NCMA TEK

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DESIGN OF ANCHOR BOLTS EMBEDDED IN CONCRETE MASONRY

TEK 12-3A
Reinforcement & Connectors (2004)

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INTRODUCTION

The function of anchor bolts is to transfer loads to the masonry from attachments such as ledgers, sill plates, weld plates, etc. Both shear and tension are transferred through anchor bolts in resisting design forces such as uplift due to wind or vertical gravity loads on ledgers (see Figure 1). The magnitude of these loads varies significantly with the application.

Anchor bolts can generally be divided into two categories: embedded anchor bolts which are placed in the grout during construction of the masonry; and post-installed anchors, which are placed after construction of the masonry. Post-installed anchors achieve shear and tension (pull out) resistance by means of expansion against the masonry or sleeves, or by bonding with epoxy or other adhesives. The design of post-installed anchors should be in accordance with the manufacturer's literature and is beyond the scope of this TEK.

This TEK provides assistance in determining the proper size, embedment length and spacing of embedded anchor bolts to resist design loads, based on the provisions of *Building Code Requirements for Masonry Structures* (ref. 1).

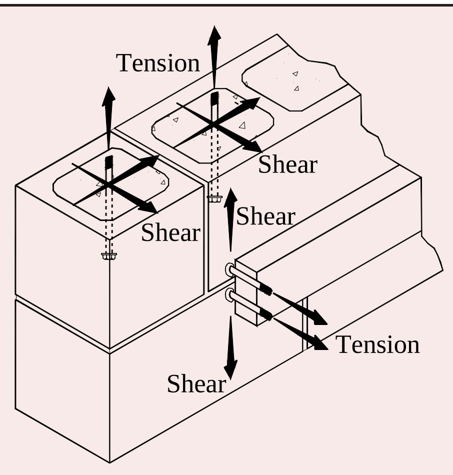


Figure 1—Functions of Anchor Bolts

Types of Embedded Anchor Bolts

Conventional bolts (headed, bent-bar and plate) are available in standard diameters and lengths or can be fabricated to meet specific project requirements.

Headed anchor bolts typically have either a square or hex-head shape and are popular due to their wide availability and relatively low cost. Washers can be placed against the bolt head to enlarge the bearing area and thereby increase pullout resistance.

Bent-bar anchor bolts are currently fabricated in a variety of shapes because no standard exists governing the geometric properties. L and J shapes are the most common.

Plate anchor bolts are fabricated by welding a square or circular steel plate at right angles to the axis of a steel bar.

Applications and Uses

In most new masonry construction, anchor bolts are commonly embedded at:

- tops of walls, to attach sill plates and weld plates for the purpose of supporting wood and steel joists, trusses and beams;
- tops of columns, to attach bearing plates for the purpose of supporting wood and steel beams; and
- surfaces of walls, to attach wood or steel ledger beams used to support wood and steel joists and trusses.

EFFECTIVE EMBEDMENT LENGTH

The minimum effective embedment length for anchor bolts is four bolt diameters or 2 in. (51 mm), whichever is greater (see Figure 2). The embedment length of plate or headed bolts, l_b, is measured from the surface of the masonry to the bearing surface of the bolt head or plate. For bent-bar anchors, the effective embedment length is measured from the surface of the masonry to the bearing surface on the bent end minus one anchor bolt diameter.

CONSTRUCTION

Existing masonry codes currently do not address tolerances for anchor bolt placement, nor do they provide guidance related to their construction. In the absence of such criteria, the construction tolerances used for placement of structural reinforcement could be modified for application to anchor bolts.

While the means and methods of construction with anchor bolts is outside the scope of code requirements, embedded

  (replaces TEK 12-3)

anchor bolts are required to be installed and in their final location prior to grouting (ref. 1).

In order to keep the anchor bolts properly aligned during grout placement, templates can be used to hold the bolts within the necessary tolerances. Templates, which are typically made of wood or steel, also prevent grout leakage in cases where anchors protrude from the side of a wall.

