# TESTING AND ANALYSIS OF THE BEARING STRENGTH OF BRICK MASONRY

# 砖砌体局部受压强度试验

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ABSTRACT Several sorts of basic failure model of local bearing of brick masonry are observed through a lot of tests. Together with the analysis of the calculated results by computer, the actual behaviour of local bearing action of brick masonry is presented. The problems existing in the formula in current Chinese code for calculating the local bearing strength of brick masonry are then studied and a practical formula more conformable to real conditions is suggested.

【提要】 通过大量试验观察发现砖砌体局部受压的几种基本破坏形态，结合电算资料分析提出了砖砌体局部受压的工作实质。根据比较系统的局部受压试验，分析了现行规范局部受压强度计算公式所存在的问题，从而提出了比较符合实际的实用计算公式。

The local bearing is one of the frequent visible bearing conditions of brick masonry. The strength coefficient $\gamma$ of bearing strength of brick masonry in the current Chinese Code (1) adopts the formula

$$\gamma = \sqrt{A_o/A_c}$$

(where $A_o$ is the calculating area affecting on bearing strength; $A_c$ is the local bearing area).

In fact, this expression was derived based on the principle of ultimate balance and the theory of assumed "strength hoop" (2), and used in the concrete code. As the differences of material behaviour it is difference between the local bearing characteristic of the brick masonry and those of the concrete. In the case of the local load acting on a corner, there is no hoop existing and it cannot be explained using the hoop principle.

Based on a lot of tests two problems, the characteristic of brick masonry under local load, and the strength coefficient of the local bearing strength, are discussed in this paper.

## 1. THE SORTS OF BASIC FAILURE MODEL OF BRICK MASONRY UNDER LOCAL LOAD

Three sorts of basic failure model of brick masonry under local load are observed:

1. Failure due to the development of vertical cracks
2. Splitting failure
3. Local failure within the bearing area.

Fig. 1 shows the distributions of the horizontal stress $\sigma_x$ and the vertical stress $\sigma_y$ at the middle line of the specimen under a local load in the middle part. It can be obtained from test measurement or analysis by the finite element method. It can be seen the brick masonry under the loading plate is in the biaxial or triaxial compressive state (under local load at centre part). So the compressive strength of the brick masonry within the local bearing area

will be strengthened greatly. There is horizontal tensile stress existing some distance away from the loading plate. When the tensile stress is greater than the tensile strength, a vertical crack will appear. The crack is observed mostly near to the part where the horizontal tensile stress is maximum. With the load increasing the crack develops down and up. Meanwhile other vertical cracks and inclined cracks appear also. At that time, the stress state of the brick masonry has changed. Biaxial stress may become uniaxial stress along the strip between two vertical cracks. When the compressive stress reaches its compressive strength, the specimen will be crushed. Before crushing some broken pieces falling down could be observed. Generally speaking, there is a main crack throughout the whole specimen as the failure occurs. This case is failure model 1 and it is illustrated in Figure 2.

