MASONRY INSIGHTS

written in conjunction with International Masonry Institute

Masonry Exterior Non-bearing Wall Design Guide

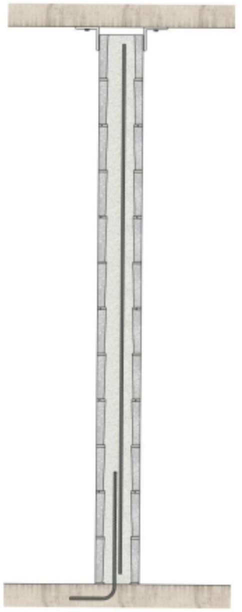


Figure 1: Wall Section
IMI Detailing Series

When a building has a structural frame that supports both the gravity and lateral loads, the exterior perimeter walls need to transfer the component and cladding wind loads and seismic self-weight loads to that frame. Masonry makes an excellent option for the exterior wall material. However, as always, the devil is in the details to determine whether the wall needs to be designed as a hybrid wall, an infill wall, a participating or non-participating wall, or a plain exterior wall (see definitions below). This article will briefly explain the difference between these wall types with a focus on the detailing and design requirements for plain exterior non-bearing walls and non-participating infill walls.

Masonry has advantages over other materials that may be used as an exterior infill for a structural frame. To start with, masonry offers durability and security as well as fire and sound control. Additionally, masonry can offer energy savings due to its thermal mass, and it can require less maintenance than other building materials. The exterior face of masonry can be painted, burnished, rock-faced, or stacked with various bond patterns, etc. allowing many aesthetic options while removing the need for other trades/materials to cover up the wall material. The prevalence of masonry in many building types clearly demonstrates these architectural and structural advantages are frequently chosen.

Masonry Wall Type Definitions

Masonry walls have many different names and detailing requirements depending on the location relative to other structural elements. To keep these terms straight, see the following definitions:

<u>Masonry Wall</u>: "A vertical element with a horizontal length to thickness ratio greater than 3, used to enclose a space." *Per TMS 402*.
<u>Load Bearing Wall</u>: "Wall supporting vertical loads greater than 200 pounds per linear foot in addition to its own weight." *Per TMS 402*.
<u>Standard Masonry Wall</u>: This wall type is not defined but it is designed typically as a wall spanning between floors as either reinforced or unreinforced per the allowable stress design or strength design methods listed in the TMS 402 code. These walls are located away from a lateral frame and can be either load bearing or non-load bearing.

Infill Wall: “Masonry constructed within the plane of, and bounded by, a structural frame”. *Per TMS 402*.
Non-Participating Infill: “Infill designed so that in-plane loads are not imparted to it from the bounding frame.” *Per TMS 402*.
Participating Infill: “Infill designed to resist in-plane loads imparted to it by the bounding frame.” *Per TMS 402*.
Hybrid Wall: “a structural system that utilizes reinforced masonry infill walls with a framed structure…used as part of the lateral load resisting system.” *Per NCMA Tek Note 14-09A*.
Partition Wall: “An interior wall without structural function.” *Per TMS 402*.

One aspect these wall types have in common is that at the exterior wall, they will all need to resist out-of-plane loads due to component and cladding wind as well as seismic forces. An important distinction for infill walls is whether they will resist lateral loads in the plane of the wall (participating infill, hybrid walls) or not (non-participating infill). Aside from the hybrid wall and participating infill, the walls are typically considered non-load bearing as they only support their own weight and are designed as a simple span between floors for the out-of-plane loads. The main distinction to be aware of is whether the exterior masonry wall is a standard masonry wall or an infill wall. As the next section will show, the there is a significant strength difference between the two wall definitions. This article will only speak to non-load bearing standard masonry walls and the non-participating infills but be aware that the detailing is critical to ensure that no lateral load transfers from the main building frame into the infill wall. See the section below on detailing requirements.

