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Performance evaluation of mortarless brick masonry

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ABSTRACT

The rising cost of construction materials need to adhere alternate construction techniques and materials. Mud brick is one of the common and basic construction units since thousands of years. In this research study the bricks with mechanical interlocking mechanism are used for comparison over economical, sustainable, environment friendly and fast track construction especially for the flood and earthquake affected areas. Naturally destructive areas require quick rehabilitation of the displaced people. A parametric study has been performed in compassion with conventional brick masonry. Performance evaluation for construction cost and time has been studied along with the durability of system to check the acceptability of mortarless masonry construction technique.

1. Introduction

Brick as a fundamental unit of construction has an age equal to the field of Civil Engineering. Brick masonry can be used in the construction of almost all types of buildings like residential, commercial, and historical monuments. In Pakistan, residential buildings with brick masonry mainly consist of one storey houses in rural areas and generally 3-storeys houses in urban areas. This type of buildings constitutes 62.38% of the total construction in Pakistan [1] The rate of construction has been drastically increasing over the past years resulting in the increased cost of construction. This situation raised a demand of methods which are cost effective and fast. Interlocking Bricks is one of the great cost-effective methods. These bricks are "interlocked" against each other without the utilization of concrete/mortar, to shape a basically stable wall that decreases the expense and time of development to approximately half. In present days, where cement prices are rising, interlocking bricks proves to be a great environmental-friendly, fast track and cheaper method of construction.

Interlocking or dry stack mortarless construction has been in Africa for thousands of years. The great Zimbabwean ruins and the Egyptian pyramids are examples of ancient interlocking construction [2-3] but this ancient construction involved usage of huge structural elements which proved to be more time and material consuming. Due to these reasons, interest was lost in this type of construction and focus was made on industrialized materials for examples fired clay brick, cement, concrete and steel. Industrialized materials, no doubt proved to be great for construction but with increased usage and demand, they have become quite expensive to be affordable for poor people. Interlocking brick masonry framework is one of most economical development of materials since soil is the most accessible construction material on the earth.

Pakistan is an under developing country located in one of the seismically active zones of the world. Earthquakes have caused heavy damages to the buildings in the past years. After the great earthquake of 2005, many people had to stay homelessly for a long time period due to massive destruction of buildings and usage of slow typical methods of construction during rehabilitation process. Those areas require quick rehabilitation as shelter being one of major concerns. Present practices are mostly insufficient and slow in terms of construction work speed so in order to lead towards fast construction techniques, this technology is introduced. In this research, mud bricks of interlocking mechanism have been produced and their acceptability for sustainable construction has been studied. Since interlocking brick construction require no or very less use of cement, so ultimately the carbon dioxide emission during cement production reduces.

Overall, this research highlights the use of interlocking brick masonry as a cost effective, fast and environment friendly method. The objective of this research, as defined by the authors is that the knowledge regarding mortarless construction might be extended for sustainable construction.

Ramamurthy et al., [4] researched about usage of interlocking bricks for walls and foundations. In this way, process of construction of foundations was also accelerated. The block design was simple and it provided good interlocking between walls and foundations. They developed a wall system with interlocking bricks and tested it in labouratory for its constructional, structural and functional performance and the results showed that this wall system enhanced structural and functional performance.

Kintingu [5] in his research studied about mortarless walling technology and in particular how the wall flexibility, wall alignment, accuracy and its behaviour (stiffness, strength) can be improved by using mortarless technology when subjected to lateral forces. He achieved greater wall flexibility by development of new bricks (centre-half bat and tee brick). He concluded in his research that using mortarless technology will save 50% of wall construction cost and 50% cement consumption, which ultimately will reduce 40% of carbon emissions.

Ali et al., [6] focused on developing such a system which can provide low cost and rapid construction for areas affected by natural disasters. They innovate special interlocking blocks with names top, half, and bottom blocks. Toughest natural fibre i.e., coconut fibre was used to achieve better interlocking among lower, upper, and adjacent blocks. Relationship between individual and multiple blocks were developed for compressive strength, and in-plane and out-of-plane shear capacities were tested. Higher compressive strength for bottom blocks and for individual blocks were declared to have higher compressive strength then multiple blocks.

