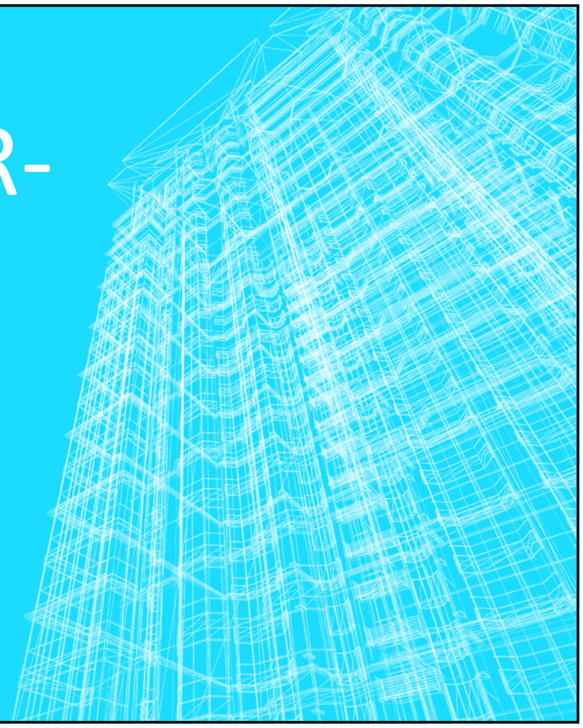
# ARE YOU OVER-ENGINEERING YOUR WALLS?



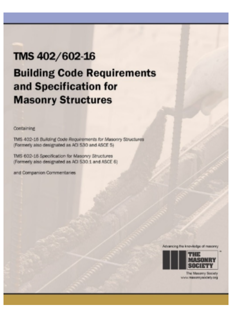
## And what's the magic with 6t?

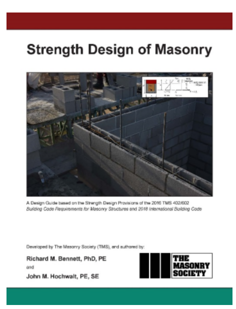
Presented by Philippe Ledent, PE, SE

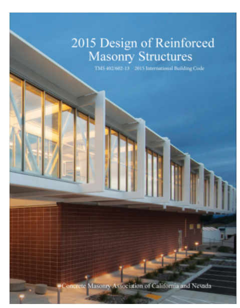

1

## REFERENCE MATERIALS

- TMS 402-16 *Building Code Requirements for Masonry Structures*
- *Reinforced Masonry Design* by Concrete Masonry Association of California and Nevada
- *Strength Design of Masonry* by The Masonry Society




2

# DEFINITIONS

- *Walls:* A member, usually vertical, used to enclose or separate spaces or uses.
  - Note: The definition only addresses architectural functions and not geometry or structural requirements.
  - Typically, a member resisting only compression is a *column.*
  - Typically, a member resisting significant lateral forces is a *wall.*
- *Walls, load-bearing:* Wall supporting vertical loads greater than 200 lb/ft in addition to its own weight.

3

# LOAD COMBINATIONS

- TMS 402 refers to the legally adopted building code for applicable loads and load combinations.
- Unlike lintels which primarily resist bending loads and columns that primarily resist axial loads, walls are typically governed by Load Combinations 5 and 7:

1. $1.4D$
2. $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
3. $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W)$
4. $1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R)$
5. $0.9D + 1.0W$
6. $1.2D + E_v + E_h + L + 0.2S$
7. $0.9D – E_v + E_h$

4

# MATERIAL PROPERTIES

- Poll Question 1: What is minimum specified compressive strength of masonry ($f'_m$) when using the Unit Strength method and Type S mortar?

**TABLE 2 Strength, Absorption, and Density Classification Requirements[A]**

| Density Classification | Oven-Dry Density of Concrete, lb/ft$^3$ (kg/m$^3$) | Maximum Water Absorption, lb/ft$^3$ (kg/m$^3$) | | Minimum Net Area Compressive Strength, lb/in$^2$ (MPa) | |
|---|---|---|---|---|---|
| | Average of 3 Units | Average of 3 Units | Individual Units | Average of 3 Units | Individual Units |
| Lightweight | Less than 105 (1680) | 18 (288) | 20 (320) | 2000 (13.8) | 1800 (12.4) |
| Medium Weight | 105 to less than 125 (1680–2000) | 15 (240) | 17 (272) | 2000 (13.8) | 1800 (12.4) |
| Normal Weight | 125 (2000) or more | 13 (208) | 15 (240) | 2000 (13.8) | 1800 (12.4) |

[A]Compressive strength, absorption, and density determined in accordance with 8.2.

**Table 2 — Compressive strength of masonry based on the compressive strength of concrete masonry units and type of mortar used in construction**

| Net area compressive strength of concrete masonry, psi (MPa)[1] | Net area compressive strength of ASTM C90 concrete masonry units, psi (MPa) | |
|---|---|---|
| | Type M or S mortar | Type N mortar |
| 1,750 (12.07) | --- | 2,000 (13.79) |
| 2,000 (13.79) | 2,000 (13.79) | 2,650 (18.27) |
| 2,250 (15.51) | 2,600 (17.93) | 3,400 (23.44) |
| 2,500 (17.24) | 3,250 (22.41) | 4,350 (28.96) |
| 2,750 (18.96) | 3,900 (26.89) | ----- |
| 3,000 (20.69) | 4,500 (31.03) | ----- |

[1] For units of less than 4 in. (102 mm) nominal height, use 85 percent of the values listed.

5

# WALL TYPES

- Poll Question 2: What is the maximum spacing in TMS 402/602 for vertical reinforcement in CMU construction?

6

# WALL TYPES

- There are two types of masonry walls:
  - Unreinforced Walls
    - Reinforcement is neglected in design even if it is present.
    - The masonry assembly resists any net tension on the section.
  - Reinforced Walls
    - Tensile capacity of the masonry is neglected in design.
    - Reinforcement resists any net tension on the section.
- Until the 1990s, most masonry construction in Michigan was unreinforced.
- Unreinforced masonry lacks ductility required in higher seismic areas.

