

## MECHANICAL PERFORMANCE OF COMPRESSED STABILIZED EARTH BRICK MASONRY WITH FOUR MORTAR TYPES: A COMPARATIVE EXPERIMENTAL STUDY

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### Abstract

Compressed stabilized earth bricks (CSEBs) offer a locally adaptable alternative to fired masonry, but wall-level performance depends strongly on the interaction between the earth units and mortar. This study experimentally evaluated the effect of four mortar systems-mud mortar, cement-stabilized mud mortar, cement-sand mortar 1:6, and cement-sand mortar 1:3-on the mechanical performance of CSEB masonry. The experimental program comprised three types of mechanical tests. Twelve masonry specimens measuring 4 ft × 4 ft were prepared and tested for diagonal shear strength. Twelve smaller masonry specimens measuring 1.5 ft × 1.5 ft (18 in × 18 in) were prepared and tested for compressive strength. In addition, 12 direct shear (triplet) specimens were prepared for each mortar type to evaluate the shear/bond behavior at the masonry joint, following the testing standard adopted in the thesis. The reported mean compressive strengths were 1.85, 3.12, 4.45, and 5.68 MPa for mud, stabilized mud, 1:6, and 1:3 mortar, respectively. Mean diagonal shear strengths were 0.12, 0.24, 0.38, and 0.52 MPa, while mean direct shear strengths were 0.10, 0.22, 0.34, and 0.48 MPa, respectively. Reanalysis of the reported replicates per group showed statistically significant between-group differences for all three outcomes (one-way ANOVA,  $p < 0.001$ ). However, the relatively limited number of specimens used for some test categories requires cautious interpretation of the statistical findings. The results demonstrate a consistent increase in measured masonry strength with the transition from unstabilized mud mortar to stabilized mud and cement-sand mortars. The findings support mortar selection as an important design variable in CSEB masonry and indicate that stabilized mud mortar can provide a substantially stronger alternative to unstabilized mud mortar while retaining lower material intensity than conventional cement-rich mortar systems. Long-term durability, environmental life-cycle performance, seismic response, and field validation were outside the scope of the present

study.

## INTRODUCTION

Construction systems based on locally available earth materials have received renewed attention because they can reduce transport demand, avoid kiln firing, and provide a pathway toward lower-impact masonry. CSEBs are produced by mechanically compacting a soil-water mixture containing a stabilizer, commonly cement or lime. Earlier studies have shown that cement stabilization can substantially improve strength and durability, while compaction, moisture, soil grading, and cement content also influence the measured properties [1-7]. The environmental rationale for earth-based construction is supported by studies showing that local-material strategies can reduce embodied energy and transport impacts relative to conventional construction [10,13].

At the masonry scale, however, the brick cannot be considered independently of the mortar. The wall behaves as a composite system in which the mortar controls load transfer, interface bonding, deformation compatibility, and crack propagation. Research on earth-brick masonry has demonstrated that compression and diagonal loading can produce brittle cracking and that the relative properties of units and joints affect the observed failure mechanism [9,19,20]. The literature also shows that testing methods and specimen geometry can materially affect reported earth-brick strength, limiting direct comparison among studies [5,6,28].

The thesis underlying this paper identified a need for a controlled comparison of locally relevant mortar systems in CSEB masonry in Pakistan. The experimental program therefore compared traditional mud mortar, cement-stabilized mud mortar, cement-sand mortar 1:6, and cement-and mortar 1:3 under the same panel geometry, curing regime, and testing framework. The objective of this paper is to present those results in a concise journal format and to quantify the differences among mortar systems.

## 2. Objectives

- To compare the compressive strength of CSEB masonry made with four mortar systems.
- To compare diagonal shear strength under diagonal compression.
- To evaluate direct shear/bond performance at the brick-mortar interface.
- To document the qualitative failure patterns associated with each mortar type.
- To assess the practical implications of mortar selection for sustainable and low-cost CSEB construction.