Jaafar et al., [7] worked on development of relationship between the compressive strength of wall panel, Individual block and Prim for a hollow brick masonry system. The blocks were named of University of PUTRA, Malaysia. Blocks consist of stretcher, corner, and half blocks. The interlocking mechanism along with crack patterns and failure mechanism of Hollow block masonry were considered. Results showed that compressive strength of prism was 0.47 times compressive strength of individual blocks. Also, compressive strength of wall panel was found to be 0.83 times compressive strength of prism and 0.39 times of individual block and results for strength and interlocking were satisfactory for load bearing wall.

Thanoon et al., [8] researched about the development of a new system, named hollow block masonry system. This system is a replacement of the Conventional Mortar Brick masonry system. The main feature of this system is that it provides 3-Dimensional interlocking of block layers. Major tests performed on twenty-one models were about weight, bearing and shear areas formation, and convenience of construction.

Thanoon et al., [9] worked on interlocking key protrusions and grooves in hollow block masonry to remove mortar layers from conventional brick masonry systems. Concrete block systems were tested against axial compression loads using Finite Element Method. Main simulated features were mechanical behaviour of dry joints, the interaction between blocks and decrease in bonding with time and material variation. The Finite Element model was further checked by demonstration of nonlinear structural response and failure mechanism and interlocking of both grouted and ungrouted prisms and results were reflection of experimental results.

Micheal et al., [10] researched about the preference of interlocking masonry over conventional type in Nigeria. Sand concrete blocks and burnt bricks are used as common building materials in Nigeria. They have a negative effect on environment due to impacts of greenhouse gases. Surveys and interviews were conducted to see the acceptability of interlocking brick masonry instead of conventional masonry and a great number of respondents showed willingness for the replacement of conventional bricks to interlocking system due to the cost-efficiency, shorter period of setting, and energy efficiency of the material.

Watile et al., [11] in their research paper gives the results of an experimental investigation in which the compressive strength, water absorption and density were investigated by using varying percentage of fly ash, stone dust, and sand with different mix proportion. A manmade fibre, glass fibre reinforce polymer (GFRP) was utilized as reinforcing material to produce the interlocking blocks which gives appreciable results. They compared the experimental results with that of ordinary burnt clay brick. Interlocking bricks were found tough in aggressive environments. Also, they have enough strength for workable construction.

Laster [12] in his research work proved the preference of mortarless construction system over conventional brick masonry in terms of better earthquake resistance and total cost. Unlike standard masonry walls which are solid, the interlocking mortar-less masonry blocks allow slight movement and lock tighter over time, aided by application of steel reinforcement. This interlocked walling technique was considered better at dissipating the energy of a seismic wave than traditional masonry. This system can also be used in conjunction with poured concrete for improved performance.

Ahmad et al., [13] in his research proved by experimentation that interlocking brick masonry is a preference to overcome the effect of weakest part of masonry, which is a mortar joint, present in conventional masonry. An increase of 30% in strength was observed when tests were conducted. Further, this technology proved to be simple i.e., a smaller number of skilled labours were required. In terms of cost, they are cost effective as they save mortar.

Ali et al., [14] carried on a study for the areas of seismically active regions should have these houses. Keeping in view of economy, this is achieved by interlocking of blocks and coconut-fibre rope reinforcement. These blocks interlocking with coconut fibre reinforcement was introduced by them. They investigated mortarless structures in plane behaviour under different effects of earthquake, impact, harmonic, pushover and snap back loadings. Moreover, four structures were introduced one was wall and other was column with and without ropes. Stiffness and damping of with rope and without rope is also studied.

Nguyen et al., [15] studied that metallurgical tubes refractory lining having mortarless masonry. To study behaviour of these structures it is necessary to use an equivalent material having dependent properties on combination of closed/open states of bed and head joints are point out.

Alex [16] did experiments to show that the behaviour of mortarless system is severely affected by dry joint behaviour. Different behaviours of deformations are observed for grouted and ungrouted masonry.