Standard Masonry Wall vs. Non-Participating Infill

A standard exterior masonry wall that is non-load bearing typically is not designed as part of the lateral resisting system but often is generally located between two floors of a building away from the structural frames. A non-participating infill is a masonry wall filling in the area of a frame between beams and columns but is detailed with gaps all around three sides so as to allow deflection of all frame elements without transferring any gravity or lateral loads into the wall through bearing. The reality is, both of these masonry wall types, when using the same edge gap detailing, only need to resist out-of-plane loads and thus may behave in the same way. However, the different terms trigger different parts of the TMS code. Standard masonry walls are designed per the main body of the TMS 402-13 code while infill walls are designed per Appendix B. Appendix B has three main sections, B.1 for general information, B.2 for non-participating infills, and B.3 for participating infills but this article will only address the first two.

Starting with the general B.1 code section, the appendix references parts 1 and 2 of the main code so that all infill walls will be designed the same as typical masonry including the seismic detailing requirements of chapter 7. Note that appendix B does deviate from the main code in two significant ways. First, the appendix only references the strength design method and secondly specifies a reduction factor $\phi = 0.60$ for shear, flexure, and axial loading in place of the main code values of $\phi = 0.90$ for flexure/axial and $\phi = 0.80$ for shear. Be aware that the strength reduction factors for anchorage and bearing remain unchanged and shall be determined per TMS 402-13 sections 9.1.4 or 11.1.5. For non-participating infill, out-of-plane flexural strength will be the biggest contributor thus a ϕ value of 0.60 instead of 0.9 has a huge impact in the amount of reinforcing required. To demonstrate the difference, see tables 1 and 2 which compare the two design cases. Per the B.1 commentary, the design for all infill walls is noted as being based on a combination of experimental research and anecdotal performance which is the likely reason for the lower reduction factor. This makes sense for participating infill walls as there is a complex interaction between the frame and the infill causing struts to form in the masonry. However, when a non-participating infill is detailed per Appendix B.2, the infill will be isolated from the frame and thus there will not be any interaction between the two elements. As described earlier, the non-participating infill will structurally behave the same as a non-load bearing standard masonry wall with the same detailing. Therefore, it is unclear why the non-participating infill should be designed with the lower resistance factor.

Out-of-Plane Wind Load Reinforcement

All exterior infill walls must resist out-of-plane wind and seismic loading. As noted earlier, the scope of this article only includes non-participating masonry, thus, in low seismic areas, the wind load will most likely govern. Per the TMS code, there are no minimum reinforcement requirements for wind loading. Similarly, per TMS 402-13 Section 7.4.1, non-participating elements located in Seismic Design Category (SDC) A or B do not have minimum reinforcement area or maximum spacing requirements. Be aware that there are minimum reinforcement and maximum spacing requirements listed in TMS 402-13 chapter 7 for buildings with SDC C and above which must be checked against the wind design to determine the final masonry wall reinforcement.

When choosing reinforcement for masonry walls, the general rule of thumb for economy is to space the rebar as far apart as possible to minimize the number of grouted cells meaning less labor. However, other items affect cost such as reinforcement lap splice length, bond beam locations, and connector capacity. The last two will be discussed in the detailing section but this section will focus on the reinforcement. Many factors influence the lap splice length including masonry assembly strength (f'm), rebar size, and cover distance. Using f'm values higher than the code minimum is recommended as masonry units off the shelf can easily develop higher strength than many engineers expect which reduces lap lengths. F'm = 2500psi is a good starting point as this can be produced in virtually all locations across the United States. Values of 3000psi or 3500psi (or even higher) can also be achieved fairly easily but verify first with local suppliers. For exterior walls discussed in this article, it is recommended to use a single bar centered in the masonry cores which also helps to minimize lap lengths. Finally, bar size is the biggest driver of lap lengths. Shorter height walls generally need less reinforcement and may not even need rebar splices at all. Rebar sizes of #4 and #5 generally have low lap lengths. Bar sizes of #6 and larger begin to have much longer lap lengths that makes rebar installation unwieldy. As can be seen later in tables 1 and 2, the recommendation is to use #4 or #5 bars as much as possible and save #6 bars for when it is necessary.