DESIGN REQUIREMENTS

Building Code Requirements for Masonry Structures (ref. 1) contains anchor bolt design provisions for both the allowable stress design and strength design methods (Chapters 2 and 3, respectively). An overview of these design philosophies can be found in *Allowable Stress Design of Concrete Masonry*, TEK 14-7A, and *Strength Design of Concrete Masonry*, TEK 14-4A (refs. 3, 4). Note that Chapter 5 of the code also includes prescriptive criteria for floor and roof anchorage which can be used when empirical design is implemented.

Allowable Stress Design (ASD) Provisions

Allowable loads for plate, headed and bent-bar anchor bolts are determined using the following equations. Alternatively, allowable loads may be established by testing in accordance with *Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements*, ASTM E 488 (ref. 2) under stresses and conditions that represent the intended use. In this case, the allowable loads are limited to 20% of the average tested strength of the anchor bolt.

Tension

The allowable load in tension is the lesser of:

$$B_a = 0.5 A_p \sqrt{f'_m}$$

$$B_a = 0.2 A_b f_y$$

$$\left[SI: B_a = 0.042 A_p \sqrt{f'_m} \quad and \quad B_a = 0.2 A_b f_y \right]$$

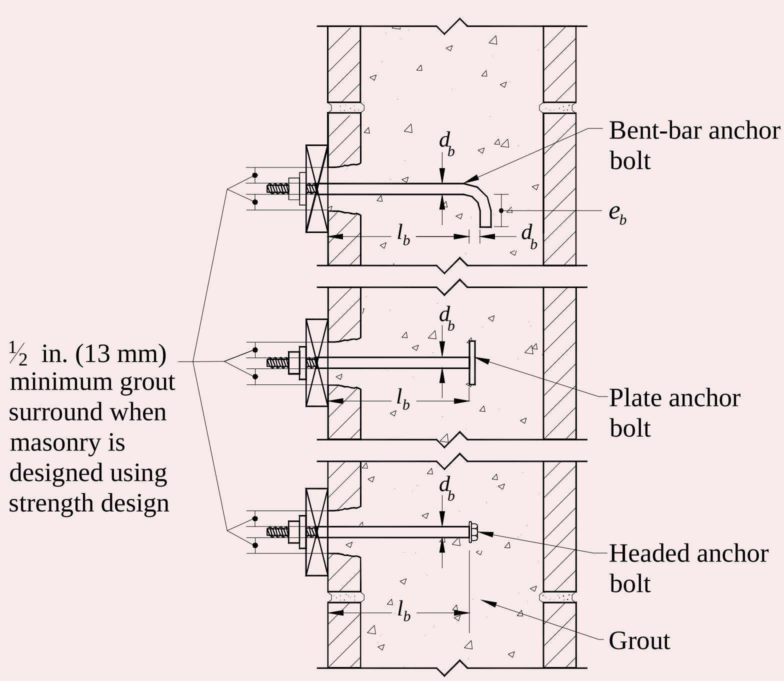
where A_p is the lesser of:

$$A_p = \pi l_b^2$$

$$A_p = \pi l_{be}^2$$

The anchor bolt edge distance, l_{be}, is illustrated in Figure 3. When the projected areas of adjacent anchor bolts overlap, A_p of each bolt is reduced by one-half of the overlapping area, as shown in Figure 4). Any portion of A_p that falls within an open cell or core is deducted from the calculated value of A_p.

Figure 7 shows allowable tension values for headed and bent bar anchor bolts. The curved portion of the graph illustrates the cases where masonry breakout governs, while the horizontal lines indicate the maximum tensile load for each bolt size and type as governed by the anchor bolt steel strength. For example, at a 4 in. (102 mm) embedment length, the allowable tension values are: 353 lb (1,570 N) for a 1/4 in. (6.4 mm) bent-bar anchor bolt; 589 lb (2,620 N) for a 1/4 in. (6.4 mm) headed anchor bolt; 795 lb (3,536 N) for 3/8 in. (9.5 mm) bent-bar anchor bolt; and 973 lb (4,328 N) for all other listed anchor bolts.



