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Study on seismic shear strength of concrete hollow block masonry[1]

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Abstract. Concrete hollow block masonry is a common method used in civil and commercial buildings. However, inadequate brittleness, tensile and shear strength of concrete hollow block masonry, especially the performance of masonry collapse and ductility under the action of earthquake, have seriously restricted the development of masonry structure. In this paper, the basic mechanical properties of concrete block masonry, such as seismic and shear strength, were studied according to standard test method. The seismic shear strength tests of 24 sets of standard specimens of 36 hollow concrete block masonry structures were carried out. Finally, the formulas for calculating the seismic shear strength of hollow block masonry were obtained, and the recommended values were given.

Key words. Concrete, hollow block masonry, shear strength, friction coefficient.

1. Introduction

The structure of hollow concrete masonry has a wide range of applications all over the world because of better convenience for the construction, good fire resistance, excellent chemical stability and atmospheric stability, long safe service life, good heat insulation and sound insulation performance [1]. The structure of masonry concrete hollow masonry is a complex anisotropic material composed of hollow brick, block, mortar, and so on [2]. In the aspect of mechanical properties of materials, the average tensile strength, flexural tensile strength and shear strength of unreinforced masonry are only about 10 % of their axial compressive strength [3]. There are three ways to improve the seismic and shear strength of concrete hollow masonry structures:

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increasing the strength of the material, changing the structure form and exerting a certain degree of pre stress [4].

After the prestressing force is applied to the masonry structure, the shear capacity will be greatly improved, and the integrity and resilience of the structure will be improved. Under the action of prestressing force, the masonry structure can bear more deformation, and it also includes the improvement of crack resistance. In this case, the masonry structure can be subjected to greater deformation, and it can even further reduce the cracking caused by temperature changes and mortar shrinkage. Cracks due to occasional loads will also tend to close after the load disappears due to preload (Yu et al. 2015 [5]). Therefore, the study on the shear behavior, the relative mechanical properties and the seismic capacity of masonry structures under the combined action of shear and compression is carried out, which is of great significance to the application of prestressed masonry structure in China.

2. State of the art

He [6] systematically collected and sorted out the failure modes of masonry during shearing, and considered that vertical joint did not transfer stress, especially shear stress. In 1990s, the concrete hollow block had gradually replaced the solid clay bricks become the mainstream in bulk. The masonry structure code revised by the American Masonry Standards Federation included the prestressed masonry structure as a separate structural form, and gave the corresponding calculation indexes [7]. Incerti carried on the shear test of masonry specimens, and proved that the experimental values of the shear strength of masonry under shear compression composite were in good agreement with Coulomb friction theory [8]. Sathiparan carried on the shearing proof and the compression test to the hollow brick masonry standard brick, and he proved the comprehensive influence of various factors such as surface treatment and groove shape of block [9]. Elmenshawi analyzed the results of double brick single shear strength test of solid brick and hollow brick masonry, and proved that it was elastic before breaking [10]. Buch conducted the two-way shear compression interaction test, and it was proved that the shear strength of standard joints was approximately linearly related to the increase of compressive strength [11]. Min carried out the masonry shear test under axial compression, and he proved that processing the bulk surface could improve the shear strength of masonry [12]. Mansouri proved that the wetting of block before masonry and maintenance could improve the shear strength of masonry [13]. The shear tests of masonry walls were carried out by Janaraj. It was proved that the calculated strength of the main tensile stress failure theory was close to the experimental results [14]. The single shear test of brick masonry was carried out by Chourasia, and the tension and compression model of masonry under shear was put forward. The results of microscopic numerical analysis and finite element analysis showed good agreement with the test [15].