7

# SEISMIC DESIGN CATEGORY

- To understand ductility requirements, Section 11.6 of *ASCE 7-16* provides a method to determine the *Seismic Design Category* based on a short-period acceleration parameter ($S_{DS}$) and a 1-s period acceleration parameter ($S_{D1}$).

Design Category F. All other structures shall be assigned to a Seismic Design Category based on their Risk Category and the design spectral response acceleration parameters, $S_{DS}$ and $S_{D1}$, determined in accordance with Section 11.4.5. Each building and structure shall be assigned to the more severe Seismic Design Category in accordance with Table 11.6-1 or 11.6-2, irrespective

**TABLE 11.6-2 Seismic Design Category Based on 1-s Period Response Acceleration Parameter**

| Value of $S_{D1}$ | Risk Category I or II or III | Risk Category IV |
|---|---|---|
| $S_{D1} < 0.067$ | A | A |
| $0.067 \le S_{D1} < 0.133$ | B | C |
| $0.133 \le S_{D1} < 0.20$ | C | D |
| $0.20 \le S_{D1}$ | D | D |

**TABLE 11.6-1 Seismic Design Category Based on Short-Period Response Acceleration Parameter**

| Value of $S_{DS}$ | Risk Category I or II or III | Risk Category IV |
|---|---|---|
| $S_{DS} < 0.167$ | A | A |
| $0.167 \le S_{DS} < 0.33$ | B | C |
| $0.33 \le S_{DS} < 0.50$ | C | D |
| $0.50 \le S_{DS}$ | D | D |

8

# SEISMIC DESIGN CATEGORY

- To assign a SDC, we first determine the mapped seismic parameters for the 0.2-s and 1-s spectral response accelerations:

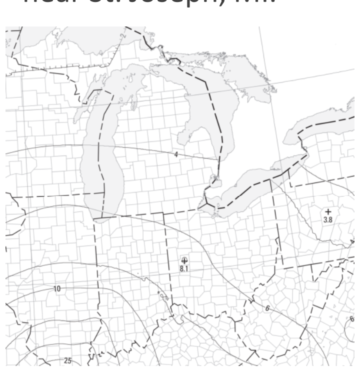
**11.4.2 Mapped Acceleration Parameters.** The parameters $S_S$ and $S_1$ shall be determined from the 0.2- and 1-s spectral response accelerations shown in Figs. 22-1, 22-3, 22-5, 22-6, 22-7, and 22-8 for $S_S$ and Figs. 22-2, 22-4, 22-5, 22-6, 22-7, and 22-8 for $S_1$. Where $S_1$ is less than or equal to 0.04 and $S_S$ is less than or equal to

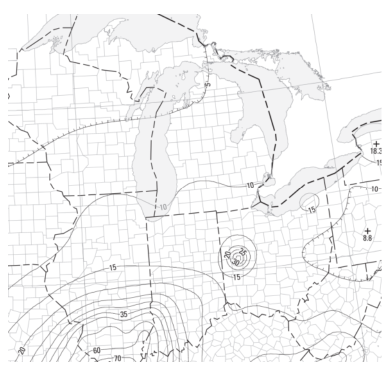
9

# SEISMIC DESIGN CATEGORY

- In Michigan, since we are not geographically located near a major fault, we have low accelerations. The highest response acceleration is found near St. Joseph, MI.

$S_1$ = 0.06 near St. Joseph, MI





$S_s$ = 0.10 near St. Joseph, MI

10

## SEISMIC DESIGN CATEGORY

- These values are then modified based upon site class and soil conditions.

**Table 11.4-1 Short-Period Site Coefficient, $F_a$**

| Site Class | Mapped Risk-Targeted Maximum Considered Earthquake ($MCE_R$) Spectral Response Acceleration Parameter at Short Period | | | | | |
|---|---|---|---|---|---|---|
| | $S_S \le 0.25$ | $S_S = 0.5$ | $S_S = 0.75$ | $S_S = 1.0$ | $S_S = 1.25$ | $S_S \ge 1.5$ |
| A | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| B | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| C | 1.3 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 |
| D | 1.6 | 1.4 | 1.2 | 1.1 | 1.0 | 1.0 |
| E | 2.4 | 1.7 | 1.3 | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 |
| F | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 |

Note: Use straight-line interpolation for intermediate values of $S_s$.

**Table 11.4-2 Long-Period Site Coefficient, $F_v$**

| Site Class | Mapped Risk-Targeted Maximum Considered Earthquake ($MCE_R$) Spectral Response Acceleration Parameter at 1-s Period | | | | | |
|---|---|---|---|---|---|---|
| | $S_1 \le 0.1$ | $S_1 = 0.2$ | $S_1 = 0.3$ | $S_1 = 0.4$ | $S_1 = 0.5$ | $S_1 \ge 0.6$ |
| A | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| B | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| C | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.4 |
| D | 2.4 | 2.2[a] | 2.0[a] | 1.9[a] | 1.8[a] | 1.7[a] |
| E | 4.2 | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 |
| F | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 | See Section 11.4.8 |

Note: Use straight-line interpolation for intermediate values of $S_1$.
[a] Also, see requirements for site-specific ground motions in Section 11.4.8.

$F_a$ = 1.6 for Site Class D
$F_v$ = 2.4 for Site Class D

$S_{MS}$ = (1.6)(0.10) = 0.160
$S_{M1}$ = (2.4)(0.06) = 0.144

11

## SEISMIC DESIGN CATEGORY

- Using these modified parameters, we can then calculate our design acceleration parameters.

