Design of Columns and Pilasters & System Behavior

TMS20210303

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

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Course Description

Masonry columns and pilasters are often used in masonry buildings to carry large, concentrated loads, and, for pilasters, to support walls subjected to out-of-plane loads. Required detailing of these elements will be reviewed and strength design provisions will be introduced for these elements. This session will also look several sample masonry buildings to discuss system behavior and overall design methodology for masonry structures.

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Learning Objectives

- Introduce masonry column and pilaster elements
- Discuss required detailing of columns and pilasters
- Review the design of masonry columns
- Review the design masonry pilasters
- Discuss behavior of masonry building systems
- Introduce an overall design methodology for masonry structures

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Tonight's Road Map

- Shear Wall Wrap-Up
- Column Design
- Pilaster Design
- Volume Change and Jointing
- Masonry Building Systems

Shear Wall Wrap-Up

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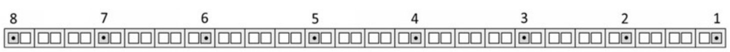
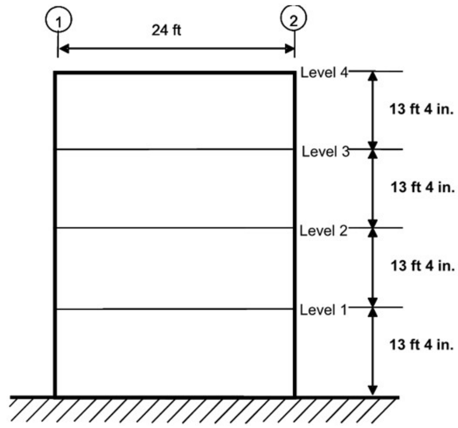
Shear Wall - Example

Special Reinforced Clay Masonry Shear Wall

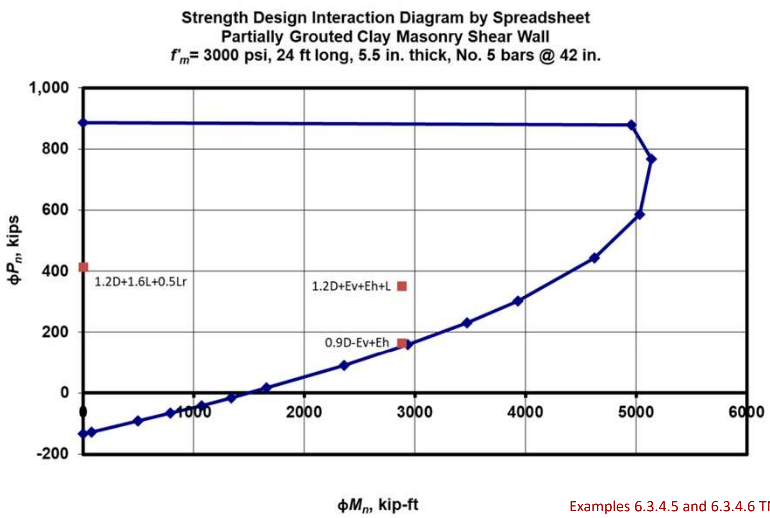
- Nominal 6” units (5.5”), 6” module
- Running bond
- Partially grouted, assume t_{eq} = 2.75”
- f'_m = 3000 psi
- Minimum P_u = 166 kips
- M_u = 2,800 kip-ft





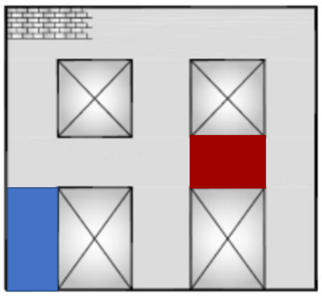
Examples 6.3.4.5 and 6.3.4.6 TMS “Strength Design of Masonry”

Shear Wall - Example

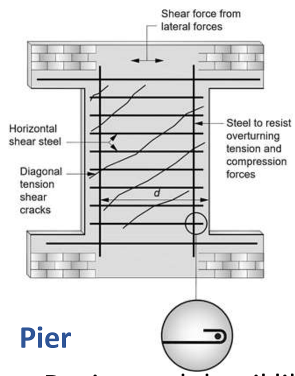


Examples 6.3.4.5 and 6.3.4.6 TMS “Strength Design of Masonry”