To understand the difference in reinforcement required for a non-bearing standard masonry wall vs. a non-participating infill wall, see the following example. Consider a hypothetical 60ft tall building located in Chicago, Illinois with a wind speed of 107 mph per ASCE 7-16. This location was chosen to represent an example applicable to a majority of the country. The reinforcement is based on component & cladding wind loads in wind zone 5 with effective wind areas based on the masonry wall height times wall height divided by three (h*h/3) and the out-of-plane load combination wind

	10 ft	12 ft	14 ft	16 ft	18 ft	20 ft	24 ft	28 ft	30 ft
4” Brick	#4 @ 40	#4 @ 24	#4 @ 16	#4 @ 16	#4 @ 8	–	–	–	–
6” Brick	#5 @ 104	#5 @ 72	#5 @ 56	#5 @ 40	#5 @ 32	#5 @ 24	#5 @ 16	#6 @ 16	#6 @ 16
6” Block	#5 @ 104	#5 @ 80	#5 @ 56	#5 @ 40	#5 @ 32	#5 @ 24	–	–	–
8” Block	#5 @ 120	#5 @ 112	#5 @ 80	#5 @ 64	#5 @ 48	#5 @ 40	#5 @ 24	#5 @ 16	#5 @ 16
10” Block	#4 @ 120	#5 @ 120	#5 @ 112	#5 @ 80	#5 @ 64	#5 @ 48	#5 @ 32	#5 @ 24	#5 @ 24
12” Block	#4 @ 120	#4 @ 120	#5 @ 120	#5 @ 104	#5 @ 80	#5 @ 72	#5 @ 48	#5 @ 32	#5 @ 32

Table 1: Standard Exterior Wall ($\phi = 0.9$)
Design for Out-of-Plane C&C Wind

	10 ft	12 ft	14 ft	16 ft	18 ft	20 ft	24 ft	28 ft	30 ft
6” Block	#5 @ 72	#5 @ 48	#5 @ 32	#5 @ 24	#5 @ 16	#5 @ 16	–	–	–
8” Block	#5 @ 104	#5 @ 72	#5 @ 56	#5 @ 40	#5 @ 32	#5 @ 24	#6 @ 24	#6 @ 16	#6 @ 16
10” Block	#5 @ 120	#5 @ 96	#5 @ 72	#5 @ 56	#5 @ 40	#5 @ 32	#5 @ 24	#5 @ 16	#5 @ 16
12” Block	#4 @ 120	#5 @ 120	#5 @ 96	#5 @ 72	#5 @ 56	#5 @ 48	#5 @ 32	#5 @ 24	#5 @ 16

Table 2: Exterior Infill Wall ($\phi = 0.6$)
Design for Out-of-Plane C&C Wind

coefficient = 0.42W for evaluating deflection per ASCE 7-16. Type S mortar with medium weight masonry (115 pcf) is assumed at f’m = 2,500psi. All reinforcement is 60ksi and is a single bar centered in the masonry core. Table 1 shows the required reinforcement for standard masonry walls designed per the main TMS 402-13 code. Table 2 follows the same assumptions but is designed per TMS 402 Appendix B. The only difference between the calculations in the two tables is the strength design reduction factor ($\phi = 0.90$ vs 0.60).

