Architecture 509
Masonry Structures

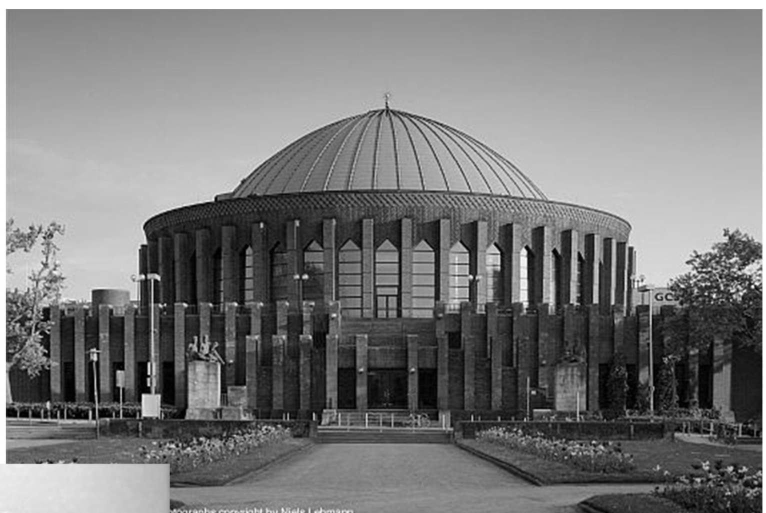
Reinforced Masonry using Strength Design

- Reinforcing requirements
- Wall design for out-of-plane loads
- Wall design for in-plane loads

Rheinhalle
Düsseldorf 1926
Arch.: Wilhelm Kreis

Rheinhalle

Düsseldorf 1926
Gesundheitspflege, soziale Fürsorge und Leibesübungen (GeSoLei) trade fair
Arch.: Wilhelm Kreis
World's largest Planitarium when built

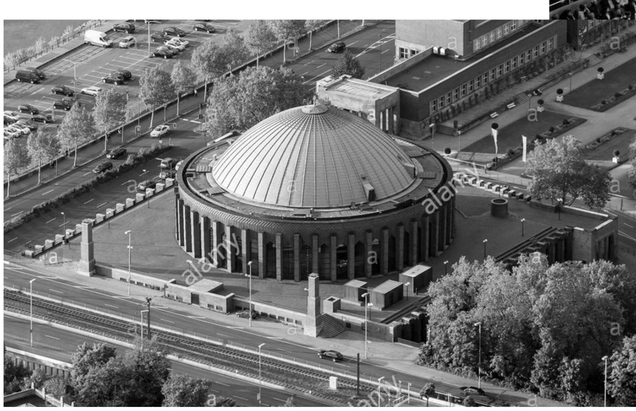


Rheinhalle

Düsseldorf 1926
(GeSoLei) trade fair
Arch.: Wilhelm Kreis
Originally a Planitarium

Rheinhalle

Düsseldorf 1926
(GeSoLei) trade fair
Arch.: Wilhelm Kreis
Converted to a concert hall
in 1970s



TMS 402 Chapter 9.3
Reinforced Masonry

9.3.1 Scope

9.3.2 Design assumptions

9.3.3 Reinforcement requirements and details,
  9.3.3.2 Maximum area of flexural tensile reinforcement

9.3.4 Design of beams and columns

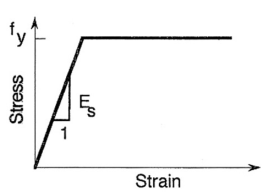
  9.3.4.1.1 nominal axial and flexural strength
  9.3.4.1.2 nominal shear strength

9.3.5 Wall design for out–of–plane loads

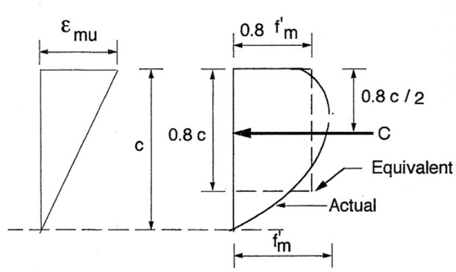
9.3.6 Wall design for in–plane loads

TMS 402 Chapter 9.3.2 Reinforced Masonry

1. Member is straight prismatic section (not in code, but an assumption for our analysis)
2. Plane sections remain plane
3. All masonry in tension is neglected
4. Perfect bond between steel and grout
5. Maximum useable compression strain of masonry
   A. clay masonry: ε_{mu} = 0.0035
   B. concrete masonry: ε_{mu} = 0.0025
6. elasto–plastic stress –strain curve for reinforcement
7. Equivalent rectangular stress block
   A. Masonry stress = $0.8f'_m$
   B. Masonry stress acts over a = 0.8c