## 3. Literature Context

Previous work provides three important foundations for the present experiment. First, stabilization and compaction strongly affect earth-block strength. Walker and Stace reported improved block and mortar properties with cement stabilization, while Walker's larger experimental program related strength and durability to soil characteristics and cement content [3,4]. Bahar et al. also demonstrated the combined influence of mechanical compaction and cement stabilization on compacted soils [7]. Morel et al. showed that block geometry and test procedure must be considered when interpreting compressive strength [5], and Morel and Pkla developed an alternative three-point bending approach for assessing compressed earth brick [6]. Second, masonry-level behavior is governed by interactions among units and joints. Miccoli et al. compared earth block masonry, rammed earth, and cob and demonstrated substantial differences in mechanical response among earthen systems [9]. Miccoli et al. subsequently combined experimental testing and finite-element modelling of earth block masonry under compression and diagonal compression, showing the relevance of cracking and interface behavior to structural response [19]. Recent work continues to examine earth-block wall shear behavior and

reinforcement, indicating that shear capacity and deformation remain important research topics [24,25].

Third, sustainability does not necessarily mean minimizing cement to zero; rather, the engineering objective is to balance mechanical performance, durability, cost, and environmental impact. Studies of fly ash-cement and cement-sand stabilized earth block demonstrate that supplementary materials can reduce cement demand while maintaining useful mechanical properties [20-23]. Recent work on stabilized soil block in Malawi similarly shows the importance of identifying cement contents that satisfy local building requirements without unnecessary stabilizer use [23]. These findings motivate the present comparison of a high-cement cement-sand mortar, a leaner cement-sand mortar, and lower-cement earth-based mortar systems.

#### **4. Materials and Methods**

**Study design.** The work was a controlled laboratory experiment based on the thesis experimental program. Twelve CSEB masonry panels were constructed, three for each of four mortar types. Each panel measured approximately 4 ft × 4 ft and used the same CSEB unit mix, stretcher-bond arrangement, and approximately 10 mm mortar joints. The panels were moist-cured for 14 days under the reported laboratory conditions before testing. The study did not include long-term weathering, water absorption, cyclic wet-dry exposure, freeze-thaw testing, thermal performance, or seismic/cyclic loading.

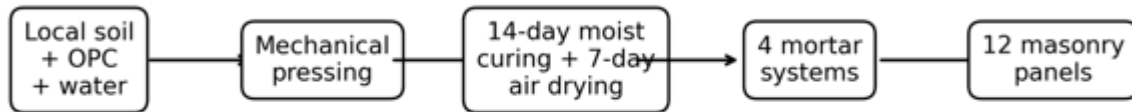
**Materials.** Locally available soil was used for the CSEB units. Ordinary Portland cement was used as the stabilizing agent. Potable water was used for mixing and curing, and locally available river sand was used for cement-sand mortars. The four mortar systems were: (1) mud mortar; (2) cement-stabilized mud mortar containing approximately

5-8% cement by dry soil mass, with the experimental discussion identifying approximately 7% stabilization; (3) cement-sand mortar at 1:6; and (4) cement-sand mortar at 1:3 by proportion.

**CSEB production and curing.** Soil was sieved, blended with the required cement and water, placed in a steel mould, mechanically pressed, and demoulded. The reported brick dimensions were approximately 9 × 4.5 × 3 in. Bricks were moist-cured under wet coverings for at least 14 days and then air-dried for approximately 7 days before use in the panels.

**Mechanical testing.** Compressive strength was assessed using the masonry-panel/prism compression procedure reported as ASTM C1314. Diagonal shear was assessed using ASTM E519/E519M, in which a square masonry assemblage is loaded along one diagonal to generate diagonal tension/shear [30,31]. Direct shear/bond behavior was reported using a triplet-type test and referenced in the thesis to ASTM C1531. Importantly, ASTM C1531 is an in-situ mortar-joint shear-strength-index method rather than a conventional laboratory triplet standard; therefore, the terminology and standard attribution should be checked against the laboratory protocol before journal submission [32]. The present paper preserves the thesis description rather than retrospectively redefining the test.

**Data analysis.** For each mortar group, the three reported specimen values were summarized as mean, standard deviation (SD), and coefficient of variation (CV). As an additional reanalysis of the thesis data, one-way ANOVA was performed separately for compressive, diagonal shear, and direct shear strength. Because each group contained only three observations, inferential results are treated as exploratory.



Standardized mechanical assessment: ASTM C1314 → ASTM E519 → direct shear assessment

Figure 1. Experimental workflow reconstructed from the thesis methodology.

