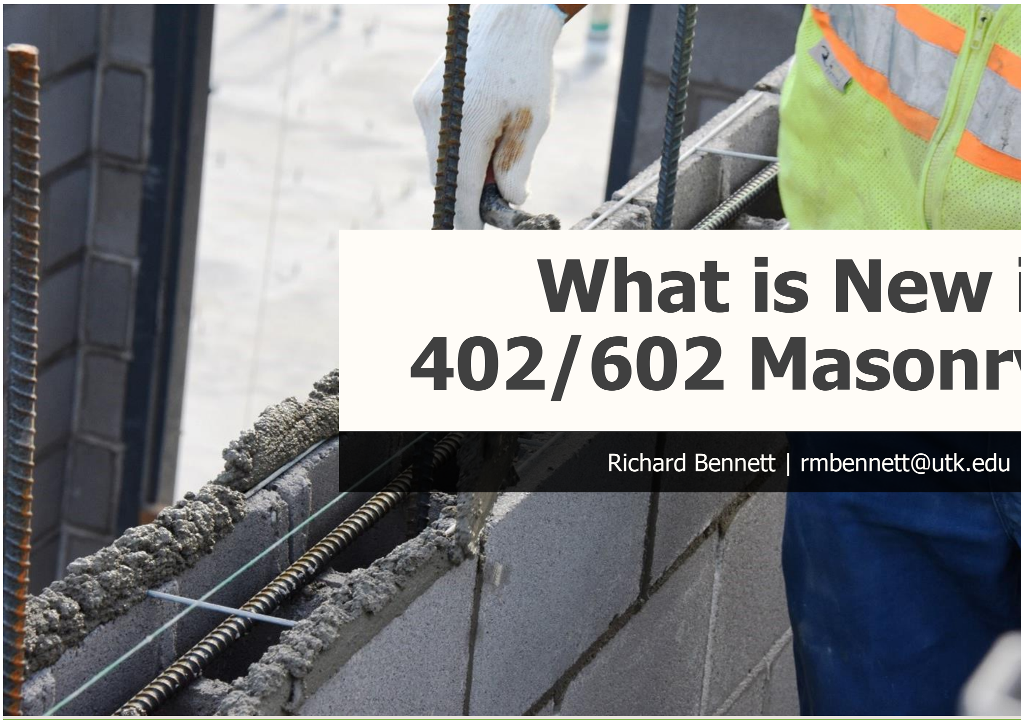

What is New in TMS 402/602 Masonry Code

Richard Bennett | rmbennett@utk.edu

NCSEA
National Council of Structural Engineers Associations

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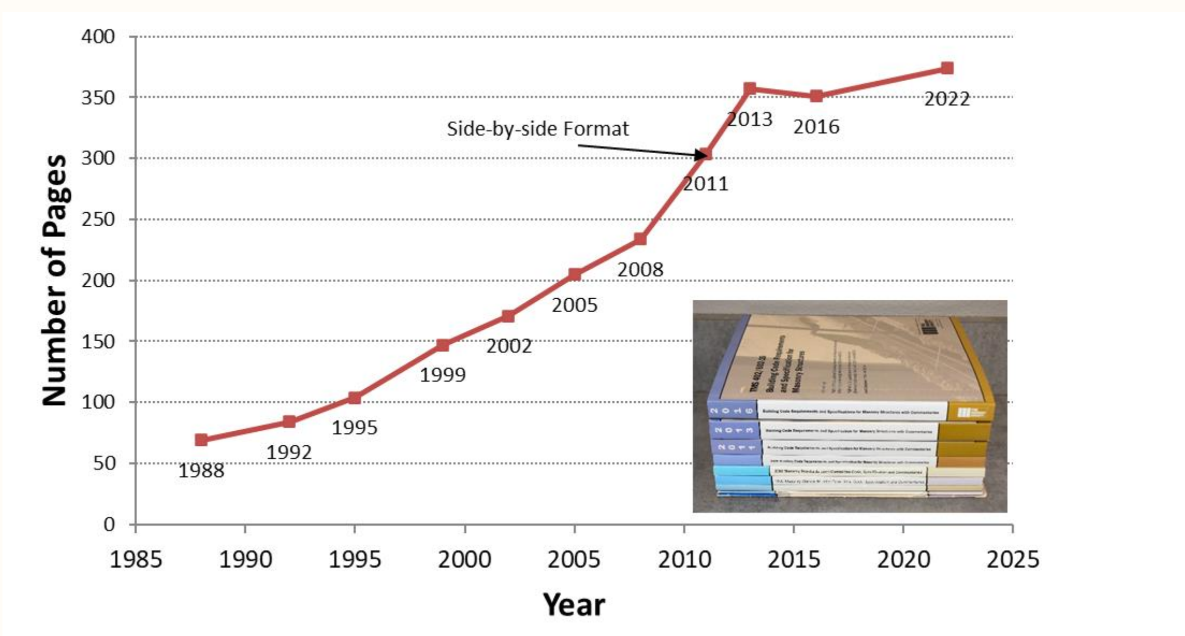


2

- Tension and compression-controlled sections in strength design
- Veneer chapter completely rewritten
- New Appendix on GFRP reinforcement

Changes by Chapter

Chapter	Name	Minor	Moderate	Major	Extreme
1	General Requirements	●			
2	Notations/Definitions	●			
3	Quality & Construction		●		
4	General Analysis & Design		●		
5	Structural Members		●		
6	Reinforcement, Metal Accessories & Anchor Bolts			●	
7	Seismic Design Requirements			●	
8	Allowable Stress Design		●		
9	Strength Design			●	
10	Prestressed Masonry	●			
11	Autoclaved Aerated Masonry	●			

Changes by Chapter

Chapter	Name	Minor	Moderate	Major	Extreme
12	Design of Masonry Infills (Prev App B)	●			
13	Veneer (Previously Chapter 12)				●
14	Glass Unit Masonry (Previously Ch 13)	●			
15	Partition Walls (Previously Chapter 14)	●			
App A	Empirical Masonry (Deleted)				●
App B	Masonry Infill (Moved to Chapter 12)				
App C	Limit Design	●			
App D	Glass Fiber Reinforced Polymer Reinf			NEW!	
Spec 1	General	●			
Spec 2	Products			●	
Spec 3	Execution		●		

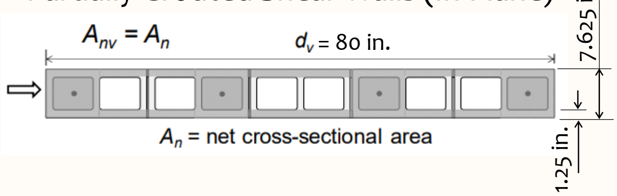
Chapter 4 - General Analysis & Design

New table showing Net Shear Area for partially and fully grouted members (including beams) (4.4.5)

Loading Direction / Member Type	Fully Grouted	Partially Grouted
Out-of-Plane / Wall	$A_{nv} = bd$; b = effective compression width (Section 5.1.2)	$A_{nv} = bd$
In-plane / Planar Shear Wall	$A_{nv} = t_{sp}d_v$	$A_{nv} = A_n$; A_n = net cross-sectional area
In-plane / Flanged Shear Wall	$A_{nv} = t_{sp}d_v$	$A_{nv} = A_n$ of segment of wall that lies parallel to the direction of applied shear
Beams	$A_{nv} = t_{sp}d$	$A_{nv} = 2t_{fs}d$

