Reinforcement and Connectors

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Scott W. Walkowicz, PE, FTMS, NCEES
Owner
Walkowicz Consulting Engineers

The Masonry Society

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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

Reinforcement and connectors are essential to ensure a proper load path in masonry buildings. This session will review basic detailing requirements for reinforcement and connectors, and specific requirements for their design when using allowable stress procedures for masonry. Lap length requirements for reinforcement, use of hooks and confinement bars, and the design of anchor bolts will also be reviewed.

Learning Objectives

- Discuss basic detailing requirements for reinforcement and connectors
- Review specific Allowable Stress design requirements for reinforcement and connectors
- Overview development and lap splice requirements for reinforcement
- Review Allowable Stress design of anchor bolts

Special Thanks:

- Basis for presentation and some graphics… SD session by:
  - Richard M. Bennett, Ph.D., P.E., FTMS
  - Professor
  - University of Tennessee

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Tonight's Outline

- Reinforcement Detailing
- Development and Splice Length
- Anchor Bolts

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Reinforcement Details

- Size
- Placement
- Protection
- Hooks

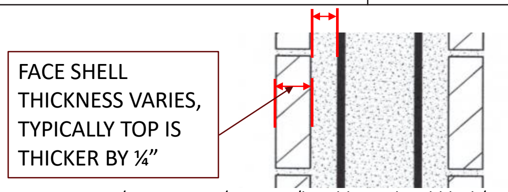
Size of Reinforcement

Masonry Designers' Guide Table 9.2.1

Provision	TMS 402 Reference
Maximum size: #11	6.1.2.1
d_b ≤ 1/2 of least clear dimension	6.1.2.2
Area of vertical reinforcement ≤ 6% cell area	6.1.2.4
d_b ≤ 1/8 least nominal dimension	6.1.2.5

Placement Requirements

Provision	TMS 402
Clear distance between bars ≥ max{d_b , 1 in.}	6.1.3.1
Columns and pilasters: Clear distance ≥ max{ 1.5d_b , 1.5 in.}	6.1.3.2
Thickness of grout between reinforcement and masonry	6.1.3.5
Coarse grout: ½ in.; Fine grout: ¼ in.	TMS 602
Cross webs can be used to support horizontal reinf.	3.4.B.3

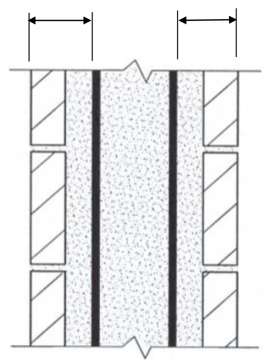


https://theconstructor.org/construction/masonry/bond-beam-lintel-block/29496/

Protection Requirements

Masonry Designers' Guide Table 9.2.1

Provision	TMS 402 Reference
Masonry exposed to earth or weather: #5 and smaller: 1½ in. larger than #5: 2 in. Masonry not exposed to weather: 1½ in.	6.1.4.1



Size of Wire Reinforcement

Masonry Designers’ Guide Table 9.2.2

Provision	TMS 402 Reference
Minimum size: W1.1 (11 GA / 0.121” dia.)	6.1.2.3
Maximum size: ½ of the joint thickness	6.1.2.3

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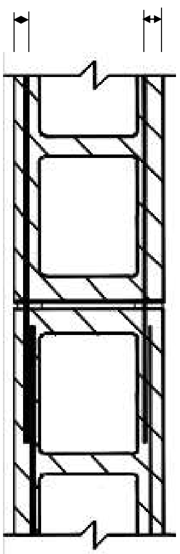
Wire Protection Requirements

Masonry Designers’ Guide Table 9.2.2

Provision	TMS 402 Reference
Cover: • Exposed to earth or weather: $^5/_8$ " • Not exposed to earth or weather: $^1/_2$ " Protection: • Exposed to earth or weather, or interior with mean RH > 75%: SS, Hot-dipped galvanized or epoxy coating • Interior with mean RH ≤ 75%: mill-galvanized or hot-dipped galvanized or SS	6.1.4.2



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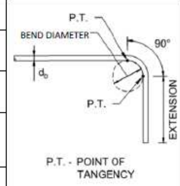
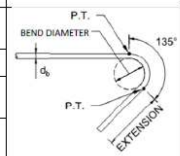
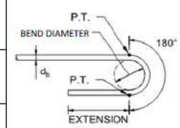
Hooks

TMS 402-16 Table 6.1.8
Standard Hooks Geometry and Minimum Inside Bend Diameters for Reinforcing Bars, Stirrups & Ties

Standard Hook Type and Use	Bar Grade	Bar Size	Min. Inside Bend Diameter	Extension	Standard Hook Figures
90 Degree Hook – Reinforcing Bars	40 (M280)	No.3 - No. 7 (M#10 - #22)	$5d_b$	$12\ d_b$	
	50 or 60 (M350 or 420)	No. 3 - No. 8 (M#10 - #25)	$6\ d_b$	$12\ d_b$	
	50 or 60 (M350 or 420)	No. 9 - No. 11 (M#29 - #36)	$8\ d_b$	$12\ d_b$	
90 Degree Hook – Stirrups & Ties	40, 50, 60 (M280,350 or 420)	No.3 - No.5 (M#10 - #16)	$4d_b$	$6\ d_b$ but not less than 2-1/2 in. (64 mm)	
	40 (M280)	No.6 and No.7 (M#19 - #22)	$5\ d_b$	$6\ d_b$	
	50 or 60 (M350 or 420)	No.6 - No.8 (M#19 - #25)	$6\ d_b$	$6\ d_b$	
	50 or 60 (M350 or 420)	No.9 - No.11 (M#29 - #36)	$8\ d_b$	$6\ d_b$	
135 Degree Hook – Stirrups & Ties	40, 50, 60 (M280, 350 or 420)	No.3 - No.5 (M#10 - #16)	$4\ d_b$	$6\ d_b$	
	40 (M280)	No.6 and No.7 (M#19 - #22)	$5\ d_b$	$6\ d_b$	
	50 or 60 (M350 or 420)	No.6 - No.8 (M#19 - #25)	$6\ d_b$	$6\ d_b$	
	50 or 60 (M350 or 420)	No.9 - No.11 (M#29- #36)	$8\ d_b$	$6\ d_b$	
180 Degree Hook – Reinforcing Bars	40 (M280)	No.3 - No.7 (M#10 - #22)	$5\ d_b$	$4\ d_b$ but not less than 2-1/2 in. (64 mm)	
	50 or 60 (M350 or 420)	No.3 - No.8 (M#10 - #25)	$6\ d_b$	$4\ d_b$ but not less than 2-1/2 in. (64 mm)	
	50 or 60 (M350 or 420)	No.9 -- No.11 (M9 -#36)	$8\ d_b$	$4\ d_b$	

Hooks

Type	Bar Grade	Bar Size	Min. Inside Bend Diameter	Extension
90° Hook	60	No. 3 – No. 8	$6d_b$	$12d_b$
90° – Stirrups and Ties	40, 60	No. 3 – No. 5	$4d_b$	max($6d_b$, 2.5 in.)
180° Hook	60	No. 3 – No. 8	$6d_b$	max($4d_b$, 2.5 in.)