Note: minimum embedment length, $l_b = 4d_b$ but not less than 2 in. (51mm)

Figure 2—Minimum Effective Embedment Lengths

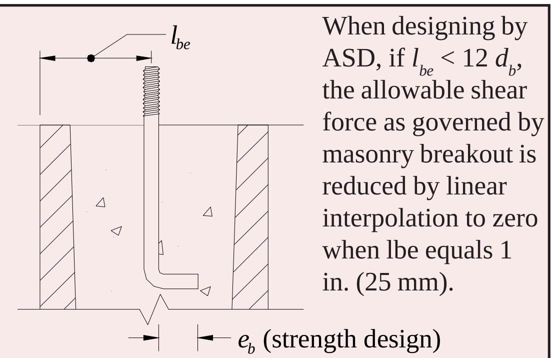
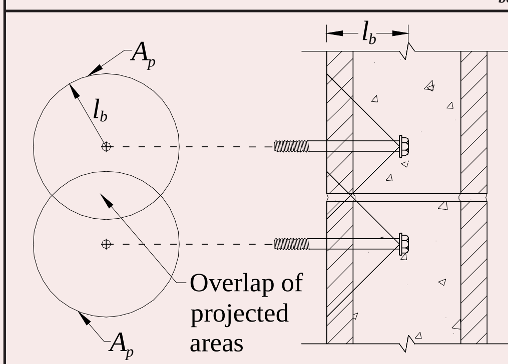


Figure 3—Anchor Bolt Edge Distance, l_{be}



$A_p = \pi l_b^2 - 1/2$ (area of overlap)

Figure 4—Reduction of Projected Area When Bolt Failure Cones Overlap

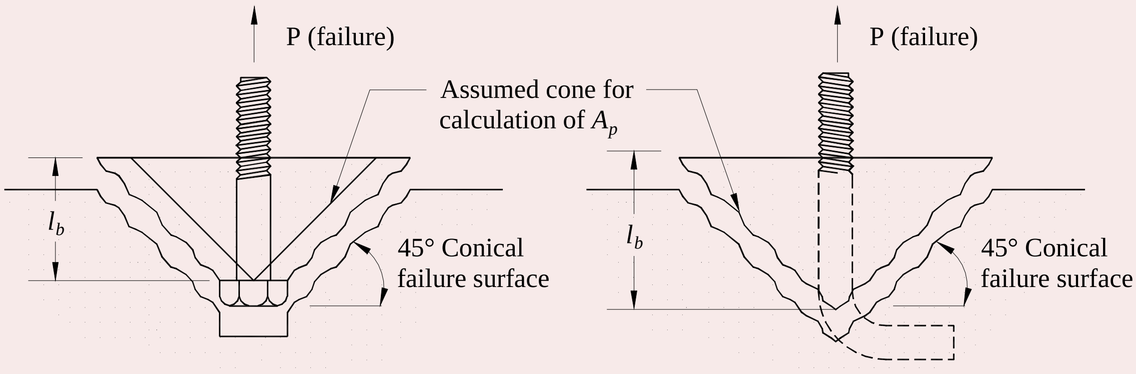


Figure 5—Assumed Anchor Bolt Failure Cone

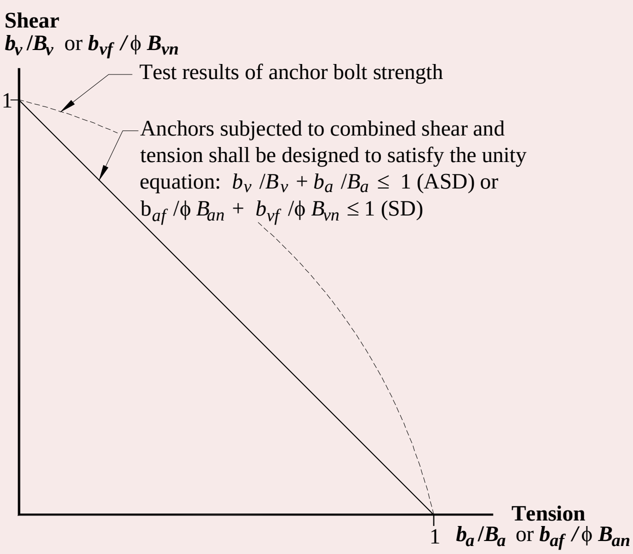


Figure 6—Unity Equation for Anchors Subjected to Combined Shear and Tension

Shear

When l_{be} equals or exceeds 12 bolt diameters, a full failure cone (as shown in Figure 5 for tension) can develop and the allowable load in shear is the lesser of:

$$B_v = 350\sqrt[4]{f'_m A_b}$$

$$B_v = 0.12 A_b f_y$$

$$\left[SI: B_v = 1{,}072\sqrt[4]{f'_m A_b} \quad and \quad B_v = 0.12 A_b f_y\right]$$

Where l_{be} is less than 12 bolt diameters, the value of B_v determined from $B_v = 350\sqrt[4]{f'_m A_b}$ is reduced by linear interpolation to zero at an l_{be} distance of 1 in. (25 mm). These reduction factors, along with allowable shear values are listed in Table 1.