Net Shear Area

Partially Grouted Shear Walls (In-Plane)



$$A_{nv} = 2t_{fs}d_v + n_{cell}(8\text{ in.})(t_{sp} - 2t_{fs})$$

$$= 2(1.25\ in.)(80 in.) + 4(8\ in.)(7.625\ in. - 2\ (1.25\ in.))$$
$$= 364\ in.^2$$

t_{fs} = face shell thickness
t_{sp} = specified wall thickness

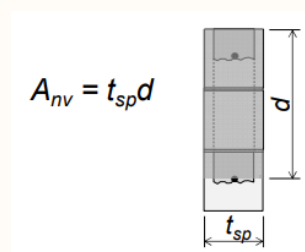
$$A_{nv} = t_{eq}d_v$$

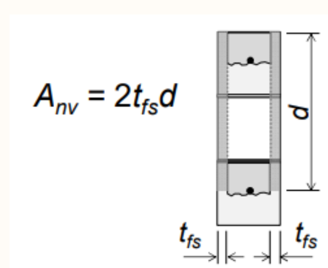
Grout Spacing (in.)	Equivalent Thickness, t_{eq} (in.)	
	8 in.	12 in.
16	5.17	7.28
24	4.28	5.69
32	3.83	4.89
40	3.57	4.41
48	3.39	4.09
72	3.09	3.56

$$A_{nv} = 4.28\ in.(80\ in.) = 342\ in.^2$$

Net Shear Area: Beams

- Clarified A_{nv} for beams is calculated using d, not d_v
- Partially grouted beams are allowed
- Beams need to be fully grouted if shear reinforcement is required





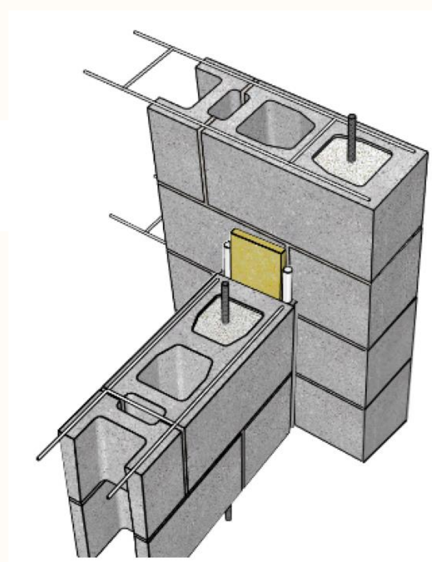
Chapter 5 - Structural Members

- Reorganized for Clarity

2016 TMS 402	2022 TMS 402
5.1 Masonry Assemblies	5.1 General
5.2 Beams	5.2 Walls
5.3 Columns	5.3 Beams
5.4 Pilasters	5.4 Columns
5.5 Corbels	5.5 Pilasters
	5.6 Corbels

Wall Intersections

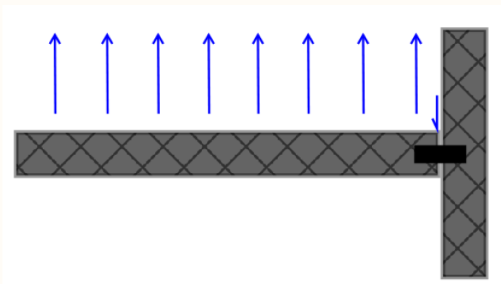
- 5.2 Walls
  - 5.2.1 Independent Walls
    No force transfer

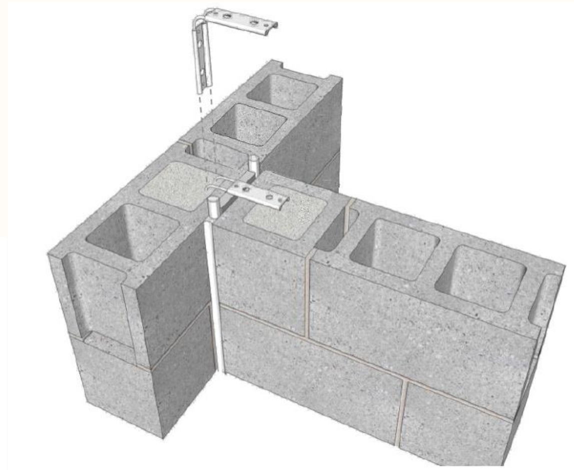


Intersecting Wall Provisions: What Changed in TMS 402-22 and Why, Heather Sustersic, 2022 TMS Annual Meeting

Wall Intersections

- 5.2 Walls
  - 5.2.2 Lateral support for walls without composite action at intersection

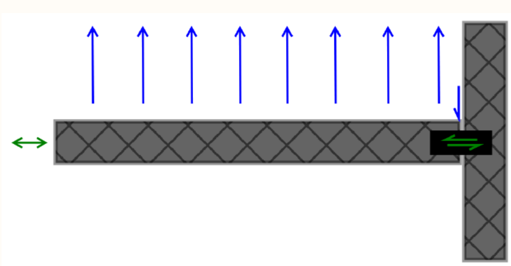


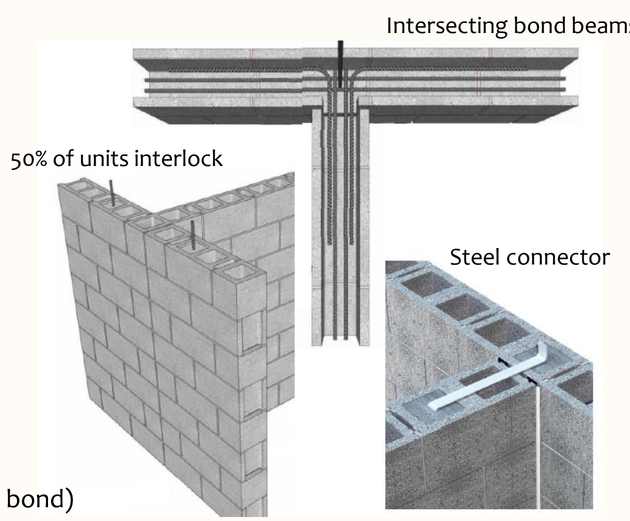


Intersecting Wall Provisions: What Changed in TMS 402-22 and Why, Heather Sustersic, 2022 TMS Annual Meeting

Wall Intersections

- 5.2 Walls
  - 5.2.3 Intersections with composite action





Masonry can be in other than running bond (stack bond) when connected by intersecting bond beams

Intersecting Wall Provisions: What Changed in TMS 402-22 and Why, Heather Sustersic, 2022 TMS Annual Meeting

Chapter 6 - Reinforcement, Metal Access.

- Clarity of Deformed Wire Requirements
- Deformed Bar Size Consistent-ASD/SD
- Size of Reinforcement in Grout
- Hooks for Shear Reinforcement
- Development Length of Hooks

Deformed Wire; Maximum Bar Size

- Clarity of Deformed Wire Requirements (6.1 Various)
- Deformed Bar Size Consistent-ASD/SD (6.1.3.2.1)
  - Maximum bar size No. 11
  - 2016 requirements
    - No. 11 in ASD
    - No 9 in SD

Deformed Wire Properties

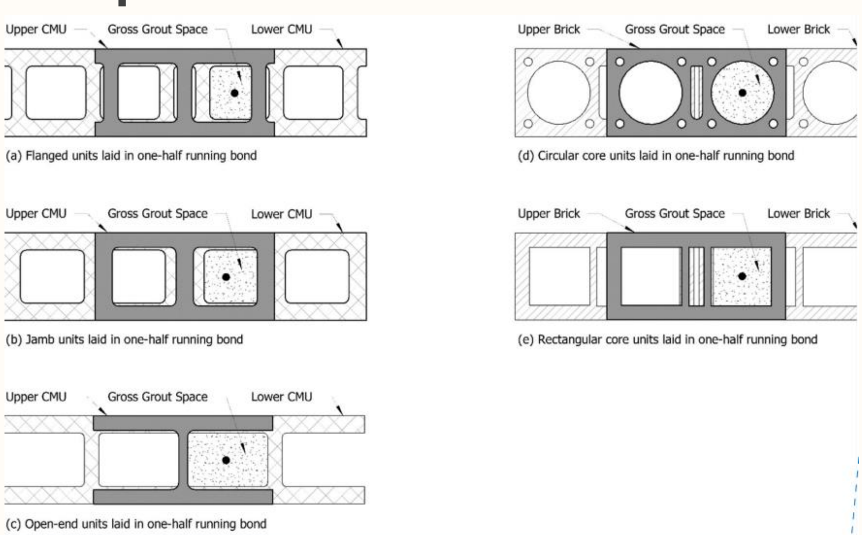
Designation	Nominal Diameter (inch)	Nominal Area, in.^{2}
D 1	0.113	0.010
D 2	0.160	0.020
D 3	0.195	0.030
D4	0.226	0.040
D 5	0.252	0.050
D 6	0.276	0.060
D 7	0.299	0.070
D 11	0.374	0.110
D 20	0.505	0.200
D 31	0.628	0.310

Size of Reinforcement in Grout

- 2016: Differing requirements in ASD and Strength Design
- 2022: Harmonized to four requirements (Chapter 6).
  - maximum size No. 11 (6.1.3.2.1)
  - one-eighth the least nominal member dimension (6.1.3.2.3).
  - one-third the least dimension of the gross grout space (6.1.3.2.4).
  - 4% of the gross grout space for clay and concrete masonry except 8% at laps (6.1.3.2.5).

