A BRIEF INTRODUCTION TO A NEWLY REVISED VERSION OF THE CHINESE CODE FOR DESIGN OF MASONRY STRUCTURES (GB50003-2001)

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ABSTRACT

A new version of the Chinese code for design of masonry structures (GB50003-2001) which covers a whole system of unreinforced and reinforced masonry members for non seismic and seismic design is presented briefly in the paper.

China is the most popular country in using masonry and with vast earthquake potential in the world. Based on the experiences of past earthquake damages to masonry buildings and massive tests and analysises, both the confined masonry for multistory and the reinforced concrete masonry for high-rises have been established and introduced into the Chinese codes: The code for seismic design of buildings and code for design of masonry structures. The masonry code only covers the part of the earthquake resistant design and structural detailings for masonry members.

Key words: Masonry Structure, Code, Reinforced Member, Confined Masonry, Seismic Design,

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INTRODUCTION

The following is a brief introduction to the Chinese masonry code (GB50003-2001) which includes 10 chapters and 4 indexes as shown in Table-1.

Table-1 Contents of code for design of masonry structures

Number of chapter	Contents
1	General principles
2	Main terms and symbols
3	Materials
4	Basic rules for design
5	Calculation of bearing capacity unreinforced masonry members
6	Structural requirements for detailing
7	Girth beams, lintels, wall beams and cantilever beams
8	Reinforced brick masonry members
9	Reinforced concrete masonry members(R.M)
10	Earthquake resistant design of unreinforced and reinforced masonry members
Appendix A	Determination of specification and strength grading for stone
Appendix B	Strength mean values and characteristic values for masonry
Appendix C	Statical calculation of rigid-elastic analysis scheme for masonry buildings
Appendix D	Influence coefficients, and $_n$

MATERIALS

1. The strength grades of units and mortars are shown in table 2.

Table 2. Strength Grades of Units and Mortars

Type	Strength Grades (Mpa)						
Burnt bricks	10	15	20	25	30		
Autoclaved sand lime and flyash bricks	10	15	20	25			
Concrete hollow blocks	5	7.5	10	15	20		
Stone materials	20	30	40	50	60	80	100
Mortars	2.5	5	7.5	10	15		
Grout	20	25	30	40			

2. The calculation data for masonry including design compression axial tensile, flexural tensile, shear strength and modulus of elasticity of different kinds of masonry evaluated by their gross cross sectional area according to respective strength grades of the masonry units and mortars.

The examples of the calculation data for bricks and blocks are shown in Table 3 and 4.

Table 3 Design compressive strength of masonry with bricks MPa

Grades of brick	Strength grades of mortar					Mortar strength
	M15	M10	M7.5	M5	M2.5	0
MU30	3.94	3.27	2.93	2.59	2.26	1.15
MU25	3.60	2.98	2.68	2.37	2.06	1.05
MU20	3.22	2.67	2.39	2.12	1.84	0.94
MU15	2.79	2.31	2.07	1.83	1.60	0.82
MU10	—	1.89	1.69	1.50	1.30	0.67

Table 4 Design compressive strength of masonry with concrete blocks MPa

Grades of blocks	Strength grades of mortar				Mortar strength
	M15	M10	M7.5	M5	0
MU20	5.68	4.95	4.44	3.94	2.33
MU15	4.61	4.02	3.61	3.20	1.89
MU10	—	2.79	2.50	2.22	1.31
MU7.5	—	—	1.93	1.71	1.01
MU5	—	—	—	1.19	0.70

The design of compressive and shear strength for grouting masonry are taken as follows:

$$f_G = f + 0.6\, a\, f_c \text{ and } f_G \le 2f \qquad (1)$$

$$f_{VG} = 0.22\sqrt{f_G} \qquad (2)$$

Where fG is the design compressive strength of grouting masonry; f is the design compressive strength of ungrouting masonry; fc is the design axial compressive strength of grout or concrete in fill; α is the Ratio of the grouted area to the gross cross section area of the masonry; and f_{VG} is the design shear strength of grouting masonry.

