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Improving The Structural Performance Of Environmentally Friendly Block Walls

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Abstract – This study investigates the structural performance of Compressed Earth Block (CEB) walls compared to conventional Concrete Masonry Unit (CMU) walls, with a focus on the impact of carbon fiber-reinforced polymer (CFRP) strengthening techniques. CEBs are recognized as a sustainable alternative to traditional building materials, offering benefits such as reduced embodied energy and lower CO_2 emissions**.** Two experimental setups were constructed to evaluate the lateral structural performance of CEB walls under both out-of-plane and in-plane loading conditions. The results demonstrated that CMU walls significantly outperformed CEB walls in terms of initial stiffness, maximum lateral load, and ductility. However, the application of CFRP to CEB walls notably increased their performance, nearly doubling the maximum lateral load in the out-of-plane direction and increasing the in-plane load to 89 % of the CMU wall's capacity. Additionally, the ductility of the CEB-CFRP wall was significantly enhanced compared to that of the CMU wall in the in-plane loading direction. The improvement in the performance in the in-plane direction was much better than that in the out-of-plane direction. These findings highlight the potential for CEB construction to serve as a viable alternative to traditional masonry, especially when enhanced with CFRP techniques. Further research is recommended to optimize design and construction practices for CEB walls, maximizing their structural and economic advantages while promoting the use of sustainable building materials.

Keywords**:** Compressed Earth Blocks, Carbon Fiber Reinforced Polymer, Large-scale Testing, Quasistatic Loading

1. Introduction

Compressed earth blocks (CEBs) have emerged as a promising sustainable and environmentally friendly alternative to traditional building materials such as fired bricks and concrete blocks. CEBs are produced by compacting a mixture of soil, water, and sometimes a stabilizing agent, such as cement or lime, into a mold under high pressure [1, 2]. This process results in a building material that is durable, thermally efficient, and requires significantly less embodied energy and CO_2 emissions compared to fired bricks [3, 4].

Several studies have evaluated the structural performance of CEBs when utilized in wall assemblies. For instance, the study by [5] investigated the effect of stabilizers percentages on the structural performance of walls made from CEBs. Another study experimentally investigated the seismic performance of CEBs indicating differences in wall shear behaviors for partially and fully grouted wall assemblies [6]. Additionally, the study by [7] investigated the effects of various structural measures on the seismic performance of the walls made from interlocking CEBs [7] establishing characteristic envelope curves, calculation methods for loading and unloading stiffness, and hysteretic trends for these walls.

In terms of thermal properties, CEBs have been observed to provide improved thermal insulation compared to fired bricks, contributing to the energy efficiency of buildings [4, 8]. This characteristic, combined with the reduced environmental impact during production, has made CEBs an attractive choice for sustainable construction practices.

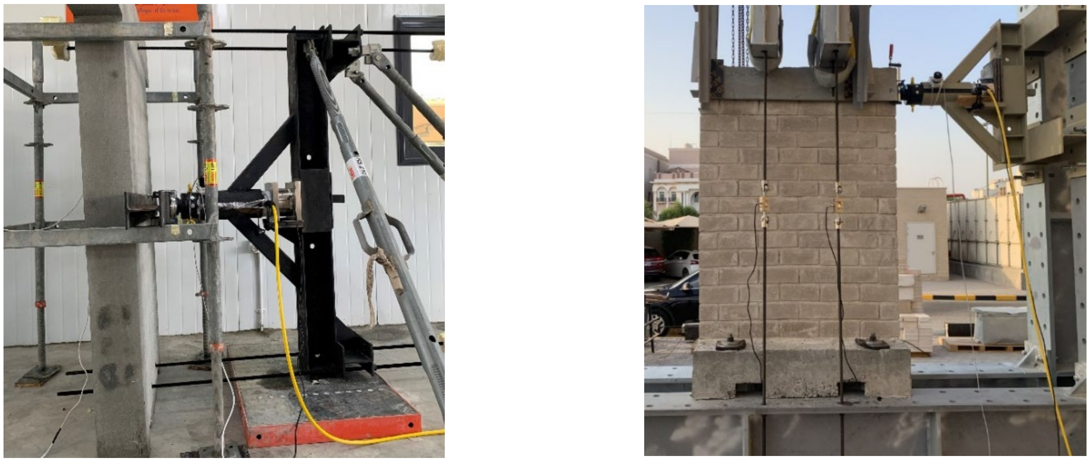
CEBs also have the potential to be more cost-effective than conventional building materials, as they can be produced on-site using local soil resources, thus reducing transportation costs and the need for energy-intensive manufacturing processes [2, 9]. This advantage has led to the increased adoption of CEBs in developing regions, where access to traditional building materials may be limited or prohibitively expensive.