Development and Splice Length

Development Length

2107.2 TMS 402, Section 6.1.6.1.1, lap splices. As an alternative to Section 6.1.6.1.1, it shall be permitted to design lap splices in accordance with Section 2107.2.1.

2107.2.1 Lap splices. The minimum length of lap splices for reinforcing bars in tension or compression, l_d, shall be:

$l_d = 0.002 d_b f_s$ **(Equation 21-1)**

For SI: $l_d = 0.29 d_b f_s$

but not less than 12 inches (305 mm). The length of the lapped splice shall be not less than 40 bar diameters.

where:

d_b = Diameter of reinforcement, inches (mm).

f_s = Computed stress in reinforcement due to design loads, psi (MPa).

In regions of moment where the design tensile stresses in the reinforcement are greater than 80 percent of the allowable steel tension stress, F_s, the lap length of splices shall be increased not less than 50 percent of the minimum required length, but need not be greater than 72 d_b. Other equivalent means of stress transfer to accomplish the same 50 percent increase shall be permitted. Where epoxy coated bars are used, lap length shall be increased by 50 percent.

DON'T DO IT!!!

Development Length

Condition	Provision	TMS 402 Section
Bars in grouted clay masonry and concrete masonry	$l_d = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}}$ K = min{masonry cover, clear spacing between adjacent splices, $9d_b$} $\gamma = \begin{cases} 1.0 \text{ for \#3 through \#5} \\ 1.3 \text{ for \#6 and \#7} \\ 1.5 \text{ for \#8 and greater} \end{cases}$	6.1.5.1.1
Hooks in tension	Equivalent embedment length: $l_d = 13d_b$	6.1.5.1.3
Epoxy-coated bars	Development length increased by 150%	6.1.5.1.1

Wire Development Length

Condition	Provision	TMS 402 Section
Wires in tension	Equivalent embedment length: $l_d = 48d_b$	6.1.5.2
Epoxy-coated wires	Development length increased by 150%	6.1.5.2

Splices (Lap Length)

Condition	Provision	TMS 402 Section
Lap splices	max{ l_d , 12 in.}	6.1.6.1.1.1
Noncontact lap splices	Transverse spacing ≤ min{1/5l_d, 8 in.}	6.1.6.1.1.3
Welded splices	Develop 1.25f_y Welding conforms to AWS 1.4 ASTM A706 bars or chemical analysis and carbon equivalent	6.1.6.1.2
Mechanical splices	Develop 1.25f_y Develop f_u in plastic hinge zones of special reinforced masonry shear walls	6.1.6.1.3 7.3.2.6

Wire and Joint Reinforcement Splices

Condition	Provision	TMS 402 Section
Lap splices	max{ $48d_b$, 6 in.}	6.1.6.2.1
Welded splices	Develop 1.25f_y	6.1.6.1.3

Example: Splice Length

Masonry Designer's Guide Example 9.2-1

Determine the required lap splice length for a #5 Grade 60 reinforcement bar placed in the center of an 8 inch masonry wall. Assume f'_m = 2000 psi.

Masonry cover: $\frac{t_{sp}}{2} - \frac{d_b}{2} = \frac{7.625\ in.}{2} - \frac{0.625 in.}{2} = 3.50 in.$

Determine K: $K = \min\{cover, 9d_b\} = \{3.50in., 9(0.625in.) = 5.625in.\} = 3.50in.$

Determine γ: for a #5 bar, $\gamma = 1$

Determine l_d: $l_d = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}} = \frac{0.13(0.625in.)^2(60000psi)(1.0)}{3.50in.\sqrt{2000psi}} = 19.5in.$

Splice length: $\max\{l_d, 12in.\} = \max\{19.5in., 12in.\} = 19.5\ in.$

Use 20 in. lap splice length

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Masonry Designer's Guide Table 9.2.5

Bar Size	Required lap splice length (inches)								
	f'_m = 2000 psi			f'_m = 2500 psi			f'_m = 3000 psi		
	8 in. Center	12 in. Center	2 in. cover	8 in. Center	12 in. Center	2 in. cover	8 in. Center	12 in. Center	2 in. cover
#3	12	12	12	12	12	12	12	12	12
#4	13	12	22	12	12	20	12	12	18
#5	20	13	35	18	12	31	16	12	28
#6	38	24	64	34	21	58	31	20	53
#7	52	33	87	47	29	78	42	27	71
#8	79	50	131	71	45	117	65	41	107
#9	-	64	167	-	57	149	-	52	136
#10	-	82	211	-	73	189	-	67	173
#11	-	102	261	-	92	233	-	84	213

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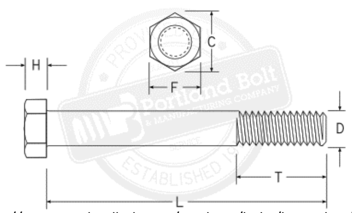
Anchor Bolts

- Sizes
- Types
- Placement
- Embedment Length
- Testing

Anchor Bolt Sizes

Strength Design Guide Table 7.3-1 (MDG-2016 Table 9.3.1)



https://www.portlandbolt.com/products/bolts/heavy-hex/

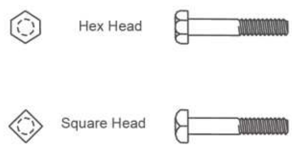
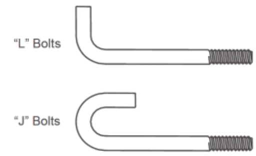
$$A_b = \frac{\pi}{4}\left(d_0 - \frac{0.9743}{n_t}\right)^2$$

A = nominal area
A_b = effective tensile stress area
F = width across flats
C = width across corners
H = height of head
d_0 = nominal anchor diameter
n_t = number of threads per inch

Bolt ($d_o - n_t$)	A (in.^{2})	A_b (in.^{2})	F (in.)	C (in.)	H (in.)
1/2 - 13	0.196	0.142	3/4	1.010	11/32
5/8 - 11	0.307	0.226	1-1/16	1.227	27/64
3/4 - 10	0.442	0.334	1-1/4	1.443	1/2
7/8 - 9	0.601	0.462	1-7/16	1.660	37/64
1 - 8	0.785	0.606	1-5/8	1.876	43/64

