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EXPERIMENTAL INVESTIGATION OF THE BEHAVIOUR OF CONCRETE BLOCK MASONRY UNDER CONCENTRATED LOADS

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ABSTRACT

A total of 12 panels were tested to investigate the behaviour of concrete block masonry under concentrated loads in terms of the crack pattern, the mode of failure and the ultimate load. The panels were equally divided into three groups, each consists of four panels with different top conditions prepared to study the possible beneficial effects of grouting one or two of the top courses or of using a reinforced top bond beam. The main difference between the groups was the height to width ratio (h/w). Depending on their dimensions, the panels exhibited different crack patterns and modes of failure. The cracks observed in the panels with high ratios of h/w were almost vertical splitting cracks initiated underneath the applied load. On the other hand, the cracks formed in the panels with low ratios of h/w tended to propagate diagonally through the blocks or following the mortar joints. Grouting the top courses or having a reinforced bond beam underneath the applied load was proven to play a significant roll in increasing the ultimate load and reducing the deformation.

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INTRODUCTION

The dramatic increase of population in Egypt has created a need for low-cost housing. Building construction using the conventional infilled reinforced concrete frames has become expensive due to the high cost of framework, reinforcement and finishing. Masonry construction, on the other hand, offers a very cost-efficient system for low rise housing (4 to 5 stories). In this method of construction, the walls and partitions, which already exist in any building, are employed efficiently as a loadbearing system, thus saving the time and the materials required for the construction of reinforced beams and columns.

It is common, in masonry construction, to find walls acting as supports for concentrated loads under beams in the roof or at the anchorage of prestressing bars. These concentrated loads result in high stress concentrations which in turn could lead to splitting or spalling failures of the walls. The distributions of the induced stresses and strains as well as the failure load depend on the nature of the concentrated load, its position and the characteristics of the wall itself. Using bond beams or fully or partially grouting the top courses of the wall could have a beneficial effect on the behaviour. These topics have been studied both experimentally (Khaled 1995 and Hosny et al. 1988 and 1989) and theoretically (Simbeya et al. 1986a and b, Page and Ali 1989 and Hosny et al. 1990).

In an attempt to achieve a higher level of understanding of the behaviour of the concrete block masonry walls under concentrated loads, a research program was initiated at Ain-Shams University. The first three phases of this program were completed and reported before (Hosny et al. 1988, 1989 and 1990). In this paper (Khaled 1995), the experimental results obtained in the fourth phase, which included a total of 12 specimens, are presented and discussed. The variables considered were the height to width ratio of the wall, the number of grouted top courses and the use of a reinforced bond beam.

EXPERIMENTAL PROGRAM

It is the main objective of this experimental program to study the behaviour of concrete block masonry in terms of the crack patterns, the modes of failure and the strength characteristics under the effect of concentrated loads. Twelve panels, divided into three equal groups, were designed to achieve this goal. The main difference between these groups was the height to width ratio (h/w). Each group consisted of four panels with different top course conditions prepared to investigate the possible beneficial effects of grouting one or two of the top courses or of using a reinforced top bond beam.

Designated W_{I-1} to W_{I-4}, the panels of Group (I) were all prepared with h/w=4/3 [h=1.6 m (5.25 ft) and w=1.2 m (3.94 ft)]. The first panel was plain with no grout or reinforcement and it was considered as the reference for comparison. The second and the third panels, W_{I-2} and W_{I-3}, were used to study the effect of grouting one and two of the top courses, respectively. Panel W_{I-4} was prepared with a reinforced bond beam.

The panels of Groups (II) and (III) were identical to those of Group (I) except for the height to width ratio. The height to width ratio was selected to be 1.0 [h=w=1.2 m (3.94 ft)] for Group (II), whereas it was 2/3 [h=0.8 m (2.62 ft) and w=1.20 m (3.94 ft)] for Group (III).

A general configuration of one of the panels is shown in Fig. 1, whereas the details of each panel are summarized in Table 1.

Table 1 Summary of Test Results.

