CHAPTER 4

LATERAL STRENGTH OF DRY-STACK MASONRY WALL SYSTEMS WITHOUT PRECOMPRESSION

4.1 Introduction

The purpose of the study was to investigate the general structural behavior of dry-stack walling systems without precompression under lateral load. The lateral loading tests were conducted on a full scale one roomed structure constructed in the laboratory using interlocking compressed earth–cement blocks, dry-stack in a stretcher bond. Series of specimens tested were built using blocks of different units strength and different depth of interlocking mechanism. An attempt was made to understand the general effect of the interlocking mechanism on lateral strength of the masonry, the effect of span, effect of unit strength, effect of plaster, effect of introducing Everbond, a thin bonding agent in the bed joints of the interlocking units. A conventional masonry wall of similar parameters was also tested for comparison.

A reinforced vetter power bag connected to a domestic water reticulation system was used to apply the lateral load to the specimens.

4.2 Materials

The specimens were built using interlocking blocks (Fig.4.1) of 5, 9 and 23 MPa unit strength. The blocks were produced using 5 to 20% cement in volume. In the construction of the specimen ordinary sand: cement mortar (1:3 by volume) was used to build the starter course. The top three courses were also laid in mortar or Everbond. The type of cement used was CEM II/A-M 42.5.

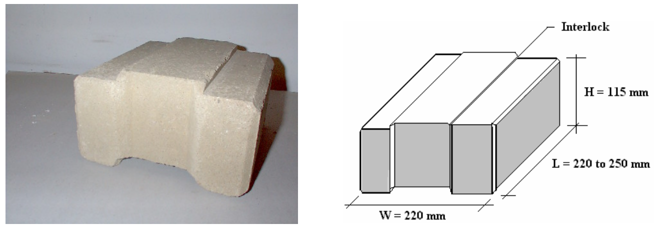


Figure 4.1 Hydraform Interlocking block

4.3 Experiment procedures

4.3.1 General

Lateral loading tests on dry-stack specimens were conducted on a full-scale one roomed structure constructed in the laboratory (Fig. 4.2). Several types of structures were tested. The testing equipment consists of a loading frame bolted to the laboratory floor as a support for application of lateral load to the wall as shown in Figure 4.3. The load was applied by means of a reinforced water bag of dimensions 1m x 1m, which is inflated by means of water pressure from the domestic water system. A pressure of 1kPa over the $1m^2$ area of the power bag therefore translates to a force of 1 kN in the wall. The power bag is connected to a pressure gauge for pressure readings. A one-way valve is also connected to the system to eliminate backpressure. The arrangement of the bag and strain gauges positions are shown in Figure 4.3 below. In this investigation a lateral deflection of about 100 mm was considered to be a total failure of the specimen.

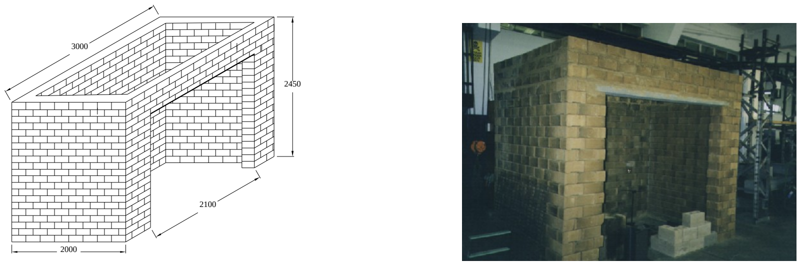


Figure 4.2 Full-scale one-room structure in the laboratory

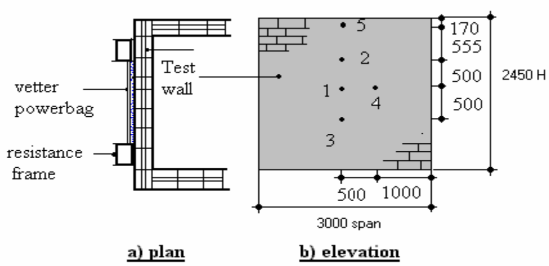


Figure 4.3 Testing rig and Position of dial gauges on the wall

4.4 Effect of span on lateral strength on dry-stack masonry wall panel

4.4.1 Introduction

A study was conducted to investigate the general effect of the span on the lateral strength of the dry-stack masonry wall system; three different spans were tested and categorized as short span (1.5 m), medium span (3 m) and long span (6 m). All the specimens were 2.45 m hight constructed using interlocking blocks of 9 MPa unit’s strength with 4 mm depth of interlocking mechanism in the bed face and 9 mm interlock in the perpend face as shown in Figure.4.1. In order to provide a level surface to keep the wall aligned vertically and horizontally the starter course was laid in ordinary sand cement mortar (1:3) and cured for 3 days without load. Mid courses were dry-stack. The top three lintel courses were also laid in mortar to provide a ring beam for tying the roof and to resist uplift. The structure was left for 14 days prior to testing. Dial gauges were positioned to monitor the deflection of the wall during lateral loading as shown in Figure. 4.3.

4.4.2 Testing of the Short Span wall

The load-deflection behavior of the short span wall (1.5 m) was characterized by a load-deformational response of the wall due to load increase. The wall exhibited stiffness at initial load of up to 3.0 kPa, followed by gradual load-deformational response to the ultimate load of 7.67 kPa at the point of failure. A maximum deflection of 84 mm was recorded at gauge 1. The failure of the wall was mainly due to the rotation of the units allowing the opening of the perpend and bed joints during the deflection of the wall. The opening of the perpend joints were more pronounced at the lintel courses (about 60 mm wide) diminishing to 3 mm at the bottom courses. The failure mode of the specimen resembles the yield line pattern in laterally loaded reinforced concrete slab (Fig. 4.5). Failure of the interlocking mechanism by shear was observed in some units at the mid section of the specimen. The load deflection results are shown in Figure 4.4 below.

