Cyclic Testing of
Hollow Inter-locking Block Masonry

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Abstract

This paper describes Reinforced Hollow Inter- Locking (HIL) Block Masonry which offers several advantages like cheaper and faster construction, efficient interlocking in different directions to withstand shear and bearing forces, self alignment to ensure accurate and simple construction practice and to construct both load bearing and non-load bearing wall structure. The developed system is an alternative to traditional bonded masonry system as the blocks are stacked on one another and virtually rules out use of mortar for binding/seating and the interlocking protrusions provided in the blocks make the wall an integral unit. The walls can be reinforced with vertical and horizontal reinforcement bands as in any hollow block masonry. Presented in this paper are results of tests conducted on reinforced HIL block masonry under constant axial load and cyclic lateral loading. The effects of reinforcement bands on the lateral resistance and ductility of the walls is studied. The experimental results are compared with the calculated capacity of the wall. As a result of the study, it is concluded that this type of masonry has adequate robustness and ductility and so can be used in moderately seismic areas.

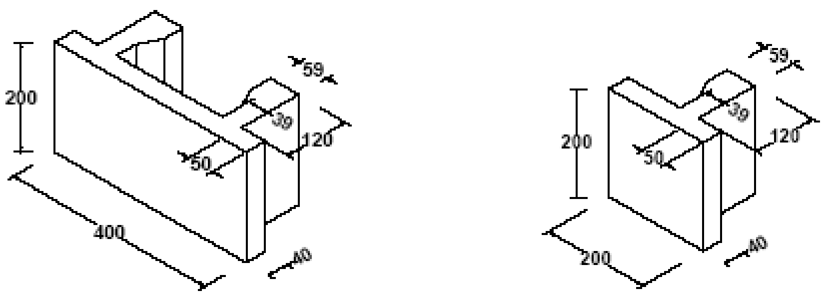
Keywords: Interlocking block masonry, cyclic tests, robustness, ductility, seismic design

1. Introduction

Reinforced masonry is a complex system consisting of several component such as masonry units, bonding agent (mortar) and reinforcing bands. The properties of each component, as well as their proportion and disposition, affect the performance of the system as a whole. Current analysis procedures and codal provisions give some guidelines to estimate the capacity of walls to resist lateral loads but since they rely heavily on empirical information, they are unable to predict the behaviour of walls with innovative masonry units. These innovative methods like surface-bonded and interlocking block masonry were evolved aiming at an acceleration of the masonry construction process.

In this paper, the cyclic behaviour of reinforced hollow interlocking block masonry is studied by carrying out tests. Reinforced Hollow Inter-Locking (HIL) Block Masonry which offers several advantages like cheaper and faster construction, efficient interlocking in different directions to withstand shear and bearing forces, self alignment to ensure accurate and simple construction practice and to construct both load bearing and non-load bearing wall structure. The developed system is an alternative to traditional bonded masonry system as the blocks are stacked on one another and virtually rules out use of mortar for binding/seating and the interlocking protrusions provided in the blocks make the wall an integral unit. The walls can be reinforced with vertical and horizontal reinforcement bands as in any hollow block masonry. Presented in this paper are results of tests conducted on reinforced HIL block masonry under constant axial load and cyclic lateral loading. The effects of reinforcement on lateral resistance and ductility of walls is studied. The experimental results are verified with the calculated capacity of the wall. As a result of the study, it is concluded that this type of masonry can be used in moderately seismic areas and guidelines are proposed to design the walls for different seismic loads.

The hollow interlocking block systems developed by Anand and Ramamurthy (2000, 2003) was adopted in this study, and a typical stretcher and jamb unit are shown in Fig. 1. Wall thickness was 200 mm. The dry-stacked masonry can be constructed by simple stacking of the blocks and pointing of joints at the outer face.



Stretcher unit

Jamb unit

Fig. 1 Hollow Interlocking Masonry Units (dimensions in mm)

2. Previous cyclic tests on reinforced masonry

Several researchers have tested a variety of masonry systems under cyclic loading. However, only two relevant papers are reviewed here; the first for its emphasis on the robustness of the unit and the second as a study of an innovative reinforced masonry system.