Bashar et al., [17] proposed concept of utilizing of waste tire rubber as a material for the production of common construction unit, a brick. Authors have produced the interlocking bricks and analysed various performance parameters of the unit block under the labouratory conditions. The cost benefit analysis was not conducted in this study in order of check the feasibility of the manufacturing/production on mass level in the local country conditions.

Palolo [18] presented a recent study on the interlocked and cohesive masonry and performed in-field test on various cases to develop an understanding of lateral loads and behaviour of both these types of masonry. With the interlocked brick unit, author studied the masonry of plan unit blocks forming a masonry pattern without adhesive mortar basically considering the dry-stone masonry.

Jeslin et al., [19] suggested an interlocking brick design and evaluated the compressive strength as compared to the conventional brick unit. The study revealed that the compressive strength of interlocking arrangement increased 15-30% when compared with standard brick used in mortar-based construction masonry. But due to smaller interlocking projection the proposed system may not work effectively against the lateral loadings.

It may be easy to conclude based on the literature that brick is the oldest and by far the most popular building material [20-21]. Its benefits like low cost, local manufacturing, and construction simplicity are well known. In addition to all these benefits some other good qualities like mechanical strength, durability, dimensional stability, significant fire resistance nature, good insulation properties of sound and heat, etc. surely makes it a premium choice for construction works. Unfortunately, in seismic regions, one attribute that it lacks, i.e., deformation capability on the brick-mortar interface is of the utmost importance. In horizontal and vertical planes, traditional brick masonry work utilizes the bonding property adhered upon by the mortar. This surface-surface friction bond between mortar and clay brick breaks down during earthquake tremors due to out-of-plane motion. Falling masonry infill events contribute to the indirect economic effect of earthquakes. This is due to occupancy interruption, as tenants are unlikely to use the building before this maintenance is completed.

In third world countries, where the construction cost in the housing sector is increasing day by day due to inflation of construction materials despite the increase in earing. An average earning hand spent a huge amount on the construction of a house and thus so demand the maximum safety to its property, to safeguard the life and households. Innovations in the construction methodologies and materials are magnificently coping with the issue of increasing cost in the construction industry. In this scenario, the basic building unit (i.e., brick) is the most critical component to be investigated. Similarly, mortarless (only mechanically interlocked) brick masonry has led the attention of researchers all over the world to provide environmental-friendly, easy, and fast ways of construction [20, 22-24].

This study also contributes to the research area of mortarless construction and thus proposed a modified interlocking sequence of construction using clay bricks. Unlike the other studies [25-26] using interlocking concrete blocks, it is fast, reliable, and cost-effective for underdeveloping countries and exclusively for the Asian countries where clay bricks are the eminent building units.

2. Methodology

The striking feature of interlocking type of masonry is that it made possible interlocking and proper joint breaking. The walls built up with these bricks having interlocking feature also guarantee another masonry requirement of joints' discontinuity. Both bed and cross joints are discontinued from inward to external face. Different possible shapes were prepared and examined for their interlocking capabilities in the lab procedures. The line sketch of final selected shape is shown in the Fig. 1. The designed system provides both horizontal and vertical interlocking as illustrated in the Fig. 2.

3. Experimental Work

Bed joint discontinuity is produced by placing the starter blocks (inner or outer) on a bed layer of half depth brick, especially care in dimensioning this assembly for the wall starts makes possible precise levelling of the first course and half depth upside projection of block is achieved. In the first layer of wall panel, the half-length corner unit is placed which provide interlock in one direction. While in the next layer, second course bricks perpendicular to the first course automatically have a locking grip in the second direction. This process is done cyclically for succeeding layers. Constructional and structural performance of conventional and mortarless brick system was studied under following headings.

