Behavior Of Low-Cost Cci Brick Prisms Subjected To Axial Cyclic Compression And Lateral Forces

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Abstract

This study focuses on CCI brick walls, which use minimal mortar and are designed to withstand axial and lateral forces. It investigates how CCI brick prisms respond to cyclic axial loading and explores their bond strength for withstanding lateral loads. The study accounts for regional soil variations in Thailand by using bricks from different areas. The results show consistent behavior in cyclic loading and an increasing load capacity until failure. Reinforced specimens with steel bars outperform those with grout only and the unaltered specimens. Combining cement-sand grout and steel bar reinforcement leads to significant improvements in compressive strength, particularly in smaller and larger height specimens. Non-shrink Cement Sand Grouts exhibit superior bond strength over Ordinary Portland Cement Sand Grouts, and CCI bricks from region 2, known for their higher compressive strength and larger grooves, demonstrate the highest bond strength. The findings emphasize the importance of groove depth in determining bond strength in CCI brick prisms.

Keywords: Cement-clay interlocking bricks, Compressive capacity, bond strength, grout, non-shrink

1. Introduction

In contemporary construction, masonry finds application in erecting load-bearing walls for low and medium-rise structures, as well as in cladding and partition wall installations [1]. Its utilization extends beyond residential projects to encompass diverse building types such as educational, industrial, and commercial facilities. Masonry wall construction offers numerous advantages, including its load-bearing capability, resilience to weather variations, fire resistance, and effective sound and thermal insulation [2]. Traditional fired clay bricks typically result from blending clays and shale as primary raw materials, followed by various shaping, drying, and high-temperature firing processes. These fired clay bricks serve as a primary building material in construction. However, they exhibit drawbacks, notably elevated energy expenditures and environmental concerns, including substantial energy consumption and the emission of carbon dioxide [3,4].

The increasing demand for construction has led to innovative solutions, including highly compressed cement-clay interlocking (CCI) hollow bricks, resembling LEGO blocks, as an alternative to traditional fired clay bricks. These CCI bricks use minimal mortar for assembly, are made by mixing various soil components, and offer advantages like higher density, lower water absorption, improved frost resistance, and increased compressive strength [5]. Walker's study [6] examined how soil characteristics and cement content impact the physical properties of stabilized soil blocks. The research concluded that adding cement content, rather than clay, enhances the strength and durability of these blocks, especially in saturated conditions. It was suggested that the most suitable soil-cement blocks should have a plasticity index between 5 and 15. Soil mixes with a plasticity index exceeding 20-25 were deemed less suitable for manual pressing due to the risk of shrinkage during drying, leading to reduced durability and lower compressive strength. In Thailand, cement-clay interlocking (CCI) hollow bricks are commonly produced using locally available clay materials. They are primarily used in the construction of low-rise residential buildings. It's worth noting that their production often occurs in small, localized factories across various regions of Thailand, without strict adherence to standardized procedures or guidelines [5]. Many rural brick manufacturing plant owners in Thailand typically source clay directly from their own land for brick production. The geological map of Thailand reveals a wide variety of sedimentary and metamorphic rock types, including mudstone, sandstone, and shale, providing diverse options for raw materials in the brick-making process [7]. CCI hollow brick manufacturing plants typically utilize diverse mix designs, drawing from locally available materials and the knowledge of local laborers. Some plants rely solely on cement and clay, while others incorporate materials like stone dust or sand. These mix variations directly influence the mechanical properties of CCI hollow bricks, including compressive strength, tensile strength, and water absorption. These properties are vital for engineering applications and the design of masonry structures.

As stated, CCI brick walls utilize minimal mortar between consecutive courses of bricks [5]. Such walls are supposed to withstand axial and lateral forces. The performance of the CCI brick prisms under axial and lateral loads has not been investigated before. Considering the high lateral and cyclic demands during earthquakes, CCI brick prisms must be tested to understand their behavior during these extreme events. Therefore, this study intends to investigate the response of CCI brick prisms against cyclic axial loading. In addition, this study explores the bond strength of the CCI brick prisms as it is supposed to keep the wall intact when subjected to lateral loadings. Furthermore, the variation in soil strata across the Thailand is considered by taking bricks from various regions in Thailand.

2. Experimental program

2.1. Details of specimens

In this study, brick prisms of two different heights were constructed, as shown in Figure 1. Three types of brick prisms were fabricated, namely un-grouted brick prisms, cement-sand grouted (un-reinforced) prisms, and reinforced prisms. A total of 12 specimens were tested under axial cyclic loading, as given in Table 1. Twelve specimens were categorized into six groups depending on the presence of grout and reinforcing bars. It is to be noted that only cement-sand grout was used to strengthen CCI brick prisms tested under axial cyclic loading. Whereas two types of grouts were used to strengthen prisms tested for bond strength, i.e., cement-sand and non-shrink cement sand grouts. A total of 18 specimens were tested for bond strength in six groups with each group containing three specimens. Two groups were used to represent bricks from each region with the difference in the type of grout used.