Detailing Requirements

Next is a discussion on the requirements in section B.2 specific to non-participating infill walls. The most important detail item is that the infill wall must be isolated from the surrounding structural frame so that no vertical or lateral load is imparted to the masonry in the plane of the wall. To ensure this, the code requires a minimum 3/8” joint on the top of the infill wall and at both ends. The joint may need to be bigger than 3/8" depending on the expected deflection of the frame members including inelastic deformation during seismic events. The joints must be made with a resilient compressible material and must not have any mortar, debris, or any other rigid material to ensure that no in-plane lateral load is transferred into the infill wall. Similar detailing should be used for non-load bearing standard masonry walls on any edges that are adjacent to a column, beam, upper slab, or any other structural element. Failure to do so may transfer unintended loads into the standard wall which could make it try to act like a shear wall or participating infill wall which it has not been designed for. If lateral loads were to transfer into the wall, compression struts would form sending resultant loads into the nearby structural elements which could lead to failure if not designed for it. Thus, it is very important to properly size these isolation joints with proper detailing to ensure load transfer only occurs when and where intended.

In contrast, both the non-load bearing standard masonry wall and the non-participating infill wall do need to resist loads out-of-the-plane of the wall from either wind or seismic loads. The difficult part of the design are the connectors to the surrounding structural frame or structural elements. The connectors must be able to transfer the out-of-plane loads, but, as noted earlier, not transfer any in-plane loads while allowing both vertical and horizontal deflections of the structural frame. For the out-of-plane loads, the masonry can either span vertically, horizontally, or both and must be designed to span between connectors as either unreinforced or reinforced masonry. The connectors must be spaced as required based on the capacity of the connection and the loads present but the maximum spacing for non-participating infill per TMS Appendix B is 48" along the perimeter. Depending on the spacing of the connectors, the spacing of the internal wall reinforcement, and the magnitude of the out-of-plane load, a top of wall bond beam may or may not be needed to transfer the loads to the connectors. Our recommendation is, when possible, to locate the connectors at the same spacing as the wall reinforcement and avoid a top of wall bond beam to minimize cost and maximize efficiency of the masonry infill wall.

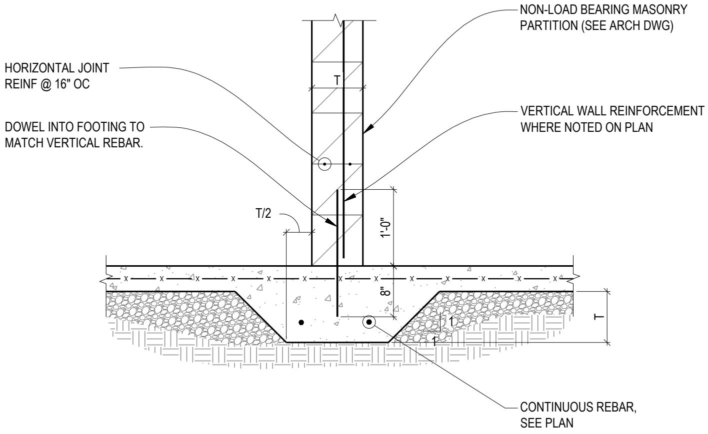


Figure 2: Simple Base of Masonry Wall Connection

Connectors for masonry meeting all of the infill wall requirements can be difficult to design, particularly the simultaneous vertical and horizontal slip requirement as noted earlier. Following is a discussion of the various connection options.

BASE OF WALL CONNECTORS

Since the walls discussed are usually designed as a simple span, a dowel from the floor or foundation below will typically extend into the bottom of the wall as shown in Figures 2 & 4. However, this dowel is not required by code since masonry walls can be designed as unreinforced. When the dowel is used to transfer shear from the wall to the support it does not need to be lapped or even located in the same cell as the wall reinforcement (if wall reinforcement is required). This allows the contractor flexibility and the result is a more affordable design.

