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EXPERIMENTAL STUDY ON HOLLOW BLOCK MASONRY WALLS FILLED WITH FOAMING CONCRETE

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ABSTRACT

Experiments on hollow concrete block walls with good thermal properties have been conducted. The materials are intended in such a way as to help retain room temperature in any surroundings especially in winter or summer and not to be influenced by the ambient temperature. The walls were constructed with and without filling by foaming concrete. This paper studies their failure modes, ultimate shear strength, deformation properties and seismic behaviour. The results indicated that filling hollow concrete block walls with foaming concrete can both enhance the cracking strength and ultimate strength of the wall, as well as improve the shear strength of the hollow block concrete masonry.

KEYWORDS: hollow concrete block, walls, filled foaming concrete, Seismic behaviour

INTRODUCTION

Along with the development of energy conserving buildings and wall materials, small hollow concrete blocks (dimensions of 390 mm×240 mm×190 mm) are becoming more widely used as a new type of wall material replacing fired clay bricks in the advancement of single family homes and larger multi-storey residential structures in China. At present, the annual production of concrete blocks is as high as 40 million m^3 covering an area of up to 90 million m^2. Buildings built with concrete blocks have the advantages of energy saving, land conservation, environment protection and sustainable development. However, some general problems that are known from the use of concrete blocks in practice are the poor crack resistance, poor seismic behaviour, and bad energy saving effect because of the deficiency of tensile strength, shear strength and thermal insulation property of the concrete masonry walls. The goal of the present study is to promote the use of masonry structures for energy saving and seismic behaviour by investigating the behaviour of masonry structures which have both good thermal properties, and good crack resistance.

In order to improve the thermal properties of the concrete hollow blocks, the holes of hollow block walls were filled with foaming concrete. A comparative experimental study between the walls filled foaming concrete and those without foaming concrete was conducted to study the failure mode, cracking load, ultimate load, and deformation ability under low-cyclic reverse load.

DESIGN AND CONSTRUCTION OF SPECIMENS

In order to compare the seismic behaviour of the walls built using small hollow blocks with and without filling by foaming concrete, two types of wall specimens were made. One of the walls was SW1 with foaming concrete in it, and the other wall was SW2 without foaming concrete. The former has met the thermal demand. Those walls were built of small 3-row-hole hollow concrete blocks manufactured by Yancheng New Wall Materials Factory (34% hollow). The analysis shows that the thermal resistance of the blocks filled with thermal insulation materials meets the demands for such properties in new wall materials. There were two basic types of concrete hollow block units: main block was 390 mm×240 mm×190 mm, secondary block was 190 mm×240 mm×190 mm; the compressive strength for both types was MU10.

The dimensions of the walls were 1800 mm×2400 mm and the thickness of the walls was 240 mm with ratio of height to thickness of 0.75. M7.5 mortar was adopted for the small-size hollow concrete blocks. On each end of the wall concrete columns with the same width as the walls were constructed. The columns were reinforced with 4 12 mm ϕ longitudinal bars and 6 mm ϕ ties @ 200 mm spacing. After the construction of masonry blocks, the concrete was cast for the columns, which were connected to the walls through a combination of joints and ties with the use of frameworks. There was also a beam constructed at the top of the wall with a cross-section of 200 mm×240 mm, and reinforced with 4 12 mm ϕ longitudinal bars and 6 mm ϕ ties @ 200 mm spacing. In the ends of the beams and the columns the ties had closer spacing. The columns and the beams were all cast with C20 fine aggregate concrete. A bottom beam with a section of 300 mm×450 mm was also used and connects to the wall in order to simulate the solid boundary conditions of the bottom of the wall. The dimensions of the specimens and the sections are shown in Figure 1.

