Engineering Notes For Design With Concrete Block Masonry

MASONRY CHRONICLES

Spring 2003

Comparison of the 1997 UBC and the 2002 MSJC Code

Introduction

This issue of "Masonry Chronicles" will highlight the differences between the masonry design provisions of the *1997 Uniform Building Code* (1997 UBC) and *Building Code Requirements for Masonry Structures: ACI 530-02/ASCE 5-02/TMS 402-02* by the Masonry Standards Joint Committee (MSJC Code). The masonry chapter of the 2003 International Building Code (2003 IBC) references the MSJC Code with some modifications.

This issue is not intended to be exhaustive of the differences between the documents, but only to emphasize major changes that impact design.

Material Properties

The primary difference in the material properties between the 1997 UBC and the MSJC Code is in the calculation of the values used for the Modulus of Elasticity. In both the 1997 UBC and the MSJC Code the values for E_m are based on the chord modulus from a stress value of 5 to 33 percent of the compressive strength of masonry as shown in Figure 1.

The *Uniform Building Code* calculates the modulus of elasticity for masonry, E_m , by the following equation for both clay and concrete masonry:

$E_m = 750 f'_m$, 3,000,000 psi max

…Section 2106.2.12.1 1997 UBC

In the MSJC CODE, the calculation of E_m is:

$E_m = 700 f'_m$ for clay masonry

$E_m = 900 f'_m$ for concrete masonry

…Section 1.8.2.2.1 MSJC Code

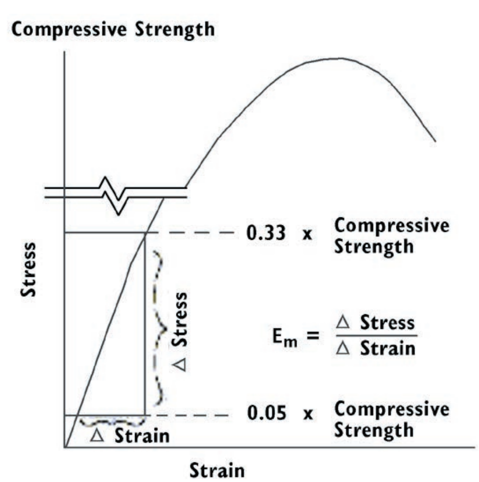

Figure 1: Calculation of Modulus of Elasticity (MSJC Code)

Special Inspection

Special Inspection is not required by the 1997 Uniform Building Code for designs developed using Working Stress Design. However, when Special Inspection is not used, the code requires a reduction in the allowable stresses:

> *"When quality assurance provisions do not include requirements for special inspection as prescribed in Section 1701, the allowable stresses for masonry in Section 2107 shall be reduced by one half."*

…Section 2107.1.2 1997 UBC

Additionally, in the 1997 UBC Special Inspection is required for designs developed using Strength Design:

> *"Special inspection during construction shall be provided as set forth in Section 1701.5, Item 7."*

…Section 2108.1.2 1997 UBC

The MSJC Code does not include any mention of Special Inspection for either Working Stress or Strength Design. Note, however, that in Section 1704.5 of the 2003 IBC two levels of special inspection are specified depending on the classification of the structure and the level of occupancy.

Working Stress Design

Strength Requirements

In the MSJC Code it is permissible to design structures using the strength design load combinations with allowable stresses from working stress design multiplied by adjustment and strength reduction factors.

When strength design load combinations are used, the design strength of a member, its connections to other members and its cross sections is given as $\phi 2.5F_a$. Where F_a is calculated according to the provisions of working stress design, the strength reduction values, ϕ, are as follows:

	ϕ
Axial load	*0.8*
Flexural compression	*0.8*
Flexural tension in unreinforced masonry	*0.4*
Shear	*0.6*
Shear and tension on anchor bolts embedded in masonry	*0.6*

…Section 2.1.3.3.3 MSJC Code

Note that this section of the MSJC Code is not allowed by the 2003 IBC per Section 2107.1.

Shear Wall Design Loads

In the 1997 UBC, shear stresses for shear walls in Seismic Zones 3 and 4 must be designed to resist 1.5 times the forces required by the minimum design lateral forces. The MSJC Code does not use a similar multiplier.