Perforated Walls

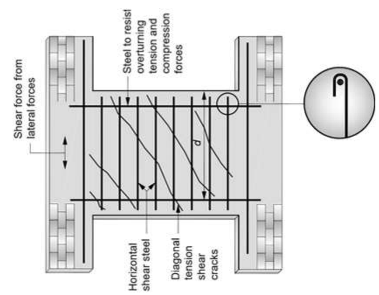


Not addressed by TMS 402
(Except Appendix C)



Pier

- Design and detail like a fixed-fixed shear wall

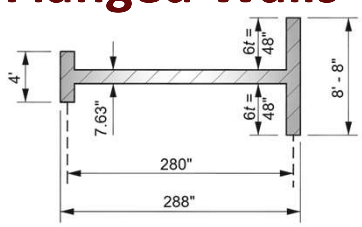


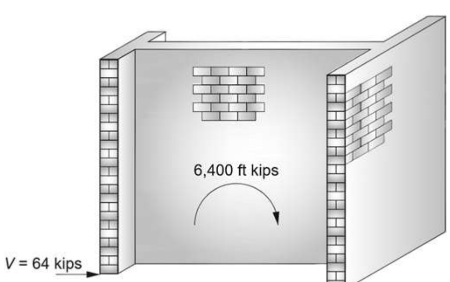
Coupling Element

- Design and detail like a fixed-fixed shear wall, oriented sideways

Images from RMEH

Flanged Walls





Images from RMEH

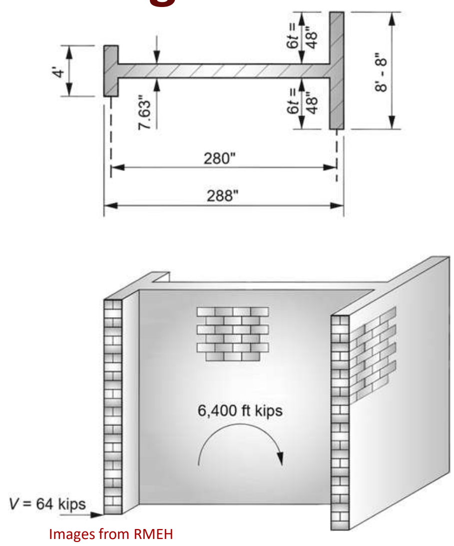
Effective Flanges

- If walls are connected at intersections, must consider effects of flanges.
- Minimum requirements for connections at intersections (TMS 5.1.1)
- Effective flange widths

Table 5.1.1.2.3 Effective Flange Width

Stress State in Flange	Unreinforced (U) or Reinforced (R) Masonry	Effective Flange Width
Compression	U, R	6 x nominal flange thickness
Tension	U	6 x nominal flange thickness
	R	0.75 x floor-to-floor wall height

Flanged Walls



Images from RMEH

Ductility

- T and L shaped walls may have difficulty complying with ρ_{max}
  - Lots of steel in flange in tension
  - Small compression area in stem
- Use alternate (boundary zone) methods discussed last time
  - Or disconnect flanges

Shear

- Only use web

Column Design

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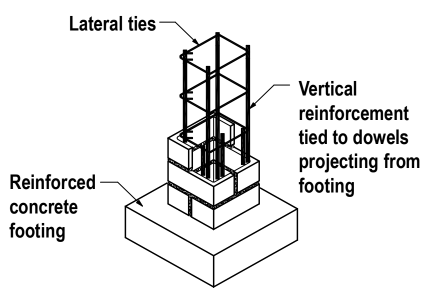
Column Design

- TMS 402 Definition (TMS 2.2)
  - Column — A structural member, not built integrally into a wall, designed primarily to resist compressive loads parallel to its longitudinal axis and subject to dimensional limitations.

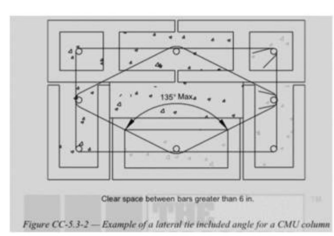
TMS "Strength Design of Masonry"

Column Design

- TMS 402 Requirements (TMS 5.3)
  - Proportions
    - $h/r \leq 99$
    - 8 in. minimum side dimension
  - Reinforcement
    - Longitudinal
      - 0.0025 A_n minimum
      - 0.04 A_n maximum
      - ρ_{max}
    - Ties
      - ¼" min diameter
      - Spacing minimum ($16d_{b,long}$, $48\ d_{b,tie}$, least cross-sectional dimension)
      - Support of longitudinal bars



TMS "Strength Design of Masonry"



TMS 402

Column Design

- TMS 402 Requirements (TMS 7.4)
  - SDC C+:

    Participating:

    Where anchor bolts are used to connect horizontal elements to the tops of columns, anchor bolts shall be placed within lateral ties. Lateral ties shall enclose both the vertical bars in the column and the anchor bolts. There shall be a minimum of two No. 4 (M #13) lateral ties provided in the top 5 in. (127 mm) of the column.