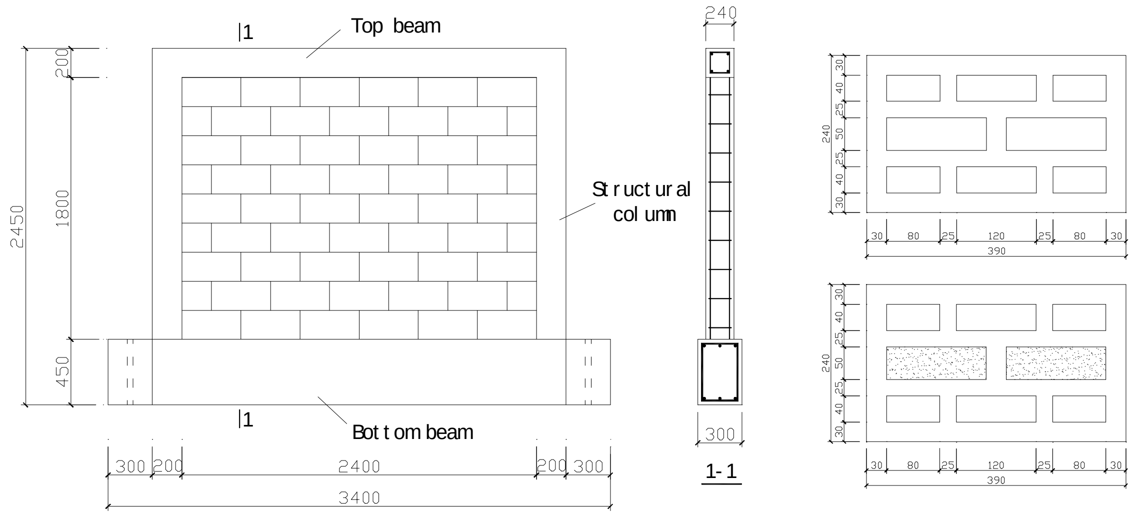


Figure 1 –Specimen Dimensions

SW1 and SW2 were built according to common construction method. The central row of holes of the blocks of wall SW1 were left hollow for the convenience of filling with foaming concrete and the other two rows of holes were covered. All the holes of the blocks of wall SW2 were covered so that it was easy to lay the mortar. The foaming concrete grout was made on the spot and when the wall reached some height, the holes were filled with foaming concrete and the concrete was vibrated with a stick vibrator. After that more foaming concrete was added to fill the holes flush.

MATERIAL PROPERTIES

Specimens for testing the compressive strength and shear strength of the hollow concrete blocks and masonry were made when the walls were built. At the same time, a number of mortar cube specimens for the masonry and the structural columns were cast and cured under the same conditions as the walls. All the mechanical properties of the hollow concrete blocks and masonry are shown in Table 1, Table 2, and Table 3, respectively.

Table 1 – Mechanical Properties of Hollow Concrete Blocks and Masonry

Type	Size	Compressive Strength (MPa)	Shear Strength (MPa)
Unfilled concrete block	390mm×240mm×190mm	10.74	–
Filled concrete block	390mm×240mm×190mm	8.8	–
Unfilled concrete block masonry	390mm×240mm×590mm	4.21	0.09
Filled concrete block masonry	390mm×240mm×590mm	4.36	0.11

Table 2 – Indexes of Mechanical Properties of Mortar and Concrete

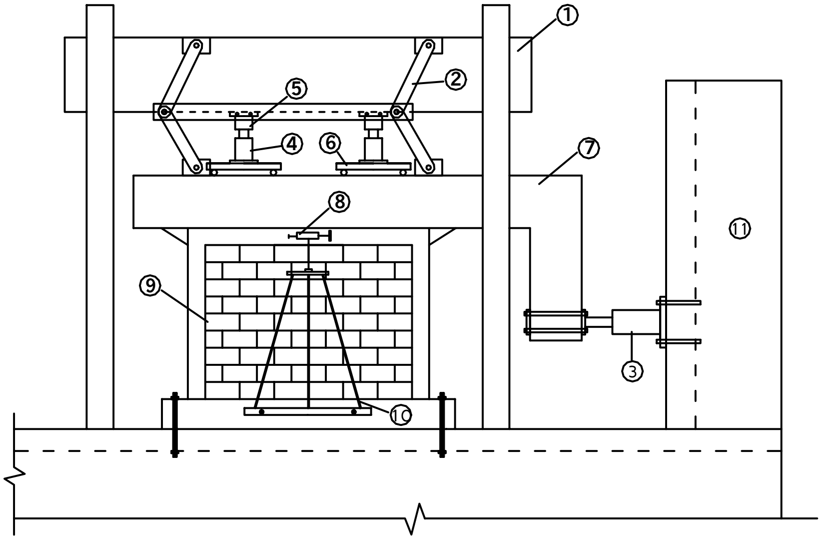
Type	Design Strength (MPa)	Experimental Crushing Strength (MPa)
Mortar for Masonry	10	10.03
Concrete for Beams and Structural Columns	20	19.8