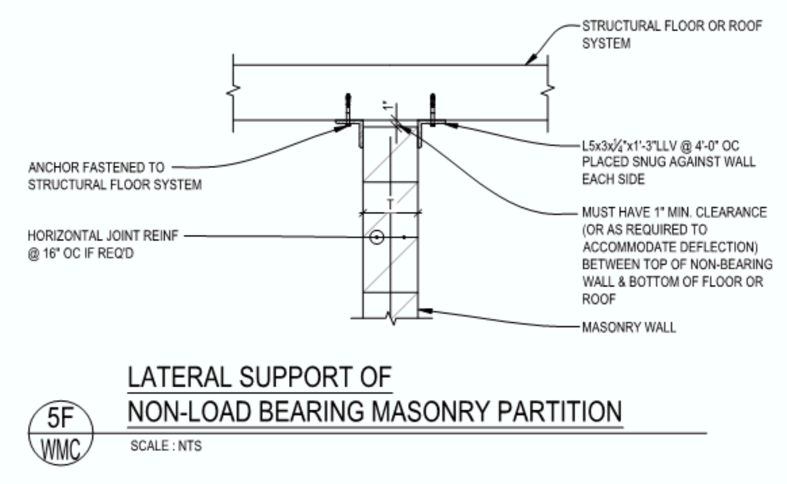


Figure 3: Top of Masonry Wall Detail

TOP OF WALL CONNECTORS

When exterior masonry walls are non load bearing, the top of wall connection detail must include a gap to allow for vertical deflection of the structure above. The first aspect of the connection is whether there will be a bond beam at the top of the wall. Since the structure above will already be in place, placing grout in the top course of the masonry wall will be very difficult for the mason requiring more labor compared to a load bearing masonry wall. When possible, the masons prefer the wall connection be a direct connection located at the grouted cells. This can be achieved in many ways but depends on the location of the wall relative to the structure above and the architectural design. For example, if a concrete slab extends past the exterior side of the masonry wall and there is a soffit, then angles on both sides of the wall can be an option as shown in Figures 3 and 4. The angles can either be continuous or intermittently located at the grouted reinforcement cores to ensure a direct load path for out-of-plane forces. The advantage to this detail is that it does not require a top of wall bond beam leading to quick installation and likely the most cost-efficient option. The disadvantages include the requirement of ample connection space on the outside of the wall, sufficient distance from concrete edge to develop the anchor capacity, and coordination of the intermittent angles with the grouted core locations. One could detail a heavier intermittent angle that is not coordinated with the wall reinforcing — for instance, the angle could be specified at 6'-0 on center. The disadvantage is that now a continuous bond beam is required at the top of the wall for attachment of the angle and for the wall to span horizontally between angles.

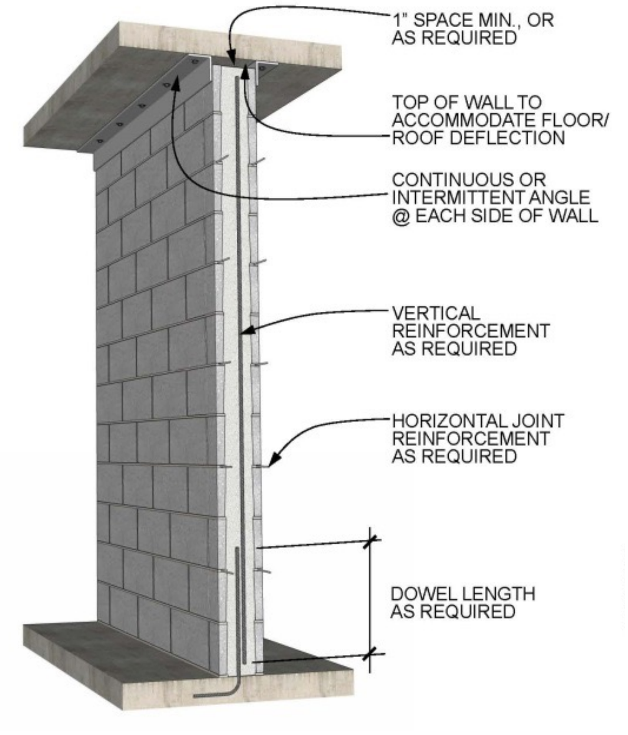


Figure 4: Full Masonry Wall Detail

When the conditions for exterior connectors are not available, there are internal connection options that can be used instead. Figures 5 and 6 show partition top anchors (PTA) which are typically used

