Control Joints and Horizontal Reinforcement for Masonry Walls

Introduction to the Code Requirements and Guidelines

Control joints and horizontal reinforcement play crucial roles in the structural performance and crack control of masonry walls. The national masonry model code, **TMS 402 Building Code Requirements for Masonry Structures**, does not have a lot of information on the topic of horizontal reinforcement for masonry walls in low to moderate seismic areas. In high seismic situations for structural masonry walls, masonry shear walls, and masonry partition walls, there are horizontal reinforcement requirements. There are three main reasons for horizontal reinforcement in masonry walls:

1. Crack Control - if the walls primarily span vertically, then there is little demand for reinforcement in the horizontal direction. Therefore, only a minimal amount of reinforcement is needed. The amount and spacing of the reinforcement will depend on movement joint locations and the crack control plan.
2. Horizontal Bending - even when the walls primarily span in the vertical direction, it is likely that portions of the wall will have horizontal bending moment, such as masonry lintels directly above openings.
3. Prescriptive Horizontal Reinforcement - shear walls that are specified as intermediate or special reinforced walls have prescriptive horizontal reinforcement based on code requirements.

This guide focuses on #1, Crack Control. The National Concrete Masonry Association (NCMA) has two documents that provide guidance:

1. CMU-TEC-009-23 Control Joints for Concrete Masonry Walls - Empirical Method
2. CMU-TEC-009-23 Control Joints for Concrete Masonry Walls - Alternate Engineered Method

TEK 10-2D is based on the historical performance of masonry walls. CMU-TEC-009-23 is based strictly on the material properties of masonry and reinforcement. There are several options for the amount and location of horizontal reinforcement in masonry walls based on the frequency of control joints, partial or

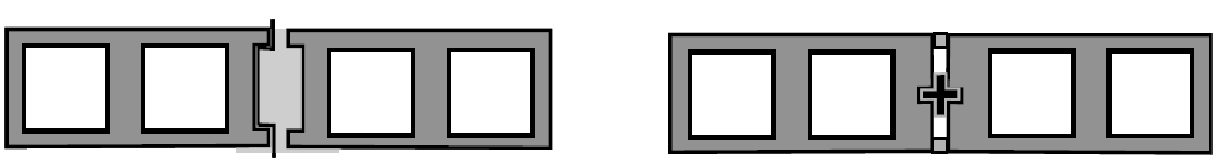


Figure 1: Concrete Masonry Control Joint examples (From Klingner 2010)

fully grouted walls, the number of openings in the walls, and the type of horizontal reinforcement. Figure 1 shows examples of concrete masonry control joints.

Crack Control

When designing masonry walls, one aspect that needs to be considered is the location of movement joints. Movement joints are continuous vertical joints where a bond breaker is placed between units, as shown in Figure 1. Concrete masonry walls, like concrete walls, will shrink after placement due to curing, moisture content reduction, and temperature. Movement joints in concrete are often referred to as Control Joints (CJ), and they provide a plane of weakness where shrinkage cracks can form in a controlled manner. Hollow clay masonry walls are structural masonry walls that will expand after placement due to moisture expansion and temperature. Movement joints in clay are often referred to as Expansion Joints (EJ), and they provide a gap where stress from this expansion can be relieved and controlled. The number and location of EJs in structural clay masonry can have a considerable effect on the capacity of the walls.

Since the purpose of a movement joint is to provide a bond break that will permit longitudinal movement and relieve horizontal tensile stresses, horizontal reinforcing is generally not continuous through the joint. Therefore, the structural engineer must locate the joints to maximize structural wall capacity, within prescribed spacing recommendations.

For the remainder of this paper, concrete masonry CJs will be discussed. NCMA CMU-TEC-009-23 recommends that concrete masonry CJs be spaced at 25 feet or 1.5 times the height of the wall, whichever is less when minimal horizontal reinforcement is provided in the masonry walls. It also recommends that joints should be located at areas of stress concentrations, such as changes in wall height or thickness or near corners. Understanding these requirements, and adding sufficient reinforcing, can result in fewer CJs.