Despite these benefits, the widespread adoption of CEBs has been hindered by a lack of standardized guidelines and building codes, as well as concerns about the long-term durability and weathering resistance of CEB structures [10]. Ongoing research and development efforts are focused on addressing these challenges and further improving the performance and acceptability of CEBs as a sustainable construction material.

To enhance the structural performance of CEB walls, researchers have explored the use of carbon fiber-reinforced polymer (CFRP) strengthening techniques. Studies have shown that the application of CFRP to CEB walls and other types of walls can significantly improve their resistance to lateral and vertical loads, making lower strength blocks more suitable for use in seismic-prone regions [11, 12, and 13]. This combined approach of using CEBs as the primary building material and CFRP for structural reinforcement has the potential to create a more resilient and sustainable construction system.

2. Experimental Setup

Two experimental setups were utilized in this study to evaluate the effectiveness of using CFRP in improving the lateral structural performance of CEB walls in the (1) out-of-plane and (2) in-plane directions of the wall. Fig. 1 illustrates the test setups of the CEB walls without CFRP laminates, the same setups were also used for the strengthened CEB walls with CFRP and the reference walls made with Concrete Masonry Units (CMUs).



(a) (b)

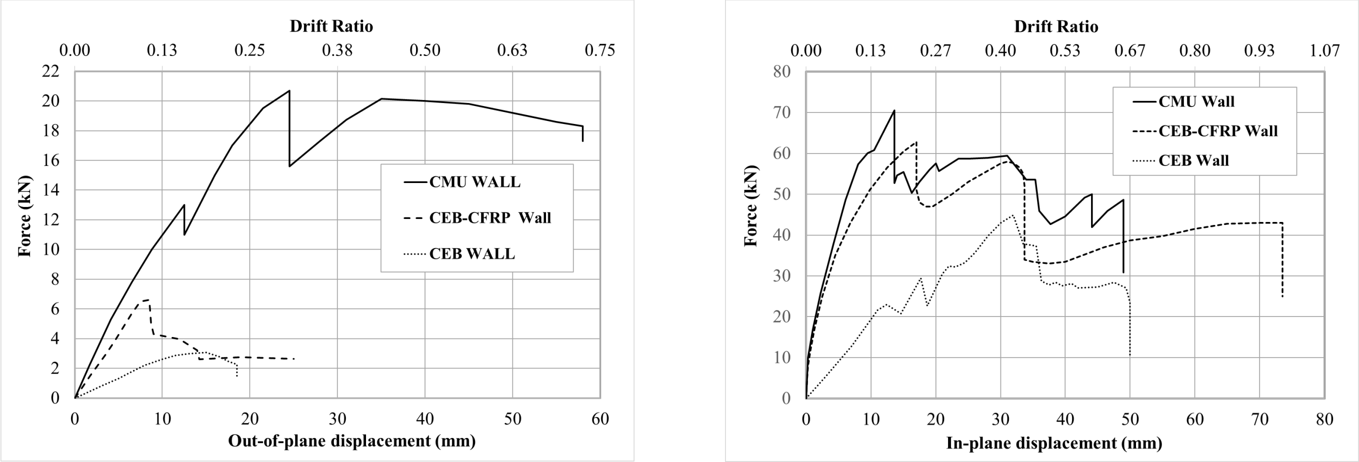
Fig. 1: (a) The out-of-plane test setup and (b) the in-plane test setup of the CEB walls.

