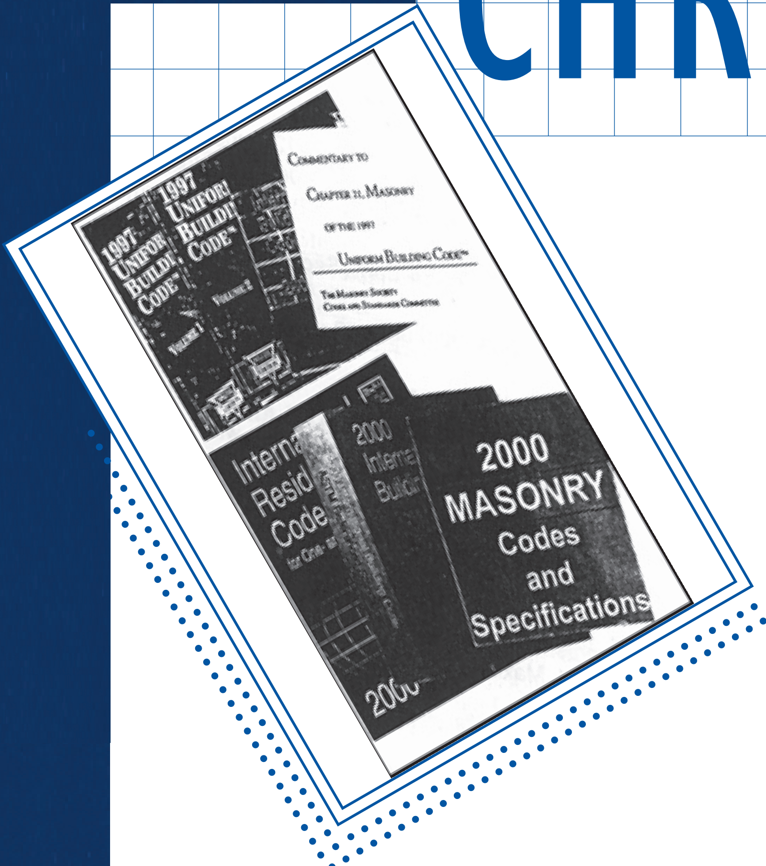
Engineering Notes For Design With Concrete Block Masonry

MASONRY CHRONICLES

Fall 2001



CODES AND SPECIFICATIONS UNDERSTANDING AND WORKING THROUGH THE MAZE

STRUCTURAL DESIGN PROVISIONS PART II

This is Part II in a series of three articles to understand and locate codes and specification provisions related to concrete masonry design and construction. The purpose of these articles is not so much to provide specific design guidance, but to direct a design engineer to various provisions, primarily in the 1998 California Building Code. Many other codes and standards such as ASTM, UBC-Standards and Masonry Standards Joint Committee (MSJC) provisions are also referenced where appropriate.

Provisions in 1998 California Building Code are discussed, rather than 1997 UBC Provisions, because it is a document based on 1997 UBC adopted in California and also covers State of California Amendments, which are applicable to public schools, community colleges, essential services buildings, and hospitals.

Part I dealt with *Material and Product Standards.*

Part III will cover *Testing, Inspection, and Construction.*

Structural design requirements related to loads are covered in Chapter 16 of the 1998 California Building Code (CBC). Division I covers dead and live loads, and Division II covers snow loads. These two divisions provide gravity load considerations. Division III covers wind design and Division IV covers earthquake design. The provisions in Chapter 16 will not be covered in this article. *It should be noted however, that even in areas where wind loads produce greater design demands on a structure, the detailing requirements and limitations of earthquake design as prescribed in Division IV of Chapter 16 shall govern.*

For public schools, community colleges and state owned or leased essential services buildings regulated by the Division of the State Architect (DSA), Chapter 16A instead of Chapter 16 governs.

Concrete Masonry Association

MASONRY CODE PROVISIONS

All structural design provisions for masonry, including glass masonry, are given in Chapter 21. State of California Amendments are given in Chapter 21A. This article attempts to summarize some of the basic code provisions, rather than discuss the detailed provisions. Furthermore, only those sections of the code which are pertinent to seismic zones 3 and 4 are covered.

Three methods of design are allowed, working stress, strength design and empirical design.

Empirical design method is not addressed in this article, as it is applicable to design for wind loads in seismic zones "0" and "1."

Stack bond for design purposes is defined in Section 2106.1.4, because the reinforcement requirements for stack bond masonry are different than those for non-stack bond masonry. These are covered in Section 2106.1.12.4 under item 2.4.

Stack bond exists when less than 75% of the units in a vertical transverse plane have a lap less than:

- One-half the unit height or
- One-fourth the unit length

WORKING STRESS DESIGN

Section 2107 of CBC covers the requirements under this design method.

Two choices in design are allowed.

