CHAPTER 3

LOAD PREDICTION MODEL FOR DRY-STACK WALL PANELS UNDER AXIAL COMPRESSION

3.1 Introduction

A series of full-scale dry-stack wall panels of similar size (3m length x 2.5m height) were tested under axial compression. Hydraform blocks are commercially available in unit strength ranging between 5 and 20 MPa. Tests were carried out on specimens built with blocks of 5, 9, 12 and 23 MPa units. In this investigation 5 MPa blocks are the weakest blocks and 23 MPa as the strongest. A conventional masonry block wall was also tested for comparison. Further tests were conducted on wall prisms consisting of 4 or 8 dry-stack blocks and compared with similar prisms, for which the blocks were bonded in mortar. The test results were used as a basis for the development of an empirical model for the prediction of the load capacity of the dry-stack system.

3.2 Materials

Hydraform interlocking compressed soil cement blocks of dimensions 220 mm width x 115 height x 220 to 250 mm length (see Figure 3.1) were used. Normal sand cement mortar class II (BS 5628) was used in the construction of the starter course. The Everbond, 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 was used to bond the units on the edges of the walls. Everbond is an acrylic-based bonding agent, which requires only a thin layer, thus retaining the same level as the dry-stack units. The basic requirements of soil for block production is shown in Table 3.1.

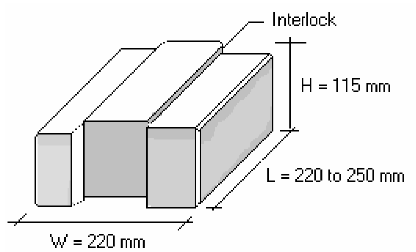

Figure 3.1 Normal Hydraform interlocking block

Table.3.1 Basic requirements of Soil for CEB′s production

Nominal Compressive Strength	% By mass passing the 0.075mm sieve		Plasticity Index (maximum)	Cement content (%)
	Min.	Max.		
4	10%	35%	15	4-7
7	10%	25%	10	7-10
20	10%	25%	10	15-20

3.3 Experimental Procedures

The in-plane load resistances were determined for wall panels using different block samples. The wall panels were constructed in the laboratory using the construction method described in the Hydraform manual. The panels (3 m span x 2.50 m height x 220 mm thick) were constructed on a Macklow-Smith machine platen that is mounted on a hydraulic Ram (Figure 3.3 and 3.4). In order to provide level surface, to keep the wall aligned vertically and horizontally, the starter course was laid in mortar and cured for three days without load. The midcourses courses were dry-stack. The end vertical strips were also bonded with Everbond as indicated by the shaded area in Figure 3.2. The last three top courses were also laid in mortar. The top surface of the specimens were made flat using mortar and checked by a spirit level followed by hardboard parking at the top. The specimens were tested at age of 14 days.

A 3m span steel beam (230 kg) was used to spread the load evenly at the top of the wall. The beam was fabricated using two channels (serial 254x89x35.74 kg/m) welded back to back to form "I" section. The web was stiffened to prevent buckling. Nine sensors (dial gauges) were placed in positions as indicated in Figure 3.2. The sensors measuring displacements were of the type with a pin. The sensor would register a positive value for any deflection causing the sensor pin to move out (i.e. away from the body of the sensor) and a negative value for any deflection causing the sensor pin to move in. The sensors were mounted on a stiff frame, free of disturbance from the loading equipment. Axial compression load was applied at a rate of 2 kN/min. The lateral displacement was recorded from the dial gauges and the corresponding load from machine control panel (see Appx. B).

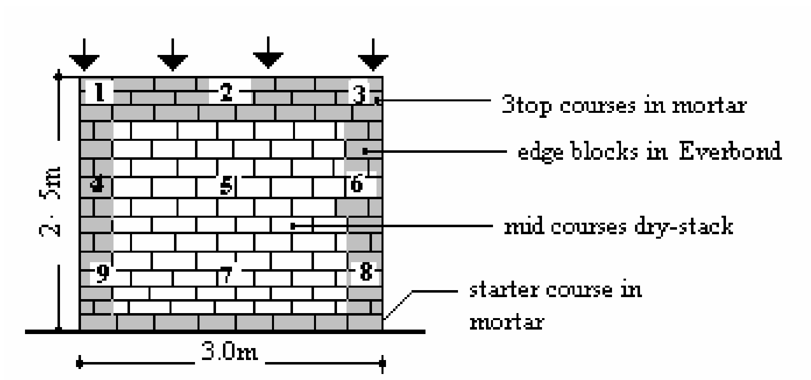

Figure 3.2. Wall panel construction details and stain gauge positions.