Table 3 – Indexes of Mechanical Properties of Steel Bars

Type	Yield Strength (MPa)	Ultimate Strength (MPa)
6 mm f	310	530
12 mm f	350	580

EXPERIMENTAL SET-UP AND METHODS

In order to simulate the shear failure characteristic of hollow concrete block masonry buildings under earthquake better, and considering that small-size hollow concrete block masonry has low bending tension strength, a system of four parallel connecting rods was used to apply the loads The four-parallel-connection-rod system was adopted in the experiment in order to apply loads that bring little influence to the bending of specimen.. The line of action of the horizontal load was at the mid-height of the specimen and thus decreased the influence of the bending moment of the top of the wall on failure mode. The system (Figure 2) prevented the top and bottom of the specimen from rotating and ensured that the stress in the specimen was distributed uniformly. The bottom of the wall was fixed on the static base by a reinforced concrete beam and the top of the wall was connected with the connection-rod system. Two synchronous hydraulic jacks on rollers applied the vertical load, which was distributed to the wall using distribution beams and the L-shaped beam. The horizontal cyclic load was applied by an actuator attached to the reaction wall and was controlled by an electric-hydraulic servo system for load control or displacement control. The set-up is shown in Figure 2.



1.Vertical framework 2.Four-connection-rod 3.Load cell 4.Jack 5.Sensor 6.Distribution beam 7.L type curving beam 8.Deformation sensor 9.Specimen 10.Trestle 11.Reaction wall

Figure 2 – Loading Equipment

At the beginning stage, a vertical load which produced σ_0=0.55MPa stress was applied and kept constant during the period of the experiment before applying the horizontal cyclic load. The process of applying the horizontal cyclic loads was controlled by load-deformation mode and was divided into two stages. The process was load - controlled in load increments of 20 kN cycles until cracks appeared in the walls. After the walls cracked, the load was applied in displacement control with equal incremental displacement of 1mm cycled 3 times for every level of displacement until the horizontal load reached 85% of the ultimate, which was regarded as failure of the wall.

Measurements taken during the experiment were steel strain in the structural columns, displacements of the wall, cracking loads and displacements, the distribution of the cracks, as well as the failure mode.

The horizontal deformations of the wall were measured by the displacement sensors attached at the middle of the top beam. In order to remove the influence of slippage of the base beam automatically, sensors of 50mm measurement range were fixed to the base beam by rigid brackets. The horizontal load was recorded and controlled by the load sensors and displacement sensors on the electric-hydraulic servo actuator and was output to a computer to get the real time load-displacement curve (P-Δ) of the wall. A static strain collector was used to collect the strain readings from strain gauges on the steel rebar of the structural columns.

EXPERIMENTAL RESULTS AND ANALYSIS

The common failure processes and modes of SW1 and SW2 were characterized as follows: The displacements and the steel strain of the structural columns on the two ends were very small before cracking and the load- deformation curve was linear. With increasing load, tiny cracks appeared along the mortar joint in the top close to the middle part of the wall and the P-Δ curve started to bend. The cracks developed along a stepped pattern in the mortar joints with increasing load, and the horizontal displacement of the specimen increases while the steel strain in the columns changed very little.

Subsequently, when the load was applied under displacement control, the specimen obviously showed plastic behaviour. The primary diagonal cracks connected with each other along the diagonal section and got wider and longer. More new cracks appeared and as the load approached the ultimate load there were many new diagonal cracks until a main crack appeared which ran diagonally from corner to corner. Then cracks in the top and bottom of the structural columns appeared and the steel strains increased significantly. When the specimen reached its ultimate strength, the main crack became even wider along its entire length, and a few of the blocks broke too. A typical X shaped crossing diagonal crack appeared in the wall when the wall was close to the ultimate strength in two directions. If more displacement were added to the wall, the wall would have collapsed.

