Wall Design for In-Plane Loads & Seismic Detailing

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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

Shear walls are critical building elements to resist in-plane loads and are, for masonry, the seismic-force-resisting system. This session will review strength design of shear walls, along with both seismic detailing requirements and minimum/ maximum detailing requirements for such walls.

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Learning Objectives

- Introduce masonry shear walls and applied loads on these critical elements
- Discuss seismic detailing requirements for masonry shear walls
- Review the strength design provisions for masonry shear walls for combined axial load and bending and for shear
- Overview maximum and minimum reinforcement limits and detailing of shear walls

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Tonight's Road Map

- Wall Design Process
- Wall Detailing
- In-Plane Wall Design
- Special Topics – Next week

Wall Design Process

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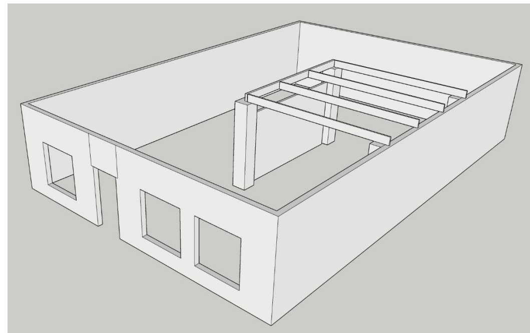
Wall Design Process

- Architectural Functionality Determines Location and Extent of Masonry Walls
- Out-of-Plane Design
  - Estimate reinforcing (Session 3)
  - Consider detailing requirements (tonight)
  - Design for second order effects (Session3)
- In-Plane Design (tonight)



Wall Detailing

- Seismic Design Category
- Non-Participating Walls
- Participating Walls

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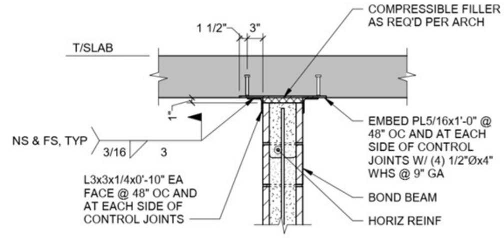
Detailing - Seismic Design Category

- Determined by ASCE 7
- Based on Risk Category and Ground Motions
  - Risk category – hazard to public, essential services
  - Ground motion – history of seismic activity
- Ranges from A to F

Detailing – Element Classification

- Types of Walls (TMS 7.3)
  - Participating = part of the lateral force resisting system = shear wall
  - Non-Participating = not part of the seismic-force-resisting system
    - must be isolated in their own plane from the seismic-force-resisting system.



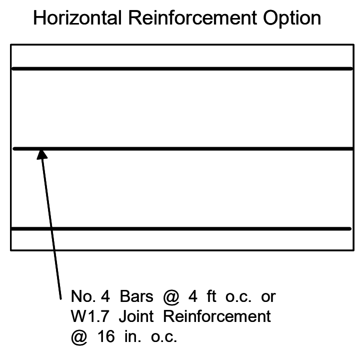
Detailing – Non-Participating (A, B)

- Seismic Design Category A and B (TMS 7.4.1.1, 7.4.2)
  - Design as reinforced or unreinforced
  - No minimum area of steel
  - Must isolate in its own plane

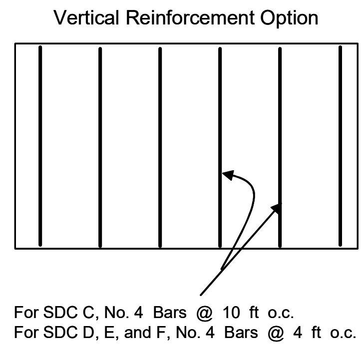
Detailing – Non-Participating (C+)

- Seismic Design Category C and Higher (TMS 7.4.3.1, 7.4.4.1, 7.4.5.1)
  - Design as reinforced or unreinforced
  - Must reinforce in either horizontal or vertical direction
    - SDC D+: Minimum vertical steel increases
    - SDC E+: If not laid in running bond, horizontal reinforcement is required and is increased.
  - Must isolate in its own plane

Detailing – Non-Participating (C+)



OR



Not laid in running bond, SDC E+:

- 0.0015 of gross area
- 24" max spacing
- 8": #5 @ 24"
- 10": (2) #4 @ 24"
- 12": (2) #5 or #6 @ 24"

Detailing – Participating (A)

- SDC A:
  - ASCE 7 Exempt from seismic Requirements (ASCE 7 11.7)
    - Compliance structural integrity provisions of ASCE 7 1.4 required.
  - TMS 402
    - Have to pick a wall type and detail accordingly
    - Includes Ordinary Plain (unreinforced)
      - Design as unreinforced
      - No minimum reinforcing required

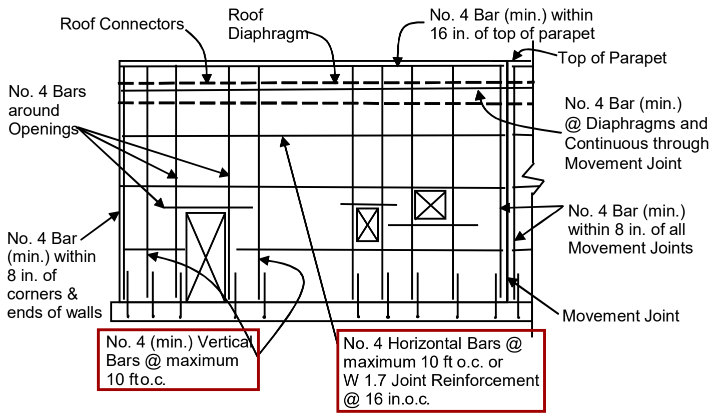
Detailing – Participating (B+)