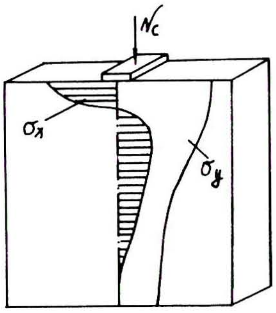


Fig. 1. The distribution of $\sigma_x$ and $\sigma_y$

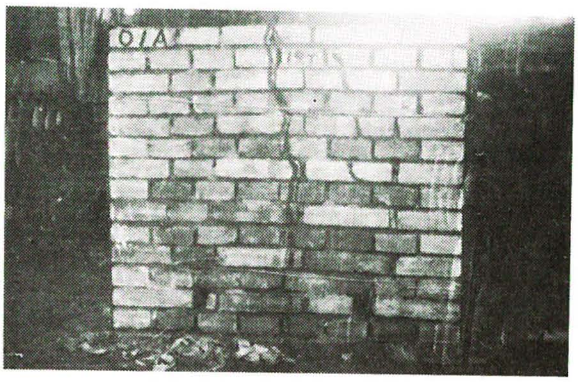


Fig. 2. Failure model 1

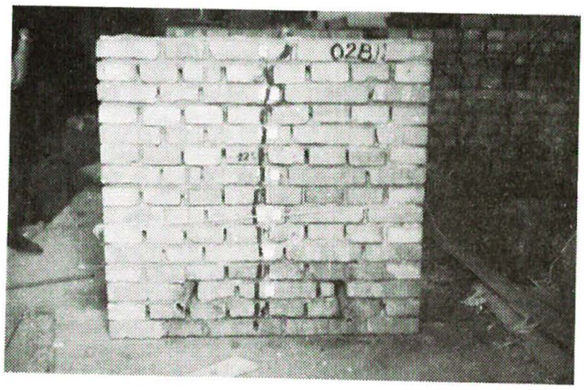


Fig. 3. Splitting failure model 2

Tests of local bearing show that the ratio of the cracking load $N_f$ and the ultimate load $N_p$ ($\beta$) increases with increasing ratio $A/A_c$ where A is cross section of the specimens. When $A/A_c$ is quite large, $\beta = 1$, so that cracking and crushing occur at the same time. In fact, this is a splitting failure, model 2 and it is illustrated in Fig. 3.

If the strength of the brick masonry is very low, failure model C may occur. For example, a specimen made of hollow pumice concrete block was crushed at the local bearing area.

We have compared three sorts of specimens:

(a) without any reinforcement

(b) with bolts ( Fig. 4)

(c) with mat reinforcement (group 76, 77, 78 respectively).

The sizes and the material grades of the specimens are all the same. The results of the test are shown in Table 1:

(i) Either bolt or mat reinforcement could strengthen the local bearing capacity, and reduce local bearing failure resulting from vertical cracks.

(ii) In spite the local bearing stresses, $\sigma_c$ under the loading plates of groups 77 and 78 reach 108-150 $kg/cm^2$, which is higher than the strength of brick, no brick crushed was observed under loading plate.

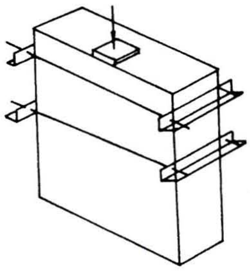

Fig. 4. The specimen with bolt

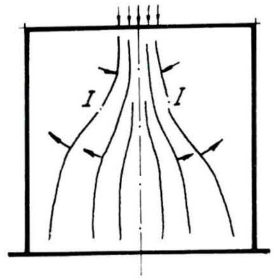


Fig. 5. Force line in the local bearing

According to Guyon's explanation (3), the reason for horizontal compressive stress and tensile stress at the centre section (Fig. 1) is that the load is spread through the specimen. The point I shown in Fig. 5 is a turning point of the force line. The force lines above are dented toward the inside of the specimen and engender the compressive stress, and the force lines below engender the tensile stress. It may be more reasonable to explain the substance of the local bearing of brick masonry by load spreading.

The local bearing of brick masonry can be described in this way; due to the spread of force lines, the brick masonry under the loading plate is in biaxial or triaxial compression, so is difficult to crush. The part below the middle of the specimen is in a stress state of horizontal tension and vertical compression. When the maximum horizontal tensile stress $\sigma_x$ reaches the tensile strength of brick masonry, the first vertical crack appears. As $\sigma_x$ reaches $R_e$ only within a small zone the brick will not fail. The calculated results by the finite element method show that the greater $A/A_c$ , the more uniform is the horizontal tensile stress $\sigma_x$ . The $\sigma_x$ distribution along the centre section could reach $R_e$ in a larger area at the same time and then the brick masonry splits suddenly.

