DESIGNER CHECKLIST FOR ANCHORAGE INTO CONCRETE MASONRY BASED ON TMS 402/602-22

Anchor bolts are used to connect masonry to other elements within a structure for support and load transfer. TMS 402/602 addresses the design and installation of anchors embedded in freshly placed grout, however, post-installed anchors are commonly used as well. Given the proprietary nature of most post-installed anchor bolts, they are outside of the scope of this Checklist. The design of veneer anchorage (e.g., veneer ties) is also outside the scope of this Checklist.

TMS 402/602 addresses two types of embedded anchors: bent-bar anchors and headed anchors. Both are addressed in this Checklist.

This Checklist is applicable to anchors embedded in masonry construction designed in accordance with TMS 402/602 for commercial structures covered under the *International Building Code*. Single family residential construction covered under the *International Residential Code* has different design, detailing, and construction requirements specific an anchor bolts embedded in masonry.

TMS 402 contains design modeling options for both allowable stress design (ASD) and strength design (SD). Where design checks differ between these two modeling approaches, they are addressed separately in this Checklist.

CHECK	REQUIREMENT	REFERENCE	DESIGNER NOTES
SECTION 1: MATERIAL REQUIREMENTS			
1	Concrete Masonry Units: CMU must comply with the requirements of ASTM C90.	TMS 602 Art. 2.3 A	Anchor bolts can be used with any CMU configuration other than solid units as anchor bolts are required to be embedded in grout. All loadbearing CMU must meet the minimum requirements of ASTM C90, however, baseline CMU compressive strengths can vary regionally as well as based on the type of CMU being specified (grey CMU vs. architectural CMU). When a specific CMU compressive strength is desired, contact producers or regional organizations in the project area for recommendations on available unit compressive strengths.
2	Mortar: Complying with ASTM C270 or ASTM C1714/C1714M.	TMS 602 Art. 2.1 A	Masonry containing anchor bolts will typically be loadbearing construction, and as such, Type S mortar is recommended. For partially grouted loadbearing masonry assemblies that are part of a structure assigned to Seismic Design Category D, E, or F, Type S portland cement-lime mortar or mortar cement mortar is required. Otherwise, masonry cement mortar is permitted by TMS 402. There is functionally no difference between mortar complying with ASTM C270 versus mortar complying with ASTM C1714/C1714M as each must meet the same constituent material requirements and proportion/property requirements. Mortars complying with ASTM C1714/C1714M are preblended and delivered to

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			jobsites in bags where water is added. ASTM C270 mortars may be batched onsite from constituent materials.
3	Specify minimum compressive strength for the masonry assembly.	TMS 602 Art. 1.4 B.2, Table 2	The most common method of specifying the minimum compressive strength of masonry construction (f'_m) is by using the unit strength table of TMS 602, which establishes the masonry assembly compressive strength based on the compressive strength of the CMU and the type of mortar used in construction. Note that when high compressive strength masonry (f'_m > 3,000 lb/in.^{2}) is warranted, the use of prisms to verify the compressive strength may provide more design economy as the unit strength table becomes more conservative at high strength ranges.
4	Grout: Must conform to ASTM C476.	TMS 602 Art. 2.2	ASTM C476 has options for coarse grout, fine grout, and self-consolidating grout. Coarse grout is most commonly used in concrete masonry construction unless the spaces to be grouted are congested. The primary difference between coarse grout and fine grout is the size of the aggregate in the mix, with the smaller aggregate size required of fine grout necessary to facilitate the placement and consolidation of the grout in tight spaces. As such, a fine grout can be substituted for coarse grout with no detrimental impact to the construction or performance of the masonry. However, if a fine grout is specified because of reinforcement congestion or small clearances, a fine grout complying with ASTM C476 should be used as a coarse grout may result in consolidation issues and voids within the final construction.
5	Anchors: Bent-bar anchors must conform to ASTM A36/A36M or ASTM F1554. Headed anchors must conform to ASTM A307, Grade A or ASTM F1554.	TMS 602 Art. 2.4 J.	Specified material properties for anchor bolts includes: • ASTM A36/A36M – Minimum yield strength of 36,000 lb/in.^{2}. The tensile strength is not defined, but can vary between 58,000 lb/in.^{2} and 80,000 lb/in.^{2}. • ASTM F1554, Grade 36 – Minimum yield strength of 36,000 lb/in.^{2}. The tensile strength can vary between 58,000 lb/in.^{2} and 80,000 lb/in.^{2}. • ASTM F1554, Grade 55 – Minimum yield strength of 55,000 lb/in.^{2}. The tensile strength can vary between 75,000 lb/in.^{2} and 95,000 lb/in.^{2}. • ASTM F1554, Grade 105 – Minimum yield strength of 105,000 lb/in.^{2}. The tensile strength can vary between 125,000 lb/in.^{2} and 150,000 lb/in.^{2}. • ASTM A307, Grade A – A minimum yield strength is not defined. The minimum tensile strength 60,000 lb/in.^{2}.
SECTION 2: DESIGN FOR TENSION			
6	Design anchors for axial tension (ASD).	TMS 402 Sec. 8.1.4.3.1	The tensile strength of bent-bar and headed anchors can be governed by tensile breakout or the tensile strength of the anchor. For bent-bar anchors, the tensile strength may also be governed by pullout of the anchor.
7	Design anchors for axial tension (SD).	TMS 402 Sec. 9.1.6.3.1	The tensile strength of bent-bar and headed anchors can be governed by tensile breakout or the tensile strength of the anchor. For bent-bar anchors, the tensile strength may also be governed by pullout of the anchor.