Anchor Bolts

The determination of the allowable loads in tension for plate, headed, and bent bar anchor bolts is the same in the 1997 UBC and the MSJC Code. However, text has been included in the MSJC Code to clarify the calculation of projected area in partially grouted masonry:

> *"That portion of the projecte*d area falling in an open cell or core shall be deducted from the value of A_p…"

…Section 2.1.4.2.2.1 MSJC Code

Concentrated Loads

The allowable bearing stress in the 1997 UBC is given by:

> *"When a member bears on the full area of a masonry element, the allowable bearing stress F_{br} is:*
>
> $F_{br} = 0.26 f'_m$
>
> *When a member bears on one third or less of a masonry element, the allowable bearing stress F_{br} is:*
>
> $F_{br} = 0.38 f'_m$

…Section 2107.2.10 1997 UBC

The increase is permitted only when the least dimension between the edges of the loaded and unloaded areas is one fourth of the parallel side dimension of the loaded area. This accounts for confinement of the bearing area by surrounding masonry, which increases the bearing capacity of the wall. Interpolation is allowed between the two values.

In the MSJC Code, the allowable bearing stress, F_{br}, is defined as a maximum of 0.25 f'_m However, an increase in capacity similar to that allowed in the 1997 UBC is allowed by the application of the concentrated vertical axial load over an increased area:

> *" $A_1\sqrt{A_2/A_1}$ but not more than $2A_1$, where A_2 is the supporting surface wider than A_1 on all sides, or A_2 is the area of the lower base of the largest frustum of a right pyramid or cone having A_1 as upper base sloping at 45 degrees from the horizontal and wholly contained within the support."*

…Section 2.1.9.2 MSJC Code

This area increase is illustrated in Figure 2. Figure 3 illustrates the differences between the allowable bearing stresses in the 1997 UBC and the MSJC Code.

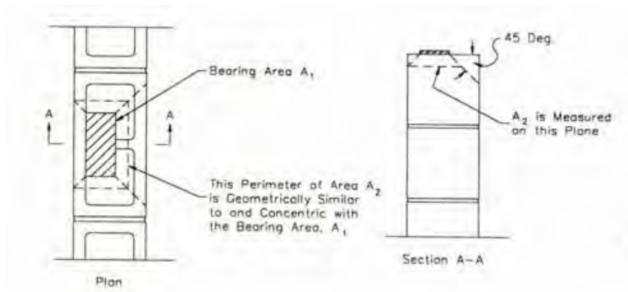

Figure 2: Bearing Area (MSJC Code)

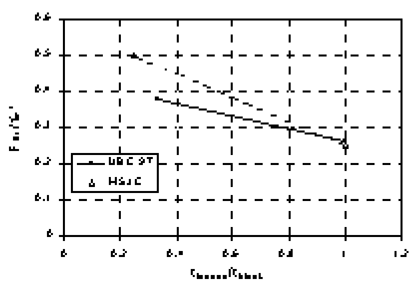

Figure 3: Comparison of Allowable Bearing Stresses

Strength Design

Strength Reduction Factors

In the 1997 UBC the strength reduction factor, ϕ for flexure, with or without axial load, is determined by:

$$\phi = 0.8 - \frac{P_u}{A_e f'_m}$$

and,

$$0.60 \le \phi \le 0.80$$

…Section 2108.1.4.1.1 1997 UBC

In the MSJC Code combinations of flexure and axial load use a constant ϕ of 0.90.

Wall Design for Out-of-Plane Loads

$P\Delta$ effects are considered for out-of-plane wall design for walls with large relative axial loads. In the 1997 UBC the axial load level that determines the use of $P\Delta$ effects is 0.04 f'_m. In the MSJC Code the axial load level for $P\Delta$ effects is 0.05 f'_m.