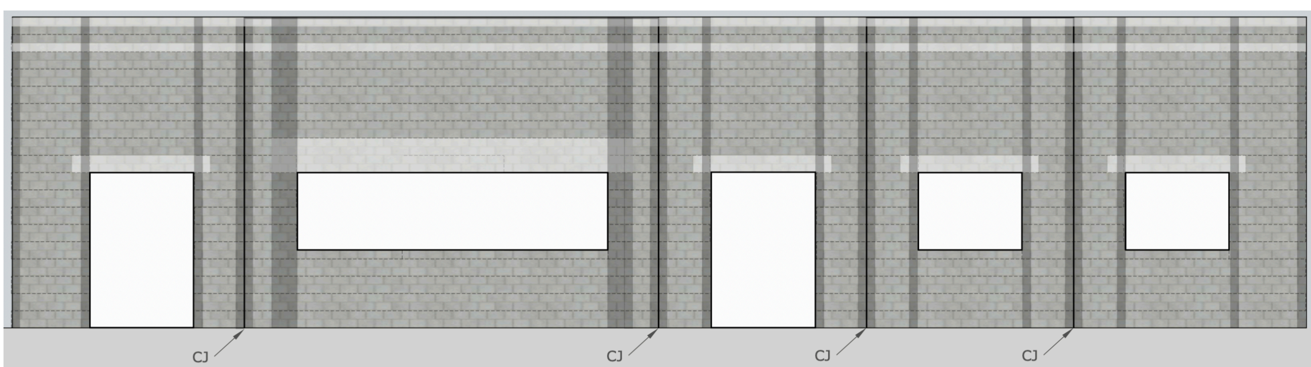


Figure 2a : Arrangement of Control Joints Away from Openings in Reinforced Walls
Recommended for ALL New Structural Masonry Walls

One of the likely spots for stress concentrations, and an increased potential for cracking, is at wall openings. With many masonry walls having at least minimal reinforcement added, and openings essentially surrounded by reinforcing—that is, jamb reinforcing on each side, masonry lintel reinforcing, and sill reinforcing (if applicable)—the wall around the opening can be considered sufficiently strengthened to avoid cracks due to stress concentrations. Movement joints can and should be placed away from the openings, as in Figure 2a. Movement joints should be spaced a minimum of two feet away from the vertical edge of openings to allow for this reinforcing.

For unreinforced walls (historic masonry walls) without sufficient reinforcement at openings, smaller openings should have a control joint at one side, while larger openings should have a joint on each side. See Figure 2b for joint arrangement and locations in unreinforced masonry walls. Also, note that the joints are "doglegged" above the opening so that the lintel can be supported by the masonry on both sides of the opening, and also to restrain the lintel against uplift by vertical reinforcement at the edges of the opening. Control joints above the windows and doors are normally offset from the jambs so that the masonry lintels produced by these joints can have 8 inches of bearing at each end. The control joints below the windows are normally aligned with the window opening because there is no need for an offset.

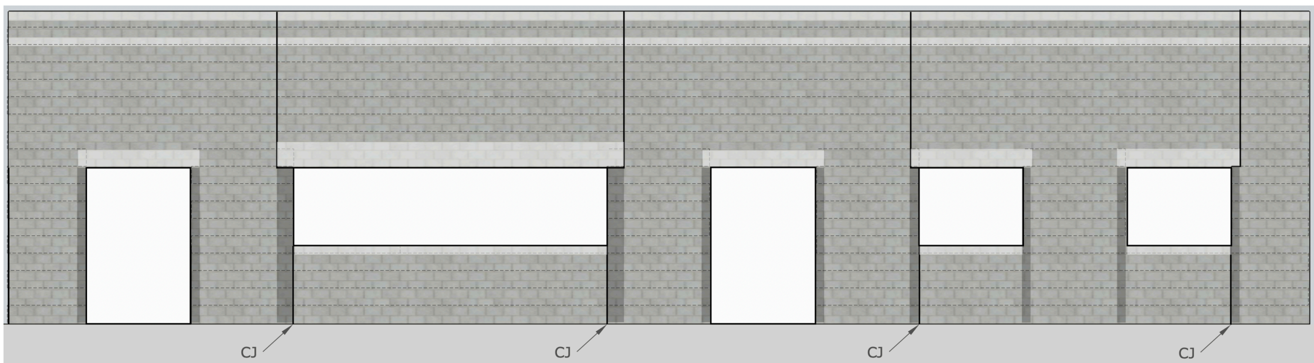


Figure 2b : Arrangement of Control Joints in Unreinforced Walls (From Klingner 2010)
Not Recommended for New Construction

Horizontal Reinforcement with Regular Control Joints (CJ)

Horizontal reinforcement is either wire joint reinforcement that is placed within the mortar joints, or standard bar reinforcement within bond beams. TMS 402-16, section 6.1.2.3 requires the minimum size of

Reinforcement size	Maximum spacing, in. (mm)
W1.7 (9 gage) (MW11)[1]	16 (406)
W2.1 (8 gage) (MW13)[1]	16 (406)
W2.8 (3/16 in.) (MW18)[1]	24 (610)
No. 3 (M#10)	48 (129)
No. 4 (M#13)	96 (2,348)
No. 5 (M#16) or larger	144 (3,658)

[1] Minimum two wires per course.

