Seventh Canadian Masonry Symposium
McMaster University
Hamilton, Ontario June 4-7, 1995

THE RESEARCH OF LOAD CARRYING CAPACITY OF REINFORCED CONCRETE-BRICK COMPOSITE WALLS UNDER VERTICAL LOADING CONDITION

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ABSTRACT

In this paper, the research work in the field of composite masonry are reviewed. The formulae of predicting load-carrying capacity of the composite masonry under horizontal or vertial loading condition are summed up. Based on the experimental results and the analysis results of finite element method, the behavior and failure modes of reinforced concrete-brick composite wall under vertial loading are analysed, especially under opening condition. Based on the experimental results of 6 pieces of brick masonry walls and the analysis results of finite element method, discussion is carried out on the relationship between the opening rate and the load-carrying capacity. By analysing results, the formula of calculating the load-carrying capacity of reinforced concrete-birck composite wall under opening condition is proposed. The predicting results are in good agreement with the test results.

Reinforced concrete-brick composite walls are formed by improving the effectiveness of the constructive frames, in which the pillars and beams of the frames are not only constructive elements but also bear some vertical and lateral load respectively. According to the Chinese Design Code for anti-seismic structures,

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buildings with normal constructive frames should be no more than seven storeys in the seven-seismic degree regions. This research is a brave attempt to develop the reinforced composite structures in China. No similar study is reported up to now. Although some institutes in China had made some experiments in this field, the study on the reinforced concrete-brick composite wall with opening is not sufficient.

ANALYSIS OF THE COMPOSITE WALL BY FINITE ELEMENT METHOD

By use of finite element method, the characteristics of stress distribution in the significant controling sections were obtained, so were the effects of many factors such as the number of storeys, the height of storey, the spacing of pillars and the size of opening on the load carrying capacity of the composite wall.

The spacing of pillars effects significantly the load carrying capacity of the reinforced concrete-brick composite walls without opening, and the smaller the spacing is, the more evidently the capacity is influenced. Under the condition of opening, the main factors influencing the load carrying capacity of the composite wall are the opening rate and the spacing of pillars. The higher opening rates and the larger spacing of pillars are, the lower the capacities are. If the materials and the sections remain constant, the increasing of layers of the composite wall will intensify the load transfering from the brick wall to the concrete pillars, and this will result in the decreasing of the stress in the brick wall and enhancing the load carrying capacity of the composite wall.

EXPERIMENT RESEARCH

Loading Equipment

The loading equipment consists of pressure frame, load distributing beams and hydraulic jacks, as shown in Fig. 1.

Specimens

Our experiment included six specimens of which four are composite walls with openings and others without openings. The spacings of pillars were 3.5m and 2.5m, and the opening rates were 0.35, 0.34, 0.24 and 0.20 respectively. Selected materials were MU 7.5 brick, M5.0 mortar, C_{20} concrete and I grade steel. The sections of pillars and beams were 240mm×240mm. The pillars were reinforced by steel bars of 4φ12, and the beams by steel bars of 5φ12. The pillars and beams were cast after the brick wall was made up. According to the loading capacity of the equipment, the sizes of all the specimens were reduced to their halves.

Deflection Property and Strain of the Composite Walls

According to the experiment results shown in Fig. 2, we conclude that as following:

The distribution of ε_y in section A-A shows that both the concrete pillars and the masonry are in compressive condition with a stress concentration region on the upper edge of the opening.

In section B-B most part of the concrete pillars and the masonry are also in compressive condition. The strains ε_y in a region just beneath the lintel are evidently larger, and the enlargement of ε_y in the region increases with enlarging the rate of opening. Only a small part of masonry on the edge of the opening is in tension.

The strains ε_y in the lower portion of the pillars are larger than those in the upper portion, strains ε_y on the exterior surface of the pillars are larger than those on the interior surface, and the steel bars near the outside of the pillars' bottom section are of the highest stress.

The distribution of strains in the concrete pillars shows clearly that the stresses were transfered from the mansory to the concrete pillars. The pillars have certain restrictive effect on the masonry nearby. The restrictive effect depends on the size of opening, and the affected range will not be larger than 1.0m away from the interior side of the pillars, even if without opening.

Because of the opening, the deflections in the upper part of the opening are somewhat larger.

Failure Pattern

Failure pattern for composite walls without openings. Experiment revealed that specimens loaded to failure had experienced three stages.