Tomaževič *et al* (2006) studied the effect of robustness of hollow clay masonry units on the seismic behaviour of the walls. They tested cantilever walls under combined axial load and cyclic bending and found that the walls failed by local crushing at the central part thereby giving significantly less resistance than that obtained by standard calculation procedures emphasizing the fact that robustness of the units is an important parameter.

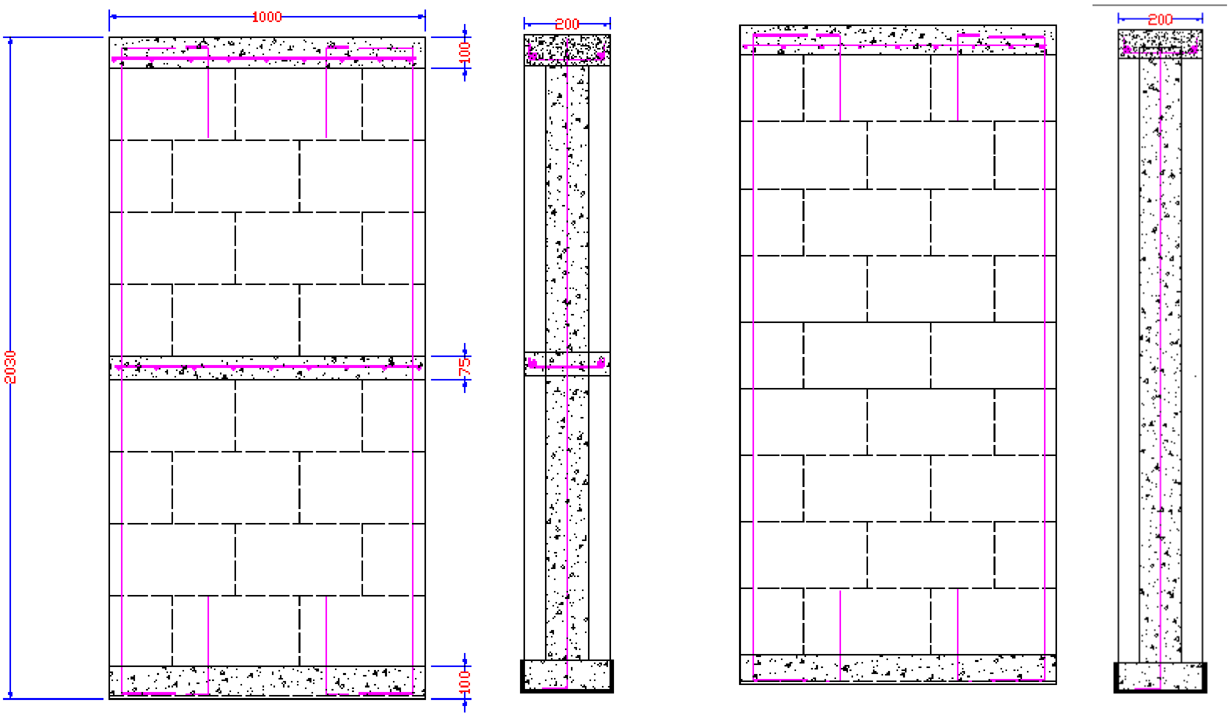
Recently da Porto *et al* (2011) studied an innovative system for reinforced clay masonry walls having a combination of horizontally and vertically perforated units under combined axial load and cyclic bending. They evaluated the behaviour of the walls using several parameters such as crack patterns, loads, displacements and rotation angles at significant limit states, ductility ratios, energy dissipation capacity, coefficient of viscous damping, and stiffness degradation. The effects of vertical and horizontal reinforcement, axial compression load, wall aspect ratio, and type of reinforcement on masonry in-plane behaviour were also investigated. One of their conclusions was that axial compression load enhanced the shear capacity of walls, at the expense of displacement capacity. However, the axial load did not affect significantly the ratio of dissipated/input energy, viscous damping coefficient or stiffness degradation.

