Behaviour of Reinforced Concrete Block Masonry Walls

Comportement des murs en maçonnerie avec renforcement en béton armé

Verhalten von Wänden aus Zementhohlsteinen mit Bewehrung

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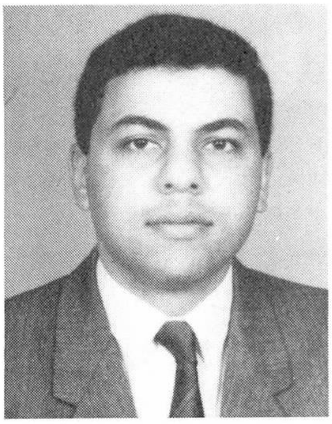

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SUMMARY

An experimental-theoretical study was conducted to investigate the general deformational behaviour of reinforced concrete block masonry walls. Seven specimens were tested under a concentrated load. The percentage of the vertical or the horizontal reinforcement was varied. The effect of the bond beam at the top of the wall was studied. The theoretical study was conducted using a non-linear finite element analysis. Some general conclusions are summarized.

RÉSUMÉ

Une étude expérimentale et théorique a été conduite afin de rechercher le comportement de déformation général des murs en maçonnerie avec renforcement en béton armé. Sept échantillons différents de mur ont été testés sous l'effet d'une charge concentrée, en faisant varier le pourcentage d'acier vertical ou horizontal. On a étudié l'effet d'une poutre de raidissement au sommet du mur. L'étude théorique a été conduite en utilisant une analyse des éléments finis non linéaires. Des conclusions sont présentées.

ZUSAMMENFASSUNG

Eine experimentelle und theoretische Studie wurde durchgeführt, um die allgemeine Verhaltensweise von Wänden aus Zementhohlsteinen mit Bewehrung zu ermitteln. Sieben Wände mit verschiedener senkrechter oder waagrechter Bewehrung, und verschiedener Bewehrung der oberen Verbundträger wurden getestet. Die theoretische Studie wurde unter Verwendung der nichtlinearen Finite Element Methode durchgeführt. Allgemeine Schlussfolgerungen werden dargelegt.

1. INTRODUCTION

Masonry structures are designed and constructed to sustain uniform loads coming from self weight, weight of slabs above, and superimposed loads, and lateral loads coming from wind, or seismic loads. Masonry structures are also subjected to concentrated loads, which can be the reaction of any cross beams dividing the slabs above. The code of practices have specified different methods for the design of masonry walls under concentrated loads. These methods do not differentiate between plain, or reinforced walls, or whether the walls with, or without a bond beam. These methods assume that the resulting stresses from the concentrated load can be considered uniform within the wall, at a certain height of these walls.

The present study aims to investigate the general deformational behaviour of reinforced masonry walls under concentrated loads. The effect of the vertical and horizontal reinforcement, on the resulting stress distribution within this type of walls, was taken into consideration. Also, the effect of the bond beam at the top of the wall, on increasing the ultimate carrying capacity of the reinforced masonry walls, was included. A comment on the resulting stress distribution in the light of the code provisions, as well as, a comparison between the behaviour of the plain and reinforced walls, are given.

2. THE EXPERIMENTAL WORK

2.1 Materials

The block units were of the two hollow core concrete block type of nominal dimensions 40 x 20 x 20. The average compressive strength was 200 kg/cm^2. The mortar was designated as a PL mortar (ASTM C-476). The average compressive srtrength was 255 kg/cm^2 after 28 days. The grout used in filling the bond beams and the vertical cores, was of a coarse grout mix according to (ASTM C-476), with average prism strength after 28 days equal 165 kg/cm^2. The steel reinforcement was of the normal mild steel with a yield strength of 2500 kg/cm^2.

2.2 Test specimens

Seven reinforced concrete block masonry walls were constructed with overall dimensions 1.20 m width x 1.00 m height x 0.20 m thickness. The walls were erected on a reinforced concrete beams to serve as bases for the specimens. The walls were reinforced vertically and horizontally, and fully grouted, as shown in fig. 1. Six of these specimens had a bond beam at the top of each wall, with the same width and thickness as the specimens, and of 0.20 m height. The bond beam reinforcement was 2ϕ13 lower, 2ϕ10 upper, and 6ϕ6 as stirrups. The vertical reinforcement was varied in 3 specimens, while the horizontal reinforcement was varied in another 3 specimens. The seventh specimen was constructed without a bond beam at the top, but with the dimensions and reinforcement as one of those with a bond beam.