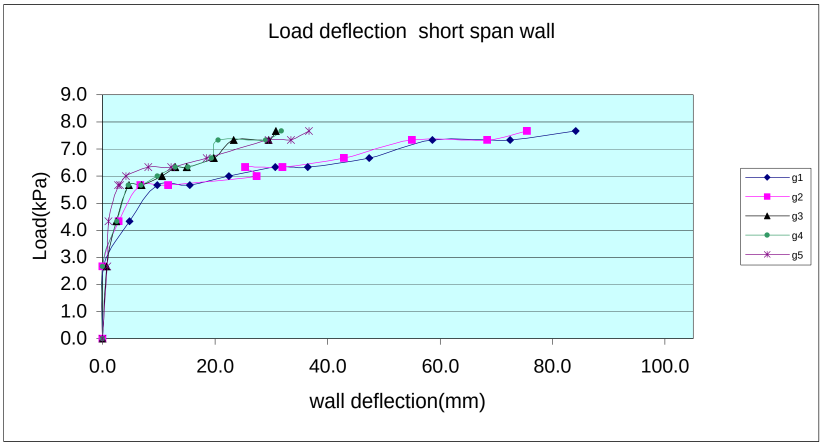


Figure 4.4 Load deflection behaviour for the short span

Figure 4.5 Mode of failure short span wall

4.4.3 Testing of the Medium Span wall

The load-deflection behaviour under lateral load was characterised by load-deformational response of the wall due to the load increase to ultimate load of 3.60 kPa at the failure point. The wall exhibited stiffness at initial load of up to 1.5 kPa, followed by gradual load-deformational response to a maximum deflection of 100 mm at gauge 2 when the loading was stopped and the wall was considered to have failed. The failure was mainly due to the rotation of the units allowing excessive deflection. The failure mode of the wall panel resembles the yield line pattern in laterally loaded reinforced concrete slab (Fig. 4.7). The opening of the perpend joints was about 55 mm wide at lintel level diminishing to 4 mm at the bottom courses. Figure 4.6 below shows load deflection results. Few blocks indicated shear failure of the interlocking mechanism at the area of maximum deflection.

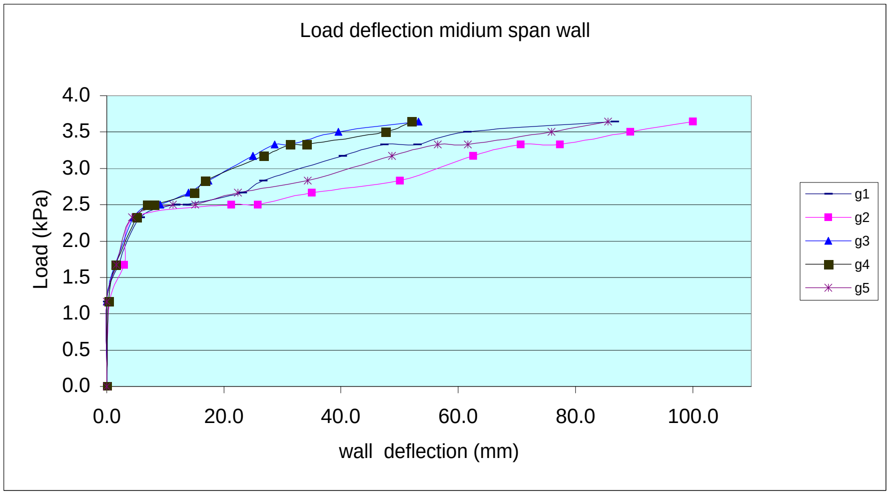


Figure 4.6 Load-deflection for the medium span wall

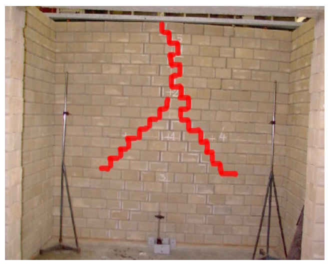


Figure 4.7 Mode of failure medium span wall

Chapter 4 .4.4 Testing of the Long Span wall

The long span wall exhibited gradual load-deformational response to ultimate load of 1.17 kPa at the point of failure. A maximum deflection of about 100 mm was recorded at gauge 5. The failure of the wall was mainly due to the rotation of the units allowing excessive deflection. The opening of the perpend joints at the lintel courses was about 30 mm wide diminishing to 2 mm at the bottom courses. Failure of the interlocking mechanism by shear in some units was also observed. The failure mode of the wall panel resembles the yield line pattern in laterally loaded reinforced concrete slab as shown in Figure 4.9. Load defection results are shown in Figure 4.8 below.

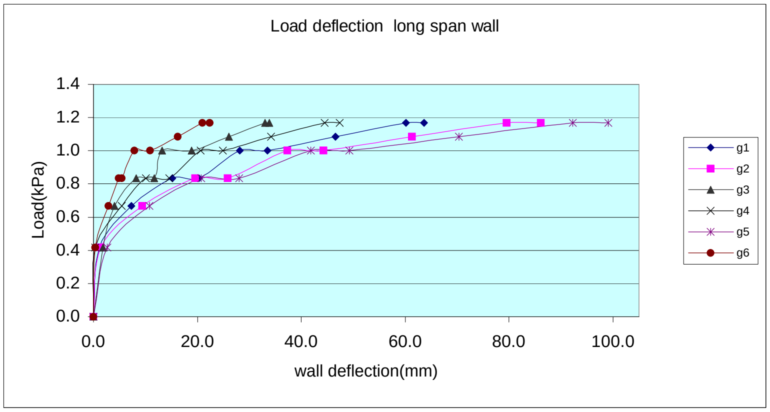
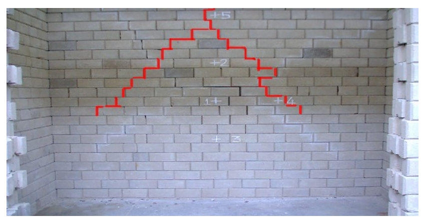


Figure 4.8 Load deflection behaviour long span wall.

a) side view



b) elevation

Figure 4.9 Deflection and mode of failure of the long span wall

4.4.5 Testing of the Medium Span- Standard Conventional masonry for comparison

For comparison purpose, a medium span (3 m), standard conventional masonry wall was constructed using ordinary conventional bricks of 15 MPa units strength. All courses were laid in class II mortar and reinforced with brick force. The wall was tested at the age of 28 days. Comparatively the wall exhibited high stiffness. At the ultimate lateral load of 5.3 kPa there was a loud snap, followed by sudden failure of the wall, which was also accompanied with sudden reduction of the magnitude of the applied load. The wall continued to deflect at constant load to maximum deflection of about 96 mm when the loading was stopped and the wall was considered to have failed. The wall deflection at the failure load was only about 4 mm at gauge1. The mode of failure resembled the yield line pattern in laterally loaded reinforced concrete slab as shown in Figure 4.11. There was a vertical crack of about 30 mm wide at the lintel courses diminishing to 10 mm at the lower courses. Load deflection test results are shown in Figure 4.10. See Figure 4.3 for the experimental set up.