3. Reversed Cyclic Tests

Preliminary tests were conducted on the HIL blocks to calculate compression capacity, sliding frictional resistance and shear capacity of the blocks. In the Direct compression test, the HIL block was subjected to direct compression as applied vertical load using Hydraulic jack. Based on these tests, the compressive stress of the blocks was determined to be 19 MPa. In the sliding friction test, three HIL blocks were stacked one over the other and the middle block was pushed to determine the coefficient of friction. The experiment was carried out on three varying vertical loads of 490, 736 and 981 N, to determine the average value of coefficient of friction. The average value obtained for the coefficient of friction was 0.62. In the Shear capacity test, the HIL block masonry was subjected to direct shearing load and the corresponding shear stress at failure was found to be 3.65 MPa.

3.1 Test Specimen

Two identical walls of one metre width and 2.03 metre height were cast, with one wall having a middle horizontal band and the other without it. Both specimens had a bottom beam to anchor the vertical reinforcement and a top beam to spread the axial and lateral load over the width of the wall. The specimens are as illustrated in the Fig. 3(a) and (b) respectively. Both walls had vertical reinforcing bands spaced 600 mm centre-to-centre. The moulds used for casting the blocks were old and so the blocks had some seating problem. To facilitate proper seating, cement mortar which consisted of 2 mm sand and cement in the proportion of 1:4 was used. A single steel bar of 12 mm diameter and grade Fe 415 was used in the vertical reinforcement bands and grouted with concrete of grade M25. The lateral band on top and middle were reinforced with 4 nos. of 12mm diameter bars with 8 nos. of 6 mm diameter shear reinforcements. The walls were constructed on a steel channel for easy handling. Shear keys were provided in HIL block masonry suitably welded with channel which is fixed on to the strong floor using bolt arrangement. A photo of the first course is shown in Fig. 4 where the interlocking of the blocks can also be observed.



(a) (b)

Fig. 3 (a) Specimen 1 with middle band and (b) Specimen 2 without middle band

3.2 Test Setup and Loading Procedure

The specimen is fixed at the bottom and free at the top. The setup is arranged to apply a constant vertical load along with a cyclic lateral load at the top (see Fig. 5). The axial load of 400 kN is applied by means of two hydraulic jacks of 250 kN capacity each, mounted under a sliding bearing while the cyclic horizontal load was applied with the help of an actuator of capacity 250 kN and stroke of 125 mm on either side of the middle position. The tests were carried out quasi-statically by applying cycles of incremental displacement amplitudes and with two cycles at each increment. The actuator force and displacement were recorded from the internal transducers of the actuator.