Types of Anchor Bolts

Masonry Designers’ Guide 3.4.4; TMS 402 Section 6.3; TMS 602 Article 2.4 D

Headed Anchor Bolts	Bent-Bar Anchor Bolts
 TMS 402 *Figure CC-6.3-1*	 TMS 402 *Figure CC-6.3-1*
ASTM A307, Grade A no specified yield strength <u>Headed Studs</u> • Not mentioned in TMS 402/602 • Can be designed using headed anchor bolt provisions	ASTM A36 <u>ASTM F1554 anchor bolts</u> • Not included in TMS 602 • Will be added in 2022 • Three specified yield strengths : 36, 55, and 105 ksi • 36 ksi usually sufficient for masonry

Placement of Anchor Bolts

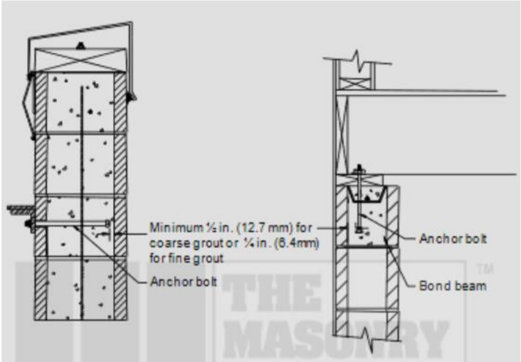
Masonry Designers’ Guide Table 9.3.2; TMS 402 6.3.1

- Placed in grout
  - Exception: 1/4 in. anchor bolts may be placed in 1/2 in. mortar joints.
- Thickness of grout between masonry unit and anchor bolt
  - Coarse grout: 1/2 in.
  - Fine grout: 1/4 in.
- Clear distance between bolts ≥ max{ d_b, 1 in.}

Placement of Anchor Bolts

Masonry Designers' Guide Table 9.3.2; TMS 402 6.3.1

- Anchor bolts in drilled holes of face shell permitted to contact face shell
    - Must maintain grout thickness (above) between head or bent leg



TMS 402-16 Figure CC-6.3-2

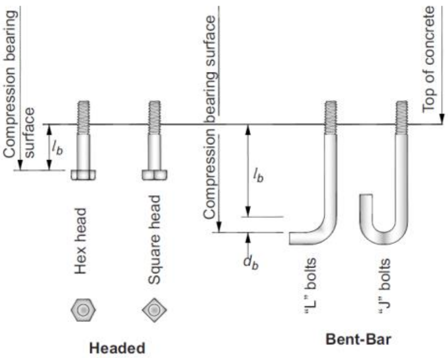
Embedment Length

Masonry Designers' Guide Table 9.3.2; TMS 402 6.3.4, 6.3.5, 6.3.6

<u>Headed bolts:</u> masonry surface to compression bearing surface of head

<u>Bent-bar bolts:</u> masonry surface to the compression bearing surface of the bent end, minus one anchor bolt diameter.

Minimum l_b = max{$4d_b$, 2in.}



Reinforced Masonry Engineering Handbook Figure 5.45

Anchor Bolt Testing

TMS 402 8.1.3.2

8.1.3.2.1 Anchor bolts shall be tested in accordance with ASTM E488, except that a minimum of five tests shall be performed.

8.1.3.2.2 Anchor bolt nominal strengths used for design shall not exceed 20 percent of the average failure load from the tests.

ASTM E488-96 (2003) — Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements

ASTM C1892-19 - Standard Test Methods for Strength of Anchors in Masonry

New – reference standard for testing in 2022 TMS 402 Public Comment Version…

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Anchor Bolts: Tension

- Allowable Tension Load
- Projected Tension Breakout Area

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Allowable Tension Load

Masonry Designers' Guide 9.3.2; TMS 402 8.1.3.3.1

Failure Mode	Allowable Axial Tensile Load
Masonry breakout	$B_{ab} = 1.25 A_{pt}\sqrt{f'_m}$
Steel yielding	$B_{as} = 0.6 A_b f_y$
Anchor pullout (Only bent bar)	$B_{ap} = 0.6 f'_m e_b d_b + [120\pi(l_b + e_b + d_b)d_b]$

Allowable Tension Load of Bolt

Masonry Designers' Guide 9.3.2; TMS 402 8.1.3.3.1

TMS 402 Section 2.1 Notation
A_b = cross-sectional area of an anchor bolt

TMS 402 Commentary Section 8.1.3 — Anchor bolt designs using ASD or SD should be approximately the same…. **See SD Commentary (9.1.6) for additional information.**

Allowable Tension Load of Bolt

Masonry Designers' Guide 9.3.2; TMS 402 8.1.3.3.1

TMS 402 Commentary Section 8.3.3.1 — Allowable capacity is calculated using the specified tensile stress area of the anchor.

TMS 402 Commentary Section 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).

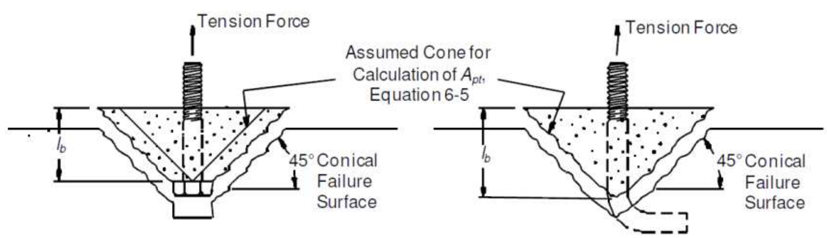
TMS 402 Commentary Section 8.1.3.3 — ASTM A307 Grade A does not specify a yield strength…. Use of a yield strength of 37 ksi in the Code design equations for A307 anchors will result in anchor capacities similar to those obtained using the AISC provisions. (many designers use 36 ksi)

Projected Tension Breakout Area

Masonry Designers' Guide 9.3.2; TMS 402 6.3.2

$$A_{pt} = \pi l_b^2$$

TMS 402 Equation 6-5

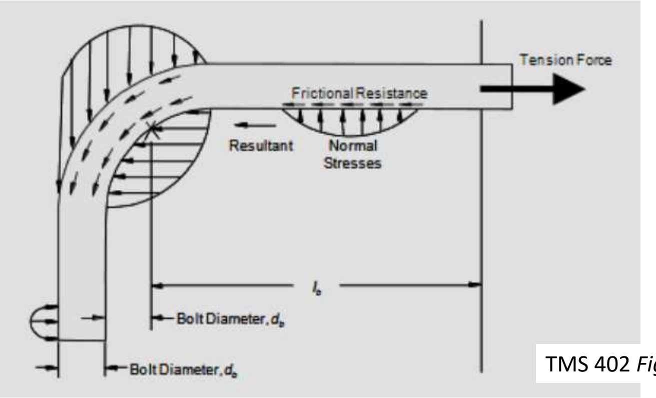


TMS 402 *Figure CC-6.3-3*

- Projected area **reduced** by that in an open cell, core, or outside the wall.
- When projected areas overlap, projected area **reduced** so no portion of the masonry included more than once.