**11.4.5 Design Spectral Acceleration Parameters.** Design earthquake spectral response acceleration parameters at short periods, $S_{DS}$, and at 1-s periods, $S_{D1}$, shall be determined from Eqs. (11.4-3) and (11.4-4), respectively. Where the alternate simplified design procedure of Section 12.14 is used, the value of $S_{DS}$ shall be determined in accordance with Section 12.14.8.1, and the value for $S_{D1}$ need not be determined.

$$S_{DS} = \frac{2}{3} S_{MS} \qquad (11.4\text{-}3)$$

$$S_{D1} = \frac{2}{3} S_{M1} \qquad (11.4\text{-}4)$$

$S_{DS}$ = (0.160)(2/3) = 0.107
$S_{D1}$ = (0.144)(2/3) = 0.096

12

# SEISMIC DESIGN CATEGORY

- Lastly, we assign a Seismic Design Category

**TABLE 11.6-1 Seismic Design Category Based on Short-Period Response Acceleration Parameter**

| Value of $S_{DS}$ | Risk Category I or II or III | Risk Category IV |
|---|---|---|
| $S_{DS} < 0.167$ | A | A |
| $0.167 \leq S_{DS} < 0.33$ | B | C |
| $0.33 \leq S_{DS} < 0.50$ | C | D |
| $0.50 \leq S_{DS}$ | D | D |

**TABLE 11.6-2 Seismic Design Category Based on 1-s Period Response Acceleration Parameter**

| Value of $S_{D1}$ | Risk Category I or II or III | Risk Category IV |
|---|---|---|
| $S_{D1} < 0.067$ | A | A |
| $0.067 \leq S_{D1} < 0.133$ | B | C |
| $0.133 \leq S_{D1} < 0.20$ | C | D |
| $0.20 \leq S_{D1}$ | D | D |

$S_{DS}$ = (0.160)(2/3) = 0.107
$S_{D1}$ = (0.144)(2/3) = 0.096

13

# SEISMIC DESIGN CATEGORY

- Most of the lower peninsula in Michigan is in SDC B, and the upper part of Michigan is in SDC A.
- Risk Category IV buildings may be in SDC C depending on geographical location.
- For SDC B, we are permitted to design either <u>unreinforced</u> or <u>reinforced</u> masonry structures.
- It is critical to identify whether the wall is <u>participating</u> (shear wall) or <u>non-participating.</u>
  - <u>Note</u>: If a wall is non-participating, it is essential that it not be connected to the building in such a way that shear can be transferred into the wall (i.e. partition walls).

14

## SEISMIC DESIGN CATEGORY

- In SDC B and higher, it is necessary to assign a shear wall type for participating walls.

**Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems**

| Seismic Force-Resisting System | ASCE 7 Section Where Detailing Requirements Are Specified | Response Modification Coefficient, $R^a$ | Overstrength Factor, $\Omega_0{}^b$ | Deflection Amplification Factor, $C_d{}^c$ | Structural System Limitations Including Structural Height, $h_n$ (ft) Limits[d] — Seismic Design Category B | C | D[e] | E[e] | F[f] |
|---|---|---|---|---|---|---|---|---|---|
| **A. BEARING WALL SYSTEMS** | | | | | | | | | |
| 1. Special reinforced concrete shear walls[g,h] | 14.2 | 5 | 2½ | 5 | NL | NL | 160 | 160 | 100 |
| 2. Ordinary reinforced concrete shear walls[g] | 14.2 | 4 | 2½ | 4 | NL | NL | NP | NP | NP |
| 3. Detailed plain concrete shear walls[g] | 14.2 | 2 | 2½ | 2 | NL | NP | NP | NP | NP |
| 4. Ordinary plain concrete shear walls[g] | 14.2 | 1½ | 2½ | 1½ | NL | NP | NP | NP | NP |
| 5. Intermediate precast shear walls[g] | 14.2 | 4 | 2½ | 4 | NL | NL | 40[i] | 40[i] | 40[i] |
| 6. Ordinary precast shear walls[g] | 14.2 | 3 | 2½ | 3 | NL | NP | NP | NP | NP |
| 7. Special reinforced masonry shear walls | 14.4 | 5 | 2½ | 3½ | NL | NL | 160 | 160 | 100 |
| 8. Intermediate reinforced masonry shear walls | 14.4 | 3½ | 2½ | 2¼ | NL | NL | NP | NP | NP |
| 9. Ordinary reinforced masonry shear walls | 14.4 | 2 | 2½ | 1¾ | NL | 160 | NP | NP | NP |
| 10. Detailed plain masonry shear walls | 14.4 | 2 | 2½ | 1¾ | NL | NP | NP | NP | NP |
| 11. Ordinary plain masonry shear walls | 14.4 | 1½ | 2½ | 1¼ | NL | NP | NP | NP | NP |
| 12. Prestressed masonry shear walls | 14.4 | 1½ | 2½ | 1¾ | NL | NP | NP | NP | NP |
| 13. Ordinary reinforced AAC masonry shear walls | 14.4 | 2 | 2½ | 2 | NL | 35 | NP | NP | NP |
| 14. Ordinary plain AAC masonry shear walls | 14.4 | 1½ | 2½ | 1½ | NL | NP | NP | NP | NP |
| 15. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance | 14.5 | 6½ | 3 | 4 | NL | NL | 65 | 65 | 65 |
| 16. Light-frame (cold-formed steel) walls sheathed with wood structural panels rated for shear resistance or steel sheets | 14.1 | 6½ | 3 | 4 | NL | NL | 65 | 65 | 65 |
| 17. Light-frame walls with shear panels of all other materials | 14.1 and 14.5 | 2 | 2½ | 2 | NL | NL | 35 | NP | NP |
| 18. Light-frame (cold-formed steel) wall systems using flat strap bracing | 14.1 | 4 | 2 | 3½ | NL | NL | 65 | 65 | 65 |

15

## SEISMIC DESIGN CATEGORY

- Ordinary Plain and Detailed Plain Walls <u>must be designed as unreinforced masonry</u>, even if reinforcing is included.
  - Ordinary Plain Walls do not have any reinforcement requirements.
  - Detailed Plain Walls have detailing requirements that are identical to those of Ordinary Reinforced Masonry Shear Walls.
    - Even though the reinforcement is required to be there, you cannot use it in analysis!

16

# SEISMIC DESIGN CATEGORY

- Ordinary Reinforced Masonry Shear Walls must be designed as reinforced masonry and are permitted in SDC A, B, and C up to 160 feet in height.

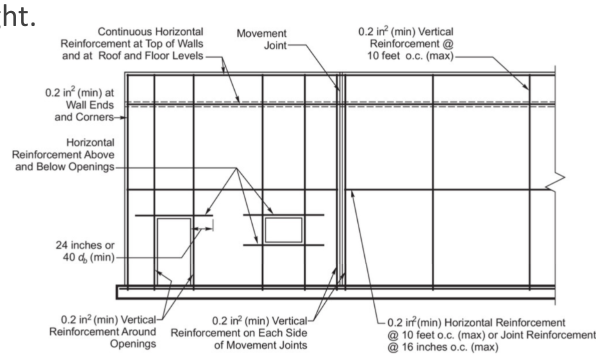



**FIGURE 3.8.4 Minimum Reinforcement Requirements for Detailed Plain and Ordinary Reinforced Masonry Shear Walls**

*Design of Reinforced Masonry Structures*

17

# SEISMIC DESIGN CATEGORY

- Special Reinforced Masonry Shear Walls must be designed as reinforced masonry and are permitted in SDC A, B, C, and D+ up to 160 feet in height.