Combined Shear & Tension

Anchor bolts subjected to both tension and shear must be designed to satisfy the following:

$$\frac{b_a}{B_a} + \frac{b_v}{B_v} \le 1$$

This relationship is illustrated in Figure 6.

Strength Design (SD) Provisions

The *Building Code Requirements for Masonry Structures* (ref. 1) strength design provisions require embedded anchor bolts to have at least 1/2 in. (13 mm) of grout between the bolt and the masonry, except that 1/4 in. (6.4 mm) diameter anchor bolts are permitted to be placed in bed joints at least 1/2 in. (13 mm) thick. Nominal strengths of headed and bent-bar anchor bolts are determined using the following equations.

When anchor bolts penetrate the face shell of a masonry unit and are designed by the strength design method, the opening in the face shell is required to provide at least **1/2** in. (13 mm) of grout cover around the perimeter of the bolt.

Nominal Axial Tensile Strength

The nominal axial tensile strength, B_{an}, of headed anchor bolts is the lesser of:

$$B_{an} = 4A_{pt}\sqrt{f'_m} \qquad (Eqn. 1)$$

$$B_{an} = A_b f_y \qquad (Eqn. 2)$$

$$\left[SI: B_{an} = 0.332A_{pt}\sqrt{f'_m} \quad and \quad B_{an} = A_b f_y\right]$$

For J- and L-shaped bent bar anchor bolts, B_{an} is the least of Equations 1 and 2 above and the following additional equation:

$$B_{an} = 1.5 f'_m e_b d_b + \left[300\pi(l_b + e_b + d_b)d_b\right] \qquad (Eqn. 3)$$

$$\left[SI: B_{an} = 0.332A_{pt}\sqrt{f'_m}, \quad B_{an} = A_b f_y \quad and\right.$$

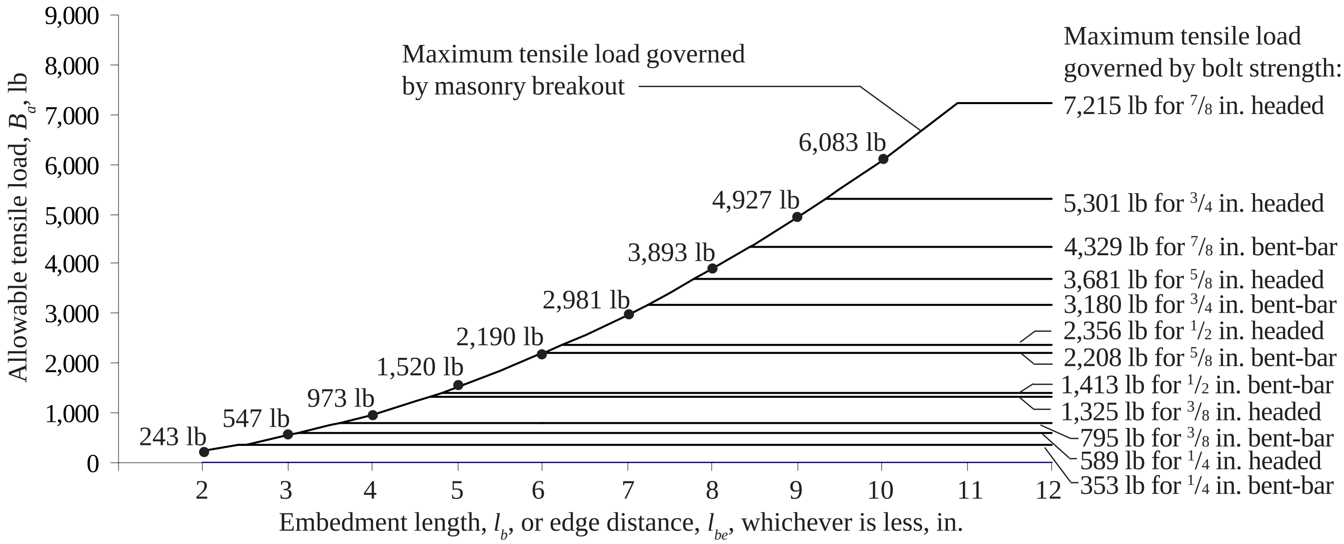
$$\left. B_{an} = 1.5 f'_m e_b d_b + \left[3.07\pi(l_b + e_b + d_b)d_b\right]\right]$$