3. Methodology

3.1. Design and manufacture of specimen

The study applied the prestressing force to masonry structures, so as to give some advantages to prestressed concrete structures. The channels of prestressed masonry structure can avoid the complicated procedures of the channel reservation and the second grouting construction during the construction of prestressed concrete, which can not only save the project cost, but also enhance the efficiency of the project. In general, the prestressing force of prestressed masonry structures is low, so that even relatively simple equipment, such as jacks and torque wrenches, can be used to perform prestressing tensioning. As a result of prestressed tensioning, the material of masonry block has basically been completed contraction. Therefore, its shrinkage and creep are smaller than the prestress loss of prestressed concrete. However, the prestressed masonry structure also has some shortcomings. For example, the prestressing bars can only be arranged in a straight line due to different type and manner of the blocks. Due to the prearranged prestressed steel bars, there will be some inconveniences in the subsequent construction process. The shear specimens used in this study were made of three skin staggered masonry, which consisted of 2 plates and 2 standard blocks. The size of the sample was 590 mm×390 mm×190 mm. The arrangement is shown in Fig. 1.

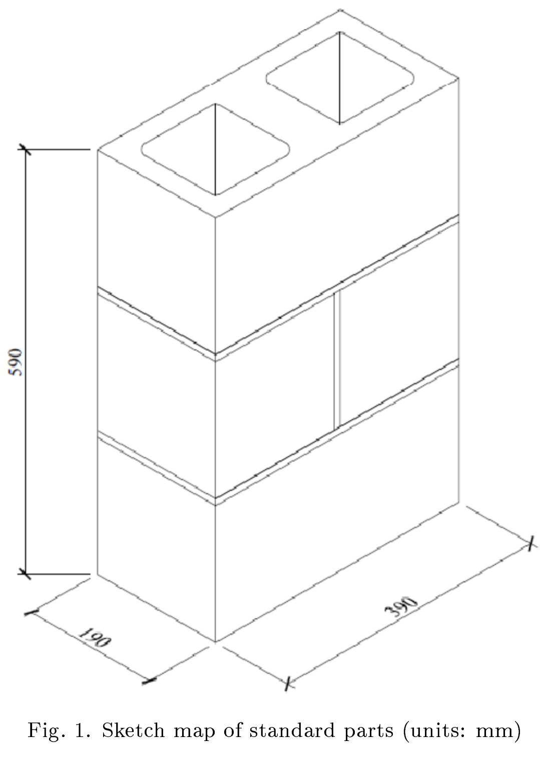

Fig. 1. Sketch map of standard parts (units: mm)

In the process of testing, the basic mechanical properties of specimens were obtained by compression test of standard parts, and further analysis was conducted. In order to ensure the consistency of the compressive and shear specimens, the shear standard component specification and the three-skin and non-five-skin staggered joint masonry standard were adopted. In this way, it can be more standardized to point out that the compressive strength of the specimens was not significantly different when the ratio of height to thickness of masonry was 3 and 5, respectively. The test method for shear strength of masonry along the through section is shown in Fig. 2.

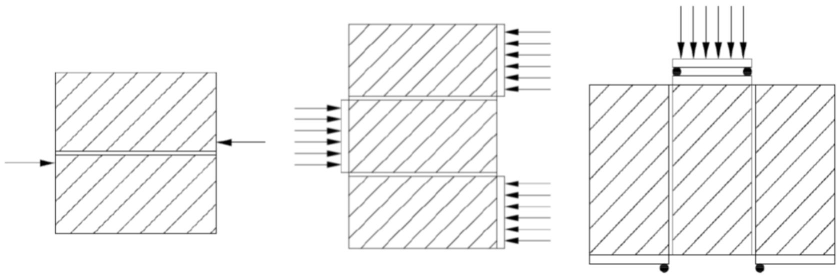

Fig. 2. Test method for shear strength of masonry along the through joint

In this experiment, the orthogonal design method was adopted to complete the one-way shear test of 24 hollow block standard parts, tests on pre compression joint shear of 12 hollow block masonry standard pieces, and uniaxial compressive test of 15 hollow block masonry standard parts. The orthogonal combination of the strength grade of block and mortar was mainly considered in the hollow standard parts. The specific design scheme is shown in Table 1.

Table 1. Design scheme of standard parts for hollow block masonry

Block strength	Mb5	Mortar strengthMb10	Mb15
MU10	K1\MK1	K2	
MU15	SK2\MK2	K3\SK1\MK3	K4\SK3
MU20		MK4	K5\MK5

The letter number K represented the shear specimen of the through seam with EN loading method. The letter number SK represented the shear specimen of the through seam with GB loading method. The letter number MK represented the uniaxial compression specimen. There were 3 specimens in each group. The material used in the pre compression joint shear test had the same strength grade as MU15, Mb10 and Cb20. The variable was the magnitude of the preload. The specific design is shown in Table 2. The letter number YK represents the prestressed hollow masonry shear specimens.