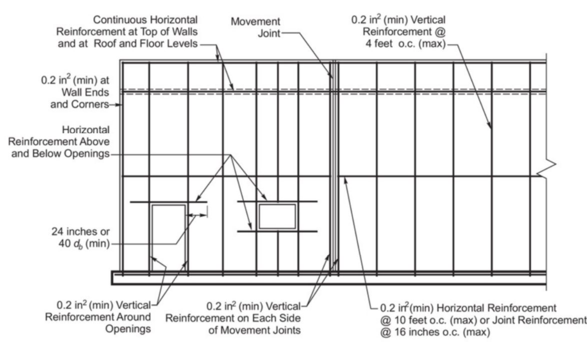



**FIGURE 3.8.5 Minimum Reinforcement Requirements for Intermediate Reinforced Masonry Shear Walls**

*Design of Reinforced Masonry Structures*

18

## UNREINFORCED MASONRY

- Unreinforced masonry design assumed the structure to be linear elastic, even at ultimate strength.
- Almost all unreinforced masonry is ungrouted, unless for increased fire resistance rating or bearing.
- The strength reduction factors for unreinforced masonry are given as follows:
  - ϕ = 0.60 for bearing
  - ϕ = 0.60 for combinations of flexure and axial
  - ϕ = 0.80 for shear

19

## UNREINFORCED MASONRY

- TMS 402 includes provisions for axial compression, flexural tension, and shear.
- Axial tension is not permitted with unreinforced masonry.

| Stress or Force | Equation | | TMS 402 Reference |
|---|---|---|---|
| Axial Compression | $P_n = 0.80\left\{0.80A_n f'_m\left[1-\left(\frac{h/r}{140}\right)^2\right]\right\}$ | $\frac{h}{r} \leq 99$ | Equation 9-11 |
| | $P_n = 0.80\left\{0.80A_n f'_m\left[1-\left(\frac{70}{h/r}\right)^2\right]\right\}$ | $\frac{h}{r} > 99$ | Equation 9-12 |
| Axial Compression and Flexure | Compressive stress does not exceed $0.80f'_m$ | | Section 9.2.4.1 (a) |
| Axial Tension | Not permitted | | Section 9.2.5 |
| Flexural Tension | | | Table 9.1.9.2 |
| Shear (minimum of values) | $V_n = 3.8A_{nv}\sqrt{f'_m} \leq 300\,A_{nv}$ | | Section 9.2.6.1 |
| | $V_n = 56A_{nv} + 0.45N_u$ | running bond, not fully grouted | |
| | $V_n = 90A_{nv} + 0.45N_u$ | running bond, fully grouted | |
| | $V_n = 56A_{nv} + 0.45N_u$ | not laid in running bond, open end units, fully grouted | |
| | $V_n = 56A_{nv} + 0.45N_u$ | not laid in running bond, other than open end units, fully grouted | |

20

# UNREINFORCED MASONRY

- Nominal flexural tension strength is based upon the direction of the stress and mortar type and presented in Table 9.1.9.2.

**Table 9.1.9.2 — Modulus of rupture, $f_r$, psi (kPa)**

| Direction of flexural tensile stress and masonry type | Mortar types | | | |
|---|---|---|---|---|
| | Portland cement/lime or mortar cement | | Masonry cement or air entrained portland cement/lime | |
| | M or S | N | M or S | N |
| Normal to bed joints | | | | |
| Solid units | 133 (919) | 100 (690) | 80 (552) | 51 (349) |
| Hollow units[1] | | | | |
| Ungrouted | 84 (579) | 64(441) | 51 (349) | 31 (211) |
| Fully grouted | 163 (1124) | 158 (1089) | 153 (1055) | 145 (1000) |
| Parallel to bed joints in running bond | | | | |
| Solid units | 267 (1839) | 200 (1379) | 160 (1103) | 100 (689) |
| Hollow units | | | | |
| Ungrouted and partially grouted | 167 (1149) | 127 (873) | 100 (689) | 64 (441) |
| Fully grouted | 267 (1839) | 200 (1379) | 160 (1103) | 100 (689) |
| Parallel to bed joints in masonry not laid in running bond | | | | |
| Continuous grout section parallel to bed joints | 335 (2310) | 335 (2310) | 335 (2310) | 335 (2310) |
| Other | 0 (0) | 0 (0) | 0 (0) | 0 (0) |

[1] For partially grouted masonry, modulus of rupture values shall be determined on the basis of linear interpolation between fully grouted hollow units and ungrouted hollow units based on amount (percentage) of grouting.

21

# UNREINFORCED MASONRY

- Slender walls (h/r > 45) require the first order-moment to be increased by a moment magnification factor to obtain a factored design moment.

**9.2.4.3** *P-Delta effects*

**9.2.4.3.1** Members shall be designed for the strength level axial load, $P_u$, and the moment magnified for the effects of member curvature, $M_u$.

**9.2.4.3.2** The magnified moment, $M_u$, shall be determined either by a second-order analysis, or by a first-order analysis and Equations 9-13 and 9-14.

$$M_u = \psi M_{u,0} \qquad \text{(Equation 9-13)}$$

$$\psi = \frac{1}{1-\dfrac{P_u}{A_n f'_m \left(\dfrac{70r}{h}\right)^2}} \qquad \text{(Equation 9-14)}$$

**9.2.4.3.3** A value of $\psi = 1$ shall be permitted for members in which $h/r \le 45$.

**9.2.4.3.4** A value of $\psi = 1$ shall be permitted for members in which $45 < h/r \le 60$, provided that the nominal strength defined in Section 9.2.4.1 is reduced by 10 percent.