Gross grout space: area within the continuous grouted cell, core, bond beam course, or collar joint, considering the effect of unit offset in adjacent courses but neglecting possible mortar protrusions and the presence of perpendicular reinforcement, if any.

Gross Grout Space



Maximum Vertical Reinforcement

Table CC-6.1.3.2.5.2.1: One-Half Running Bond Two-Celled Hollow Concrete of Clay Masonry

Nominal Unit Thickness	Maximum Vertical Reinforcement per Cell		
	Flanged Units	Jamb Units	Open-End Units
6 in.	1 - #6 or 2 - #4	1 - #6 or 2 - #5	1 - #6 or 2 - #5
8 in.	1 - #7 or 2 - #5	1 - #8 or 2 - #6	1 - #8 or 2 - #6
10 in.	1 - #8 or 2 - #6	1 - #9 or 2 - #6	1 - #10 or 2 - #7
12 in.	1 - #9 or 2 - #6	1 - #10 or 2 - #7	1 - #11 or 2 - #8

Table CC-6.1.3.2.5.2.1: Stack Bond Two-Celled Hollow Concrete of Clay Masonry

Nominal Unit Thickness	Maximum Vertical Reinforcement per Cell		
	Flanged Units	Jamb Units	Open-End Units
6 in.	1 - #6 or 2 - #5	1 - #6 or 2 - #5	1 - #6 or 2 - #6
8 in.	1 - #8 or 2 - #6	1 - #8 or 2 - #6	1 - #8 or 2 - #7
10 in.	1 - #9 or 2 - #6	1 - #9 or 2 - #6	1 - #10 or 2 - #8
12 in.	1 - #10 or 2 - #7	1 - #11 or 2 - #8	1 - #11 or 2 - #8

Hooks for Shear Reinforcement

2016 TMS 402

6.1.7.1 *Horizontal shear reinforcement*

6.1.7.1.1 Except at wall intersections, the end of a horizontal reinforcing bar needed to satisfy shear strength requirements of Section 9.3.4.1.2 (Strength Design) shall be bent around the edge vertical reinforcing bar with a 180-degree standard hook.

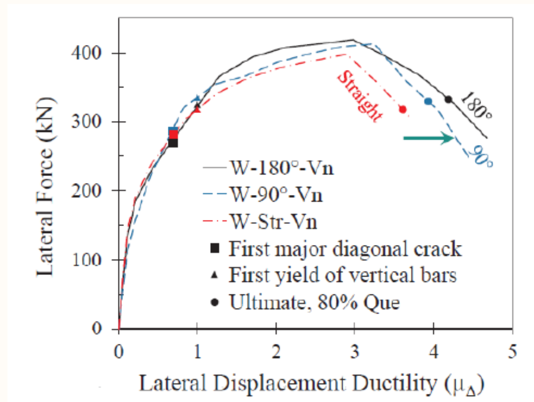
6.1.7.1.2 At wall intersections, horizontal reinforcing bars needed to satisfy shear strength requirements of Section 9.3.4.1.2 (Strength Design) shall be bent around the edge vertical reinforcing bar with a 90- degree standard hook and shall extend horizontally into the intersecting wall a minimum distance at least equal to the development length.

2022 TMS 402

Hooks for Shear Reinf.: The Research

Hoque (2013): The tests showed no significant difference in strength due to changes in the bond beam anchorage type from straight to 180° hooks.

Rizaee (2015): The results of this research and comparisons to past studies showed no beneficial effect of having 180° hooks at the ends of horizontal rebar over having it straight, having 90° hooks, or having studded ends.



Seif ElDin, H.M., and Galal, K. (2017)

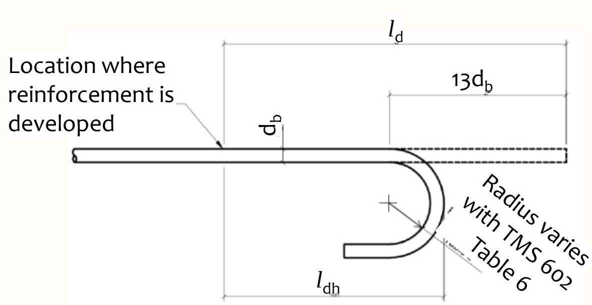
Hooks: Development Length

2016: Equivalent embedment length of $13d_b$

2022: Required development length: $l_{dh} = l_d - \gamma_h d_b$

$\gamma_h = 9.0$ for No. 3 through No. 8 bars

$\gamma_h = 8.0$ for No. 9 through No. 11 bars



Chapter 7 - Seismic Design Requirements

- Exception for Isolating Non-Participating Elements
- Joint Reinforcement Used for Shear
- Shear Capacity Design (Special Reinforced Shear Walls)
- Hooks in Special Reinforced Shear Walls
- Non-participating Element Seismic Steel

Non-Participating Elements

7.3.1 *Nonparticipating elements* — Masonry elements that are not part of the seismic-force-resisting system shall be classified as nonparticipating elements and shall be isolated in their own plane from the seismic-force-resisting system ~~except as required for gravity support~~. Isolation joints and connectors shall be designed to accommodate the design story drift.

Exception was added.

Non-Participating Elements

Exception: Isolation is not required if a deformation compatibility analysis demonstrates that the non-participating element can accommodate the inelastic displacement, Δ, of the structure in a manner complying with the requirements of this Code. Elements supporting gravity loads in addition their self-weight shall be evaluated for gravity load combinations of $(1.2D + 1.0L + 0.15S)$ or $0.9D$, whichever is critical, acting simultaneously with the inelastic displacement and shall have a ductility compatible with the ductility of the lateral force resisting system. The influence of any non-isolated nonparticipating elements on the lateral force resisting system shall be considered in design in accordance with Section 4.1.6 of this code.

Shear Capacity Design: ASD

TMS 402-16

7.3.2.6.1 *Shear capacity design*

7.3.2.6.1.2 When designing special reinforced masonry shear walls in accordance with Section 8.3.5, the calculated shear stress, f_v, or diagonal tension stress resulting from in-plane seismic forces shall be increased by a factor of **1.5**.

TMS 402-22

7.3.2.5.1 *Shear capacity design*

7.3.2.5.1.1 When designing special reinforced masonry shear walls in accordance with Section 8.3.5, the calculated shear stress, f_v, or diagonal tension stress resulting from in-plane seismic forces shall be increased by a factor of **2.0**.

