11th Canadian Masonry Symposium, Toronto, Ontario, May 31- June 3, 2009

# EXPERIMENTAL STUDY ON HOOP REINFORCEMENT BUILT-IN MASONRY OF REINFORCED BLOCK WITH AXIAL LOAD

**Jiang hongbin[1] and Wang shilei[2]**

[1] Associate Professor, Structural Engineering, School of Civil Engineering, Harbin Institute of Technology , Harbin , 150090, China, 86282081@163.com

[2] Master, Structural Engineering, School of Civil Engineering, Harbin Institute of Technology, Harbin, 150090, China, 86283116@163.com

## ABSTRACT

In order to study the structural performance of a grouted concrete block masonry structure and the improvement of its seismic behaviour, experiments of seven grouted block wall specimens with hoop reinforcement located inside the concrete blocks and one grouted block masonry wall with concrete blocks (typical block wall) under axial compression load have been made. The parameters investigated include: the ratio of hoop reinforcement, the type and the space of hoop reinforcement. The experimental results indicate that the compressive bearing capacity and the ultimate deformation capacity of grouted block wall specimens with hoop reinforcement inside were improved significantly in comparison to the concrete block wall specimen. Based on the test results and analysis a calculation method for the compressive strength of hoop-reinforced blocks in grouted block masonry is proposed. The results of the experiment can be used to design practical structures.

**KEYWORDS:** restraint flange member; bearing capacity; distortion; volume ratio of hoop reinforcement

## INTRODUCTION

Solid clay bricks waste soil and damage fields. At present, therefore, concrete blocks have become the preferable wall material over solid clay bricks. Also, concrete block masonry shear-wall structures have developed greatly. In the newly revised "*Masonry Structure Design Specifications*" [1] (GB50003-2001), however, only the structure boundary specimen of concrete block shear-wall is defined, and because of characteristics of concrete block masonry itself, the result is that the space between transverse constraints is constant and large, so constraint effect is not obvious [2]. In this paper, a new type of block is developed containing hooped bars inside the block. A simplified axial load specimen representing end constraint specimens for shear-walls, and considering volume reinforcement ratio, hooped bar type and hooped bar space factors. Mechanics performance tests and analysis under axial load conditions were also performed.

## DESIGN AND MANUFACTURE OF NEW TYPE BLOCKS

The new developed blocks were manufactured by setting up closed constraint hooped reinforcement inside the block mould during fabrication of the blocks. Therefore, the block test, adopted a self-made mould for cast-in-place. The mould was an assembly type mould made of thin steel sheets machined and welded, see Figure 1 for the details. The hooped reinforcement inside blocks was a welded reinforcing cage. As per design requirements of the specimen, there were three types of hooped bar diameter including 4, 6, and 8mm. The short bars at the four corners were used for formation of reinforcing cage and were not considered to contribute to the vertical force bearing capacity. Figure 2 illustrates the actual reinforcing cage. The concrete block containing inside hooped bars consisted of self-compacted concrete with small particle aggregates. A 5~10mm particle size crushed stone and medium size sand were used. In order to obtain the self-compacted effect and improve the fluid and slump of the concrete, a high efficiency water reducing agent was added.

**Figure 1: Actual Mould**

**Figure 2: Actual Hooped Bars**

## DESIGN OF AXIAL COMPRESSIVE SPECIMEN AND LOADING TEST

In this test, there were 8 specimens designed in total, of which 6 specimens contained the built-in rectangular hooped reinforcement, 1 specimen contained the circular hooped reinforcement, and 1 specimen with no hooped reinforcement that was used for comparison. The effect on the specimen's axial compressive performance volume reinforcement ratio, hooped reinforcement space and type were considered. The particular design parameters of specimens are listed in Table 1. See Figure 3 for specimen measurement locations arrangement, and forms of cross sections. See Table 2 for strength indices and elastic modulus of hooped reinforcement.