Bent-Bar Anchor Bolt Stresses

TMS 402 6.3.5



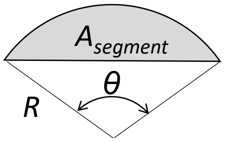
TMS 402 *Figure CC-6.3-8*

- Testing indicated that bent-bar anchor bolts correlated best with a reduced embedment length

Geometry

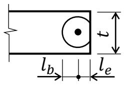
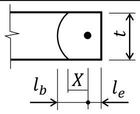
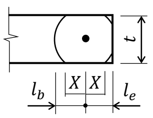
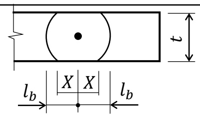
Masonry Designers' Guide 9.3.2

$$A_{segment} = \frac{R^2}{2}\left(\frac{\pi\theta}{180} - \sin\theta\right)$$



Following table can be developed

1. θ and θ_1 in degrees
2. $X = \sqrt{l_b^2 - (t/2)^2}$

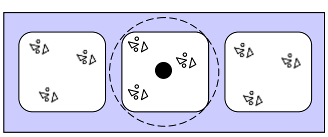
Configuration	Geometry	Projected tension area, A_{pt}
	$l_b \le t/2$ $l_e \le l_b$	$A_{pt} = \pi l_b^2 - \frac{l_b^2}{2}\left(\frac{\pi\theta}{180} - \sin\theta\right)$ $\theta = 2\arccos(l_e/l_b)$
	$l_b > t/2$ $l_e \le l_b$ $l_e \le X$	$A_{pt} = (X + l_e)t - \frac{l_b^2}{2}\left(\frac{\pi\theta}{180} - \sin\theta\right)$ $\theta = 2\arcsin\left(\frac{t/2}{l_b}\right)$
	$l_b > t/2$ $l_e \le l_b$ $l_e > X$	$A_{pt} = 2Xt + l_b^2\left(\frac{\pi(\theta - \theta_1)}{180} - sin\theta + \sin\theta_1\right)$ $\theta = 2\arcsin\left(\frac{t/2}{l_b}\right)$ $\theta_1 = 2\arccos(l_e/l_b)$
	$l_b > t/2$ $l_e > l_b$	$A_{pt} = 2Xt + l_b^2\left(\frac{\pi\theta}{180} - \sin\theta\right)$ $\theta = 2\arcsin\left(\frac{t/2}{l_b}\right)$

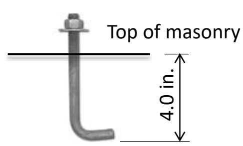
MDG-2016 Table 9.3.4

Example: Bent-bar Anchor Bolt

Masonry Designers' Guide Example 9.3-1

- 1/2-in. diameter, A36 bent-bar anchor with a 1-in. hook
- Embedded vertically in a grouted bond beam of an 8-in. masonry wall
- Bottom of the anchor hook is embedded a distance of 4.0 in.
- f'_m = 2,000 psi





Example: Bent-bar Anchor Bolt

Masonry Designers' Guide Example 9.3-1

Effective embedment $l_b = 4.0in. - d_b - d_b = 4.0in. - 2(0.5in.) = 3.0in.$

Projected tensile area $A_{pt} = \pi l_b^2 = \pi(3.0in.)^2 = 28.3in.^2$

Allowable Tensile Load:

Masonry breakout: $B_{ab} = 1.25A_{pt}\sqrt{f'_m} = (1.25)(28.3in.^2)\sqrt{2{,}000psi} = \boxed{1{,}581\ lb}$

Steel yielding: $B_{as} = 0.6A_b f_y = 0.6(0.142in.^2)(36{,}000psi) = \boxed{3{,}067\ lb}$

Anchor pullout:

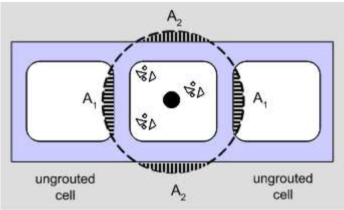
$$B_{ap} = [0.6f'_m e_b d_b + 120\pi(l_b + e_b + d_b)d_b]$$
$$= 0.6(2000psi)(1.0in.)(0.5in.)$$
$$+120\pi(3.0\ in. + 1.0in. + 0.5in.)(0.5in.) = \boxed{1{,}448\ lb}$$

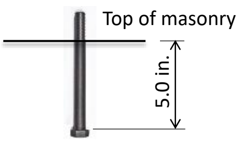
Allowable Tensile Load = 1,448 lb

Example: Headed Anchor Bolt

Masonry Designers' Guide Example 9.3-2

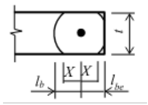
- 1/2-in. diameter, A307 headed anchor bolt
- Embedded vertically in a grouted bond beam of an 8-in. masonry wall
- Embedment length, l_b, is 5.0 in.
- f'_m = 2,000 psi





Example: Projected Tensile Area

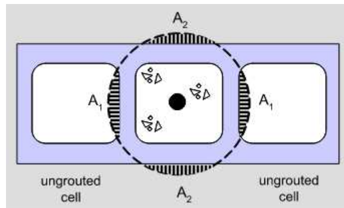
Masonry Designers' Guide Example 9.3-2

	$l_b > t/2$ $l_e \le l_b$ $l_e > X$	$A_{pt} = \pi l_b^2 - 2A_1 - 2A_2$ $\theta = 2\arcsin\left(\frac{t/2}{l_b}\right)$ $\theta_1 = \theta_1 = 2\arccos\left(\frac{l_e}{l_b}\right)$

$$X = \sqrt{l_b^2 - (t/2)^2} = \sqrt{(5.0in.)^2 - (7.625in./2)^2} = 3.235in.$$

$$\theta_1 = 2\arccos\left(\frac{*length*/2}{l_b}\right) = 2\arccos\left(\frac{8.0in./2}{4.66in.}\right) = 61.6\,°$$

$$A_1 = \frac{l_b^2}{2}\left(\frac{\pi\theta_1}{180} - sin\theta_1\right)$$
$$= \frac{(4.66in.)^2}{2}\left(\frac{\pi(61.6°)}{180} - sin61.6°\right) = 2.12\text{in.}^2$$



