide sufficient resistance to in-plane and out-of-plane displacement of blocks, thus maintaining the structural integrity (2). Geometrical interlocking being relatively similar to topological interlocking holds the structure intact without tensioning forces.

Transformation of simplified block arrangement to interlocking mechanism has emphasized the importance of mortarless construction. Energy dissipation through interlocking develops tolerance against out-of-plane loading and prevents brittle shear failure (3). Challenges in interlocking structures arise when performance is desired against dynamic loading. Interlocking mechanism enhances structural integrity by providing tolerance and flexibility in terms of local failures (4). Topological interlocking holds the structure intact by peripheral and kinematic constraints. globally and locally, respectively. Estrin et al., (5) discussed the topological interlocking in platonic bodies (identical faces, regular polygons) and in osteomorphic blocks (concavo-convex contact surfaces) with emphasis on multi-layered structures.

Interlocking masonry construction has the prime benefit of cost effectiveness due to absence of bonding material. Interlocking mechanisms in block elements encourage the avoidance of mortar for construction (6). The primary advantage of hollow block over solid block becomes the lower consumption of material which makes the block lightweight (7). Reduction in weight of the structure enhances elastic response against lateral movement. Underdeveloped regions in Asia have limited resources and manpower for state-of-the-art infrastructure development. Interlocking masonry construction with reduced cost and semi-skilled labor is a viable option for housing in underdeveloped regions.

To the best of author's knowledge, potential of mortarless construction in local regions of Pakistan has not been reported in literature. Thus, the literature about the potential of mortarless construction in local regions has been comprehensively reviewed in perspective of structural performance. The study is limited to the relevant literature produced in past one decade. Construction of mortarless structures with different hollow block shapes has also been reported to enhance the significance of this research.

2. NEED FOR MORTARLESS STRUCTURES

Conventional construction of masonry structures for housing is the most commonly adopted technique in Pakistan. The components of these structures include brick/block units with mortar, slabs, lintels and foundations. Presence of mortar stiffens the structures resulting in restricted displacement and unintended torsion (8). Strength of mortar is usually lower than brick which leads to initiation of damage from mortar layers (9). Importance of confinement in masonry walls and coherence of brick-mortar bond has been usually neglected due to unskilled labor. Also, the significance of connections between walls and slabs is not considered. Considering such issues in masonry structures, mortarless structures has evolved as a reliable solution. The absence of mortar is often dealt with mechanisms like interlocking of block units, external or/and internal tensioned ropes. Interlocking structures dominate the conventional structures by eliminating issues of confinement and connections between different elements. In addition, problems like shrinkage cracking in mortar are also eliminated.

Another major factor that gives advantage to interlocking mortarless structures is the rapid assembling and dissembling. Conventional structures require plenty of time at different stages during construction formwork, concreting and curing, etc. Also, the skillset of labor determines the quality of work produced in term of safety as well as economy (10). Contrary to that, interlocking mortarless structures require already precast block units for quick assembling. In addition, requirement of skilled labor for assembling the structure is not necessary. Absence of mortar decreases the wastage and reduces the influence of workmanship.

Table -1: Comparison of conventional and interlocking masonry construction

Sr. No.	Parameters	Conventional Masonry Construction	Interlocking Hollow Block Construction
1.	Construction constraints	Skilled labor and extensive formwork are required.	Semi-skilled labor and limited formwork is required.
2.	Construction speed	Slow construction with intervals due to onsite concreting and curing.	Rapid construction due to assembling of structure with pre-fabricated blocks.
3.	Earthquake resistance	Compromised performance due to inadequate lateral resistance.	Better performance due to interlocking effect of blocks.
4.	Financial aspect	Costly due to excessive material usage in solid blocks/bricks, and mortar.	Cost-effective due to limited material usage in hollow blocks and mortar lessness.