A. Use of one-half allowable stresses

B. Use of full allowable stresses

A. Use of One-half Allowable Stresses

1. When "no special inspection" is provided
2. Masonry compressive strength f'_m limited to 1500 psi
3. A letter of certification for unit strength is *not required*

B. Use of Full Allowable Stresses

1. "Special inspection" per Section 1701 is required
2. Masonry compressive strength $f'_m \nless 1500$ psi $\ngtr 4000$ psi
3. Letter of certification for unit strength is required

Minimum sizes (nominal not actual) of members as given below are required.

- Bearing walls - 6 inches
- Columns - 12 inches (8 inches when one-half stresses are used)

REINFORCEMENT (Section 2107.2)

1. Maximum bar size - #11
2. Maximum ratio - 6% of cell area
12% of cell area with splices
3. For <u>Columns</u>

Minimum reinforcement ratio - 0.5% (4 #3 bars minimum)

Maximum reinforcement ratio - 4%

4. For <u>Walls</u>

Minimum ratio of horizontal and vertical reinforcement combined - 0.002

Minimum in any direction - 0.0007

5. Allowable Tensile stress (F_s)

   a. Deformed bars

   - $0.5f_y$ but, $\ngtr$ 24 ksi

   b. Wire reinforcement

   - $0.5\ f_y$ but, $\ngtr$ 30 ksi

   c. Ties, anchors and smooth bars

   - $0.4\ f_y$ but, $\ngtr$ 20 ksi

6. Allowable Compressive stress (F_{sc})

   a. Deformed bars in columns

   - $0.4\ f_y$ but, $\ngtr$ 24 ksi

   b. Deformed bars in flexural members

   - $0.5\ f_y$ but, $\ngtr$ 24 ksi

c. Deformed bars in shear walls

- $0.4\ f_y$ but, $\not>$ 24 ksi

(See section 2107.2.11 item 2.3 for other details)

7. Development Length (ld) for deformed bars or deformed wires

a. In tension - $0.002\ d_b f_s$

b. In compression - $0.0015\ d_b f_s$

Where

d_b = diameter in inches

f_s = computed stress in psi

If smooth bars are used, the development length as calculated above is to be doubled.

8. Allowable Bond stress (u)

a. Deformed bars - 200 psi

b. Deformed bars without special inspection
- 100 psi

c. Plain bars - 60 psi

9. Splices (Section 2107.2.2.6)

Splice length is to be sufficient to transfer allowable stress in reinforcement, however, the minimum length shall be:

a. Bars in tension - $40d_b$

b. Bars in compression - $30d_b$

Splice length needs to be increased by 30% if bars are spaced 3 inches or less.

Other details on splices are given in Sections 2107.2.2.6 and 2107.2.12.

10. Hooks

All details given in Section 2107.2.2.5.

MASONRY

1. Allowable Compressive stress in flexure (F_b)
- $0.33\ f'_m$ but not greater than 2000 psi.

2. Allowable Axial compressive stress (F_a) for <u>walls</u> varies based upon slenderness of the wall (Section 2107.2.5). e.g., for 8-inch fully grouted wall,

when $\frac{h'}{r} = 70$, Fa = $0.1875\ f'_m$

$\frac{h'}{r} = 100$, Fa = $0.1225\ f'_m$

$\frac{h'}{r} = 140$, Fa = $0.0625\ f'_m$

where

h' = height of wall in inches

r = radius of gyration. (See Table 21-H-1)

For <u>columns</u>, capacity contribution of steel needs to be added to masonry capacity.

ALLOWABLE SHEAR STRESSES (F_v) (Section 2107.2.8)

a. Flexural members with *no* reinforcement

$1.0\sqrt{f'_m}$ but not greater than 50 psi

b. Flexural members *with* reinforcement

$3.0\sqrt{f'_m}$ but not greater than 150 psi

c. For <u>shear walls</u>, see section 2107.2.9 for details. In general, the allowable shear stress depends upon M/Vd ratio.

ALLOWABLE BEARING STRESS (F_{br})

a. Bearing on full masonry - $0.26\ f'_m$

b. Bearing on one-third or less area of masonry element
- $0.38\ f'_m$

For walls with $\frac{h'}{t}$ ratio greater than 30,

analysis is required, which considers axial loads, variable moment of inertia, effect on stiffness and fixed end moments, effect of deflections on moments and forces and effect of duration of loads.

STRENGTH DESIGN

Section 2108 of CBC covers the provisions for strength design.

When designing under strength design method, special inspection of masonry during construction as stipulated in section 1701.5 item 7 is required.