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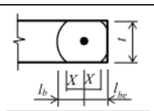
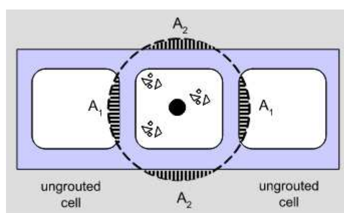
Example: Projected Tensile Area

Masonry Designers' Guide Example 9.3-2

	$l_b > t/2$ $l_e \le l_b$ $l_e > X$	$A_{pt} = \pi l_b^2 - 2A_1 - 2A_2$ $\theta = 2\arcsin\left(\frac{t/2}{l_b}\right)$ $\theta_1 = \theta_1 = 2\arccos\left(\frac{l_e}{l_b}\right)$

$$\theta_2 = 2\arccos\left(\frac{t/2}{l_b}\right) = 2\arccos\left(\frac{7.625in./2}{4.66in.}\right) = 70.1\,°$$

$$A_2 = \frac{l_b^2}{2}\left(\frac{\pi\theta_2}{180} - sin\theta_2\right)$$
$$= \frac{(4.66in.)^2}{2}\left(\frac{\pi(70.1°)}{180} - sin70.1°\right) = 3.07\text{in.}^2$$

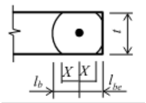


42

42

Example: Projected Tensile Area

Masonry Designers' Guide Example 9.3-2

	$l_b > t/2$ $l_e \le l_b$ $l_e > X$	$A_{pt} = \pi l_b^2 - 2A_1 - 2A_2$ $\theta = 2\arcsin\left(\frac{t/2}{l_b}\right)$ $\theta_1 = \theta_1 = 2\arccos\left(\frac{l_e}{l_b}\right)$

$$A_{pt} = \pi l_b^2 - 2A_1 - 2A_2 = \pi(4.66in.)^2 - 2\left(2.12in.^2\right) - 2\left(3.07in.^2\right) = 57.7in.^2$$

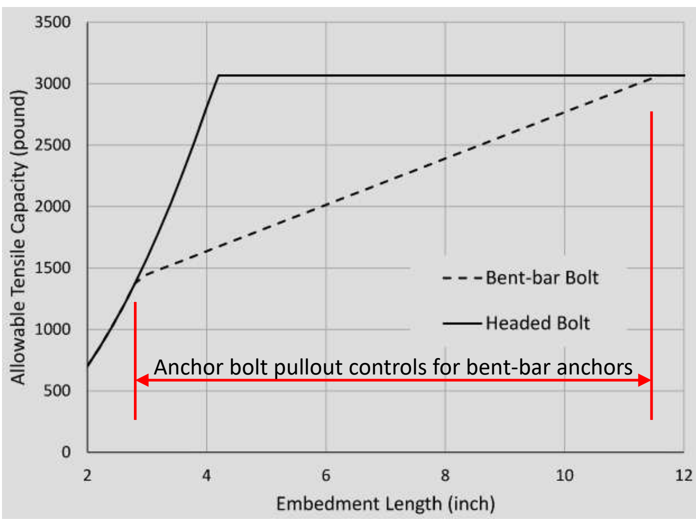
Masonry breakout: $B_{ab} = 1.25A_{pt}\sqrt{f'_m} = (1.25)(57.7in.^2)\sqrt{2{,}000psi} = \boxed{3{,}228\ lb}$

Steel yielding: $B_{as} = 0.6A_b f_y = 0.6(0.142in.^2)(36{,}000psi) = \boxed{3{,}067\ lb}$

Allowable Tensile Load = 3,067 lb

Bent-bar vs. Headed Anchor Bolts

Masonry Designers' Guide Figure ???



Bent-bar vs. Headed Anchor Bolts

Masonry Designers' Guide

Table 9.3.5 Headed Anchor Bolt Allowable Tensile Capacities: Anchor Bolt Embedded in the Center of a Top Cell in a CMU wall (f_y = 36 ksi)

Anchor Bolt		Allowable tensile load and minimum required effective embedment length					
		8 in. CMU			12 in. CMU		
Diameter		f'_m = 2 ksi	f'_m = 2.5 ksi	f'_m = 3 ksi	f'_m = 2 ksi	f'_m = 2.5 ksi	f'_m = 3 ksi
1/2 in.	Allowable	3,070 lb	3,070 lb	3,070 lb	3,070 lb	3,070 lb	3,070 lb
	Minimum l_b	4.4 in.	4.0 in.	3.8 in.	4.2 in.	4.0 in.	3.8 in.
5/8 in.	Allowable	3,410 lb	3,810 lb	4,180 lb	4,880 lb	4,880 lb	4,880 lb
	Minimum l_b	5.5 in.	5.5 in.	5.5 in.	6.0 in.	5.4 in.	5.1 in.
3/4 in.	Allowable	3,410 lb	3,810 lb	4,180 lb	5,200 lb	5,810 lb	6,370 lb
	Minimum l_b	5.5 in.	5.5 in.	5.5 in.	7.1 in.	7.1 in.	7.1 in.
7/8 in.	Allowable	3,410 lb	3,810 lb	4,180 lb	5,200 lb	5,810 lb	6,370 lb
	Minimum l_b	5.5 in.	5.5 in.	5.5 in.	7.1 in.	7.1 in.	7.1 in.
1 in.	Allowable	3,410 lb	3,810 lb	4,180 lb	5,200 lb	5,810 lb	6,370 lb
	Minimum l_b	5.5 in.	5.5 in.	5.5 in.	7.1 in.	7.1 in.	7.1 in.

Note: Allowable capacities controlled by masonry breakout are shaded.