Group	Wall	Dimensions (m)			No. of grouted courses	Bond beam	Cracking load (KN)	Ultimate load (KN)	Gain* in strength (%)
		Height	Width	h/w					
I	W_{I-1}	1.6	1.2	4/3	no	no	161.9	210.9	-
	W_{I-2}				1	no	215.8	294.3	40
	W_{I-3}				2	no	235.4	313.9	49
	W_{I-4}				no	yes	264.9	402.2	91
II	W_{II-1}	1.2	1.2	1	no	no	215.8	250.2	-
	W_{II-2}				1	no	181.5	299.2	20
	W_{II-3}				2	no	220.7	333.5	33
	W_{II-4}				no	yes	294.3	441.5	77
III	W_{III-1}	0.8	1.2	2/3	no	no	196.2	289.4	-
	W_{III-2}				1	no	225.6	323.7	12
	W_{III-3}				2	no	299.2	402.2	39
	W_{III-4}				no	yes	294.3	520.0	80

1 KN = 0.225 Kip.

*Gain in strength = (ultimate load of a panel - ultimate load of the reference panel) / ultimate load of the reference panel.

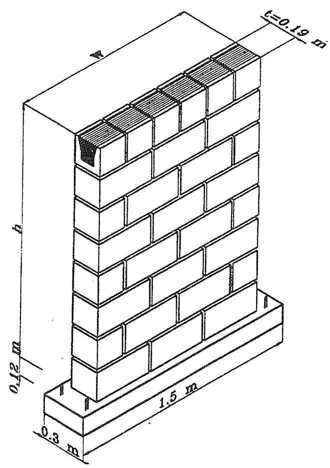

Fig. General configuration of a panel.

Fabrication of Specimens

All the specimens tested in this experimental program were built using standard normal weight 190 mm (7.48 in.) two-cell blocks. They were built by an expert mason in running bond pattern with full bedded mortar joints of 10 mm (3/8 in.) thickness. Figure 2 shows cross-sections in the four panels of group (I). For those panels with a grouted top course, the blocks of the second top course were filled with foam to hold the grout from running to the lower courses as indicated in Fig. 2(b). Similarly, the blocks of the third course were filled with foam to prepare the panels with two grouted courses. As indicated before, the fourth panel of each group had a bond beam. Forty eight hours after building these panels, top and bottom reinforcing bars were placed carefully in the bond beam. Bars of 10 mm diameters (i. e. 78.5 mm^2 (0.12 $in.^2$) cross-section area) were used. The grout was then poured to fill the desired courses or the bond beam.

Each of the panels was laid upon a reinforced concrete beam which was provided with four hooks to facilitate the handling of the panel.

Four-course prisms, both ungrouted and grouted, were also prepared with the panels to determine the compressive strengths of the masonry assemblages. They were stored and tested with the corresponding panels.

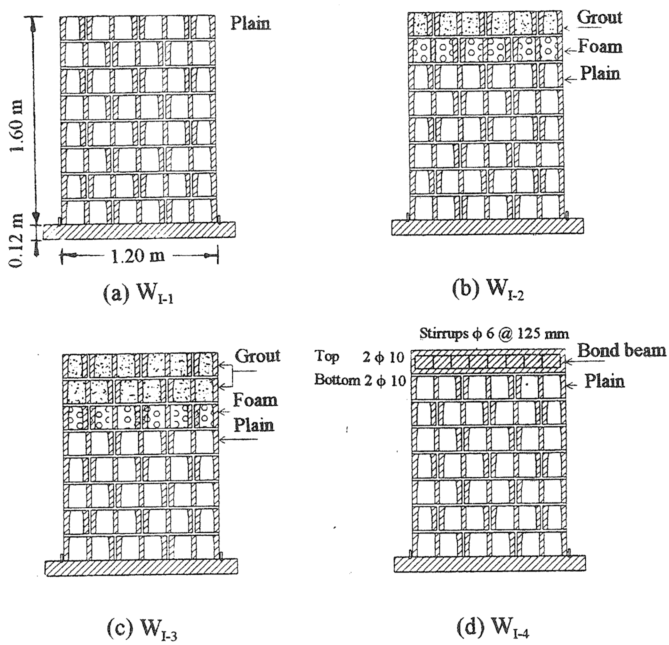

Fig. 2 Cross-section of the panels of group I.

Materials Properties
Type M mortar composed of 1.0:2.5 parts by volume of portland cement and sand was used throughout this program. The water-cement ratio of 0.75 was established to satisfy the mason's requirements for workability. Cubes of 70.6 mm (2.78 in.) were prepared as control specimens from each batch. They were water-cured. The average compressive strength determined after 28 days was 20.3 Mpa (2.94ksi) with a coefficient of variation of 11.9%.