22

# UNREINFORCED MASONRY

- Almost all unreinforced masonry, whether loaded in-plane or out-of-plane, is controlled by flexural tension. We can quickly check with this equation:

$$-\frac{P_u}{A_n} + \frac{M_u}{S_n} \leq \phi f_r$$

$P_u$ = factored axial load
$A_n$ = net area
$M_u$ = factored moment
$S_n$ = net section modulus
ϕ = strength-reduction factor (0.6)
$f_r$ = modulus of rupture

23

# UNREINFORCED MASONRY

- Section properties can be found in NCMA TEK 14-1B and are summarized below:

| Section Property | Nominal Wall Thickness (in) | | | | |
|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 |
| | Ungrouted | | | | |
| Net Area (in²/ft) | 18.0 | 24.0 | 30.0 | 30.0 | 30.0 |
| Net Section Modulus (in³/ft) | 21.0 | 46.3 | 81.0 | 110.1 | 139.6 |
| Net Moment of Inertia (in⁴/ft) | 38.0 | 130.3 | 308.7 | 530.0 | 811.2 |
| Radius of gyration (in) | 1.35 | 2.08 | 2.84 | 3.55 | 4.28 |
| | Fully Grouted | | | | |
| Net Area (in²/ft) | 43.5 | 67.5 | 91.5 | 115.5 | 139.5 |
| Net Section Modulus (in³/ft) | 26.3 | 63.3 | 116.3 | 185.3 | 270.3 |
| Net Moment of Inertia (in⁴/ft) | 47.6 | 178.0 | 443.3 | 891.7 | 1571.0 |
| Radius of gyration (in) | 1.05 | 1.62 | 2.20 | 2.78 | 3.36 |

24

# UNREINFORCED MASONRY

- CMU wall weights can be found in NCMA TEK 14-13B:

**Table 4—8-in. (203-mm) Single Wythe Wall Weights**

| Units | Vertical grout spacing, in. (mm) | Mortar bedding | Wall weight, lb/ft² (kg/m²) for concrete densities, lb/ft³ (kg/m³) of: 85 (1,362) | 95 (1,522) | 105 (1,682) | 115 (1,842) | 125 (2,003) | 135 (2,163) |
|---|---|---|---|---|---|---|---|---|
| Hollow | No grout | Face shell | 25 (122) | 28 (137) | 31 (151) | 33 (161) | 36 (176) | 39 (191) |
| Hollow | No grout | Full | 26 (127) | 28 (137) | 31 (151) | 34 (166) | 37 (181) | 39 (191) |
| Solid | No grout | Full | 56 (274) | 62 (303) | 68 (332) | 74 (362) | 80 (391) | 86 (420) |
| Hollow | 8 (203) | Full | 73 (357) | 76 (371) | 78 (381) | 81 (396) | 84 (411) | 86 (420) |
| Hollow | 16 (406) | Face shell | 49 (239) | 52 (254) | 55 (269) | 57 (279) | 60 (293) | 63 (308) |
| Hollow | 24 (610) | Face shell | 41 (200) | 44 (215) | 47 (230) | 49 (239) | 52 (254) | 55 (269) |
| Hollow | 32 (812) | Face shell | 37 (181) | 40 (195) | 43 (210) | 45 (220) | 48 (235) | 51 (249) |
| Hollow | 40 (1,016) | Face shell | 35 (171) | 38 (186) | 40 (195) | 43 (210) | 46 (225) | 48 (235) |
| Hollow | 48 (1,219) | Face shell | 33 (161) | 36 (176) | 39 (191) | 41 (200) | 44 (215) | 47 (230) |
| Hollow | 56 (1,422) | Face shell | 32 (156) | 35 (171) | 38 (186) | 40 (195) | 43 (210) | 46 (225) |
| Hollow | 64 (1,626) | Face shell | 31 (151) | 34 (166) | 37 (181) | 39 (191) | 42 (205) | 45 (220) |
| Hollow | 72 (1,829) | Face shell | 31 (151) | 33 (161) | 36 (176) | 39 (191) | 41 (200) | 44 (215) |
| Hollow | 80 (2,032) | Face shell | 30 (147) | 33 (161) | 35 (171) | 38 (186) | 41 (200) | 44 (215) |
| Hollow | 88 (2,235) | Face shell | 30 (147) | 32 (156) | 35 (171) | 38 (186) | 40 (195) | 43 (210) |
| Hollow | 96 (2,438) | Face shell | 29 (142) | 32 (156) | 35 (171) | 37 (181) | 40 (195) | 43 (210) |
| Hollow | 104 (2,642) | Face shell | 29 (142) | 32 (156) | 34 (166) | 37 (181) | 40 (195) | 42 (205) |
| Hollow | 112 (2,845) | Face shell | 29 (142) | 31 (151) | 34 (166) | 37 (181) | 39 (191) | 42 (205) |
| Hollow | 120 (3,048) | Face shell | 28 (137) | 31 (151) | 34 (166) | 37 (181) | 39 (191) | 42 (205) |

25

# UNREINFORCED MASONRY

- CMU wall weights can be found in NCMA TEK 14-13B:

**Table 6—12-in. (305-mm) Single Wythe Wall Weights**

| Units | Vertical grout spacing, in. (mm) | Mortar bedding | Wall weight, lb/ft² (kg/m²) for concrete densities, lb/ft³ (kg/m³) of: 85 (1,362) | 95 (1,522) | 105 (1,682) | 115 (1,842) | 125 (2,003) | 135 (2,163) |
|---|---|---|---|---|---|---|---|---|
| Hollow | No grout | Face shell | 32 (156) | 35 (171) | 39 (191) | 42 (205) | 46 (225) | 49 (239) |
| Hollow | No grout | Full | 33 (161) | 36 (176) | 40 (195) | 43 (210) | 47 (230) | 50 (244) |
| Solid | No grout | Full | 86 (420) | 95 (464) | 104 (508) | 113 (552) | 122 (596) | 131 (640) |
| Hollow | 8 (203) | Full | 114 (557) | 118 (577) | 121 (591) | 125 (611) | 128 (626) | 132 (645) |
| Hollow | 16 (406) | Face shell | 73 (357) | 77 (376) | 80 (391) | 84 (411) | 87 (425) | 90 (440) |
| Hollow | 24 (610) | Face shell | 59 (288) | 63 (308) | 66 (323) | 70 (342) | 73 (357) | 77 (376) |
| Hollow | 32 (812) | Face shell | 52 (254) | 56 (274) | 59 (288) | 63 (308) | 66 (323) | 70 (342) |
| Hollow | 40 (1,016) | Face shell | 48 (235) | 52 (254) | 55 (269) | 59 (288) | 62 (303) | 66 (323) |
| Hollow | 48 (1,219) | Face shell | 46 (225) | 49 (239) | 53 (259) | 56 (274) | 59 (288) | 63 (308) |
| Hollow | 56 (1,422) | Face shell | 44 (215) | 47 (230) | 51 (249) | 54 (264) | 57 (279) | 61 (298) |
| Hollow | 64 (1,626) | Face shell | 42 (205) | 46 (225) | 49 (239) | 53 (259) | 56 (274) | 59 (288) |
| Hollow | 72 (1,829) | Face shell | 41 (200) | 44 (215) | 48 (235) | 51 (249) | 55 (269) | 58 (283) |
| Hollow | 80 (2,032) | Face shell | 40 (195) | 44 (215) | 47 (230) | 50 (244) | 54 (264) | 57 (279) |
| Hollow | 88 (2,235) | Face shell | 39 (191) | 43 (210) | 46 (225) | 50 (244) | 53 (259) | 57 (279) |
| Hollow | 96 (2,438) | Face shell | 39 (191) | 42 (205) | 46 (225) | 49 (239) | 53 (259) | 56 (274) |
| Hollow | 104 (2,642) | Face shell | 38 (186) | 42 (205) | 45 (220) | 49 (239) | 52 (254) | 55 (269) |
| Hollow | 112 (2,845) | Face shell | 38 (186) | 41 (200) | 45 (220) | 48 (235) | 52 (254) | 55 (269) |
| Hollow | 120 (3,048) | Face shell | 37 (181) | 41 (200) | 44 (215) | 48 (235) | 51 (249) | 55 (269) |

26

## UNREINFORCED MASONRY

- Poll Question 3: What is the maximum interior 8-inch wall height you can build with Type N masonry cement mortar?

27

## UNREINFORCED MASONRY

- We can quickly check a 12’-8” tall, 8-inch normal weight ungrouted wall with Type N masonry cement mortar:

$$-\frac{P_u}{A_n}+\frac{M_u}{S_n}\leq \phi f_r$$

28

| 8" Ungrouted CMU | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mortar Type** | **Density Classification** | **Maximum Wall Height (ft) Interior** | | **Fire Resistance Rating** | | | | **STC Rating** |
| | | **Vertical** | **Horizontal** | **1 hr** | **2 hr** | **3 hr** | **4 hr** | |
| **Type N Masonry Cement** | **Lightweight** | 12' - 8" | 16' - 0" | 2 | 2 | 2*** | 2*** | 46 |
| | **Medium Weight** | 12' - 8" | 16' - 0" | 1 | 1 | 1*** | 1*** | 47 |
| | **Normal Weight** | 12' - 8" | 16' - 0" | 1 | 1 | 1*** | 1*** | 49 |
| **Type S Masonry Cement** | **Lightweight** | 15' - 4" | 20' - 0" | 2 | 2 | 2*** | 2*** | 46 |
| | **Medium Weight** | 16' - 0" | 20' - 0" | 1 | 1 | 1*** | 1*** | 47 |
| | **Normal Weight** | 16' - 0" | 20' - 0" | 1 | 1 | 1*** | 1*** | 49 |
| **Type N PCL or Mortar Cement** | **Lightweight** | 17' - 4" | 22' - 8" | 2 | 2 | 2*** | 2*** | 46 |
| | **Medium Weight** | 17' - 4" | 22' - 8" | 1 | 1 | 1*** | 1*** | 47 |
| | **Normal Weight** | 18' - 0" | 22' - 8" | 1 | 1 | 1*** | 1*** | 49 |
| **Type S PCL or Mortar Cement** | **Lightweight** | 20' - 0" | 26' - 0" | 2 | 2 | 2*** | 2*** | 46 |
| | **Medium Weight** | 20' - 0" | 26' - 0" | 1 | 1 | 1*** | 1*** | 47 |
| | **Normal Weight** | 20' - 0" | 26' - 0" | 1 | 1 | 1*** | 1*** | 49 |

*Interior wall assumes uniform 5psf load with a 1.6 load factor

**Support condiitons are assumed as pinned-pinned

*** Cell fill required to meet fire resistance rating

| 8" Fully Grouted CMU | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mortar Type** | **Density Classification** | **Maximum Wall Height (ft) Interior** | | **Fire Resistance Rating** | | | | **STC Rating** |
| | | **Vertical** | **Horizontal** | **1 hr** | **2 hr** | **3 hr** | **4 hr** | |
| **Type N Masonry Cement** | **Lightweight** | 30' - 0" | 23' - 4" | 2 | 2 | 2 | 2 | 56 |
| | **Medium Weight** | 30' - 0" | 23' - 4" | 1 | 1 | 1 | 1 | 56 |
| | **Normal Weight** | 30' - 0" | 23' - 4" | 1 | 1 | 1 | 1 | 57 |
| **Type S Masonry Cement** | **Lightweight** | 30' - 8" | 30' - 0" | 2 | 2 | 2 | 2 | 56 |
| | **Medium Weight** | 30' - 8" | 30' - 0" | 1 | 1 | 1 | 1 | 56 |
| | **Normal Weight** | 30' - 8" | 30' - 0" | 1 | 1 | 1 | 1 | 57 |
| **Type N PCL or Mortar Cement** | **Lightweight** | 31' - 4" | 33' - 4" | 2 | 2 | 2 | 2 | 56 |
| | **Medium Weight** | 31' - 4" | 33' - 4" | 1 | 1 | 1 | 1 | 56 |
| | **Normal Weight** | 31' - 4" | 33' - 4" | 1 | 1 | 1 | 1 | 57 |
| **Type S PCL or Mortar Cement** | **Lightweight** | 31' - 4" | 38' - 0" | 2 | 2 | 2 | 2 | 56 |
| | **Medium Weight** | 31' - 4" | 38' - 0" | 1 | 1 | 1 | 1 | 56 |
| | **Normal Weight** | 31' - 4" | 38' - 0" | 1 | 1 | 1 | 1 | 57 |

