EXPERIMENTAL STUDY ON BASIC MECHANICAL PROPERTIES OF CONCRETE PERFORATED BRICK MASONRY

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SUMMARY

A series of tests, including compressive strength test, shear strength test, eccentric compression test for short columns and axial compression test for long columns, were carried out. The results indicate that the compressive strength and elastic modulus of the masonry increase with the increase of mortar strength in the form of logarithm; the Poisson's ratio is bigger than that of normal masonry; the shear strength is larger than normal masonry; the eccentric compression coefficient for short columns is close to that of normal masonry; and the stability coefficient for long columns decreases with the increase of ratio of height to sectional thickness.

INTRODUCTION

Fired common bricks used to be the main construction material in China. Because of many advantages, this kind of masonry material has been used for thousands of years. But the production of fired common brick will consume the nonrenewable farmland, energy and produce many pollutants. With the urgency of protecting farmland, protecting environment and saving energy, the traditional fired common brick masonry material has been replaced by new materials step by step in recent years.

As the main substitute of fired common brick, concrete perforated brick with multi-rows of holes is a specialized brick type in China, using cement as binder, sand and stone as main aggregate, and made up through mixing sand and water, stirring, shaping and curing (National Development and Reform Commission 2004). Compared with the fired common brick, concrete perforated brick has the advantages of saving farmland, reducing energy dissipation, lightening self weight and improving seismic performance. Unlike concrete block masonry, which has been widely used and studied worldwide (Hendry 2001; Santos 2006), the research

results for concrete perforated brick masonry are very limited now in China. So, it is very important to do the extensive study on the mechanical properties of concrete perforated brick masonry and develop the corresponding specifications for the application of this kind of masonry material.

CPB24-1 type concrete perforated brick produced by Shanghai Obbo Concrete Product Ltd. was used in the tests. With different mortar strength, the concrete perforated brick masonry compressive strength test, shear strength test, short column compression test and long column compression test were carried out in Tongji University, which are the base for the development of “Technical Specifications of Concrete Perforated Brick Masonry Buildings” in China.

TEST PROGRAM

Compressive test for masonry material

In order to study the influence of mortar strength to the masonry compressive strength, 5 groups of compressive specimens were designed, which represented 5 grades of mortar strength, each group had 3 specimens. The dimensions of the specimens are 240mm×365mm×690mm. 1:3 cement mortar was used to level the top of the specimens after bricklaying. After curing for 28 days the specimens were tested (Ministry of Construction of the People’s Republic of China 1990). A jack of 2000kN was used to apply compressive force step by step. In order to measure the vertical and horizontal deformation, two displacement meters were placed vertically and horizontally on each side of the specimen. The test setup and displacement meters are shown in Figure 1 and Figure 6(a).

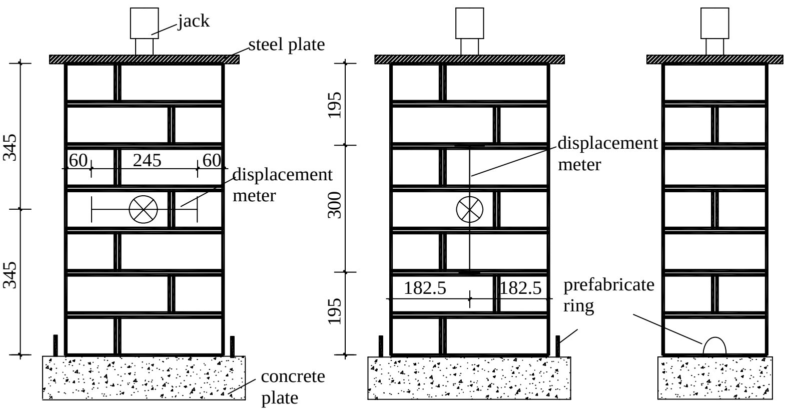

Figure 1 Compressive strength test setup and displacement meters

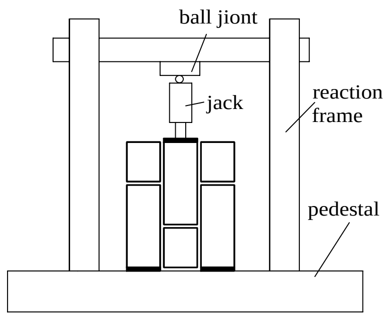

Figure 2 Shear test setup and specimen

Shear test for masonry material

In order to study the influence of mortar strength to the masonry shear strength, 6 groups of shear specimens were designed, which represented 6 grades of mortar strength, each group had 3 specimens. The specimen was made up of 9 bricks, which had two planes bearing shear stress. The specimen was constructed horizontally and was compressed with a layer of bricks for at least 14 days. When the strength of the mortar reached 70% of the ultimate