Table 1 shows the advantages of interlocking hollow block construction over conventional masonry construction. Pakistan being a seismic prone region has a history of major earthquakes. Conventionally constructed masonry structures are highly vulnerable to damage against seismic activities. An obvious reason is the insignificant resistance to lateral loading. However, interlocking mortarless structures can provide sufficient resistance to lateral loading by preventing blocks from sliding over due to provision of shear keys (11). These keys and their interfacial contact surfaces act as a medium to dissipate frictional forces during lateral movement. Weight of the block amplify the performance against gravity loading (12) but flexibility in terms of lightweight is desired against in-plane and out-of-plane movement. Robustness of interlocking structure is also influenced by restraining mechanism to hold the overall structure intact. Dyskin et al., (13) utilized internal and external tension cables with surcharge beam to improve the structural integrity and prevent the in-plane and out-of-plane displacement of blocks. The tensioned cables along with interlocked surfaces provide excessive resistance to horizontal and vertical deformation. The dominant advantages of interlocking hollow block construction makes it a feasible option to replace conventional masonry construction to utilize the advantages.

3. VARIOUS SHAPES OF INTERLOCKING HOLLOW BLOCKS AND THEIR STRUCTURES

Lateral performance of interlocking structure is associated with effective block geometry. Weizmann at al., (14) discussed topological optimization by reducing the weights of individual block units. The unnecessary use of material was highlighted as the transfer of forces is only dependent on the contact edges of block. The redistribution of material within the design limitations enhances the efficiency towards material stresses and strains. The reduced weight of elements can be cost-effective but the complexity of shape to reduce weight can intensify the fabrication costs. Li et al., (15) proposed recycled aggregates concrete hollow blocks that could help in improving construction efficiency by 56% in comparison to ordinary concrete hollow blocks. Topologically interlocked structures are geometrically constrained through contact and friction of neighboring elements (16). Design of block shape includes effective horizontal, vertical and inclined area of contact with neighboring blocks, geometry of interlocking key, inclination angle between adjoining surfaces and planar mass distribution. Inclined faces are the crucial boundaries to withstand in-plane and out-of-plane displacements through energy dissipation (17).

Fig -1: Full-scale houses constructed using hollow blocks; (a) Thamboo et al., (18), (b) Nasly and Yassin (19), (c) Imai et al., (20)

Figure 1 shows houses constructed using different shapes of hollow interlocking blocks. Thamboo et al., (18) reviewed various prospects of designing and constructing interlocking mortarless structures. The recommendations made were restricted tolerance of blocks for improved construction and surface evenness for better vertical load resistance. Universiti Teknologi Malaysia developed a system for manufacturing of blocks followed by design and construction of house (19). The pilot project resulted in favorable outcomes in terms of reduced cost through time and material saving along with avoidance of high waged skilled labor. Post-project gains included saved cost and time in terms of material and semi-skilled labor. Imai et al., (20) reported the use of non-engineered houses constructed using concrete hollow blocks. Lack of feasible design in developing block shape and capacity, absence of restraining mechanism leads to collapse and casualties. Two house models (engineered and non-engineered) were made using concrete hollow blocks and were tested against seismic record Kobe 1995. Engineered model performed better with minor damage in comparison to non-engineered model which experienced consistent failure. Promising mechanical properties of blocks have confirmed the feasibility of interlocking block structures for practical applications (21). Interlocking arrangement of blocks prevent rigid body movement without requiring adhesives (22). Development of block shape for better performance against lateral loading and easy manufacturing at industrial scale needs comprehensive full-scale experimentation.

4. POTENTIAL APPLICATION IN LOCAL REGIONS

Pakistan being a developing country has limited resources to deal with natural disasters like earthquakes. Also, construction industry is facing issues, like economic crises (23), labor shortages and resource depletion (24). Severe damage to human lives and infrastructure has resulted in the past due to poor construction practices and lack of adequacy in design in local regions. A high level of seismic hazard exists in Pakistan due to active crustal faults (25). Conventional construction using mud bricks and mortar are commonly employed at large scale without proper detailing for seismic resilience. These conventionally constructed structures perform sufficiently well under gravity

loading but fail under the action of earthquakes. This highlights a serious issue of life threat in addition to financial loss. Mortarless structures with interlocking hollow block mechanism can be a viable solution with the benefits of cost effectiveness and seismic resilient (26). The rapid population growth in Pakistan with an annual population growth rate of 2.4% is leading towards extensive housing demand (27). Chart 1 shows the trend of population growth in Pakistan over a period of 66 years.