Stage 1: This stage starts from the begining of loading and ends when the first crack appears. At this stage, the strains inerease with loading, and the deformation of the composite walls could be reversed with unloading. So, this stage is considered as elastic. The values and distribution pattern of stresses obtained from the experiment are similar to those obtained by finite element method. Stresses σ_y in the walls decrease along from top section to bottlm section, and stresses σ_y at the middle part of the section are larger than those at the parts near the concrete pillars in the same section. Conerete stresses and steel stresses of the lower parts of the pillars are larger than those of the upper parts. The first crack usually appears at the middle part or the upper part of the masonry when the load is approximately the half of failure load.

Stage 2: At this stage, with increasing the load, many new cracks appear at the middle part or upper part of the masonry and would develop downward in the vertical direction, showing the tendency that cracks reach the pillars' bottoms. However, the development of the cracks is slow because of the restrict effect of the concrete pillars. Stresses σ_y in the masonry increase more slowly than those in the concrete pillars, and the increasing of stresses σ_y in the bottom sections of the pillars is much evident. As far as the beam is considered, steel bars' stresses in the middle part of the beam are larger than those in other parts. Obsearving the variation of stresses σ_y in the masonry, we could see that stresses in the middle span increase more rapidly than in the area near the pillars. And the closer to the pillars the area is, the more slowly the stresses σ_y increase. This shows that the stresses transfer from masonry to the pillars. In this stage the deformation, both in vertical and in lateral, is larger than that in stage 1.

Stage 3: By loading furthermore, crcaks appeared previously develop more quickly to the bottoms of the pillars, even through the thickness of the masonry. In this stage, many cracks could be found at the lower surface of the beam which would develop upward due to tensile stresses. In specimen ZQ-2, some cracks could also be found at the lower parts of the concrete pillars. At the end of this stage, the middle part of the masonry reaches its ultimate strength. Then, the specimen is considered failure because the load could not be added further. Because the minute cracks in the parts near the pillars could be seen only when the specimen is nearly failure, the cooperation of concrete pillars and the masonry is reliable during the whole loading procedure.

Failure pattern for composite walls with openings. According to test results of four composite walls with openings, the whole loading procedure can also be divided into three stages.

Stage 1: This stage starts from the begining of loading and ends when the first crack appears, just the same as in the condition of composite walls without openings. With loading, stresses at the upper corners of the opening and beneath the lintel increase more rapidly than in other area of masonry, showing the stress concentration. On the other hand, stresses beneath the opening are much small, and this means that this part of masonry has little contribution to the whole specimen. In the concrete pillars, the compressive stresses at lower part are larger than those at upper part, showing that stresses have been transfered from masonry to pillars. In this stage, neither the lateral deformation nor the vertical deformation is large. When the principal strain, at the upper corners of the opening, reaches the ultimate tensile strain, the first crack will appear at the corner. This stage can be considered elastic, and the load comes up to 25~30% of the failure load.

Stage 2: Increasing the load, we can observe that the crack in the masonry appeared in the first stage develops, and that new cracks occure near the upper corners of the opening. These new cracks will develop along the directions of the principal compressive stresses, having the tendency to reach the bottoms of the pillars.

Stresses σ_y in this region increase with loading, and the stresses reach the ultimate value when the load is approximately 70% of the failure load. Although the stresses in the upper corner areas have reached their ultimate value, the specimen as a whole is still effective, being capable of working further. Now, a couple of arches are formed due to the cracks. The outside arch consists of the concrete beam, the concrete pillars and the masonry near the pillars. The inside arch consists of the lintel and the masonry beneath and above the lintel. In this period of time, the stresses of the concrete and of the steel of the pillars develop rapidly, but the stresses in the masonry near the pillars increase slowly. And this means that the redistribution of the stresses is more obvious than before. The mechanical model is shown in Fig. 3.

Stage 3: When the penetrative cracks have formed, the couple of arches are shaped. Then the added load will be mainly supported by the outside arch. With loading, the stresses and the deformation in the middle and at two ends joining the pillars of the concrete beam increase. And the concrete cracks, and the steel bars become yielding. Gradually, the plastic hinges are formed in the outside arch. After that, the proportion of load sustained by the inside arch will increase quickly and the stresses in the masonry on the sides of the opening beneath the lintel will develop rapidly because of the stress concentration. At the end, the whole specimen fails when the stresses in the masonry reach their ultimate compressive strength. Sometimes, the masonry could be crashed because of compression. At this time, the steels in the middle of the beam and in the lower parts of the pillars are near the state of yielding.