strength, made the specimen stand up, used 1:3 cement mortar to level the loading face and bearing faces of the specimen (Ministry of Construction of the People's Republic of China 1990). A jack of 2000kN was used to apply shear force which was added continuously. The specimen was regarded as damaged when one plane broke. The test setup is shown in Figure 2 and Figure 9(a).

Test for columns

Compressive test for short columns

In order to study the influence of mortar strength and eccentricity of the load to the compressive capacity of short columns, 3 groups of mortar strength were designed, each group of the specimen was loaded with 3 relative eccentricities, which was 0.1, 0.2 and 0.3 of the height of the column section respectively. The specimen was constructed on the 20mm thick steel plate. The way of bricklaying and the dimensions of the specimen were the same as that of the specimen in the compressive strength test. A jack of 2000kN was used to apply compressive force step by step. Five displacement meters were placed vertically on one side of the specimen, which were used to measure the vertical deformation. The test setup and displacement meters are shown in Figure 3 and Figure 11(a).

Compressive test for long columns

In order to study the influence of mortar strength and ratio of height to sectional thickness to the compressive capacity of long columns, 3 groups of mortar strength were designed, each group had 4 specimens, which represented 4 ratios of height to sectional thickness, that was 3, 6, 10, 14 respectively. The specimen was constructed on the 20mm thick steel plate. A ball joint was added on the top of the specimen, and a jack of 2000kN was used to apply compressive force step by step. The test setup is shown in Figure 4 and Figure 14(a).

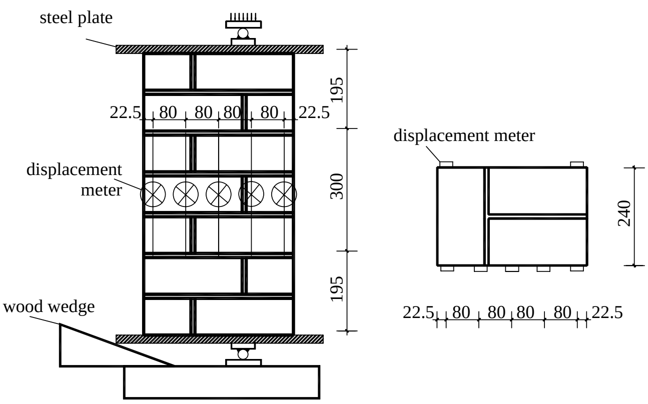

Figure 3 Compression test setup for short columns

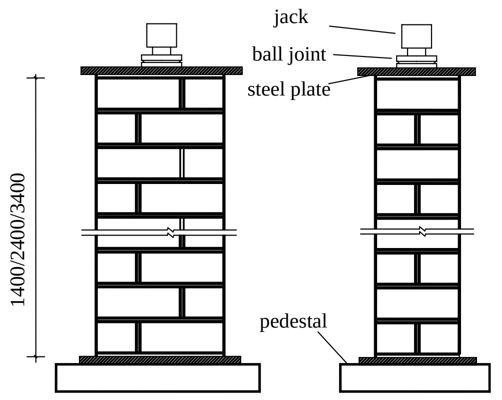

Figure 4 Compression test setup for long columns

PROPERTIES FOR BRICK AND MORTAR

Compressive strength of the brick

CPB24-1 is the main type of concrete perforated brick which is used as load-bearing wall material. The dimensions of the brick are 240mm×115mm×90mm, self-weight is 13.74kN/m^3, hole rate is 34%. The shape of the brick is shown in Figure 5. 5 bricks were tested to check the strength of the brick. The results are shown in Table 1.