Figure 3.3 Setting out the starter course on machine platen

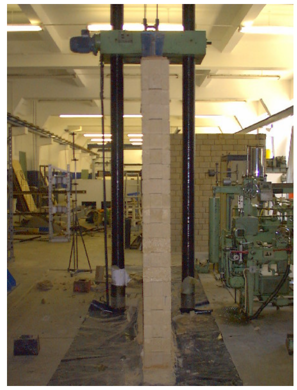

Figure 3.4 Specimen under vertical load

The prism samples (scaled down models), consisted of 4 or 8 units, which were dry-stack or bonded and tested under axial compression as shown in Figure 3.5 and Figure 3.6. The top and bottom of the specimens were made level. The specimens were tested on Amsler testing machine. The axis of the specimen was carefully aligned with the centre of the machine platen and the load was applied to the specimen in the same direction as in service at a loading rate of 2 kN/min. The Amsler loading pattern does not allow rotation during compressive load. In each sample 4 specimens were tested.

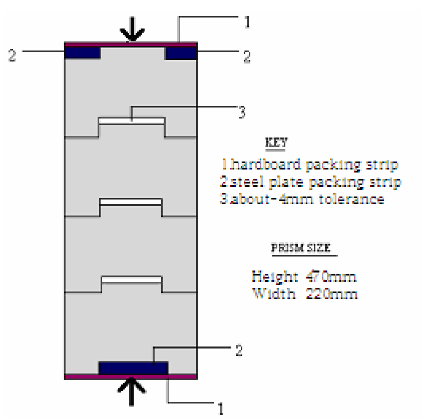

Figure 3.5 Sketch of the dry-stack prism test set up

Figure. 3.6 Testing bonded prism

3.4. Test results

3.4.1 Wall Panel Tests

Wall panel tests indicate that the onset of failure is characterised by the formation of a vertical crack (less than 3mm wide) parallel to the axis of loading along the mid section of the wall (see Figure 3.7). At ultimate state, cracks also appeared on the faces and edges of the specimen (Figure 3.8). The appearance of the cracks was accompanied in each case by a loud snap and sudden reduction in the magnitude of the load applied, which quickly reduced to zero.

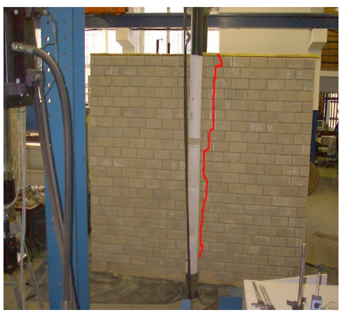

Figure 3.7. Front view of wall panel showing failure line

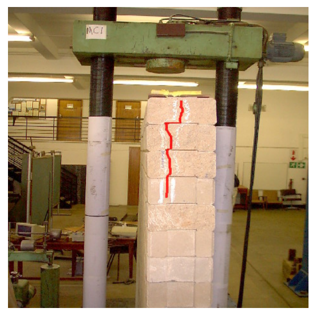

Figure 3.8 Side view of cracks at top

The main failure plane was along the vertical joint of the interlocking mechanism as shown in Figure 3.11. However, failure in low-strength unit walls was characterised by a local crushing of the top courses as shown in Figure 3.9. The weakest sample (5MPa) failed in this manner, by the crushing of the top 10 courses.

Figure.3.9 Side view, crushing of the top courses (5 MPa specimen)

The ultimate load at the point of failure including the maximum lateral displacement of each wall panel is given in the Table 3.2. The total panel load capacities for the 3m width panels are plotted for the various samples in Figure 3.10. A near linear relationship may be observed between the panel load and the strength of the masonry units. Appendix B shows the failure pattern of each specimen including the relative load vs. lateral displacement.