NCMA TEK 10-2D: TABLE 2A
Table 1. Maximum Spacing of Horizontal Reinforcement
to Provide 0.025 sq in/ft of Masonry Height

horizontal joint reinforcement to be W1.1 (MW7), and a maximum wire size of one-half the joint thickness. Based on a standard joint size of 3/8", the maximum wire size would be 3/16" in diameter.

The most common joint reinforcement used in masonry is W1.7 (9 gauge). Contractors prefer to use this size of reinforcement as larger sizes can be challenging to place when constructing the wall, especially hot-dipped galvanized 3/16" wire that can be larger than twice the mortar joint thickness. Using the chart within NCMA CMU-TEC-009-23, W1.7 (9 gauges) should be placed at 16-inches in the center. As shown in table 1, this is based on control joint placement of 1.5x wall height up to a 25-feet spacing. See NCCMU-TEC-009-23: Table 2 below.

Wall thickness, in. (mm)	Maximum spacing of horizontal reinforcement, in. (mm) Reinforcement size								
	No. 5 (M 16)	No. 4 (M 13)	No. 3 (M 10)	4 x3/16 in. (MW 18)	4 x 8 gage (MW 13)	4 x 9 gage (MW 11)	2 x3/16 in. (MW 18)	2 x 8 gage (MW 13)	2 x 9 gage (MW 11)
Ungrouted or partially grouted walls									
6 (152)	144 (3658)	128 (3251)	64 (1626)	72 (1829)	56 (1422)	48 (1219)	40 (1016)	24 (610)	24 (610)
8 (203)	144 (3658)	96 (2438)	40 (1016)	64 (1626)	48 (1219)	40 (1016)	32 (813)	24 (610)	16 (406)
10 (254)	136 (3458)	80 (2032)	32 (1219)	56 (1422)	40 (1016)	32 (813)	16 (406)	16 (406)	16 (406)
12 (305)	120 (3048)	72 (1829)	24 (610)	48 (1219)	40 (1016)	32 (813)	16 (406)	16 (406)	16 (406)
Fully grouted walls									
6 (152)	72 (1829)	48 (1219)	24 (610)	24 (610)	16 (406)	16 (406)	8 (203)	8 (203)	8 (203)
8 (203)	56 (1422)	32 (813)	16 (406)	16 (406)	8 (203)	8 (203)	8 (203)	8 (203)	—
10 (254)	40 (1016)	24 (610)	16 (406)	16 (406)	8 (203)	8 (203)	8 (203)	—	—
12 (305)	32 (813)	24 (610)	8 (203)	8 (203)	8 (203)	8 (203)	—	—	—

1. A_n includes cross-sectional area of grout in bond beams

NCMA TEK 10-3: TABLE 2

Table 2. Maximum Spacing of Horizontal Reinforcement to Meet the Criteria, As > 0.0007

Incorporating the criteria from CMU-TEC-009-23 requires a reinforcement ratio of 0.0007 for the area of steel (As) to the net cross-sectional area of concrete masonry (An). This ratio considers the total possible movement from drying shrinkage, carbonation shrinkage, and contraction due to temperature over a certain length of wall. The table from CMU-TEC-009-23 also considers the additional material with thicker walls and solid grouted masonry.

Therefore both NCMA TEK 10-2D and NCMA TEK 10-3 indicate joint reinforcement of W1.7 (9 gage) at 16-inches on the center for ungrouted or partially grouted walls.