Since the standard block had very strong water absorption, it was necessary to ensure that all the blocks were adequately wetted before masonry. All the smooth boards were prepared in advance, and all the standard pieces were made on the boards. In order to ensure the smoothness of the boards, cement mortar was used before the masonry. In the construction process, we effectively discriminate the plasma surface and bulk surface, so as to avoid the reverse situation. Because the bulk was inevitable certain difference, it was difficult to ensure bulk of the two planes parallel. Therefore, in carrying out specific construction, the main task was to ensure the parallelism of each paste surface and each surface. The plumpness of mortar directly affected the shear area of the ash joint, and then affected the shear strength. Therefore, it was necessary to ensure the mortar plumpness of the test block. The mortar was cleaned or removed if the mortar was smoothed.

Table 2. Design standard for shear compression standard piece of pre compression joint

Specimen	Preload size				
	0.28	0.41	0.55	0.68	1.02
Hollow	YK1	YK2		YK3	YK4

After the completion of masonry, it needed to be cured and sealed with test film. Continuous watering during the maintenance period was needed to ensure a moist environment for 7 days. Grouted standard parts needed pouring column 7 days later in the masonry. The adopted concrete was fabricated by field mixing, and the method of layered casting was adopted in the pouring process. After pouring, the vibrator should be vibrated to ensure the compactness of the concrete. In the 30 days after the completion of the casting, the sealed moisture conservation was needed, so as to ensure the strength of concrete.

In the building design of standard parts, because the bulk may have rough surface inequality defects and construction error, it was difficult to ensure absolute flatness and surface parallel test on the surface. If the masonry surface was not smooth, it may cause uneven stress within the masonry and affect the mechanical properties in the shear stress and compression test. Therefore, during the construction process, reasonable measures must be taken to ensure the smoothness of the surface of the specimen and ensure the uniformity of the specimen.

3.2. Measurement scheme

In the test process, the concrete steps of loading scheme were as follows.

(1) Firstly, the initial limit load of block and mortar strength specimens were estimated.

(2) The appearance breakage and defects of the specimen were inspected and recorded, and the force surface size of the standard parts was measured in detail. In particular, it was necessary to measure the height difference between the upper and lower surfaces of the shear and prestressed specimens, so as to ensure their parallelism.

(3) The installation of the specimens was carried out. The relevant measuring instruments were checked, calibrated and reset to ensure the normal use of the measuring instruments.

(4) The loading of the specimens: the loading schemes of different specimens were

different, and the shear standard parts were subjected to continuous loading with constant rate. The standard component of prestressing force adopted horizontal pressure loading. Preloading was used for compression of standard parts.

(5) As long as a shear surface was destroyed, the one-way shear criterion determined the loss of its bearing capacity. The prepressed standard continued to load when the peak was reached, until a sudden drop or slippage of the load occurred. The pressure gauge continued to load until it was broken.

(6) The loading of the specimen: the cracks and characteristics of the specimens were observed, and the corresponding load values were recorded. After loading the load, a crack map and took pictures were drawn.

In the process of testing, the data of shear standard parts should be continuously measured, including shear load, shear deformation, horizontal axial pressure and so on. Among them, the load sensor was used to measure the load size, and high precision displacement sensors were used to measure shear deformation. In addition, the measurement of horizontal and vertical deformation of standard parts was also included. The vertical load was measured by force sensors.

In the test of the compressive strength, according to the test requirements in the test method, the 190 mm standard block with the same batch of masonry blocks was selected. In order to minimize the influence of the uneven surface of the block on the results of the test, it was necessary to use high-strength gypsum (1:2) to process the upper and lower surfaces of the block and test it on the 5000KN press. Sand filling method was used to measure the void ratio of standard blocks, and the final porosity was 46.7 %. The mean strength and coefficient of variation of compressive strength of each block are shown in Table 3.

