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PERFORMANCE OF INTERLOCKING COMPRESSED EARTH BLOCK INFILL IN CONFINED MASONRY CONSTRUCTION

I.G. Castro[1] , P.T. Laursen[2], D.C. Jansen[3], B. Qu[3]

ABSTRACT

This paper presents preliminary results from an experimental program investigating the behavior of confined interlocking compressed earth block (CEB) walls subjected to lateral in-plane cyclic loading. Two (2) walls were constructed and tested. Design of the walls was based on the current design practice in Indonesia. The first wall was built with CEBs from a hand-operated block press and the second wall with CEBs from a hydraulic block press. Results pertaining to strength and drift capacity is be presented and compared to results from an experimental program conducted on (non-confined) reinforced CEB walls. Interlocking compressed earth blocks investigated herein are cement stabilized and commonly used in dry stack masonry construction in developing countries, e.g. Thailand and Indonesia, due to its low cost and simplicity. Current application in these regions consists of a mildly reinforced concrete frame cast around the mildly reinforced CEB infill. The current design practice for this construction form in countries with severe natural hazards (typhoons and earthquakes) is highly questionable in terms of structural integrity. This is accentuated by a complete lack of experimental load testing. However, scientific evidence to improve the current design practice could make this a safer and more reliable construction form. The experiments showed that confined CEB walls were ductile and provided significant lateral strength, despite the low block strength. It was also found that block geometry significantly affected the behavior. Comparison with results from testing of a bare CEB panel showed a 20% increase in lateral strength and a 100% increase of drift capacity as a result of the confining frame.

[1]Nishkian Chamberlain, 3710 S. Robertson Blvd, Suite 220, Culver City, CA 90232
[2]Associate Professor, Dept. of Architectural Engineering, California Polytechnic State University, San Luis Obispo, CA 93407, USA, email: plaursen@calpoly.edu
[3]Professor, Dept. of Civil and Environmental Engineering, California Polytechnic State University, San Luis Obispo, CA 93407, USA.

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This paper presents preliminary results from an experimental program investigating the behavior of confined interlocking compressed earth block (CEB) walls subjected to lateral in-plane cyclic loading. Two (2) walls were constructed and tested. Design of the walls was based on the current design practice in Indonesia. The first wall was built with CEBs from a hand-operated block press and the second wall with CEBs from a hydraulic block press. Results pertaining to strength and drift capacity is be presented and compared to results from an experimental program conducted on (non-confined) reinforced CEB walls. Interlocking compressed earth blocks investigated herein are cement stabilized and commonly used in dry stack masonry construction in developing countries, e.g. Thailand and Indonesia, due to its low cost and simplicity. Current application in these regions consists of a mildly reinforced concrete frame cast around the mildly reinforced CEB infill. The current design practice for this construction form in countries with severe natural hazards (typhoons and earthquakes) is highly questionable in terms of structural integrity. This is accentuated by a complete lack of experimental load testing. However, scientific evidence to improve the current design practice could make this a safer and more reliable construction form. The experiments showed that confined CEB walls were ductile and provided significant lateral strength, despite the low block strength. It was also found that block geometry significantly affected the behavior. Comparison with results from testing of a bare CEB panel showed a 20% increase in lateral strength and a 100% increase of drift capacity as a result of the confining frame.

Introduction

A pilot study on the use of cement stabilized interlocking hollow compressed earth blocks as masonry infill in reinforced concrete (RC) confining frames is presented in this paper. Stabilized compressed earth block (CEB) structures are popular in developing parts of the world because of the low cost, sustainable use of indigenous materials, and its inherent simplicity. In Thailand and Indonesia, the structural system for single-story school house buildings often consists of lightly reinforced concrete framing with CEB masonry infill. The masonry infill provides inexpensive enclosure of the classrooms and is also expected to assist in carrying gravity forces.

The current design practice for RC confined CEB walls in developing countries with severe natural hazards (typhoons and earthquakes) is questionable in terms of structural integrity.

[1]Engineer, Nishkian Chamberlain, 3710 S. Robertson Blvd, Suite 220, Culver City, CA 90232
[2]Associate Professor, Dept. of Architectural Engineering, California Polytechnic State University, San Luis Obispo, CA 93407, USA, email: plaursen@calpoly.edu
[3]Professor, Dept. of Civil and Environmental Engineering, California Polytechnic State University, San Luis Obispo, CA 93407, USA.

