CHAPTER 7

DEVELOPMENT OF DRY-STACK WALL SYSTEM FOR SEISMIC CONSTRUCTION USING HYDRAFORM INTERLOCKING BLOCKS

7.1 Introduction

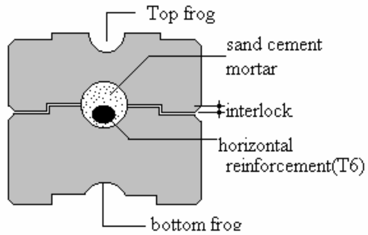
A study was conducted to develop a dry-stack masonry system with improved resistance to lateral loading, using compressed interlocking soil-cement blocks. Interlocking blocks suitable in seismic condition were developed. The idea was to develop interlocking blocks that can accommodate reinforcements and allow dry stacking at the same time. In the development of the blocks, interlocking features and cavities to accommodate reinforcement were introduced, taking into consideration the low strength of soil-cement blocks. The blocks were designed to allow horizontal and vertical reinforcements including grouting. Two types of blocks were developed, including corner blocks. In this chapter the developed blocks will be referred to as "seismic" blocks.

The new seismic blocks were further used in the development of two types of seismic dry-stack wall systems, which were tested under static lateral load. Similar testing procedures reported in chapter 4 were used. Therefore for the test set up and the gauge positions see Figure 4.3. A lateral deflection of about 100mm was considered to be a total failure of the specimen. The ultimate goal of the investigation is to develop a seismic wall system for low-rise buildings in seismic zones.

7.2 Study of the seismic motarless blocks

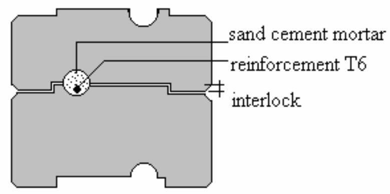
The interlocking mortarless seismic blocks were designed to be dry-stacked and to accommodate reinforcements at the same time. Two types of interlocking blocks were developed namely “centred conduit block” and “staggered conduit block” shown in Figure 7.1 and 7.2 respectively. Because of low strength in soil cement blocks it was necessary that the blocks should be solid i.e.; the grooves must not exceed the recommended 25 % of the gross volume of the units and must be able to accommodate horizontal and vertical reinforcement including grouting. The percentage of grooves in the designed blocks is about 10 % of the gross volume of the unit and therefore considered a solid block based on the recommendations used in conventional masonry (BS 3921,1970).

The overall size of the interlocking seismic block was 220 mm to 240 m length x 115 mm height x 220 mm width with depth of interlocking mechanism of 4 mm in the bed face and 9 mm in the perpend face. The production process is the same as in previous blocks except that the moulds were modified to introduce the conduit.



(a) block profile (b) placements of horizontal reinforcement

Figure 7.1 Conduit Block type I (centred conduit)



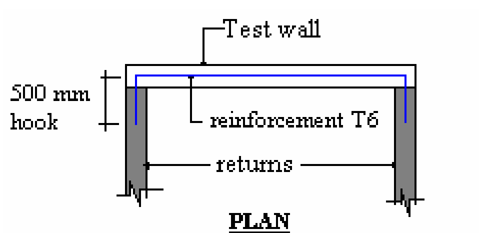
(a) block profile b) placements of horizontal reinforcements

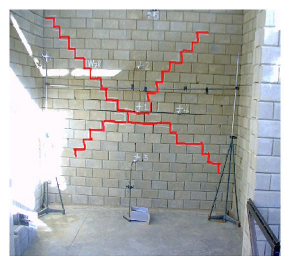
Figure 7.2 Conduit block Type II (staggered conduit)

The two types of seismic interlocking blocks were used to develop two types of wall systems with improved resistance to lateral loading. The investigations were conducted on a full-scale one roomed structure constructed in the laboratory. The systems tested consist of a full-scale dry-stack wall panel with horizontal reinforcements in each course anchored into the supporting walls (returns) and the second type, a full-scale wall panel with horizontal reinforcements anchored into the side columns. Initially the systems were tested under lateral static loading and its performance compared with other systems discussed in chapter four.