During the tests, the masonry and the concrete pillars cooperated very well. Four specimens with opening did not collapse.

CALCULATION ON LOAD CARRYING CAPACITY

Calculation on Load Carrying Capacity of the Composite Wall Without Opening

The enhancement factor γ_a equals to the ratio of the ultimate load value of composite wall to that of pure masonry wall. In table 1, some values of γ_a with various spacings of concrete pillars are shown.

Table 1. γ_a obtained from test

spacing of pillars L (m)	1.00	1.75	1.80	2.00	2.50	2.92	3.20	3.52
γ_a	2.67	1.27	1.56	1.51	1.34	1.61	1.20	1.55

By means of regressing, we can get the relationship between L and γ_a as follows

$$\gamma_a = 1.89e^{-0.6L} + 1 \quad (1)$$

Calculating height of the masonry H_0. The calculating height, H_0, of the masonry can be determined as follows.

$$H_0 = \begin{cases} 0.6L & (L > H) \\ 0.4 + 0.2H & (2H \geqslant L > H) \\ 1.0H & (L > 2H) \end{cases} \quad (2)$$

in which H is the height of the wall.

The longitudinal bending factor, φ, of pure masonry wall can be obtained as follows

$$\varphi = 1/(1 + \alpha\beta^2) \quad (3)$$

in which

α: parameter related to the strength of mortar. α=0.0015 when the strength is higher than M_5.

β: the ratio of the height to the thickness of the wall.

Load carrying capacity of masonry wall. The capacity of the masonry wall

$$N = \gamma_a \varphi f A \quad (4)$$

in which, N represents the axial force under the action of designed load, A is the section area of the wall, and f is the designed strength of the masonry.

Loading Capacity of the pillar. The capacity of the pillar

$$N = q[L - (L - b)/\eta] \quad (5)$$

in which

q: distributed load on the wall

b: width of the pillar

$$\eta = (A_m + A_c E_c/E_m)/(A_m + A_c) \quad (6)$$

In equation (6), A_m and A_c represent the section areas of the masonry wall and of concrete pillars respectively, and E_m and E_c the moduli of the masonry and of the concrete respectively.

Calculation on Load Carrying Capacity of Composite Wall with Opening

Strength reducing factor γ_b. In order to calculate the load carrying capacity of composite wall with different opening rates, we have analysed the strength reducing factor γ_a for the composite wall with a single opening by means of the finite element analysis program ANSYS. All the analysed models have the same spacing of pillars, but the openings are different. In calculating, we assumed the brick

MU7.5, the mortar M 5.0, concrete C_{20} and I grade steel bar. The sections of concrete beams, pillars and the lintels were the same, 240mm×240mm. The concrete beams and pillars were reinforced with steel bars of 4φ12, and the lintels were reinforced with steel bars of 5φ12. The height of specimens were 2.8m. The tests revealed that there are linear relationships between the capacities and the stresses of the steel bars at the bottoms of the pillars before the ultimate load. The turning points in the curves, shown in Fig. 4, indicate the load transfering from the masonry to the pillars after the cracks appear in the masonry. So, the curves representing the relationships between the loads and the steel stresses at the bottoms of the pillars reveal the loading characteristic of composite wall. In calculating, if the steel stresses at the bottoms of the pillars reach certain values, the ratios of corresponding load on walls with openings to those on walls without openings were taken as the factors γ_b. In this way, the ratios of steel stresses at the bottoms of pillars in the walls with openings to those in the walls without openings under the same loading condition are just the factors γ_b. Some values of γ_b are shown in table 2.

Table 2. Calculated factors γ_b

Spacing of pillars (mm)	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
opening size (mm)	0	250	570	700	857	1000	1200	1500	1650	1780	2260
opening rate μ	0	0.100	0.228	0.280	0.343	0.400	0.480	0.600	0.660	0.712	0.904
factor γ_b	1	0.905	0.808	0.771	0.730	0.695	0.650	0.601	0.546	0.546	0.277

By regressing, we can get following formula

$$\gamma_b = 1 - 0.7\mu \tag{7}$$

The calculating height H_0 can still be determined by equation (2), but the longitudinal bending factor φ should be the stable factor of axial-loaded reinforced masonry.

Load carrying capacity of masonry wall with opening. The load carrying capacity of masonry wall with opening can be expressed as follows

$$N \geqslant \gamma_a \gamma b_\varphi f A \tag{8}$$

This formula is in good agreement with tests, and this can be shown in following table 3.