We consider that as long as there is some masonry beyond the bearing area, the spreading will occur. Then biaxial stress or triaxial stress will be engendered and local bearing strength can be increased more or less. In this way we can explain the local bearing action rationally, not only to a load in the middle part, but also to a load at a corner or at an edge.

| No | The size of specimen (cm) | A ($cm^2$) | $A_c$ ($cm^2$) | $A/A_c$ | R ($kg/cm^2$) | $N_f$ (t) | $N_c$ (t) | $\gamma$ |
|---|---|---|---|---|---|---|---|---|
| 76A | 36.2x74.6 | 2701 | 440.8 | 6.15 | 31.5 | 20 | 32.5 | 2.34 |
| 76B | 36.7x73.8 | 2708 | " | 6.15 | 31.5 | 25 | 30.0 | 2.17 |
| average | | | | | | | 31.25 | 2.26 |
| 77A | 36.5x74.3 | 2712 | 440.8 | 6.15 | 31.5 | 25 | 45 | 3.25 |
| 77B | 36.8x73.5 | 2705 | " | 6.15 | 31.5 | 25 | 50 | 3.62 |
| average | | | | | | | 47.5 | 3.42 |
| 78A | 37x73.5 | 2720 | 440.8 | 6.15 | 57 | 40 | 63 | 2.5 |
| 78B | 36.8x74.5 | 2740 | 284.4 | 9.5 | >57 | 20 | 45 | <2.8 |

TABLE 1. The contrasting tests of three sorts of specimen

## 2. LOCAL BEARING TESTS UNDER UNIFORM LOADING IN THE MIDDLE, AT THE END AND AT THE CORNER OF WALL

The strength coefficient of local bearing strength of brick masonry adopted in the current Chinese code is:

$$\gamma = \sqrt{A_o/A_c} \qquad (1)$$

For central local bearing the calculated value of $\gamma$ from the formula (1) is greater than that calculated from Bauchinger's formula

$$\gamma = \sqrt[3]{A_o/A_c} \; .$$

But for middle local bearing on a length of wall, the value of $\gamma$ is lower because the value $A_o$, according to the law of minimum hoop, is very small. Local bearing of a length of wall is the most common case in engineering. We have done systematic tests with a uniform bearing area ($A_c$ = 20x25 $cm^2$) on specimens of different section. The ratio of $A/A_c$ is taken as a variable (Fig. 6).

We have found from the tests results ( Table 2) that $\gamma$ is closely related with the value of $A/A_c$. Considering the value of $\gamma$ should be 1 when $A/A_c = 1$, we have regressed the following formula:

$$\gamma = 1+0.378\sqrt{A/A_c - 1} \qquad (2)$$

with interrelation coefficient R = 0.95. The values of $\gamma_2$ in Table 2 are calculated from formula (2).

Formula (2) consists of two terms. That means the local bearing strength of brick masonry contains two parts, one of them is the bearing strength of area $A_c$ itself, and the other is the contribution of lateral pressure from

nonpressed area $(A-A_c)$. This formula has a clear physical concept.