Table 9.3.6 Headed Anchor Bolt Allowable Tensile Capacities: Anchor Bolt Embedded in the Center of a Top Bond Beam in a CMU wall (f_y = 36 ksi)

Anchor Bolt		Allowable tensile load and minimum required effective embedment length					
		8 in. CMU			12 in. CMU		
Diameter		f'_m = 2 ksi	f'_m = 2.5 ksi	f'_m = 3 ksi	f'_m = 2 ksi	f'_m = 2.5 ksi	f'_m = 3 ksi
1/2 in.	Allowable	3,070 lb	3,070 lb	3,070 lb	3,070 lb	3,070 lb	3,070 lb
	Minimum l_b	4.3 in.	4.0 in.	3.8 in.	4.2 in.	4.0 in.	3.8 in.
5/8 in.	Allowable	4,880 lb	4,880 lb	4,880 lb	4,880 lb	4,880 lb	4,880 lb
	Minimum l_b	6.2 in.	5.6 in.	5.2 in.	5.3 in.	5.0 in.	4.8 in.
3/4 in.	Allowable	7,210 lb	7,210 lb	7,210 lb	7,210 lb	7,210 lb	7,210 lb
	Minimum l_b	8.8 in.	7.9 in.	7.3 in.	6.6 in.	6.1 in.	5.8 in.
7/8 in.	Allowable	9,980 lb	9,980 lb	9,980 lb	9,980 lb	9,980 lb	9,980 lb
	Minimum l_b	11.9 in.	10.7 in.	9.8 in.	8.4 in.	7.7 in.	7.2 in.
1 in.	Allowable	13,090 lb	13,090 lb	13,090 lb	13,090 lb	13,090 lb	13,090 lb
	Minimum l_b	15.5 in.	13.9 in.	12.7 in.	10.6 in.	9.6 in.	8.9 in.

Bent-bar vs. Headed Anchor Bolts

Masonry Designers' Guide

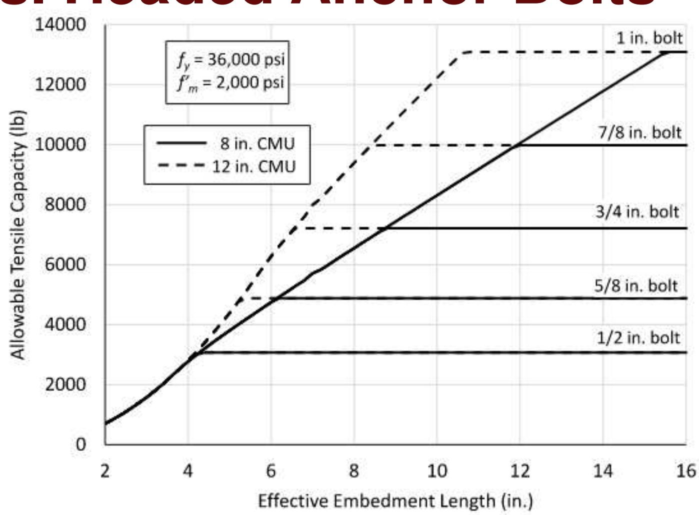
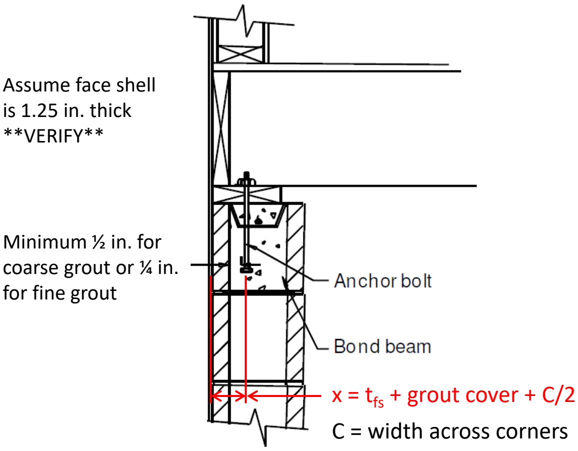


Figure 9.3-2 Allowable Tensile Capacity for Anchor Bolts vs. Effective Embedment Length

Headed Anchor Bolt: Placement



TMS 402 *Figure CC-6.3-2*

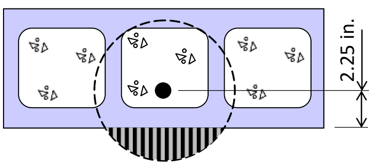
Bolt	C (in.)	x_{fine} (in.)	x_{coarse} (in.)
1/2	1.010	2 (2.01)	2-1/4 (2.26)
5/8	1.227	2-1/4 (2.11)	2-1/2 (2.36)
3/4	1.443	2-1/4 (2.22)	2-1/2 (2.47)
7/8	1.660	2-1/2 (2.33)	2-3/4 (2.58)
1	1.876	2-1/2 (2.44)	2-3/4 (2.69)

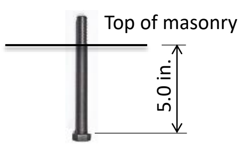
x = closest centerline of bolt can be to edge of masonry

Example: 1/2 in bolt, coarse grout
x = 1.25 in. + 0.5 in. + (1.010 in.)/2 = 2.26 in.

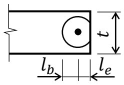
Example: Headed Anchor Bolt

- 1/2-in. diameter, A307 headed anchor bolt
- Embedded vertically in a grouted bond beam of an 8-in. masonry wall
- Embedment length, l_b, is 5.0 in.
- 2.25 in. from edge of wall
- f'_m = 2,000 psi





Example: Projected Tensile Area

	$l_b \leq t/2$ $l_e \leq l_b$	$A_{pt} = \pi l_b^2 - \frac{l_b^2}{2}\left(\frac{\pi\theta}{180} - \sin\theta\right)$ $\theta = 2\arccos(l_e/l_b)$

$$\theta = 2\arccos\left(\frac{l_{be}}{l_b}\right) = 2\arccos\left(\frac{2.25in.}{5.0in.}\right) = 126.5\,°$$

$$A_{pt} = \pi l_b^2 - \frac{l_b^2}{2}\left(\frac{\pi\theta}{180} - sin\theta\right)$$

$$= \pi(5.0in.)^2 - \frac{(5.0in.)^2}{2}\left(\frac{\pi(126.5°)}{180} - sin126.5°\right) = 61.0\text{in.}^2$$

Example: Design Strength

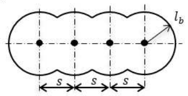
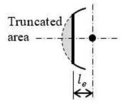
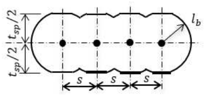
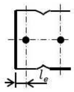
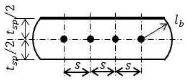
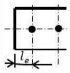
Masonry breakout: $B_{ab} = 1.25A_{pt}\sqrt{f'_m} = (1.25)(61.0in.^2)\sqrt{2000psi} = \boxed{3{,}410\ lb}$

Steel yielding: $B_{as} = 0.6A_b f_y = 0.6(0.142in.^2)(36{,}000psi) = \boxed{3{,}067\ lb}$