- SDC B+:
  - ASCE 7
    - Must pick a permitted wall type per ASCE 7 Table 12.2-1. Types:
      - Special reinforced masonry shear walls (F max)
      - Intermediate reinforced masonry shear walls (C max)
      - Ordinary reinforced masonry shear walls (C max)
      - Detailed plain masonry shear walls (B max)
      - Ordinary plain masonry shear walls (B max)
    - Must decide “Building frame” versus “Bearing wall”
      - “essentially complete space frame providing support for vertical loads.”
    - Chapter 14 not adopted by IBC

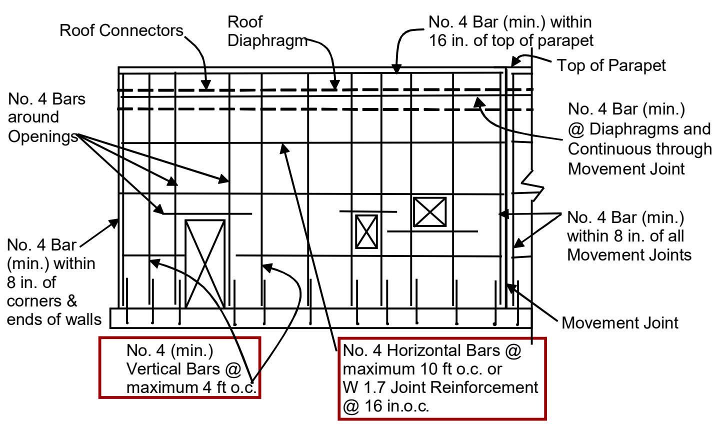
Detailing – Participating (B+)

- SDC B+ (continued):
  - TMS 402 Provides:
    - Minimum detailing requirements based on wall type
    - Minimum detailing and material requirements based on SDC
    - Additional design requirements for special walls
  - SDC Based Requirements
    - SDC D+
      - Type S or M Mortar:
        - Fully grouted: cement-lime, masonry cement, or mortar cement.
        - Partially grouted: cement-lime or mortar cement.
      - Lateral Ties: Anchor with 135 or 180 degree hook

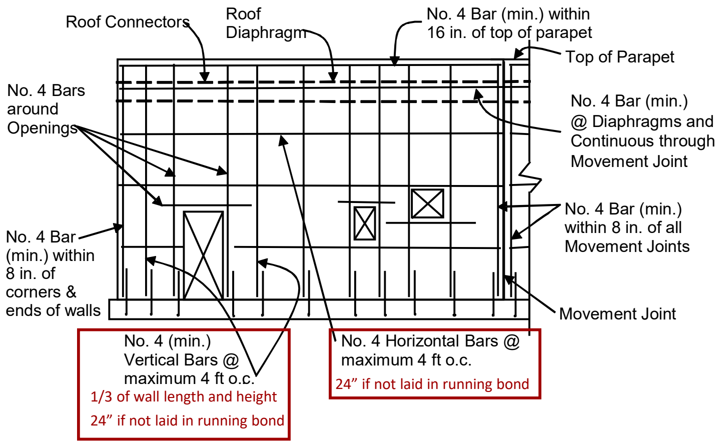
Detailing – Detailed Plain Ordinary Reinforced



Detailing – Intermediate Reinforced



Detailing – Special Reinforced



Detailing – Special Reinforced

- Special Walls – Minimum Reinforcement Ratios
  - Vertical: 0.0007 of gross cross sectional area
  - Horizontal:
    - Running Bond: 0.0007
    - Not Laid in Running Bond: 0.0015
  - Total: 0.002

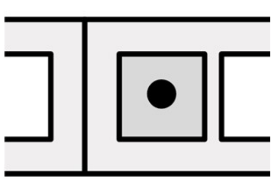
Reinforcement Ratio	6 in. wall		8 in. wall		12 in. wall	
	A_s (in.^{2}/ft)	Possibilities	A_s (in.^{2}/ft)	Possibilities	A_s (in.^{2}/ft)	Possibilities
0.0007	0.047	No. 4 @ 48 in.	0.064	No. 4 @ 32 in. No. 5 @ 48 in.	0.098	No. 4 @ 24 in. No. 5 @ 32 in. No. 6 @ 48 in.
0.0010	0.068	No. 4 @ 32 in. No. 5 @ 48 in.	0.092	No. 4 @ 24 in. No. 5 @ 40 in. No. 6 @ 48 in.	0.140	No. 4 @ 16 in. No. 5 @ 24 in. No. 6 @ 32 in.
0.0013	0.088	No. 4 @ 24 in. No. 5 @ 40 in.	0.119	No. 4 @ 16 in. No. 5 @ 32 in. No. 6 @ 40 in.	0.181	No. 4 @ 8 in. No. 5 @ 16 in. No. 6 @ 24 in.