Table1 Compressive strength of the brick

Specimen	Dimensions (mm^3)	Compressive strength (MPa)	Average strength (MPa)	Minimum strength (MPa)	Variance
CB-1	239×115×89	8.1	10.2	8.1	3.8
CB-2	238×115×90	8.8			
CB-3	239×115×89	12.7			
CB-4	241×114×90	11.7			
CB-5	239×115×90	9.8			

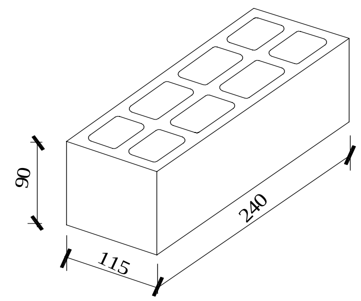

Figure 5 Shape of the brick

The average compressive strength of the brick is bigger than 10MPa and the minimum compressive strength is bigger than 8MPa, which meet the requirements of Chinese building material industry standard, *Concrete Perforated Brick* (National Development and Reform Commission 2004).

Strength of the mortar

Lime mixed mortar was used when the strength of the mortar was less than 10MPa; powder mortar was used when the strength of the mortar was larger than 10MPa. The powder mortar was produced by Shanghai Zhan'ou New Building Material Company, Ltd., whose admixture was flyash and thickening powder. 6 cubic mortar blocks were tested to check the strength of any type of mortar. The dimensions of the mortar block were 70.7mm×70.7mm ×70.7mm (Ministry of Construction of the People's Republic of China 1991), and the curing condition was the same as that of the masonry. The compressive strength of the mortar is listed in the following tables.

COMPRESSIVE BEHAVIOR OF CONCRETE PERFORATED BRICK MASONRY

Failure mode

According to the appearance and development of the crack, the failure process of the specimen can be divided into 3 stages. The first stage is from the beginning of loading to the appearance of the crack. The cracking load is about 70%~80% of the ultimate load. The first crack arises in one brick and it is stable. The second stage is the process of the development of cracks. The crack in one brick gradually develops vertically in several bricks. Because of the thin walls of the concrete perforated brick, the local surface of the

brick will spall. The third stage is that the masonry forms some independent small columns caused by cracks, then it is crushed and completely damaged.

(a) Test setup (b) Cracks on the facade (c) Cracks on the side

Figure 6 Test setup and compression failure mode of concrete perforated brick masonry mechanical behavior of the masonry

Mechanical behavior of the masonry

The test results including cracking load, ultimate load, elastic modulus and Poisson's ratio are shown in Table 2. The elastic modulus in Table 2 is the secant modulus when the stress is 40% of ultimate stress. The Poisson's ratio is obtained when the stress is 40% of ultimate stress (Ministry of Construction of the People's Republic of China 1990).

Table 2 Compressive test results for masonry

Specimen	f_1 (MPa)	f_2 (MPa)	N_{cr} (kN)	N_u (kN)	f (MPa)	f_m (MPa)	E (N/mm^2)	E_m (N/mm^2)	υ	υ_m
CP10-5-1	10.2	1.8	270	430	5.12	4.61	6192	5731	0.160	0.121
CP10-5-2			210	359	4.04		4462		0.083	
CP10-5-3			300	418	4.67		6540		0.120	
CP10-7.5-1	10.2	2.9	270	481	5.43	5.23	15977	15006*	0.151	0.251*
CP10-7.5-2			360	454	5.21		8640		0.176	
CP10-7.5-3			330	442	5.04		20411		0.426	
CP10-15-1	10.2	6.5	400	572	6.51	6.83	11141	11284	0.183	0.188
CP10-15-2			480	623	7.03		10199		0.184	
CP10-15-3			510	630	6.96		12513		0.198	
CP10-E10-1	10.2	14.8	500	640	7.22	7.08	13094	13721	0.198	0.189
CP10-E10-2			450	610	6.87		13980		0.190	
CP10-E10-3			550	632	7.14		14090		0.178	
CP10-E15-1	10.2	16.4	400	694	7.87	7.56	13793	14663	0.195	0.200
CP10-E15-2			500	650	7.38		17156		0.242	
CP10-E15-3			450	654	7.43		13040		0.163	

Notes: f_1—brick strength; f_2—mortar strength; N_{cr}—cracking load; N_u—ultimate load; f—compressive strength of masonry; f_m—average compressive strength of masonry; E—elastic modulus of masonry; E_m—average elastic modulus of masonry; v—Poisson's ratio of masonry; v_m—average Poisson's ratio of masonry.