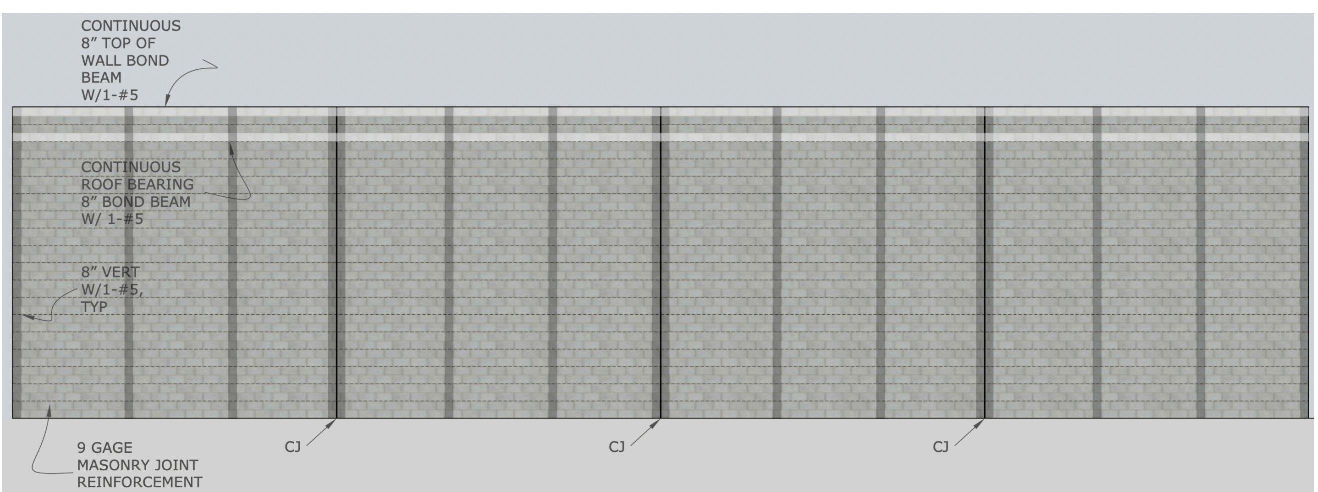


Figure 3: WALL ELEVATION WITH JOINT REINFORCEMENT

Contractors can also consider placing standard reinforcement within bond beams and not use joint reinforcement as another effective and efficient means to reinforce the masonry walls. Using a #5 bar in a bond beam at 12-feet on center would be effective for 6-inch and 8-inch masonry walls. 10-inch and 12-inch walls would require slightly closer spacing. See Figure 3 as an option for joint reinforcement and Figure 4 as an option with standard reinforcement in a bond beam.

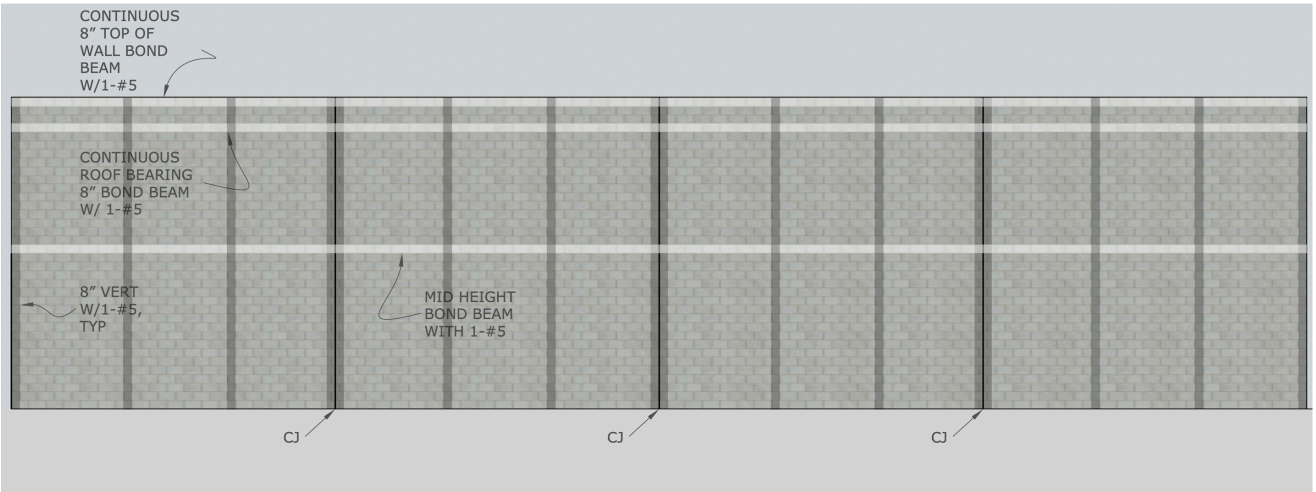


FIGURE 4: WALL ELEVATION WITH STANDARD REINFORCEMENT/BOND BEAMS

These examples show the options for horizontal reinforcement with regular CJ locations. There are situations when regularly spaced CJ's are either not possible or not desirable for a variety of reasons.

Walls with Additional Horizontal Reinforcement and No Control Joints

Within CMU-TEC-009-23, there are also criteria for designing a masonry wall without control joints, see Example 3 below. The reinforcement ratio of 0.002 for the area of steel (As) to the net area of concrete is the requirement for not needing regular control joints in concrete masonry. This ratio considers the total possible movement from drying shrinkage, carbonation shrinkage, and contraction due to temperature.