Shear Capacity Design: ASD

TMS 402-16

8.3.5.1.3 The allowable shear stress resisted by the masonry, F_{vm}, shall be calculated using **Equation 8-25 for special reinforced masonry shear** walls and using Equation 8-26 for other masonry:

$$F_{vm} = \mathbf{\frac{1}{4}}\left[\left(4.0 - 1.75\left(\frac{M}{Vd_v}\right)\right)\sqrt{f'_m}\right] + 0.25\frac{P}{A_n}$$

(Equation 8-25)

$$F_{vm} = \frac{1}{2}\left[\left(4.0 - 1.75\left(\frac{M}{Vd_v}\right)\right)\sqrt{f'_m}\right] + 0.25\frac{P}{A_n}$$

(Equation 8-25)

TMS 402-22

8.3.5.1.3 The allowable shear stress resisted by the masonry, F_{vm}, shall be calculated using Equation 8-23:

$$F_{vm} = \mathbf{\frac{1}{2}}\left[\left(4.0 - 1.75\left(\frac{M}{Vd_v}\right)\right)\sqrt{f'_m}\right] + 0.20\frac{P}{A_n}$$

(Equation 8-23)

Shear Capacity Design: SD

TMS 402-16

7.3.2.6.1 *Shear capacity design*

7.3.2.5.1.1 When designing special reinforced masonry shear walls to resist in-plane forces in accordance with Section 9.3, the design shear strength, ϕV_n, shall exceed the shear corresponding to the development of 1.25 times the nominal flexural strength, M_n, of the element, except that the nominal shear strength, $\boldsymbol{V_n}$, need not exceed **2.5** times required shear strength, V_u.

TMS 402-22

7.3.2.5.1 *Shear capacity design*

7.3.2.5.1.2 When designing special reinforced masonry shear walls to resist in-plane forces in accordance with Section 9.3, the design shear strength, ϕV_n, shall exceed the shear corresponding to the development of 1.25 times the nominal flexural strength, M_n, of the element, except that the design shear strength, $\boldsymbol{\phi V_n}$, need not exceed **2.0** times required shear strength, V_u.

Hooks in Shear Reinforcement

TMS 402-16

7.3.2.6 *Special reinforced masonry shear walls*

(d) Shear reinforcement shall be anchored around vertical reinforcing bars with a standard hook.

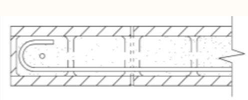
TMS 402-22

7.3.2.5 *Special reinforced masonry shear walls*

(i) When the ratio of V/F_{vm} for masonry designed in accordance with Chapter 8 or when the ratio $V_u/\phi V_{nm}$ for masonry designed in accordance with Chapter 9 exceeds **0.40**, the termination of horizontal reinforcement embedded in grout shall meet one of the following:

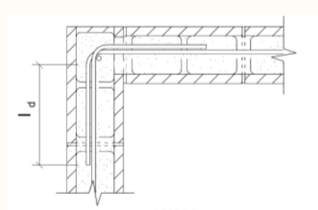
Hooks in Shear Reinforcement

1. Except at wall intersections, the ends of horizontal reinforcement shall be bent around the edge vertical reinforcement with a 180-degree standard hook.



WALL END

2. At wall intersections, horizontal reinforcement shall be bent around the edge vertical reinforcement with a 90-degree standard hook and shall extend horizontally into the intersecting wall a minimum distance at least equal to the development length.



WALL INTERSECTION

Non-Participating Seismic Steel

TMS 402-16

7.4.3 *Seismic Design Category C*

7.4.3.1 *Design of nonparticipating elements* — Nonparticipating masonry elements . . . shall be reinforced in **either the horizontal or vertical direction** . . .

TMS 402-22

7.4.3.1 *Design of nonparticipating elements* — Nonparticipating masonry elements . . . shall be reinforced in **the direction of span** . . .

Horizontal Reinforcement: Joint reinforcement at 16 in. or No. 4 at 48 in.
Vertical Reinforcement: No. 4 at 120 in.

Chapter 8 - Allowable Stress Design

- Masonry Allowable Axial Compressive Force increased from 0.25 to 0.30 (8.3.4.2.1)
- Axial Load Masonry Shear Strength Reduced 0.25 to 0.20 (8.3.5.1.3)
- Beam Shear Force Moved to Chapter 5 to Apply to All Beams

Chapter 8 - Allowable Stress Design

- Masonry Allowable Axial Compressive Force increased from 0.25 to 0.30 (8.3.4.2.1)

$h/r \leq 99 \qquad P_a = (\mathbf{0.30} f'_m A_n + 0.65 A_{st} F_s) \left[1 - \left(\frac{h}{140r}\right)^2\right]$ Equation 8-16

$h/r > 99 \qquad P_a = (\mathbf{0.30} f'_m A_n + 0.65 A_{st} F_s) \left(\frac{70r}{h}\right)^2$ Equation 8-17

- Axial Load Masonry Shear Strength Reduced 0.25 to 0.20 (8.3.5.1.3)

$F_{vm} = \frac{1}{2}\left[\left(4.0 - 1.75\left(\frac{M}{Vd_v}\right)\right)\sqrt{f'_m}\right] + \mathbf{0.20}\frac{P}{A_n}$ Equation 8-23

Chapter 8 - Allowable Stress Design

- Section 8.3.5.4 (Beam Shear) moved to Section 5.3.1.5

~~8.3.5.4~~ 5.3.1.5 *Shear* — In cantilever beams, the maximum shear shall be used. In noncantilever beams, the maximum shear shall be used except that sections located within a distance $d/2$ from the face of support shall be permitted to be designed for the same shear as that calculated at a distance $d/2$ from the face of support when the following conditions are met:

(a) support reaction, in direction of applied shear force, introduces compression into the end regions of the beam, and

(b) no concentrated load occurs between face of support and a distance $d/2$ from face.

Chapter 8 & 9 – ASD & SD

- Anchor Bolt Design changed from Yield to Ultimate Strength (8.1.4.3, 9.1.6.3)
- Partially Grouted Shear Wall Factor Decreased 0.75 to 0.70 (8.2.5.1.2, 9.3.3.1.2)
- Shear Friction Factor Changed from 0.6 to 0.75 (8.3.6); Shear Friction Harmonized (9.3.5.5)

Chapter 8 & 9 – Anchor Bolt Strength

TMS 402-16 Commentary:

9.1.6.3 Anchors conforming to A307, Grade A specifications are allowed by the Code, but the ASTM A307, Grade A specification does not specify a yield strength. **Use of a yield strength of 37 ksi** in the Code design equations for A307 anchors will result in anchor capacities similar to those obtained using the American Institute of Steel Construction provisions.

9.1.6.3.1.1 Steel strength is calculated **using the effective tensile stress area of the anchor** (that is, including the reduction in area of the anchor shank due to threads).

Anchor Bolt Steel Strength

Anchor bolt steel strength changed from being based on f_y to being based on f_u.

	Strength Design	Allowable Stress Design
Tensile Strength	$B_{ans} = A_b f_u \quad \phi = 0.75$ Equation 9-2	$B_{as} = 0.5 A_b f_u$ Equation 8-2
Shear Strength	$B_{vns} = 0.6 A_b f_u \quad \phi = 0.65$ Equation 9-7	$B_{vs} = 0.25 A_b f_u$ Equation 8-7

The value of f_u shall not be taken greater than the smaller of $1.9 f_y$ and 125,000 psi (862 MPa).