Table 3.2. Wall panel tests results

Type of wall panel	Ultimate compressive load (kN)	Maximum lateral displacement (mm)
5 MPa units	595	2.25
9 MPa units	721	10.00
12 MPa units	938	3.40
23 MPa units	1360	40.00

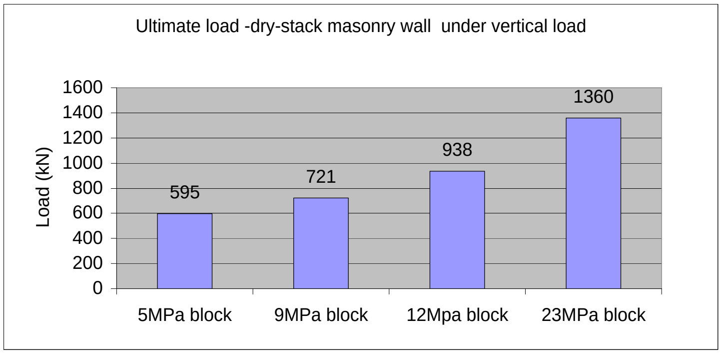

Figure 3.10. Panel load vs unit strength

3.4.2 Prism test results

In the dry-stack prism tests, four-unit and eight-unit prisms were tested in axial compression. 4 specimens were tested in each sample. A typical mode of failure observed was the formation of two parallel vertical cracks between the contact area along the interlocking mechanism on both sides of the specimen (see Figure 3.11). The appearance of cracks was accompanied in each case by loud snap and sudden failure.

For the prisms that are bonded with mortar, the mode of failure observed was formation of x-crack pattern as shown in Figure 3.12. The results are summarised in the Table 3.3.

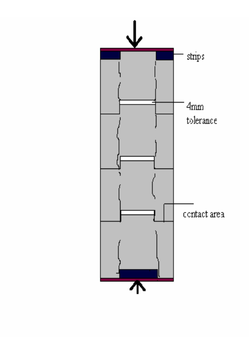

Figure 3.11. Four-unit dry-stack prism

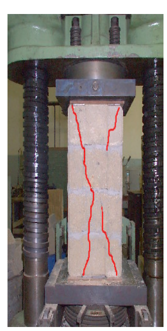

Figure 3.12. Four-unit prism bonded with mortar

Table 3.3 Prism compressive test results.

Type of Prism	Prisms average compressive strength (MPa *)				h/t ratio
	9 MPa specimens	C.O.V % of failure load	23 MPa specimens	C.O.V % of failure load	
4 unit prism dry-stack	2.85	5	5.92	4	2.10
4 unit prism in mortar	8.90	4	17.80	3	2.20
8 unit prism dry-stack	3.10	6	6.20	5	4.20
8 unit prism in mortar	5.80	4	11.90	4	4.45

*based on gross area

3.4.3 Test on conventional wall panel

A similar wall panel was constructed using 12 MPa units strength, all joints filled with ordinary sand cement mortar class II of 5.6 N/mm² cube strength. The structure was cured and tested at 28 days. The failure of the wall was characterised by the formation of vertical crack (less than 2 mm wide) parallel to axis of loading along the mid section of the wall. At the point of failure at ultimate load of 1553 kN, cracks appeared on the faces of the specimen as shown in Figure 3.13. The appearance of the cracking was accompanied by a sudden reduction in the magnitude of applied load, which quickly reduced to zero. No cracks appeared on the edges of the specimen. The maximum mid height lateral deflection range was from 0 to ± 5 mm. The lateral displacements of the tested specimens are given in appendix B, Figure 10.

 

a) Face view b) Edge view after test

Figure 3.13 mode of failure conventional panel

Figure 3.14 compares the load capacity of the conventional wall panel vs dry-stack panel of similar units strength (12 MPa).