Design Shear Strength

In walls designed to resist in plane forces a ductile response is preferred. In the 1997 UBC, ductile behavior of shear walls is encouraged by increasing the strength reduction factor:

> *"Shear: ϕ = 0.60…The value of ϕ may be 0.80 for any shear wall when its nominal shear strength exceeds the shear corresponding to development of its nominal flexural strength…"*

…Section 2108.1.4.3.2 1997 UBC

In the MSJC Code the ductile response of a shear wall is encouraged by similarly increasing the design shear strength of the section:

> *"The design shear strength, ϕV_n, shall exceed the shear corresponding to the development of 1.25 times the nominal flexural strength, M_n, of the member, except that the nominal shear strength, V_n, need not exceed 2.5 times required shear strength, V_u."*

…Section 3.1.3 MSJC Code

Nominal Shear Strength

In the 1997 UBC, when the nominal shear capacity of a shear wall exceeds the shear corresponding to the development of its nominal flexural strength, two shear regions exist. At the base of the wall, the nominal shear strength is given by:

$$V_n = A_{mv} \rho_n f_y$$

…Section 2108.2.5.5 (8-39) 1997 UBC

Note that $V_n = A_{mv}\rho_n f_y$, thus the nominal shear strength at the base of the wall is equal to the shear strength provided by the shear reinforcement.

In the MSJC Code, the masonry strength is included in the calculation of the nominal shear strength:

$$V_n = V_m + V_s \qquad (3\text{-}18)$$

$$V_n \le 6 A_n \sqrt{f'_m} \quad \frac{M}{Vd_v} \le 0.25 \qquad (3\text{-}19)$$

$$V_n \le 4 A_n \sqrt{f'_m} \quad \frac{M}{Vd_v} \le 1.00 \qquad (3\text{-}20)$$

…Section 3.2.4.1.2 MSJC Code

Where the shear strength provided by the masonry is given by:

$$V_n = \left[4.0 - 1.75\left(\frac{M}{Vd_v}\right)\right] A_n \sqrt{f'_m} + 0.25P$$

$\frac{M}{Vd_v}$ need not be taken greater than 1.0

…Section 3.2.4.1.2.1(3-21) MSJC Code

The nominal shear strength provided by reinforcement in MSJC Code includes a 0.5 multiplier:

$$V_n = 0.5\left(\frac{A_v}{S}\right) f_y \, d_v$$

…Section 3.2.4.1.2.2 (3-22) MSJC Code

The nominal shear capacities given by the 1997 UBC and the MSJC Code at the base of a shear wall are compared in Figure 4.

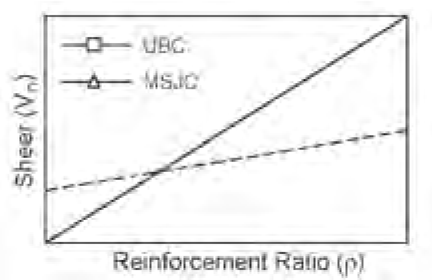

Figure 4: Comparison of Nominal Shear Strength

<u>Anchor Bolts</u>

The calculation of capacity for bent bar and headed anchor bolts in the 1997 UBC is as follows and the strength reduction factor, ϕ, for anchor bolts is a constant value of 0.80:

Nominal tensile capacity is the lesser of:

$$B_{tn} = 1.0\,A_p \sqrt{f'_m} \qquad (8\text{-}5)$$

$$B_{tn} = 0.4\,A_b\, f_y \qquad (8\text{-}6)$$

Nominal shear capacity is the lesser of:

$$B_{sn} = 900\,A_p \sqrt[4]{f'_m\, A_b} \qquad (8\text{-}7)$$

$$B_{sn} = 0.25\,A_b f_y \qquad (8\text{-}8)$$

…Section 2108.1.5.2 1997 UBC

In the MSJC Code the capacity of headed anchor bolts is calculated:

Nominal tensile capacity is the lesser of:

$$B_{an} = 4.0 A_p \sqrt{f'_m} \qquad (3\text{-}1), (3\text{-}4)$$

$$B_{an} = A_b f_y \qquad (3\text{-}2), (3\text{-}5)$$

Nominal shear capacity is the lesser of:

$$B_{vn} = 4 A_{pv} \sqrt{f'_m} \qquad (3\text{-}8)$$

$$B_{vn} = 0.6 A_b f_y \qquad (3\text{-}9)$$

…Section 3.1.6 MSJC Code

The MSJC includes an additional equation for bent bar anchor bolts that checks the connection for anchor pullout:

> *Nominal tensile capacity is the lesser of*
>
> ***Eqn (3-4), Eqn (3-5)*** *and:*

$$B_{an} = 1.5 f'_m\, e_b\, d_b + \left[300\pi\,(l_b + e_b + d_b)\, d_b\right] \qquad (3\text{-}6)$$

…Section 3.1.6.2 MSJC Code

The strength reduction factors for anchor bolts in the MSJC Code vary depending on the failure mode of the connection:

Masonry breakout	ϕ= 0.50
Anchor bolt steel	ϕ= 0.90
Anchor pullout	ϕ= 0.65

In addition, text clarifying the calculation of projected area in partially grouted masonry similar to that in Working Stress Design is included in the MSJC Code.