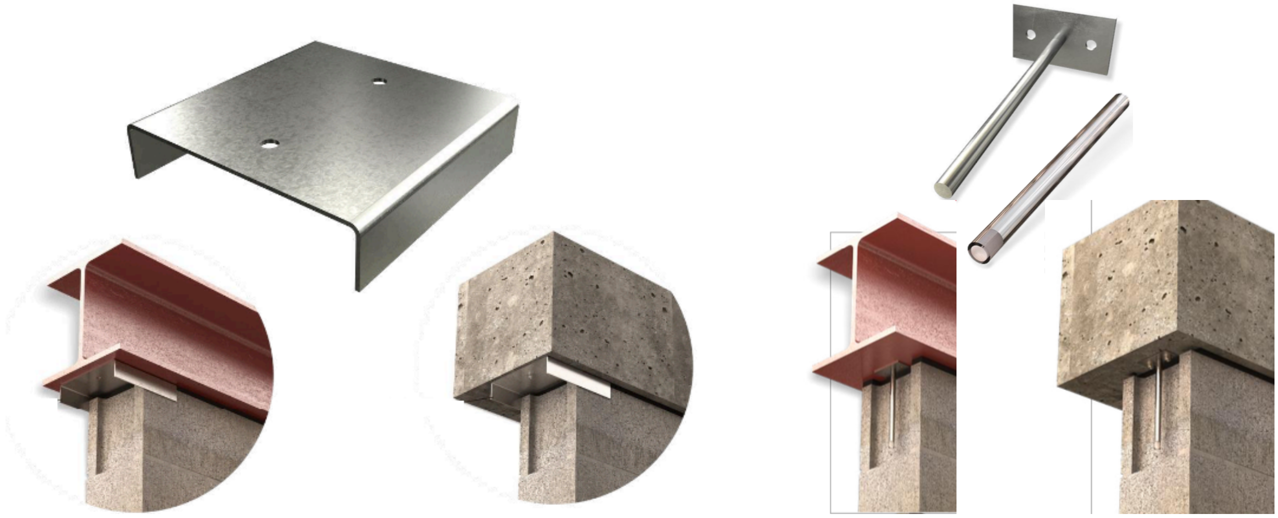


Figure 5: Partition Top Anchors (PTA)
source: www.wirebond.com

for interior partition walls. These anchors provide aesthetic benefits since they are installed internally. However, many of these anchors are only designed to resist the much smaller 8psf interior partition load so they either need to be spaced very close together or must make some modifications to increase the capacity for exterior wind loads. The PTAs can be attached to concrete or steel and work by using a rod or rebar inserted in a tube with compressible material in the bottom that allows the connector to slide vertically while still providing bearing against the masonry for load transfer. The rod and tube are typically grouted into the head joint of a stretcher block at interior partition walls. To reach the capacities needed at exterior walls, the rod and tube should either be located in the grouted rebar cell by using an open ended masonry unit or in a continuous bond beam. Generally, the breakout and bearing strength of he masonry has sufficient capacity so the controlling strength factor is the flexural strength of the steel rod or top plate. Below is an example demonstrating how to calculate the capacity of one top of wall anchor type.

Top of Wall Anchor Design Example

Design the top of wall anchorage for a 6" CMU wall spanning 12'-0" vertically with a 3/4" gap between the top of wall and structure above.