Table 1. Details of specimens tested under axial cyclic loading.

Specimen Type	Prism ID	Grout	Steel Bars	No. of Specimens
Axial Cyclic	2B-CS00-R0	None	None	2
	2B-CS12-R0	Cement-Sand	None	2
	2B-CS12-R2	Cement-Sand	2RB6	2
	3B-CS00-R0	None	None	2
	3B-CS12-R0	Cement-Sand	None	2
	3B-CS12-R2	Cement-Sand	2RB6	2
Bond Strength	R1-B-OPC	Cement-Sand	None	3
	R1-B-NSC	Non-Shrink Cement Sand	None	3
	R2-B-OPC	Cement-Sand	None	3
	R2-B-NSC	Non-Shrink Cement Sand	None	3
	R3-B-OPC	Cement-Sand	None	3
	R3-B-NSC	Non-Shrink Cement Sand	None	3

Table 2. Details of specimens tested for bond strength.

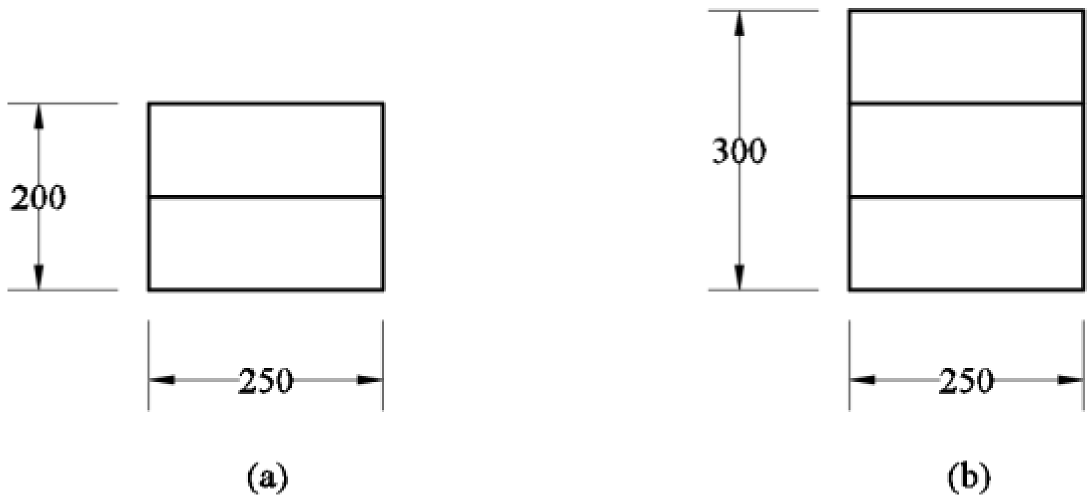


Figure 1. Specimen details (a) small height and (b) large height.

2.2. Material Properties

2.2.1. CCI Bricks

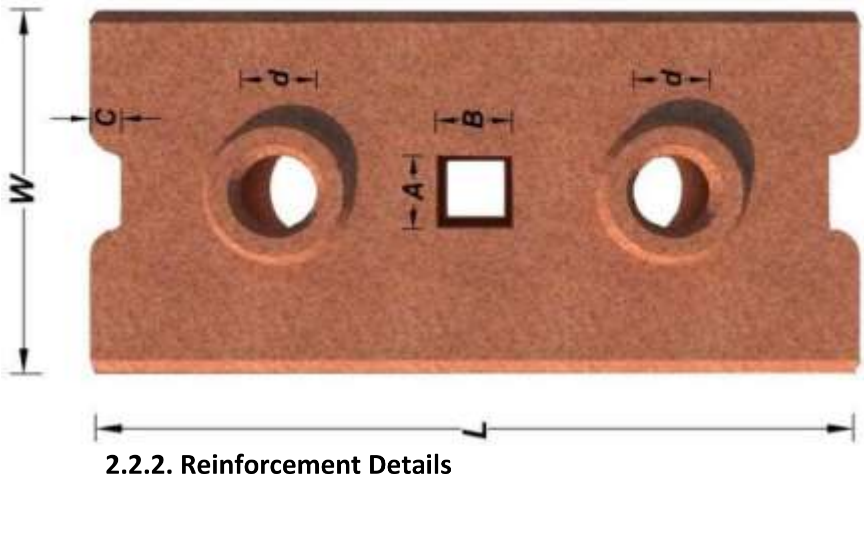
In this study, CCI bricks were sourced from various provinces or regions in Thailand, including Navanakorn province (Region 1), Saraburi province (Region 2), and ChachengSao province (Region 3). A typical CCI brick from each region is shown in Figure 2. The soil stratum of CCI bricks from Region 1 mainly comprised Siltstone, sandstone, claystone and congiomerate. Region 2 bricks mainly comprised Mudstone, limestone, sandstone, claystone and congiomerate, whereas Region 3 bricks comprised Semi-consolidated and consolidated rocks, Limestone, dolomitic limestone, chert and dolomite, Mudstone, siltstone, sandstone, and limestone. Geometrical details of CCI bricks are provided in Table 2. The production process of CCI bricks involves three main steps. First, large clay boulders are broken into smaller pieces using a mechanical grinding machine. Second, the finely ground clay is mixed with cement and water in a mechanical concrete mixer. Finally, the cement-clay mixture is placed into aluminum molds and pressed using either hydraulic or manual machines. The pressed bricks are then left at room temperature for a curing period of 7-10 days. The compressive strength of the CCI bricks was estimated at 6.26 MPa, 9.06 MPa, and 7.59 MPa for Region 1, Region 2, and Region 3, respectively, by following the ASTM C1314-23a standard protocols [8].