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SECTION 3: DESIGN FOR SHEAR			
8	Design anchors for shear (ASD).	TMS 402 Sec. 8.1.4.3.2	The shear strength of bent-bar and headed anchors can be controlled by shear breakout, crushing of the masonry, pryout of the anchor, or the shear strength of the anchor.
9	Design anchors for shear (SD).	TMS 402 Sec. 9.1.6.3.2	The shear strength of bent-bar and headed anchors can be controlled by shear breakout, crushing of the masonry, pryout of the anchor, or the shear strength of the anchor.
SECTION 4: DESIGN FOR COMBINED TENSION AND SHEAR			
10	Design anchors for combined axial tension and shear (ASD).	TMS 402 Sec. 8.1.4.3.3	When subjected to combined tension and shear, the interaction of these two orthogonal loads reduces the strength of an anchor when considering these loads separately.
11	Design anchors for combined axial load and shear (SD).	TMS 402 Sec. 9.1.6.3.3	When subjected to combined tension and shear, the interaction of these two orthogonal loads reduces the strength of an anchor when considering these loads separately.
SECTION 5: DETAILING REQUIREMENTS			
12	Verify corrosion protection requirements.	TMS 402 Sec. 6.2.1	When directly exposed to earth, weather, or a mean relative humidity greater than 75%, anchors are required to be mill galvanized or hot-dip galvanized. Otherwise, no corrosion protect is required.
13	Verify placement of anchors within the masonry.	TMS 402 Sec. 6.3.1 TMS 602 Art. 3.4 E	TMS 402 requires anchors to be placed within grouted cells of masonry units, either at the top of the unit or through the face shell of a unit. An exception to this applies to anchors that are $^1/_4$ in. in diameter, which are permitted to be embedded in mortar joints that are at least $^1/_2$ in. thick. A minimum clearance between the anchor and the masonry unit of $^1/_4$ in. when using fine grout and $^1/_2$ in. when using coarse grout is required. When designing anchor groups, the clear distance between individual anchors cannot be less than the nominal diameter of the anchors or 1 in., whichever is greater. When an anchor is installed through the face shell of a CMU, it is permitted to be tight-fitted to the masonry unit.
14	Verify minimum embedment length.	TMS 402 Sec. 6.3.6	The minimum effective embedment length for anchors is $4d_b$ (4 times the nominal diameter of the anchor bolt) or 2 in., whichever is greater.
15	Connection to masonry columns in SDC C and above.	TMS 402 Sec. 7.4.3.2.1	In SDC C, D, E, and F, anchors used to connect elements to the top of masonry columns are required to be placed within the confined area of grout.