7.3 Wall system with reinforcements anchored to the returns

A wall panel (3 m span x 2.45 m height x 220 mm thickness) was constructed using block type I (centred conduit) blocks of 10 MPa strength. The starter course was laid in class II mortar and left for 3 days without load. Middle courses were dry-stacked and reinforced with horizontal bars, bedded in class II cement mortar and anchored to the supporting walls (Fig.7.3a). A single bar, high tensile steel diameter 6mm (T6) was used in each course. The mortar for bedding the horizontal reinforcements was carefully placed not to interfere with the interlocking mechanism in the bed joints of the blocks as shown in Figure 7.1(b) and 7.2(b) above. The top three courses were also laid in mortar to form a ring. The wall was left for 14 days prior testing. The wall was tested under lateral static load. Figure 7.3b shows the mode of failure of the specimen.





a) anchorage of the reinforcements b) mode of failure

Figure 7.3 Reinforcing details and mode of failure

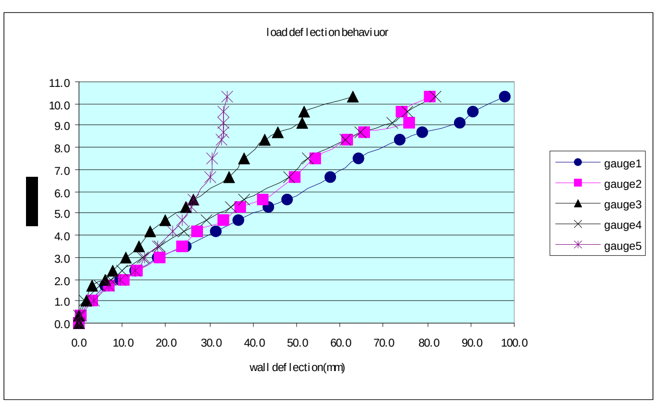


Figure 7.4. Load - deflection behaviour under lateral load

The wall load-deflection behaviour was characterised by a gradual load-deformational response (Fig.7.4). There was little resistance to the initial load. The ultimate lateral load at failure was 10.3 kPa at maximum deflection of 97.7 mm recorded from gauge 2. Few units at the maximum deflection zone, failed by shear of the interlocking mechanism. Figure 7.5 shows the construction details of the system using seismic block type I.

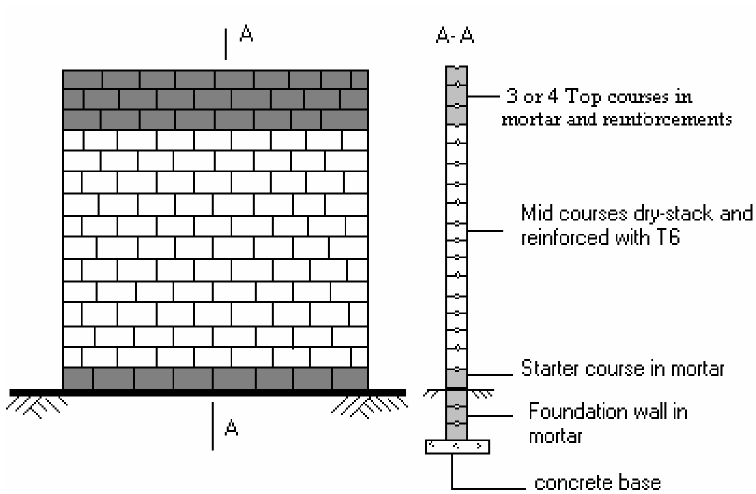


Figure 7.5 Wall cross-section details

7.4 Wall system with corner columns

The test was also conducted on a full-scale one roomed structure (Fig.7.6a). The wall panel (3 m span x 2.45 m height x 220 mm thick) was constructed using seismic blocks type II (Fig. 7.2) of 10 MPa strength, with 4 mm depth of interlocking mechanism on the bed face. The starter course was laid in class II mortar, the mid courses were dry-stacked and reinforced with horizontal reinforcements (T6) carefully laid in mortar not to interfere with the interlocking mechanism and anchored to the side reinforced concrete columns. The three top courses were also laid in mortar to form a ring beam. The wall was tested under lateral static load and mode of failure is shown in Figure 7.6b below.

a) casting side columns in steel forms b) mode of failure

Figure 7.6 Construction and mode of failure of the specimen

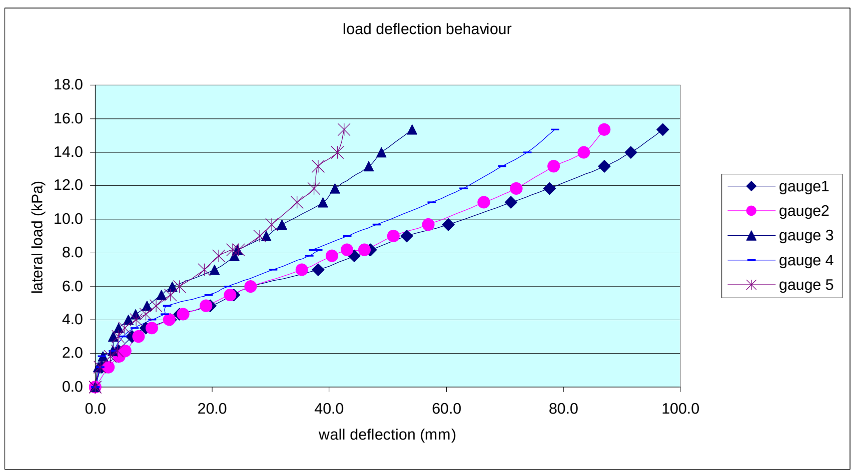


Figure 7.7 Load - deflection behaviour under lateral load.