(a) Elastoplastic Stress-Strain Relationship for Reinforcement

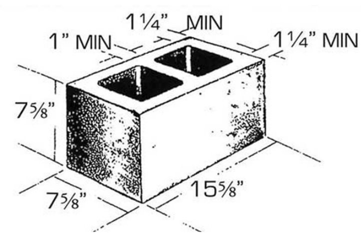


(b) Equivalent Rectangular Stress Relationship for Masonry

TMS 402 Chapter 9.3.3 Reinforced Masonry

Reinforcement:

- Size Limitations (9.3.3.1)
  - Maximum bar size is #9
  - Bar diameter ≤1/8 nominal wall thickness (6.1.2.5)
  - Bar diameter ≤¼ least clear dimension of cell (9.3.3.1)
  - Area ≤4% of cell area (8% at splices) (9.3.3.1)
  - Joint reinforcement min. 3/16” (9.3.3.1)
- Shear Reinforcement (6.1.7.1)
  - Bend around edge reinforcement with a 180°hook
  - At wall intersections, bend around edge reinforcement with a 90°hook and extend horizontally into intersecting wall a minimum of development length
- Bars not allowed to be bundled (9.3.3.3)



TMS 402 Chapter 9.3.3.2 Reinforced Masonry

Minimum and Maximum Requirements

Minimum reinforcement: (9.3.4.2.2.2, 9.3.4.2.2.3)

- Mn ≥ 1.3 x cracking strength
  - or As ≥ (4/3)As,req’d
- Modulus or rupture, f_r= Table 9.1.9.2

Maximum based on ρ = As/bd

Maximum reinforcement: (9.3.3.2)

$$\rho_{\max} = \frac{0.8(0.8)f'_m}{f_y}\left(\frac{\varepsilon_m}{\varepsilon_m + \varepsilon_s}\right)$$

$$\varepsilon_s = 1.5\varepsilon_y$$

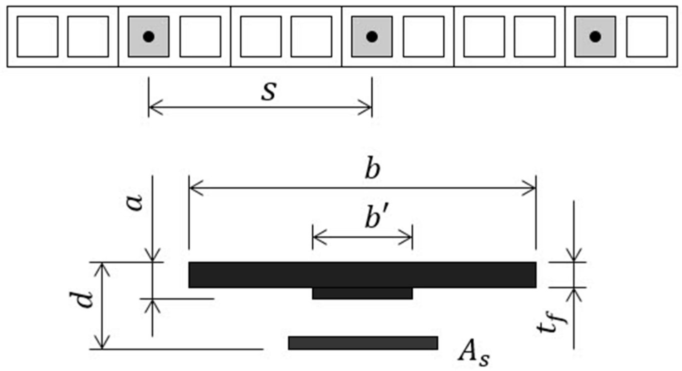
	Grade 60 steel	
	Clay	CMU
ρ_{max}	$0.00565f'_m$ $0.843\rho_{bal}$	$0.00476f'_m$ $0.815\rho_{bal}$
ρ_{max} f'_m = 2 ksi	0.01131	0.00952

f'_m in ksi

TMS 402 Chapter 9.3 Reinforced Masonry

Partially Grouted Walls

b = effective compressive width per bar = min{s, 6t, 72 in.} (5.1.2)
t = nominal thickness
As min. (none) As max. (same as beams)



Neutral axis in flange
- almost always the case
- design for solid section

Neutral axis in web
- design as a T-beam section

Can design based on 1 ft width

TMS 402 Chapter 9.3 Reinforced Masonry

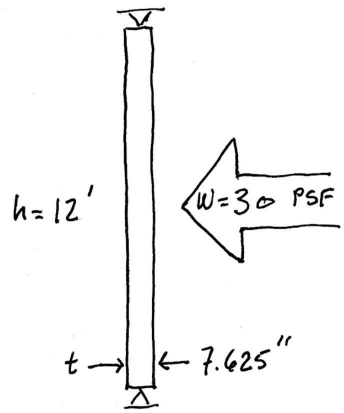
steel areas for
partially grouted walls

Spacing (inches)	Steel Area in.^{2}/ft			
	#3	#4	#5	#6
8	0.16	0.30	0.46	0.66
16	0.082	0.15	0.23	0.33
24	0.055	0.10	0.16	0.22
32	0.041	0.075	0.12	0.16
40	0.033	0.060	0.093	0.13
48	0.028	0.050	0.078	0.11
56	0.024	0.043	0.066	0.094
64	0.021	0.038	0.058	0.082
72	0.018	0.033	0.052	0.073
80	0.016	0.030	0.046	0.066
88	0.015	0.027	0.042	0.060
96	0.014	0.025	0.039	0.055
104	0.013	0.023	0.036	0.051
112	0.012	0.021	0.033	0.047
120	0.011	0.020	0.031	0.044

TMS 402 Chapter 9.3 Reinforced Masonry - example

Given: 8 in. CMU wall
h = 12 ft
Grade 60 steel
f'm = 2000 psi
reinforced at center of wall
Loading: wind load = 30 psf