**Table 1: Parameter Comparison of Specimens**

| No. of specimens | Size of specimens (mm) | Dia. of hooped bars (mm) | Space of Hooped bars (mm) | Form of Hooped bars | Volume reinforcement ratio |
|---|---|---|---|---|---|
| GJ—1 | 590×190×990 | 4 | 50 | rectangular | 0.00336 |
| GJ—2 | 590×190×990 | 4 | 40 | rectangular | 0.00420 |
| GJ—3 | 590×190×990 | 4 | 30 | rectangular | 0.00504 |
| GJ—4 | 590×190×990 | 6 | 50 | rectangular | 0.00756 |
| GJ—5 | 590×190×990 | 6 | 40 | rectangular | 0.00943 |
| GJ—6 | 590×190×990 | 4 | 50 | circular | 0.00335 |
| GJ—7 | 590×190×990 | 8 | 200 | rectangular | 0.00336 |
| GJ—8 | 590×190×990 | —— | —— | —— | —— |

**Table 2: Mechanic Performance of Reinforcement**

| Diameter (mm) | $f_y$(MPa) | $\varepsilon_y$ | $f_u$(MPa) | $E_s$ (MPa) |
|---|---|---|---|---|
| 4 | 402 | 1433 | 838 | 280369 |
| 6 | 455 | 2346 | 608 | 193950 |
| 8 | 332 | 1580 | 473 | 210008 |

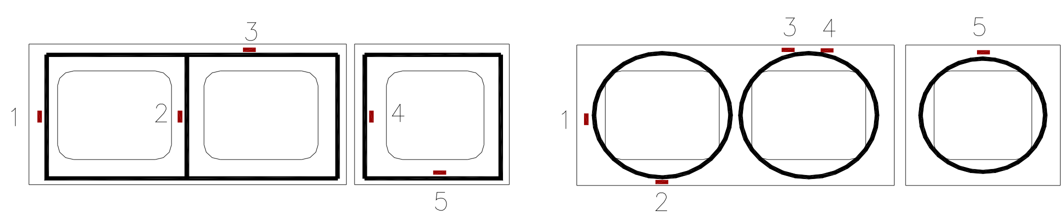


**Figure 3: Strain Measuring Spots Arrangement of Reinforcement a) Rectangular hooped reinforcement b) Circular hooped reinforcement**

In Table 1, the blocks of walls GJ-1～GJ-3, were set up with φ4 diameter rectangular hooped reinforcement; for walls GJ-4 and GJ-5 the blocks, were set up with φ6 diameter rectangular hooped reinforcement; and to demonstrate the difference between the constraint forms of hooped reinforcement, for walls GJ-6 blocks, were set up with circular hooped reinforcement. The comparison of specimen of GJ-1 with large diameter and large space, resulted in for GJ-7 block, adopting a φ8 diameter @200 hooped reinforcement set up inside horizontal construction joints. Finally, GJ-8 block was a free boundary specimen used to compare with other 7 specimens.

This test was an axial static loading test that used the 5000 kN screen display hydraulic test machine, with four columns and located at the structural test centre of Harbin Industry University. Electronic movement meters, paper base and rubber base strain pieces were used to measure concrete vertical deformation, concrete transverse deformation, hooped reinforcement deformation and block concrete strain. See Figure 3 for strain measuring locations and layout of hooped reinforcement.

Vertical pressure loading system conformed to the regulations in "*Structure Test Technology*" [3]. This test is a single static loading test, i.e. during the test the specimen is loaded stably and continuously from zero until the specimen is damaged.

**Test phenomena and failure form**

In this test, the whole loading process used force to control. Every level of load was 100 kN. According to the configuration of the hooped bars and the volume-reinforcement ratio, etc, of the specimen, the following 4 types of failure occurred:

(1) Failure of rectangular hooped bars: specimens GJ-1～GJ-5 use rectangular hooped bars with gradually increased volume reinforcement ratio. Their failure forms were basically similar. During initial period of loading, few cracks were found because of stress redistribution in the specimen; a great deal of short, fine and dense cracks were found when loading to 75％～80％ of the limit load. After reaching the limit load, portions of the cracks became wider. Once the specimen was damaged, the concrete protective layer of hooped reinforcement dropped, and the core column concrete within the hooped bar constraint area had no obvious failure characteristics, see Figure 4a.

(2) Failure of circular hooped bars: the block GJ-6 used circular hooped bars with the same bar quantity as the block GJ-1. Its failure characteristics had great improvement over the rectangular bars. Cracks distribution was more even. The core concrete was effectively constrained and destruction of the protective layer was delayed. The initial crack load had no great difference with that of blocks containing rectangular hooped bars. But the bearing capacity increases by 11.8％. This adequately indicated the reasonability of constraint of circular hooped bars as compared to rectangular hooped bars. See Figure 4b for the failure mechanism.

(3) Failure of rectangular hooped bars inside horizontal construction joints: inside the block GJ-7, rectangular hooped bars were used in the horizontal construction joint bed joint. The quantity of hooped bars was similar to that of the block GJ-1. In Figure 4c it can be seen that the failure form of the specimen had obvious fracture failure characteristics. The block shells ruptured suddenly and fell off, the core concrete was also not constrained well, and there was no decline section in the stress-strain curve.