*Interior wall assumes uniform 5psf load with a 1.6 load factor

**Support conditions are assumed as pinned-pinned

29

| 12" Ungrouted CMU | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mortar Type** | **Density Classification** | **Maximum Wall Height (ft) Interior** | | **Fire Resistance Rating** | | | | **STC Rating** |
| | | **Vertical** | **Horizontal** | **1 hr** | **2 hr** | **3 hr** | **4 hr** | |
| **Type N Masonry Cement** | **Lightweight** | 18' - 0" | 20' - 8" | 1 | 1 | 1 | 1 | 50 |
| | **Medium Weight** | 18' - 8" | 20' - 8" | 2 | 2 | 2 | 2 | 51 |
| | **Normal Weight** | 19' - 4" | 20' - 8" | 1 | 1 | 1 | 3*** | 53 |
| **Type S Masonry Cement** | **Lightweight** | 22' - 0" | 26' - 0" | 1 | 1 | 1 | 1 | 50 |
| | **Medium Weight** | 22' - 8" | 26' - 0" | 2 | 2 | 2 | 2 | 51 |
| | **Normal Weight** | 23' - 4" | 26' - 0" | 1 | 1 | 1 | 3*** | 53 |
| **Type N PCL or Mortar Cement** | **Lightweight** | 24' - 8" | 29' - 4" | 1 | 1 | 1 | 1 | 50 |
| | **Medium Weight** | 24' - 8" | 29' - 4" | 2 | 2 | 2 | 2 | 51 |
| | **Normal Weight** | 25' - 4" | 29' - 4" | 1 | 1 | 1 | 3*** | 53 |
| **Type S PCL or Mortar Cement** | **Lightweight** | 27' - 4" | 33' - 4" | 1 | 1 | 1 | 1 | 50 |
| | **Medium Weight** | 27' - 4" | 33' - 4" | 2 | 2 | 2 | 2 | 51 |
| | **Normal Weight** | 28' - 0" | 33' - 4" | 1 | 1 | 1 | 3*** | 53 |

*Interior wall assumes uniform 5psf load with a 1.6 load factor

**Support condiitons are assumed as pinned-pinned

*** Cell fill required to meet fire resistance rating

| 12" Fully Grouted CMU | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Mortar Type** | **Density Classification** | **Maximum Wall Height (ft) Interior** | | **Fire Resistance Rating** | | | | **STC Rating** |
| | | **Vertical** | **Horizontal** | **1 hr** | **2 hr** | **3 hr** | **4 hr** | |
| **Type N Masonry Cement** | **Lightweight** | 47' - 4" | 36' - 8" | 1 | 1 | 1 | 1 | 60 |
| | **Medium Weight** | 47' - 4" | 36' - 8" | 2 | 2 | 2 | 2 | 61 |
| | **Normal Weight** | 47' - 4" | 36' - 8" | 1 | 1 | 1 | 1 | 63 |
| **Type S Masonry Cement** | **Lightweight** | 48' - 8" | 46' - 0" | 1 | 1 | 1 | 1 | 60 |
| | **Medium Weight** | 48' - 8" | 46' - 0" | 2 | 2 | 2 | 2 | 61 |
| | **Normal Weight** | 48' - 8" | 46' - 0" | 1 | 1 | 1 | 1 | 63 |
| **Type N PCL or Mortar Cement** | **Lightweight** | 49' - 4" | 51' - 4" | 1 | 1 | 1 | 1 | 60 |
| | **Medium Weight** | 49' - 4" | 51' - 4" | 2 | 2 | 2 | 2 | 61 |
| | **Normal Weight** | 49' - 4" | 51' - 4" | 1 | 1 | 1 | 1 | 63 |
| **Type S PCL or Mortar Cement** | **Lightweight** | 49' - 4" | 58' - 8" | 1 | 1 | 1 | 1 | 60 |
| | **Medium Weight** | 49' - 4" | 58' - 8" | 2 | 2 | 2 | 2 | 61 |
| | **Normal Weight** | 49' - 4" | 58' - 8" | 1 | 1 | 1 | 1 | 63 |

*Interior wall assumes uniform 5psf load with a 1.6 load factor

**Support conditions are assumed as pinned-pinned

30

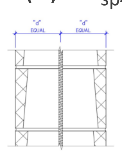
## REINFORCED MASONRY

- Reinforced masonry design assumes the structure to be cracked.
- In low seismic areas, most reinforced masonry walls are partially grouted.
- In higher seismic areas, most reinforced masonry walls are fully grouted.
- The strength reduction factors for reinforced masonry are given as follows:
  - $\phi$ = 0.90 for combinations of flexure and axial
  - $\phi$ = 0.80 for shear and shear friction

31

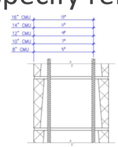
## REINFORCED MASONRY

- Most 8-inch walls are singly-reinforced with the reinforcement centered in the wall (Effective depth ($d$) = $t_{sp}/2$):




WALL SECTION–SINGLE REINFORCING
"d" = 1/2 x SPECIFIED UNIT THICKNESS

- Most 12-inch walls are double-reinforced to maximize the effective depth (Be careful if you specify rebar positioners!):




WALL SECTION–DOUBLE REINFORCING
"d" = NOMINAL UNIT THICKNESS MINUS 3.00 INCHES

32

# REINFORCED MASONRY

- The maximum effective compression width per bar is included in TMS 402 Section 5.1.2.
  - Note: This is NOT the maximum bar spacing, though it is often misinterpreted as such. Remember back to the seismic requirements!
- For masonry not laid in running bond and having bond beams spaced not more than 48-inches and masonry laid in running bond, the width of the compression area is the minimum of:
  - Center-to-center bar spacing
  - 6 multiplied by the nominal wall thickness
  - 72-inches