Table 3. Comparison load carrying capacity from test with those from calculation

specimen	Spacing of pillars (mm)	γ_a	opening rate μ	γ_b	factor for size-effect	load capacity from test p^t_μ (N/mm)	load capacity from calculation P_μ (N/mm)	P_μ/P^t_μ
2Q-3	1460	1.14	0.24	0.832	0.83	123.6	124.8	1.010
2Q-4	1460	1.41	0.34	0.762	0.83	123.6	114.0	0.922
2Q-5	1760	1.22	0.35	0.755	0.83	94.8	98.4	1.038
2Q-6	1760	1.22	0.20	0.860	0.83	145.2	112.8	0.777
awerage								0.937
variation factor								0.108

Load carrying capacity of pillars. Under the condition that the added bending moment is insiginficant, we can get

$$N = q[L - (L - b)/\eta] + q\mu L \tag{9}$$

If the added bending moment is significant, we have to make checking computations on the pillars.

Checking computations on the local compression of masonry beneath the lintel. In checking, we should ensure

$$\varphi N_o + N_L \leqslant \eta\gamma f A \tag{10}$$

in which

φ: reducing factor of upper load

η: compression pattern factor on the bottom surfaces of the beams' ends, $\eta=1$

N_L: supporting pressure at the beam's end under designed load.

While

$$\varphi = 1.5 - 0.05\, A_0/A_L \tag{11}$$

CONCLUSIONS

The composite wall will experience three stages: elastic, cracked and failure stage.

The significant factor influencing the load carrying capacity of composite wall without opening is spacing of pillars, and that of composite wall with opening is the opening rate.

The load carrying capacities of composite walls without and with openings can be estimated with equatious (1)~(6) and equations (7)~(11) respectively. And the test results are in good accordence with calculation.

REFERENCES

1. Chinese Standard (1988): Design Code for Masonry Buildings, GBJ 3-88.
2. Yiliang Qian and Chuxian Shi (1989), Proceedings on Masonry Buildings, Hunan University Press, P. R. China.
3. Yahan Shong (1993, 12), The study of behavior of the concrete-brick composite wall loaded in vertical direction, Research on Construction, Education Ministry of P. R. China.
4. Xingzhi Cheng (1991, 6), Compressive load carrying capacity of reinforced concrete-brick wall, Journal of Hunan University.

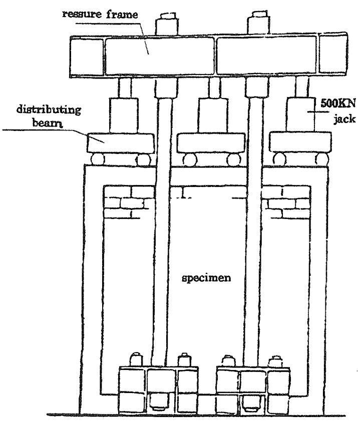

Fig.1. Loading equipment

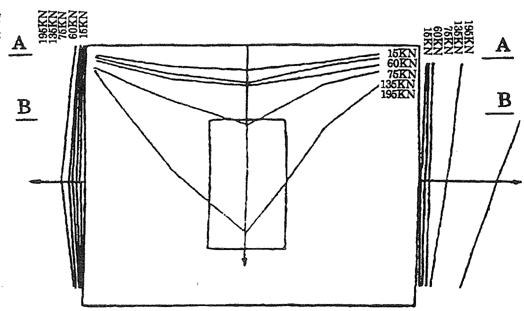

Fig.2. ZQ-3

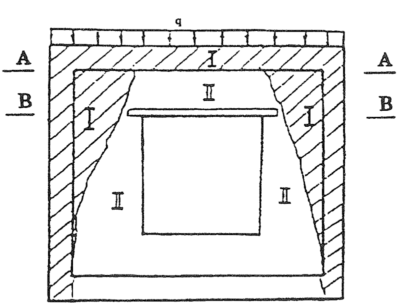

Fig.3. Bearing model

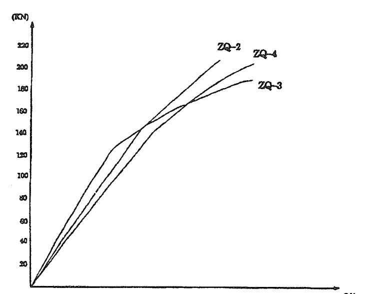

Fig.4. Relationships between load and steel stresses in the bottoms of concrete pillars