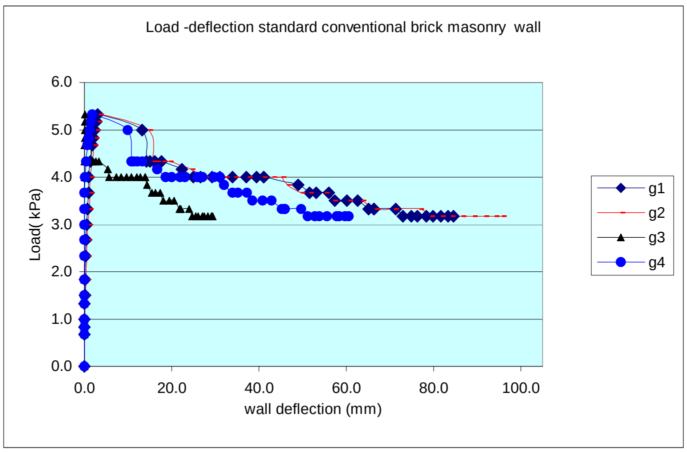


Figure 4.10 Load-deflection behaviour standard conventional masonry wall.

Figure 4.11 Mode of failure standard conventional masonry (medium span)

4.4.6 Discussions

The results from the tested dry stack wall panels suggest that if the span is doubled the strength capacity of the wall decreases by almost 50 %. And if the span is increased four times, the wall strength decreases by about 85 %. The ultimate lateral load at the point of failure for the medium span in dry-stack masonry was 3.60 kPa, which was about 70 % of that of standard conventional masonry of similar span. The failure load for the standard conventional masonry was 5.3 kPa. Figure 4.12 shows the load-deflection behaviour and Figure 4.13 shows the comparison of ultimate lateral load at the point of failure for tested specimens.

The wall panels tested fall in the category of wall panels without precompression. In conventional masonry this category of walls represents those found in low-rise buildings. Their resistance depends primarily on the flexural strength of the block work, without pre-compression, no frictional resistance is mobilized in the joints. Only adhesion between mortar and blocks/bricks. The lateral loading on this walls usually arises from wind pressure, and small incidental loads e.g. movement of people and equipment in building. Considering the size of the specimen, which was only 3 m span x 2,45 m height, the degree of precompression is minimal due to small self-weight. This is supported by the fact that in all dry-stack specimens tested no unit failure was recorded beside the minor shear of interlocks during rotation of some blocks in the area of maximum deflection. The rotation of the units allowed excessive deflection and opening of the dry-stack joints. The dry-stack walls tested were supported on the three edges with the top free. The mode of failure of all specimens demonstrated some similarity with the conventional masonry. The failure pattern of all specimens was similar to the yielding line pattern in laterally loaded concrete slab, which is similar in the case of conventional masonry. It was also noted that all specimens tends to lift at the base before failure.