(4) Failure of the block without hooped bars: the block GJ-8 was a comparison specimen with no hooped bars. The failure load of this specimen was much smaller than the specimens containing hooped bars. Few cracks can be seen on the specimen surface in Figure 4d below. When it was damaged, se expected, through cracks were found, the strain of concrete is small. The hooped bars would be far from their yield condition.


**Figure 4: Failure Form of Specimens a) Rectangular hooped bars b) Circular hooped bars c) Rectangular hooped bars inside horizontal joint d) Without hooped bars**

## SPECIMEN BEARING CAPACITY ANALYSIS

For comparison of the test values and the calculated values of the limit bearing capacity of the various specimens, see Table 3. With increased reinforcement ratio, the limit bearing capacity increased gradually; comparing blocks GJ-1 and GJ-6, it can be seen that the block GJ-6 with circular reinforcement had a higher bearing capacity than the block GJ-1 with rectangular reinforcement; however the block GJ-7 with reinforcement inside horizontal joint had a much lower bearing capacity than the block GJ-1.

**Table 3: Comparison of Limit Bearing Capacity of Specimens**

| Specimen No. | Test value of limit | Calculated value of limit load | Test value/calculating value | Volume reinforcement ratio $\rho_v$ | Comparing with no constraint condition |
|---|---|---|---|---|---|
| GJ—1 | 2370 | 2027 | 1.17 | 0.00336 | 1.16 |
| GJ—2 | 2670 | 2213 | 1.21 | 0.00420 | 1.20 |
| GJ—3 | 2570 | 2096 | 1.23 | 0.00504 | 1.22 |
| GJ—4 | 2600 | 2245 | 1.16 | 0.00756 | 1.15 |
| GJ—5 | 2612 | 2103 | 1.24 | 0.00943 | 1.24 |
| GJ—6 | 2800 | 2199 | 1.27 | 0.00335 | 1.27 |
| GJ—7 | 2400 | 2247 | 1.07 | 0.00336 | 1.06 |
| GJ—8 | 2100 | 2087 | 1.01 | —— | —— |

When the volume reinforcement ratio was increased, the concrete within the hooped bar constraint area can be constrained better, the spalling of the concrete protective layer was effectively delayed, and the limit bearing capacity can be improved. For rectangular hooped bars, weak constraint areas exist, under the effect of load; the concrete deformation will originate at these weak points and lead to the failure of the specimen. However, for a plane with circular hooped bars, concrete will be subject to similar constraints in every direction, the bearing capacity can be improved, and the failure of specimen can be delayed; but for large diameter and large space hooped bars, during the test process, the constraint stress of hooped bars was not used adequately, and fracture failure occurred easily.

## SPECIMEN DEFORMATION ANALYSIS

In Table 4, comparison of the concrete limit deformation of various specimens is listed. It can be seen in the table that the limit deformation of the specimen concrete became gradually greater with an increase in the volume reinforcement ratio, in which the increasing tend of transverse deformation is more obvious. From comparison of the block GJ-1 and the block GJ-7, it was found that the block GJ-7 with large diameter and large space hooped bars did not constrain the concrete well, and its limit deformation was close to that of the specimen without constraint.

**Table 4: Limit Deformation Comparison of Specimen Concrete**

| Specimen No. | Vertical limit deformation | Comparing with the specimen without constraint | Transverse limit deformation | Comparing with the specimen without constraint |
|---|---|---|---|---|
| GJ—1 | 2849 | 1.448 | 2483 | 1.108 |
| GJ—2 | 3401 | 1.729 | 3600 | 1.606 |
| GJ—3 | 3155 | 1.604 | 2925 | 1.305 |
| GJ—4 | 3423 | 1.740 | 5125 | 2.287 |
| GJ—5 | 5942 | 3.021 | 14391 | 6.422 |
| GJ—6 | 7358 | 3.741 | 11000 | 4.909 |
| GJ—7 | 2110 | 1.073 | 950 | 0.424 |
| GJ—8 | 1967 | —— | 2241 | —— |

## COMPRESSIVE STRENGTH AND STRAIN CALCULATION OF SPECIMENS

Employing the calculating method used for concrete structures [4], the calculating formulas of the compressive strength and limit strain for blocks with rectangular hooped bars was established (formula 1 and 2 respectively). These formulae take the reinforcement quantity feature value $\lambda_v$ and hooped bar space, S, as parameters. The details of reinforcement quantity feature value $\lambda_v$ are listed in Table 5. Comparison of the calculated value and the test value for compressive strength and limit strain is listed in Table 6.