<u>Flexural Design Assumptions</u>

The maximum usable strain, e_{mu}, at the extreme masonry compression fiber given by the 1997 UBC is 0.003 for the design of beams, piers, columns and walls. In the MSJC Code e_{mu} is assumed to be 0.0035 for clay masonry and 0.0025 for concrete masonry.

Also, the strength of the masonry compressive zone in the 1997 UBC is calculated using 85% of the masonry compressive stress and 85% of the area of the compressive zone. In the 2003 IBC it is calculated as follows:

> *"Masonry stress of 0.80 f'_m shall be assumed uniformly distributed over an equivalent compression zone bounded by edges of the cross section and a straight line located parallel to the neutral axis at a distance, a=0.80c, from the fiber of maximum compressive strain."*

…Section 3.2.2(g) MSJC Code

The differences between the 1997 UBC and the MSJC Code are shown in Figure 5.

Accordingly, the formulas for the nominal axial compressive strength in the MSJC Code are:

$$P_n = 0.80\left[0.80\,f'_m(A_n - A_s)\right]\left(1 - \left(\frac{h}{140r}\right)^2\right) \quad \ldots\, h/r \le 99$$

$$P_n = 0.80\left[0.80\,f'_m(A_n - A_s)\right]\left(\frac{70r}{h}\right)^2 \quad \ldots\, h/r > 99$$

…Equations 3-16 & 3-17 MSJC Code

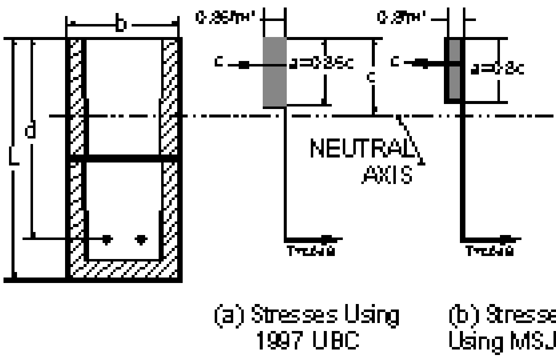

Figure 5: Masonry Compressive Block
(a) 1997 UBC and (b) MSJC Code

<u>Boundary Elements & the Maximum Reinforcement Ratio</u>

In Section 2108.2.5.6 of the 1997 UBC Boundary elements are specified for walls resisting in plane loads when the compressive strains in the wall, determined using factored forces and R_w equal to 1.5, exceed 0.0015. Also the maximum reinforcement ratio in the 1997 UBC is given as $0.5\rho_b$.

Note that in this section the 1997 UBC refers to the obsolete R_w factor that has been replaced by the R factor in the 1997 UBC. As discussed in *Design of Reinforced Masonry Structures* by Brandow, Hart and Virdee, published by the Concrete Masonry Association of California and Nevada, a comparison of the old R_w factor and the R factor (4.5 vs. 6 for masonry bearing walls) results in using an R of 1.1.

In the MSJC Code no boundary elements are specified for shear walls, however, strain is limited by the calculation of the maximum reinforcement ratio to 0.0025 for masonry and 5 times yield in the extreme tension reinforcement when the stress in the tension reinforcement is assumed to be $1.25f_y$ and the strength of the compression zone is 80% f'_m times 80% of the area of the compressive zone.

Conclusions

Although the 1997 UBC and the MSJC Code are similar in approach, there are some differences in the design equations. Engineers need to be aware of these differences in order to use the codes effectively. Future issues of Masonry Chronicles will investigate the effect of the differences on design solutions.

This issue of "Masonry Chronicles" was written by Melissa Kubischta of Hart-Weidlinger.

"Masonry Chronicles" is a publication of the Concrete Masonry Association of California and Nevada.

Please contact the Association Office, with any comments or suggestions for future issues.

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