where $\left[300\pi(l_b + e_b + d_b)d_b\right]$ is included only if the specified quality assurance program includes verification that shanks of bent bar anchor bolts are free of debris, oil and grease when installed.

For both headed and bent-bar bolts, $A_{pt} = \pi l_b^2$ (see Figure 2 for definition of l_b).

In cases where A_{pt} of adjacent anchor bolts overlap, A_{pt} of each anchor bolt is reduced by one-half of the overlapping area. The portion of A_{pt} overlapping an open cell, open head joint or which is outside the wall is deducted from the value of A_{pt} calculated above.

Figure 7—Allowable Stress Design, Allowable Tension, B_a [a]



[a] f'_m = 1,500 psi (10.34 MPa). For headed anchor bolts, f_y = 60,000 psi (413.6 MPa), for bent-bar, f_y = 36,000 psi (248.2 MPa). lb x 4.448222 = N; in. x 25.4 = mm. Values assume that projected areas of adjacent anchor bolts do not overlap (anchor spacing greater than or equal to $2l_b$ or $2l_{be}$)

Table 1—Allowable Stress Design, Allowable Shear

Table 1a—Allowable shear, B_v, lb[a]

Bolt type:	Bolt diameter, d_b, in. 1/4	3/8	1/2	5/8	3/4	7/8
headed	353	795	1,413	1,621	1,775	1,918
bent-bar	212	477	848	1,325	1,775	1,918

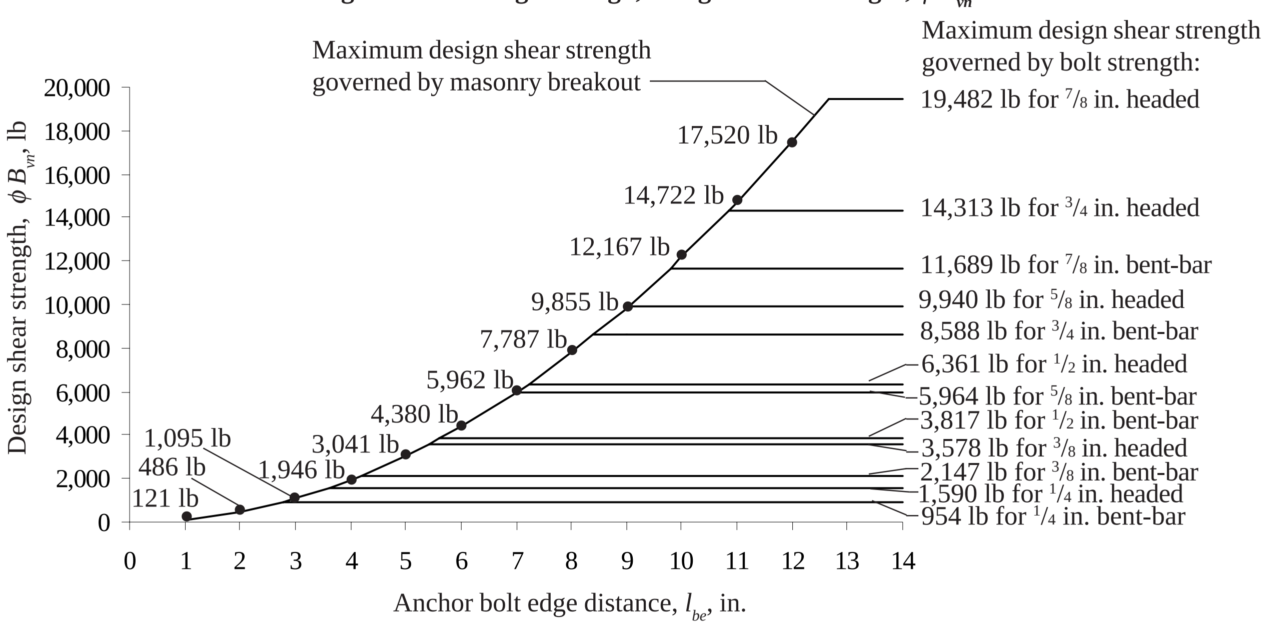
[a] f'_m = 1,500 psi (10.34 MPa). Values assume $l_{be} \geq 12d_b$. For headed anchor bolts, f_y = 60,000 psi (413.6 MPa), for bent-bar, f_y = 36,000 psi (248.2 MPa). lb x 4.448222 = N; in. x 25.4 = mm.