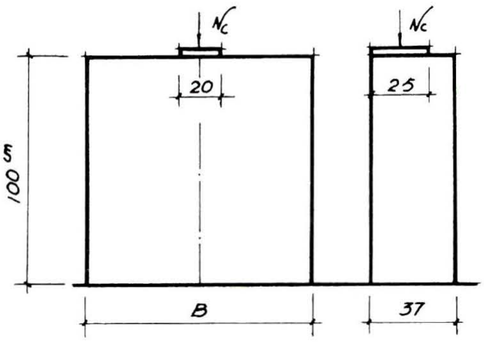


Fig. 6. Local bearing in the middle of wall

| group | number of specimen | the size of specimen (cm) | A ($cm^2$) | $A/A_c$ | R ($kg/cm^2$) | $\gamma_1$ tested | $\gamma_2$ calculated | $\gamma_1/\gamma_2$ | $N'_f$ (t) | $\gamma_f$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 07 | 3 | 37x100x100 | 3656 | 7.31 | 22.0 | 2.04 | 1.95 | 1.05 | 20.83 | 1.89 |
| 08 | 3 | 37x100x100 | 3620 | 7.24 | 18.2 | 1.83 | 1.95 | 0.94 | 14.33 | 1.57 |
| 09 | 3 | 37x100x100 | 3636 | 7.27 | 18.8 | 2.12 | 1.95 | 1.09 | 17.33 | 1.84 |
| 11 | 3 | 37x87x100 | 3182 | 6.36 | 21.6 | 1.86 | 1.88 | 0.99 | 16.66 | 1.54 |
| 12 | 3 | 37x87x100 | 3215 | 6.43 | 21.8 | 1.83 | 1.88 | 0.97 | 16.00 | 1.47 |
| 13 | 3 | 37x87x100 | 3497 | 6.39 | 20.0 | 2.00 | 1.88 | 1.06 | 16.00 | 1.60 |
| 14 | 3 | 37x74x100 | 2733 | 5.47 | 18.6 | 1.68 | 1.80 | 0.93 | 13.33 | 1.43 |
| 15 | 3 | 37x74x100 | 2707 | 5.41 | 18.6 | 1.72 | 1.79 | 0.96 | 11.33 | 1.22 |
| 16 | 3 | 37x74x100 | 2725 | 5.45 | 18.2 | 1.76 | 1.80 | 0.98 | 12.67 | 1.39 |
| 18 | 3 | 37x62x100 | 2228 | 4.46 | 23.7 | 1.68 | 1.70 | 0.99 | 15.33 | 1.29 |
| 19 | 3 | 37x62x100 | 2245 | 4.49 | 21.2 | 1.64 | 1.71 | 0.96 | 12.00 | 1.13 |
| 20 | 3 | 37x62x100 | 2244 | 4.49 | 21.2 | 1.77 | 1.71 | 1.04 | 12.00 | 1.13 |
| 17 | 3 | 37x49x100 | 1779 | 3.56 | 18.0 | 1.63 | 1.61 | 1.01 | 10.66 | 1.18 |
| 26 | 2 | 37x74x82 | 2688 | 3.69 | 26.6 | 1.62 | 1.62 | 1.00 | | |
| 37 | 3 | 24x74x84 | 1756 | 3.66 | 27.6 | 1.76 | 1.62 | 1.09 | | |

TABLE 2. Bearing tests in the middle of wall

The curves (1) and (2) in Fig. 7 are based on formulas (1) and (2) respectively. We have calculated value $\gamma$ through group 07 to 20 according to the current code, and always got $\gamma = 1.67$ due to $A_o/A_c = 2.8$ in every group. The statement above is reflected in Fig. 7. When $A/A_c < 2.8$, we use formula (1) to calculate the value of $\gamma$. When $A/A_c > 2.8$, we use $\gamma = 1.67$ as a horizontal line. Evidently, the result is conservative when $A/A_c$ is large and unconservative when $A/A_c$ is small.

Using the formula $N_f = \gamma_f A_c R$, where $N_f$ is the cracking load, we have calculated the cracking strength coefficient $\gamma_f$ for group 07-20 tested under uniform local load in the middle (Table 2). It is found that the $\gamma_f$ is a curve with slight curvature (Fig. 8).

The ultimate strength curve (2) intersects with curve $\gamma_f$ at the point $A/A_c = 9$ ( Fig. 8). The failure is caused by specimen cracking when $A/A_c < 9$ . It belongs to the failure model 1. When $A/A_c > 9$, a sudden

splitting failure may happen. This kind of situation is unsatisfactory. The value $\gamma$ equals 2.1 at the intersecting point, so we choose 2.0 as the up-limit value of $\gamma$ .