FIGURE 5: WALL WITH BOND BEAMS AND NO JOINT REINFORCEMENT AND NO CJ

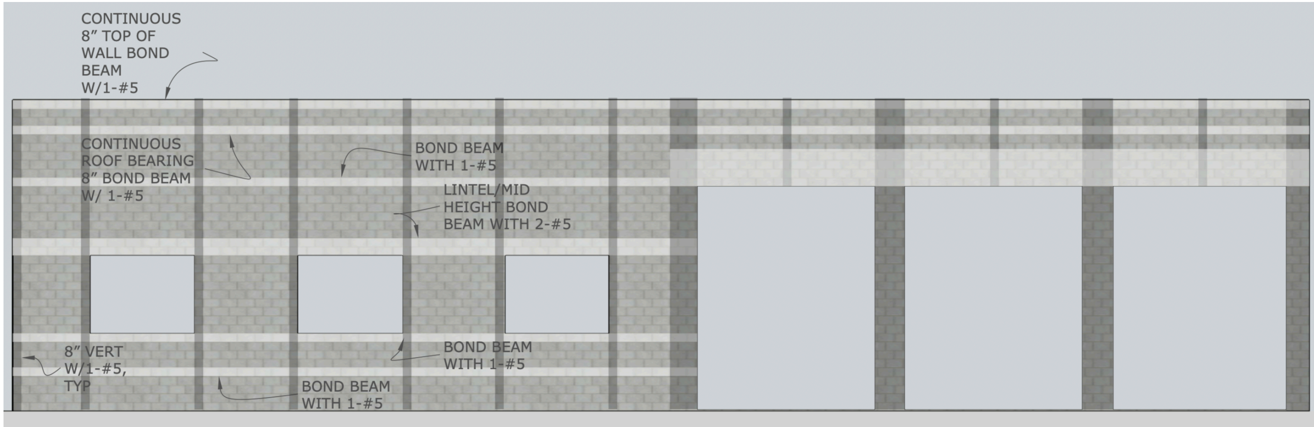


FIGURE 6: WALL WITH OPENINGS AND HORIZONTAL REINFORCEMENT AT BOND BEAMS AND NO JOINT REINFORCEMENT AND NO CJ

This ratio is similar to the ratio used in the ACI concrete code. There are still other factors for designers to consider that may result in control joints such as different wall heights, wall corners, and different support conditions, etc. Also, the total change in wall length that would occur due to the accumulation of stresses from expansion or contraction forces must be considered and may result in control joints being necessary if the wall is too long.

CMU-TEC-009-23 also has a requirement for the reinforcement to be distributed throughout the wall and be at a maximum horizontal spacing of 48-inches on center - in the table below [48*] indicates reinforcement scenarios that could have been spaced further apart, but the spacing was capped at 48-inches. Also, note in the table that the partially grouted wall requires much less reinforcement than the solid grouted wall.

Walls with openings as in Figure 6, especially a series of openings, are good candidates for using more horizontal reinforcement without CJs because of the lintel and sill reinforcement that is already present in the wall, in addition to the top of wall bond beam and bond beams at floor and roof levels. Walls with a lot of large, closely spaced openings, can benefit greatly by using a continuous masonry lintel, see the right side of the elevation in Figure 6. CJs forced into these locations would negatively impact the lintel design and also reduce the capacity of the masonry jambs.

Finally, using the criteria we have defined above, we also have another option shown in Figure 7 where masonry walls have both horizontal joint reinforcement and bond beams. The joint reinforcement can easily satisfy the maximum spacing requirement of 48-inches on-center, and then the bond beam reinforcement is supplementary and a good choice at locations such as above and below openings where stress concentrations can occur. There are also architectural reasons, especially in single wythe walls, to design with fewer bond beams from a moisture management perspective, so incorporating joint reinforcement in the design with fewer bond beams has other non-structural advantages as well.