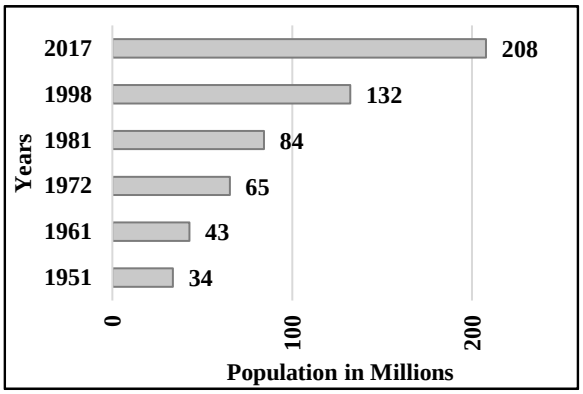

Chart -1: Population growth in Pakistan, Hussain et al., (27)

Interlocking hollow block construction eliminates many on-site factors due to use pre-fabricated block units (28). Manufacturing of interlocking hollow blocks at industrial scale require specially designed molds with relatively high precision (29). Provision of restraining mechanism in hollow block shape is an added advantage. Local industries can be developed in different regions for the manufacturing of hollow blocks. Semi-skilled labor can be utilized for the construction of single-storey houses using hollow blocks. In seismically active regions, additional tensioning ropes can be used for restraining block walls and surcharge beams and slabs can withstand the upward movement of elements. This mechanism of internal as well as boundary constraints can make interlocking structure perform well against gravity and lateral loading. Cost-effective rapid construction of interlocking hollow block structures through semi-skilled labor can perform better against earthquakes in comparison to conventional masonry structures (30, 31). Thus, resource limited environment of local regions in Pakistan needs simplified construction of houses with cost effectiveness in the form of interlocking mortarless construction.

5. CONCLUSIONS

Mortarless construction of interlocking structures has gained a significant admiration due to better performance and cost-effectiveness. Pakistan having severely underdeveloped regions with exposure to natural disasters like earthquakes, needs cost-effective solution for housing. Thus, potential of interlocking mortarless construction has been reviewed in perspective of Pakistan's local environment and conclusions have been drawn.

- Interlocking mortarless construction has dominance over conventional construction due to cost-effectiveness in terms of material saving and semi-skilled labor requirement.
- Performance of interlocking mortarless against lateral loading makes it viable for earthquake resistant housing.
- Rapid constructability of interlocking mortarless structures eases its adaptability in local region in comparison to conventional masonry construction.

Future research should be oriented towards design guidelines for construction interlocking mortarless structures after taking into account the effects of vertical seismic component for practical application in seismically prone local regions.

ACKNOWLEDGEMENT

The authors would like to thank every person who supported in conducting this research. The careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged.

REFERENCES

[1] Sarhosis V, Garrity S, Sheng Y. Influence of brick–mortar interface on the mechanical behaviour of low bond strength masonry brickwork lintels. Engineering Structures. 2015;88:1-11.
[2] Gul A, Alam B, Khan IU, Shah SAA, Khan SW, Shahzada K. Improving seismic capacity of dry stacked interlocking masonry structure through confinement at corners. Soil Dynamics and Earthquake Engineering. 2023;165:107710.
[3] Gul A, Alam B, Shahzada K. Seismic performance evaluation of unconfined dry stacked block masonry structure. Engineering Structures. 2022;265:114529.