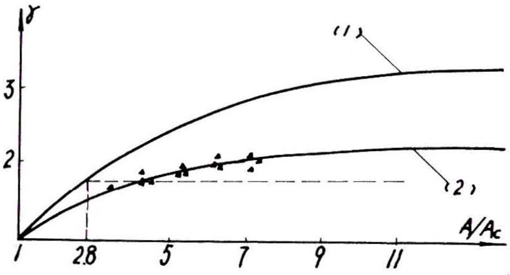


Fig. 7. The $\gamma$ curve of middle bearing

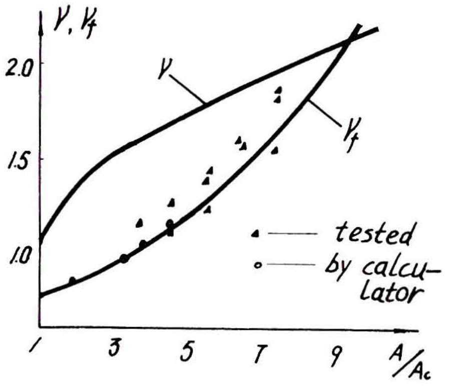


Fig. 8. The $\gamma$ curve and $\gamma_f$ curve of middle bearing

We have tested 8 groups of local bearing specimens under uniform load at the end of wall. In order to prevent the specimen from non-local bearing failure ( Fig. 9), a steel beam is put on the other end of the wall (Fig. 10). In this way a tested specimen canbe used again, and almost the same bearing strength can be achieved.

We have tested 3 groups of tests under uniform load at the corner of angle wall. The same method is adopted to prevent non-local bearing failure (Fig. 12).

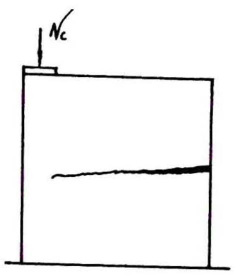

Fig. 9. Non-local bearing failure

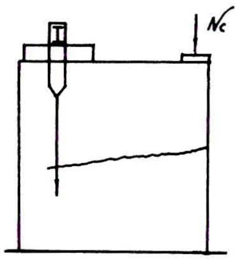

Fig. 10. The specimen with anchor

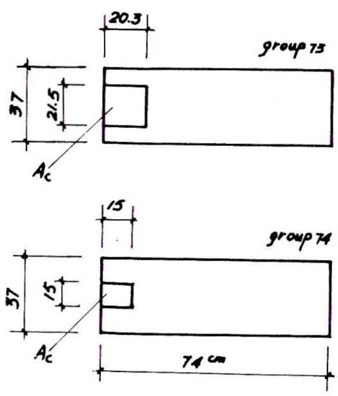


Fig. 11. The bearing position of group 73.74

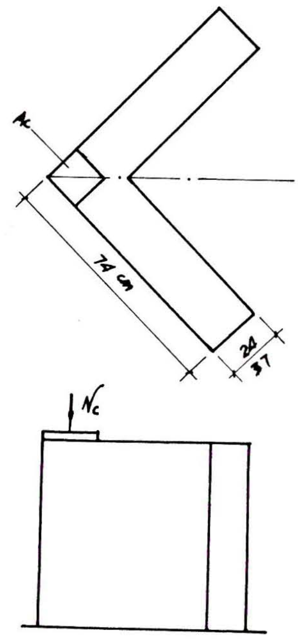


Fig.12. Local bearing at the corner of wall

The test results are listed in Table 3.

It can be seen that taking the ratio $A/A_c$ as the only parameter of local bearing is unsuitable. Test results of groups 70 and 71 give us evidence that a higher value of $\gamma$ can also be obtained when the opposite end of the wall has been broken. So, the effective area $A_o$ is not the whole specimen. It is required to calculate the effective area $A_o$.

| | group | the size of specimen | A ($cm^2$) | $A_c$ ($cm^2$) | $A_o$ ($cm^2$) | $A_o/A_c$ | R ($kg/cm^2$) | $\gamma$ |
|---|---|---|---|---|---|---|---|---|
| at the end | 41A~C | 24x74x82 | 1769 | 884 | 1464 | 1.65 | 25.3 | 1.05 |
| | 54A~C | 37x74x82 | 2762 | 737 | 2109 | 2.85 | 31.0 | 1.50 |
| | 61A,B, E | 24x74x82 | 1781 | 573 | 1143 | 2.00 | 41.2 | 1.41 |
| | 62A~F | 24x74x82 | 1763 | 714 | 1280 | 1.79 | 41.2 | 1.34 |
| | 70A ,E,F | 24x74x82 | 1751 | 473 | 1056 | 2.20 | 42.8 | 1.22 |
| | 71A,D,F | 24x74x82 | 1763 | 475 | 1056 | 2.20 | 42.8 | 1.25 |
| | 73A~C | 37x74x82 | 2742 | 441 | 2128 | 4.80 | 43.5 | 1.47 |
| | 74A~C | 37x74x82 | 2739 | 225 | 1924 | 8.60 | 43.5 | 1.84 |
| at the corner | 80A~C | 24x74x82 | 2942 | 400 | 1536 | 3.84 | 47.3 | 1.29 |
| | 89B,C | 24x74x82 | 2946 | 560 | 1678 | 3.00 | 35.8 | 1.45 |
| | 90A~C | 24x74x82 | 2933 | 225 | 1278 | 5.68 | 35.8 | 1.82 |