## 5. Results

### 5.1 Descriptive mechanical results

| Outcome                       | Mortar                 | Mean (MPa) | SD (MPa) | CV (%) | n |
|-------------------------------|------------------------|------------|----------|--------|---|
| Compressive strength (MPa)    | Mud mortar             | 1.850      | 0.050    | 2.7    | 3 |
| Compressive strength (MPa)    | Stabilized mud mortar  | 3.120      | 0.089    | 2.8    | 3 |
| Compressive strength (MPa)    | Cement-sand mortar 1:6 | 4.450      | 0.062    | 1.4    | 3 |
| Compressive strength (MPa)    | Cement-sand mortar 1:3 | 5.677      | 0.075    | 1.3    | 3 |
| Diagonal shear strength (MPa) | Mud mortar             | 0.120      | 0.010    | 8.3    | 3 |
| Diagonal shear strength (MPa) | Stabilized mud mortar  | 0.240      | 0.010    | 4.2    | 3 |

|                               |                        |       |       |      |   |
|-------------------------------|------------------------|-------|-------|------|---|
| Diagonal shear strength (MPa) | Cement-sand mortar 1:6 | 0.377 | 0.015 | 4.1  | 3 |
| Diagonal shear strength (MPa) | Cement-sand mortar 1:3 | 0.520 | 0.010 | 1.9  | 3 |
| Direct shear strength (MPa)   | Mud mortar             | 0.100 | 0.010 | 10.0 | 3 |
| Direct shear strength (MPa)   | Stabilized mud mortar  | 0.220 | 0.010 | 4.5  | 3 |
| Direct shear strength (MPa)   | Cement-sand mortar 1:6 | 0.340 | 0.010 | 2.9  | 3 |
| Direct shear strength (MPa)   | Cement-sand mortar 1:3 | 0.480 | 0.010 | 2.1  | 3 |

The original thesis reports specimen-level measurements and group means; the table above adds SD and CV from those same three

observations per group. The source thesis reports the underlying values for all three tests.  
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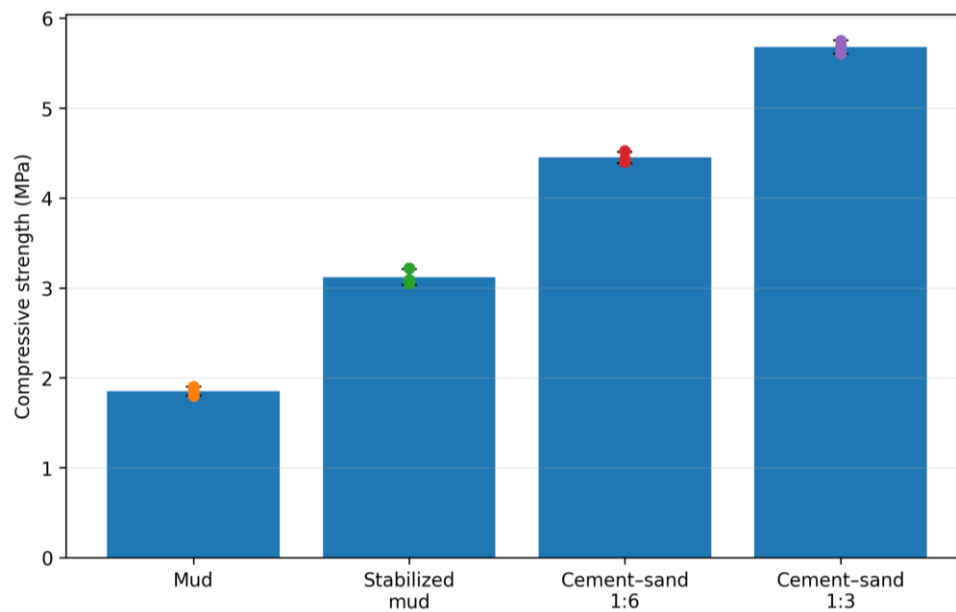


Figure 2. Compressive strength by mortar type. Bars show mean  $\pm$  SD; points show the three reported replicates.