From Table 2, it can be seen that the compressive strength and the elastic modulus of the masonry increase with the increase of the mortar strength. The relationship between compressive strength of masonry and the strength of the mortar is shown in Figure 7. And the relationship between elastic modulus of masonry and the strength of the mortar is shown in Figure 8. By regression analysis, the compressive strength and elastic modulus of masonry can be expressed as Eq. (1) and Eq. (2) respectively.

$$f = 3.96 + 1.31 \ln f_2 \quad (1)$$

$$E = 3577 + 3910 \ln f_2 \quad (2)$$

Table 2 also shows that the Poisson's ratio of concrete perforated brick masonry ranges from 0.12 to 0.25, which matches the result gained by Grimm and is little bit larger than that of common masonry (Shi 2003).

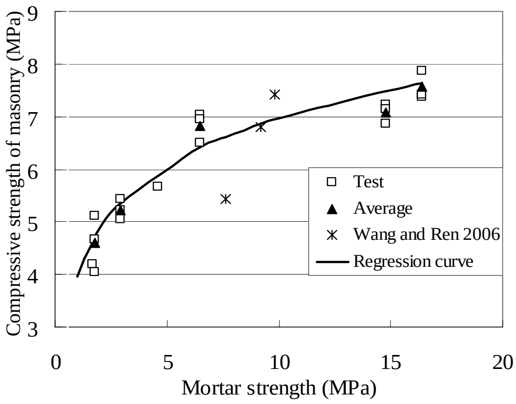

Figure 7 Relationship between compressive strength of masonry and mortar strength

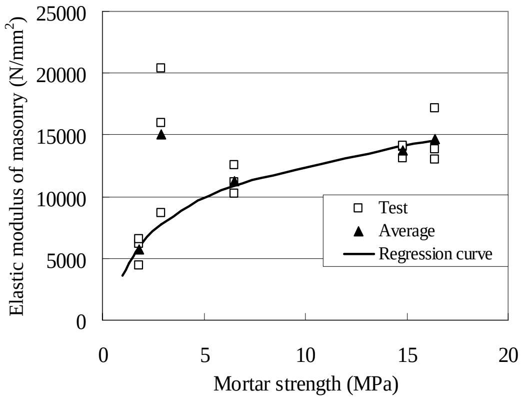

Figure 8 Relationship between elastic modulus of masonry and mortar strength

SHEAR BEHAVIOR OF CONCRETE PERFORATED BRICK MASONRY

Failure mode

In the test, shear load was applied continuously. The specimen suddenly lost its shear strength when the load was up to ultimate load. The specimen would be separated along one plane or two planes by the load. Brittle failure mode was observed in the test. Comparing with the common brick masonry, the dowel action caused by interlocking of mortar and brick holes is significant, which could increase the shear strength of the masonry.

(a) Test setup (b) Single plane failure (c) Double planes failure (d) Dowels are cut off

Figure 9 Test setup and shear failure mode of concrete perforated brick masonry

Shear strength of the masonry

The shear test results are shown in Table 3.

Table 3 Shear test results for masonry

Specimen	f_1 (MPa)	f_2 (MPa)	f_v (kN)	$f_{v,m}$ (MPa)	Eq.(3) (MPa)	Specimen	f_1 (MPa)	f_2 (MPa)	f_v (kN)	$f_{v,m}$ (MPa)	Eq.(3) (MPa)
SP-5-1	10.2	3.2	0.24	0.32	0.33	SP-15-1	10.2	9.5	0.52	0.53	0.56
SP-5-2			0.40			SP-15-2			0.62		
SP-5-3			0.41			SP-15-3			0.51		
SP-5-4			0.30			SP-15-4			0.58		
SP-5-5			0.25			SP-15-5			0.47		
SP-5-6			0.32			SP-15-6			0.46		
SP-10-1	10.2	4.4	0.42	0.38	0.38	SP-E10-1	10.2	12.4	0.59	0.66	0.64
SP-10-2			0.40			SP-E10-2			0.69		
SP-10-3			0.36			SP-E10-3			0.80		
SP-10-4			0.35			SP-E10-4			0.63		
SP-10-5			0.34			SP-E10-5			0.56		
SP-10-6			0.42			SP-E10-6			0.72		
SP-7.5-1	10.2	6.0	0.40	0.47	0.45	SP-E15-1	10.2	16.4	0.73	0.75	0.74
SP-7.5-2			0.38			SP-E15-2			0.88		
SP-7.5-3			0.48			SP-E15-3			0.60		
SP-7.5-4			0.30			SP-E15-4			0.79		
SP-7.5-5			0.60			SP-E15-5			0.75		
SP-7.5-6			0.65			SP-E15-6			0.75		

Notes: f_v—masonry shear strength; $f_{v,m}$—masonry average shear strength.