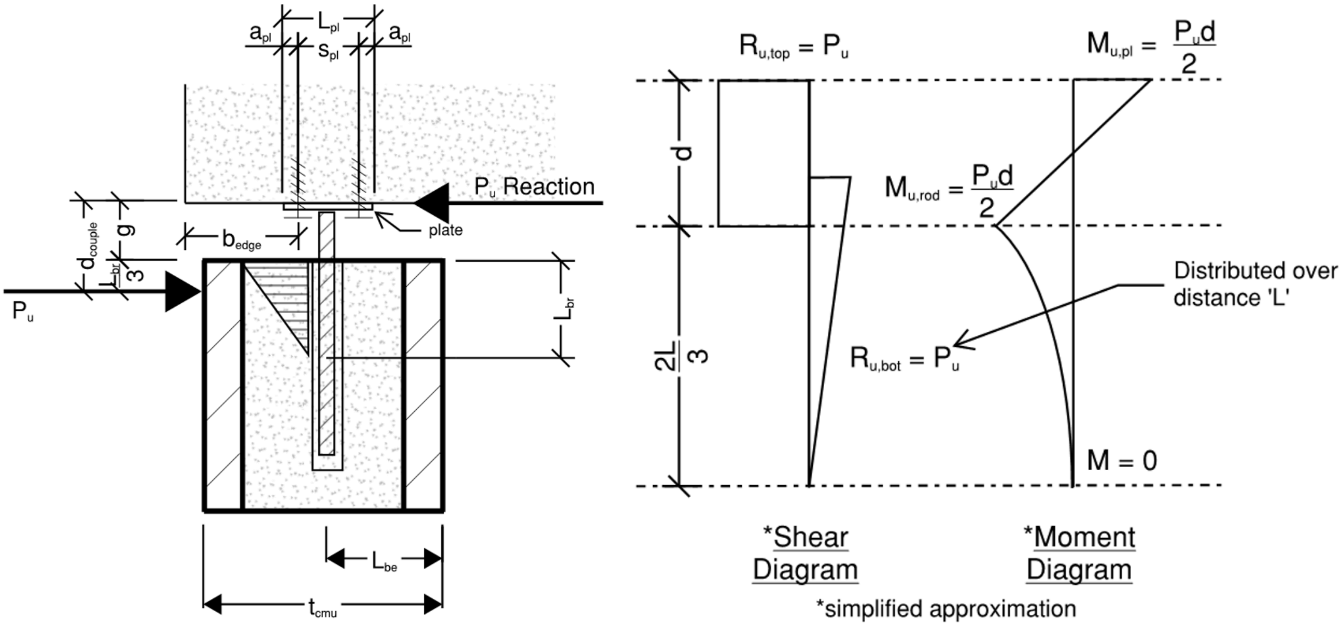
GEOMETRY & LOADING

$w_u = 33.7$ *psf zone 5 wind load based on effective area 1.0W factor.*

6" CMU Wall Reinforcing = #5@72" on center

Locate top of wall connector centered in each vertically grouted core to avoid the need for a bond beam in the top course of the wall.

Top of wall connector reaction = $P_u = 33.7psf * (12ft/2) * 72in/(12in/ft) = 1{,}213\#$



$f'_m = 2{,}500$ *psi* gap $g = 0.75$ *in* $d_{couple} = g + \frac{L_{br}}{3}$

$t_{cmu} = 7.625$ *in* $L_{be} = \frac{t_{cmu}}{2} = 3.8125$ *in*

ROD DESIGN

Rod = #4 Rebar x 7" Long   A615 $F_{y,rod} = 60$ *ksi*

$\phi P_{n,br} = \phi * 0.8 * f'_m = 0.6 * 0.8 * f'_m = 1{,}200$ *psi*

$A_{br} = 2P_u / \phi P_{n,br} = 2.02$ *in² (based on a triangular bearing distribution)*

$d_{rod} = \frac{1}{2}$ *in (diameter of rod)* $d_{sleeve} = d_{rod} + \frac{3}{16} in = \frac{11}{16}$ *in (diameter of rod sleeve)*

$L_{br} = A_{br} / d_{sleeve} = 2.94$ *in (minimum bearing length of rod)*

$d_{couple} = g + \frac{L_{br}}{3} = 1.73$ *in*

$Z_{rod} = \frac{d_{rod}^3}{6} = 0.012$ *in³* $S_{rod} = \frac{\pi d_{rod}^3}{32} = 0.021$ *in³*