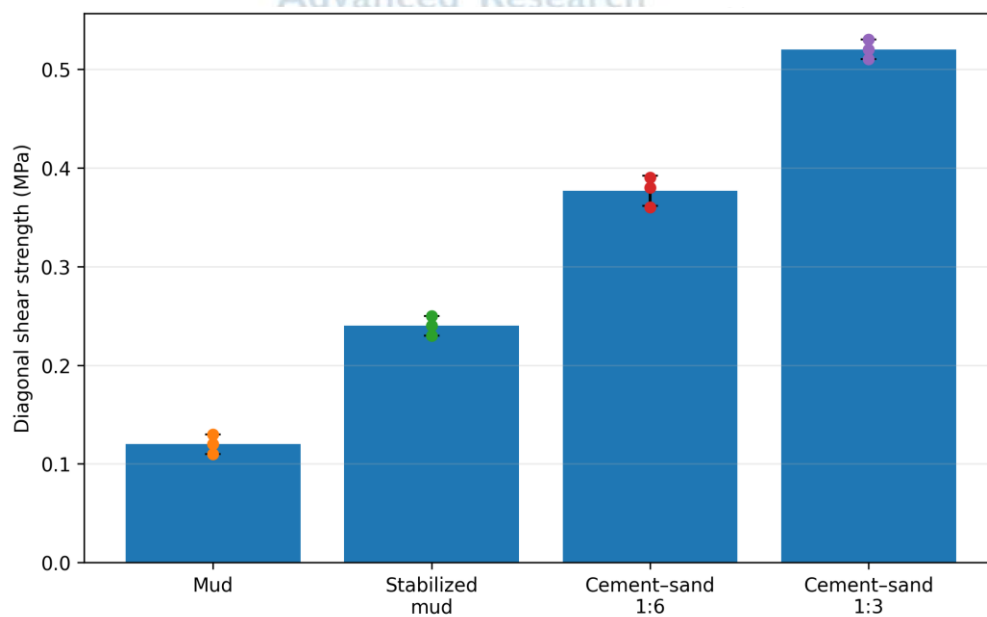


Figure 3. Diagonal shear strength by mortar type. Bars show mean  $\pm$  SD; points show the three reported replicates.

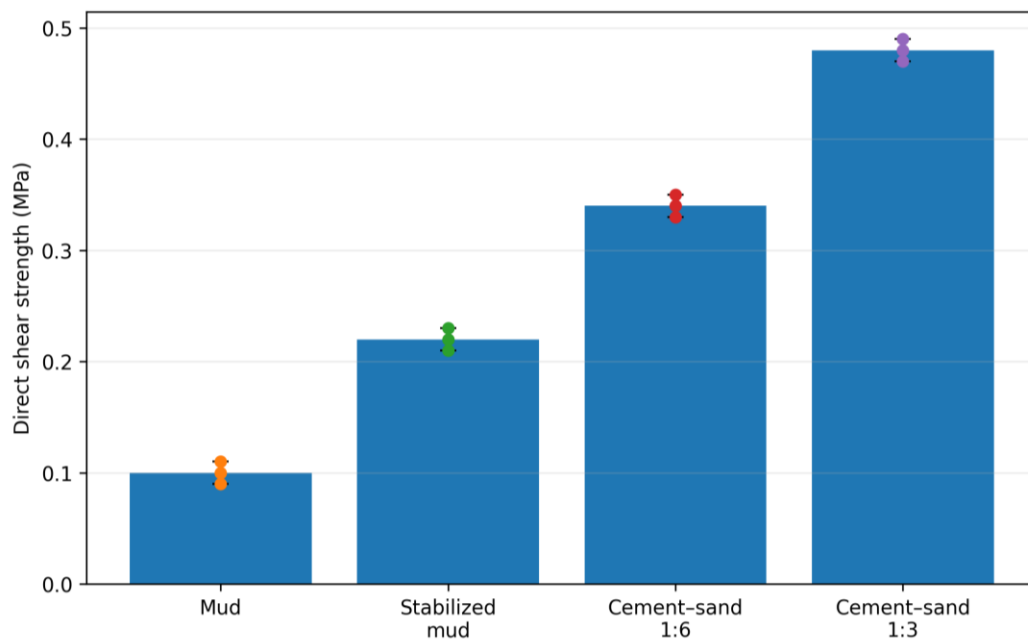


Figure 4. Direct shear strength by mortar type. Bars show mean  $\pm$  SD; points show the three reported replicates.

