THE PROBABILITY-BASED LIMIT STATE DESIGN OF BRICK MASONRY WITH REINFORCED NETWORK

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ABSTRACT Based on theoretical analysis and experimental research, this paper proposes the calculation formula of coefficient of eccentricity, the ratio of the height to the thickness and the buckling factor effect for brick masonry with reinforced network. According to the probability-based limit state design method, the expression for the design of brick masonry with reinforced network is established. The load-bearing capacity and the material service amount obtained from the above formula are also compared with the value of the current Chinese Code.

1. INTRODUCTION

Brick masonry with reinforced network is the brickwork in the mortar joints of which that steel-wire nets are horizontally place (Fig. 1). The transveral deformation of the brickwork is then restrained due to the combined action of the two materials (the reinforcement and brickwork), and the elastic modulus of the reinforcement is greater than the elastic modulus of the brickwork, thus the compressive strength of the brickwork is also greater than the reinforcement is not used in it. The brick masonry with reinforced network is mainly used as the compressive member [1] . It possesses the definite economical interests in civil engineering.

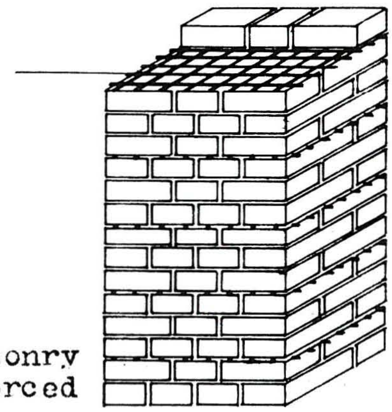

Fig. 1 Brick Masonry with Reinforced Network

2. ANALYSIS OF THE BASIC FACTOR INFLUENCING THE COMPRESSIVE STRENGTH

In the current Chinese Code for Masonry Structures [2] , the load-bearing capacity for the compressive members of brick masonry with reinforced network may be calculated by the following formula:

$$KN \leqslant \varphi \alpha f_n A \tag{1}$$

where

K = the factor of safety, the value 2.3 is used

N = the vertical compressive load (kN)

φ = the buckling coefficient

α = the coefficient of the eccentric effect

f_n = the compressive strength of the brick masonry with reinforced network (kPa)

A = the cross sectional area (m^2).

In reference [1] the perfective calculation formula of the coefficient of the eccentric effect is proposed:

$$\alpha_p = \frac{1}{1 + 4.5\,(e/y)^2} \tag{2}$$

where

e = the eccentricity of the vertical compressive load (m)

y = the distance between the centroid of the section and the bigger compressed side of the section (m).

The values (α_p) calculated by formula (2) have been compared with our own experimental values (α'_p) obtained from 163 test prisms (the ratio of reinforcement μ = 0.067 ~ 2.0%, the eccentricity e/y = 0 ~ 0.5). The mean value of α_p/α'_p is 0.999 and the coefficient of variation is 0.267.

Because under the eccentric compression the additional deflection (f) influence on the eccentric compressive member must be considered, let the value of the eccentricity be equal to $e+f$ [3] . By applying formula (2), the effective factor of brick masonry with reinforced network subject to the eccentric compression will be:

$$\alpha_n = \frac{1}{1 + 4.5\,\left(\frac{e+f}{y}\right)^2} \tag{3}$$

where, when $e = o$, $\alpha_n = \varphi$, then

$$\varphi = \frac{1}{1 + 4.5\,(f/y)^2} \tag{4}$$

We can see from formula (4):

$$f = y\sqrt{\frac{1}{4.5}\left(\frac{1}{\varphi} - 1\right)} \tag{5}$$

From equations (3) and (5), as the increase of the additional deflection of members and the plastic deform of the section have influence, finally we can get:

$$\alpha_n = \frac{1}{1 + 4.5\left[\frac{e}{y} + \frac{1}{4.5}\left(\frac{1}{\varphi} - 1\right)(0.025\beta + 0.4)\right]^2} \tag{6}$$

where

β = the ratio of the height to the thickness of the member.

In formula (6), when $\beta \leqslant 3$, that is $\varphi = 1$, then $\alpha_n = \alpha_p$. In this case, formula (6) becomes formula (2).