  - SDC D+:

    Participating:

    Lateral ties in masonry columns shall be spaced not more than 8 in. (203 mm) on center and shall be at least 3/8 in. (9.5 mm) diameter.

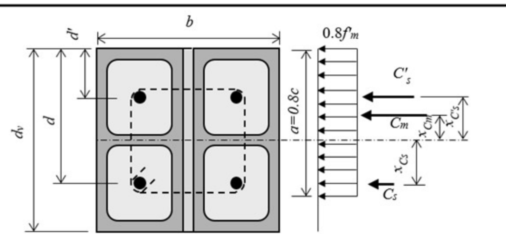
    Standard hooks for lateral tie anchorage shall be either a 135-degree standard hook or a 180-degree standard hook

    Non-Participating:

    . . .should also be more heavily tied at the tops and bottoms for more ductile performance and better resistance to shear.

Column Design

$d < c \leq d_v$

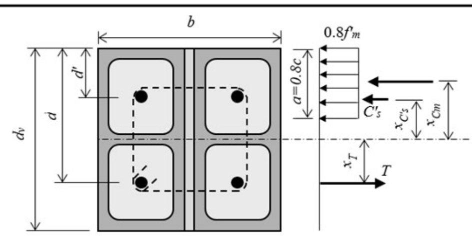


$C_m = 0.8 f'_m ba$ $C_{s'} = A'_s \left[\min\left\{f_y, E_s \varepsilon_{mu} \frac{c - d'}{c}\right\}\right]$ $C_s = A_s \left[\min\left\{f_y, E_s \varepsilon_{mu} \frac{c - d}{c}\right\}\right]$	$P_n = C_m + C'_s + C_s$ $M_n = C_m x_{Cm} + C'_s x_{C's} - C_s x_{Cs}$	$x_{Cm} = \frac{d_v}{2} - \frac{a}{2}$ $x_{C's} = \frac{d_v}{2} - d'$ $x_{Cs} = d - \frac{d_v}{2}$

TMS "Strength Design of Masonry"

Column Design

$d' < c \le d$

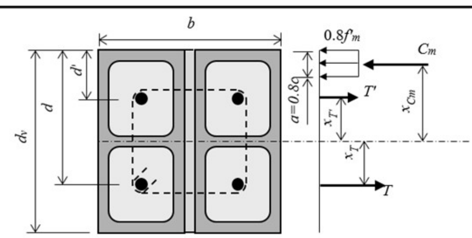


$C_m = 0.8f'_m ba$ $C_{s'} = A'_s\left[\min\left\{f_y, E_s\varepsilon_{mu}\frac{c-d'}{c}\right\}\right]$ $T = A_s\left[\min\left\{f_y, E_s\varepsilon_{mu}\frac{d-c}{c}\right\}\right]$	$P_n = C_m + C'_s - T$ $M_n = C_m x_{Cm} + C'_s x_{C's} + T x_T$	$x_{Cm} = \frac{d_v}{2} - \frac{a}{2}$ $x_{C's} = \frac{d_v}{2} - d'$ $x_T = d - \frac{d_v}{2}$

TMS “Strength Design of Masonry”

Column Design

$c \le d'$



$C_m = 0.8f'_m ba$ $T = A_s\left[\min\left\{f_y, E_s\varepsilon_{mu}\frac{d-c}{c}\right\}\right]$ $T' = A'_s\left[\min\left\{f_y, E_s\varepsilon_{mu}\frac{d'-c}{c}\right\}\right]$	$P_n = C_m - T' - T$ $M_n = Cx_c - T'x_{T'} + Tx_T$	$x_c = \frac{d_v}{2} - \frac{a}{2}$ $x_T = d - \frac{d_v}{2}$ $x_{T'} = \frac{d_v}{2} - d'$

TMS “Strength Design of Masonry”