[4] Estrin Y, Dyskin AV, Pasternak E. Topological interlocking as a material design concept. Materials Science and Engineering: C. 2011;31(6):1189-94.
[5] Estrin Y, Krishnamurthy VR, Akleman E. Design of architectured materials based on topological and geometrical interlocking. Journal of Materials Research and Technology. 2021;15:1165-78.
[6] Shi T, Zhang X, Hao H, Chen C. Experimental and numerical investigation on the compressive properties of interlocking blocks. Engineering Structures. 2021;228:111561.
[7] Kasinikota P, Tripura DD. Flexural behavior of hollow interlocking compressed stabilized earth-block masonry walls under out-of-plane loading. Journal of Building Engineering. 2022;57:104895.
[8] Dorji S, Derakhshan H, Thambiratnam DP, editors. Experimental investigation of semi-interlocking mortarless masonry-infilled frames. Structures; 2022: Elsevier.
[9] Shi T, Zhang X, Hao H, Xie G. Experimental and numerical studies of the shear resistance capacities of interlocking blocks. Journal of Building Engineering. 2021;44:103230.
[10] Zahra T, Dorji J, Thamboo J, Asad M, Kasinski W, Nardone A. In-plane and out-of-plane shear characteristics of reinforced mortarless concrete block masonry. Journal of Building Engineering. 2023:105938.
[11] Casapulla C, Mousavian E, Argiento L, Ceraldi C, Bagi K. Torsion-shear behaviour at the interfaces of rigid interlocking blocks in masonry assemblages: Experimental investigation and analytical approaches. Materials and Structures. 2021;54(3):134.
[12] Schapira Y, Chernin L, Shufrin I. Blast energy absorption in topological interlocking elastic columns. Mechanics of Advanced Materials and Structures. 2022:1-13.
[13] Dyskin AV, Pasternak E, Estrin Y. Mortarless structures based on topological interlocking. Frontiers of Structural and Civil Engineering. 2012;6(2):188-97.
[14] Weizmann M, Amir O, Grobman YJ. Topological interlocking in buildings: A case for the design and construction of floors. Automation in Construction. 2016;72:18-25.
[15] Li J, Zhou H, Chen W, Chen Z. Shear properties of a new type recycled aggregate concrete interlocking hollow block masonry with axial load. Advances in Structural Engineering. 2021;24(12):2735-47.
[16] Koureas I, Pundir M, Feldfogel S, Kammer DS. On the failure of beam-like topologically interlocked structures. International Journal of Solids and Structures. 2022;259:112029.
[17] Xie G, Zhang X, Hao H, Bi K, Lin Y. Response of reinforced mortar-less interlocking brick wall under seismic loading. Bulletin of Earthquake Engineering. 2022;20(11):6129-65.
[18] 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.
[19] Nasly M, Yassin A, editors. Sustainable housing using an innovative interlocking block building system. Proceedings of the Fifth National Conference on Civil Engineering (AWAM'09): Towards Sustainable Development, Kuala Lumpur, Malaysia; 2009: Citeseer.
[20] Imai H, Minowa C, Lanuza AG, Penarubia HC, Narag IC, Soridum Jr RU, et al. A full-scale shaking table test on philippine concrete hollow blocks (Chb) masonry houses. Journal of Disaster Research. 2015;10(1):113-20.
[21] Lan G, Wang T, Wang Y, Zhang K. Seismic performance of interlocking compressed-earth block composite walls. Composite Structures. 2023:116704.
[22] Aharoni L, Bachelet I, Carstensen JV. Topology optimization of rigid interlocking assemblies. Computers & Structures. 2021;250:106521.
[23] Anusha M, Surendra H, Dhar N, Choudhary M, Khan IA, Pasha SFA. Enhancing sustainability of polypropylene band and bamboo-reinforced structural elements for rural low cost housing. Environment, Development and Sustainability. 2022:1-14.
[24] Chen J, Qiao G, Wang R. Turning desert sand into building material products: An ambitious attempt of solar 3D printing. Journal of Cleaner Production. 2022;380:134790.
[25] Rahman Au, Najam FA, Zaman S, Rasheed A, Rana IA. An updated probabilistic seismic hazard assessment (PSHA) for Pakistan. Bulletin of Earthquake Engineering. 2021;19:1625-62.
[26] Dorji S, Derakhshan H, Thambiratnam DP, Zahra T, Mohyeddin A. Behaviour and material properties of versaloc semi-interlocking mortarless masonry. Materials and Structures. 2023;56(1):17.
[27] Hussain A, Ahmed A, Hussain W. Increasing Housing Demand in Pakistan. Accessible Housing for South Asia: Needs, Implementation and Impacts: Springer; 2022. p. 103-25.
[28] Agha A, Shibani A, Hassan D, Zalans B. Modular construction in the United Kingdom housing sector: barriers and implications. Journal of Architectural Engineering Technology. 2021;10(2):236.
[29] Zahra T, Dhanasekar M. Characterisation and strategies for mitigation of the contact surface unevenness in dry-stack masonry. Construction and Building Materials. 2018;169:612-28.
[30] Sokairge H, Rashad A, Elshafie H. Behavior of post-tensioned dry-stack interlocking masonry walls under out of plane loading. Construction and Building Materials. 2017;133:348-57.
[31] Huang L, Gao C, Yan L, Li X, Ma G, Wang T. Experimental and analytical modeling of GFRP strengthened grouted mortarless masonry prisms. Fibers. 2017;5(2):18.