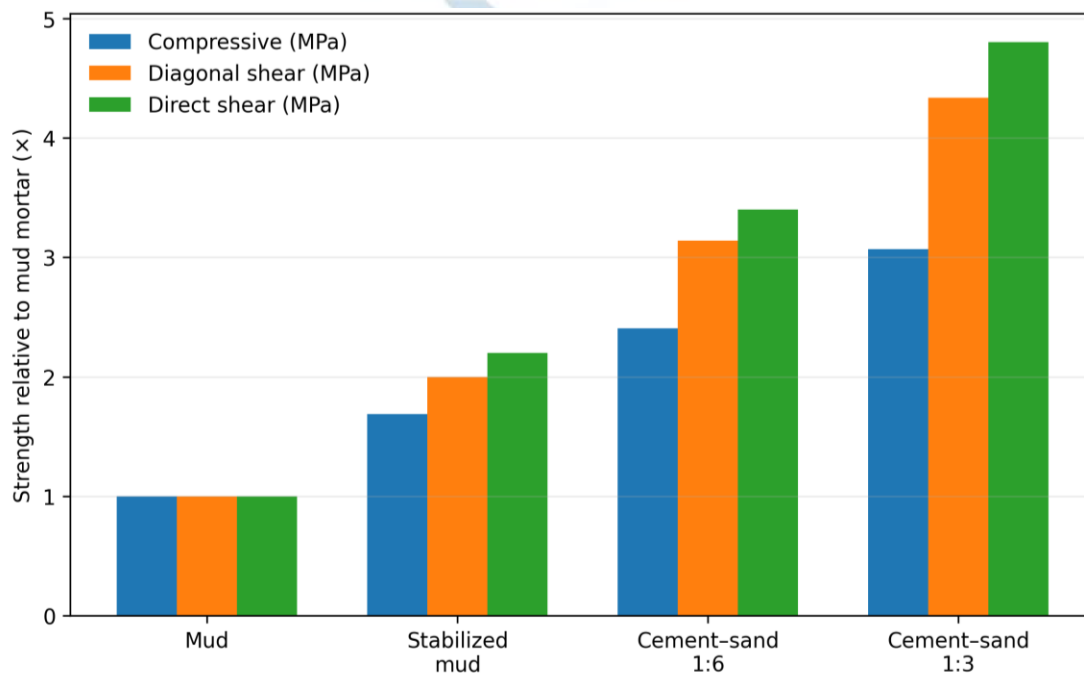


Figure 5. Relative mean strength compared with unstabilized mud mortar (baseline = 1.0).

## Inferential reanalysis

- Compressive strength (MPa): one-way ANOVA  $F = 1646.81$ ,  $p = 1.68e-11$ .
- Diagonal shear strength (MPa): one-way ANOVA  $F = 671.06$ ,  $p = 6.03e-10$ .
- Direct shear strength (MPa): one-way ANOVA  $F = 795.00$ ,  $p = 3.07e-10$ .

These ANOVA results are a secondary analysis of the three reported replicates per mortar type; they were not reported as inferential statistics in the original thesis and should therefore be treated as exploratory.

## 6. Discussion

The consistent ranking across compression, diagonal shear, and direct shear indicates that mortar composition was a major determinant of the measured wall-level mechanical response in this experimental program. The result is compatible with the composite nature of masonry: mortar provides the immediate load-transfer path between CSEB units and its stiffness, cohesion, and adhesion influence how stresses are distributed and how cracks develop. Earlier earth-masonry studies likewise emphasize the importance of unit-mortar interaction and the relative mechanical characteristics of the constituents [9,19].

The improvement obtained by stabilizing the mud mortar is particularly relevant to resource-constrained construction. The mean compressive strength increased from 1.85 to 3.12 MPa, while diagonal and direct shear strength approximately doubled. This confirms that modest cement stabilization can substantially change the mechanical response of an earth-based joint. Similar research on cement-stabilized earth materials has reported improved strength and durability with increasing stabilizer content, although the optimum amount is soil-specific and excessive cement may reduce the environmental and economic advantages of earth construction [3,4,7].

The 1:3 cement-sand mortar produced the highest values in every test. This is not unexpected because the stronger cementitious

mortar can provide greater cohesion and bond capacity[20–23]. However, maximum laboratory strength should not automatically be equated with overall system optimality. Cement manufacture carries environmental burdens, and the present study did not measure cost, embodied carbon, water resistance, or long-term durability. Consequently, the results support a performance comparison, not a universal prescription that one mortar is optimal under every structural, economic, or environmental criterion.