BASIC RULES FOR DESIGN

It covers the principles of design and stipulations for statical calculation of buildings.

1.This code adopts the probability-based limit state design method, the degree of reliability of structural members is measured by the reliability index and the design expression of a member of partial safety factors used in design.

2.All masonry structures should be designed on the theory of ultimate limit state and shall satisfy the requirements of normal serviceability limit state, and classified in accordance with the stipulation for safety classes shown in Table 5.

Table 5. Safety classes of building structures

Safety class	Consequences of failure	Type of building
1	Very serious	Prima important industrial and civil buildings
2	Serious	General industrial and civil buildings
3	Not serious	Secondary important buildings

Note: 1 for special buildings, the safety class may be determined separately in accordance with specific conditions required.

2 for design of masonry structures in seismic regions, class of buildings for design should be determined according to their importance stipulated in National "Code for Seismic Design of Buildings" in force.

3. For increasing the probability of the members dominated by dead loads, a combination expression is introduced as follows:

$$\gamma_0 (1.35 S_{Gk} + 1.4 \sum_{i=1}^{n} \psi_{ci} S_{Qik}) \le R(f, \alpha_k \ldots) \quad (3)$$

Where Factors of importance of masonry structures. Based on duration and safety classes,
γ_0— which should be taken from 0.9~1.1;
S_{GK},S_{Gik}— Characteristic internal forces by permanent loads or by the *i* th variable load;
ψ_{ci}— Combination factor for the *i* th variable load;
f — design strength of masonry, $f = f_k / \gamma_f$;
f_k— Characteristic strength of masonry, $f_k = f_m$ -1.645 σ_f
γ_f— Partial safety factor based on categories of construction control, where A, B, C, then 1.5, 1.6, 1.8 taken respectively;
f_m— Mean strength of masonry;
σ_f— Standard deviation of masonry strength;
α_k— Nominal value of geometric parameters.

UNREINFORCED MASONRY MEMBERS

It consists of 5 parts: compression, local compression, axial tensile, flexural and shear members of masonry, 2 of which are introduced briefly.

1. The capacity of a compression member should be calculated by the following formulas:

$$N \le \boldsymbol{j} \;\; f \;\; A \qquad (4)$$

$$\boldsymbol{j} = \frac{1}{1+12\left[\frac{e}{h}+\sqrt{\frac{1}{12}\left(\frac{1}{\boldsymbol{j}_o}-1\right)}\right]^2} \text{ (e in one direction)} \qquad (5)$$

$$\boldsymbol{j} = \frac{1}{1+12\left[\left(\frac{e_b+e_{ib}}{b}\right)^2+\left(\frac{e_h+e_{ih}}{h}\right)^2\right]} \text{ (bi - eccentric)} \qquad (6)$$

$$e_{ib} = \frac{b}{\sqrt{12}}\sqrt{\frac{1}{\boldsymbol{j}_0}-1}\left(\frac{\frac{e_b}{b}}{\frac{e_b}{b}+\frac{e_h}{h}}\right) \qquad (7)$$

$$e_{ih} = \frac{h}{\sqrt{12}}\sqrt{\frac{1}{\boldsymbol{j}_0}-1}\left(\frac{\frac{e_h}{h}}{\frac{e_b}{b}+\frac{e_h}{h}}\right) \qquad (8)$$

$$\boldsymbol{j}_o = \frac{1}{1+\boldsymbol{ab}^2} \qquad (9)$$

Where $\boldsymbol{j}$— Capacity reduction factor with respect to slenderness ratio $\boldsymbol{b}$ and eccentricity;

$\boldsymbol{j}_0$— Stable coefficient of a masonry member subjected to the axial compressive load;

e— eccentricity of the axial load, not greater than 0.6y, where y is the distance from the centroid to the edge of the section at the direction of the eccentric load;

e_b ,e_h— eccentricity of the axial load at the direction of the centroid x, y respectively;

e_{ib} ,e_{ih}— Additional eccentricity of the axial load at the direction of the centroid x, y respectively;

2. The load compression includes the uniform and nonuniform local compression and local compression of masonry underneath a block or beam.