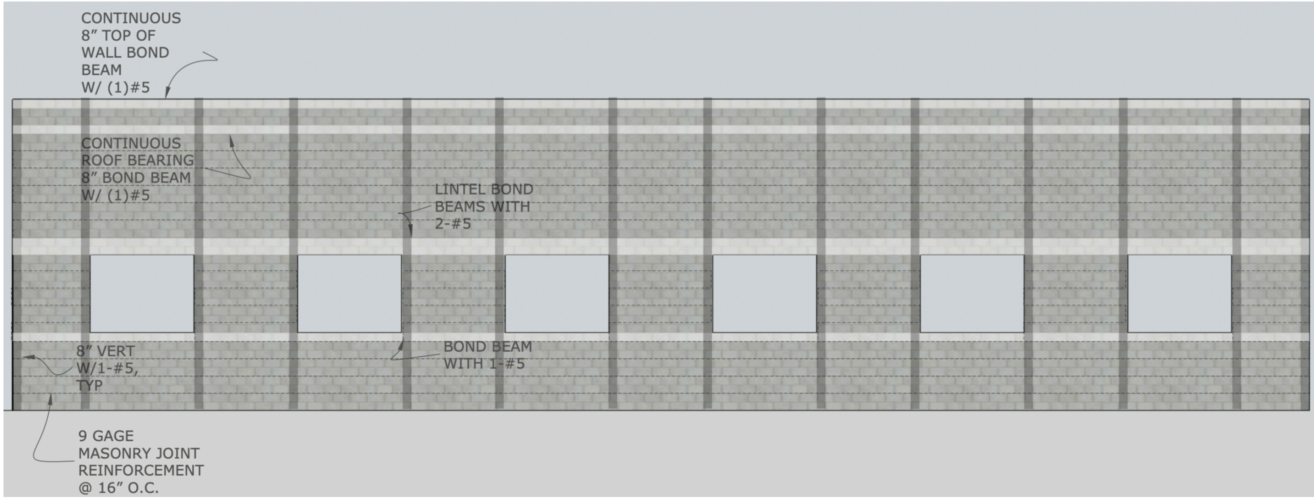


FIGURE 7: WALL WITH OPENINGS AND HORIZONTAL REINFORCEMENT AT BOND BEAMS AND JOINT REINFORCEMENT AND NO CJ

CMU PROPERTIES & WEIGHT

ASTM C-90 MINIMUM CONCRETE MASONRY UNIT DIMENSIONS

PARTIAL GROUT				Masonry Joint Reinforcement based on NCMA TEK 10-3, based on criteria As > 0.002 - Using a combination of bar reinforcement and 2x9gage joint reinforcement at 16" o.c.								
Nominal Width (in)	Actual Width (in)	Face-Shell Thickness (in)	Face Shell Area (in²/8 inch)	Reinf	(2) #6	(2) #5	(2) #4	#6	#5	#4		2 x 9ga
				Reinf Area	0.88	0.62	0.4	0.44	0.31	0.2		0.034
6	5.625	1.00	16.0	Horiz Spacing of Reinf				144.000	128.000	72.000		16.000
8	7.625	1.25	20.0				104.000	120.000	72.000	40.000		16.000
10	9.625	1.375	22.0			144.000	80.000	96.000	56.000	24.000		16.000
12	11.625	1.5	24.0		144.000	120.000	64.000	72.000	40.000	8.000		16.000
14	13.625	1.5	24.0		144.000	112.000	48.000	56.000	24.000			16.000
16	15.625	1.5	24.0		144.000	104.000	40.000	48.000	16.000			16.000

SOLID GROUTED				Masonry Joint Reinforcement based on NCMA TEK 10-3, based on criteria As > 0.002 - Using a combination of bar reinforcement and 2x9gage joint reinforcement at 16" o.c.								
Nominal Width (in)	Actual Width (in)		Masonry Area (in²/8 inch)	Reinf	(2) #6	(2) #5	(2) #4	#6	#5	#4		2 x 9ga
				Reinf Area	0.88	0.62	0.4	0.44	0.31	0.2		0.034
6	5.625		45.0	Horiz Spacing of Reinf				48.000	32.000	16.000		16.000
8	7.625		61.0		64.000	40.000	24.000	32.000	16.000	8.000		16.000
10	9.625		77.0		48.000	32.000	16.000	24.000	16.000	8.000		16.000
12	11.625		93.0		40.000	24.000	16.000	16.000	8.000	8.000		16.000
14	13.625		109.0		32.000	24.000	8.000	16.000	8.000			16.000
16	15.625		125.0		24.000	16.000	8.000	8.000	8.000			16.000

Comments on Movement Joint Locations affecting Lateral Capacity

It is also important to consider CJs during the design of the lateral force-resisting system. For example, a masonry wall could have four walls with three joints spaced at 12-feet (Figure 8) or three walls with two joints spaced at 16-feet (Figure 9). The longer walls with fewer CJs will have significant in-plane moment capacity for shear wall design, just from spacing the CJs farther apart. In this case, it is advantageous to space CJs as far as possible in order to have longer individual wall panels.