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In general, the vulnerability of confined masonry due to severe lateral loading is of concern (EERI 2000[1]). To determine the lateral load capacity and ductility of confined CEB, major aspects must be addressed. One aspect that needs further investigation is if the current reinforcing detailing assures appropriate continuity between the RC frame and the CEB panel. The other main aspect is that the presence of the CEB panel is expected to increase the strength and stiffness of the structure.

Significant research has been done on RC frames with clay brick or concrete brick infill, most recently Mehrabi et al. [2], Henderson et. al. [3], Corte et al. [4] and Shing et al. [5]. Much of this research contributed to the 'Seismic Design Guide for Low-Rise Confined Masonry Buildings', developed by the Confined Masonry Network [6]. Unfortunately, this research does not adequately cover the use of CEB as masonry infill, notably because the CEB infill is dry-stacked, and because of different geometry and reinforcing detailing. Furthermore, the concrete to masonry strength ratio applicable to CEB is much larger than those of clay brick and concrete blocks.

However, scientific evidence to improve the current design practice could make this a safer and more reliable construction form. Recent research on (non-confined) reinforced CEB walls by Bland et al. [7],[8] and Laursen et al. [9] demonstrated that a properly designed CEB wall structure is a viable construction form but that the design formulae in the current masonry codes, e.g. for shear strength, are un-conservative when applied to ICEB walls.

The objective is to examine the current construction practice, in particular the interaction between the RC frame and the ICEB infill panel. Two walls were be tested, one with CEBs made with a hand operated press and one with CEBs made with a hydraulic press. The geometry and reinforcement remained the same.

Prototype Walls

The first type of CEB used in this research was the 'Rhino' block developed by the Center for Vocational Building Technology in Thailand (CVBT) [10]. This block was chosen to maintain consistency between this research and previous work on CEBs. The Rhino block, shown in Fig. 1(a) is a 100 mm (4 in.) tall by 150 mm (6 in.) by 300 mm (12 in.) interlocking compressed earth block manufactured with the hand-operated Soeng Thai BP6 press shown in Fig. 1(b). Two interlocking keys protrude from the face of the block and fit into two depressions of the same size on the bottom of the block. These interlocking keys provide a mechanism for shear transfer between the blocks and guide during the construction process. All holes and groves are grouted. The second type of block was the 'V Lock' block shown in Fig. 2(a) and manufactured with the Vermeer BP714 hydraulic block press shown in Fig. 2(b) This press is manufactured by Dwell Earth [11] and produces 100 mm (4") tall by 175 mm (7 in.) by 350 mm (14 in.) blocks with two 100 mm (4 in.) cavities that can be reinforced and grouted.

Figure 1: (a) Rhino block (b) Soeng Thai BP6 Block Press

Figure 2: (a) V Lock Block (b) Vermeer BP714 Hydraulic Block Press

Prototype Wall 1 is shown in Fig. 3. The masonry panel made of Rhino blocks was constructed first. Then the confining frame was cast directly against the panel. The overall dimensions of the panel were 2.10 m wide, 1.95 m tall and 150 mm thick and corresponded to approximately 4/5 scale of a full size wall. The masonry was reinforced with Grade 40 (276 MPa) D10 (#3) deformed bars in the longitudinal and transverse directions. The layout of the reinforcement was typical of what is used in Indonesia and Thailand, with the longitudinal reinforcement every 600 mm and horizontal reinforcement every 4^{th} masonry course. The confining frame consisted of 150 mm x 150 mm columns and beam, each reinforced axially with four (4) Grade 40 D10 bars and transversely with Grade 60 (414 MPa) 6 mm pencil rod stirrups spaced at approximately 200 mm. Reinforcement layouts for both the frame and the infill are shown in Figs. 3 and 4. Prototype Wall 2 was constructed to similar overall dimensions (2.10 m wide, 2.00 m tall and 175 mm thick), however the CEB panel was 1.75 m by 1.8 m and the RC elements were slightly larger (175 mm by 175 mm) due to the wider V Lock block. The blocks for both walls were dry-stacked and fully grouted. The walls were constructed atop a RC foundation clamped to the strong-floor. Fig. 5 shows Wall 1 during construction and Fig. 6 shows the walls ready for testing.