1) The verification of masonry member subjected to local uniform compressive force shall be done with the following formulas:

$$N_L \le \gamma f A_L \qquad (10)$$

$$\gamma = 1 + 0.35\sqrt{\frac{A_0}{A_L} - 1} \qquad (11)$$

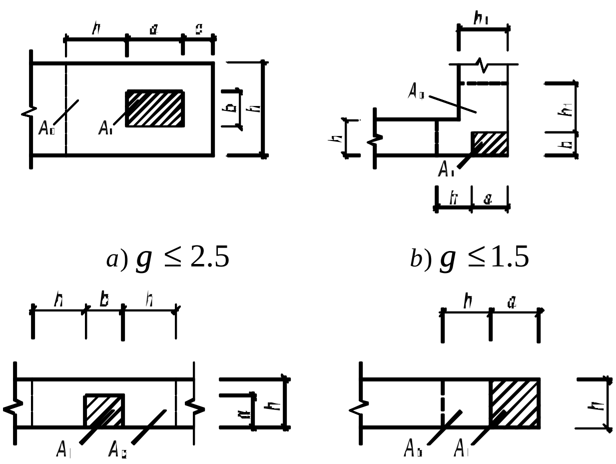
Where

N_L— design axial force acting on the local compressive area;

γ— Magnifying factor for local compression strength of masonry based on locations;

A_L— local compression area;

A_0— Calculated area affecting local compression strength of a masonry member (Fig .1).



a) $\gamma \le 2.5$ b) $\gamma \le 1.5$

c) $\gamma \le 2.0$ d) $\gamma \le 1.25$

Fig .1

2) The capacity of masonry member subjected to nonuniform local compression force shall be calculated with the following formulas:

$$\psi N_0 + N_l \le \eta\gamma f A_l \qquad (12)$$

$$\psi = 1.5 - 0.5\frac{A_0}{A_l}\text{, where }\frac{A_0}{A_l} \ge 3\text{, then }\psi = 0 \qquad (13)$$

$$N_0 = \sigma_0 A_l \qquad (14)$$

$$A_l = a_0 b \qquad (15)$$

$$a_0 = 10\sqrt{\frac{h}{f}} \qquad (16)$$

Where

ψ— Reduction factor of the upper load;

N_0— Design axial load on the top part of the member within local compression area;

s_0— Design mean compressive stress above the upper part of the member;
b— Width of the beam cross section;
a_0— Effective support length of the beam end;
h— Depth of the cross section of the beam.

3) Where providing a concrete bearing block or beam underneath the beam support, the capacity of local compression of the masonry underneath the bearing block or beam should be calculated by the following formulas:

$$N_0 + N_l \le j \; g_1 f \; A_b \tag{17}$$

$$N_0 = s_0 A_b \tag{18}$$

$$A_b = a_b \, b_b \tag{19}$$

Where
N_0— Design axial load transmitted from the upper part within the area A_b of the bearing block;
j— Influence factor for the combination of N_0 and N_l acting on the bearing block, which should be taken as assuming $b \le 3$;
g_1— Favourable influence factor for masonry area outside the bearing block, which should be $0.8g$, but not less than 1.0;
A_b— Area of the bearing block or beam.

STRUCTURAL REQUIREMENTS FOR DETAILING

It covers 3 parts: allowable slenderness ratios for walls or columns, general structural requirements and main measures to prevent walls from cracking.

The structural requirements and crack-proof measures are strengthened in nowadays in China, because the building of residential houses are booming and seeking high quality, without cracking and leakage, of cause, so that:

1. heightening the lowest strength grades of masonry materials;
2. enhancing the crack-proof measures:
   1) reducing the maximum distance of expansion joint of masonry buildings made of materials with higher shrinkage rates, such as flyash, sandlime bricks and concrete blocks, from 50 m to 40 m, for example and,
   2) arranging movable control joints where potential forces or displacements from shrinkage or expansion or big changes in height or section of masonry walls exist and,
   3) Increasing the minimum ratio of reinforcement in masonry walls.