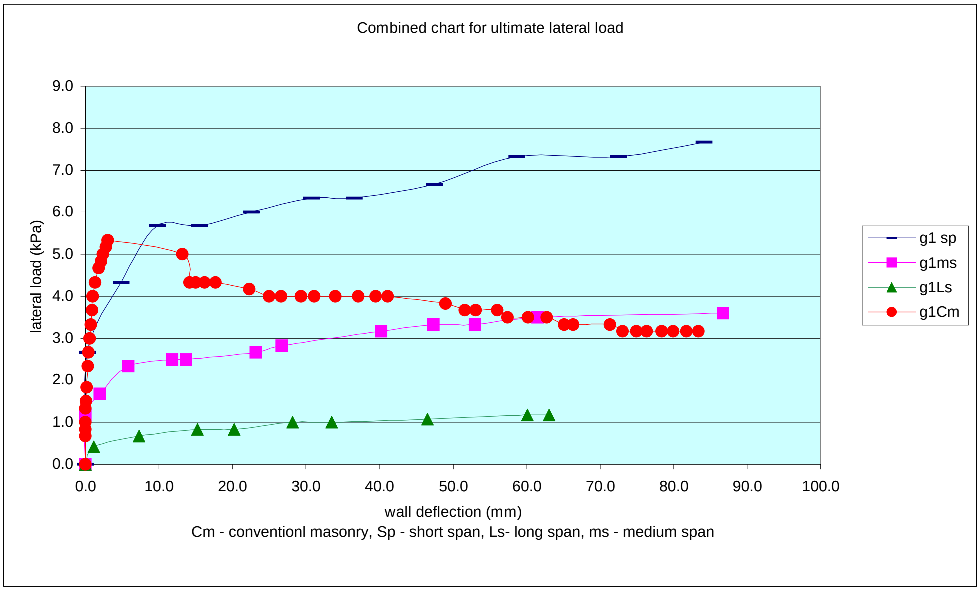


Figure 4.12 Load - deflection behaviour of different specimens

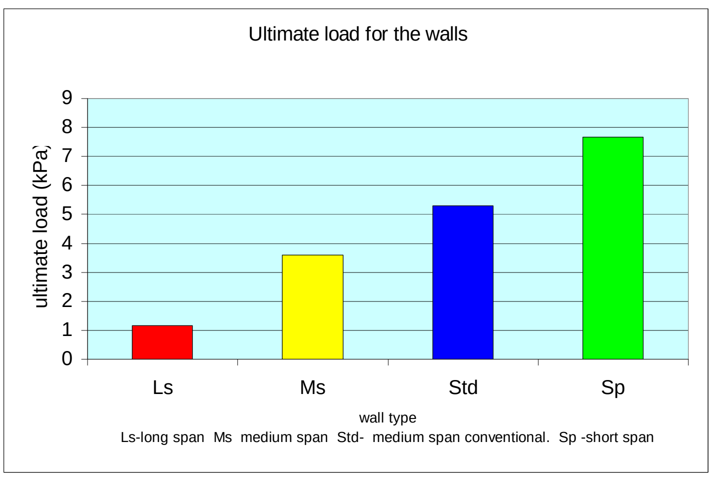


Figure 4.13 Wall ultimate lateral load for various spans

4.5 Effect of Block unit Strength on Lateral strength of Dry-stack masonry.

4.5.1 General

The purpose of these investigations was to study the general structural effect of unit strength on the lateral strength of dry-stack masonry wall panel. Three strength categories of full-scale wall panels were tested; 5 MPa units strength wall (low strength), 9 MPa (medium strength), and 23 MPa (high strength) wall panel. All the specimens were 3 m span x 2.45 m height. The experimental set up is as shown in Figure 4.3. In order to provide a level surface to keep the wall aligned vertically and horizontally the starter course was laid in ordinary sand cement mortar (1:3) and cured for 3 days without load. Mid courses were dry-stack. The top three courses were also laid in mortar to provide a ring beam for tying the roof and to resist uplift. The structure was left for 14 days prior to testing. Dial gauges were positioned to monitor the deflection of the wall during lateral loading as shown in Fig. 4.3. Figure 4.14 shows the blocks used which consist of 4 mm deep interlock in the bed face and 9 mm deep interlock in the perpend face.

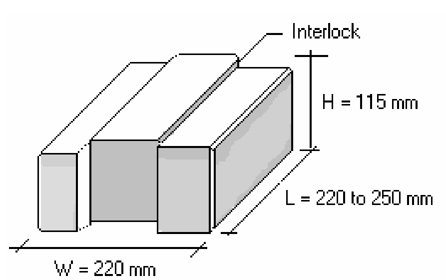
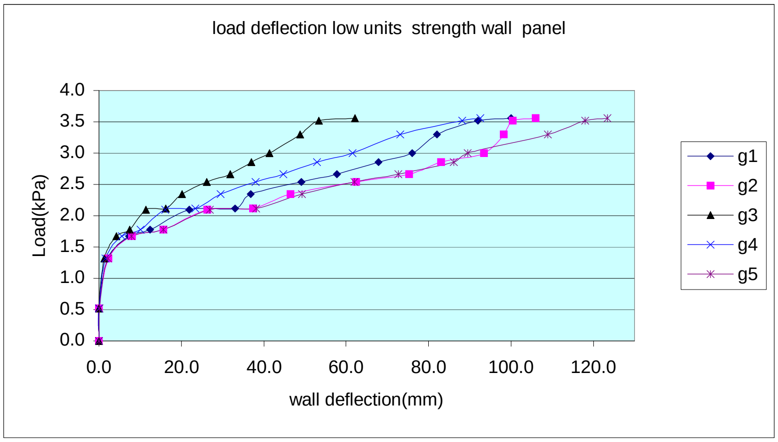


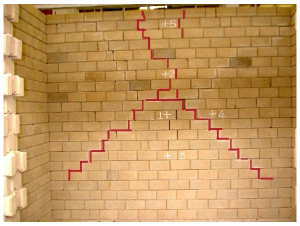
Figure 4.14. Interlocking block

4.5.2 Testing of the low units strength wall panel (5 MPa)

The load-deformational response of the wall in response to load increase characterized the wall behavior under lateral loading. The wall exhibited load-deformational response to ultimate load of 3.56 kPa at failure point. The maximum deflection was 123 mm at gauge 5. Load deflection test results are shown in Figure 4.15a. The failure pattern resembles the yield line pattern in a laterally loaded reinforced concrete slab as shown in Figure 4.15b. The failure of the wall was mainly due to the rotation of the units resulting into opening of the interlocking joints from the lintel courses diminishing to the lower course. Failure of the interlocking mechanism by shear was observed in some of the units.



a) Load-deflection behavior



b) Mode of failure

Figure 4.15 Test results low strength wall panel

4.5.3 Testing of the medium units strength wall panel (9 MPa)

The load-deflection behaviour of the wall was characterised by a gradual load-deformational response of the wall due to load increase to ultimate load of 3.60 kPa at failure point. Initially the wall exhibited stiffness at initial load of up to 1.5 kPa followed by load-deformational response up to max deflection of 100 mm when the loading was stopped and the wall was considered to have failed. The failure was mainly due to the rotation of the units with opening of the perpend joints (55 mm wide) at lintel courses diminishing to 4 mm the bottom courses. In some units failure of the interlocking mechanism by shear was observed. Figure 4.16 below shows load deflection results and Figure 4.17 shows the mode of failure of the wall.

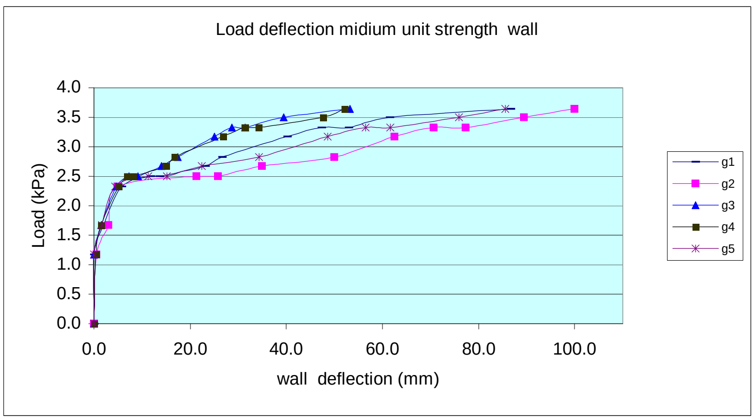


Figure 4.16 Load deflection for the medium units strength wall

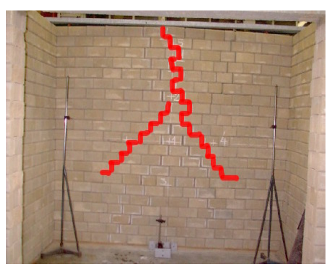


Figure 4.17 Mode of failure medium units strength wall

4.5.4 Testing of the high units strength wall panel (23 MPa)

Load-deformational response of the wall due to load increase, characterized the wall behavior. Initially the wall exhibited stiffness at initial load of up to 1.5 kPa, followed by gradual load-deformational response with the load increase to ultimate load of 3.67 kPa. The wall kept on deflecting to maximum deflection of 98.5 mm at gauge 1 (Fig.4.18). The failure of the wall was due to deformation caused by the rotation of the units which resulted into opening of the interlock between the units, leading to maximum joints opening of about 50 mm at the lintel courses, decreasing to 20 mm at the middle and diminishing to a minimum of 5 mm at the bottom as shown in Figure 4.19. It was observed that, before failure the wall tends to lift at the base. In some units, failure of the interlocking mechanism by shear was observed. The wall recovered up to 75% of the deflection after removal of the load. The failure mode resembles the yield line pattern in a laterally loaded reinforced concrete slab.