Fig. 4 Photo of wall construction showing interlocking of the blocks

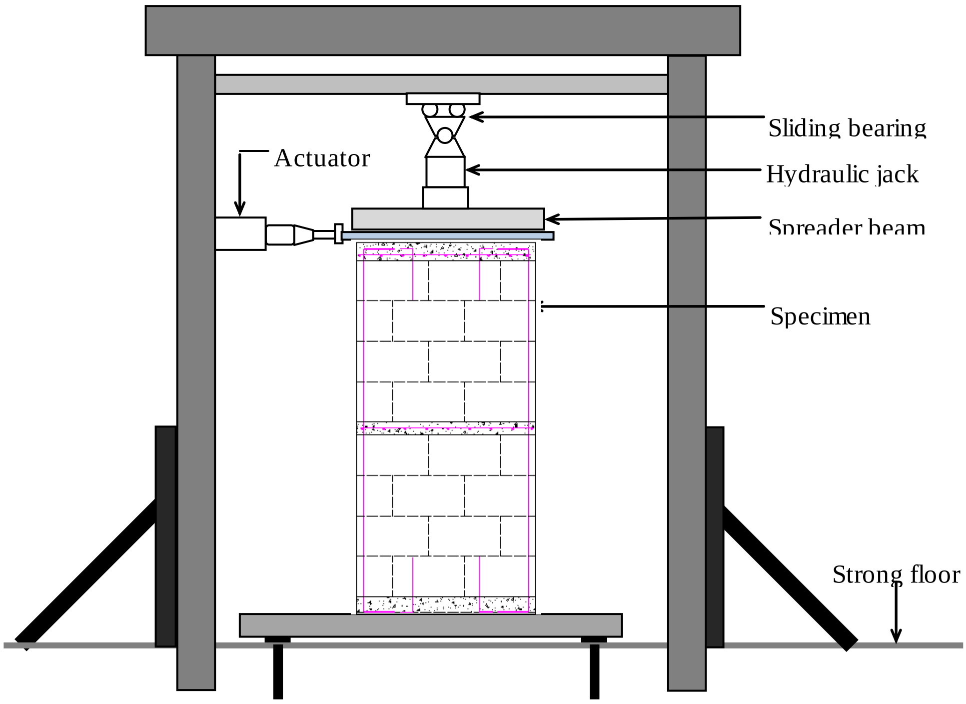


Fig 5 Schematic Diagram of Test Setup

4. Test Results

In the first test, initially a 5 mm cycle was applied followed by two 8 mm cycles. Thereafter, the cycle amplitude was stepped up by 4 mm with two cycles applied at each amplitude. The lateral load-displacement hysteretic curve is shown in Fig. 6 (a).

Initial response to loading in the linear range exhibited very little outward evidence of damage. The first instance of damage was the formation of vertical cracks in the top and middle section of the wall at 5 mm displacement. The length of the cracks varied from half the length of stretcher unit to full height of one masonry block. The cracks were located at the interface between the grouted vertical cell and the adjacent un-grouted masonry. The cracks are the outcome of tensile stress concentration at the discontinuity. The stresses were generated by the horizontal loads applied to the top of the HIL block masonry. A maximum load of 71.5 kN was taken by the HIL block masonry wall at a lateral displacement of 7.5 mm and this capacity was maintained until 11.5 mm. Both strength and stiffness degradation can be observed in the hysteretic behaviour. Soon after the attainment of the maximum load it was observed that significant resistance deterioration took place due to bulging of HIL block masonry units at the central part of the wall (see Fig. 7(a)), similar to the wall tested by Tomaževič *et al* (2006). Eventually, the wall collapsed due to breaking of interlocks.

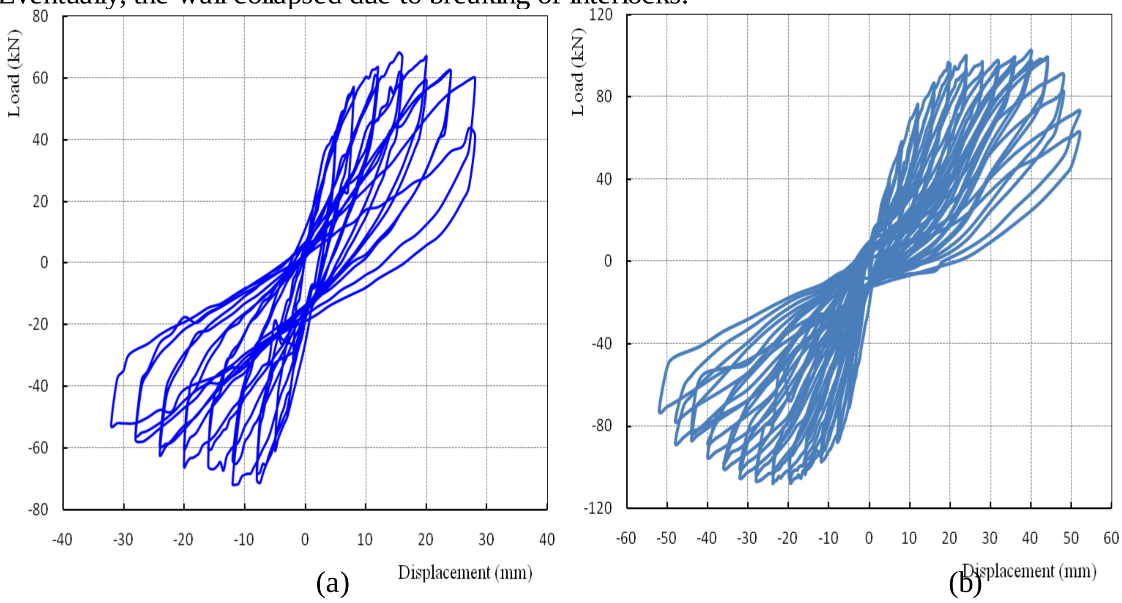


Fig. 6 Load-deformation hysteretic curves for (a) Specimen 1 and (b) Specimen 2

Specimen 2 was tested by following the same procedure as for specimen 1. Specimen 2 had a horizontal reinforcing band in the middle. Initial cracks were observed on the stretcher unit just below the top beam at a displacement of 16 mm and interestingly no signs of damage occurred in the wall below the lateral band. The maximum load taken by the wall is 107.7 kN at a corresponding lateral displacement of 19.4 mm and this capacity was maintained until 24 mm. After this the strength dropped due to crushing at the bottom corner of the wall (Fig. 7(b)).