The direct-shear results also require careful interpretation. The thesis describes this test as a triplet test while citing ASTM C1531. Current ASTM C1531-22 addresses in-situ mortar-joint shear strength index measurements, whereas laboratory triplet shear testing is commonly associated with EN 1052-3. This distinction should be resolved in the experimental methods section of any journal submission so that the exact apparatus, boundary conditions, normal stress, and calculation procedure are reproducible. The current manuscript deliberately retains the reported data but flags the standard-method terminology for verification [29,32].

From a sustainability perspective, the data suggest that stabilized mud mortar deserves further investigation rather than being treated only as an inferior version of cement-sand mortar. Modern CSEB research increasingly explores reduced-cement systems, supplementary cementitious materials, recycled constituents, and improved mix optimization [20-23]. A logical next step would be to combine the present strength framework with cost, embodied-carbon, wet-dry durability, water absorption, and field-exposure measurements [26,27].

## 7. Practical and Research Implications

From an engineering standpoint, the dataset demonstrates that mortar selection should be considered alongside CSEB unit properties when assessing wall performance. The stabilized-mud condition is particularly relevant for future optimization because it markedly improved all

three measured strength indicators without requiring the same cement-sand proportion as the 1:3 system. However, implementation decisions should incorporate durability, workmanship, moisture exposure, local material availability, construction codes, and economic and environmental indicators. Future studies should test a broader range of stabilizer contents, include larger sample sizes, quantify mortar and unit material properties separately, and evaluate wet-dry durability and cyclic lateral loading.

### 8. Limitations

The study has several limitations that should be explicit in a journal article. Only three panels were tested per mortar condition, limiting statistical power and generalizability. The experimental program was performed under laboratory curing conditions and did not include wetting-drying, erosion, water absorption, freeze-thaw, thermal, acoustic, cyclic, or seismic testing. Soil characterization values and complete mix-design data (including exact particle-size distribution, Atterberg limits, moisture content, compaction pressure, cement content of the CSEB units, and mortar water-to-cement ratios) are not fully reported in the thesis text available for this manuscript. These omissions should be supplied from laboratory records before submission to a journal requiring full reproducibility. Finally, the precise direct-shear standard and test configuration should be verified against the original laboratory setup.

### Conclusion

Compressed stabilized earth bricks (CSEBs) offer a locally adaptable alternative to fired masonry, but wall-level performance depends strongly on the interaction between the earth units and mortar. This study experimentally evaluated the effect of four mortar systems-mud mortar, cement-stabilized mud mortar, cement-sand mortar 1:6, and cement-sand mortar 1:3-on the mechanical performance of CSEB masonry. The experimental program comprised three types of mechanical tests. Twelve masonry specimens

measuring 4 ft × 4 ft were prepared and tested for diagonal shear strength. Twelve smaller masonry specimens measuring 1.5 ft × 1.5 ft (18 in × 18 in) were prepared and tested for compressive strength. In addition, 12 direct shear (triplet) specimens were prepared for each mortar type to evaluate the shear/bond behavior at the masonry joint, following the testing standard adopted in the thesis. The reported mean compressive strengths were 1.85, 3.12, 4.45, and 5.68 MPa for mud, stabilized mud, 1:6, and 1:3 mortar, respectively. Mean diagonal shear strengths were 0.12, 0.24, 0.38, and 0.52 MPa, while mean direct shear strengths were 0.10, 0.22, 0.34, and 0.48 MPa, respectively. Reanalysis of the reported replicates per group showed statistically significant between-group differences for all three outcomes (one-way ANOVA,  $p < 0.001$ ). However, the relatively limited number of specimens used for some test categories requires cautious interpretation of the statistical findings. The results demonstrate a consistent increase in measured masonry strength with the transition from unstabilized mud mortar to stabilized mud and cement-sand mortars. The findings support mortar selection as an important design variable in CSEB masonry and indicate that stabilized mud mortar can provide a substantially stronger alternative to unstabilized mud mortar while retaining lower material intensity than conventional cement-rich mortar systems. Long-term durability, environmental life-cycle performance, seismic response, and field validation were outside the scope of the present study.

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