Column Design - Example

- Construct Interaction Diagram Given:
  - 20 foot tall, 16 in. x 16 in. CMU column
  - f'_m = 2,000 psi
  - (4) #6 centered in cells
- Axial capacity

$$r = {}^{t}/_{\sqrt{12}} = {}^{15.625}/_{\sqrt{12}} = 4.51\ in.$$

$$^{h}/_{r} = {}^{240}/_{4.51} = 53.2$$

Column Design - Example

- Axial capacity (cont'd)

$$P_n = 0.80[0.80f'_m(A_n - A_{st}) + f_y A_{st}]\left[1 - \left(\frac{h/r}{140}\right)^2\right]$$

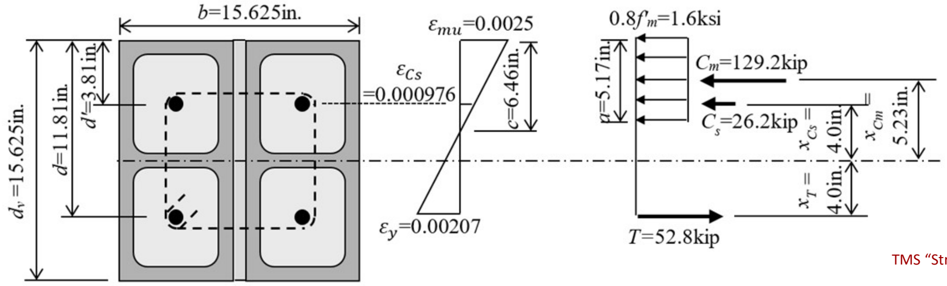
$$P_n = 0.80[0.80(2)(244.1 - 1.76) + (60)(1.76)]\left[1 - \left(\frac{53.2}{140}\right)^2\right]$$

$$P_n = 337.7 \text{ kip}$$

$$\phi P_n = 0.9(337.7) = 303.9 \text{ kip}$$

Column Design - Example

- Capacity at Balanced Condition



TMS "Strength Design of Masonry"

$P_n = C_m + C_s - T =$

$P_n = 129.2\text{kip} + 26.2\text{kip} - 52.8\text{kip}$

$P_n = 102.6\text{kip}$

$\phi P_n = 0.9(102.6\text{kip}) = 92.4\text{kip}$

$M_n = C_m x_{Cm} + C_s x_{Cs} + T x_T$

$M_n = 129.2\text{kip}(5.23\text{in.}) + 26.2\text{kip}(4.0\text{in.}) + 52.8\text{kip}(4.0\text{in.})$

$M_n = 991.5\text{k}\cdot\text{in.} = 82.62\text{k}\cdot\text{ft}$

$\phi M_n = 0.9(82.6\text{k}\cdot\text{ft}) = 74.36\text{k}\cdot\text{ft}$

Column Design - Example

- Capacity in Flexure
  - Use only (2) bars to simplify calculation

$$a = \frac{A_s f_y}{0.8 f'_m b} = \frac{(0.88)(60)}{0.8(2)(15.625)} = 2.11\ in.$$

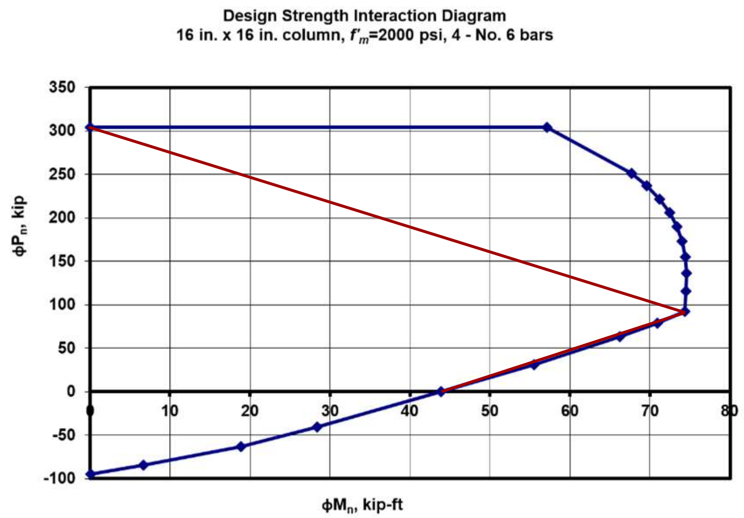
$$M_n = A_s f_y\left(d - \frac{a}{2}\right) = (0.88)(60)\left(11.81 - \frac{2.11}{2}\right) = 568\text{ k} - \text{in} = 47.3\text{ k} - \text{ft}$$