(a) (b)

Fig. 7 Photo showing damage to (a) Specimen 1 and (b) Specimen 2

Due to the presence of lateral band in the middle, specimen2 exhibited better ductility and improved seismic performance. The crack propagation was limited to upper part of the wall above the middle band.

5. Theoretical Calculation of Ultimate Horizontal Resistance

Since no equations are given in Eurocode 6 for calculating the strength of reinforced masonry walls, the approach proposed by Tomaževič *et al* (2006) is used. Accordingly, the resistance to lateral load can be calculated by first calculating the vertical stress induced due to axial load and then calculating the flexural moment of resistance by the following equation:

$$M_u = \frac{\sigma_o t l^2}{2}\left(1 - \sigma_o / f_{cm}\right) + (l - 2l_o) A_{rv} f_y \qquad (1)$$

Where, M_u is the flexural capacity of wall; σ_o is the vertical stress induced; f_{cm} is the compressive strength of masonry; t is the thickness of the wall; l is the length of the wall; l_o is the distance of the vertical reinforcing bar from the edge of the wall and A_{rv} is the area of reinforcement on each side.

Using the values of σ_o = 400 kN/ (1000x200) = 2 MPa; f_{cm} = 19 MPa; t = 200 mm; l = 1000 mm; l_o= 200 mm and A_{rv} = 113.1 mm^2; Mu can be calculated to be 207.1 kN-m. The corresponding horizontal resistance is obtained by dividing this flexural capacity by the height of the wall h = 2.03 m and works out to be 102 kN.

Since there is no provision to include the effect of the horizontal reinforcement band in the above calculations, the calculated horizontal resistance of both the tested walls will be the same. Thus, the strength of the first specimen, which failed at an ultimate horizontal load of 71.5 kN is over estimated while the calculation is accurate enough in predicting the strength of the second wall. The reason for this is clear as the first wall failed by diagonal compression failure while the second failed by pure flexural failure. It is also well known that the former is less ductile than the latter (da Porto *et al*, 2011).

6. Summary and Conclusions

Experiments were carried out to obtain the cyclic response of HIL Block masonry. The experimental program, the test set up and also the measurements taken during the experiments were described. The program consisted of testing two specimens under same axial loads condition having approximately same aspect ratios and increasing cyclic horizontal displacements. Specimen1 was constructed without a horizontal band and specimen2 had a horizontal reinforcement band at mid-height.

The results of the experiments were presented in the form of load-displacement hysteretic curves and photos showing the type of damage sustained. It was observed that the second specimen performed much better than the first in terms of both ultimate horizontal load as well as deformation capacity. This shows that providing a horizontal reinforcement band can compensate for the lack of robustness of the masonry unit. Theoretical flexural capacity was worked out and was found to compare well with the results obtained for the second specimen but grossly over predicted the capacity of the first specimen. Further tests will be required to develop guidelines for strength and ductility estimation.

References

Anand K. B., Vinod V, Ramamurthy K (2003), Water permeability assessment of alternative masonry systems, Building and Environment, 38, Pergamon, 947-957.

Anand K. B and Ramamurthy K (2000), Development and performance evaluation of Interlocking-Block Masonry, Journal of Architectural Engineering, Vol. 6, No. 2, 45-51.

Tomaževič M, Lutman M, Bosiljkov V, (2006) Robustness of hollow clay masonry units and seismic behaviour of masonry walls, Construction and Building Materials, Vol. 20, Issue 10, 1028-1039.

da Porto F, Mosele F and Modena C (2011) In-plane cyclic behaviour of a new reinforced masonry system: Experimental results, Engineering Structures, In Press, Corrected Proof, Available online 12 June 2011.