1. Strength Analysis
2. Material Consumption
3. Construction-Time Analysis
4. Labour Output
5. Cost Analysis
6. Environmental Impacts

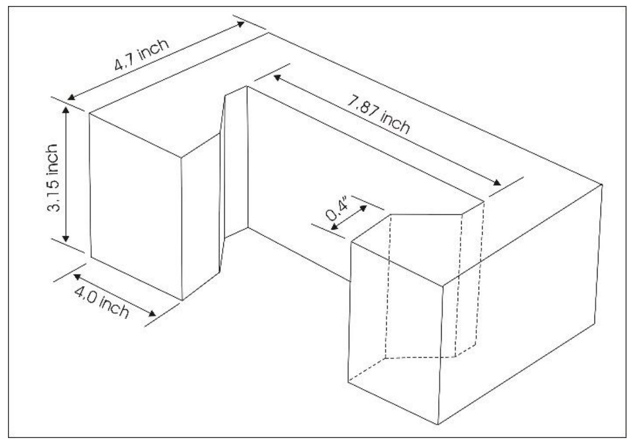

Fig. 1. Design of interlocking brick

Fig. 2. Mortarless bricks with both ways interlocking system

3.1 Strength Analysis

Compressive strength test was conducted for structural durability. Tests were carried out on prisms/wallets to check the influence of interlocking bedding with physical interlocking feature. Single brick unit and a panel (~ 9 in x 9 in) of both conventional and mortarless bricks were prepared for testing. The testing arrangement is shown in the Fig. 3. The results are presented in Table 1.

(a) Compression test of Single Mortarless Brick | (b) Compression test of Single Conventional Brick unit | (c) Compression test of Mortarless Bricks' Panel | (d) Compression test of Conventional Bricks' Panel

Fig. 3. Testing arrangements

Table 1

Compression test results

Test Specimens	Strength (PSI)
	2204 2300 2033 2179 Average
	1137 1564 1351 1350 Average
	1706 995 1350.5 Average
	810 1251 1030.5 Average

3.2 Analysis of Material Consumption

Total 30 typical house-plans were selected with areas ranging from 5 Marla (1356 sq. ft.) to 12 Marla (3264 sq. ft.). Estimation of different quantities was carried out to form a comparison between the conventional construction and mortarless brick construction.

Cement mortar will be used only on top and bottom layers of mortarless construction. Taking the average of calculated number of bricks and cement bags for 30 houses both for conventional brick masonry and mortarless brick masonry, results are summarised in the Table 2, whereas Fig. 4 and Fig. 5 illustrate the graphical comparison.

Table 2

Comparison of material consumption

Type of Masonry	Cement Required	Number of Bricks Required
Conventional Brick Masonry	121 Bags	34,500
Dry Stacked Mortarless Brick Masonry	10 Bags	25,800

It is clearly shown in the results that number of bricks and cement bags reduces reasonably with mortarless construction.

3.3 Analysis of Time of Construction

Although, the production cost of interlocking bricks is slightly more as compared to typical bricks, but it is compensated by the less labour cost, time of construction activity and material consumption (like savings in mortar). These bricks are more suitable for rehabilitation works after natural disasters like earthquake etc. because of following reasons.

1. Bricks/blocks can be casted on site either using one's own efforts and resources or through setting up a temporary shed for casting and then supplying to nearby areas.

2. Development of interlocking bricks does not require specially trained workmanship. The requirement of transportation of bricks to the sites is thus eliminated. There is no requirement of highly trained labour in case of mortarless bricks as compared to conventional mortar-bedded brick masonry. Semi-skilled labour itself is enough for the construction of interlocking brick masonry.