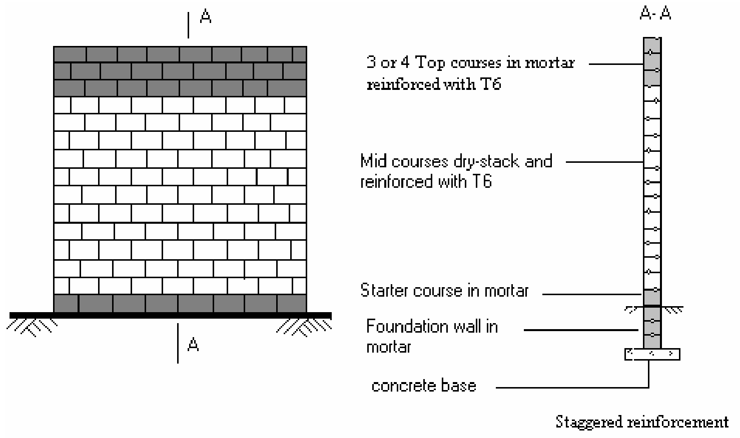


Figure 7.8 Wall cross-section – seismic block type II

The wall load-deflection behaviour was characterised by a load-deformational response due to the load increase (Fig.7.7). The wall demonstrated very little lateral resistance at initial loading, followed by gradual deflection with the load increase to maximum deflection of 97 mm when the loading was stopped and the wall was considered to have failed. The result indicates that the failure of the wall was due to excessive deflection caused by the rotation of the units. The lateral load at failure was 15.3 kPa with maximum deflection at the middle of the upper half of the wall. There was shear failure of few units at the area of maximum deflection. Figure 7.8 shows the construction details of the system using seismic block type II.

The load-deflection and load capacity test results from the seismic wall systems were then compared to the standard conventional masonry and plain dry-stack wall systems, initially tested and reported in chapter four. Figure 7.9 and 10 show the comparisons of the systems tested.