The values (α_n) calculated by using formula (6) have been compared with the values ($\varphi\alpha_p$) of reference [1] and the values ($\varphi\alpha$) of the current Chinese Code [2] (See Table 1.). From table 1, we know that the mean value of $\alpha_n/\varphi\alpha_p$ is 0.982 and the coefficient of variation is 0.055, the mean value of $\alpha_n/\varphi\alpha$ is 0.932 and the coefficient of variation is 0.087.

The effect of the eccentricity, the ratio of the height to the thickness and buckling has been considered in formula (6) of this paper, it is also more rational.

Table 1. The comparison of the influence coefficient

$\frac{e}{y}$	β	Ratio of reinforcement μ %											
		0.1			0.5			0.9			1.0		
		α_n	$\varphi\alpha$	$\varphi\alpha_p$	α_n	$\varphi\alpha$	$\varphi\alpha_p$	α_n	$\varphi\alpha$	$\varphi\alpha_p$	α_n	$\varphi\alpha$	$\varphi\alpha_p$
0.1	4	0.917	0.941	0.931	0.897	0.912	0.902	0.886	0.892	0.883	0.880	0.883	0.874
	8	0.848	0.863	0.854	0.798	0.786	0.778	0.756	0.718	0.710	0.744	0.698	0.691
	12	0.746	0.757	0.749	0.655	0.631	0.624	0.591	0.543	0.538	0.576	0.524	0.518
	16	0.626	0.650	0.643	0.502	0.495	0.490	0.421	0.398	0.394	0.405	0.378	0.374
0.2	4	0.792	0.863	0.825	0.767	0.837	0.799	0.754	0.819	0.782	0.747	0.774	0.810
	8	0.713	0.792	0.757	0.662	0.721	0.689	0.622	0.659	0.629	0.611	0.641	0.612
	12	0.612	0.694	0.663	0.532	0.579	0.553	0.478	0.498	0.476	0.466	0.481	0.459
	16	0.507	0.596	0.570	0.406	0.454	0.434	0.343	0.363	0.349	0.330	0.347	0.332
0.3	4	0.656	0.766	0.689	0.632	0.743	0.667	0.619	0.727	0.653	0.614	0.719	0.646
	8	0.582	0.703	0.632	0.538	0.640	0.575	0.504	0.585	0.525	0.495	0.569	0.511
	12	0.496	0.616	0.554	0.431	0.514	0.462	0.388	0.442	0.398	0.378	0.427	0.383
	16	0.411	0.529	0.476	0.331	0.403	0.362	0.282	0.324	0.291	0.272	0.308	0.277

3. DESIGN EXPRESSION

Based on the probability-based limit state design method [4] , the characteristic value for the property of the material and the partial coefficient for the property of the material of the member are adopted. The expression for the design of brick masonry with reinforced network of the member subject to compression are: when the axial compression (including $e < 0.1y$) exists, then

$$N_d \leqslant \frac{1}{\gamma} \varphi f_{nk} A \tag{7}$$

when the eccentric compression ($0.1y \leqslant e < \frac{1}{3}y$) exists, then

$$N_d \leqslant \frac{1}{\gamma} \alpha_n f_{nk} A \tag{8}$$

where

N_d = the design value of the compressive loads, the standard values of dead load and live load are used, and the coefficients for their effects correspondingly are 1.2 and 1.4

γ = the partial coefficient for the property of the material of the member, a value of 1.35 is used

f_{nk} = the characteristic value for the property of the material, a value of $f_m - 1.64\sigma$ is used

f_m = the mean value of the strength of the material

σ = the standard deviation.

When the above stated expression for the design is calibrated, the reliability index (β) approaches or reaches it, to the required value, $\beta \approx 3.7$.

The calculated values (N_2) of the load-bearing capacity obtained from formula (7) and (8) have been compared with the values (N_1) of the current Chinese Code. The results are shown in tables 2, 3 and 4.

Because the value of φ obtained from the formula in this paper is equal to the value of the current Chinese Code, for the slender column subject to the axial compression the values of N_2/N_1 are also equal to the value in table 2. We can find from table 2, 3 and 4 that for the axial compressive culumn and the short culumn subjected to the eccentric compression, the calculated values of

Table 2. The load-bearing capacity of the column subjected to the axial compression

μ* (%)	N_2 (kN)	N_1 (kN)	$\frac{N_2}{N_1}$
0.1	1500 A	1570 A	0.955
0.3	1980 A	2060 A	0.961
0.5	2470 A	2550 A	0.969
0.7	2950 A	3040 A	0.970
0.9	3430 A	3530 A	0.972
mean value			0.965

* μ = ratio of reinforcement.