33

# REINFORCED MASONRY

- For non-bearing walls, the only axial load is due to self-weight
  - Note: Typically, we can conservatively ignore self weight for reinforced masonry and design for pure flexure. If the rectangular stress block is contained in the face shell, then we can design as a solid section.
- To determine the required reinforcement, we can quickly:
  - Calculate design moment ($M_u$)
  - Solve for the depth of the stress block (a):

$$a = d - \sqrt{d^2 - \frac{2M_u}{0.8\phi f_m' b}}$$

  - If a is less than $t_{fs}$, then it can be designed as a solid section and we can solve for steel area:

$$A_{s,req}: \frac{0.8 f_m' ba}{f_y}$$

34

# REINFORCED MASONRY

| Spacing (inches) | Steel Area ($in^2/ft$) | | | | | |
|---|---|---|---|---|---|---|
| | No. 3 | No. 4 | No. 5 | No. 6 | No. 7 | No. 8 |
| 8 | 0.165 | 0.300 | 0.465 | 0.660 | 0.900 | 1.185 |
| 16 | 0.083 | 0.150 | 0.233 | 0.330 | 0.450 | 0.593 |
| 24 | 0.055 | 0.100 | 0.155 | 0.220 | 0.300 | 0.395 |
| 32 | 0.041 | 0.075 | 0.116 | 0.165 | 0.225 | 0.296 |
| 40 | 0.033 | 0.060 | 0.093 | 0.132 | 0.180 | 0.237 |
| 48 | 0.028 | 0.050 | 0.078 | 0.110 | 0.150 | 0.198 |
| 56 | 0.024 | 0.043 | 0.066 | 0.094 | 0.129 | 0.169 |
| 64 | 0.021 | 0.038 | 0.058 | 0.083 | 0.113 | 0.148 |
| 72 | 0.018 | 0.033 | 0.052 | 0.073 | 0.100 | 0.132 |
| 80 | 0.017 | 0.030 | 0.047 | 0.066 | 0.090 | 0.119 |
| 88 | 0.015 | 0.027 | 0.042 | 0.060 | 0.082 | 0.108 |
| 96 | 0.014 | 0.025 | 0.039 | 0.055 | 0.075 | 0.099 |
| 104 | 0.013 | 0.023 | 0.036 | 0.051 | 0.069 | 0.091 |
| 112 | 0.012 | 0.021 | 0.033 | 0.047 | 0.064 | 0.085 |
| 120 | 0.011 | 0.020 | 0.031 | 0.044 | 0.060 | 0.079 |

35

# REINFORCED MASONRY

- Poll Question 4: What is the required spacing of a #6 bar in a partially grouted 12’-0” tall, 8” CMU wall with a design wind speed of 115mph?

| Wall Height | 8" CMU Partial Grout With Bars Centered – Reinforcement Spacing | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2000 psi | | | 2500 psi | | | 3000 psi | | |
| | #5 | #6 | #7 | #5 | #6 | #7 | #5 | #6 | #7 |
| 10' - 0" | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |
| 12' - 0" | 112 | 120 | 120 | 112 | 120 | 120 | 112 | 120 | 120 |
| 14' - 0" | 88 | 120 | 120 | 88 | 120 | 120 | 88 | 120 | 120 |
| 16' - 0" | 64 | 96 | 120 | 64 | 96 | 120 | 64 | 96 | 120 |
| 18' - 0" | 56 | 72 | 104 | 56 | 80 | 104 | 56 | 80 | 104 |
| 20' - 0" | 40 | 64 | 88 | 48 | 64 | 88 | 48 | 64 | 88 |

36

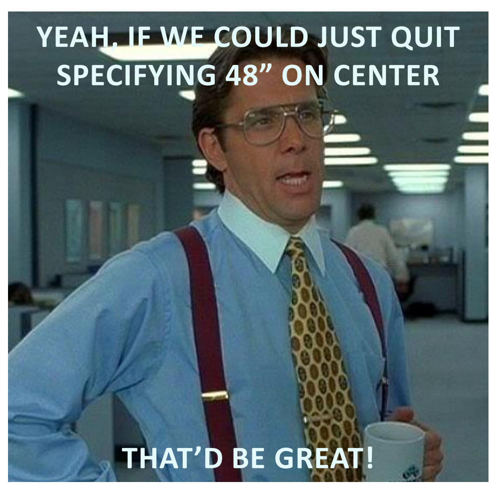
# REINFORCED MASONRY

- Most walls are not flexure only and have axial load applied, and so interaction diagrams must be developed.
- TMS 402 does require second order effects to be included, as well.
- TMS 402 contains *maximum reinforcement* provisions in Strength Design intended to promote ductility.
- All of these items can be discussed through MIM's out-of-plane spreadsheet which will soon be available on our website for engineers to use.

37

# CONCLUSIONS

- Use an appropriate specified masonry compressive strength; remember that 2000 psi is the minimum per ASTM C90. This affects more than rebar spacing!
- Stop pretending we're designing in Northridge, CA! Consider unreinforced, ungrouted CMU walls for interior demising walls and corridors.
- There is no magic to 6t, stop using 48" as a cure all! In many cases, with modest wall heights we can achieve rebar spacings of 120" on center.




38

# QUESTIONS?

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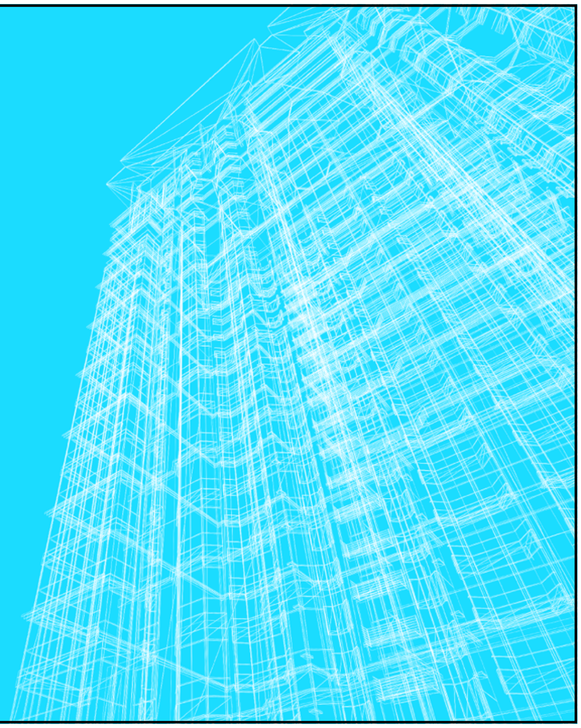
www.masonryinfo.org



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39