Design strength = 3,067 lb

Multiple Anchor Bolts

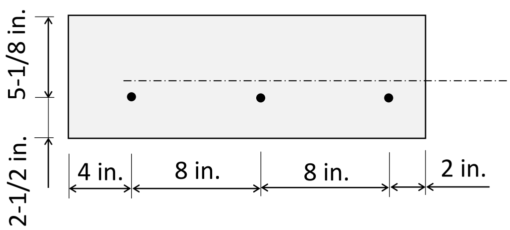
Table 7.3-5 Projected Areas for Multiple Anchor Bolts

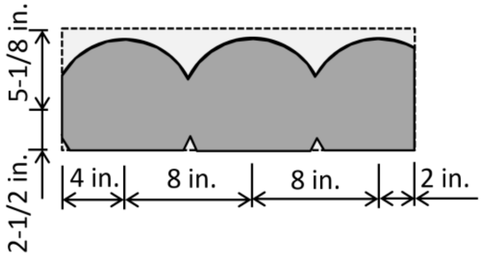
Configuration	Projected Tension Area	Truncated End Modification
$t_{sp} \geq 2l_b$ 	$\theta = 2\arccos\left(\frac{s/2}{l_b}\right)$ $A_{pt} = \left[n\pi - (n-1)\left(\frac{\pi\theta}{180} - \sin\theta\right)\right] l_b^2$	 Truncated area; $\theta_e = 2\arccos\left(\frac{l_e}{l_b}\right)$ $A_{mod,1} = -\frac{l_b^2}{2}\left(\frac{\pi\theta_e}{180} - \sin\theta_e\right)$
$\sqrt{4l_b^2 - s^2} \leq t_{sp} < 2l_b$ 	$\theta = 2\arccos\left(\frac{s/2}{l_b}\right)$ $\theta_1 = 2\arccos\left(\frac{t_{sp}}{2l_b}\right)$ $A_{pt} = \left[n\pi - (n-1)\left(\frac{\pi\theta}{180} - \sin\theta\right) - n\left(\frac{\pi\theta_1}{180} - \sin\theta_1\right)\right] l_b^2$	$l_e > \sqrt{l_b^2 - (t_{sp}/2)^2}$, use $A_{mod,1}$ $l_e \leq \sqrt{l_b^2 - \left(\frac{t_{sp}}{2}\right)^2}$  $A_{mod} = -\frac{1}{2}\pi l_b^2 + \frac{l_b^2}{2}\left(\frac{\pi\theta_1}{180} - \sin\theta_1\right) + l_e t_{sp}$
$t_{sp} < \sqrt{4l_b^2 - s^2}$ 	$\theta_2 = 2\arcsin\left(\frac{t_{sp}}{2l_b}\right)$ $A_{pt} = \left[(n-1)s + 2l_b\cos\left(\frac{\theta_2}{2}\right)\right] t + l_b^2\left(\frac{\pi\theta_2}{180} - \sin\theta_2\right)$	$l_e > \sqrt{l_b^2 - (t_{sp}/2)^2}$, use $A_{mod,1}$ $l_e \leq \sqrt{l_b^2 - \left(\frac{t_{sp}}{2}\right)^2}$  $A_{mod} = -l_b t\cos\left(\frac{\theta_2}{2}\right) - \frac{l_b^2}{2}\left(\frac{\pi\theta_2}{180} - \sin\theta_2\right) + l_e t_{sp}$

where A_{mod} = modification to projected tension area; A_{pt} = projected tension area; l_b = effective embedment length of anchor bolt; l_e = distance from anchor bolt to end; n = number of anchor bolts; s = spacing of anchor bolts; t_{sp} = specified thickness of masonry

Example: Multiple Anchor Bolts

- Determine projected tension area for bolts placed in top of wall
- Embedment length, l_b, is 5.0 in.





Projected tension area: $A_{pt} = \frac{1}{2}(169.5 in.^2 + 109.4 in.^2) = 139.4 in.^2$

Anchor Bolts: Shear

- Allowable Shear Capacity
- Shear Breakout Area

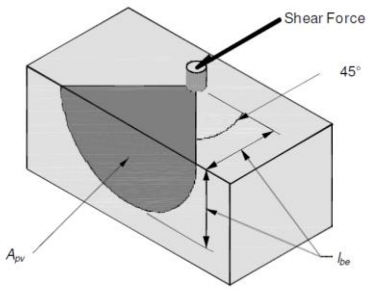
Allowable Shear Capacity

Masonry Designers' Guide 9.3.3; TMS 402 8.1.3.3.2

Failure Mode	Design Strength
Masonry breakout	$B_{vb} = 1.25A_{pv}\sqrt{f'_m}$
Masonry crushing (changed in 2016)	$B_{vc} = 580\sqrt[4]{f'_m A_b}$
Anchor bolt pryout	$B_{vpry} = 2.5A_{pt}\sqrt{f'_m} = 2.0B_{ab}$
Steel yielding	$B_{vs} = 0.36A_b f_y$

Shear Breakout Area

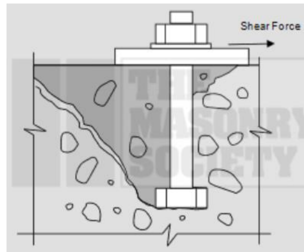
Masonry Designers' Guide 9.3.3; TMS 402 6.3.3



TMS 402 *Figure CC-6.3-6*

$$A_{pv} = \frac{\pi l_{be}^2}{2}$$

l_{be} = edge of masonry to center of bolt in direction of load

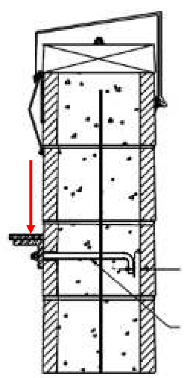


TMS 402 *Figure CC-6.3-7* 55

Example: Bent-Bar Anchor Bolt

Masonry Designers' Guide Example 9.3-5

- 1/2-in. diameter, A307 bent-bar anchor bolt
- Embedded horizontally in the side of an 8-in. masonry wall
- Depth to bottom of bolt = 5.0 in.
- Embedment length, l_b, is 4.0 in.
- f'_m = 2,000 psi
- Anchor is located far from free edge in direction of applied shear



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Example: Allowable Shear Capacity

Masonry Designers' Guide Example 9.3-5

Masonry crushing: $B_{vc} = (580)\sqrt[4]{f'_m A_b}$

$= (580)\sqrt[4]{(2000psi)(0.196in.^2)} = \boxed{2{,}581\ lb}$

Steel yielding: $B_{vns} = 0.36 A_b f_y = (0.36)(0.142in.^2)(36{,}000psi) = \boxed{1{,}840\ lb}$