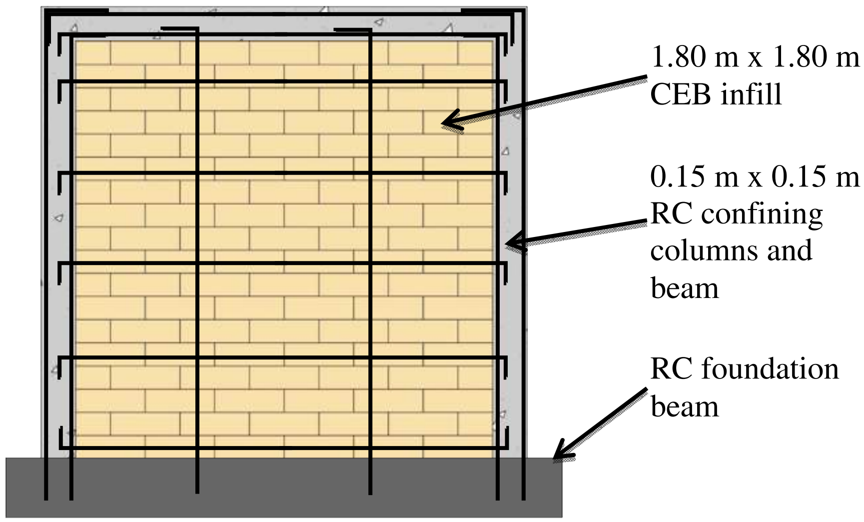


Figure 3: Wall 1, Elevation

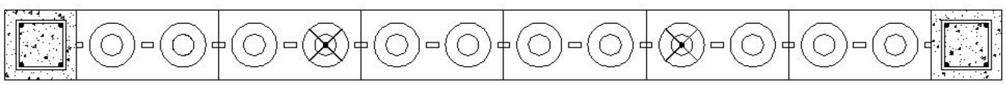


Figure 4: Wall 1, Cross section

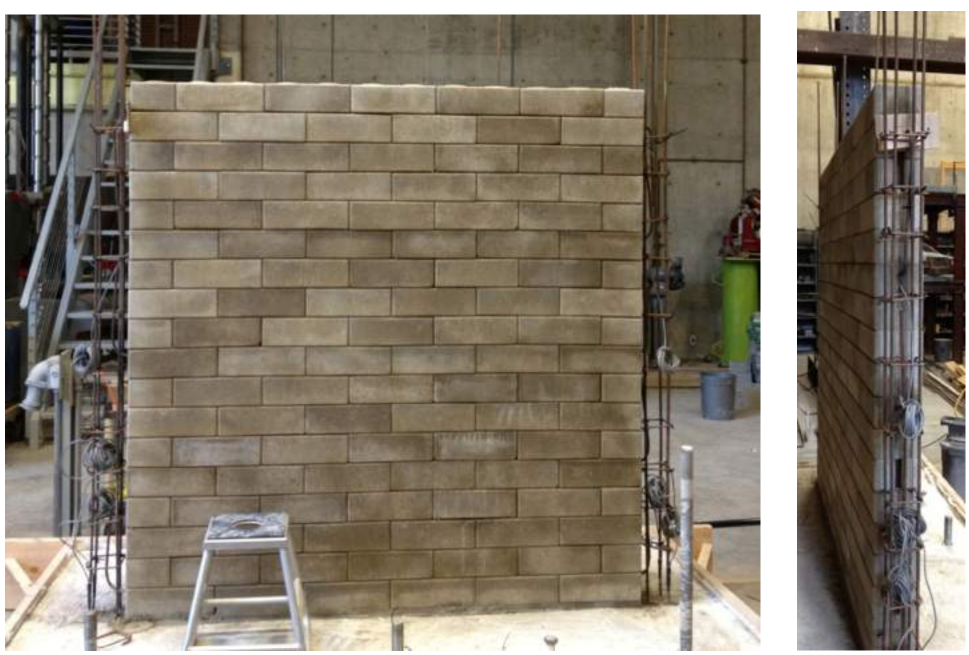


Figure 5: Wall 1 Construction

Figure 6: (a) Wall 1 Ready for testing (b) Wall 2 Ready for Testing

Material Properties

All blocks used this research were manufactured using local soil comprised of approximately 22% clay (particles finer than 0.002 mm). The soil was air dried and broken down using a soil pulverizer. Once pulverized, 10% sand and 6.7% cement by weight were dry mixed into the soil using a cement mixer. Approximately 10% water was added to the homogenous mixture to achieve the desired consistency for block pressing. After pressing, the blocks were subjected to 7 days of humid curing before they were used in the wall construction. The block strengths are shown in Table 1. The concrete strengths were 16 MPa for Wall 1 and 40 MPa for Wall 2, and the D10 (#3) bar strength was 368 MPa.