** The tensile strength of reinforcement is 235(MPa).

Table 3. The load-bearing capacity of the short column subjected to the eccentric compression

μ (%)	$\frac{e}{y}$	N_2 (kN)	N_1 (kN)	$\frac{N_2}{N_1}$
0.1	0.1	1420 A	1470 A	0.966
	0.2	1230 A	1310 A	0.939
	0.3	1020 A	1120 A	0.911
0.3	0.1	1830 A	1850 A	0.989
	0.2	1560 A	1570 A	0.994
	0.3	1260 A	1280 A	0.984
0.5	0.1	2240 A	2240 A	1.000
	0.2	1890 A	1830 A	1.033
	0.3	1500 A	1430 A	1.049
0.7	0.1	2650 A	2620 A	1.015
	0.2	2210 A	2090 A	1.057
	0.3	1740 A	1590 A	1.094
0.9	0.1	3070 A	3000 A	1.023
	0.2	2540 A	2360 A	1.076
	0.3	1980 A	1740 A	1.138
mean value				1.018

See the notes in Table 2.

Table 4. The load-bearing capacity of the slender column subjected to the eccentric compressive

$\frac{e}{y}$	β	μ = 0.1 %			μ = 0.5 %			μ = 0.9 %		
		N_2 (kN)	N_1 (kN)	$\frac{N_2}{N_1}$	N_2 (kN)	N_1 (kN)	$\frac{N_2}{N_1}$	N_2 (kN)	N_1 (kN)	$\frac{N_2}{N_1}$
0.1	4	1360 A	1430 A	0.951	2150 A	2100 A	1.024	2950 A	2760 A	1.069
	8	1250 A	1310 A	0.954	1990 A	1810 A	1.099	2720 A	2220 A	1.225
	12	1100 A	1150 A	0.957	1750 A	1450 A	1.207	2400 A	1680 A	1.429
	16	930 A	990 A	0.939	1470 A	1140 A	1.289	2010 A	1230 A	1.634
0.2	4	1150 A	1270 A	0.906	1760 A	1720 A	1.023	2370 A	2170 A	1.092
	8	1040 A	1160 A	0.897	1590 A	1480 A	1.074	2140 A	1740 A	1.230
	12	890 A	1020 A	0.873	1360 A	1190 A	1.143	1830 A	1320 A	1.386
	16	740 A	880 A	0.841	1130 A	930 A	1.215	1520 A	970 A	1.567
0.3	4	940 A	1090 A	0.862	1380 A	1350 A	1.022	1820 A	1600 A	1.138
	8	830 A	1000 A	0.830	1230 A	1160 A	1.060	1620 A	1290 A	1.256
	12	710 A	880 A	0.807	1040 A	930 A	1.118	1380 A	980 A	1.408
	16	590 A	750 A	0.787	870 A	730 A	1.192	1140 A	710 A	1.606
									mean value	1.114

See the notes in Table 2.

the load-bearing capacity obtained from the formulas in this paper are close to those in our current national code. For the slender column subjected to the eccentric compression, the values of the former are increased only a little.
Besides, the material service amount calculated by the formulas in this paper have been compared with the value of the current Chinese Code. The results show that under the axial compression the material service amount in the both case are also close, under the eccentric compression the amount of the former is decreased only a little.

4. CONCLUSION

Based on the theoritical analysis and experimental research, this paper proposes the calculation formula of coefficient of eccentricity the ratio of the height to the thickness and the buckling factor effect for brick masonry with reinforced network. The formula possesses characteristics, that is, when the member is subjected to the eccentric compressive loading, the influence of the additional deflection and plastic deform etc. on it has been considered. Based on the probability-based limit state design method, in this paper the expression for the design of brick masonry with reinforced network is established. Though the calibration we learn that reliability index approaches or reaches to the required value. In this paper the load-bearing capacity and the material service amount are also compared with the value of the current Chinese Code. The results are more satisfactory.
This paper has provided the basis for revising the "Chinese Design Code for Masonry Structures".

5. REFERENCES

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