  - Accounting for both layers of reinforcement

$M_n = 48.8\text{ k} - \text{ft}$ less than 5% increase in capacity

$\phi M_n = 0.9(48.8) = 43.9\text{ k} - \text{ft}$

Column Design - Example



TMS "Strength Design of Masonry"

Pilaster Design

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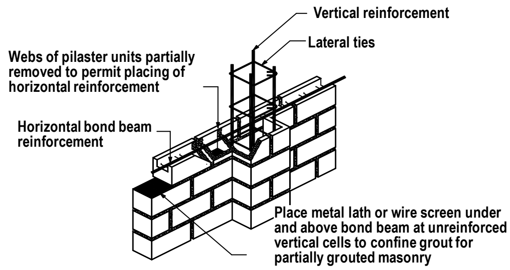
Pilaster Design

- TMS 402 Definition (TMS 2.2)
  - Pilaster - A vertical member, built integrally with a wall, with a portion of its cross section typically projecting from one or both faces of the wall.
- Uses
  - Out-of-plane support for wall spanning horizontally
  - Support concentrated loads
  - Strengthen wall at openings
  - Strengthen end of shear wall

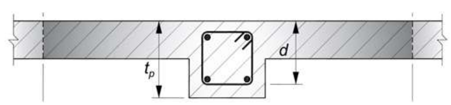


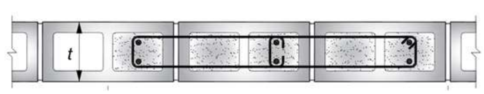
TMS "Strength Design of Masonry"

Figure from RMEH

Pilaster Design

- Types
  - Projecting
    - Treat wall as flange if comply with TMS 402 5.1.1.2.1 and 5.1.1.2.5.
    - Flange width per TMS 5.1.1.2.3.
  - Flush
- Ties only required if:
  - Longitudinal bars used to resist compression
  - Then meet column requirements

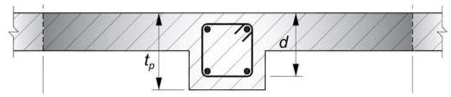


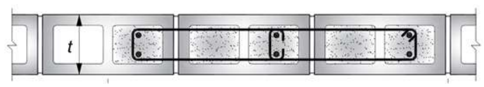


Figures from RMEH

Pilaster Design

- Longitudinal reinforcement
  - No minimum quantity
  - ρ_{max}
- Must consider P-δ; can use same techniques as for out-of-plane walls





Figures from RMEH

Volume Change and Jointing

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Colin, Officially control joints are NOT required. But you must account for differential movement. I would let you know that the discussion on how many joints you need depends on many things. First, if you are using clay masonry, we use expansion joints, not control joints as clay expands. But let's hold on that for now. Next....

… the number of joints you need somewhat depends on what you are willing to accept in cracks. That is, if you have cmu, covered by studs and drywall on the inside, and a veneer on the outside, no one will ever see the cracks, so you may space them farther apart. Also, if you have a ton of horizontal steel that "stitches" cracks to microcracks, you may go longer on your spacing. I've seen buildings 100 ft long in CA with NO control joints, as they were worried more about seismic issues than shrinkage cracks. Having said all of that, it is TYPICAL to place control joints about every 24 ft for exposed masonry but no more than about 1.5 to 2.5 times the height of the wall. NCMA TEK notes have great information on their recommendations. Enough for now?

- Phil Samblanet (Chat message, Session #4)

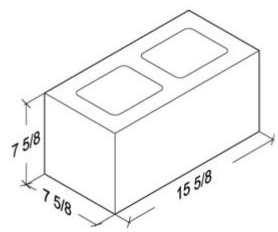
Volume Change and Jointing

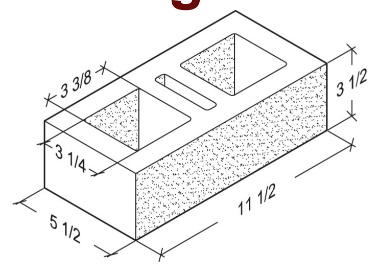
TMS 402/602

4.1.5 *Other effects*

Consideration shall be given to effects of forces and deformations due to prestressing, vibrations, impact, shrinkage, expansion, temperature changes, creep, unequal settlement of supports, and differential movement.