By regression analysis shown in Figure 10, the shear strength of concrete perforated brick masonry can be expressed as Eq. (3) and the calculation results for testing specimens using Eq. (3) are also given in Table 3.

$$f_v = 0.183\sqrt{f_2} \quad (3)$$

Eq. (4) is the shear strength of fired perforated brick given by Tao (2005).

$$f_v = 0.125(1+1.48\rho)\sqrt{f_2} \quad (4)$$

in which, ρ is the hole rate of perforated brick. For CPB24-1 type bricks, ρ is 34%, so Eq. (4) can be transformed into Eq. (5).

$$f_v = 0.188\sqrt{f_2} \quad (5)$$

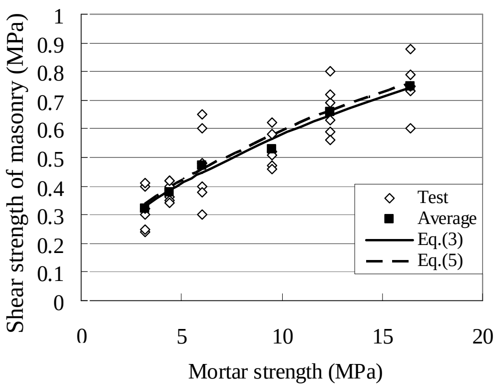

Figure 10 Relationship between shear strength of masonry and mortar strength

Comparing Eq. (3) with Eq. (5), it can be concluded that the shear strength of concrete perforated brick masonry is close to that of fired perforated brick masonry. So it is indicated that for perforated brick masonry the material itself is not the main factor to affect the shear strength, but the shape of the brick.

BEARING CAPACITY OF CONCRETE PERFORATED BRICK COLUMN

Compressive capacity of short columns

Failure mode

Comparing with the axial compression, the difference of failure process for eccentric compression is that the first crack occurred at the side near the load. When the side near the load was crushed, and a horizontal crack developed in the joint of the brick and the mortar on the other side, the column was damaged. The test setup and failure mode of the specimen are shown in Figure 11. For the specimen EP10-5-0.2-1, the strain distribution along the section is shown in Figure 12, in which it is verified that the plane section assumption is applicable in the analysis.

(a) Test setup (b) Cracks on the facade (c) Cracks on the side

Figure 11 Test setup and failure mode of the eccentrically loaded short column

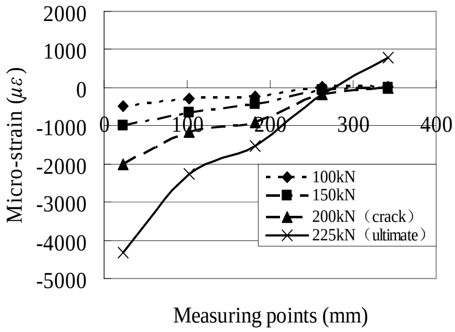

Figure 12 Distribution of the strain along the height of the section for EP10-5-0.2-1

Bearing capacity

The test results for short columns are shown in Table 4. By regression analysis shown in Figure 13, the eccentric influence coefficient taking into account the influence of loading eccentricity to the compressive capacity of the short column can be calculated using Eq. (6).

$$\alpha = \frac{1}{1 + 11.3(\frac{e}{h})^2} \tag{6}$$

The equation is almost same as that for normal masonry columns, which is shown in Eq. (7) (Ministry of Construction of the People's Republic of China 2002).