TABLE 3. Bearing tests at the end and at the corner of wall

The three kinds of specimen above often occur in the case of a wall supporting a beam at its end. We calculate A like this: the edge of A on a wall is the line distance d (wall thickness) from each side of the beam (Fig. 13). In this way, the law of $\gamma$ in the three kinds of situation is almost the same. That means it is possible to simplify a complex problem when we calculate the value of $\gamma$ using the method above, which considers the influence of relative areas $A_c$ and A.

Using $A_o/A_c$ as a parameter of test data we have got a regressive expression.

$$\gamma = 1+0.364\sqrt{A_o/A_c - 1} \tag{3}$$

Curve (3) in Fig. 14 is based on expression (3) with an interrelation coefficient R = 0.88.

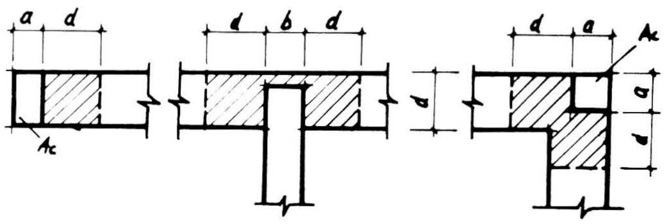


Fig. 13. The calculation of the area of bearing

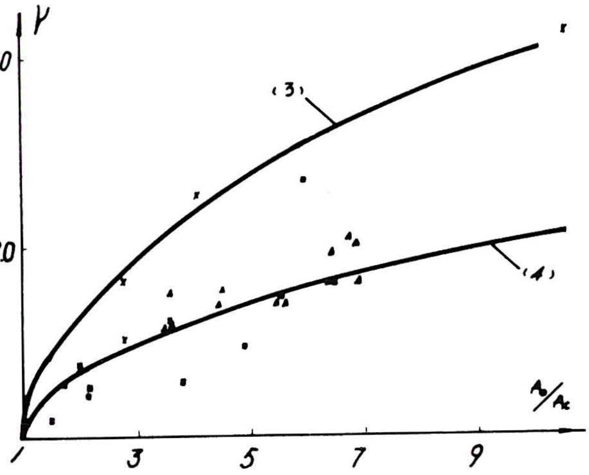


Fig. 14. Suggested $\gamma$ curve

## 3. THE STRENGTH OF BRICK MASONRY UNDER CENTRAL UNIFORM LOCAL LOADING

Through the tests of central uniform local bearing of brick masonry, we can also get the ultimate strength curve ( $\gamma$ curve) and cracking strength curve ($\gamma_f$ curve), see Fig. 15.

Based on the test results, we have regressed the expression of $\gamma$ :

$$\gamma = 1+0.708\sqrt{A/A_c - 1} \tag{4}$$

with the interrelation coefficient R = 0.74.