Volume Change and Jointing





Concrete Units:
- Cementitious product
- Shrinks over time

Joint = Control Joint

Clay Units:
- Kiln fired ceramic
- Expands as it gains moisture

Joint = Expansion Joint

Figures from Mutual Materials

Volume Change and Jointing

Concrete Masonry

Comparison to cast-in-place concrete

- Amount of movement (units are preshrunk)
- Amount of reinforcing
  - Cast-in-place wall: 0.0012 to 0.0015 (ACI 318-14, Table 11.6.1)
  - Masonry:
    - Non-participating – may have no horizontal reinforcing
    - Participating:
      - Ordinary ~ 0.00022
      - Special – 0.0007 (0.0015 if not laid in running bond)

Volume Change and Jointing

Concrete Masonry

Resources and Recommendations

- NCMA Technical Notes
  - 10-01A – Control of Cracking
  - 10-02D – Empirical Method
  - 10-03 – Alternative Engineered Method
- Regional Recommendations

Volume Change and Jointing

If Joints Provided

	Maximum Length-to-Height Ratio of Concrete Masonry Panel	Maximum spacing, in. (mm)
Above Grade Concrete Masonry Walls		
Nominal Unit Height: 8 in. (203 mm)[2]	1.5 to 1	25 ft. (7.62 m)
Nominal Unit Height: 4 in. (102 mm)[3]	1.5 to 1	20 ft. (6.10 m)

[1]Adjust spacing as needed where local experience or project conditions warrant.
[2]Include horizontal reinforcement having an equilavent area of not less than 0.025 in.^{2}/ft. (52.9 mm^2/m) of height. See Table 2A.
[3]Include horizontal reinforcement having an equivalent area of not less than 0.034 in.^{2}/ft. (72.0 mm^2/m) of height. See Table 2B.

Reinforcement size	Maximum spacing, in. (mm)
W1.7 (9 gage) (MW11)[1]	16 (406)
W2.1 (8 gage) (MW13)[1]	16 (406)
W2.8 (3/16 in.) (MW18)[1]	24 (610)
No. 3 (M#10)	48 (129)
No. 4 (M#13)	96 (2,348)
No. 5 (M#16) or larger	144 (3,658)

[1] Minimum two wires per course.

NCMA Technical Note 10-02D

Minimum Reinforcement for No Joints

Table 1—Maximum Spacing of Horizontal Reinforcement to Meet the Criteria As > 0.002An[1]

Wall thickness, in. (mm)	Maximum spacing of horizontal reinforcement, in. (mm) Reinforcement size		
	No.6(M19)	No.5(M16)	No.4(M13)
Ungrouted or partially grouted walls			
6(152)	48(1219)	48(1219)	32(813)
8(203)	48(1219)	40(1016)	24(610)
10(254)	48(1219)	32(813)	16(406)
12(305)	48(1219)	24(610)	8(203)
Fully grouted walls			
6(152)	32(813)	24(610)	16(406)
8(203)	24(610)	16(406)	8(203)
10(254)	16(406)	16(406)	8(203)
12(305)	16(406)	8(203)	8(203)

1. A_n includes cross-sectional area of grout in bond beams

NCMA Technical Note 10-01A

Volume Change and Jointing

Clay Masonry

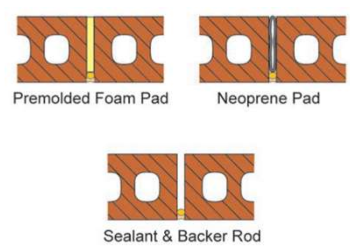
Resources and Recommendations

- BIA Technical Notes
  - 18 – Volume Changes - Analysis and Effects of Movement
  - 18A – Accommodating Expansion of Brickwork
    - Joint spacing should not exceed:
      - 25’ if no openings
      - 20’ with openings

Volume Change and Jointing

Joint Sizing

Previous references provide recommendations on determining the magnitude of movement that needs to be accommodated at the joints.