GIRTH BEAMS, LINTELS, WALLBEAMS AND CANTILEVER BEAMS

The briefing of the wall beams in the chapter is only explained below.
The wall beams include simply supported, continuous wall beams and wallbeams supported by a trame structure at the ground floor, which are should be designed by the following stipulations.

General

1)The scope of the wall beams should be used in accordance with Table 6.

Table 6. Scope of wall beams

Type	No. of story	total height (m)	span (m)	wall height h_w/l_{oi}	beam height h_b/l_{oi}	width of opening b_h/l_{oi}	height of opening h_h
Bearing wall beam	≤7	≤22	≤9	≥0.4	≥1/10	≤0.3	≤5 h_w /6 and h_w-h_h≥0.4m
Non bearing wall beam		≤18	≤12	≥1/3	≥1/15		

Note: In the table, where,

l_{oi}— *Calculation span of wall beams: for simply supported and continuous take 1.1 times the clear span l_n (l_{n1}) or the distance between the centers of the supports l_c (l_{c1}), which ever is the lesser; for frame supported wall beam, take the distance between the centers of the columns of the frame;*

h_w— *Calculation height of the wall may be taken as one story height from the top surface of the supporting beam, where $h_w > l_0$, then $h_w = l_0$.*

2) The calculation loads of a wall beam in the stage of normal serviceability are as follows:

a) The design loads on the surface of the supporting beam (Fig.2);

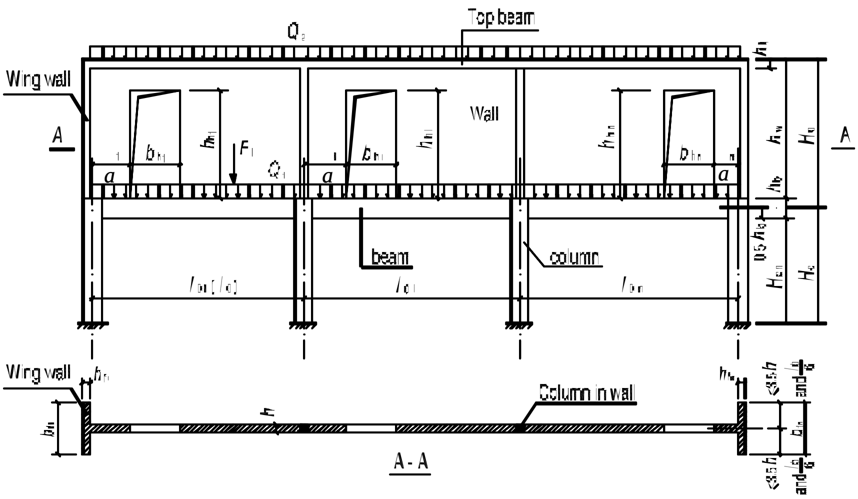


Fig. 2

Q_1 ,F_1— Weight of the supporting beam and dead load and live load on the floor of the story under consideration;

b) The design loads on the top surface of the wall beam (Fig. 2);

Q_2— Total weight of the walls above the supporting beam and dead load and live load acting on each floor above. Where concentrated loads acting on each floor above and on the top surface of the wall beam are met, the sum of the concentrated loads may be approximately assumed as a uniform load by dividing the calculation span.

<u>Design calculation</u>

The verification of a wall beam includes the supporting beam and said wall on the beam.