2.3 Testing

The walls were loaded by a single concentrated load applied at the top mid point of the wall. The load was increased from zero up to the failure load. During the testing, the strain measurements across the mortar joints and in the steel reinforcement, were measured. Also, the deformations of the walls were observed at different load stages.

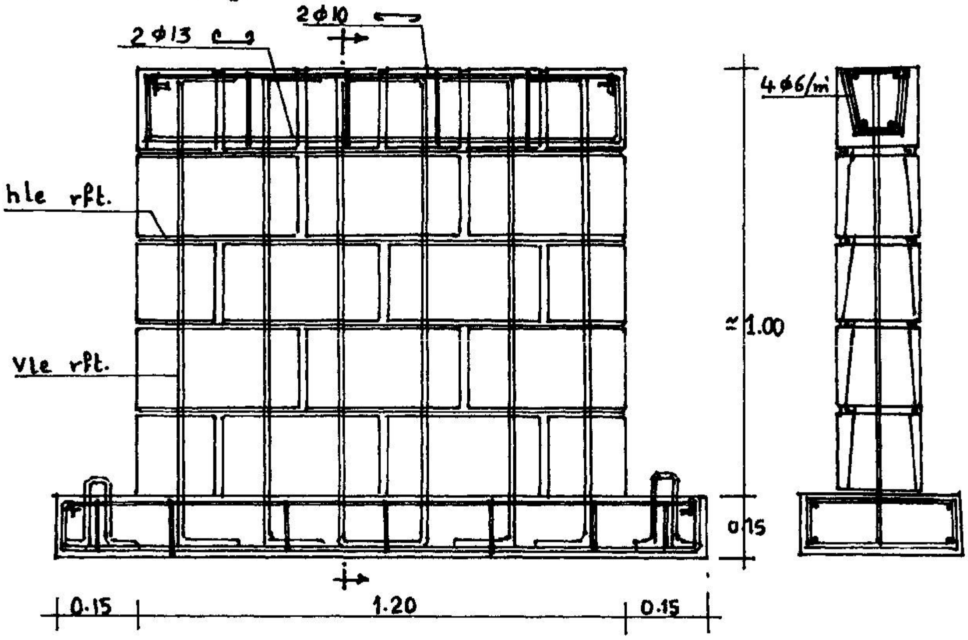


Fig.1 Details of the reinforced walls

3. RESULTS AND DISCUSSION

3.1 Crack pattern and failure mode

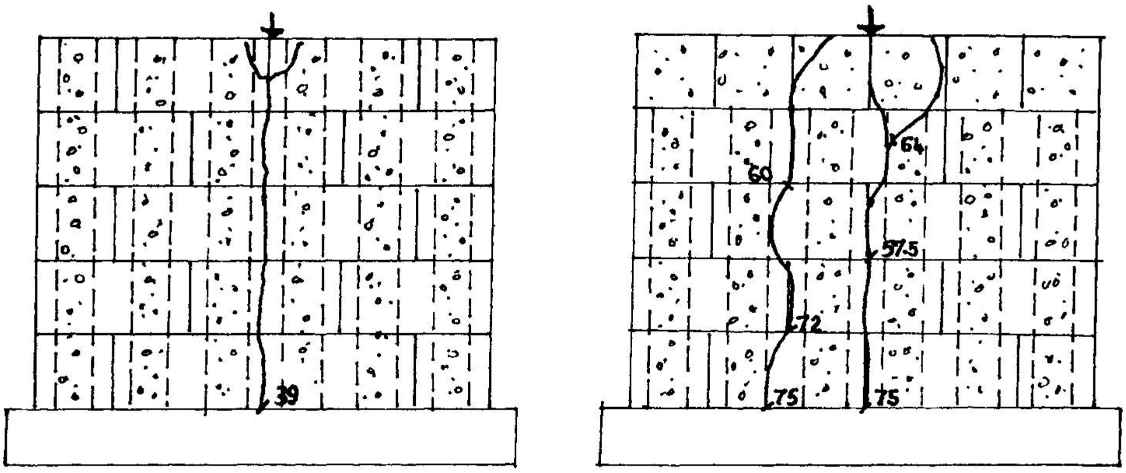
The behaviour of the tested walls with a bond beam at the top was almost the same. At a load level ranging from 50 to 60 % of the ultimate load, the face shells of the lintel units directly beneath the load, spalled off. This may be attributed to the lateral expansion of the grout in the bond beam, which produces out-of-plane bending stresses on the face shells of the lintel units.

The first crack appeared at the second course beneath the applied load at a load level ranging from 55 to 85 % of the failure load as shown in table 1. This crack was vertical and separating the grout from the units beneath the applied load, splitting the blocks' face shells, and debonding the vertical mortar joints. The major crack extended through the total height, at the middle width of the wall as shown in fig. 2.a. The failure occurred mainly due to the lateral tensile forces induced from the concentrated load.