BIA Technical Note 18A

Must also consider sealant compressability / extensibility. Typical values:

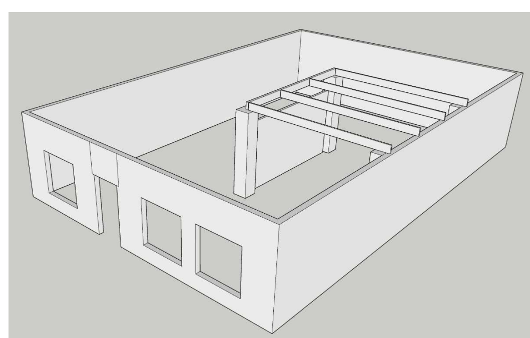
- 50% Compressibility
- 50% to 100% Extensability

Confirm with specified product

Masonry Building Systems

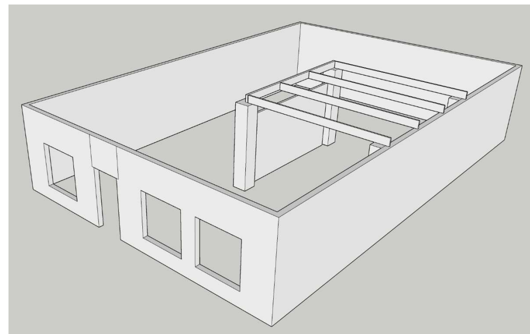
Masonry Building Design Process

- Assess Global Lateral Behavior
  - Enough wall for lateral?
  - Will torsion be an issue?
  - Will diaphragm spans be adequate?
  - Where will columns be located?
  - Select wall type.
- Out-of-Plane Design
  - What direction will walls span?
  - Are walls thick enough?
  - Determine out-of-plane reinforcement
  - Consider openings



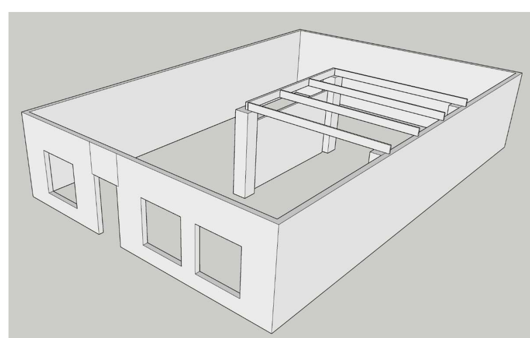
Masonry Building Design Process

- Locate Joints
  - What is maximum length between joints?
  - Where should joints be located?
  - How wide should joints be?
- Lateral Analysis
  - Will building respond elastically?

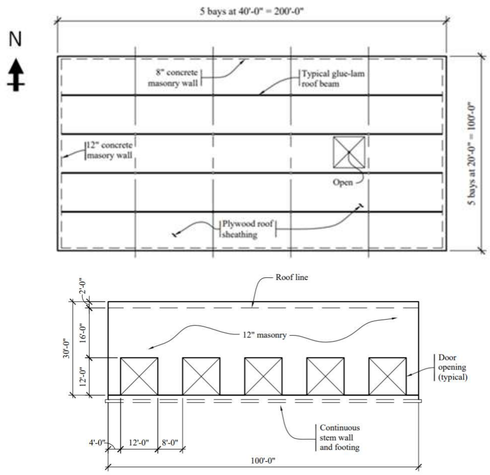


Masonry Building Design Process

- In-Plane Design
  - Min reinforcing for wall type.
  - Shear design (horizontal reinforcement)
    - Shear capacity design
  - Flexure/Axial design (vertical reinforcement)
    - Verify ductility
  - Consider Openings
  - Check sliding



Example 1 - Warehouse

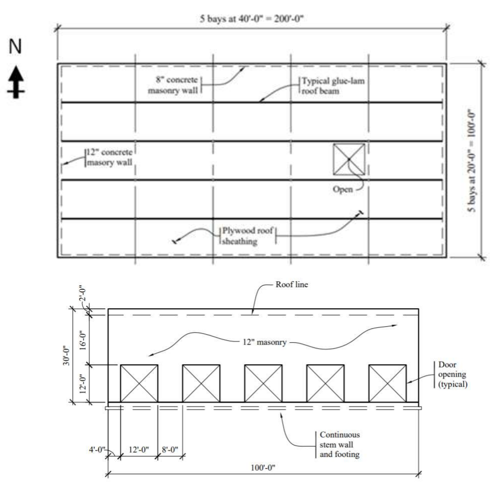


East and West Wall Elevation

Figures 13.1-1 and 13.1-2 from FEMA P-1051

- Assess Global Lateral Behavior
  - Enough wall for lateral?
    - East Wall – Check shear in piers
      - Increase wall thickness
      - Increase masonry strength
      - Add wall
        - Interior wall
        - Infill opening on east wall
  - Will torsion be an issue?
  - Will diaphragm spans be adequate?