Anchor Bolt Steel Strength

TMS 402 6.3.8 Effective Cross-Sectional Area

$$A_b = \frac{\pi}{4}\left(d_o - \frac{0.9743}{n_t}\right)^2$$

d_o = nominal anchor diameter
n_t = number of threads per inch

Bolt size – threads per inch	A_b (in.^{2})
1/2 – 13	0.142
5/8 – 11	0.226
3/4 – 10	0.334
7/8 – 9	0.462
1 – 8	0.606

Chapter 8 & 9 – Grouted Shear Wall Factor

Reinforced Masonry Shear Strength

$F_v = (F_{vm} + F_{vs})\gamma_g$ Equation 8-20

$V_n = (V_{nm} + V_{ns})\gamma_g$ Equation 9-15

γ_g changed from **0.75** to **0.70**
for partially grouted shear walls

Chapter 8 – Shear Friction Strength

Shear Span Ratio	Allowable Shear Friction	
	2016	2022 (8.3.6)
$\frac{M}{Vd_v} \le 0.5$	$F_f = \frac{\mu(A_{sp}F_s + P)}{A_{nv}}$	
$\frac{M}{Vd_v} \ge 1.0$	$F_f = \frac{0.65(\mathbf{0.6}A_{sp}F_s + P)}{A_{nv}}$	$F_f = \frac{0.65(\mathbf{0.75}A_{sp}F_s + P)}{A_{nv}}$

For $0.5 < \frac{M}{Vd_v} < 1.0$

Linear Interpolation

- $\mu = 1.0 \quad F_f = \frac{\left(0.488+1.024\left(1-\frac{M}{Vd_v}\right)\right)A_{sp}F_s+\left(0.65+0.70\left(1-\frac{M}{Vd_v}\right)\right)P}{A_{nv}}$
- $\mu = 0.7 \quad F_f = \frac{\left(0488+0.424\left(1-\frac{M}{Vd_v}\right)\right)A_{sp}F_s+\left(0.65+0.10\left(1-\frac{M}{Vd_v}\right)\right)P}{A_{nv}}$

Chapter 9 – Shear Friction Strength

Shear Span Ratio	Nominal Shear Friction Strength	
	2016	2022 (9.3.5.5)
$\frac{M_u}{V_u d_v} \le 0.5$	$V_{nf} = \mu(A_{sp} f_y + P_u)$	
$\frac{M_u}{V_u d_v} \ge 1.0$	$V_{nf} = 0.42 f'_m A_{nc}$	$V_{nf} = 0.65(0.75 A_{sp} f_y + P_u)$

$0.5 < \frac{M_u}{V_u d_v} < 1.0$

Linear Interpolation

$$\mu = 1.0 \quad V_{nf} = \left(0.488 + 1.024\left(1 - \frac{M_u}{V_u d_v}\right)\right) A_{sp} f_y + \left(0.65 + 0.70\left(1 - \frac{M_u}{V_u d_v}\right)\right) P_u$$

$$\mu = 0.7 \quad V_{nf} = \left(0488 + 0.424\left(1 - \frac{M_u}{V_u d_v}\right)\right) A_{sp} f_y + \left(0.65 + 0.10\left(1 - \frac{M_u}{V_u d_v}\right)\right) P_u$$

Chapter 9 - Strength Design

- Added Compression Controlled Sections for Combinations of Flexure and Axial Load (9.1.4.4)
- Maximum Reinforcement (Except Beams, Intermediate and Special Reinforced Masonry Shear Walls) Deleted
- Modified Cracked Moment of Inertia Formula (Eq 9-28)

Cracked Moment of Inertia: OOP Loading

2016 Equation 9-30 $$I_{cr} = n\left(A_s + \frac{P_u}{f_y}\frac{t_{sp}}{2d}\right)(d-c)^2 + \frac{bc^3}{3}$$

Centered Reinforcement: $$I_{cr} = n\left(A_s + \frac{P_u}{f_y}\right)(d-c)^2 + \frac{bc^3}{3}$$

2022 Equation 9-28 $$I_{cr} = nA_s(d-c)^2 + \frac{nP_u}{f_y}\left(\frac{t_{sp}}{2} - c\right)^2 + \frac{bc^3}{3}$$

Centered Reinforcement: $$I_{cr} = n\left(A_s + \frac{P_u}{f_y}\right)(d-c)^2 + \frac{bc^3}{3}$$

Tension and Compression Controlled Sections

- Motivation
- Provisions
- Design Aids

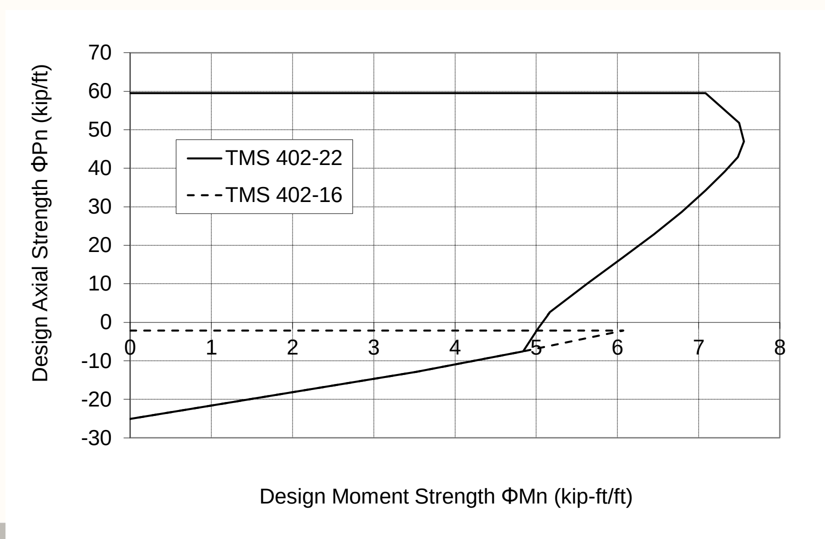
402-16 Maximum Reinforcement (9.3.3.2)

Area of flexural tensile reinforcement ≤ area required to maintain axial equilibrium under the following conditions

- A strain gradient corresponding to ε_{mu} in masonry and $\alpha\varepsilon_y$ in tensile reinforcement
  - α = 1.5 for all except intermediate and special reinforced shear walls with $M_u/(V_u d_v) \geq 1$
- Axial forces from loading combination $D + 0.75L + 0.525Q_E$
- Compression reinforcement, with or without lateral restraining reinforcement, can be included.

Motivation

8 in. CMU wall, f'_m = 2 ksi, Grade 60 No. 5 at 8 in., out-of-plane loading



Requirements

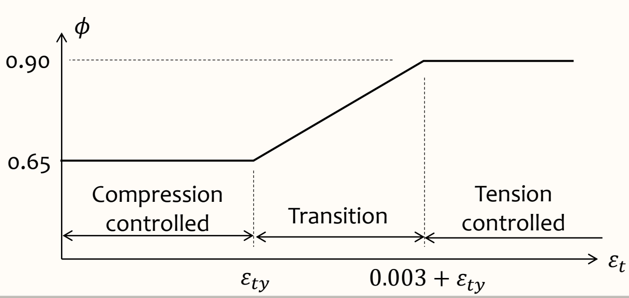
9.1.4.4 *Combinations of flexure and axial load in reinforced masonry* — The value of ϕ for reinforced masonry subjected to flexure, axial load, or combinations thereof shall be in accordance with Table 9.1.4.

9.1.4.4.1 The value of ε_{ty} shall be f_y / E_s. For Grade 60 reinforcement it shall be permitted to take ε_{ty} equal to 0.002.