The wall without a bond beam was failed also by splitting of the blocks' face shells. The failure was sudden as there was no cracks appeared before failure, as shown in fig. 2.b. The failure load was about 50 % of the failure load of the wall with the bond beam.

Wall	vle. rft. per core	hle. rft. per joint	bond beam	cracking ld. tons	ultimate ld. tons
W1	1φ13	2φ6	No	39	39
W2	1φ13	2φ6	Yes	57.5	75
W3	1φ10	2φ6	Yes	60	70
W4	1φ16	2φ6	Yes	77.5	77.5
W5	1φ13	2φ4	Yes	50	75
W6	1φ13	---	Yes	45	80
W7	1φ13	2φ6	Yes	59	76.5

Table.1 Cracking & ultimate loads of the tested walls

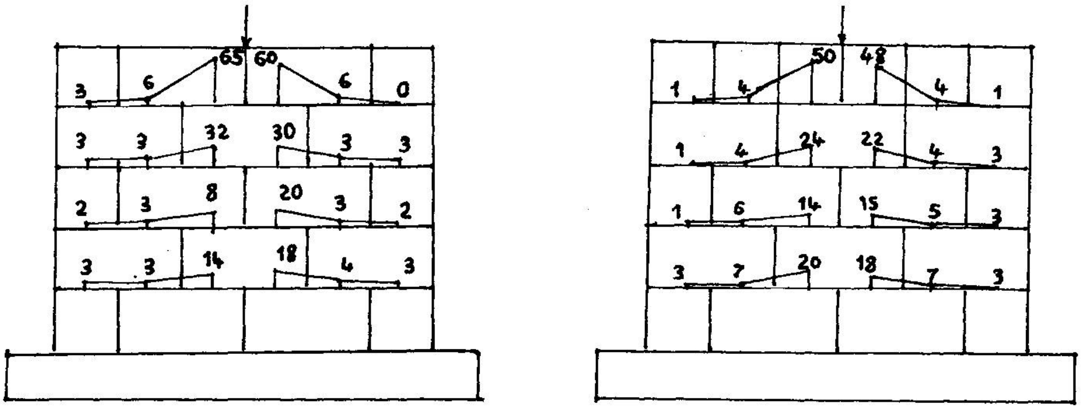


wall without a bond beam wall with a bond beam

Fig. 2 Crack pattern of the reinforced walls

3.2 Strain distribution characteristics

The characteristics of the strain distribution within the walls with and without the bond beam, were rather similar. The strains were concentrated over the area of the two grout columns beneath the applied load, and decreasing through the depth of the wall. However, the strain distribution at the edges increased through the depth of the wall. The vertical strain values under the concentrated load for the wall without the bond beam, was about 40 % higher than that of the wall with the bond beam, as shown in fig. 3. However, the vertical strains can not be considered uniform at any horizontal section within the wall.



wall without a bond beam wall with a bond beam

Fig. 3 Vertical strain distribution in the reinforced walls

4. THE THEORETICAL WORK

The wall panels were analysed using a finite element technique which considers the cracking of the blocks and the grout, and the non-linear behaviour of the mortar. Four different types of elements were used in the analysis of these walls, as shown in fig. 4.

1- Grouted block element: represents the grout and the blocks, with average material properties. the biaxial state of stress was considered in the failure criterion of this element. Also, the effect of the cracking of this element was introduced.

2- Grout element: represents the grout contigeous to the horizontal mortar.

3- The horizontal and the vertical mortar joint elements: represent the bed and the head joints. A failure criterion was set for these elements taking into consideration, the shear-tension, and shear-compression state of stress. The non-linearity of the stress-strain relationship of mortar in compression, was also included.

4- The steel element: used to represent the steel reinforcement with a perfect bond with the grout. It is assumed to carry a uniial load only.