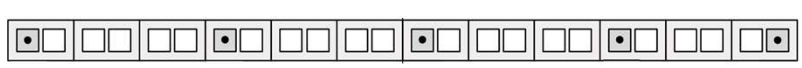
In-Plane Wall Design

- Axial Design (done as part of out-of-plane)
- Flexure + Axial Design
- Shear Design
- Shear Friction Design

Flexure + Axial Design

- Same concepts as Session 3
- No second order effects
- Partially grouted
- Distributed reinforcing (multiple layers)

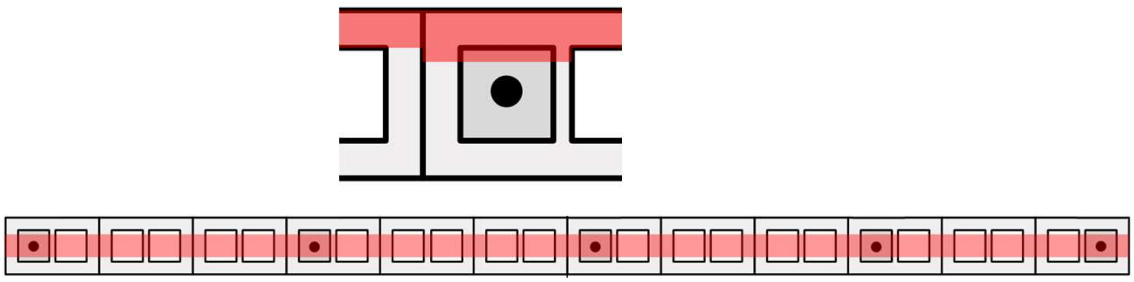




Flexure + Axial Design

Partially Grouted

- Out-of-Plane – Explicitly accounted for
- In-Plane – Approximate with equivalent thickness



Flexure + Axial Design

Partially Grouted – Equivalent thickness

Table 6.2-1 Equivalent Thickness (in.) for Partially Grouted Walls, 8 in. Module

Grout Spacing	Nominal Wall Thickness (in.)			
	6	8	10	12
48 in.	2.62	3.39	3.74	4.09
40 in.	2.75	3.57	3.99	4.41
32 in.	2.94	3.83	4.37	4.89
24 in.	3.26	4.28	4.98	5.68
16 in.	3.88	5.17	6.23	7.28

Table 6.2-2 Equivalent Thickness (in.) for Partially Grouted Walls, 6 in. Module

Grout Spacing	Nominal Wall Thickness (in.)	
	6	8
48 in.	2.44	3.13
42 in.	2.53	3.25
36 in.	2.58	3.33
30 in.	2.70	3.50
24 in.	2.88	3.75
18 in.	3.17	4.17
12 in.	3.75	5.00

Tables from TMS "Strength Design of Masonry"

Flexure + Axial Design

- Methods for flexural + axial design with distributed reinforcing
  - Approximate
    - Lumped reinforcement
    - Smeared reinforcement
  - Exact (strain compatibility analysis)

- Commercial software / spreadsheets commonly used

Flexure + Axial Design

Lumped Reinforcement Model

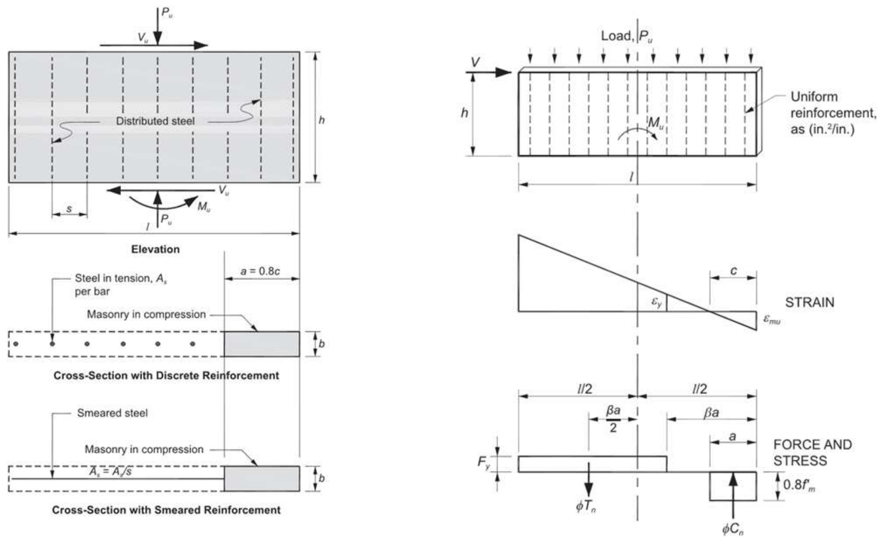
- Estimate area of steel required if single layer (Session 3)
  - Assume d = 0.9 d_v
  - $A_{s,reqd} \sim \frac{M_u}{0.72\ \ _y d_v} - \frac{P_u}{2f_y}$

- Determine area of distributed reinforcement:

$$A^*_{s,re\ \ 'd} \sim \frac{A_{s,reqd}}{0.6d_v} = \frac{M_u}{0.45f_y d_v^2} - \frac{P_u}{1.2f_y d_v}$$

Flexure + Axial Design

Smeared Reinforcement Model



Flexure + Axial Design

Smeared Reinforcement Model

- Solve quadratic equation for depth of compression block, *a*:

$$\frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

where

$A = (\beta - 1)0.36f'_m t$

$B = 0.36f'_m t d_v - 0.5\beta P_u$

$C = -M_u$

where

$\beta = 2.3$ for Fy = 60, concrete masonry

$\beta = 2.0$ for Fy = 60, clay masonry

Flexure + Axial Design

Smeared Reinforcement Model

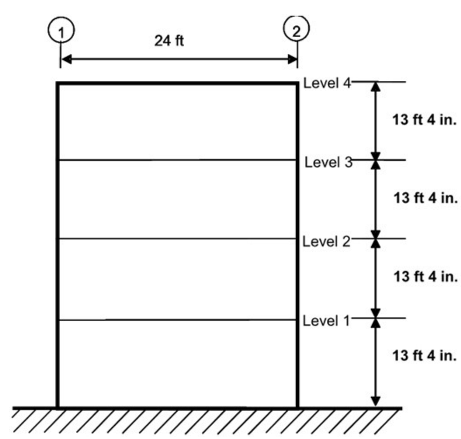
- Solve for required area of steel per inch of wall length:

$$A^*_{s,re\ \ 'd} = \frac{0.72f'_m at - P_u}{\phi f_y (d_v - \beta a)}$$

Flexure + Axial Design - 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”