9.1.4.4.2 In the tension-controlled and transition regions, the value of ϕ for axial load shall be limited so that $\phi P_n \leq 0.65 P_{bal}$, where P_{bal} is determined using a strain gradient corresponding to a strain in the extreme tensile reinforcement equal to ε_{ty} and a maximum strain in the masonry as given by Section 9.3.2(c). {0.0025 for concrete masonry and 0.0035 for clay masonry}

TMS 402 Table 9.1.4

Net Tensile Strain	Classification	Strength-reduction factor, ϕ
$\varepsilon_t \leq \varepsilon_{ty}$	Compression controlled	0.65
$\varepsilon_{ty} < \varepsilon_t < 0.003 + \varepsilon_{ty}$	Transition	$0.65 + 0.25\dfrac{\varepsilon_t - \varepsilon_{ty}}{0.003}$
$\varepsilon_t \geq 0.003 + \varepsilon_{ty}$	Tension controlled	0.90



ε_t = net tensile strain in extreme longitudinal reinforcement

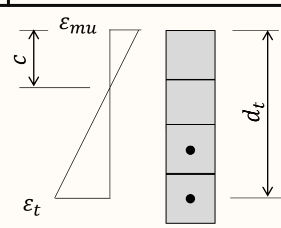
ε_{ty} = value of net tensile strain in extreme layer of longitudinal tension reinforcement used to define a compression-controlled section; yield strain

c/d_t Ratio

Useful for drawing interaction diagram

c/d_t ratio		Strength-reduction factor, ϕ
CMU	Clay	
$c/d_t \geq 0.556$	$c/d_t \geq 0.636$	0.65
$0.333 < c/d_t < 0.556$	$0.412 < c/d_t < 0.636$	$0.65 + \frac{0.25}{0.003}\left(\left(\frac{1}{c/d_t} - 1\right)\varepsilon_{mu} - \varepsilon_{ty}\right)$
$c/d_t \leq 0.333$	$c/d_t \leq 0.412$	0.90

c = depth to neutral axis
d_t = distance from compression surface to furthest longitudinal tension reinforcement



Maximum Reinforcement

- Deleted for out-of-plane, ordinary reinforced shear walls, columns, and pilasters
- Same maximum reinforcement (ductility) requirements for intermediate and special reinforced shear walls
- Beams need to be tension controlled

Beams: Tension Controlled

2016: Strain limit of $1.5\varepsilon_y$

2022: Strain limit of $\varepsilon_{ty} + 0.003 = 2.5\varepsilon_y$ for Grade 60 steel

$$\rho_t = \frac{0.8(0.8)f'_m}{f_y}\left(\frac{\varepsilon_{mu}}{\varepsilon_{mu} + \varepsilon_{ty} + 0.003}\right)$$

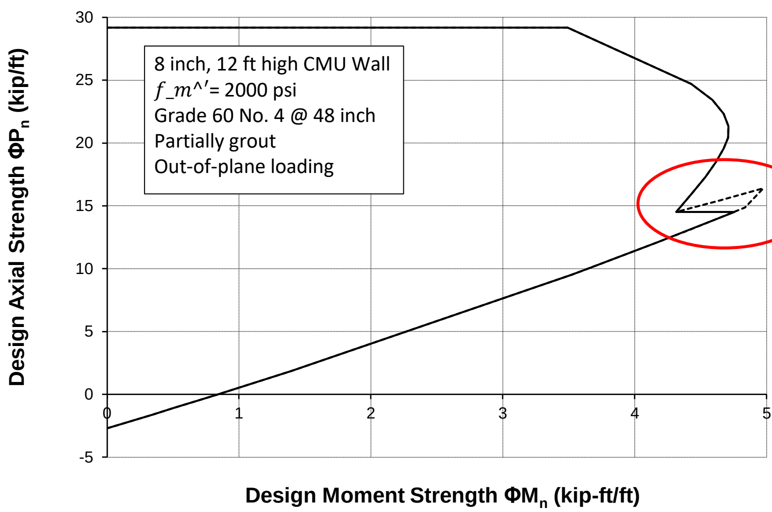
Grade 60 steel, f'_m in ksi

CMU	$\rho_t = 0.00356f'_m$	$\rho_t = 0.00711$ for $f'_m = 2$ ksi	$\rho_t = 0.60\rho_{bal}$
Clay	$\rho_t = 0.00439f'_m$	$\rho_t = 0.0132$ for $f'_m = 3$ ksi	$\rho_t = 0.65\rho_{bal}$

Non-Load-Bearing Walls: Tension Controlled

Masonry	Concrete	Clay
f'_m	2,000 psi	3,000 psi
ρ_t	0.00711	0.01318
Nominal Wall Thickness	Max. reinforcement to be tension controlled (in.²/ft)	
6 in.	0.24	0.44
8 in.	0.32	0.60
10 in.	0.41	0.76
12 in.	0.50	0.92

Partially Grouted Walls: Out-of-Plane



9.1.4.4.2 In the tension-controlled and transition regions, the value of ϕ for axial load shall be limited so that $\phi P_n \leq 0.65 P_{bal}$

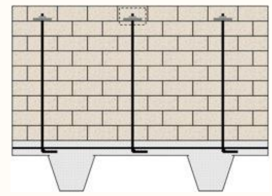
Bearing Walls

Maximum Axial Load, P_u, for Section to be Tension Controlled
Out-of-Plane Loads
Concrete Masonry, f'_m = 2 ksi , Grade 60 Reinforcement,

Bar Size	Bar Spacing					
	8 in.	16 in.	24 in.	32 in.	40 in.	48 in.
	8 in. unit, centered reinforcement					
No. 4	1.2 kip/ft	9.3 kip/ft	12.0 kip/ft	13.3 kip/ft	14.1 kip/ft	14.5 kip/ft
No. 5	-7.7 kip/ft	4.8 kip/ft	9.0 kip/ft	11.1 kip/ft	12.4 kip/ft	13.2 kip/ft
No. 6	-18.2 kip/ft	-0.4 kip/ft	5.5 kip/ft	8.5 kip/ft	10.3 kip/ft	11.4 kip/ft
	12 in. unit, centered reinforcement					
No. 4	10.3 kip/ft	16.2 kip/ft	17.1 kip/ft	16.8 kip/ft	16.5 kip/ft	16.4 kip/ft
No. 5	1.4 kip/ft	11.8 kip/ft	15.0 kip/ft	15.1 kip/ft	15.2 kip/ft	15.3 kip/ft
No. 6	-9.1 kip/ft	6.5 kip/ft	11.6 kip/ft	13.2 kip/ft	13.7 kip/ft	14.0 kip/ft
	12 in. unit, offset reinforcement, d = 11.625 in. – 2.5 in. = 9.125 in.					
No. 4	25.4 kip/ft	24.0 kip/ft	23.2 kip/ft	21.3 kip/ft	20.2 kip/ft	19.4 kip/ft
No. 5	16.5 kip/ft	19.5 kip/ft	20.2 kip/ft	19.7 kip/ft	18.9 kip/ft	18.3 kip/ft
No. 6	6.0 kip/ft	14.3 kip/ft	16.7 kip/ft	17.8 kip/ft	17.4 kip/ft	17.1 kip/ft

Chapter 10 - Prestressed Masonry

- New equation for laterally restrained and unrestrained walls (10-1)
- Added section for Design of Beams and Lintels (10.6)



Chapter 13-Masonry Veneer

- Completely rewritten in 2022
- Anchored veneer
  - Prescriptive provisions simplified
  - Simplified engineered provision
- Adhered veneer
  - Polymer modified mortar required for prescriptive design
  - Provisions expanded and clarified

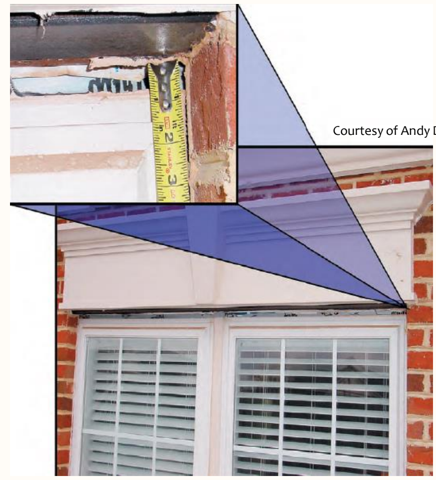
Clay Brick with Wood Frame Backing

TMS 402-16

12.2.2.6.1 Anchored veneer with a backing of wood framing shall not exceed 30 ft, or 38 ft at a gable, in height above the location where the veneer is supported.

TMS 402-22

13.1.2.2.2 *Wood light frame backing* — Exterior veneer tied connected to wood light frame construction exceeding 30 ft, or 38 ft at a gable, in height above the vertical support shall be designed and detailed to accommodate differential movement.