Table 1: Block Strength

Rhino (MPa)	V Lock (MPa)	Comment
2.7 / 3.1	3.2 / 4.2	gross area/net area

CEB Structural Behavior

Both Walls were designed such that the anticipated lateral load required to cause flexural failure (overturning) of the confined CEB wall would be significantly higher than the expected shear strength of the CEB panel alone. It was therefore expected that the CEB panel would fail in shear (typical X-pattern). In order to promote a ductile failure/gradual strength degradation of the wall, it was desired that the confining column shear strength be higher than the force required to fail the CEB panel [6]. The best available estimate of the Wall 1 CEB panel shear strength was obtained from testing of a CEB wall with identical blocks, dimensions and reinforcement [8] It was found that the panel (without a confining frame and shear reinforcement) failed in shear at a lateral force of 43.0 kN. The shear corresponding to the predicted wall flexural overturning capacity was in excess of 80 kN and the predicted RC column shear strength (two columns) was about 50 kN. Given the conservative estimate of the column shear strength, it was expected that Wall 1 ultimately would fail due to extensive diagonal cracking in the CEB panel in a gradual fashion. The reinforcing detailing of the RC confining frame for Wall 2 was identical to that of Wall 1. Although no previous structural testing had been done on the V Block, it was expected that Wall 2 CEB panel strength would be higher than that of Wall 1 because of the stronger blocks. CEB failure was also expected in this case.

Testing

Cyclic in-plane loading was applied to the top of the walls with a 220 kN actuator is mounted to a steel reaction frame as seen in Figs. 6(a) and 6(b). The loading protocol consisted of a sequence of pseudo-static displacement controlled cycles. Each target displacement sequence consisted of two pull/push cycles to the specified displacement.

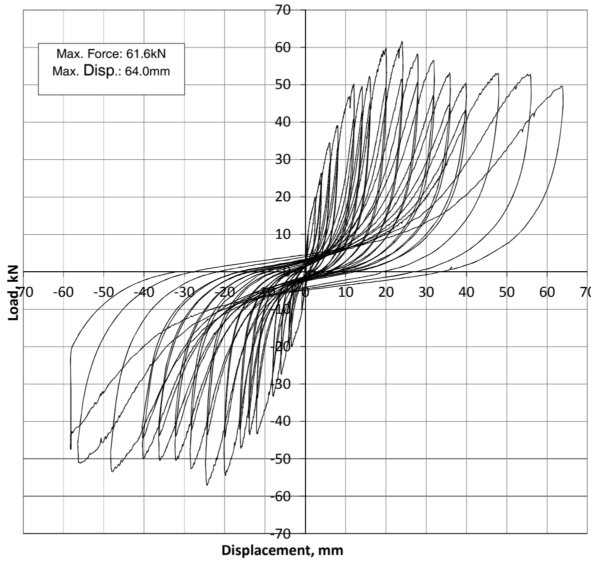
Test of Wall 1

The hysteresis curve for Wall 1 is shown in Fig. 7(a). The panel exhibited sliding in the horizontal joints and cracking along the diagonal. Some flexural cracking in the RC occurred in the columns and the beam-column joints. Sliding in the horizontal joints was first observed in the 20 kN cycle. In the initial 28 mm cycle blocks began sliding far enough relative to each other that daylight could be seen in the gaps between the blocks. Block faces started to protrude out of the plane of the wall, indicative of the blocks failing in compression. The beam-column joints saw significant cracking in both pull and push cycles throughout the test as did the blocks in the center of the panel. At 36 mm the top half of the panel seemed to be sliding past the bottom half rather than the panel moving together and resisting the lateral load through the diagonal, as in previous cycles. At 40 mm displacement block debris started to fall out of the panel. Despite this, at 48 mm the strength picked up, likely due to the fact that the blocks slid further than in previous cycles and were able to engage adjacent blocks once again. At 56 mm, the concrete columns were showing wide flexural cracks at their bases and the entire assembly appeared to be “racking” over. Failure occurred at 64 mm displacement when the entire middle course fell out of the wall. The Wall 1 force-displacement response can be characterized as ductile with a drift capacity of more than 3.1% (ratio of lateral displacement of the loading beam to the height of the loading above the base). Gradual strength degradation was observed. Block debris first fell out of the wall at a drift of 2%. Fig. 8 shows Wall 1 at failure.