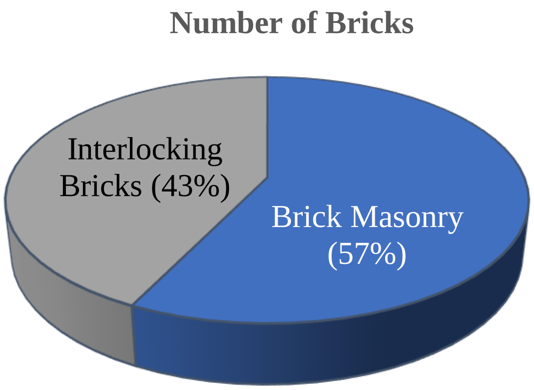

Fig. 4. Comparison of bricks consumption

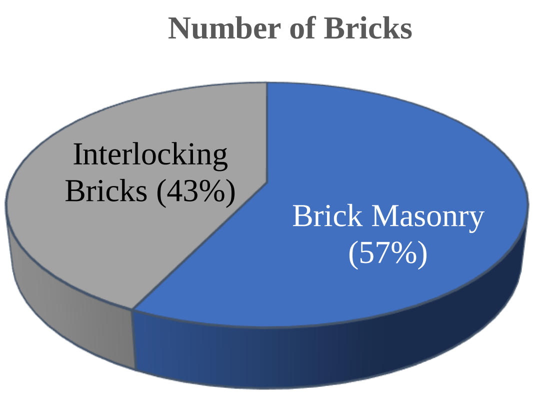

Fig. 5. Comparison of cement consumption

The time of construction for conventional brick masonry system was estimated from different real constructional sites. Construction time estimation for mortarless brick masonry, the 4 x 4 sq. ft. panels were built in lab by 3 different persons one by one and time of construction was observed. Average of these recorded values was used further to calculate the time of construction for mortarless brick system. Further, time of construction for both conventional and mortarless bricks was compared and the results are shown in Table 3 and demonstrated graphically in Fig. 6.

3.4 Analysis of Labour Output

For observing key difference in the work outlines between conventional and interlocking brick-masonry, crew-based work sampling was done. The results used to estimate the constructional performance i.e., a relation of output over productive-hour of conventional and interlocking brick masonry and are shown in Table-4. An improvement in output of around 67.7% was observed for dry-stacked masonry. Number of labours will reduce with the reduced time of construction. Also, the labour output is more in construction with mortarless brick masonry as there is no use of mortar and requires no or less skills and care even for proper vertical alignment.

Table 3

Comparison of time of construction

Type of Masonry	Average time required for work (days)
Conventional Brick	45
Dry Stacked Mortarless Brick	22

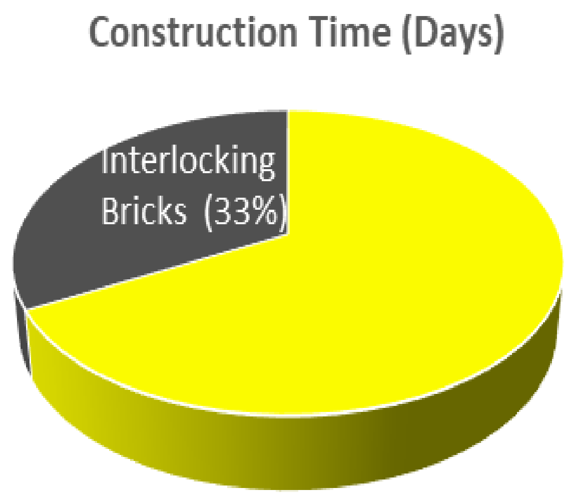

Fig. 6. Construction time comparison

It is clearly shown that time of construction reduces to almost half with mortarless construction as compared to conventional brick construction.

Table 4

Comparison of productive output

Type of Masonry	Labour Output (sq. ft./hr)	Contributory Work Time (hr)	Net Productive Output (sq. ft./hr)
Conventional Brick	8.12	9.04	17.16
Dry Stacked Mortarless	25.19	1.75	26.94

3.5 Cost Analysis

The costs of cement and bricks was estimated for both mortarless bricks and conventional bricks separately. Table 5 and Fig. 7 show the estimated number of bricks and cement bags for each type of brick construction. The following unit cost was used in the estimation process at the time of this study.

- Unit price of brick (including manufacturing cost and carriage from kiln to the project place) ~ PKR 7.5
- Unit price for the specially designed mortarless interlocking brick ~ PKR 10.2
- Unit price of cement bag ~ PKR 450
- Unit skilled labour (Mason) per day ~ PKR 600

Table 5

Comparison of cost (PKR)

Type of Masonry	Cost of Cement	Cost of Bricks	Labour Cost
Conventional Brick	54,450	258,750	29,250
Dry Stacked Mortarless Brick	4,500	270,900	14,300

Cost of construction will be reduced in terms of cost of cement and labour in case of mortarless brick construction as presented in Table 6.