Courtesy of Andy Dalrymple

Vertical Differential Movement at a window head, four story building constructed in 2003

Anchored Veneer – Prescriptive Design

Minimum Permitted Design Method

p_{veneer} (psf)	Permitted Design Method	
	SDC A, B, and C	SDC D and higher
≤ 50	Basic Prescriptive	Enhanced Prescriptive
> 50 and ≤ 75	Enhanced Prescriptive	
> 75	Engineered	

Prescriptive Design

	Basic	Enhanced
Maximum tributary area per tie	2.67 ft^2 (24 in. x 16 in.)	1.78 ft^2 (16 in. x 16 in.)
Maximum spacing	24 in.	16 in.

Anchored Veneer – 2016 Engineered Design

12.2.1 *Alternative design of anchored masonry veneer*

The alternative design of anchored veneer, which is permitted under Section 1.3, shall satisfy the following conditions:

(a) Loads shall be distributed through the veneer to the anchors and the backing using principles of mechanics.

(b) Out-of-plane deflection of the backing shall be limited to maintain veneer stability.

(c) The veneer is not subject to the flexural tensile stress provisions of Section 8.2 or the nominal flexural tensile strength provisions of Section 9.1.9.2.

(d) The provisions of Section 12.1 (General Requirements), Section 12.2.2.9 (Veneer not laid in running bond), and Section 12.2.2.10 (Requirements in seismic areas) shall apply.

Stability of Backing (13.2.1.5)

Deemed to comply (Table 13.2.1.5) or a stability analysis with a factor of safety of 1.5

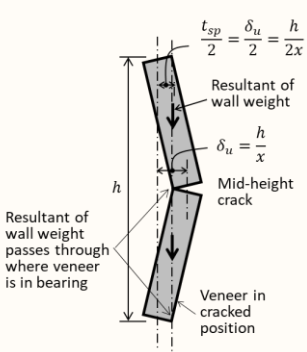


Table 13.2.1.5

h_b/t_{sp}	h_b for $t_{sp} = 3.625$ in.	Maximum Deflection of the Backing for Stability	
		Wind[1], δ_{ser}	Seismic[2], δ_u
67	20.2 ft	h_b / 240	h_b / 100
100	30.2 ft	h_b / 360	h_b / 150
133	40.2 ft	h_b / 480	h_b / 200
167	50.4 ft	h_b / 600	h_b / 250

[1] Under application of 0.42W. Applicable to backing whose stiffness is the same for service level and strength level wind loads. Otherwise evaluate using W and seismic deflection limits.

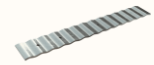
[2] Under application of strength level seismic load.

Engineered Design: Tributary Area Method (13.2.3.2)

Tie Stiffness	Tie Force
$k_{tie} \le 2500$ lb/in.	$2p_u A_t$
2500 lb/in. $< k_{tie} \le 5000$ lb/in.	$2.5p_u A_t$
5000 lb/in. $< k_{tie} \le 8000$ lb/in.	$3p_u A_t$
$k_{tie} > 8000$ lb/in.	$4p_u A_t$

Table 13.2.3.1

Veneer Tie	Design Strength	Stiffness
Corrugated	125 lb	500 lb/in.
Adjustable - slotted	330 lb	3000 lb/in.
Adjustable – two leg pintle	210 lb	2500 lb/in.

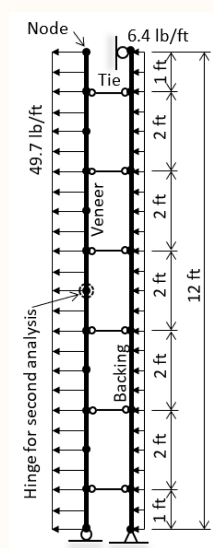

Corrugated Tie


Adjustable - Slotted


Adjustable – Two Leg Pintle

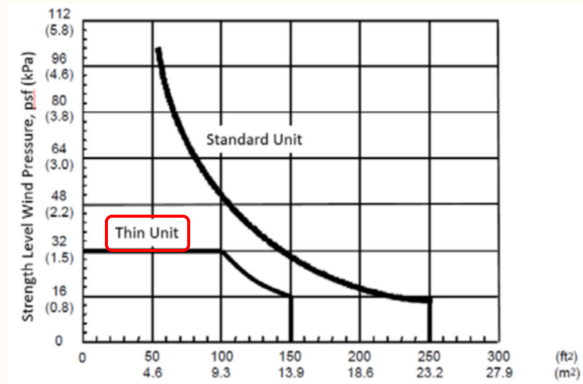
Engineered Design: Modeling Analysis Method (13.2.3.3)

- Backing: Beam elements; simply supported
- Veneer: Beam elements; pinned at bottom, free at top
- Veneer ties: Spring elements (or axial elements)
- Pseudo nonlinear analysis
    - If modulus of rupture is exceeded (veneer cracks), replace with a hinge
    - Rerun model until all tensile stresses in veneer are below modulus of rupture



Chapter 14 - Glass Unit Masonry

- Panel Size Limitations put into table format (Table 14.2)
- Requirements for thin unit glass masonry were added to the strength level wind pressure chart (Figure 14.2) which clarifies the provisions and makes them easier to use.



Appendix D - GFRP Reinforced Masonry

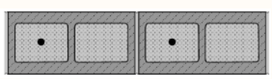
- New Section (Appendix) recognizing Glass Fiber Reinforced Polymer as an acceptable masonry reinforcement in limited applications
  - Limited to Non-Participating elements
  - Limited to SDC C or less

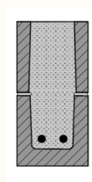
Key benefits:

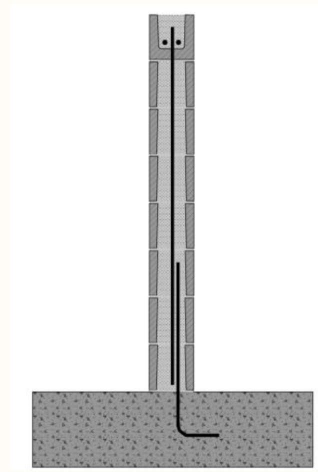
- Non-corrosive
- Thermally neutral
- Non-conductive
- Lightweight
- Improved workability and installation speed

Appendix D Scope and Limitations

- TMS 402/602 Appendix D includes:
  - GFRP deformed, *solid bars* in concrete or clay masonry, up to #6
  - Non-bearing walls and lintels in such walls
  - Retaining walls







Appendix D Scope and Limitations

D.1 GENERAL
- **D.1.1** Scope
- **D.1.2** Nonparticipating Elements
- **D.1.3** Reinforcement Materials
- **D.1.4** Strength-Reduction Factors

D.2 MATERIAL PROPERTIES
- **D.2.1** Design Tensile Strength and Strain
- **D.2.2** Modulus of Elasticity

D.3 REINFORCEMENT
- **D.3.1** GFRP Reinforcement
- **D.3.2** Size of GFRP Reinforcement
- **D.3.3** Development
- **D.3.4** Splices
- **D.3.5** Standard Hooks and Bends

D.4 FLEXURAL MEMBERS
- **D.4.1** Compression Reinforcement
- **D.4.2** Nominal Flexural Strength
  - **D.4.2.1** Compression-Controlled Sections
  - **D.4.2.2** Tension-Controlled Sections
- **D.4.3** Lintels
- **D.4.4** Nominal Shear Strength
- **D.4.5** Deflections
  - **D.4.5.1** Effective Moment of Inertia
  - **D.4.5.2** Wall Deflections

D.5 CREEP RUPTURE

GFRP-Reinforced Wall Behavior

Masonry Crushing
Compression-Controlled Section

GFRP Rupture
Tension-Controlled Section

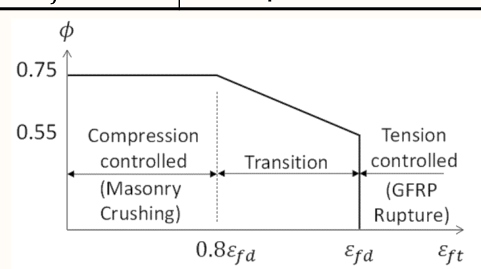
Image Credit: Tumialan, Torres, Quintana, & Nanni, "Masonry Walls Reinforced with FRP Bars Subjected to Out-of-Plane Loading".