Coarse grout consisting of 1.0:2.5:1.5 parts by volume of portland cement, sand and 10 mm (3/8 in.) pea gravel was used. A water-cement ratio of 0.6 was used. Absorbent prisms were block moulded with the dimensions of 90x90x190 mm (3.54x3.54x7.48 in.). They were tested under uniaxial compression and the obtained average strength after 28 days was 16.2 Mpa (2.35 Ksi) with a coefficient of variation of 6.0%.

It is important to indicate that, even with the differences between the methods used to define the material properties in this experimental program and those commonly used in North America, the results obtained from testing the panels are valuable information that shed light on the behaviour of masonry walls, with different h/w ratio, under concentrated loads.

Test Set-up
Each of the twelve panels was tested in a hydraulic machine of 2.5 MN (551 Kip) capacity and 4.9 KN (1.1 Kip) accuracy. As shown in Fig. 3, the machine had a moving upper head and a rigid floor which was used to support the panel. The concentrated load was applied at the top centre of the panel through a steel plate of 200x120x50 mm (7.87x4.72x1.97 in.) dimensions.

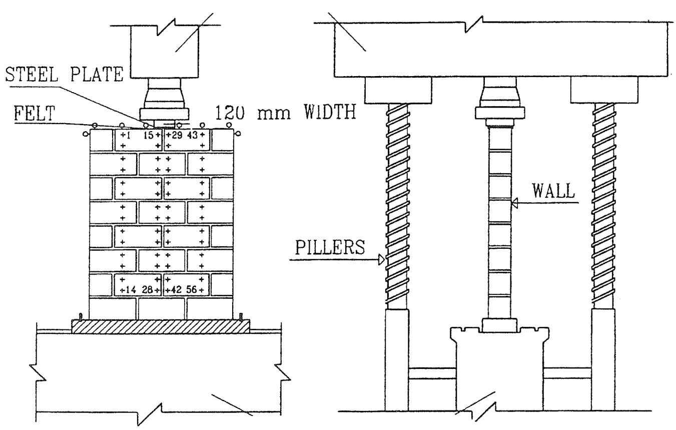

Fig. 3 Test set-up.

DISCUSSION OF RESULTS

Crack Patterns and Modes of Failure

Depending on the height to width ratio (h/w) and the top course condition, the panels exhibited different crack patterns and modes of failure. The crack patterns observed in the twelve panels are sketched in Fig. 4.

Group (I) [h/w=4/3]. The first crack in the plain panel W_{I-1} occurred just beneath the concentrated load. With the increase in the applied load, more cracks appeared and tended to propagate downward towards the base. These cracks were almost vertical with an angle, measured from the horizontal direction, in the range of 75-90°. The failure took place in the form of splitting cracks in the block face shells as well as the webs of the blocks beneath the concentrated load. Grouting the top courses of panels W_{I-2} and W_{I-3} resulted in significant increases in the cracking and failure loads. In panel W_{I-4}, the crack appeared first in the second course due to the existence of the bond beam. This splitting crack propagated downward similar to the previous panels, but with the formation of more splitting cracks in the bond beam as the applied load approached the failure load. Horizontal cracks were also observed along the bed joint just beneath the bond beam propagating from the ends towards the centre under the loading point.

Group (II) [h/w=1]. The failures of the four panels ($W_{II-1}$to W_{II-4}) took place by the formation of splitting cracks propagating downward almost vertically (with angles ranging from 70-90°). Grouting the top courses or having a bond beam improved the behaviour in terms of increasing the ability of the panel to sustain more load after cracking. These strengthening methods also resulted in a larger number of cracks which indicated a more uniform stress distributions.

Group (III) [h/w=2/3]. Unlike the panels of the previous two groups, the cracks tended to propagate diagonally towards the edges of the base at angles ranging from 45-60° measured from the horizontal direction. Fewer Cracks propagated vertically in some of these panels. This behaviour could be attributed to the reinforced concrete base which confined the lateral deformation of the masonry and thus restricted the propagation of the splitting cracks. Some of the cracks were observed to follow the mortar joints in a stepped manner, whereas some cracks propagated diagonally through the blocks. The modes of failure were diagonal failures rather than splitting failures. This change was also accompanied by significant increases in the cracking and the ultimate loads of the panels of this group compared to the previous groups.