1)The supporting beam

a) The verification of a section at the midspan should be done as an eccentric tension member, its internal forces should be calculated as follows:

$$M_{bi} = M_{1i} + \alpha_M M_{2i} \tag{20}$$

$$N_{bti} = \eta_N \frac{M_{2i}}{H_o} \tag{21}$$

For simply supported

$$\alpha_M = \psi_M \left(1.7 \frac{h_b}{l_o} - 0.03 \right) \tag{22}$$

$$\psi_M = 4.5 - 10 \frac{a}{l_o} \tag{23}$$

$$\eta_N = 0.44 + 2.1 \frac{h_w}{l_o} \tag{24}$$

For continuous and frame supported

$$\alpha_M = \psi_M \left(2.7 \frac{h_b}{l_{oi}} - 0.08 \right) \tag{25}$$

$$\psi_M = 3.8 - 8 \frac{a_i}{l_{oi}} \tag{26}$$

$$\eta_N = 0.8 + 2.6 \frac{h_w}{l_{oi}} \tag{27}$$

Where M_{1i} ,M_{2i}— Maximum bending moment at the midspan caused by Q_1, F_1 or Q_2 of simply supported or continuous or frame supported wall beam respectively;

α_M, η_N— moment or tension coefficient at the midspan considering the composite action of the wall beam, where non bearing wall beam is met, then $0.8a_M$ or $0.8h_N$ respectively;

y_M— Influence factor of bending moment of the beam with openings, for wall beam without opening, then $y_M = 1.0$;

a_i— Nearest distance between the edge of a opening and a support of the wall beam, where $a_i > 0.35 l_{0i}$, then $a_i = 0.35 l_{0i}$.

b) The verification of a section at the ends of a support should be done as a flexural member, its internal forces be calculated as follows:

$$M_{bj} = M_{1j} + a_M M_{2j} \tag{28}$$

$$a_M = 0.75 - \frac{a_i}{l_{oi}} \tag{29}$$

Where M_{1j} ,M_{2j}— Design moment due to Q_1, F_1 or Q_2 at the ends of the supporting beam for continuous or frame supported wall beam respectively;

a_M— moment coefficient at the ends of the supporting beam considering the composite action of the wall beam. Where the wall without opening, then $a_M = 0.4$.

c)The shear at the ends of the supporting beam should be calculated by the formula:

$$V_{bj} = V_{1j} + b_V V_{2j} \tag{30}$$

Where V_{1j} ,V_{2j}— Design shear due to Q_1, F_1 or Q_2 at the ends of the supporting beam for continuous or frame supported or simply supported wall beam respectively;

b_V— Shear coefficient of the supporting beam considering the composite action of the wall beam. For wall beam without openings: at the side support, then 0.6, at the midspan, then 0.7; for wall beam with openings: at the side support, then 0.7, at the midspan, then 0.8.

3. The shear capacety of said wall and local compression on masonry panel above the supporting beam should be verified(omit).

4. The structural requirements for wall beams should be secured (omit).

REINFORCED BRICK MASONRY MEMBERS

It covers 3 types: mesh reinforced, composite brick masonry and composite of masonry wall and columns (or composite wall). The composite wall is explained only below:
The capacity of a composite wall subjected to axial compressive loads should be calculated as following (Fig. 3):

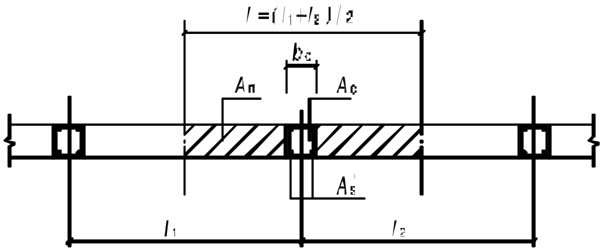


Fig. 3

$$N \le \boldsymbol{j}_{com}[\, fA_n + \boldsymbol{h}(f_c A_c + f_y^{'} A_s^{'})] \qquad (31)$$

$$\boldsymbol{h} = [\frac{1}{\frac{l}{b_c} - 3}]^{\frac{1}{4}} \qquad (32)$$

Where $\boldsymbol{j}_{com}$— Stable coefficient of the composite wall;
$\boldsymbol{h}$— Factor, where $l/b_c<4$, then $l/b_c=4$;
l— Spacing between 2 columns along the wall;
b_c— Width of the section of a column along the wall;
A_n— Net area of the wall excluding columns;
A_c— Cross section area of the columns in the wall.

The main structural requirements of composite wall should be secured (omit).