STANDARD	REFERENCE
ASTM	ASTM A36/A36M, ASTM A307, ASTM C90, ASTM C270, ASTM C476, ASTM C1714/C1714M, and ASTM F1554.
TMS 402 – General	Sections 6.2.1, 6.3.1, 6.3.6, and 7.4.3.2.1
TMS 402 – Allowable Stress Design	Section 8.1.4

TMS 402 – Strength Design	Section 9.1.6
TMS 602	Article 1.4 B.2, 2.1 A, 2.2, 2.3 A, 2.4 J, 3.4 E,

DESIGN EXAMPLE

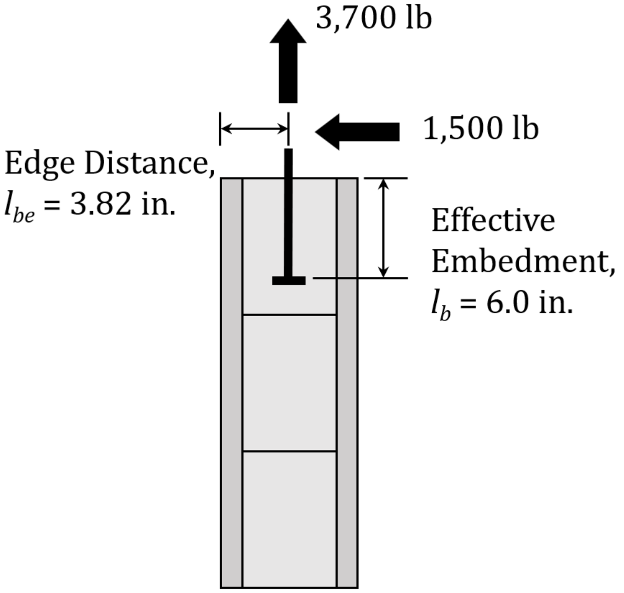
This example illustrates the design checks and detailing requirements per TMS 402/602 for an anchor bolt embedded into the top of a concrete masonry wall. Per Checklist Items 1-5, material considerations include:

1. Concrete Masonry Units – Although some markets (as well as some specific unit types such as split face or ground face unis) may exhibit higher compressive strengths, assume here the default minimum compressive strength of 2,000 lb/in.^{2} required by ASTM C90 applies.
2. Mortar – As this is loadbearing construction, specify a Type S mortar. If this assembly is not assigned to a high seismic design category (e.g., not assigned to SDC D, E, or F), any type of mortar cement is permitted. The type of cement specified for the mortar does not impact the design or detailing of anchors embedded in the masonry.
3. Specified Masonry Compressive Strength (f'_m) – Per Table 2 of TMS 602, a concrete masonry unit with a minimum compressive strength of 2,000 lb/in.^{2} laid in Type S mortar will produce an assembly compressive strength of 2,000 lb/in.^{2}. Hence, f'_m = 2,000 lb/in.^{2} for this example.
4. Grout – Unless a highly congested detail is anticipated, coarse grout should be specified. Per ASTM C476, the minimum compressive strength of grout is 2,000 lb/in.^{2} and in accordance with TMS 402, the minimum specified compressive strength of grout (f'_g) must be equal to or greater than the specified f'_m. Hence, for this example the specified compressive strength of the grout can default to the minimum of 2,000 lb/in.^{2} (e.g., f'_g = 2,000 lb/in.^{2}).
5. Anchors – Here, use a headed anchor bolt complying with ASTM F1554, Grade 36. The nominal diameter required will be determined in subsequent design checks. Headed anchor bolts have the additional advantage over bent-bar anchors as their strength is not governed by pullout. For design, assume a tensile strength of 58,000 lb/in.^{2}.