Flexure + Axial Design - Example

Special Reinforced Clay Masonry Shear Wall

- Estimate reinforcing with lumped model:

$$A^*_{s,req'd} \sim \frac{M_u}{0.45 f_y d_v^2} - \frac{P_u}{1.2 f_y d_v}$$

$$A_{s,reqd} \sim \frac{(2880)(12)}{0.45(60)[(24)(12)]^2} - \frac{166}{1.2(60)(24)(12)}$$

$$A_{s,reqd} \sim 0.0154 - 0.0080 = 0.0074\ in^2/in$$

Flexure + Axial Design - Example

Special Reinforced Clay Masonry Shear Wall

- Estimate reinforcing with smeared reinforcement model:

$$a = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} = \frac{-689 \pm \sqrt{(689)^2 - 4(2.97)(34{,}560)}}{2(2.97)} = 42.4\ in$$

where

$$A = (\beta - 1)0.36 f'_m t = (2 - 1)0.36(3)(2.75) = 2.97\ kip/in$$

$$B = 0.36 f'_m t d_v - 0.5 \beta P_u = 0.36(3)(2.75)(24)(12) - 0.5(2)(166) = 689\ kips$$

$$C = -M_u = 2880(12) = 34{,}560\ kip - in$$

where

$\beta = 2.0$ for Fy = 60, clay masonry

Flexure + Axial Design - Example

Special Reinforced Clay Masonry Shear Wall

- Estimate reinforcing with smeared reinforcement model:

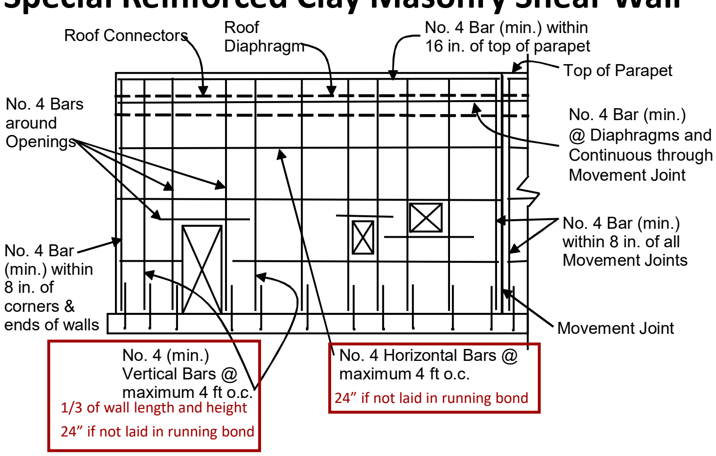
$$A^*_{s,req'd} = \frac{0.72f'_m at - P_u}{\phi f_y(d_v - \beta a)} = \frac{0.72(3)(42.4)(2.75) - 166}{\phi(60)[(24)(12) - 2(42.4)]}$$

$$A^*_{s,re\ \ 'd} = 0.0078\ in^2/in$$

Try #5 @ 42” $= 0.0074\ in^2/in$

Detailing – Special Reinforced

Special Reinforced Clay Masonry Shear Wall



Size: #5 > #4

Spacing: 42” <

- 48”
- 1/3 height = 212”
- 1/3 length = 96”

Steel ratio:

$$\rho = \frac{A_S}{st} = \frac{0.31}{(42)(5.5)} = 0.0013 > 0.0007$$

Flexure + Axial Design - Example

Special Reinforced Clay Masonry Shear Wall

Table 6.2-2 Equivalent Thickness (in.) for Partially Grouted Walls, 6 in. Module

Grout Spacing	Nominal Wall Thickness (in.)	
	6	8
48 in.	2.44	3.13
42 in.	2.53	3.25
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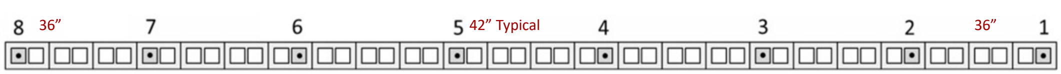
Flexure + Axial Design - Example

Special Reinforced Clay Masonry Shear Wall



- Construct interaction diagram (Session 3)
- Example, c = 57.0 inches

Layer	Distance from comp. face, d_i (inch)	Strain, $\varepsilon_{si} = \varepsilon_{mu} \frac{d_i - c}{c}$	Stress, (ksi)	Force (kip)	Moment arm (in.)
3	81	0.00147	42.7	13.2	-63
4	123	0.00405	60	18.6	-21
5	165	0.00663	60	18.6	21
6	207	0.00921	60	18.6	63
7	249	0.01179	60	18.6	105
8	285	0.01400	60	18.6	141