$$\alpha = \frac{1}{1 + 12(\frac{e}{h})^2} \tag{7}$$

Table 4 Test results for short columns

Specimen	f_1 (MPa)	f_2 (MPa)	e/h	N_{cr} (kN)	N_u (kN)	α
EP10-5-0-1	10.2	1.65	0	270	368	1.00
EP10-5-0.1-1			0.1	200	305	0.83
EP10-5-0.2-1			0.2	200	225	0.61
EP10-5-0.3-1			0.3	100	155	0.42
EP10-5-0-2	10.2	6.40	0	420	500	1.00
EP10-5-0.1-2			0.1	400	480	0.96
EP10-5-0.2-2			0.2	270	398	0.80
EP10-5-0.3-2			0.3	210	270	0.54
EP10-E10-0-1	10.2	14.8	0	500	627	1.00
EP10- E10-0.1-1			0.1	480	604	0.96
EP10- E10-0.2-1			0.2	390	459	0.73
EP10- E10-0.3-1			0.3	269	339	0.54
EP10-E10-0-2	10.2	14.8	0	500	627	1.00
EP10- E10-0.1-2			0.1	440	568	0.90
EP10- E10-0.2-2			0.2	319	369	0.59
EP10- E10-0.3-2			0.3	210	300	0.48

Notes: e/h—relative eccentricity; h—section height; α—eccentric influence coefficient.

Compressive capacity of long columns

Failure mode

When the load increased, the crack first appeared on the top of the column. And the column would be damaged when small columns caused by the cracks on the top part of the column crushed. The test setup and the failure mode of the specimen are shown in Figure 14.

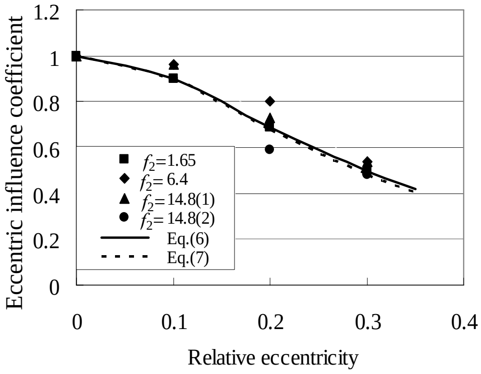

Figure 13 Relationship between eccentric influence coefficient and relative eccentricity

Bearing capacity

The test results for long columns under axial compressive load are shown in Table 5, in which φ_0 is the stability coefficient, which was derived from the compressive capacity of the long column divided by the compressive capacity of the short column with the same material strength.

(a) (b) (c)

Figure 14 Test setup and failure mode of the axially loaded long column

Table 5 Test results for long columns

Specimen	f_1 (MP)	f_2 (MP)	β	N_{cr} (kN)	N_u (kN)	φ_0
LP10-5-3	10.2	1.65	3	270	368	1
LP10-5-6		1.65	6	270	338	0.92
LP10-5-10		3.70	10	270	378	0.76*
LP10-5-14		3.03	14	260	339	0.71*
LP10-10-3	10.2	4.61	3	390	496	1
LP10-10-6		4.61	6	——	——	—
LP10-10-10		4.61	10	210	353	0.71
LP10-10-14		4.61	14	300	391	0.79
LP10-E10-3	10.2	12.4	3	500	627	1
LP10-E10-6		12.4	6	560	592	0.94
LP10-E10-10		12.4	10	600	686	1.09
LP10-E10-14		12.4	14	510	595	0.95

Notes：β—height-thickness ratio.

The stability coefficient of long column decreases with the increase of ratio of height to sectional thickness. By regression analysis shown in Figure 15, the stability coefficients φ_0 can be calculated using Eq. (8).

$$\varphi_0 = \frac{1}{1+0.00133\beta^2} \tag{8}$$

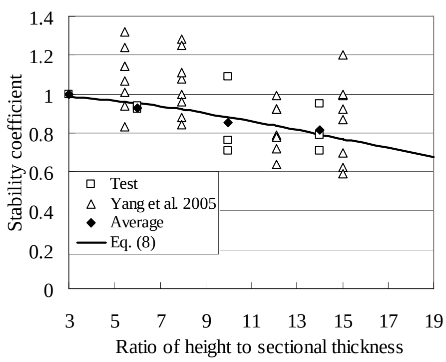

Figure 15 Relationship between ratio of height to sectional thickness and stability coefficient

CONCLUSIONS

The compression test results indicate that the compressive strength and elastic modulus of concrete perforated brick masonry increase with the increase of the mortar strength in the form of logarithm; the Poisson's ratio of concrete perforated brick masonry is larger than that of normal masonry. Because of the dowel action, the shear strength of concrete perforated brick masonry is larger than that of normal masonry.

The eccentric compression coefficient for short columns decreases with the increase of the eccentricity, which is close to that for normal masonry short columns; the stability coefficient for long columns decreases with the increase of ratio of height to sectional thickness.

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