Required: reinforcing

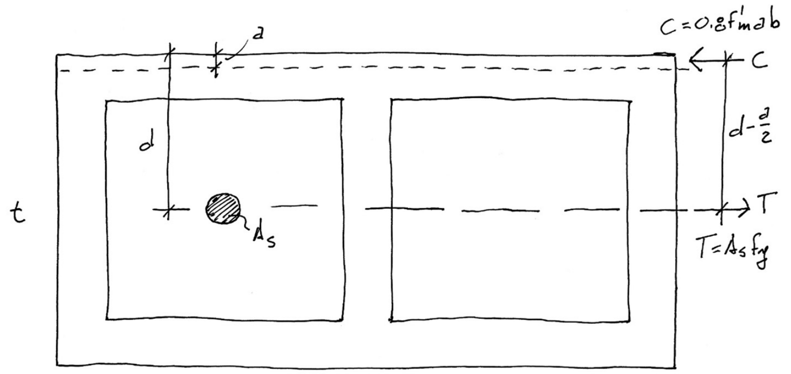


1. Determine Mu

$$M_u = \frac{w_u h^2}{8} = \frac{(30\text{ PSF} \times 1')\,12'^2}{8} = 540\text{ FT-LBS}$$

$$d = \frac{t}{2} = \frac{7.625''}{2} = 3.8125''$$

TMS 402 Chapter 9.3 Reinforced Masonry - example



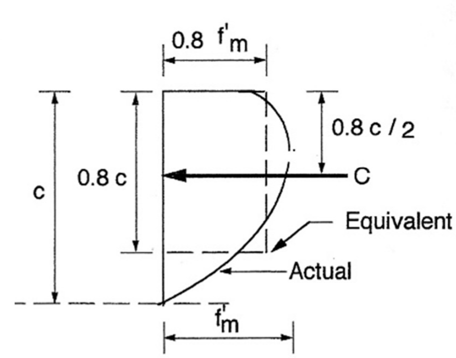
$$M_n = C\left(d - \frac{a}{2}\right)$$

$$C = T$$

$$0.8 f'_m a b = A_s f_y$$

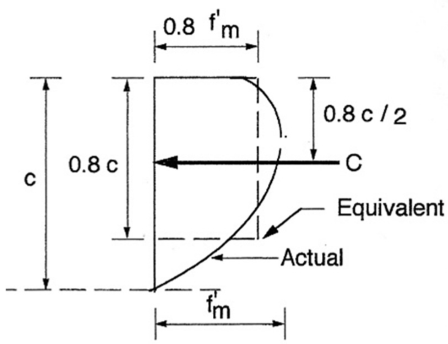
$$a = \frac{A_s f_y}{0.8 f'_m b} \qquad A_s = \frac{M_n}{f_y\left(d - \frac{a}{2}\right)}$$

$$M_u \leq \phi M_n$$



TMS 402 Chapter 9.3 Reinforced Masonry - example

2. Calculate a



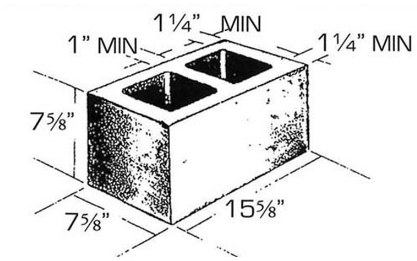
$$a = \frac{A_s f_y}{0.8 f'_m b} \qquad A_s = \frac{M_u}{\phi f_y \left(d - \frac{a}{2}\right)}$$

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

$$a = 3.81'' - \sqrt{3.81''^2 - \frac{2(540\ \text{'-\#})(12''/')}{0.9(0.8)2000\text{psi}(12'')}}$$

$$a = 3.81 - \sqrt{14.535 - \frac{12960}{17280}} = 3.81 - \sqrt{13.785}$$

$$a = 3.81 - 3.713 = 0.0997''$$



TMS 402 Chapter 9.3 Reinforced Masonry - example

3. Calculate As required

4. Determine As used

5. Check ρ max

$$A_{s\,REQD} = \frac{0.8 f'_m a b}{f_y} = \frac{0.8(2000^{psi})(0.0997'')(12'')}{60000\ psi}$$

$$A_{s\,REQD} = 0.0319\ in^2/FT$$

USE #4 @ 72" o.c. = $0.033\ in^2/FT$

$$\rho = \frac{A_s}{bd} = \frac{0.033''/'}{12''(3.8125'')} = 0.00072$$

$$\rho_{max} = 0.00952 > 0.00072 \therefore OK$$

Spacing (inches)	Steel Area in.^{2}/ft			
	#3	#4	#5	#6
8	0.16	0.30	0.46	0.66
16	0.082	0.15	0.23	0.33
24	0.055	0.10	0.16	0.22
32	0.041	0.075	0.12	0.16
40	0.033	0.060	0.093	0.13
48	0.028	0.050	0.078	0.11
56	0.024	0.043	0.066	0.094
64	0.021	0.038	0.058	0.082
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88	0.015	0.027	0.042	0.060
96	0.014	0.025	0.039	0.055
104	0.013	0.023	0.036	0.051
112	0.012	0.021	0.033	0.047
120	0.011	0.020	0.031	0.044