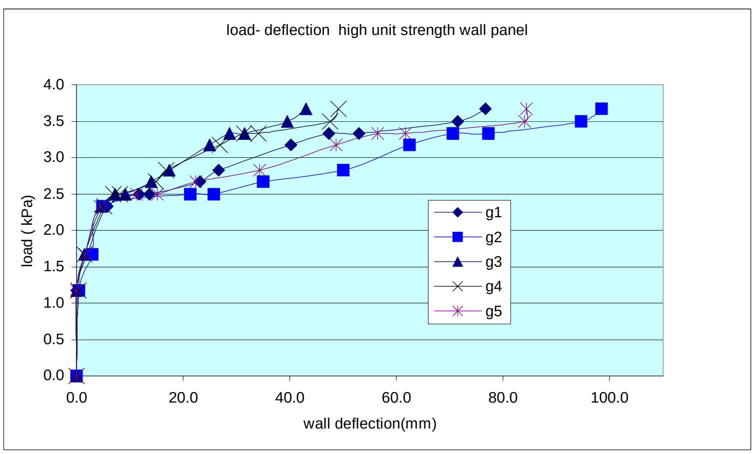


Figure 4.18 load deflection high unit strength wall (23 MPa)

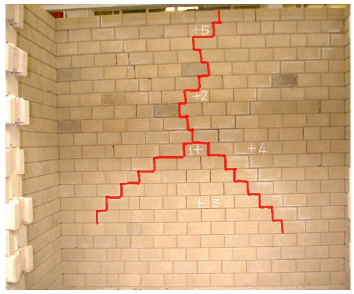


Figure 4.19 Mode of failure high unit strength wall panel

4.5.5 Discussions

Results from the tested dry-stack wall panels suggest that an increase in the unit strength has no significant effect on the capacity of the wall against lateral pressure. By increasing the unit strength by four times, from 5 MPa to 23 MPa the lateral pressure resistance of the wall increased from 3.56 kPa to 3.67 kPa, an increase of only about 3 %. The low degree of precompression due to small self-weight of the test wall specimens and the small depth of interlocking mechanism (4 mm) in the bed face of the units, are likely to be the major reason for low resistance to lateral pressure in the dry-stack wall panels tested. Test Table 4.1 and Figure 20 below summarize the test results.

Table 4.1 Lateral load test results -walls of different units strength

Unit strength	Ultimate lateral load (kPa)	Max. deflection (mm)	Location of max. deflection*
5 MPa	3.56	123 mm	gauge 5
9 MPa	3.60	100 mm	gauge 2
23 MPa	3.67	98.5 mm	gauge 1

*gauge positions see Figure 4.3

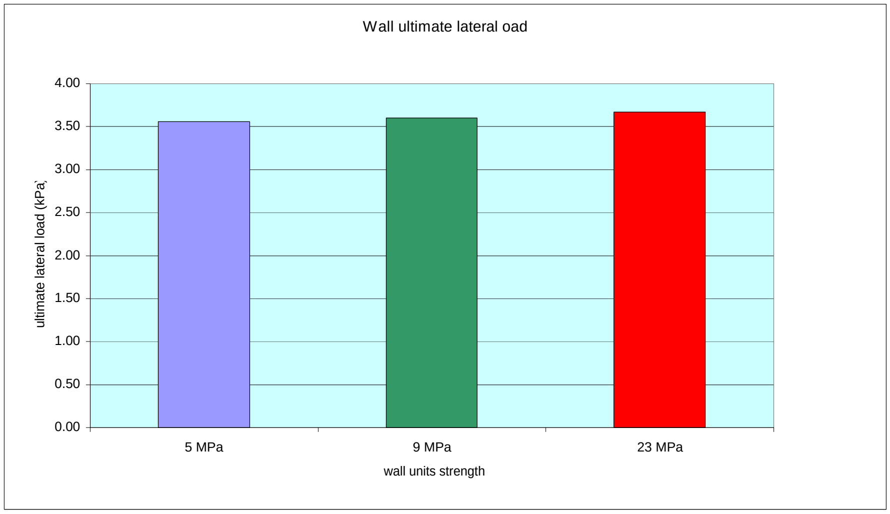


Figure 4.20. Wall ultimate lateral load

4.6 Effect of degree of Interlocking mechanism on lateral strength

4.6.1 General

The purpose of the study was to investigate the general structural effect of depth of interlocking mechanism of the units on the lateral strength in dry-stack masonry wall panel. The tests were conducted on a full-scale wall panels (3 m span x 2.45 m height) constructed using units of strength 9 MPa. Two categories of blocks were tested. Blocks with 4 mm depth of interlocking key in the bed face were categorised as a "shallow" interlocking mechanism and blocks with 15 mm depth of interlock in the bed face as "deep" interlocking mechanism. The 9 mm interlocking mechanism in the perpend face of the blocks remained unchanged in both cases. The test set up is as shown in Figure 4.3. The starter course was laid in mortar (1:3) and left for 3 days without load, mid courses were dry-stacked; top 3 courses were also laid in mortar to provide a ring beam for tying the roof and resist uplift. The structures were tested at 14 days.

4.6.2 Testing of the wall of shallow interlocking mechanism

The wall behaviour under lateral load was characterised by load-deformational response due to the load increase to ultimate load of 3.60 kPa at failure. Maximum deflection of 100 mm was recoded at gauge 2. The failure was mainly due to the rotation of the units with the opening of the perpend joints (55 mm wide) at the lintel courses diminishing to 4 mm at the bottom. Few units in the zone of maximum deflection experienced failure by shear of the interlock. Figure 4.21 shows the load deflection results and Figure 4.22 shows the mode of failure of the wall, which resembles the yield line pattern in laterally loaded reinforced concrete slab.