Flexure + Axial Design - Example

Special Reinforced Clay Masonry Shear Wall

											Nominal Strength		Design Strength	
	c	*C*	*T*(1)	*T*(2)	*T*(3)	*T*(4)	*T*(5)	*T*(6)	*T*(7)	*T*(8)	Moment	Axial	Moment	Axial
	inch	kips	kips	kips	kips	kips	kips	kips	kips	kips	kip-ft	kips	kip-ft	kips
axial compression											0	984	0	886
Points controlled by masonry	201.25	998	0.0	0.00	0.0	0.0	0.0	0.9	7.5	13.1	5,505	977	4,955	879
Balanced	179.12	888	0.0	0.00	0.0	0.0	0.0	4.9	12.2	18.6	5,708	853	5,137	767
Points controlled by steel	142.50	707	0.0	0.00	0.0	0.0	5.0	14.2	18.6	18.6	5,588	650	5,030	585
	114.00	565	0.0	0.00	0.0	2.5	14.1	18.6	18.6	18.6	5,135	493	4,622	444
	85.50	424	0.0	0.00	0.0	13.8	18.6	18.6	18.6	18.6	4,367	336	3,930	302
	71.25	353	0.0	0.00	4.3	18.6	18.6	18.6	18.6	18.6	3,857	256	3,472	230
	57.00	283	0.0	0.00	13.2	18.6	18.6	18.6	18.6	18.6	3,264	176	2,938	159
	42.75	212	0.0	0.00	18.6	18.6	18.6	18.6	18.6	18.6	2,623	100	2,361	90
	28.50	141	0.0	11.6	18.6	18.6	18.6	18.6	18.6	18.6	1,842	18	1,658	16
	22.80	113	0.0	18.6	18.6	18.6	18.6	18.6	18.6	18.6	1,489	-17	1,341	-15
	17.10	85	0.0	18.6	18.6	18.6	18.6	18.6	18.6	18.6	1,188	-45	1,069	-41
	11.40	57	0.0	18.6	18.6	18.6	18.6	18.6	18.6	18.6	876	-74	788	-66
	5.70	28	0.0	18.6	18.6	18.6	18.6	18.6	18.6	18.6	552	-102	497	-92
	5.70	28	0.0	18.6	18.6	18.6	18.6	18.6	18.6	18.6	552	-102	497	-92
	1.43	7	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	84	-142	76	-128
axial tension		0	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	0	-149	0	-134

Flexure + Axial Reinforcing Limits

- Methods to ensure ductility
  - ρ_{max} (Session 2)
  - ~~Provide boundary elements~~
  - Demonstrate boundary elements aren't required

- Suggested order (easiest to hardest)
  - Compression stress check (TMS 9.3.6.6.4)
  - Screening checks (TMS 9.3.6.6.1)
  - If special wall with inelastic drift less than 0.5%, compression strain check (TMS 9.3.6.6.3)
  - Else, ρ_{max} (TMS 9.3.3.2)

Flexure + Axial Reinforcing Limits

- Compression Stress Check (TMS 9.3.6.6.4)
  - ρ_{max} need not be checked if boundary zone provisions met
  - Boundary zone not required if:
    $$\frac{P_u}{A_g} + \frac{M_u}{S_g} < 0.2f'_m$$
  - Note: assumes linear elastic behavior and gross section properties
    - Recommend using net section properties for partially grouted walls
  - P_u, M_u from strength level load cases

Flexure + Axial Reinforcing Limits

- Screening Checks (TMS 9.3.6.6.1)
  - ρ_{max} need not be checked if boundary zone provisions met
  - Boundary zone not required if:
    - Axial Load
      $P_u \leq 0.10A_g f'_m$ for geometrically symmetrical sections
      $P_u \leq 0.05A_g f'_m$ for geometrically **unsymmetrical** sections
    - And either
      $\frac{M_u}{V_u d_v} \leq 1.0$

      Or

      $\frac{M_u}{V_u d_v} \leq 3.0$ and $V_u \leq 3A_{nv}\sqrt{f'_m}$

Recommend net area for partially grouted walls

Flexure + Axial Reinforcing Limits

- Compression Strain Check (TMS 9.3.6.6.3)
  - ρ_{max} need not be checked if boundary zone provisions met
  - Boundary zone not required if:
    - The axial force from the load combination 1.2D + E_v + E_h + L + 0.2S is less than the axial capacity, P_n, of the wall when the neutral axis is located at c_{target}.

$$c_{target} = \frac{l_w}{600(\frac{C_d \delta_{ne}}{h_w})}$$

    - Note: Unlike ρ_{max}, unconfined compression steel cannot be relied upon when using this method.

Flexure + Axial Reinforcing Limits

- ρ_{max} Check (TMS 9.3.3.2)

Table 6.3.4-1 Required α Based on Element Type

Element Type	Yield stain multiplier, α	
	$M_u/V_u d_v < 1$	$M_u/V_u d_v \geq 1$
Other Than Shear Walls	No Limit	1.5
Detailed Plain and Ordinary Reinforced Shear Walls	1.5	1.5
Intermediate Reinforced Shear Walls	1.5	3.0
Special Reinforced Shear Walls	1.5	4.0

Flexure + Axial Reinforcing Limits

- ρ_{max} Check (TMS 9.3.3.2)
  - If wall is fully grouted, and reinforcement is:
    - Uniformly distributed, maximum reinforcement per unit length is:

$$\frac{A_s}{d_v} = \frac{0.64f'_m b\left(\frac{\varepsilon_{mu}}{\varepsilon_{mu} + \alpha\varepsilon_y}\right) - \frac{P}{d_v}}{f_y\left(\frac{\alpha\varepsilon_y - \varepsilon_{mu}}{\varepsilon_{mu} + \alpha\varepsilon_y}\right)}$$