Pryout: $A_{pt} = \pi l_b^2 = \pi(4.0in.)^2 = 50.3\text{in.}^2$

$B_{vpry} = 2.5 A_{pt}\sqrt{f'_m} =$

$= (2.5)(50.3in.^2)\sqrt{2000psi} = \boxed{5{,}624\ lb}$

- generally only controls for short embedment lengths

Allowable Shear Capacity= 1,840 lb

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Example: Minimum Edge Distance

Masonry Designers' Guide Example 9.3-5

Set masonry breakout = Steel Yielding limit:

Masonry Breakout: $B_{vb} = 1.25 A_{pv}\sqrt{f'_m} = 1.25\frac{\pi}{2} l_{be}^2 \sqrt{2{,}000\ psi} = 1{,}840\ lb$

$\boxed{l_{be} = 4.6\ in.}$

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Example: Minimum Embedment Depth

Masonry Designers' Guide Example 9.3-5

Set anchor bolt pryout = Steel Yielding limit:

Anchor Bolt Pryout: $B_{vpry} = 2.5A_{pt}\sqrt{f'_m} = 2.5\pi l_b^2\sqrt{2{,}000\ psi} = 1{,}840\ lb$

$$l_b = 2.3\ in.$$

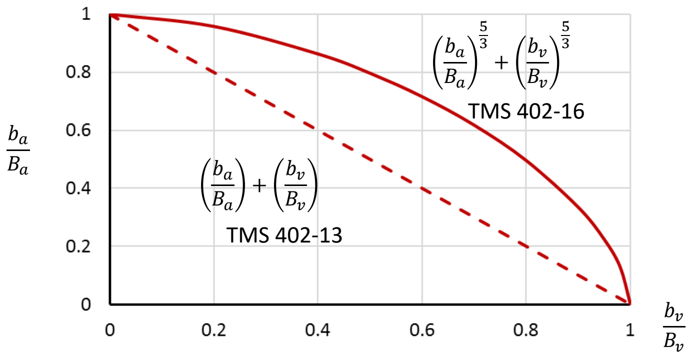
Anchor Bolts: Combined Tension and Shear

Combined Allowable Capacity

Masonry Designers' Guide 9.3.4; TMS 402 8.1.3.3.3

$$\left(\frac{b_a}{B_a}\right)^{\frac{5}{3}} + \left(\frac{b_v}{B_v}\right)^{\frac{5}{3}} \leq 1$$

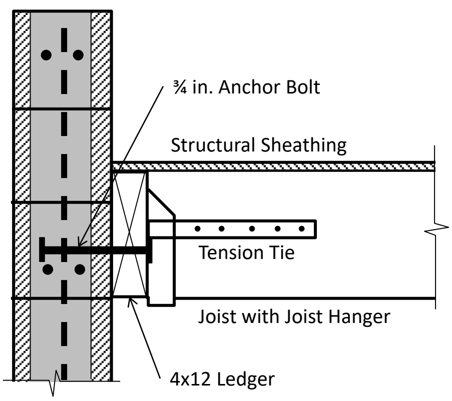
TMS 402-13: Exponent was 1.0, or linear interaction – updated in 2016 due to testing by by Fabrello-Streufert et al (2003) and McGinley (2006)



Example: Combined Loading

Masonry Designers' Guide Example 9.3-7

- 3/4-in. diameter, A307 headed anchor
- Embedded 5-1/2 inches (to the bottom of the bolt) in the side of a fully grouted, 8-in. CMU wall
- Tension force of 1.50 kip/ft
- Shear force of 0.60 kip/ft
- Anchors not near edge
- f'_m = 2,000 psi
- Determine the required anchor bolt spacing



Example: Tension Capacity

Masonry Designers' Guide Example 9.3-7

Effective Embedment Length $l_b = 5.5\ in. - 0.5\ in. = 5.0\ in.$ (head of anchor bolt = 0.5 in. thick)

Projected tensile area $A_{pt} = \pi l_b^2 = \pi(5.0in.)^2 = 78.5in.^2$

Tension Capacity:

Masonry breakout:
$$B_{ab} = 1.25A_{pt}\sqrt{f'_m} = (1.25)(78.5in.^2)\sqrt{2000psi} = 4{,}391\ lb.$$

Steel yielding:
$$B_{as} = 0.6A_b f_y = 0.6(0.334in.^2)(36{,}000psi) = 7{,}214\ lb.$$

Masonry breakout controls

Use B_a = 4,391 lb.

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Example: Shear Capacity

Masonry Designers' Guide Example 9.3-7

Masonry crushing:
$$B_{vc} = (580)\sqrt[4]{f'_m A_b} = (580)\sqrt[4]{(2000psi)(0.442in.^2)} = 3{,}163\ lb.$$

Masonry pryout:
$$B_{vpry} = 2.5A_{pt}\sqrt{f'_m} = (2.5)(78.5in.^2)\sqrt{2000psi} = 8{,}771\ lb.$$

Steel yielding:
$$B_{vs} = 0.36A_b f_y = (0.36)(0.334in.^2)(36{,}000psi) = 4{,}329\ lb.$$

Masonry crushing controls

Use B_v = 3,163 lb.

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Example: Determine Spacing

Masonry Designers' Guide Example 9.3-7

Interaction equation: $\left(\frac{b_a}{B_a}\right)^{5/3} + \left(\frac{b_v}{B_v}\right)^{5/3} \leq 1.0$

Solve for spacing, s: $\left(\frac{\left(1{,}500\ \frac{lb.}{ft.}\right)s}{4{,}391\ lb.}\right)^{5/3} + \left(\frac{\left(600\ \frac{lb.}{ft.}\right)s}{3{,}163\ lb.}\right)^{5/3} = 1.0$

s = 2.42 ft = 29.0 inch
Use s = 24 inch

65

Example: Effect of Code Changes

Design Basis	Required spacing, s
TMS 402-16	29.0 inch
TMS 402-13 (linear interaction)	22.6 inch

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Anchor Bolts: Looking Ahead

Anchor Bolts: Looking Ahead

- Research: Post-Installed Anchors in Grouted CMU
- New ICC Acceptance Criteria
- Simplified Calculations
- Will be looking at TMS 402 applicability

Thursday, October 14, 2021 *Nashville, TN*

2021 TMS Annual Meeting — THE MASONRY SOCIETY — General Session 2 - Research

Performance of Post-Installed Anchors in Grouted Concrete Block Masonry

Arturo E. Schultz
University of Texas at San Antonio

Kenton McBride
Hilti Corporation

This concludes The American Institute of Architects Continuing Education Systems Course

THE MASONRY SOCIETY

Scott Walkowicz, PE, FTMS, NCEES
Walkowicz Consulting Engineers, LLC
scott@walkowiczce.com

The Masonry Society

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