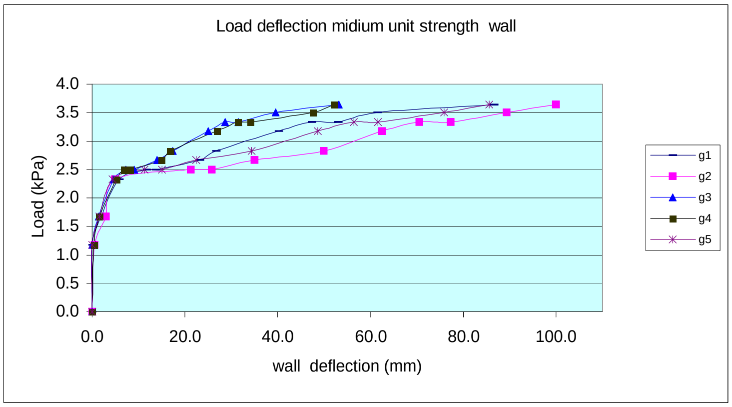


Figure 4.21 Load-deflection for the wall of shallow interlocking mechanism

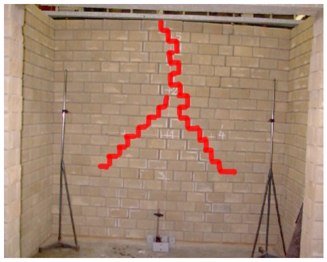


Figure 4.22 Mode of failure wall of shallow interlocking mechanism

4.6.3 Testing of the wall of deep interlocking mechanism

Load-deformational response of the wall due to load increase, characterized the wall behavior. Initially there was little resistance to lateral pressure followed by load-deformational response with the load increase to ultimate load of 3.85 kPa. The wall kept on deflecting to maximum deflection of 114 mm at lintel level (Fig.4.23). The failure mode resembles the yield line pattern in laterally loaded reinforced concrete slab (Fig.4.24). The failure of the wall was mainly due to excessive deflection caused by the rotation of the units.

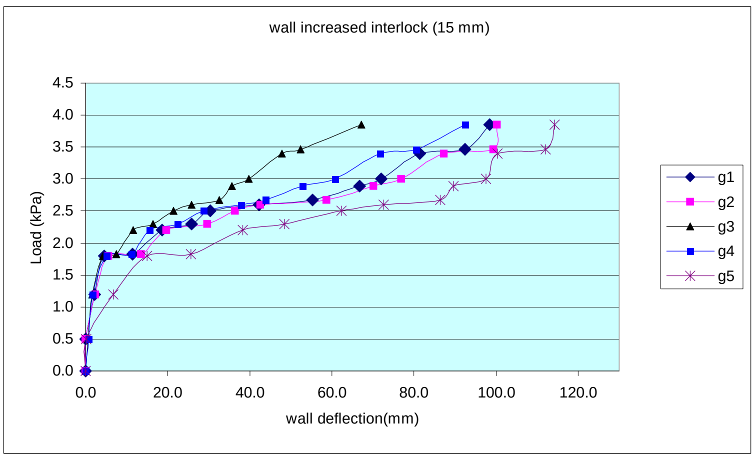
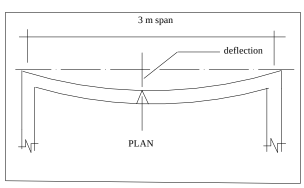
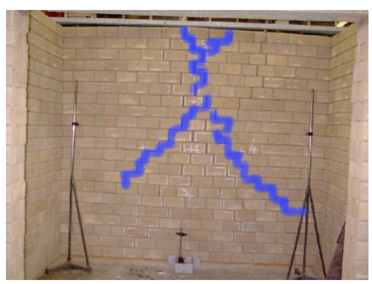


Figure 4.23 load deflection wall with increased interlock





a) plan b) elevation

Figure 4.24 Mode of failure wall of deep interlocking units

4.6.4 Discussions

Test results suggest that the increased depth of interlock enhances the capacity of the interlocking units to rotate as rigid bodies. Test results indicate that by increasing the depth of interlocking mechanism of the units, stresses in the panel were distributed more evenly over a larger area compared to the panels constructed with blocks of shallow depth of interlocking mechanism (4 mm). This is reflected in the failure pattern of the wall, where almost a uniform curvature was formed at the upper half of the wall as shown in Figure 4.24a. There was no significant increase to the lateral pressure resistance likely due to the small degree of precompression allowing the units to rotate easily. This is supported by the fact that there was no unit failure beside shear failure of the interlocks of a few units. The wall with deep interlock recorded an ultimate lateral pressure of 3.85 kPa compared to 3.6 kPa for the shallow interlock - an increase in strength of about 6%. Table 4.2 below summarizes the test results.

Table 4.2 Lateral load test results – specimens with different depth of interlock.

Depth of Interlock (bed face)	Depth of interlock (perpend face)	Ultimate lateral load	Max. deflection	Location*	Bed face interlock category
4 mm	9 mm	3.60 kPa	100 mm	gauge 2	shallow
15 mm	9 mm	3.85 kPa	114 mm	gauge 2	deep

*gauge positions see Figure 4.3

4.7 Effect of Everbond on the lateral strength on dry-stack masonry wall panel

4.7.1 General

The objective of the test was to investigate the general structural effect of introducing Everbond as bonding material in the bed joints of the interlocking units. Everbond is a sealant of dry-film thickness of about 500 microns at one litre per m^2 with bonding tensile strength of 2 N/mm^2. Everbond is an acrylic-based agent, which requires only a thin layer, thus retaining the same level as the dry stacked interlocking units. Any thick layer of bonding material between the interlocking mechanisms of the units makes stacking of the interlocking blocks impossible. Full-scale, 3 m span x 2.45 m high specimens of units with strength 9 MPa. The test set up is as shown in Figure 4.3. The starter course was laid in mortar and left for 3 days without load. The specimens were tested at 14 days.

4.7.2 Testing of the wall with Everbond after every three courses.

During the construction of the specimen Everbond was introduced in the bed joints after every 3^{rd} course. The last three top courses were also in Everbond to provide a ring beam for tying the roof and to resist uplift. Lateral loading test results indicate that initially the wall exhibited significant stiffness to a load of up to 1.6 kPa; then followed by gradual deflection with load increase to maximum deflection of 137 mm when the wall was considered to have failed and the loading was stopped. The ultimate lateral load at point of failure was 4.16 kPa. Everbond is an elastic material; at lintel level it provided insignificant resistance against rotation of the units, which was the major cause of the wall failure. Few units in the zone of maximum deflection failed by shear of the interlocking mechanism. Figure 4.25 shows the load-deflection behaviour and the mode of failure of the specimen is shown in Fig. 4.26 below.