    - Concentrated at ends and symmetric, ρ_{max} is:

$$\frac{A_s}{bd} = \frac{0.64f'_m\left(\frac{\varepsilon_{mu}}{\varepsilon_{mu} + \alpha\varepsilon_y}\right) - \frac{P}{bd}}{f_{y-min}\left(\varepsilon_{mu} - \frac{d'}{d}(\varepsilon_{mu} + \alpha\varepsilon_y), \varepsilon_y\right)E_s}$$

    - P is from load combination D + 0.75L + 0.525Q_E

Flexure + Axial Reinforcing Limits

- ρ_{max} Check (TMS 9.3.3.2)
  - Else
    - Determine greatest neutral axis depth for which strain limits can be met:

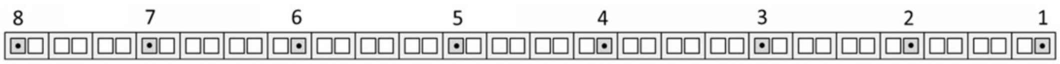
Table 6.3.4-2 Ratio of Depth to Neutral Axis to Distance to Extreme Tension Reinforcement

α	c/d_t, CMU	c/d_t, Clay
1.5	0.446	0.530
3	0.287	0.360
4	0.232	0.297

    - Solve for P_n for that neutral axis location, using steel in compression.
    - If $P_n \geq P$ from D + 0.75L + 0.525Q_E

Flexure + Axial Limits Example

Special Reinforced Clay Masonry Shear Wall (continued)



- (8) #5
- Maximum P_u = 351 kips
- M_u = 2,880 kip-ft
- P for D + 0.75L + 0.525Q_E = 276 kips

Examples 6.3.4.5 and 6.3.4.6 TMS "Strength Design of Masonry" (continued)

Flexure + Axial Limits Example

Special Reinforced Clay Masonry Shear Wall (continued)

- Compression Stress Check (TMS 9.3.6.6.4)
  - ρ_{max} need not be checked if boundary zone provisions met
  - Boundary zone not required if:

$$\frac{P_u}{A_n} + \frac{M_u}{S_n} < 0.2f'_m$$

$$\frac{351}{(288)(2.53)} + \frac{(2880)(12)}{\frac{1}{6}(2.53)(288)^2} = 1.47\ ksi > 0.2(3) = 0.6\ ksi \text{ NG}$$

  - Note: Used max P_u, net properties

Examples 6.3.4.5 and 6.3.4.6 TMS "Strength Design of Masonry" (continued)

Flexure + Axial Limits Example

Special Reinforced Clay Masonry Shear Wall (continued)

- Screening Checks (TMS 9.3.6.6.1)
  - ρ_{max} need not be checked if boundary zone provisions met
  - Boundary zone not required if:
    - Axial Load

      $P_u = 351\ kips > 0.10 A_n f'_m = (0.10)(288)(2.53)(3) = 218\ kips$ NG

Flexure + Axial Limits Example

Special Reinforced Clay Masonry Shear Wall (continued)

- ρ_{max} Check (TMS 9.3.3.2)
  - Wall is partially grouted – can't use equations.

Table 6.3.4-2 Ratio of Depth to Neutral Axis to Distance to Extreme Tension Reinforcement

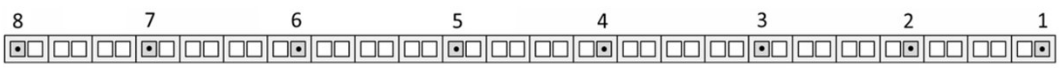
α	c/d_t, CMU	c/d_t, Clay
1.5	0.446	0.530
3	0.287	0.360
4	0.232	0.297

  - c = 0.297 (285) = 84.6 inches

Flexure + Axial Limits Example

Special Reinforced Clay Masonry Shear Wall (continued)

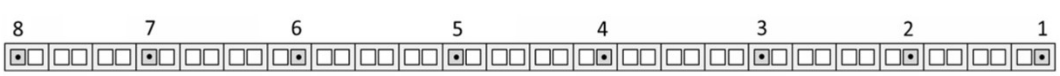
- ρ_{max} Check (TMS 9.3.3.2)
  - Check stresses and strains on first few bars
    - Bar 1: Bar is in compression. $\varepsilon_1 = \frac{84.6-3}{84.6} 0.0035 = 0.0030$. Yielded at 60 ksi.
    - Bar 2: Bar is in compression. $\varepsilon_1 = \frac{84.6-39}{84.6} 0.0035 = 0.0019$. 55 ksi
    - Bar 3: Bar is in compression. $\varepsilon_1 = \frac{84.6-81}{84.6} 0.0035 = 0.0001$. 4.3 ksi
    - Bar 4: Bar is in tension. $\varepsilon_1 = \frac{123-84.6}{84.6} 0.0035 = 0.0016$. 46.1 ksi
    - Bars 5-8: Yielded in tension.