Additional design parameters include:

Material Properties	
Specified Compressive Strength of CMU	2,000 lb/in.^{2}
Specified Compressive Strength of Masonry, f'_m	2,000 lb/in.^{2}
Specified Yield Strength of Anchors, f_y	36,000 lb/in.^{2}
Specified Tensile Strength of Anchors, f_u	58,000 lb/in.^{2}
Specified Compressive Strength of Grout, f'_g	2,000 lb/in.^{2}
Mortar Type	Type S
Assembly Properties	
Nominal Wall Thickness	8 in.
Fully grouted top course	

Design Loads	
Factored Tensile Load	3,700
Factored Shear Load	1,500



Design for Tension (Checklist Items 6-7)

For headed anchors, axial tensile strength is governed by either tensile breakout or the tensile strength of the anchor steel as axial pullout only applies to bent-bar anchors. For tensile breakout per Equation 9-1 of TMS 402 applying a strength reduction factor of 0.50 in accordance with Section 9.1.4.1, the design axial strength as controlled by tensile breakout is:

$$\phi B_{anb} = (0.50)4A_{pt}\sqrt{f'_m}$$

The projected area for tensile breakout is given by Equation 6-5 of TMS 402. Because this is a single anchor, there is no overlapping breakout area from adjacent anchors (or the spacing of the anchors is such that their breakout areas do not overlap), however, a portion of the breakout cone will fall outside of the wall and must be deducted. TMS 402 Commentary Figure CC-6.3-5 includes the following expression for determining the reduced breakout area:

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

Where:

$$\theta = 2\sin^{-1}\left(\frac{t_{sp}/2}{l_b}\right) = 2\sin^{-1}\left(\frac{7.63\text{ in.}/2}{6.0\text{ in.}}\right) = 78.9\text{ degrees}$$

The resulting projected breakout area is then:

$$A_{pt} = (2)(7.63\text{ in.})\left(\sqrt{(6.0\text{ in.})^2 - \left(\frac{7.63\text{ in.}}{2}\right)^2}\right) + (6.0\text{ in.})^2\left(\frac{\pi(78.9°)}{180} - \sin(78.9°)\right) = 84.9\text{ in.}^2$$

The design axial strength as controlled by breakout is then:

$$\phi B_{anb} = (0.50)(4)(84.9\text{ in.}^2)\sqrt{2{,}000\ ^{\text{lb}}/_{\text{in.}^2}} = 7{,}590\text{ lb}$$

The axial tensile strength of the anchor governed by the anchor steel if given by TMS 402 Equation 9-2. Applying a strength reduction factor of 0.75 per Section 9.1.4.1 results in:

$$\phi B_{ans} = (0.75)(A_b)(f_u)$$

The area of the bolt (A_b) must be reduced to account for the reduction in the cross-sectional area resulting from threading the bolt. Assuming an anchor with a nominal diameter of 5/8 in. and having 11 threads per inch along the length of the bolt, the effective area of the anchor can be found in TMS 402 Table CC-6.3.1 or calculated per Equation 6-7 of TMS 402 as follows based on the number of threads per inch (n_t) and the nominal diameter of the anchor (d_o):

$$A_b = \left(\frac{\pi}{4}\right)\left(d_o - \frac{0.9743}{n_t}\right)^2 = \left(\frac{\pi}{4}\right)\left(0.625\text{ in.} - \frac{0.9743}{11}\right)^2 = 0.226\text{ in.}^2$$

TMS 402 limits the tensile strength of anchors (f_u) to the smaller of $1.9f_y$ and 125,000 lb/in.^{2} to preclude the anchors from yielding under allowable stress level loads. Here, (1.9)(36,000 lb/in.^{2}) = 68,400 lb/in.^{2}. The specified anchor tensile strength of 58,000 lb/in.^{2} is less than both these values. The resulting tensile strength of the anchor as controlled by the anchor steel is then:

$$\phi B_{ans} = (0.75)(0.226\text{ in.}^2)\left(58{,}000\ ^{\text{lb}}/_{\text{in.}^2}\right) = 9{,}830\text{ lb}$$

For this combination of design variables, the axial strength of the anchor is controlled by breakout: 7,590 lb, which is also greater than the factored axial load applied to the anchor of 3,700 lb.