$$\frac{f_{cgm}}{f_{gm}} = 1 + 0.55\sqrt{\lambda_v (1 - S/D)} + 0.09\lambda_v \tag{1}$$

$$\frac{\varepsilon_{\mathrm{cu}}}{\varepsilon_{\mathrm{c}}} = 1 + 38.6\lambda_v^2 (1 - \mathrm{S}/\mathrm{D}) + 2.8\alpha\lambda_{\mathrm{v}} \tag{2}$$

Where, $f_{gm}$, and $\varepsilon_c$ express the compressive strength and peak strain of the specimen without hooped bars respectively; $f_{cgm}$ and $\varepsilon_{cu}$ express the compressive strength and peak strain of the boundary constraint specimen; $\alpha$ is the effect coefficient of construction joint cement mortar to the specimen, and generally taken as 0.90. In Table 5, the reinforcement quantity feature value $\lambda_v$ of every specimen is listed.

**Table 5: $\lambda_v$ of Specimens**

| Specimen No. | $\mu_{sv}$ (%) | $f_c$ (MPa) | $f_{yv}$ (MPa) | $\lambda_v = \mu_{sv} f_{yv} / f_c$ |
|---|---|---|---|---|
| GJ—1 | 0.336 | 18.08 | 402 | 0.0747 |
| GJ—2 | 0.420 | 19.74 | 402 | 0.0855 |
| GJ—3 | 0.504 | 18.70 | 402 | 0.1083 |
| GJ—4 | 0.756 | 20.03 | 455 | 0.1717 |
| GJ—5 | 0.943 | 18.76 | 455 | 0.2287 |

From the comparison results in Table 6, the effect of the formula established to calculate compressive strength is good. Given that the factors affecting concrete deformation are complicated, the conformity of the individual calculating formula for the limit strain was not perfect.

**Table 6: Comparison between Calculated Value from the Formula and the Test Value**

| Specimen No. | Compressive strength (MPa) | | | Limit strain ( $\mu\varepsilon$ ) | | |
|---|---|---|---|---|---|---|
| | formula $f_{cgm}$ | Test $f_{cgm}'$ | $f_{cgm}' / f_{cgm}$ | formula $\varepsilon$ | test $\varepsilon'$ | $\varepsilon' / \varepsilon$ |
| GJ—1 | 20.54 | 21.14 | 1.03 | 2650 | 2849 | 1.08 |
| GJ—2 | 22.71 | 23.82 | 1.05 | 2830 | 3401 | 1.20 |
| GJ—3 | 21.99 | 22.93 | 1.04 | 3256 | 3155 | 0.97 |
| GJ—4 | 24.26 | 23.19 | 0.96 | 4470 | 3423 | 0.77 |
| GJ—5 | 23.53 | 23.30 | 0.99 | 6239 | 5942 | 0.95 |

## CONCLUSIONS

From comparison and analysis of the results of the axial compressive test of specimens of a new type of concrete block with built-in hooped reinforcement and comparison and analysis, the following conclusions were drawn:

(1) The failure condition of specimens of concrete block masonry with certain quantity of built-in hooped reinforcement had a great degree of improvement than the specimen without hoop reinforcement. The failure mechanism of the specimen changed into an obvious ductile failure condition.

(2) The specimens with built-in hooped reinforcement greatly improved axial compressive bearing capacity and deformation capacity of the block masonry.

(3) By using regression analysis on the test data, formulae for the calculation of compressive strength and vertical limit strain of the specimens constrained by built-in hooped reinforcement were obtained.

According to the above conclusions, using concrete blocks with built-in hooped reinforcement can increase height of building and improve the structural earthquake resistance of buildings constructed with concrete blocks. The results promote the use application of concretes block structures in high intensity earthquake defence districts, and further extend the application scope of concrete block as a structural material.

## REFERENCES


1. "Masonry Structure Design Specifications", GB50003—2001, Chinese Construction Industry Publishing Company
2. He Yanli. Test Study of Axial Compressive Mechanic Performance of Constrained Grouted-core Concrete Block Masonry, Harbin Industry University master degree paper, 2005.9,77
3. Hunan University, Taiyuan Industry University, and Fuzhou University jointly compile. Construction Structure Tests, Chinese Construction Industry Publishing Company, 1991:4-46
4. Hu Haitao, Ye Zhiman. Stress and Strain Performance of High Strength Concrete Constrained by Complex Hooped Reinforcement, Industry Construction, 1997,27 (10): 23-28