Example 1 - Warehouse



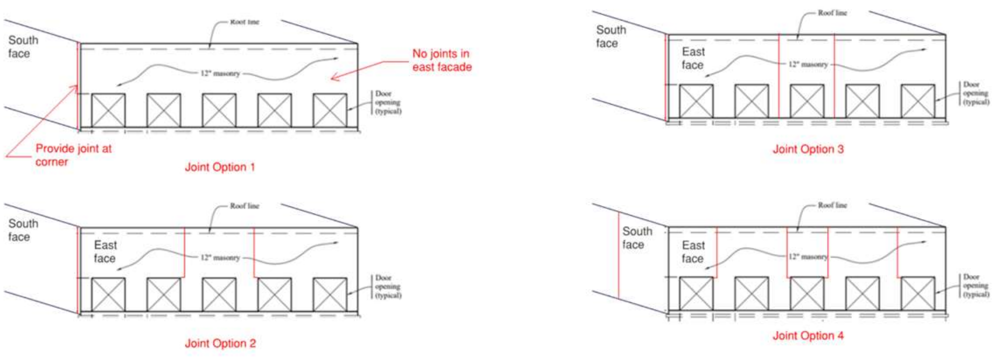
East and West Wall Elevation

Figures 13.1-1 and 13.1-2 from FEMA P-1051

- Out-of-Plane Design
  - What direction will walls span?
    - Start at 8" for CMU spanning vertically
    - For clay units start at 4" or 6".
  - Are walls thick enough?
    - Tall walls
      - 12" versus 8" plus pilasters

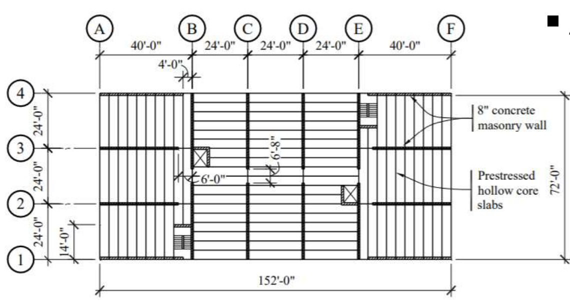
Example 1 - Warehouse

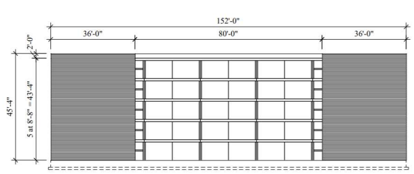
- Locate Joints
- In-Plane Design



TMS "Strength Design of Masonry"

Example 2 - Residential



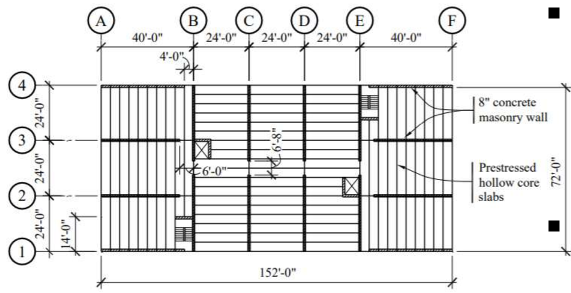


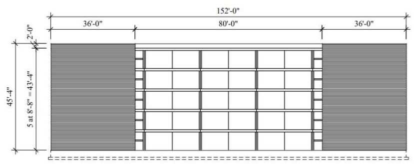
North and South Wall Elevation

Figures 13.2-1 and 13.2-2 from FEMA P-1051

- Assess Global Lateral Behavior
  - Enough wall for lateral?
  - Will torsion be an issue?
    - Ways to improve torsional response
      - Add short walls on east and west ends
      - Stiffen walls on grids 1 and 4
      - Soften north-south walls
  - Will diaphragm spans be adequate?
    - Note cantilevered diaphragms

Example 2 - Residential





North and South Wall Elevation

Figures 13.2-1 and 13.2-2 from FEMA P-1051

- Out-of-Plane Design
  - What direction will walls span?
    - Short floor to floor height
  - Are walls thick enough?
- In-Plane Design
  - Consider Openings
  - Consider Minor Walls

This concludes The American Institute of Architects Continuing Education Systems Course

The Masonry Society