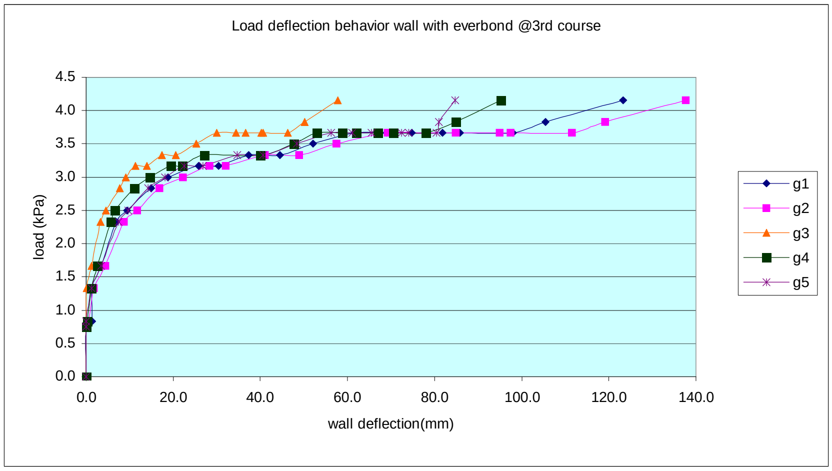


Figure 4.25 Load deflection wall with Everbond each 3rd course

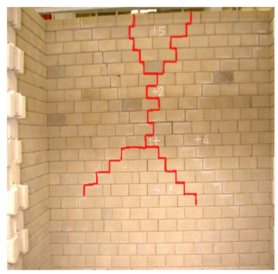


Figure 4.26 Mode of failure wall with Everbond each 3rd course

4.7.3 Testing of the wall with Everbond each course.

Load-deformational response of the wall due to load increase, characterized the wall behaviour under lateral loading. Initially the wall exhibited stiffness at initial load of up to about 2.0 kPa, followed by gradual load-deformational response to the failure load of 5.0 kPa at deflection of 63.4 mm. The wall continued to deflect with load decrease to max deflection of 91.8 mm when the loading was stopped and the wall was considered to have failed. The failure of the wall was mainly due to the rotation of the units, resulting into excessive deflection. Failure of the interlocking mechanism by shear in some units was also observed. Figure 4.27 shows the load-deflection tests results and Figure 4.28 shows the mode of failure.

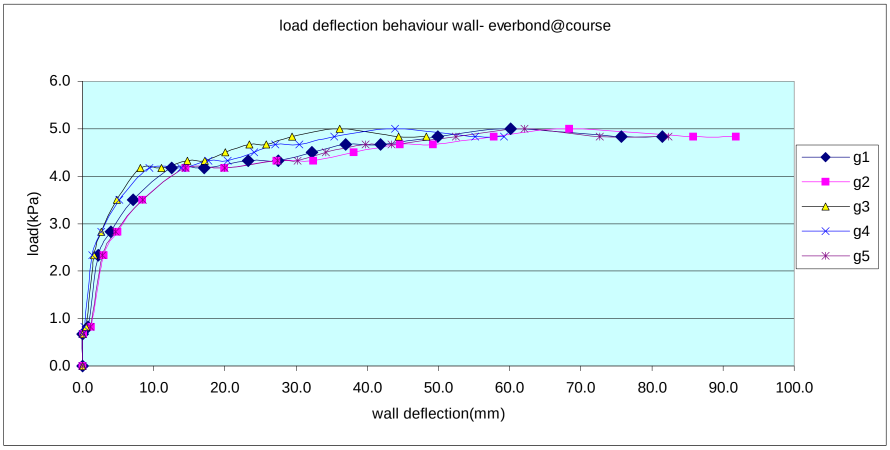


Figure 4.27 Load - deflection wall with Everbond every course.

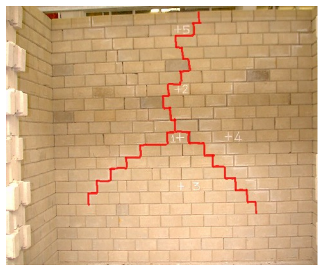


Figure 4.28 Mode of failure wall with Everbond each course

4.7.4 Discussions

Test results indicate that the introduction of Everbond in dry-stack masonry significantly increased the resistance of the wall against lateral pressure. The wall with Everbond in every third course recorded failure load of 4.16 kPa, an increase of 15% in strength as compared to the same specimen, plain dry stack all courses, which recorded an ultimate failure load of 3.6 kPa. The specimen with Everbond each course recorded ultimate failure load of 5 kPa, an increase of 38% in strength compared to plain dry-stack.

4.8 Effect of plaster on the lateral strength on dry-stack masonry wall panel

4.8.1 General

The purpose of the test was to investigate the general structural effect of plaster on the lateral strength of dry-stack masonry wall panels. A dry-stack masonry wall plastered only internally (PI) and one plastered both externally and internally (PB) were tested. A similar masonry wall reinforced with brick force and all bed joints bonded in class II mortar (JM) and the perpends dry-stack was also tested for comparison. In all tests, in order to provide level surface to keep the wall aligned vertically and horizontally the starter course was laid in class II mortar and left to harden without load for 3 days. For the plastered walls the mid courses were first dry-stacked before plastered. All specimens were full-scale wall panels – 3 m span x 2.45 m height. The test set up is as shown in Figure 4.3. Figure 4.29 shows load – deflection responses for the tested walls.