Due to the restraint of the structural columns, the specimen still worked as a whole. However, there were obviously two distinct parts above and below the main crack, as the mortar in the main crack spalled off and the width of the crack increased significantly. The strain in the steel bars in the top and bottom of the structural columns went up quickly and the steel yielded. The specimen failed finally because the diagonal sections of the top and bottom of the structural columns reached their shear strength and lost the restraint conditions and a large slippage along the stepped main crack occurred. The failure showed typical shear-slippage characteristics. The distribution of the cracks is shown in Figure3.

Figure 3 – Failure Patterns of Walls

The comparison of the failure mode of the concrete block walls filled (SW1) and unfilled (SW2) with foaming concrete shows that the cracks in SW1 appear later and are more scattered. The main crack developed more slowly and the ultimate strength was larger. On the contrary, SW2's cracks appeared earlier and developed faster and the cracking strength and ultimate strength were both lower than those of SW1. All these indicate that filling with foaming concrete improves the shear strength of hollow concrete block walls.

The hysteretic and envelope curves of the two specimens indicate typical shear failure characteristics and are shown in Figure 4 and Figure 5, respectively.

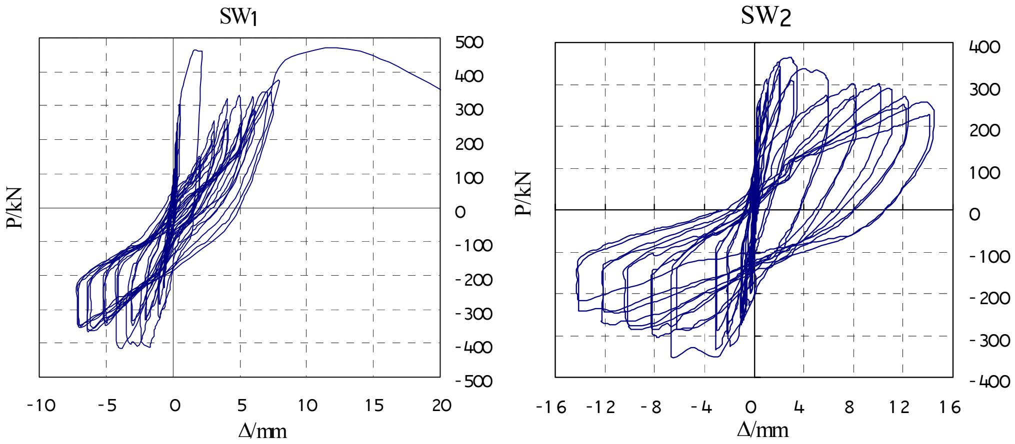


Figure 4 – Hysteric Curves of Specimens SW1 and SW2

We can see from Figure 4, the hysteretic curves of the two walls were like a shuttle shape before cracking and the hysteretic area was very small. An obvious inflection point appears on the curve with the increase of the load after cracking. The hysteretic transforms to the shape of a reverse S that indicates the slippage of the masonry and the restraint effect on the masonry of the structural columns. When the loads reached the ultimate, the shear strengths of the walls increased slowly and the hysteretic area of the curve keeps on growing. The residual deformation increased gradually. Due to the restraint effect of the structural columns, the masonry keeps on working as a whole and the changes in the hysteretic curve stabilize. The hysteretic behaviour of the specimens indicates good energy dissipating ability and good ductility and restoring force.

Comparing the hysteretic curves of SW2 and SW1, the peak value for SW1 is higher but the hysteretic area is smaller and the load descends more slowly. The hysteretic curve of SW2 is fuller. At the descending stage of the load, the horizontal load is supported by frictional resistance between the blocks because of the restraint of the structural columns. The hysteretic curve shows the characteristic of energy dissipation due to friction.

Figure 5 shows the envelope curve of load-displacement and it indicates that the curve not only has an obvious transition point but also reaches peak values quickly after cracking. The increasing stage of this curve is very steep indicating that the initial stiffness of these hollow concrete masonry walls was very big. After reaching ultimate load, this curve starts to descend, and the descending part of this curve is smoother. We can conclude that the material's deformation ability is strong and this curve reflects the failure characteristic of the shear-friction of blockwork. Comparing the two, the peak value of the envelope curve of specimen SW1 masonry is higher and the descending part is longer, indicating that filling the wall with foaming concrete could improve the shear resistance, but the deformation and ductility change little.