The $\gamma_f$ curve intersects with the curve $\gamma$ at the point when $A/A_c = 10$. It is the limit of splitting failure under central local loading, at this very point corresponding $\gamma = 3.1$.

| group | the size of specimen | A ($cm^2$) | $A_c$ ($cm^2$) | $A/A_c$ | R ($kg/cm^2$) | $\gamma_1$ tested | $\gamma_2$ calculated | $\gamma_1/\gamma_2$ | $N_f$ (t) | $\gamma_f$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 67A~C | 49x49x83 | 2414 | 225 | 10.7 | 50.6 | 3.16 | 3.20 | 0.99 | 36.00 | 3.16 |
| 68A~C | 49x49x83 | 2412 | 900 | 2.68 | 50.6 | 1.81 | 1.92 | 0.94 | 63.00 | 1.38 |
| 83A~C | 37x37x83 | 1331 | 225 | 5.89 | 27.6 | 2.36 | 2.56 | 0.92 | 12.67 | 2.04 |
| 84A~C | 37x37x83 | 1343 | 441 | 3.05 | 27.6 | 2.03 | 2.01 | 1.01 | 20.67 | 1.70 |
| 2a~C | 37x37x97 | 1332 | 324 | 4.15 | 30.5 | 2.48 | 2.25 | 1.10 | | |
| 3a~C | 37x37x97 | 1315 | 159 | 8.25 | 31.7 | 3.33 | 2.91 | 1.14 | | |
| 4a~C | 37x37x97 | 1332 | 64 | 20.9 | 31.7 | 7.39 | 4.16 | 1.78 | | |
| 6a~C | 37x37x72 | 1332 | 324 | 4.15 | 43.9 | 1.78 | 2.25 | 0.79 | | |
| 7a,b | 37x37x72 | 1332 | 159 | 8.39 | 43.9 | 2.12 | 2.93 | 0.72 | | |
| 9a,b | 49x49x150 | 2445 | 600 | 4.07 | 30.2 | 2.22 | 2.24 | 0.99 | | |
| 10a,b | 49x49x150 | 2455 | 306 | 8.02 | 29.7 | 3.70 | 2.88 | 1.28 | | |

TABLE 4. The tests of central bearing of brick masonry

Based on the test results by the author and other researchers, in the case of central bearing, we may take the maximum supporting area as $A_o$ which has the same centre as $A_c$. In this way, we may substitute A in formula (4) with $A_o$.

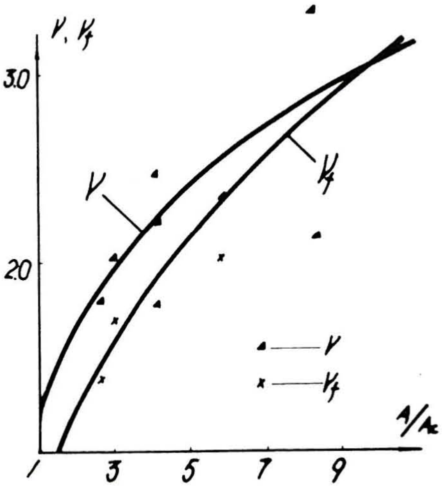


Fig. 15. The $\gamma$ curve and $\gamma_f$ curve of central bearing

## 4. SUMMARY

4.1 Failure due to development of vertical cracks is a basic failure model of brick masonry under local loading. Splitting failure may happen when $A/A_c$ is large (larger than 10 in central bearing or 9 in middle bearing).

A local failure in loading area may occur when the strength of brick is very low.

4.2 The reason for the higher bearing strength of brick masonry is that the masonry area just under the loading plate is in a state of two or three dimensional compression. The reason for local bearing failure of masonry is the formation and development of vertical cracks, which happens when the tension stress of masonry is higher than the ultimate tension strength of the masonry. The lateral compression and tension stress are produced in the masonry due to diffusion of load.

4.3 The following formula is suggested for design of masonry under uniform local loading.

$$KN_c \leqslant \gamma A_c R$$

where

$$\gamma = 1 + \xi\sqrt{A_o/A_c - 1}$$

$\xi = 0.708$ for central local bearing, $\xi = 0.364$ for a length of wall under load in the middle, at end and at the corner of the wall. The upper limit of $\gamma$ is 3.0 and 2.0 for the former and latter respectively.

## 5. REFERENCES


(1) The design code of brick masonry (GBJ-3-73).

(2) Cai Shao-Huai: The strength of concrete and reinforced concrete under local loading. Journal of Civil Engineering, No. 6, 1963.

(3) Y. Guyon, Beton Precontraint Etude Treorique et Experimentale, 1953.

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