Strength Characteristics

The cracking loads as well as the ultimate loads of the twelve panels are summarized in Table 1. Shown also in Figs. 5 and 6 are the variations of the cracking load and the ultimate load, respectively, with the height to width ratio. In these figures, the values recorded for the plain panels were used as reference for comparison to understand the effects of the different parameters considered on the behaviour of masonry under concentrated loads.

From the curves shown in Fig. 5, it is hard to define a consistent trend for the relationship between the cracking load and the height to width ratio. Comparing the curves of the cracking load for the panels with grouted top courses to that of the plain panels shows the effect of grouting one or two courses. Again, the inconsistency in these effects with the ratio of h/w is apparent in Fig. 5(a) and (b). Similar conclusion can also be drawn for the effect of having a reinforced bond beam (Fig. 5(c)). The obtained results also provided enough evidence to conclude that increasing the number of grouted courses increased the cracking load.

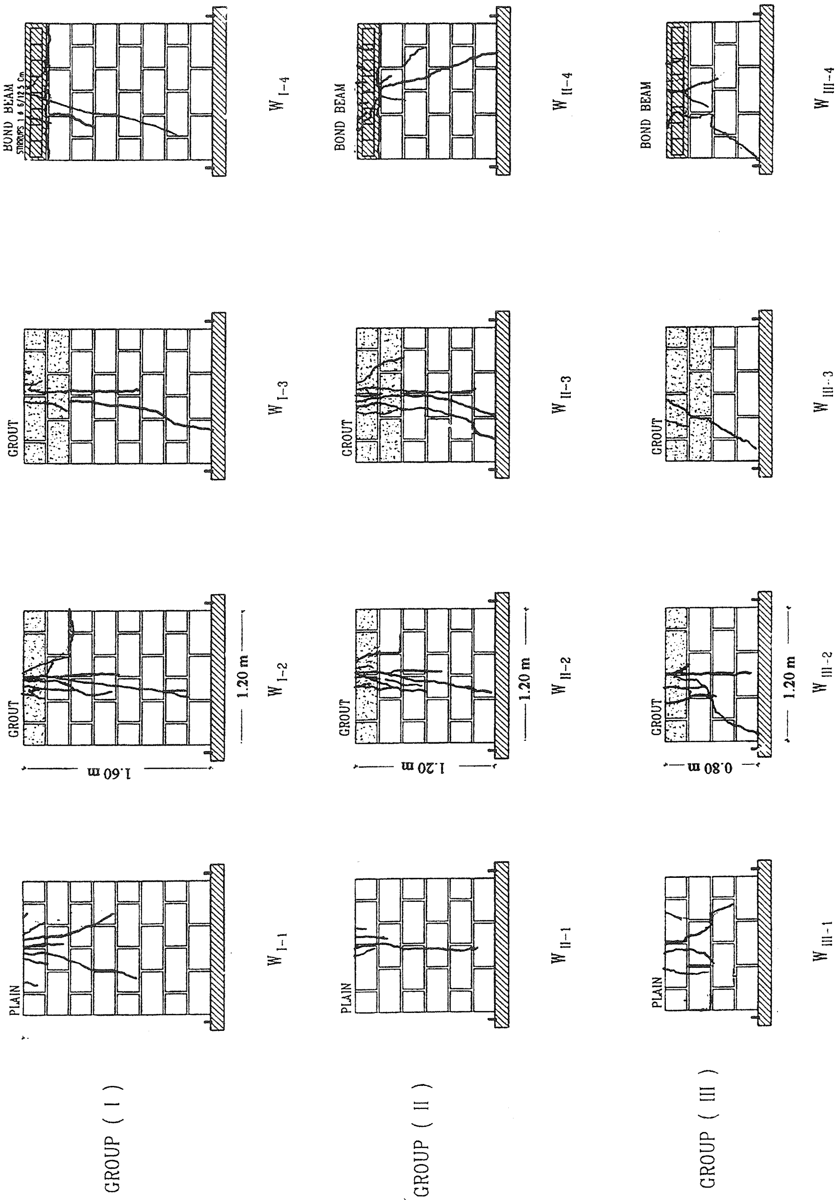

Fig. 4 Crack patterns of the panels.