Table 1b—Allowable shear reduction factors [b]

Anchor diameter	Anchor bolt edge distance, in. 2	3	4	5	6	7	8	9	10
1/4 in.	0.500	1.000	NA	NA	NA	NA	NA	NA	NA
3/8 in.	0.285	0.571	0.857	NA	NA	NA	NA	NA	NA
1/2 in.	0.200	0.400	0.600	0.800	1.000	NA	NA	NA	NA
5/8 in.	0.153	0.307	0.461	0.615	0.769	0.923	NA	NA	NA
3/4 in.	0.125	0.250	0.375	0.500	0.625	0.750	0.875	1.000	NA
7/8 in.	0.105	0.210	0.315	0.421	0.526	0.631	0.736	0.842	0.947

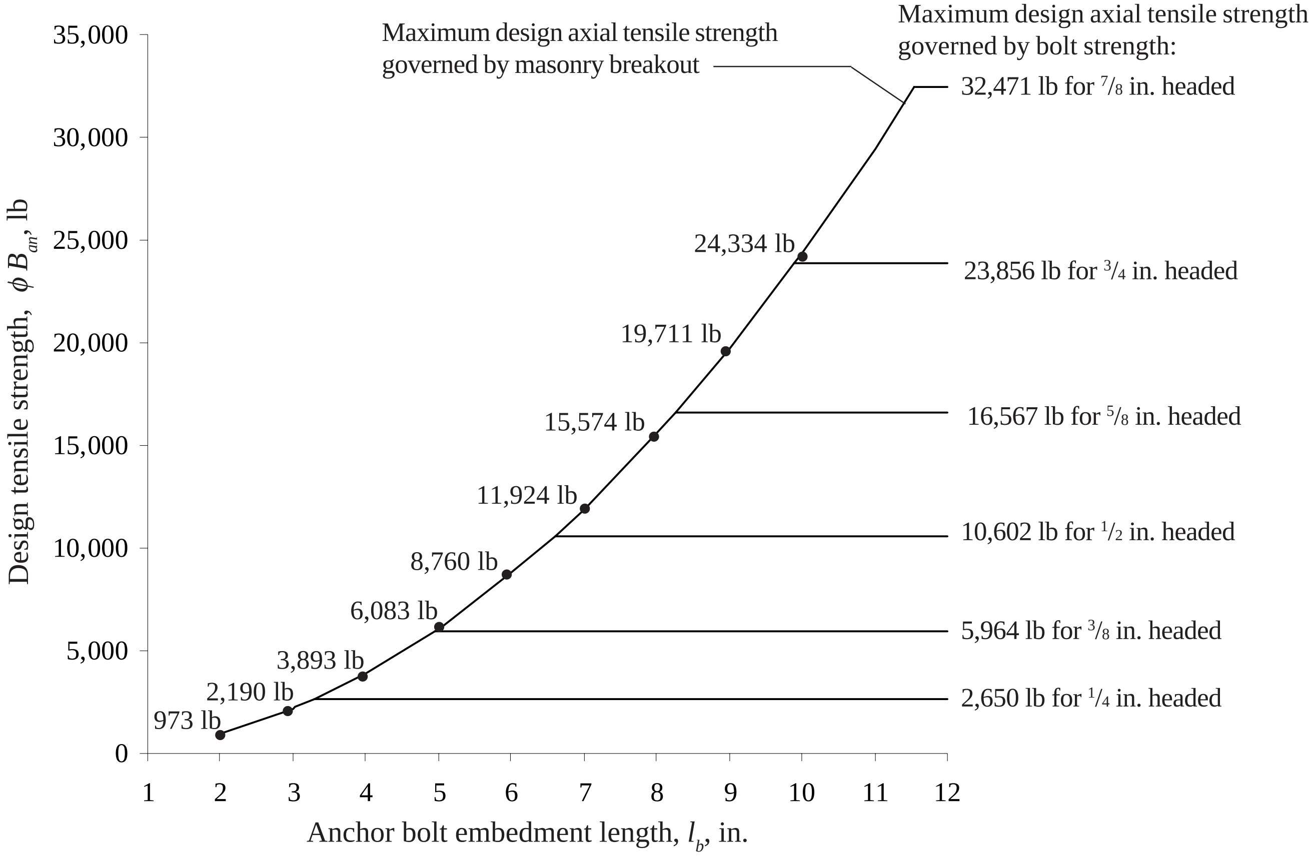
[b] Multiply the values in Table 1a by the above factors when $l_{be} < 12d_b$, B_v (reduction factor = $l_{be}/(12d_b-1) - 1/(12d_b-1)$).