Table 3. Block compressive strength

Strength grade	Average compressive strength	Single block minimum strength	Coefficient of variation	Rating of strength
MU10	13.51	11.73	8.15%	MU10
MU15	19.86	16.05	9.68%	MU15
MU20	20.91	19.01	12.61%	MU20

Standard blocks were leveled and damaged, as shown in Fig. 3.

4. Result analysis and discussion

The failure state and crack propagation of concrete hollow compression specimens are shown in Fig. 4.

Based on the comprehensive research at home and abroad, the experimental phenomena and results, the study was carried out in this paper. When the concrete block masonry was subjected to uniaxial compression, the loading failure process could be divided into the following four stages according to the development of cracks.

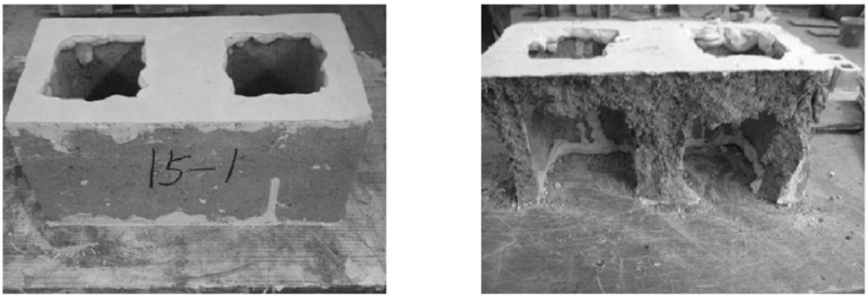

Fig. 3. Setting and destruction of building blocks

Fig. 4. Failure state of hollow compression standard parts

The first stage was the compression of the standard piece and the presence of the first crack. In this stage, the vertical deformation of the standard parts was relatively small. This stage was the elastic force state, and the load displacement had the linear relationship. The strain at this stage failed to produce initial microcracks. The second stage had the first crack. As the load continued to increase, the standard parts began to make minor noises from the inside, and cracks began to appear at the chamfer of the specimen. The cracks in this stage were slender and developed slowly, and the load displacement was linear.

The third stage: as the load increased to the peak, the cracks continued to expand, and the final specimen had plastic deformation. Cracks expanded with the increase of load, and more narrow vertical cracks appeared in the narrow surface of standard parts, which showed a remarkable nonlinear load displacement curve. The slope decreased until the final plastic deformation occurred.

The fourth stage: when the load exceeded the peak value, the specimen presented a brittle failure and lost the ability to continue bearing. When the load exceeded the peak value, the bearing capacity of the specimen continued to decline, and the specimens began to appear through the vertical cracks, which had eventually brittle fracture and the loss of carrying capacity. The initial load, the peak load, the compressive strength, the initial crack coefficient and the coefficient of variation measured by the hollow compression standard are shown in Table 4.

Table 4. Compressive strength of hollow standard parts

Group	Number	Initial crack load (kN)	Peak load (kN)	Compressive strength (MPa)	Compressive strength average (MPa)	Coefficient of variation of Compressive strength	Initial crack coefficient	Mean of initial crack coefficient	Coefficient of variation of initial crack coefficient (%)
MK1	MK1-1 MK1-2 MK1-3	268 523 276	482 640 401	6.49 8.61 5.38	6.82	19.5	0.556 0.816 0.688	0.687	10.5
MK2	MK2-1 MK2-2 MK2-3	404 333 569	711 739 741	9.60 9.94 9.99	9.84	1.74	0.568 0.450 0.767	0.595	6.19
MK3	MK3-1 MK3-2 MK3-3	422 466 589	734 797 911	9.95 10.68 12.29	10.94	9.24	0.576 0.584 0.646	0.602	6.10
MK4	MK4-1 MK4-2 MK4-3	411 464 385	569 938 687	7.63 12.55 9.19	9.79	20.9	0.722 0.494 0.560	0.592	7.75
MK5	MK5-1 MK5-2 MK5-3	1147 614 830	1229 1069 966	16.53 14.34 2.89	14.59	10.2	0.932 0.574 0.878	0.788	4.76

Through the analysis results, it can be seen that under the action of load, the specimen usually cracked from the hole of the block. The stress tended to focus on the block than rib thickness reduced parts, so that the transverse tensile specimen stress was much greater than its tensile strain limit of material. Furthermore, it could be seen from the table that the initial split coefficient of hollow standard parts was in the range of 0.6∼0.8. Because of the great brittleness of the specimen, the crack was developed rapidly and finally destroyed.