TMS 402 Chapter 9.3 Reinforced Masonry - example

6. Check effective compressive width

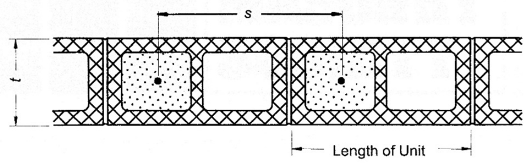
5.1.2 *Effective compressive width per bar*

5.1.2.1 For masonry not laid in running bond and having bond beams spaced not more than 48 in. (1219 mm) center-to-center, and for masonry laid in running bond, the width of the compression area used to calculate member capacity shall not exceed the least of:

(a) Center-to-center bar spacing.

(b) Six multiplied by the nominal wall thickness.

(c) 72 in. (1829 mm).



For masonry not laid in running bond with bond beams spaced less than or equal to 48 in. (1219 mm) and running bond masonry, *b* equals the lesser of:

- $b = s$
- $b = 6t$
- b = 72 in. (1829 mm)

For masonry not laid in running bond with bond beams spaced greater than 48 in. (1219 mm), *b* equals the lesser of:

- $b = s$
- b = length of unit

$$6t = 6(8) = 48''$$

scale b

$$b = \frac{48}{72}(12) = 8''$$

TMS 402 Chapter 9.3 Reinforced Masonry - example

7. Recalculate a and As

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

$$a = 3.81'' \sqrt{3.81^2 - \frac{2(540)(12)}{0.9(0.8)(2000)(8)}}$$

$$a = 0.1531 \text{ in}$$

$$A_{s\,REQD} = \frac{0.8 f'_m b a}{f_y} = \frac{0.8(2^{ksi})8''/1(0.1531)}{60^{ksi}}$$

$$A_{s\,REQD} = 0.0326 \text{ in}^2/\text{FT}$$

Spacing (inches)	Steel Area in.²/ft			
	#3	#4	#5	#6
8	0.16	0.30	0.46	0.66
16	0.082	0.15	0.23	0.33
24	0.055	0.10	0.16	0.22
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8. Check ρ max …

TMS 402 Chapter 9.3 Reinforced Masonry example

Horizontal spanning masonry between bars:

- Some treat as unreinforced masonry, although debate as to whether you can mix unreinforced and reinforced masonry.
- There is arching occurring, so not truly a simply supported flexural member between vertical bars.
- Can use joint reinforcement

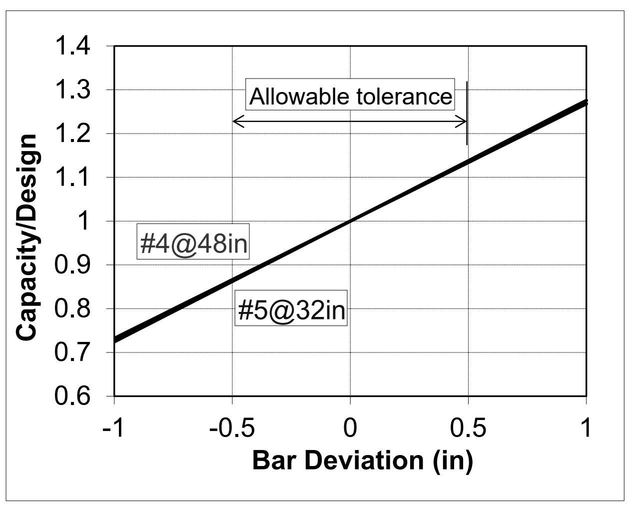
Wire Size	d_b (in.)	A_s (in.^{2})	Spacing (in.)	ϕM_n (kip-ft/ft) 8 in. CMU	ϕM_n (kip-ft/ft) 12 in. CMU
W1.7 (9 gage)	0.148	0.017	8	0.921	1.456
			16	0.462	0.730
W2.8 (3/16)	0.187	0.028	8	1.506	2.388
			16	0.841	1.198

TMS 402 Chapter 9.3 Reinforced Masonry example

Placement tolerances: (3.4.B.11)

- d ≤ 8 in. ± 1/2 in.
- 8 in. < d ≤ 24 in. ± 1 in.
- d > 24 in. ± 1 1/4 in.

- Along wall: ± 2 in.



8 in. CMU; f'_m=2000 psi; Grade 60