REINFORCED CONCRETE MASONRY SHEAR WALLS (OR R.M SHEAR WALL)

It is the newcomer of the masonry code of China, which is a system with the reinforced concrete one alike based on the massive tests and researches in domestic and abroad, such as calculation assumptions, normal section calculation and so on. The R.M shear wall is introduced only below.

1. The section control of R.M shear wall should be satisfied with the following:

$$V \le 0.6\sqrt{f_G}\; bh \qquad (33)$$

2. The shear resistance of a shear wall should be calculated by the following:

$$V \le \frac{1.5}{\boldsymbol{l} + 0.5}(0.13\sqrt{f_G}\, bh_0 + 0.12N\frac{A_w}{A}) + 0.9 f_{yh}\frac{A_{sh}}{S}h_0 \qquad (34)$$

$$\boldsymbol{l} = M/V h_0 \qquad (35)$$

Where M,N,V— Moment, axial load and shear of the section under consideration respectively, where $N > 0.5\sqrt{f_G}\,bh$, $N = 0.5\sqrt{f_G}\,bh$;

l— Ratio of shear span to depth for the calculated section, where $l<1$, then $l=1$, or $l\geq 2.2$, then $l=2.2$;
h_0— Efficient depth of the shear wall;
A_{sh}— Area of the shear reinforcement;
s— Spacing of the shear reinforcement;
f_{yh}— Design tensile strength of reinforcement.

3. The coupled shear walls (omit).
4. The structural requirements of shear walls (omit).

EARTHQUAKE RESISTANT DESIGN OF UNREINFORCED AND REINFORCED MASONRY MEMBERS

It covers 5 parts: General stipulations, unreinforced masonry members, reinforced masonry members, R.M shear walls and wallbeams.

For the sake of space, introducing some points of the chapter as follows:

1. This code only deals with earthquake design for masonry members, and the buildings in seismic regions should be analyzed in accordance with the Chinese Code for seismic design of buildings.

2. For buildings of R.M shear walls, their height should be in accordance with the stipulation in Table 7.

Table 7 Maximum height of R.M buildings (m)

Minimum thickness of shearwall	Intensity			
	6	7	8	9
190 (mm)	60	55	45	25

Note. The height of building refers to the height from the outdoor ground level to the eaves level of a building;

3. R.M building shall be graded according to intensity, building height, and shall be in accordance with corresponding requirements of computation and structural measures taken, such as:

1) The shear capacity of R.M shear wall should be strengthened as follows:
for intensitying botton zone:
seismic grade 1 is 1.5V;
seismic grade 2 is 1.2V;
seismic grade 3.4 is 1.0V;
for others all is 1.0V.
Where V— Design combination shear of the section under consideration.

2) The minimum ratios of reinforcement and confinement zone in R.M shearwall should be in accordance with Table 8 and 9 respectively.

Table 8. Minimum ratio of reinforcement (h/v) in R.M shearwall (%)

Seismic grade	Intensifying zone	others	Maximum spacing (mm)	Minimum diameter (mm)
1	0.13	0.13	400	8/12
2	0.13	0.10	600	8/12
3.4	0.10	0.07	600/800	6/12

Note : For (h/v) of the table head, h—horizontal, v—vertical.

Table 9. Minimum ratio of continement zone in R.M shearwall

Seismic grade	Intensifying zone	others	Tie or stirrup and spacing (mm)
1	$0.08A_{mc}$ (4Φ16)	3Φ18 (4Φ16)	Φ8 200
2	$0.06A_{mc}$ (4Φ16)	3Φ16 (4Φ12)	Φ8 200
3	$0.04A_{mc}$ (4Φ12)	3Φ14 (4Φ12)	Φ8 200
4	3Φ12 (4Φ12)	3Φ12 (4Φ12)	Φ8 200

Note : where 1, A_{mc}— confinement zone area should not be less than 3 times the thickness of a wall and 600 mm;

2, The figures in brackets can be used for concrete columns.

With the measures taken, the capacity and ductility for buildings of R.M shear wall will be secured and satisfied with the safety standards designed by the code.