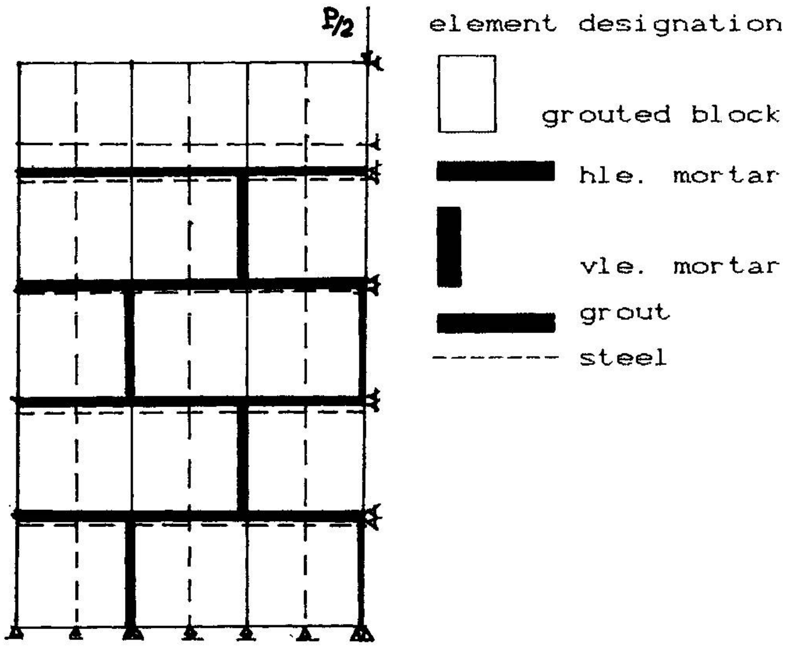


Fig. 4 Idealized model for a wall with a bond beam.

4.1 Results of the theoretical work

For walls with and without a bond beam, the predicted crack pattern was similar to the observed one. The failure mode of the walls was due to the splitting force induced in the wall. The predicted cracking and failure loads of the walls, were higher than the observed values, with about 12 % .

The characteristics of the predicted strain distribution, were also similar to those obtained experimentally.

It has been noticed that, increasing the percentage of the vertical reinforcement increases the ultimate capacity of the wall, as well as decreases the total vertical deformation. Also, the increase of the horizontal reinforcement, increases the cracking load and the ratio between the cracking to the ultimate load.

5. COMMENT ON THE CODE PROVISIONS

The stress distribution within the walls obtained experimentally and theoretically, was compared with those obtained from the ACI code, and the British standards. A large deviation was observed as those obtained from the codes were uniform, while the predicted and observed stresses were concentrated over the area under the concentrated load, and can not

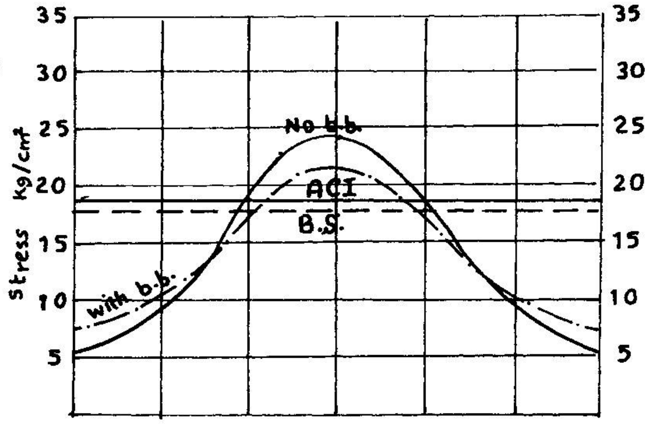


Fig. 5 Vle. stress distribution

be considered uniform at any horizontal section as shown in fig. 5. For walls with and without a bond beam at the top, the maximum stresses under the concentrated load, were about 20 and 35 % respectively higher than those obtained from the codes.

6. COMPARISON BETWEEN THE REINFORCED AND PLAIN WALLS

A comparison was conducted between the behaviour of the reinforced and the plain walls.[4] The cracking of the plain walls, started at about 50 % of the failure load, and the cracks were inclined. While the cracking load of the reinforced walls was about 75 % of the ultimate load, and the cracks were vertical at the mid-width of the wall. the failure mode of both types of walls, was mainly due to the splitting of the block units. For the plain walls provided with a bond beam, the strains were assumed to be uniform at 0.4 the wall height from the top, and following 45° with the horizontal. While, for the plain walls without a bond beam, the strains were uniform at 0.6 the wall height from the top, and following 60° with the horizontal. While, for the reinforced walls, the strains were concentrated beneath the concentrated load, and were not uniform at any horizontal level.

7. CONCLUSIONS

1. Adding a bond beam at the top of the wall, increases the failure load significantly, and prevents the occurrence of the sudden failure.
2. Increasing the percentage of the vertical reinforcement, increases the failure load, and decreases the total vertical deformation of the walls.
3. Increasing the percentage of the horizontal reinforcement, increases the cracking load, and the ratio between the cracking to the ultimate load.
4. The vertical strain distribution can not be considered uniform at any horizontal section. It is concentrated over the area of the blocks containing the two grout columns under the concentrated load.

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