(a) (b) (c)

Figure 1. Typical CCI brick wall used in this study from (a) region 1, (b) region 2, and (3) region 3.

Table 2. Details of CCI bricks.

Region	L	W	H	d	A x B	C x D	Weight (kg)
1	250	125	100	35	20 x 20	10 x 20	4.95
2	200	100	100	20	30 x 25	10 x 25	3.02
3	250	125	100	30	25 x 25	10 x 25	5.01



2.2.2. Reinforcement Details

The compressive strength of grouts was estimated by testing standard cubes of 50 mm dimensions, as shown in Figure 3. The compressive strength of cement-sand and non-shrink cement sand grouts was estimated at 25 MPa and 50 MPa, respectively. In some specimens, round steel bars of 6 mm diameter were used in addition to the grouts. The yield and ultimate strength of steel bars were estimated at 340 MPa and 420 MPa, respectively.

Figure 3. Cubes ready for testing compressive strength of cement-sand grout.

2.3. Experimental Setup

A Universal Testing Machine with a capacity of 500 kN was used to apply axial cyclic load, as shown in Figure 4(a). In this case, the direction of the applied load was perpendicular to the direction of the courses. On the contrary, brick prisms were tested to fail in shear parallel to the direction of the courses, as shown in Figure 4(b).

(a) (b)

Figure 4. Typical test setup for (a) axial cyclic compression and (b) bond strength

3. Experimental Results

*3.1 **Failure Modes of Specimens***

Figure 5 displays the failure modes for both specimen configurations. It's evident that in both configurations, cracks developed parallel to the prism's plane. This type of failure is commonly observed in clay masonry, consistent with findings from other researchers. Notably, the specimens that were reinforced with grout and reinforcement, specifically 2B-CS12-R2 and 3B- CS12-R2, showed more extensive cracking compared to the unreinforced masonry specimens. It is important to note that only failure modes of small height specimens are shown as the failure of specimens with large height was identical. Figure 6 shows the failure of bond test. It is evident that these specimens failed by shearing off the face along the course direction.

2B-CS00-R0

2B-CS12-R0

2B-CS12-R2

Figure 5. Failure modes of specimens tested under axial cyclic loads.

Region 1

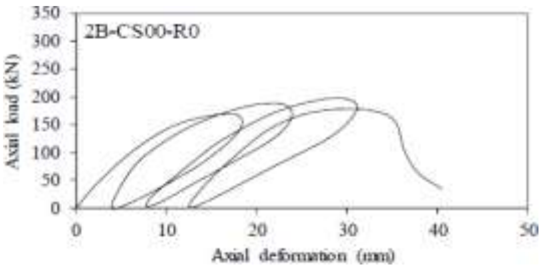
Region 2

Region 3

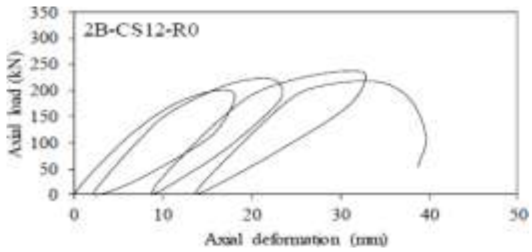
Figure 6. Failure modes of specimens tested for bond strength

3.2. Compressive Load vs. Deformation Curves

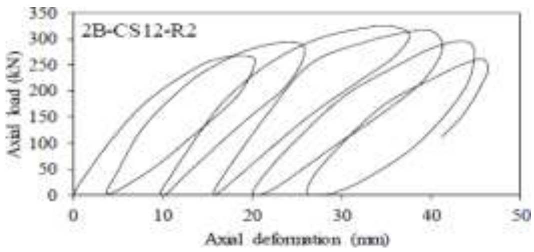
The compressive load vs. deformation graphs are shown in Figure 7. It is noteworthy that the slope of the cyclic load vs deflection curves did not change for loading and unloading. Furthermore, the capacity of each successive cyclic was higher than previous one until the failure was observed. Another important observation is that the highest capacity was observed for specimens strengthened with steel bars, followed by specimens strengthened with grout only, and bare specimens, respectively. Table 3 provides the summary of experimental results. As presented in Table 3, an improvement of up to 74% and 69% in compressive capacity was observed for small and large height specimens, respectively, corresponding to a combination of cement-sand grout and steel bar strengthening.