Figure 10—Strength Design, Design Shear Strength, ϕB_{vn} [a]



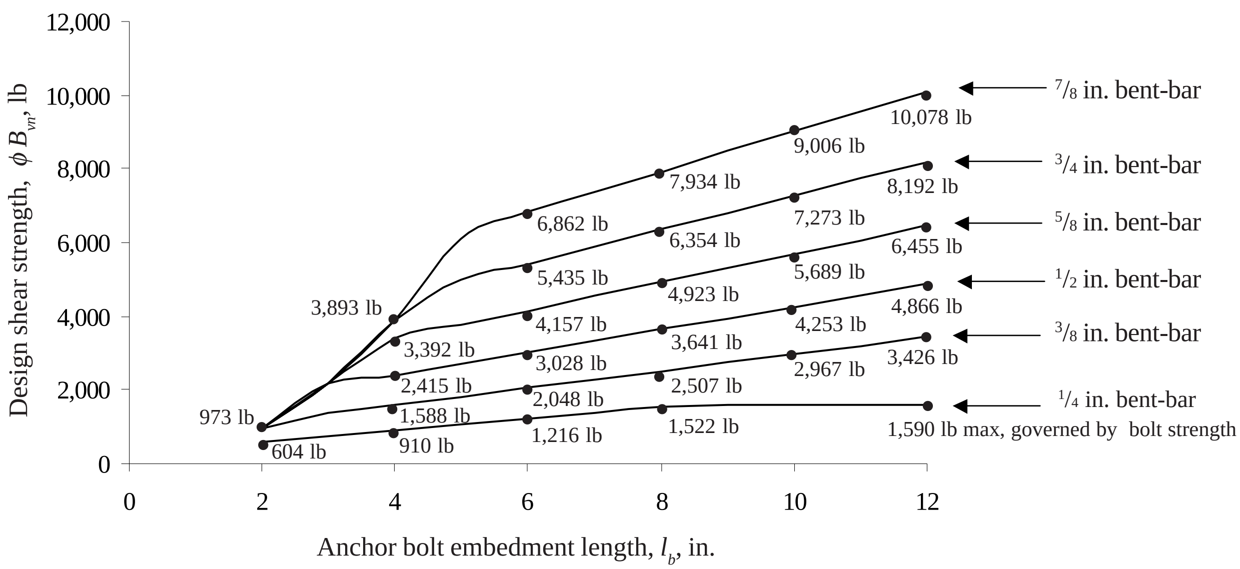
[a] f'_m = 1,500 psi (10.34 MPa). For headed anchor bolts, f_y = 60,000 psi (413.6 MPa), for bent-bar, f_y = 36,000 psi (248.2 MPa). Strength reduction factors: 0.50 for masonry breakout; 0.90 for anchor bolt steel. lb x 4.448222 = N; in. x 25.4 = mm.