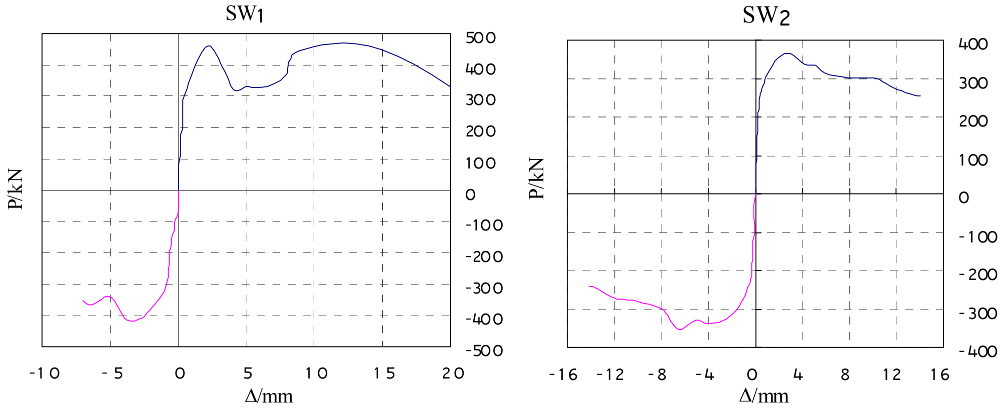


Figure 5 – Envelope Curves of Specimens SW1 SW2

The cracking load is that measured when the cracks appeared in the masonry walls. From the envelope curve we can see that it coincides with the obvious inflection points on the curves. The final crack load V_{cr} equals the average of the cracking loads in the two directions and the initial cracking displacement Δ_{cr} equals the average of the displacement when the cracking load occurs in the two directions.

The ultimate load V_u equals the peak value of the curve that is the largest load of the two directions. The average displacement corresponding to the largest force in the two directions is the displacement Δ_u corresponding to the ultimate load.

According to the method of [4], we can determine the ultimate displacement Δ_w, which is the displacement corresponding to reaches 85% of the peak value on the descending branch. The cracking load, the ultimate load and the corresponding displacements are shown in Table 4.

Table 4 -Cracking load, Ultimate load and Corresponding Displacements

Type	**P_{cr} (kN)**	**Δ_{cr} (mm)**	**P_u (kN)**	**Δ_u (mm)**	**P_{cr}/P_u**	**Ultimate Displacement Δ_w at 85% P_u (mm)**
SW1	313.5	0.75	438.3	3.00	0.72	5.52
SW2	292.7	1.02	350.3	3.03	0.84	8.99

It can be observed from Table 4 that the cracking and ultimate load of specimen SW1 filled with foaming concrete (heat insulating material) are both higher than for SW2 without filling. It reflects that the hollow concrete block masonry partly filled with foaming concrete can improve the cracking and ultimate load of masonry structures to a certain extent.

CONCLUSIONS AND SUGGESTIONS

Comparing the experimental results on walls constructed with 3-row-hole hollow concrete blocks filled or unfilled with foaming concrete under low-cyclic reverse loading, we can draw the following conclusions:

(1). The multi-row hole hollow concrete block masonry filled with foaming concrete under low cyclic repeated loads has the same failure characteristics as those of common masonry: that is, they both show shear-slippage failure mode and their failure mechanism is consistent with shear-friction failure theories.

(2). Filled the hollow concrete block masonry wall with foaming concrete changed the distribution of the cracks. The initial cracks in the hollow concrete block wall without foaming concrete appeared earlier, were more concentrated and the number of cracks was fewer while the width was bigger. The appearance of the cracks in the hollow concrete block wall filled with foaming concrete was delayed and the cracks were scattered and developed slowly, which indicates that such walls bear the loads homogeneously and have stronger collapse resistance.

(3). Partially filling the multi-row-hole hollow concrete blocks with heat insulating materials such as foaming concrete not only improves the thermal performance of the masonry but also increases the shear strength and the ultimate strength of the masonry.

(4). There are still more factors of construction and application of hollow concrete block masonry filled with foaming concrete heat insulating materials that need to be studied.

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