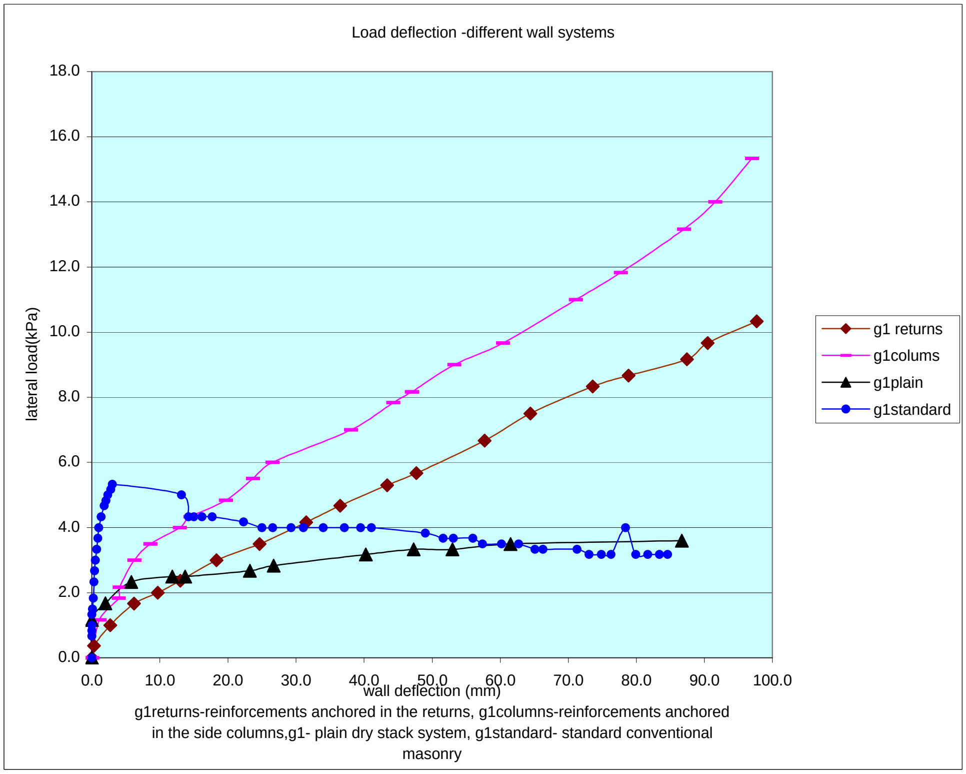


Figure 7.9 Load-deflection – different wall systems

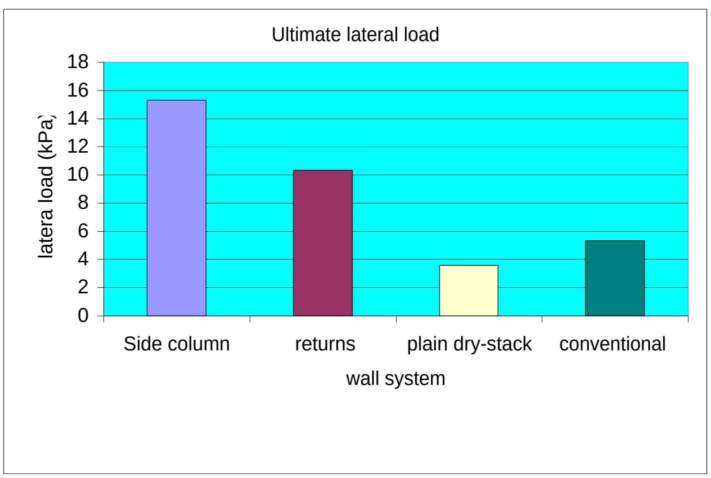


Figure 7.10 Load capacity of wall systems

The dry-stack corner blocks were designed to accommodate vertical and horizontal reinforcements and most importantly, to allow grouting without incurring extra costs for building formworks around the corners as shown in Figure 7.6a. Cost saving and speed of construction were the major criteria in the development of the corner blocks. The blocks were also applied in the phase II of this project, the shaking table seismic test which is discussed in chapter 8. Figure 7.11 shows the developed corner blocks.

Figure 7.11 Corner blocks profile

7.5 Discussions and recommendations

Figure 7.10 compares the performance of four different systems tested, the two dry-stack seismic systems developed, the ordinary plain dry stack system and the standard conventional mortar bonded system. The seismic system with reinforcements anchored into the supporting walls failed at ultimate load of 10.33 kPa and that supported by side columns failed at an ultimate load of 15.30 kPa. The lateral resistance of the seismic system with side column was almost three times as strong as the standard conventional masonry and about four times as strong as the plain dry-stack wall system.

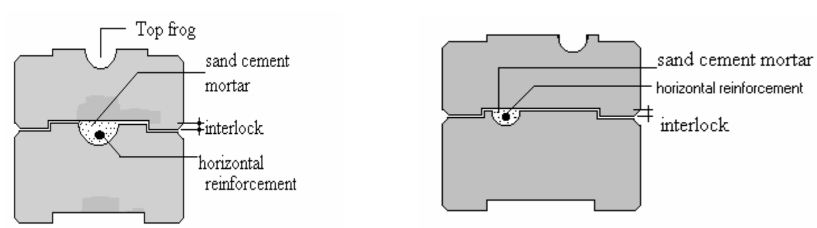
Despite higher lateral resistance the seismic systems show low stiffness at the initial loading. There was load-deformational response of the specimens with load increase until the wall reached deflection of about 100 mm when the loading was

stopped and the wall considered to have failed. The load capacity of seismic system with horizontal reinforcements anchored to side columns was 48 % more than the seismic system with reinforcements anchored to the supporting walls.
Bedding of the horizontal reinforcements in mortar without interfering with interlocking mechanism of the units is a relatively slow process. To improve the efficiency, mortar of higher workability was used. The depth of the round frog at the top and bottom of the seismic blocks is about 16 mm, therefore reinforcements of smaller diameter up to 10 mm is recommended. There was a recovery of between 85 % to 90 % of the walls tested after the removal of the load. During the demolition of the test walls no crushing of the mortar around the reinforcements was observed. Only some isolated cracks were found particularly at the area of maximum deflection - at the middle of the upper half of the wall. Also there was a lifting of the starter course (up to 10 mm) just before the failure of the wall. The system supported with side columns, which was the strongest, had the highest up lift of 10 mm. The system with corner columns was the most efficient and is recommended for further study under dynamic loading using a shaking table. This is similar to the banding method of masonry construction for highly seismic zones in conventional masonry.

Appendix D shows details of ordinary Hydraform block now used in construction in ordinary condition, which was modified to conduit block for seismic construction.

7.6 Recommendations for further study

In future investigations it is proposed to modify the seismic blocks by removing the bottom frog and a comparison in terms of speed of construction and strength of the system to be investigated. Reducing the tolerance between the interlocks is another area of investigations. The proposed modification is shown in Figure 7.12 below.



a) centred top frog b) staggered top frog

Figure 7.12. Modified conduit blocks