Minimum sizes (nominal not actual) of members shall be as follows:

1. Beams
   - Width $\geq$ 6 inches
   - Depth $\geq$ 8 inches
2. Piers
   - Width $\geq$ 6 inches, $\leq$ 16 inches
   - Length $\geq$ 3 times width, $\leq$ 6 times width
   - Clear Height $\leq$ 5 times length
3. Columns
   - Width $\geq$ 12 inches
   - Length $\geq$ 12 inches, $\leq$ 3 times the width

REINFORCEMENT (Section 2108.2.2)

1. Maximum bar size - # 9
but, one fourth the least dimension of cell

2. No more than 2 bars in a cell of a wall

3. <u>For columns</u>
Minimum 4 bars (one in each corner of the column)

Longitudinal reinforcement ratio $\geq$ 0.5%, $\leq$ 3.0%

Lateral reinforcement ratio $\geq$ 0.18%

4. <u>For piers</u>
Minimum 1 bar in end cells
longitudinal reinforcement ratio $\geq$ 0.07%
Transverse reinforcement ratio $\geq$ 0.15%

5. Specified yield strength (f_y) $\leq$ 60 ksi
Actual yield strength $\leq$ 1.3 f_y

6. Development length (l_d)
The basic required embedment length is a function of cover of reinforcement, diameter of bar, yield strength of bar and compressive strength of masonry. (See Section 2108.2.2.6)

Maximum l_d - 65 d_b

7. Splices (Section 2108.2.2.7)

   Minimum lap length - 12 inches

   Maximum lap length - 65 d_b

Mechanical or welded splices shall develop 1.25 f_y

8. Hooks
Details are given in Section 2108.2.2.4 and are not covered here.

MASONRY (f'_m)

Minimum - 1500 psi
Maximum - 4000 psi

1. Maximum usable compressive strength
   - 0.85 f'_m

2. Shear strength (V_m)

   Depends upon M/Vd ratio and f'_m of masonry.

   For the highest $f'_m \approx$ 4000 psi,

   V_m varies from $\approx$ 76 A_e to 151 A_e

Saying it differently, the maximum shear stress masonry can sustain varies from 76 psi to 151 psi.

STRENGTH REDUCTION FACTORS (Section 2108.1.4)

It is important to recognize that design strength is calculated by multiplying *nominal strength with a strength reduction factor.*

For ease of use, the following table of strength reduction factors (ϕ) is prepared:

STRENGTH REDUCTION FACTORS (ϕ)

Beams Columns and Piers	Flexure (For interpolation see Section 2108.1.4.1)	Minimum 0.60 Maximum 0.80
	Shear	0.60
Wall for out of plane loads	Flexure when axial load $< 0.04\ f'_m$	0.80
	Flexure when axial load $> 0.04\ f'_m$ with flexure	0.80
	Shear when axial load $> 0.04\ f'_m$	0.60
Wall for in-plane loads	Axial load and axial load with flexure (See Section 2108.1.4.3.1 for increase in ϕ)	0.65
	Shear (See Section 2108.1.4.3.2 when ϕ can be increased)	0.60
Moment resisting wall frames	Flexure with or without axial load (For interpolation see Section 2108.1.4.4.1)	Minimum 0.65 Maximum 0.85
	Shear	0.80
Reinforcement	Development	0.80
	Splices	0.80
Anchor bolts	Anchorage	0.80

CALIFORNIA STATE AMENDMENTS

These are detailed in Section 2107A. These provisions apply to public schools, community colleges, essential services buildings and hospitals.

Because special inspection of masonry is always required, use of one-half allowable stresses method is not permitted.

Minimum column size - 12 inches with unsupported length not exceeding 20 times the least width

REINFORCEMENT

Maximum bar size - Smaller of one fourth the cell dimension but $\not>$ #9

Maximum ratio - 4% of the cell area
8% of the cell area with splices

Deformed bars without special inspection are not allowed.

Minimum size of bar for walls - # 4 except for ties and stirrups

Minimum ratio of horizontal and vertical reinforcement combined - 0.003

SPLICES

a. Bars in tension - $48\ d_b$

b. Bars in compression - $36\ d_b$

Bars # 8 or larger shall be spliced by welding or approved mechanical connectors.

MASONRY

1. Shear stress is to be calculated for 1.5 times the forces required by Section 1629.A.1

2. Maximum compressive strength assumed in design - 2500 psi

STRENGTH DESIGN

For out of plane wall design with axial load $< 0.04\ f'_m$ minimum nominal thickness is to be 8 inches

EXISTING MASONRY

Existing masonry for structural purposes is allowed with some restrictions. If the existing masonry does not meet the requirements of reinforced grouted masonry, its use is not allowed.

Strengthening of existing masonry, which does not meet the requirements of reinforced grouted masonry is allowed by shortcreting or other concrete structural system.

Detail provisions are given in Section 2114 A of CBC.

This issue of Masonry Chronicles was written by Vilas Mujumdar, Executive Director of Concrete Masonry Association of California and Nevada.

"Masonry Chronicles" is a publication of the Concrete Masonry Association of California and Nevada. Please contact the Association Executive Director, Dr. Vilas Mujumdar, with any comments or suggestions for future issues.

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