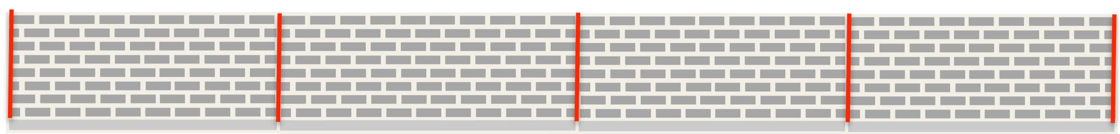


Figure 8 : More CJs result in shorter walls with less in-plane moment capacity than the elevation below

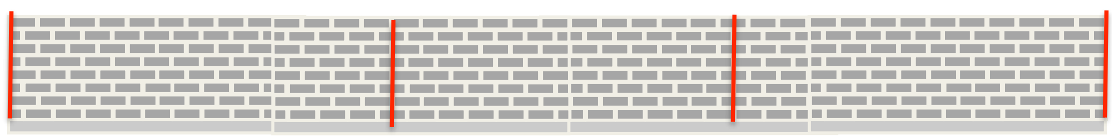
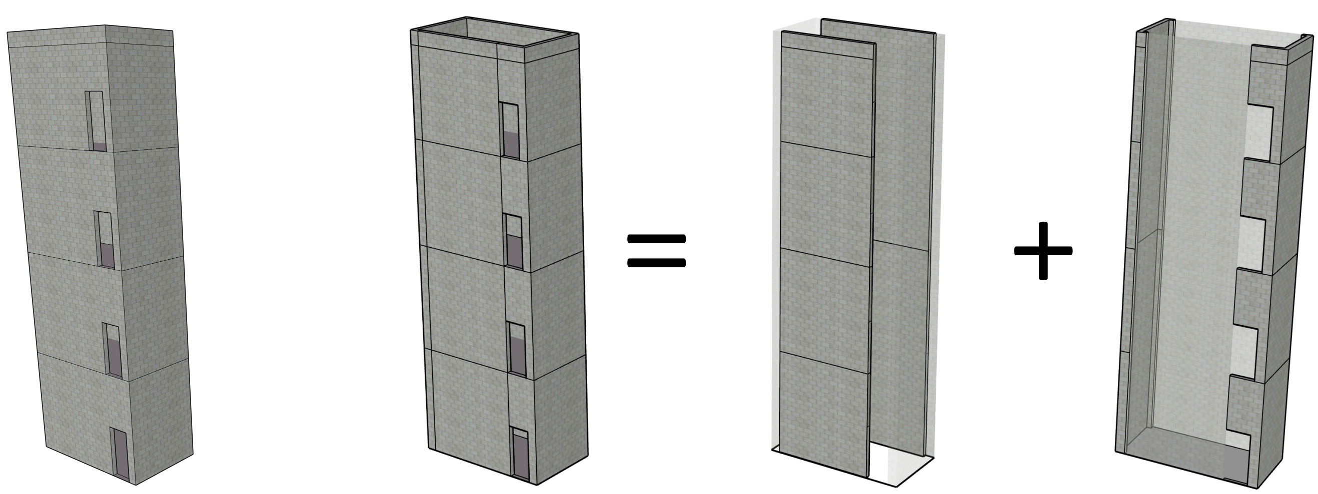


Figure 9 : Less CJs result in longer walls with increased in-plane moment capacity for shear wall design

By not having CJs in stair and elevator core walls, see Figure 10 below, there are large benefits from the stiffness of a box shape rather than individual walls. As an example, a masonry core when analyzed as a box, could have a moment of inertia of two or three times greater than if it were analyzed as a box group instead of just the individual walls.



Boxed Wall Group vs. Walls with CJ have less capacity = Long walls + Short End Walls

Figure 10 : No CJs in shaft walls result in boxed wall groups which have far more capacity

Architectural Insight

Movement Joints in Cavity Walls

Another consideration for cavity walls (multi-wythe*) is that movement joints will be in different locations in each wythe. EJs in clay brick veneer wythe will often be at different locations than CJs in the structural concrete wythe; see Figure 11 below. For example, it is common practice to place EJs in unreinforced clay masonry veneer at the edge of the opening, while CJs in the reinforced structural concrete masonry backup wall should be away from the openings in reinforced masonry walls.

(as shown in Figure 2a above).

In historic composite masonry walls, where the clay masonry and concrete masonry wythes were built together without a wall cavity (gap), CJs in concrete masonry and EJs in clay masonry were aligned. However, in modern cavity wall design, we understand the movement of masonry better and recognize that clay masonry expands and concrete masonry shrinks over time and that the two wythes should not be built together. Therefore, EJs and CJs do not need to align in modern walls with a gap between the wythes.