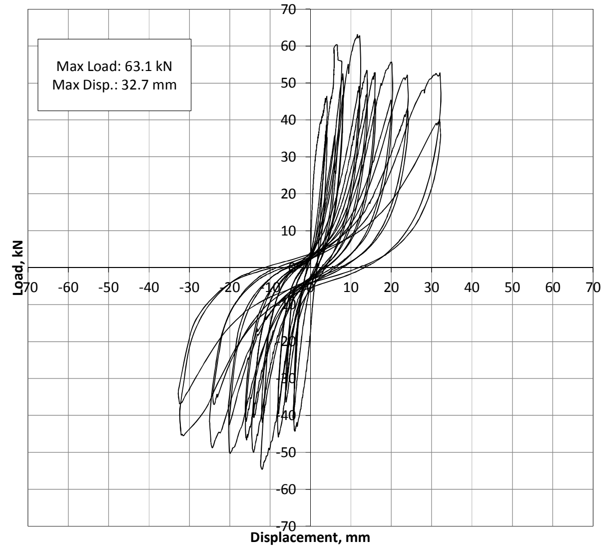
Test of Wall 2

This wall was subjected to the same loading protocol as Wall 1. Fig. 7(b) shows the hysteresis curve. This wall behaved in a similar fashion as Wall 1, but was clearly less ductile than the first wall. Cracking started at the very first cycle of 4 mm at the beam-column joint and the blocks adjacent to the joint. By 8 mm displacement the panel was significantly cracked, with the block in the center of the panel exhibiting multiple cracks along its face. The beam-column joints in this frame showed much more cracking than in the first test. Blocks started to protrude out of plane at 20 mm displacement and by 24 mm could be freely removed by hand. Failure occurred in the same way as the first test, with courses falling out of plane all at once. The Wall 2 force-displacement response can be characterized as ductile with a drift capacity of more than 1.6%. Gradual strength degradation was observed. Block debris first fell out of the wall at a drift of

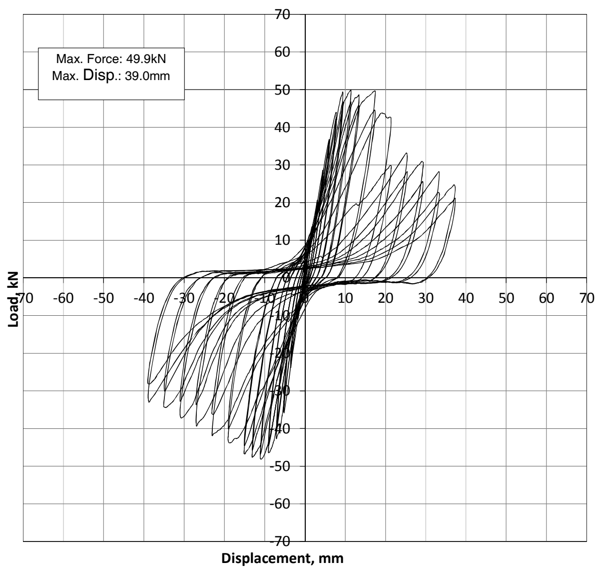
1.3%. Fig. 9 shows the block crack formation in Wall 2.



(a) Wall 1 (Rhino)



(b) Wall 2 (V Lock)



(c) Wall 3, Bare panel (Rhino) [8]

Figure 7: Experimental hysteresis curves

Figure 8: Wall 1, Damage at Failure

Figure 9: Wall 2, Typical block crack pattern

Conclusions

Both confined wall showed ductile response to in-plane loading. Wall 1 and Wall 2 achieved drifts of 2.0% and 1.3% before block debris fell off the panel, respectively. Wall 1 and Wall 2 achieved drifts of 3.1% and 1.6% before significant strength degradation. The walls achieved similar strengths of about 62 kN.

Both walls failed in a combination of cracking along the diagonal and sliding in the bed joints.

Clearly, the block geometry significantly affected the behavior. The V Lock block appeared to be less suitable as masonry infill with the soil composition used in this research. It is however believed that the hydraulically pressed V Lock block would be superior to the Rhino block with a more suitable soil-cement composition.

Fig. 7(c) shows the hysteresis curve recorded in an experiment with a (non-confined) CEB panel (called Wall 3) of identical dimensions and reinforcing as Wall 1 (Bland [8]). It is noted that the Rhino blocks for Wall 3 were at least twice as strong as those used for Wall 1. Comparing Figs. 7(a) and 7(c), it is concluded that the RC confining frame increased the total strength with about 20% relative to the bare wall. Also, the drift capacity was about doubled.

The RC frames were relatively unharmed after testing.

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