Flexure + Axial Limits Example

Special Reinforced Clay Masonry Shear Wall (continued)

- ρ_{max} Check (TMS 9.3.3.2)
  - Sum forces to determine P_n
    - Compression
      - Masonry: $C_m = 0.64f'_m bc = 0.64(3)(2.53)(84.6) = 411$ kips
      - Steel: $C_s = A_s \sum(f_s - f_m) = 0.31[(60 - 2.4) + (55 - 2.4) + 4.3] = 35.5\ kips$
    - Tension: $C_s = A_s \sum(f_s) = 0.31[(46.1) + 4(60)] = 88.7\ kips$
  - 411 + 35.5 – 88.7 = 358 kips > 276 kips OK



Shear Design

- Shear Capacity
  - Same concepts/equation as Session 2
  - Partially grouted shear walls: γ_g =0.75
- Shear Demands
  - Special walls: Shear Capacity Design
- Detailing
  - Joint reinforcing: Minimum area of steel
  - 180 degree hook required at ends of walls
  - Special walls: Special provisions

Shear Design - Capacity

$$V_n = (V_{nm} + V_{ns})\gamma_g$$

$$V_{nm} = \left[4.0 - 1.75\frac{M_u}{V_u d_v}\right] A_{nv}\sqrt{f'_m} + 0.25P_u$$

$$V_{ns} = 0.5\left(\frac{A_v}{s}\right) f_y d_v$$

$\frac{M_u}{V_u d_v} \geq 1.0$:

$$V_n = (4A_{nv}\sqrt{f'_m})\,\gamma_g$$

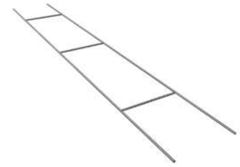
$\frac{M_u}{V_u d_v} \leq 0.25$:

$$V_n = (6A_{nv}\sqrt{f'_m})\gamma_g$$

- d_v = actual depth of masonry
- A_{nv} = net shear area = bd_v
- γ_g = 0.75 (partially grouted walls only)
- ϕ= 0.8
- $\frac{M_u}{V_u d_v} \leq 1.0$
- Interpolate as required

Shear Design - Detailing

- Minimum quantities of joint reinforcing used to resist shear (TMS 9.3.3.4)
  - SDC A, B: (2) 3/16” wires @ 16” on center
  - SDC C+:
    - Partially grouted: (2) 3/16” wires @ 8” on center
    - Fully grouted: (4) 3/16” wires @ 8” on center
  - SDC D: Special wall required, joint reinforcing can not be used to resist shear
    - “Horizontal reinforcement required to resist in-plane shear . . . shall be embedded in grout.” (TMS 7.3.2.6 (b))



Figures from Wire-Bond

Shear Design - Detailing

- Terminating shear reinforcement (TMS 6.1.7.1)
  - Wall ends: “shall be bent around the edge vertical reinforcing bar with a 180-degree standard hook.”
  - Wall intersections: “shall be bent around the edge vertical reinforcing bar with a 90-degree standard hook and shall extend horizontally into the intersecting wall a minimum distance at least equal to the development length.”
  - Joint Reinforcement:

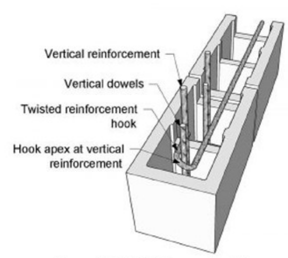
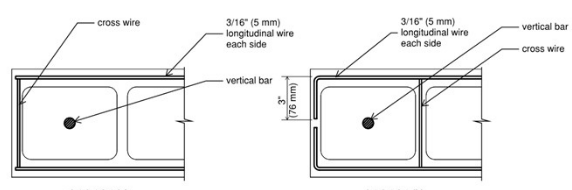


Figure 6.2.4-1 180-Degree Hook in Shear Reinforcement at End of Wall (Baltimore and Chandler, 2019).



Shear Design – Special Walls Demand

- Shear Capacity Design (TMS 7.3.2.6.1.1)
  - Either:
    - Ensure plastic hinge: $\phi V_n > \frac{1.25 \quad {}_{n}}{M_u} V_u$, or
    - Design for essentially elastic response: $V_n \geq 2.5V_u$
  - Note, M_n:
    - Must be an upper bound; use largest P_u associated with V_u
    - Must include all reinforcing contributing to capacity
  - Often $2.5V_u$ is not much greater; much easier to calculate.

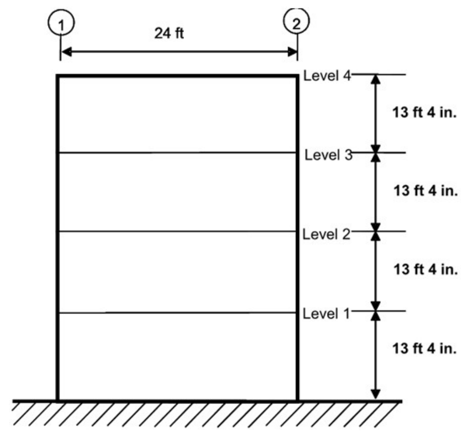
Shear Design – Special Walls Detailing

- Special Shear Wall Detailing (TMS 7.3.2.6.1.1)
  - If reinforcing is required to resist shear, then
    - Spacing, minimum of:
      - 1/3 wall height
      - 1/3 wall length
      - 48" for running bond
      - 24" for non laid in running bond:
    - Joint reinforcing not permitted (shall be embedded in grout)
    - Vertical reinforcement must be at least 1/3 of shear reinforcement
    - 180-degree hook in Chapter 6 controls over "standard hook"

Shear Design - Example

Special Reinforced Clay Masonry Shear Wall

- Nominal 6" units (5.5"), 6" module
- Running bond
- Flexural design, partially grouted (8) #5
- f'_m = 3000 psi
- M_u = 2,800 kip-ft
- V_u = 74 kip



Examples 6.3.4.5 and 6.3.4.6 TMS "Strength Design of Masonry"