The load was applied quasi-statically using a hand operated hydraulic jack until failure. In the out-of-plane wall tests, the load was applied at the mid-height of the wall using a steel spreader beam, with the top and bottom of the walls prevented from movement by threaded rods connecting the wall specimen to a strong column behind the jack. Alternatively, the in-plane walls were built on a concrete footing, with the load applied to a concrete cap beam at the top of the wall (See Fig. 1). All tested walls, in both test setups, were internally reinforced with a single layer of reinforcing bars positioned at the middle of the wall section to ensure safety during the handling of the wall specimens.

3. Results

The force displacement curves from both experimental evaluations are presented in Fig. 2. The recorded displacements were measured at the load application. In the out-of-plane testing results, the CMU wall showed significantly better performance compared to the CEB wall across all measured parameters (See Table 1). The maximum lateral load achieved by the CEB wall was less than 15% of that reached by the CMU wall. Furthermore, the maximum reached displacement observed in the CEB wall was less than 25% of that reached by the CMU wall, indicating substantially reduced ductility in that loading direction.

The In-plane testing results also demonstrated a better performance of the CMU wall compared to the CEB wall, although the differences were less pronounced than in the out-of-plane loading direction (see Table 2). Both walls reached reached nearly the same displacement at failure (50mm), while the maximum lateral load in the CEB wall was approximately64% of that reached by the CMU wall.



(a) (b)

Fig. 2: Force displacement curves for (a) the out-of-plane test and (b) the in-plane test of the three walls

Laminating the CEB walls with CFRP significantly improved their performance in all aspects, reducing the performance gap between the CEB walls and the CMU walls. In the out-of-plane direction, the maximum lateral load nearly doubled (from 3.10 kN to 6.60 kN) and the ductility was enhanced, although the CMU wall performance was still significantly better. In the in-plane direction, the maximum load increased from 44.8 kN to 62.80 kN (from 64% to 89% of the maximum reached load of the CMU wall). Notably, the ductility of the CEB-CFRP wall outperformed that of the CMU wall, achieving a maximum displacement of 73.50 mm (150% of the failure displacement of the CMU wall).

Table 1: Out-of-plane lateral performance parameters for the tested walls.

	CMU Wall	**CEB Wall**	**CEB-CFRP Wall**
Initial Stiffness (kN/mm)	1.29	0.26	0.83
Maximum Lateral Load (kN)	20.70	3.10	6.60
Displacement @ Wall Failure (mm)	58.00	18.50	25.00

Table 2: In-plane lateral performance parameters for the tested walls.

	CMU Wall	**CEB Wall**	**CEB-CFRP Wall**
Initial Stiffness (kN/mm)	36.05	10.80	27.78
Maximum Lateral Load (kN)	70.56	44.88	62.80
Displacement @ Wall Failure (mm)	49.00	50.00	73.50

4. Conclusion

This study evaluated the structural performance of CEB walls compared to conventional CMU walls, with a emphasis on the effectiveness of CFRP strengthening techniques. The experimental results demonstrated that CMU significantly outperformed CEB wall across key metrics, including initial stiffness, maximum lateral load, and ductility. Specifically, in the out-of-plane tests, the maximum lateral load of the CEB was less than 15 % of that of the CMU wall, while the in-plane tests showed that the CEB all achieved approximately 64 % of the CMU wall's maximum load.

However, the use of CFRP significantly enhanced the performance of the CEB walls, nearly doubling their maximum lateral load in the out-of-plane direction and increasing the in-plane load to 89% of that of the CMU wall. Notably, the ductility of the CEB-CFRP wall exceeded that of the CMU wall during in-plane testing, indicating improve energy dissipation and structural resilience. These findings demonstrate the potential for CEB construction as a sustainable alternative to traditional masonry, particularly when combined with cost-effective retrofitting techniques such as CFRP lamination. The results suggest that CEB walls, when properly designed and reinforced, can provide a competitive option for modern construction practices. Future research should focus on optimizing the design and construction methods of CEB walls to maximize their structural and economic benefits, while further promoting the use of sustainable earth-based building materials in the construction industry.

Acknowledgements

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