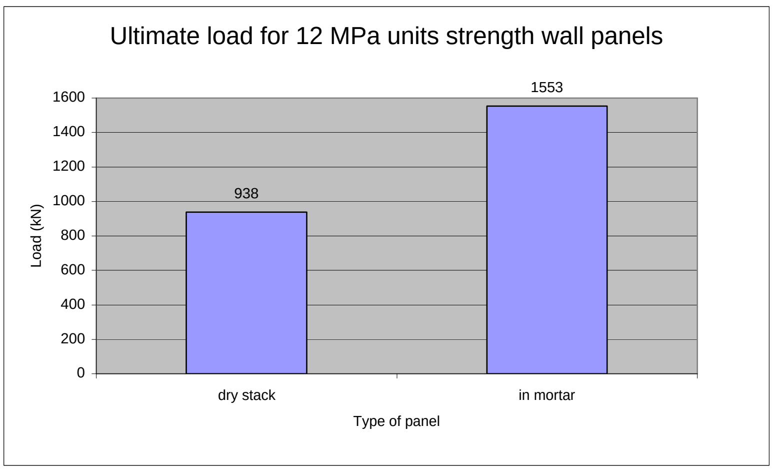

Fig.3.14 Panels of similar units strength

Tests results indicate that the strength of dry stack masonry is about 60% of the conventional masonry in mortar. The reduction in strength in dry-stack is attributed to the interlock which reduces the contact area to 52% of the gross area.

The failure modes were different; compression in the bonded wall and shear in the dry-stack system.

3.5 Discussions and Conclusions

3.5.1 Relationship between wall panel capacity and masonry unit strength

The contact area between the masonry units was 52% of the gross area and this net area was used in stress calculations. The results show the existence of proportionality between the unit strength and the wall capacity (see Figure 3.15).

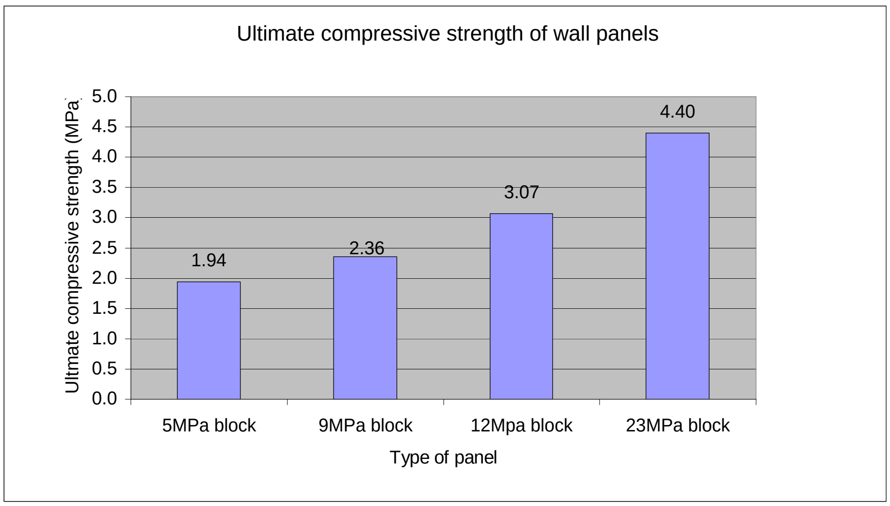

Figure 3.15. Panel load vs unit strength

The results were used for regression analysis to establish strength relationship between the units and the masonry. The average compressive strength of the dry-stack wall panel f_{panel} as a function of the masonry unit cube strength, f_{cu} is given in equation 1.

$$f_{panel} = \phi_m 0.15 f_{cu} + 1 \quad \ldots\ldots(1)$$

Where ϕ_m safety factor for material = 0.9

The experimental and theoretical model for load capacity prediction of the system shown in Figure 3.16 indicates a reasonable agreement with test data.

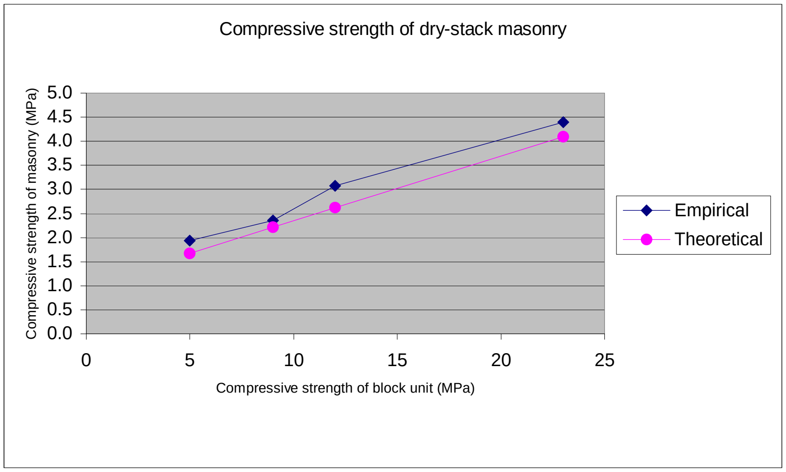

Figure 3.16 Wall strength vs masonry unit strength

3.5.2 Relationship between the strengths of masonry unit, prism and wall panel

In order to establish the relationship between the prism strength, wall strength and unit strength the test results were calculated based on the contact area and the results are summarised in Table 3.4 to 3.6.