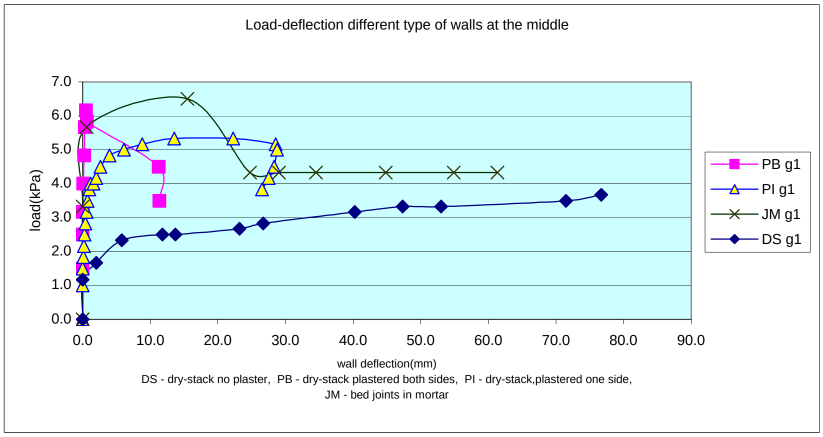


Figure 4.29 Load - deflection responses for the plastered walls in comparison to dry-stack and bonded walls

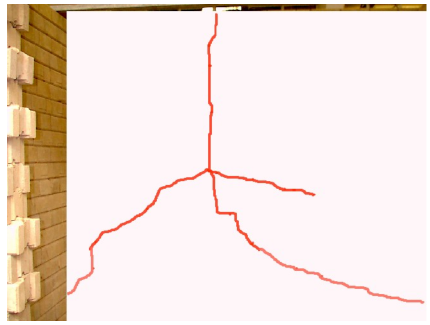


Figure 4.30 Typical mode of failure - plastered wall

4.8.2 Test results and Discussions

The results from the wall panel plastered both sides (PB) and that plastered only inside (PI) indicate that plastered walls exhibited a high stiffness evidenced by the near vertical initial part of the load deflection curve as shown in Figure 4.29. A higher strength but lower ductility behavior was observed. In the plastered specimen the appearance of the cracks was accompanied by a loud snap as the plaster failed accompanied by the failure of the wall. The crack pattern was similar to typical failure of a concrete slab simply supported along the three edges and free at one edge. (see Figure.4.30). The maximum deflection was recorded in the upper half of the wall.

The average ultimate lateral load at failure for plain dry-stack panels tested was 3.6 kPa. By introducing the plaster on one side of the wall, the failure load increased to 5.33 kPa, an increase of almost 50 %, and by plastering both sides the failure load was 6.17 kPa an increase of 70 %. The strength of the plain dry-stack masonry was about 55 % of the strength of the similar panel with all joints in class II mortar and reinforced with brick force, which recorded ultimate lateral load resistance of 6.50 kPa at failure. Figure 4.31 and Table 4.3 below summarize the test results.

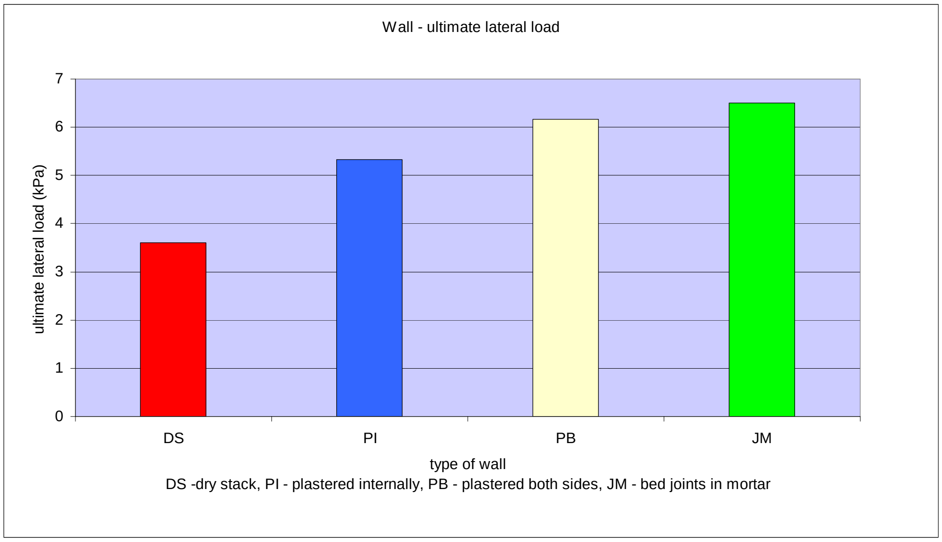


Figure 4.31 Ultimate lateral load different walls

Table 4.3 Tests results -load deflection different walls of same span (3m)

Type of wall	Ultimate lateral load (kPa)	Wall deflection at gauge 1* at ultimate lateral load (mm)
Plain dry-stack (DS)	3.60	86.70 mm
Dry-stack and plastered inside only (PI)	5.33	13.52 mm
Dry-stack and plastered both sides (PB)	6.17	0.60 mm
All bed joints in mortar, perpend joints dry-stack (JM)	6.50	15.50 mm

*gauge positions see Figure 4.3

In conventional masonry, codes (BS 5628) suggest that minimum lateral load = 0.015 Gk, where Gk is the self-weight. Considering the average self-weight of the tested panels was about 5 kN/m², the demonstrated performance of dry stacking is satisfactory. Test results indicate that in the absence of bonding mortar, the interlocking mechanism in the units influence performance of the wall against lateral pressure resistance. By introduction of plaster the capacity of the dry-stack masonry is almost equal to that of conventional mortar bonded masonry.

4.9 Conclusions and Recommendations for Future Study

Because of the limited number of samples tested in each test in this study, the tests results in this chapter are therefore general and conservative. It is not possible to make conclusive recommendations from each experiment. It is the opinion of the author that the test results in this chapter will be used in future as the basis for providing guide line into detail study and improvement of the dry-stack system investigated.

For future analytical study of the system the following are the recommendations-:

- In order to establish the effect of block units strength on the resistance of the dry-stack walling system investigated, testing of panels with precompression is recommended. In testing of small wallets, a closed frame, which restrains vertical movement and allows only rotation along the horizontal axis, is recommended. An adequate number of samples should be tested.

- From the test results the effect of plaster on the lateral capacity of the dry-stack masonry was clear. However for future development and improvement of the system, it is important to establish the "adequate plaster thickness and strength" for dry-stack masonry, to establish whether the recommendations used in conventional masonry is appropriate for dry-stack system. If not, recommendations for the dry-stack masonry system tested must be established. Adequate number of samples should be tested.

- EVERBOND was found to enhance the capacity of the dry-stack masonry without interference with the coursing of the interlocking blocks. The thin bonding agent limits rotation and uplift of the units under load. However in future it is important to establish "how much" EVERBOND or similar bonding agent is required per surface area to achieve optimum structural performance. Adequate number of samples should be tested.