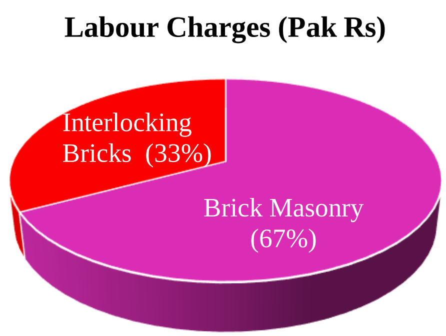

Fig. 7. Comparison of labour charges

3.6 Analysis of Environmental Impacts

The worldwide CO_2 emissions from cement industry is given by following calculations for the year 2014.

- CO_2 per ton of cement from energy use is 0.75 tons
- CO_2 per ton of cement from calcining limestone is 0.50 tons
- CO_2 per ton of the total cement is 1.25 tons [16]
- Cement produced in 2014 is 4.59 billion tons [27]
- Annual production of CO_2 emissions is 5.73 billion tons
- Total Global CO_2 emissions is 37.5 billion tons [28]
- Thus, percent CO_2 emissions from cement to the total global emmissions is around 15%.

Table 6

Comparison of total savings for labour and cement

Type of Masonry	Cost Savings (PKR)			
	Bricks	Cement	Labour	Savings
Conventional Brick	12,000	0	0	12,000
Dry Stacked Mortarless Brick	-12,150	49,950	14,950	52,750

Approximately 15% of global CO_2 emissions is contributed by the cement manufacturing industry. Being one of the major CO_2 emitting industries, this needs special attention to cut short the demand of cement in construction industry so that ultimately the earth could be saved from the effect of green house. Table 7 shows the CO_2 global share.

Table 7

Comparison of global share of CO_2

Type of Masonry	Cement Per Annum	Requirement of Cement	CO_2 Global Share
Conventional Brick	4.59 Billion Ton (Average)	100 %	15%
Dry Stacked Mortarless Brick		8.26%	1.24%

Fig. 8 shows the percentage of CO_2 emission contribution of mortarless brick construction in production of CO_2 which contributes to Global warming is way lesser than the contribution of conventional brick system in production of CO_2.

As described in the experimental section, a total of 30 houses of various sizes, referring to the common contraction practices in Pakistan, were adopted for this study. The average cost which adhering to the grey structure of the house (excluding slab) above the DPC (damp proof course) level was estimated as 1.0 MRS based on the use of the cement grout/mortar for the conventional brick masonry work.

Literature shows many studies regarding the new techniques and shapes of interlocking bricks and showed the cost-effectiveness in comparison to the conventional brick masonry work. For example, the research carried out in the Department of Civil and Environmental Engineering, the University of Alberta in 2010 [29] shows the merits and demerits of interlocking brick masonry. That study extensively discussed various structural parameters and cost variations using the interlocking bricks. A significant saving of 24% over conventional masonry was reported in the labour cost. But the material cost for the mortarless system as presented in the work was exceed those of traditional construction due to the higher cost of the large quantity of grout used. The proposed mechanism reported by Korany [29] was effective from a structural point of view but at the same time cost benefits were limited overall construction cost is considered. Whereas, in the present study the cost trade-off was made with the usage of mortar between the consecutive brick course above DPC level without compromising the structural stability. Structural integrity was ensured using a better mechanical interlocking concept providing both out-of-plane and in-plane resistance to movement.

4. Conclusions

This study presented an improved methodology based on the unique shape of interlocking clay brick. Different inherent limitations of masonry work like finishing work referred to as the vertical plumb of the wall etc. This dry-stacked mortarless brick masonry permitted above grade buildings of nominal heights about 12-feet (typical height of single-story house). Mortarless bricks-based construction yields an overall saving in the construction up to 15% as observed in this study. Due to the fast construction procedures, depending on the nature of the project, this technique offers potential for additional monetary gains from a structure that is operational at an earlier date. Some other conclusions are as follows.

1. Unlike conventional brick masonry, interlocking block masonry requires less level of trained labour.
2. Construction followed by mortarless brick masonry proposed in this study demands less; construction time, manpower/labour, and material requirement.
3. Construction time reduces to almost 50% comparing to that of conventional brick masonry.
4. Mortarless brick construction is suited for post-disaster reconstruction and rehabilitation activities.
5. Environment friendly construction as it reduces the CO_2 emission to 92% out of the 15% of the share by cement industry.

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