The compressive strength of mortar with block and mortar were f_1 and f_2. The coefficient of masonry category and the coefficient of mortar strength were k_1 and k_2, respectively. For hollow masonry with the strength grade of MU20, the compressive strength needed to be multiplied by 0.95 of the correction factor. A formula for calculating the average compressive strength of concrete hollow block masonry f_{m}^0 is as follows.

$$f_{\mathrm{m}}^0 = k_1 f_1^{0.9}(1 + 0.07 f_2) k_2 \,. \tag{1}$$

The comparison between the measured compressive strength and the calculated values is shown in Table 5.

Table 5. Comparison of compressive strength test values and calculated values of hollow standard parts

Group	f_1 (MPa)	f_2 (MPa)	f_{m} (MPa)	f'_{m} (MPa)	f^0_{m} (MPa)	$f_{\mathrm{m}}/f^0_{\mathrm{m}}$
MK1	13.49	5.78	6.82	12.81	6.78	1.006
MK2	19.84	5.96	9.84	18.47	9.59	1.025
MK3	19.84	10.48	10.94	20.53	11.68	0.936
MK4	20.89	10.48	9.79	18.38	11.62	0.842
MK5	20.98	13.72	14.59	20.89	12.71	1.146
Average value						0.991
Coefficient of variation						10.1 %

From the further analysis in Table 5, it could be seen that the results obtained from this test had a good fitting effect with the calculated results based on the specifications, which showed that the data was relatively reasonable. However, there were still some problems. When calculating the compressive strength of masonry, the ratio of the load value to the gross sectional area was obtained. This was not sufficiently related to the failure criteria of mortar and block materials. Therefore, it was difficult to carry out the relevant mechanical analysis and formula deduction based on theory. Even when considering the coefficient of 1.1 times, because the void ratio was small, the hollow block masonry was still low in formula calculation. In the calculation of high strength block and mortar, we must consider the correction factor, which increased the complexity of calculation.

In fact, the compressive strength of hollow block masonry was determined by the compressive strength of the material and its net cross sectional area A. The formula for calculating the compressive strength f'_m of material per unit area is

$$f'_m = \frac{N}{A(1-\alpha)}\,, \tag{2}$$

where N is the pressure, A denotes the per unit area, α is the effect of hole ratio coefficient on compressive strength of masonry (this formula considering the effect of hole ratio on compressive strength of masonry with $A(1-\alpha)$ net section area, calculated in the calculation of compressive strength of f'_m). Even the masonry bearing capacity to meet the requirements, but due to the void ratio are not satisfied with limited time and the compressive strength of material f'_m is insufficient, the calculating method for bearing hollow block masonry in numerical value is the same. In the design and construction practice, should be void ratio δ as a control index.

5. Conclusion

Based on the seismic shear strength test of standard parts of hollow concrete block masonry and the existing research results, the influences of loading mode, material strength, structure form and pre-stress on the seismic and shear resistance of masonry were analyzed. Main results were as follows: the modulus of elasticity of hollow block masonry was higher than the calculation value of masonry in the present standard, and the value of masonry was improved to a certain extent. The results of the compression test coincided with the calculated results. The shear stress composite stress coefficient given in the present masonry specifications was not applicable to concrete hollow block masonry built with special mortar, which presented a low state. Therefore, it was necessary to cancel the correction factor of the average formula on the basis of the original standard, and the friction coefficient was 0.7. Based on the measured shear load displacement curve, the coefficient expressions of seismic shear strength of prestressed hollow brick masonry were obtained. Furthermore, a piecewise expression of the dimensionless load displacement curve of masonry under seismic shear was obtained. In this paper, the seismic shear strength of hollow block masonry was studied in this paper, and the seismic shear strength of grouted masonry will be studied in the next step. Because of the higher shear capacity of grouted masonry, the grouted masonry test under different axial compression ratio was used to establish the intact shear compression bearing capacity curve of masonry.

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