Table 3.4 Relationship between block strength and prism strength

Block strength	Average Prism strength *	Prism/unit strength ratio
9 MPa	6.18 MPa	0.69
23 MPa	12.76 MPa	0.55

*based on net area

Table 3.5 Relationship between dry -stack prism and dry-stack masonry wall panel

Block strength MPa	Prism strength* MPa	Wall strength* MPa	Wall/prism strength ratio
9	6.18	2.37	0.38
23	12.76	4.4	0.34

*based on net area

Table 3.6 Relationship between dry-stack masonry wall and unit strength

Block strength MPa	Wall Panel strength* MPa	Panel/ unit strength ratio
5	1.94	0.39
9	2.37	0.26
12	3.07	0.26
23	4.4	0.19

*based on net area

It can be seen that the overall strength of the panel increases with the strength of the masonry unit. However, the ratio (wall: unit) strength decreases with increase in the unit strength. This is mainly because the mode of failure is in shear and therefore the full compressive strength capacity is not allowed to develop.

3.5.3 Comparison with Conventional masonry.

Hendry (1981) carried out research work in Australia where prism tests were used as a basis for determining brickwork design strength in conventional masonry. It was reported that the ratio of wall (panel) strength to prism strength is on average 0.9. The ratio of panel strength to masonry unit strength is 0.3 – 0.4. This compares well with the dry-stack system where the panel strength to unit strength ratio is 0.35. However the panel: prism ratio indicates a big difference between the two systems. The values obtained for dry-stack system is 0.3 – 0.4 compared with 0.9 for conventional masonry.

Also Monk (1967) reported on series of experiments conducted by Structural Clay Products Research Foundation in the United States, which examined the effect on the compressive strength of brick couplet specimens in which different bonding materials were used, including dry bonding with brick face ground flat. The specimens with faces ground flat (dry bond) were two times stronger than the specimen bonded with mortar. Some of the results of those experiments are summarised in Table 3.7.

Table 3.7 Effect of different joint materials on compression strength of brick couplets.

Joint Material	Compressive Strength (MPa)	Couplet / brick strength ratio
Mortar (1:½:4½)	44	0.40
Dry sand	65	0.59
Ground surfaces	98	0.89

Source: Monk, 1967

Similarly Morsy (1968) investigated the effect of bed material on brick prism strength. In these experiments different bed materials were tested including dry bonding. The results were similar to Monk's results, suggesting that brickwork prism consisting of loose bricks, (dry-stack) the bedding planes of which has been ground flat, achieved compressive strength approximately twice as high as those obtained from prism bonded with mortar. The results of these experiments are summarised in the Table 3.8.

Table 3.8 Effect of different joint materials on the compressive strength of prisms

Joint Material	Compressive Strength (MPa)	Prism/ brick strength ratio
No joint material	37.20	0.93
Mortar (1:½:3)	14.0	0.35

Source: Morsy 1968

From Morsy and Monk investigations, one may suggest that the absence of bonding material in dry stacking does not have an adverse effect on the performance of masonry under compressive load. Therefore the major challenge to the developers of interlocking blocks is to limit the tolerance between the block interlocking mechanism in order to increase the surface contact area and hence the load capacity of the dry-stack masonry.

3.5. 4 Conclusion

The following are the conclusions that may be drawn from the investigations:

- Dry stack masonry under uniform compression load usually fails by the development of tension cracks parallel to the axis of loading.
- The compressive strength of dry-stack masonry tested is about 0.3 of the nominal compressive strength of the masonry units.
- Interlocking mechanism in the dry-stack units, assist alignment and stability of the wall.
- As in conventional masonry, results suggest that the strength of the dry-stack system tested is proportional to the strength of the masonry units.
- By bonding the masonry units in mortar, the strength in compression was increased by about 50%.
- The failure of the interlocking mechanism of the units in the system investigated is governed by shear; the compressive strength capacity is not attained before failure.