Strength-Reduction Factors (D.1.4)

ϕ	Strain	Description
0.55	$\varepsilon_{ft} = \varepsilon_{fd}$	Tension controlled
$1.55 - \frac{\varepsilon_{ft}}{\varepsilon_{fd}}$	$0.80\varepsilon_{fd} < \varepsilon_{ft} < \varepsilon_{fd}$	Transition
0.75	$\varepsilon_{ft} \leq 0.80\varepsilon_{fd}$	Compression controlled

$\varepsilon_{fd} = f_{fd}/E_f$: design tensile strain for GFRP reinforcement

ε_{ft} = tensile strain at failure



Strength Controlled by Masonry

- Analogous to "over-reinforced beam"
  - Steel reinforcement: stress less than yield
- Masonry: equivalent rectangular stress block
- GFRP reinforcement: stress determined from

$$f_f = \sqrt{\frac{\left(E_f \varepsilon_{mu}\right)^2}{4} + \frac{0.64 f'_m}{\rho_f} E_f \varepsilon_{mu}} - \frac{1}{2} E_f \varepsilon_{mu}$$

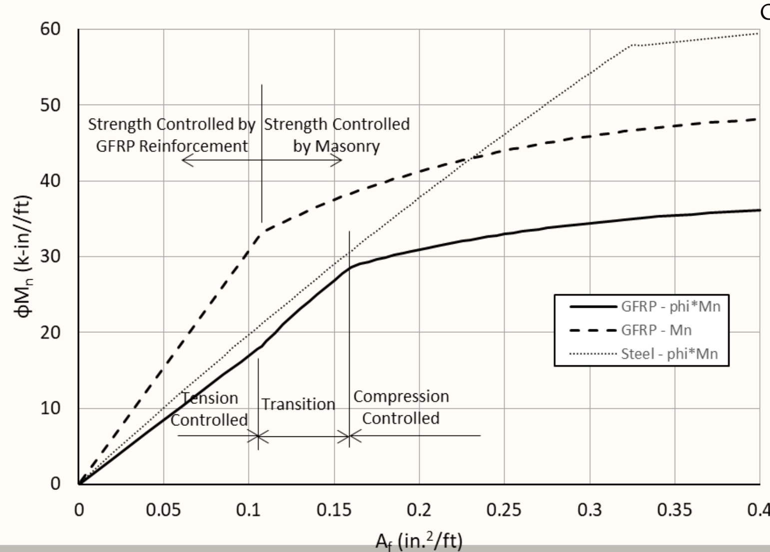
$$\rho_f = \frac{A_f}{bd}$$

Strength Controlled by GFRP Reinforcement

- GFRP reinforcement linear up to failure
- Stress in masonry at GFRP rupture less than ultimate
- Permitted to assume equivalent rectangular stress block:
  - Depth of $a = 0.80 c_{bal}$
  - Stress of $\frac{A_f f_{fd}}{0.80 c_{bal} b} \leq 0.80 f'_m$

Flexural Behavior

8 inch CMU
$f'_m = 2{,}000$ psi
Centered reinforcement



TMS 602 Article 1 - General

- Added periodic inspection requirement for adhered veneer when the height of the veneer exceeds 60 ft above grade plane (Table 4, Item 3.f)
- Added section on GFRP Reinforcing Bars (Article 1.7 F)
    1. Avoid damaging or abrading GFRP bars; do not drag or drop bars.
    2. Store above surface of ground; cover is stored outdoors for more than 2 months to protect from ultra-violet rays.
    3. Prevent exposure to temperatures above 120°F during storage.
    4. Do not use GFRP bars with visible fibers or any cut or defect greater than 0.04 in. deep.

Specification Article 2 - Products

- Preblended mortars (ASTM C1714) added (Article 2.1 A)
- Adhered veneer setting mortar required to be ANSI A118.4 or A118.15 polymer modified mortars (Article 2.1 B)
- Added F1554 bent-bar and headed anchor bolts (Article 2.4 J)
- Requirements were added for adhered veneer system products: cementitious backer units (2.5 G), lath fasteners (2.5 H), weep screeds (2.5 I), and lath (Article 2.5 O)
- Standard reinforcement bends and hook table moved from Code (2016 TMS 402 Table 6.1.8) to Specification (2022 TMS 602 Table 6). Table now includes deformed wire reinforcement in addition to deformed bars.

Specification Article 2 - Products

Stainless Steel Joint Reinforcement (Article 2.4 D.1)

- Commonly available ASTM A580/A580M stainless steel wire does not conform to the minimum yield and tensile strengths required by ASTM A951 (Standard Specification for Joint Reinforcement)
- Fabricated in accordance with ASTM A951 (welded and knurled) with AISI Type 304 or Type 316 stainless steel wire, having a minimum yield strength of 45 ksi and a minimum ultimate tensile strength of 90 ksi.

Courtesy of WireBond

Specification Article 2 - Products

Added a term for (single) wire reinforcement in veneer (Article 2.4 E)

2.4 E. *Veneer wire reinforcement* —

1. Wire with deformations knurled in conformance with ASTM A951. Either:

    (a) ASTM A1064/A1064M wire meeting the minimum mechanical properties of ASTM A951.

    (b) ASTM A580/A580M, AISI Type 304 or Type 316 stainless steel and having a minimum yield strength of 45 ksi and a minimum ultimate tensile strength of 90 ksi.

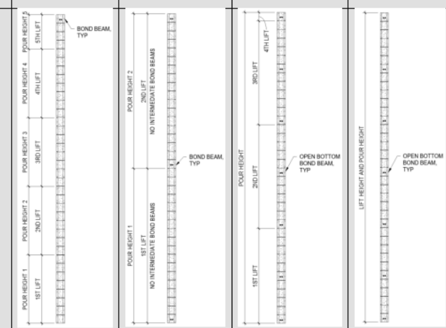
2. Deformed wire that conforms to ASTM A1064/A1064M.
3. Joint reinforcement that conforms to Article 2.4 D.

Specification Article 3 - Execution

- Clarify mechanical splice cover and clear distance between mechanical splices are the same as for reinforcing bars (Article 3.4 B)
- Veneer ties placement tolerance of ± 1 in. added (Article3.4 D)
- Added tolerance for adhered veneer fasteners (fasteners for backer units) of ± 0.25 in. (Article 3.4 F)

Specification Article 3 - Execution

- Added figure to clarify grout pour and lift requirements (Figure SC-20)

Type of Grouting*	Grouting with no cure time limit	Conventional grout with no intermediate bond beams	Conventional grout with intermediate bond beams	Self-consolidating grout with or without intermediate bond beams
TMS 602 Article	3.5 D.1.c 3.5 D.2.b	3.5 D.1.a	3.5 D.1.b	3.5 D.2.a
Lift Limit	5 ft-4 in.	12 ft-8 in.	See Limitation	Pour Height
Pour Height	Per Table 7	Per Table 7	Per Table 7	Per Table 7
Configuration				
Limitations	• Grout slump between 8 and 11 inches • Conventional grout or self-consolidating grout • Lift height is 1-1/2 inches less than pour height for shear key, except at top of wall.	• Masonry cured for at least 4 hours • Grout slump between 10 and 11 inches	• Masonry cured for at least 4 hours • Grout slump between 10 and 11 inches • Lift cannot exceed maximum 12 ft-8 in. • Limit grout lift to the bottom of lowest bond beam that is more than 5 ft-4 in. above bottom of grout lift • Lift height is 1-1/2 inches below the top of block for shear key, except at top of wall	• Masonry cured for at least 4 hours
Cleanouts Required	No	Yes	Yes	Yes

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