$M_{u,rod} = \frac{P_u d_{couple}}{2} = 1{,}049$ *in-#*

$\phi M_{n,rod} = 0.9F_{y,rod} * min(Z_{rod}, 1.6S_{rod}) = 1{,}060$ *in-# > 1,049 in-# OK*

[AISC 360-16 Eq. F11-1]

ROD SHEAR ANCHORAGE IN CMU

$A_{pv} = \frac{\pi L_{be}^2}{2} = 12.4$ *in² (area fits within single vertical grout core) [TMS402-13 Eq. 6-2]*

$A_{pt} = \pi l_b^2$ *(area extends past edge of vertical grout core)*   *[TMS402-13 Eq. 6-1]*

Assume $b_{cmu} = 8$ *in width of masonry at grouted core*

Reduced $A_{pt} \approx b_{cmu} L_{be} = 45.0$ *in²*

$B_{vnb} = 4A_{pv}\sqrt{f'_m} = 2{,}485\#$ *[TMS402-13 Eq. 9-6]*

$B_{vnc} = 1050A_{pv}\sqrt[4]{f'_m A_b} = 4{,}942\#$ *[TMS402-13 Eq. 9-7]*

$B_{vnpry} = 8A_{pt}\sqrt{f'_m} = 18{,}000\#$ *[TMS402-13 Eq. 9-8]*

$B_{vnb} = 0.6A_b f_y = 7{,}069\#$ *[TMS402-13 Eq. 9-9]*

$\phi B_{vn} = 0.8 * MIN(B_{vnb}, B_{vnc}, B_{vnpry}, B_{vns}) = 1{,}988\# > P_u = 1{,}213\#$ *OK*

PLATE FLEXURAL DESIGN

$F_{y,pl} = 50\ ksi$ *(A572 Gr. 50)* *PL1/4 x 2 x 3*

$b_{pl} = 2\ in \qquad t_{pl} = \frac{1}{4}\ in \qquad s_{pl} = 1\frac{1}{2}\ in \qquad a_{pl} = \frac{3}{4}\ in$

$Z_{pl} = \frac{b_{pl}t_{pl}^2}{4} = 0.023\ in^3 \qquad S_{pl} = \frac{b_{pl}t_{pl}^2}{6} = 0.016\ in^3$

$$M_{u,pl} = \frac{P_u d_{couple}}{2} = 1{,}049\ in\text{-}\#$$

$$\phi M_{n,pl} = 0.9F_{y,pl} * min(Z_{pl}, 1.6S_{pl}) = 1{,}055\ in\text{-}\# > 1{,}049\ in\text{-}\#\ OK$$

[AISC 360-16 Eq. F11-1]

CONCRETE ANCHORAGE

Out of the scope of this article but these are the anchor design loads for attachment to the structure above:

$$V_{u,anchor} = \frac{R_{top}}{2} = \frac{P_u}{2} = 607\ \#/anchor$$

$$T_{u,anchor} = \frac{M_{u,pl}}{(s+a)} = 466\ \#/anchor$$

Summary

Masonry is a great choice for exterior walls due to the durability and aesthetic options. The difficult part is keeping track of all the different terms for walls in the TMS code and the associated requirements for each. The most important part of the design is the detailing especially when isolating from the rest of the structural system for gravity and lateral loads. Any time a wall is isolated on the top and ends, engineering judgement should be used when applying the provisions of the masonry code. Whether installing an exterior wall or infilling a frame, the masonry will behave the same. Remember to call out appropriate connectors that consider architectural aesthetic requirements plus deflections of the structure to ensure full compatibility with the design while not transferring unintended loads into the wall. Finally, for economy, locate the connectors at the vertical reinforcement grout locations when possible to avoid the installation difficulties of bond beams at the top of the wall. A good coordinated design makes masonry an effective, cost-competitive option for exterior non-load bearing walls.