Figure 8—Strength Design, Design Axial Tensile Strength of Headed Anchor Bolts, ϕB_{an} [a]



[a] f'_m = 1,500 psi (10.34 MPa), f_y = 60,000 psi (413.6 MPa). Strength reduction factors: 0.50 for masonry breakout; 0.90 for anchor bolt steel. Values assume that projected areas of adjacent anchor bolts do not overlap (anchor spacing greater than or equal to $2l_b$). lb x 4.448222 = N; in. x 25.4 = mm.

Figure 9—Strength Design, Design Axial Tensile Strength of Bent-Bar Anchor Bolts, ϕB_{an} [a]



[a] Assumes that the specified quality assurance program includes verification that shanks of J and L bolts are free of debris, oil and grease when installed. f'_m = 1,500 psi (10.34 MPa), $e_b = 2d_b$, f_y = 36,000 psi (248.2 MPa). Strength reduction factors: 0.50 for masonry breakout; 0.90 for anchor bolt steel; 0.65 for anchor pullout. Values assume that projected areas of adjacent anchor bolts do not overlap (anchor spacing greater than or equal to $2l_b$). lb x 4.448222 = N; in. x 25.4 = mm.

Figures 8 and 9 show design axial tensile strength values, ϕB_{an}, for headed and bent bar anchor bolts, respectively.

Nominal Shear Strength

The nominal shear strength, B_{vn}, of headed and bent bar anchor bolts is the lesser of:

$$B_{vn} = 4A_{pv}\sqrt{f'_m} \qquad (Eqn.\ 4)$$

$$B_{vn} = 0.6A_b f_y \qquad (Eqn.\ 5)$$

$$[SI: B_{vn} = 0.332A_{pv}\sqrt{f'_m} \quad and \quad B_{vn} = 0.6A_b f_y]$$

where $A_{pv} = \frac{1}{2}\pi l_{be}^2$

Figure 10 shows design shear strength values, ϕB_{vn}, for headed and bent bar anchor bolts.

Combined Axial and Shear Strength

Similar to ASD, in accordance with the strength design provisions anchor bolts subjected to both tension and shear must be designed to satisfy the following unity equation:

$$\frac{b_{af}}{\phi B_{an}} + \frac{b_{vf}}{\phi B_{vn}} \le 1$$

Strength Reduction Factors

When nominal strength of anchor bolt is governed by:	ϕ equals:
masonry breakout (Eqn. 1 or 4)	0.50
anchor bolt steel (Eqn. 2 or 5)	0.90
anchor pullout (Eqn. 3)	0.65

NOTATIONS

A_b = cross-sectional area of an anchor bolt, in.^{2} (mm^2)
A_p = projected area on the masonry surface of a right circular cone for anchor bolt allowable shear and tension calculations, in.^{2} (mm^2)
A_{pt} = projected area on the masonry surface of a right circular cone for calculating tensile breakout capacity of anchor bolts, in.^{2} (mm^2)
A_{pv} = projected area on the masonry surface of one-half of a right circular cone for calculating shear breakout capacity of anchor bolts, in.^{2} (mm^2)
B_a = allowable axial force on an anchor bolt, lb (N)
B_{an} = nominal axial strength of an anchor bolt, lb (N)
B_v = allowable shear force on an anchor bolt, lb (N)
B_{vn} = nominal shear strength of an anchor bolt, lb (N)
b_a = total applied design axial force on an anchor bolt, lb (N)
b_{af} = factored axial force in an anchor bolt, lb (N)
b_v = total applied design shear force on an anchor bolt, lb (N)
b_{vf} = factored shear force in an anchor bolt, lb (N)
d_b = nominal diameter of anchor bolt, in. (mm)
e_b = projected leg extension of bent bar anchor, measured from inside edge of anchor at bend to farthest point of anchor in the plane of the hook, in. (mm)
f'_m = specified compressive strength of masonry, psi (MPa)
f_y = specified yield strength of steel for anchors, psi (MPa)
l_b = effective embedment length of plate, headed or bent-bar anchor bolts, in. (mm)
l_{be} = anchor bolt edge distance, measured in the direction of load, from edge of masonry to center of the cross section of anchor bolt, in. (mm)
ϕ = strength reduction factor

REFERENCES

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2. *Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements*, ASTM E 488-96 (2003). ASTM International, 2003.
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