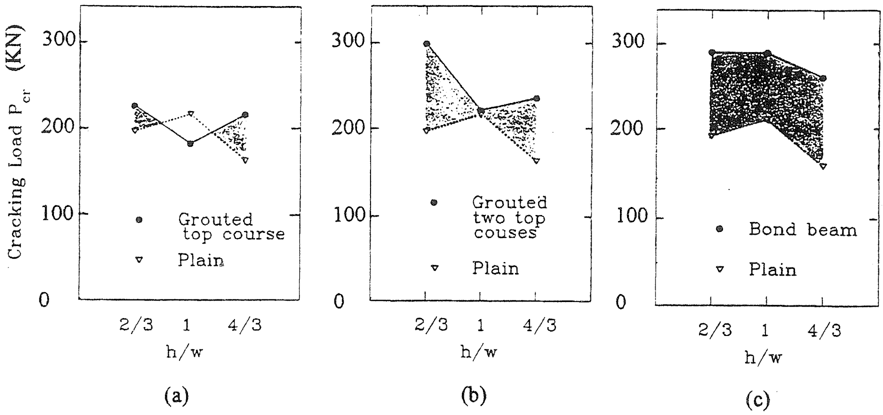

Fig. 5 Variations of cracking load with h/w.

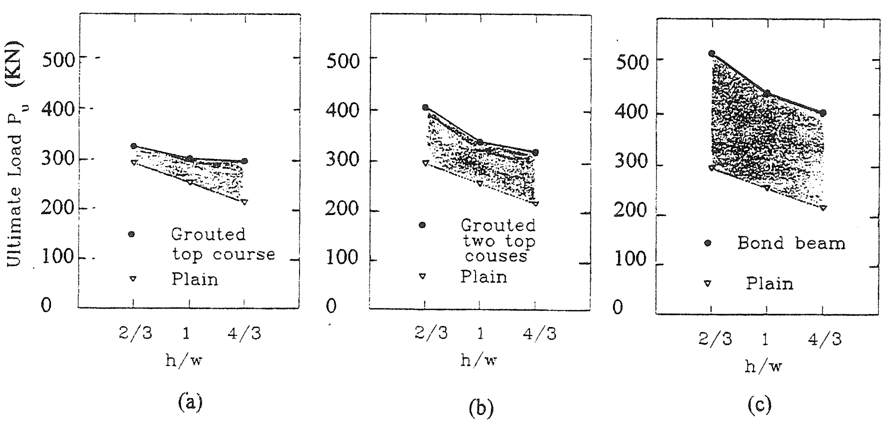

Fig. 6 Variation of ultimate load with h/w.

Having reinforced bond beam underneath the concentrated load had a more significant and consistent effect.

The results shown in Fig. 6 clearly indicate a consistent increase in the ultimate load with the decrease in the height to width ratio. The rates of increase are almost the same for the cases of plain panels, panels with two grouted courses and panels with bond beams. A lower rate of increase was observed for the panels with only the top course grouted. Based on these results, it is recommended that more tests should be done to determine the effect of adding a confining member, not only underneath the concentrated load, but also in the middle height of the wall. This confining member could take the form of a reinforced concrete beam or a reinforced bond beam which provides confinement against the lateral deformation and results in more uniform stress distributions.

The gain in the strength due to grouting the top courses or having a bond beam is represented in Fig. 6 by the shaded area between the corresponding curve and that of plain masonry. The calculated values are also given in Table 1. Grouting a top course increased the ultimate load of plain masonry by 12 to 40% with an average of 23.7%. The increase in the ultimate load was 33 to 49%, with an average of 40.3%, in the case of grouting the two top courses. Having a bond beam increased the ultimate load by 77 to 91% with an average of 82.3%. Therefore, using a reinforced bond beam underneath the concentrated load seems to be more efficient than grouting the two top courses.

CONCLUSIONS

The panels exhibited different behaviour depending on the height to width ratio and the condition of the top courses. In those panels with large height to width ratios (h/w=4/3 and 1), the cracks were mainly vertical splitting cracks which first formed just underneath the applied load. The crack patterns changed with the low ratio of h/w=2/3 to diagonal cracks through the blocks or/and following the mortar joints. The effect of the height to width ratio extended also to cover the ultimate load. Reducing the height to width ratio by introducing confining members in the middle height of the wall is thought to be a possible way to increase the ultimate load.

Grouting the top courses of the panels or having a reinforced bond beam resulted in a more uniform stress distribution in the wall. This in turn played a significant roll in improving the masonry behaviour under concentrated loads. Average increases in the ultimate load of 23%, 40% and 82% were observed, respectively, due to grouting one course, grouting two courses and having a reinforced bond beam.

ACKNOWLEDGEMENT

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