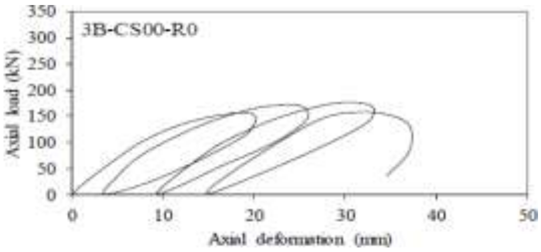
2B-CS00-R0



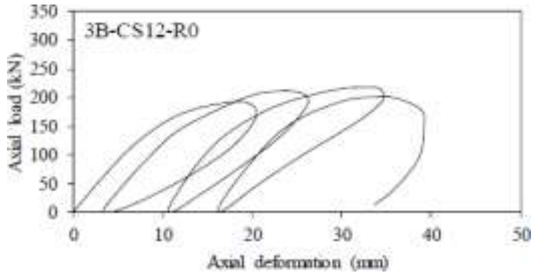
2B-CS12-R0

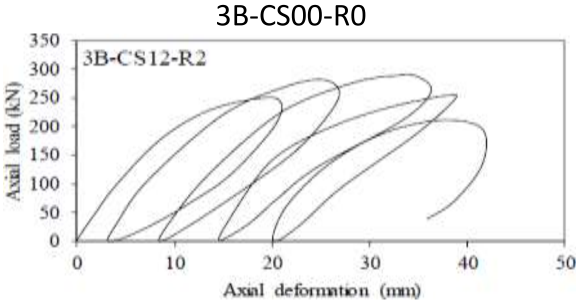


2B-CS12-R2



3B-CS00-R0





3B-CS12-R0 3B-CS12-R2

Figure 7. Compressive load vs. deflection graphs

Table 3. Summary of compressive strength and bond strength.

Prism ID	Peak Compressive Capacity (kN)	Improvement in Compressive Capacity (%)	Bond Strength (MPa)
2B-CS00-R0	181	-	-
2B-CS12-R0	222	22.6	-
2B-CS12-R2	315	74.1	-
3B-CS00-R0	171	-	-
3B-CS12-R0	205	19.9	-
3B-CS12-R2	289	69.0	-
R1-B-OPC	-	-	0.25
R1-B-NSC	-	-	0.32
R2-B-OPC	-	-	0.44
R2-B-NSC	-	-	0.56
R3-B-OPC	-	-	0.28
R3-B-NSC	-	-	0.36

3.3. Bond Strength

The experimental results clearly indicate that among the two types of grouts tested, namely Ordinary Portland Cement and Non-shrink Cement Sand Grouts, the bond strength is higher with Non-shrink Cement Sand Grouts compared to Ordinary Portland Cement Sand Grouts. Furthermore, the highest bond strength is observed in the case of CCI bricks from region 2 for both types of cement sand grouts. This can be attributed to the following factors: The CCI bricks from region 2 exhibit the highest compressive strength when compared to those from region 1 and 3. The grooves on the underside of the CCI bricks from region 2 are relatively larger than those in region 1 and 3 (as shown in the figure). This results in a greater amount of cement-sand grout in the groove, providing higher resistance to bond failure. These factors collectively contribute to the superior bond strength observed in CCI bricks from region 2, particularly when using Non-shrink Cement Sand Grouts.

4. Conclusions

The compressive load versus deformation graphs highlighted several key observations. Notably, the slope of the cyclic load versus deflection curves remained consistent during loading and unloading phases, with each successive cyclic load exhibiting higher capacity until failure. Specimens reinforced with steel bars exhibited the highest compressive capacity, followed by those strengthened with grout alone, and bare specimens. Significant improvements of up to 74% and 69% in compressive capacity for small and large height specimens were observed, respectively, when combining cement-sand grout and steel bar strengthening. Results reveal that Non-shrink Cement Sand Grouts outperform Ordinary Portland Cement Sand Grouts in terms of bond strength, and CCI bricks from region 2, with their superior compressive strength and larger grooves, display the highest bond strength for both types of cement-sand grouts. These findings suggest that the depth of groove plays an important role in determining the bond strength of CCI brick prisms.

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