Shear Design - Example

Special Reinforced Clay Masonry Shear Wall

- Shear Capacity Design (TMS 7.3.2.6.1.1)
  - Design for essentially elastic response: $V_n \geq 2.5V_u = 2.5(74) = 185\ kips$
  - Check upper bound on V_n

$$\frac{M_u}{V_u d_v} = \frac{2880}{(74)(24)} = 1.62 \geq 1.0:$$

$$V_n \leq \left(4A_{nv}\sqrt{f'_m}\right)\gamma_g = 4(2.53)(288)\sqrt{3000}(0.75) = 120 kips \text{ NG}$$

Shear Design - Example

Special Reinforced Clay Masonry Shear Wall

- What to do?
  - Increase f'_m?
  - Increase wall thickness?
  - Fully grout?
- Elected to fully grout
  - Mass increased, V_u = 87 kips
  - Redo flexural design (#5 @ 36"), including ductility checks
  - Minimum P_u = 180 kips

Shear Design - Example

Special Reinforced Clay Masonry Shear Wall

- Shear Capacity Design (TMS 7.3.2.6.1.1)
  - Design for essentially elastic response: $V_n \geq 2.5V_u = 2.5(87) = 218\ kips$
  - Check upper bound on V_n

$$\frac{M_u}{V_u d_v} = \frac{3400}{(87)(24)} = 1.62 \geq 1.0:$$

$$V_n \leq \left(4A_{nv}\sqrt{f'_m}\right)\gamma_g = 4(5.5)(288)\sqrt{3000}(1.0) = 347 kips \text{ OK}$$

Shear Design - Example

Special Reinforced Clay Masonry Shear Wall

- Shear Capacity Design (TMS 7.3.2.6.1.1)
  - Determine V_{nm}

$$V_{nm} = \left[4.0 - 1.75\frac{M_u}{V_u d_v}\right] A_{nv}\sqrt{f'_m} + 0.25P_u$$

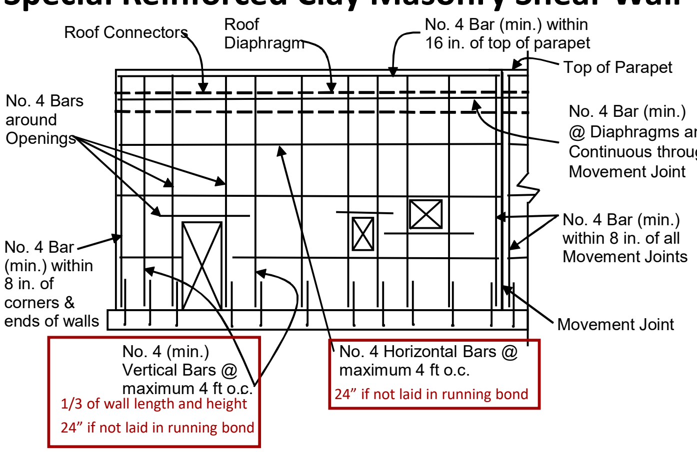
$$V_{nm} = [4.0 - 1.75(1.0)](5.5)(288)\sqrt{3000} + 0.25(180{,}000)$$

$$V_{nm} = 240\ kips$$

No reinforcement is required to resist shear.

Shear Design - Example

Special Reinforced Clay Masonry Shear Wall



#4 @48"?

Horizontal steel ratio:

$$\rho = \frac{A_S}{st} = \frac{0.20}{(48)(5.5)} = 0.0008 > 0.0007$$

Vertical steel ratio:

$$\rho = \frac{A_S}{st} = \frac{0.31}{(36)(5.5)} = 0.0016 > 0.0007$$

Total steel ratio:

$$\rho = 0.0008 + 0.0016 = 0.0024 > 0.0020$$

Shear Friction Design - Capacity

- Shear Friction Design (TMS 9.3.6.5)
  - Check at interfaces (e.g. foundation)

$\frac{M_u}{V_u d_v} \leq 0.50$:

$$V_{nf} = \mu(A_{sp} f_y + P_u) \geq 0$$

$\frac{M_u}{V_u d_v} \geq 1.0$:

$$V_{nf} = 0.42 f'_m A_{nc}$$

- μ = coefficient of friction3
  - 0.7 unfinished concrete
  - 0.7 intentionally roughened concrete
  - 1.0 all other conditions
- A_{sp} = shear friction reinforcement
  - Not additive
- A_{nc} = *bc* (calculate neutral axis depth)
- ϕ= 0.8
- Interpolate as required

Shear Friction Design - Capacity

- Shear Friction Design (TMS 9.3.6.5)
  - Approximation for $\frac{M_u}{V_u d_v} \geq 1.0$:
    - Option 1: Estimate *c* for A_{nc}

$$c \sim \frac{A_s f_y + P_u}{0.64 f'_m t_{sp}}$$

    - Option 2: Use ASD equation

$$V_{nf} = 0.65(0.6 A_{sp} f_y + P_u)$$

- A_s = assume # bars yielded
  - Smaller # is conservative
  - Can assume bars at 2c and further have yielded

Shear Friction Design – Example

Special Reinforced Clay Masonry Shear Wall

- Use approximate option 2, (9) #5 vertical bars:

$$V_{nf} = 0.65(0.6(9)(0.31)(60) + 180) = 182\ kips$$

$$\phi V_{nf} = 0.80 V_{nf} = 0.8(182) = 146\ kips > V_u = 87\ kips\ \text{OK}$$

This concludes The American Institute of Architects Continuing Education Systems Course

The Masonry Society