Design for Shear (Checklist Items 8-9)

In checking the shear strength of the anchor, several additional checks are required to determine the shear strength as governed by either shear breakout, masonry crushing, pryout, or the shear strength of the anchor steel. The shear breakout strength is given by TMS 402 Equation 9-4. Applying a breakout-governed strength reduction factor of 0.50, the design shear strength governed by shear breakout is:

$$\phi B_{vnb} = (0.50)(4)(A_{pv})\sqrt{f'_m}$$

The projected shear breakout area (A_{pv}) is given by TMS 402 Equation 6-6:

$$A_{pv} = \frac{\pi(l_{be})^2}{2} = \frac{\pi(3.82\text{ in.})^2}{2} = 22.9\text{ in.}^2$$

The resulting design shear strength as governed by shear breakout is:

$$\phi B_{vnb} = (0.50)(4)(22.9\text{ in.}^2)\sqrt{2{,}000\ {}^{\text{lb}}/_{\text{in.}^2}} = 2{,}040\text{ lb}$$

Checking the design shear strength as controlled by crushing of the masonry and applying a strength reduction factor of 0.50 per Section 9.1.4.1, TMS 402 Equation 9-5 gives:

$$\phi B_{vnc} = (0.50)(1{,}750)\sqrt[4]{(f'_m)(A_b)} = (0.50)(1{,}750)\sqrt[4]{\left(2{,}000\ {}^{\text{lb}}/_{\text{in.}^2}\right)(0.226\text{ in.}^2)} = 4{,}030\text{ lb}$$

Checking the design shear strength as controlled by pryout and applying a strength reduction factor of 0.50 per Section 9.1.4.1, TMS 402 Equation 9-6 gives:

$$\phi B_{vnpry} = (0.50)(8)(A_{pt})\sqrt{f'_m} = (0.50)(8)(84.9\text{ in.}^2)\sqrt{2{,}000\ {}^{\text{lb}}/_{\text{in.}^2}} = 15{,}180\text{ lb}$$

Finally, checking the design shear strength as controlled by the anchor steel shear strength and applying a strength reduction factor of 0.65 per Section 9.1.4.1, TMS 402 Equation 9-7 gives:

$$\phi B_{vns} = (0.65)(0.6)(A_b)(f_u) = (0.65)(0.6)(0.226\text{ in.}^2)\left(58{,}000\ {}^{\text{lb}}/_{\text{in.}^2}\right) = 5{,}110\text{ lb}$$

The design shear strength of this anchor bolt configuration is governed by shear breakout: 2,040 lb, which is also greater than the factored shear load applied to the anchor of 1,500 lb.

Design for Combined Tension and Shear (Checklist Items 10-11)

Under combined axial and shear loading, anchors must also satisfy TMS 402 Equation 9-8:

$$\left(\frac{b_{au}}{\phi B_{an}}\right)^{5/3} + \left(\frac{b_{vu}}{\phi B_{vn}}\right)^{5/3} \leq 1.0$$

For the factored axial and shear design loads and the governing axial and shear design strengths, this expression results in:

$$\left(\frac{3{,}700\text{ lb}}{7{,}590\text{ lb}}\right)^{5/3} + \left(\frac{1{,}500\text{ lb}}{2{,}040\text{ lb}}\right)^{5/3} = 0.90$$

And thus satisfies the design check for combined shear and axial loading.

Detailing Requirements (Checklist Items 12-15)

12. For corrosion protection, when anchors are directly exposed to earth, weather, or a mean relative humidity greater than 75%, they must be specified to be mill galvanized or hot-dip galvanized.
13. To ensure adequate space and flow of grout around the anchor, a minimum clearance between the anchor and the masonry unit of $^1/_4$ in. when using fine grout and $^1/_2$ in. when using coarse grout is required. When designing anchor groups, the clear distance between individual anchors cannot be less than the nominal diameter of the anchors or 1 in., whichever is greater. The single anchor placed in the center of the masonry wall satisfies these requirements. Note that when reinforcement

is present in the masonry, the location of the anchor will need to be coordinated with the placement of the vertical/horizontal reinforcement.

14. Per Section 6.3.6 of TMS 402, the minimum effective embedment length is the larger of $4(d_b) = 4(^5/_8$ in.) = 2.5 in. and 2.0 in. The 6.0 in. effective embedment length here satisfies this requirement.
15. For structures assigned to SDC C or larger, anchors used to connect elements to the top of masonry columns are required to be located within the lateral ties of the column. This design check does not apply to this example.