* wythe / ˈwiTH/ noun: a continuous vertical section of bricks or other masonry that is one unit thick.

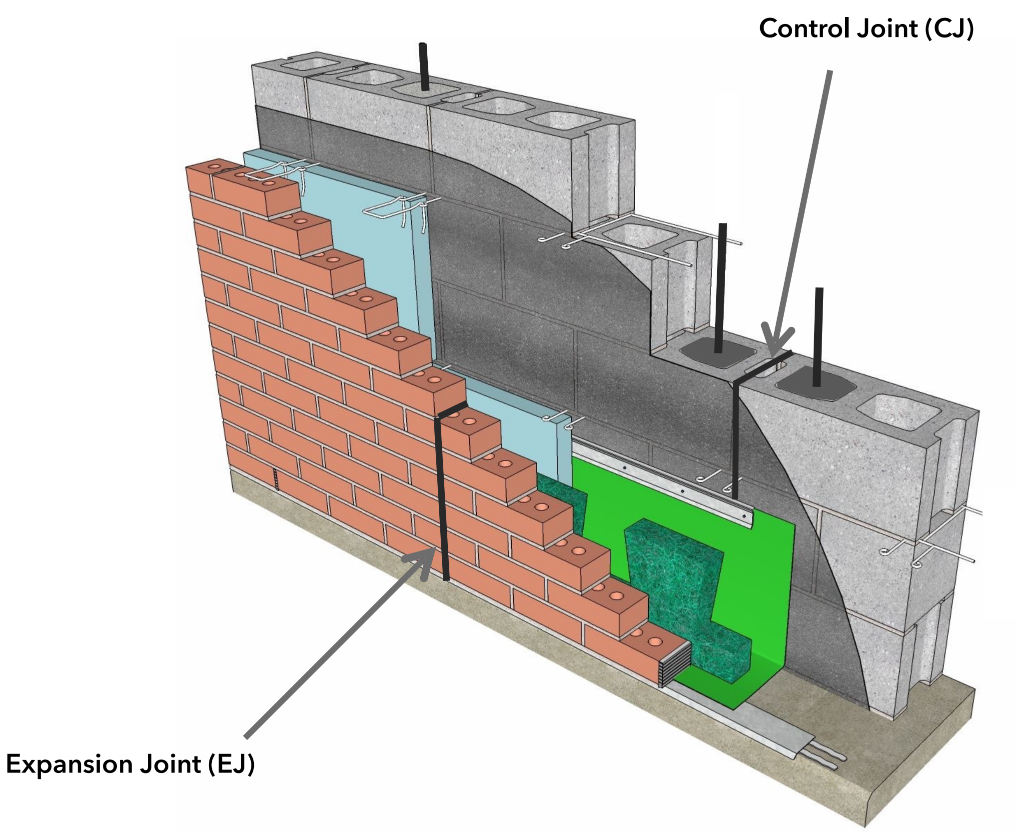


Figure 11 : EJs in the Clay Brick Veneer and CJs in the Structural Concrete Masonry

Contractor Insight

Who is Responsible for Locating Masonry Movement Joints?

Architects and structural engineers have to indicate specific locations of masonry movement joints on the project drawings. It is not acceptable to define vague criteria in the project notes in an attempt to pass the responsibility of locating movement joints onto the contractor or mason contractor. Specific movement joint locations are necessary to prevent contractors from locating movement joints during construction in locations that could compromise aspects of the design.

Only designers know the intent of their design. Movement joints can affect the aesthetics of a masonry building, and the locations of the joints in structural masonry walls can have a significant impact on their structural performance.

TMS 402-16, Section 12.1.6.3, states that movement joints be located in the veneer to accommodate differential movement. Later in the code, TMS 602-16 Mandatory Requirements Checklist states, "Notes to Architect/Engineer", Part 3, 3.3 D.6, page S-73. "Indicate type and location of movement joints on the project drawings."

It is critical for all movement joints to be specifically located for structural load-resisting masonry walls, non-load bearing masonry walls, and masonry veneers. Veneer movement joints are typically shown on architectural wall elevation drawings, and control joints for structural masonry walls can be located on structural plans or structural wall elevation drawings.

TMS Building Code Requirements and Specification for Masonry Structures

Mandatory Requirements Checklist - Notes to **Architect / Engineer**

"Indicate type and location of movement joints on the project drawings."

