NCMA TEK

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EMPIRICAL DESIGN OF CONCRETE MASONRY WALLS

TEK 14-8A
Structural (2001)

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INTRODUCTION

Empirical design is a procedure of proportioning and sizing unreinforced masonry elements based on known historical performance for a given application. Empirical provisions preceded the development of engineered masonry design, and can be traced back several centuries. This approach to design is based on historical experience in lieu of analytical methods. It has proven to be an expedient design method for typical loadbearing structures subjected to relatively small wind loads and located in areas of low seismic risk. Empirical design has also been used extensively for the design of exterior curtain walls and interior partitions.

Using empirical design, vertical and lateral load resistance is governed by prescriptive criteria which include wall height to thickness ratios, shear wall length and spacing, minimum wall thickness, maximum building height, and other criteria, which have proven to be effective through years of experience.

This TEK is based on the provisions in Chapter 5 of *Building Code Requirements for Masonry Structures* (ref. 1). These empirical design requirements do not apply to other design methods such as allowable stress or limit states design.

APPLICABILITY OF EMPIRICAL DESIGN

All elements of masonry structures are permitted to be designed by empirical methods when assigned to Seismic Design Category (SDC) A, B or C and where the basic wind speed (three-second gust, not fastest mile) is less than or equal to 110 mph (145 km/hr), as defined in *Minimum Design Loads for Buildings and Other Structures,* ASCE 7-98 (ref. 3). A wind speed of this velocity generally applies along the East and Gulf coasts of the United States. When empirically designed elements are part of the seismic lateral force resisting system, their use is limited to SDC A.

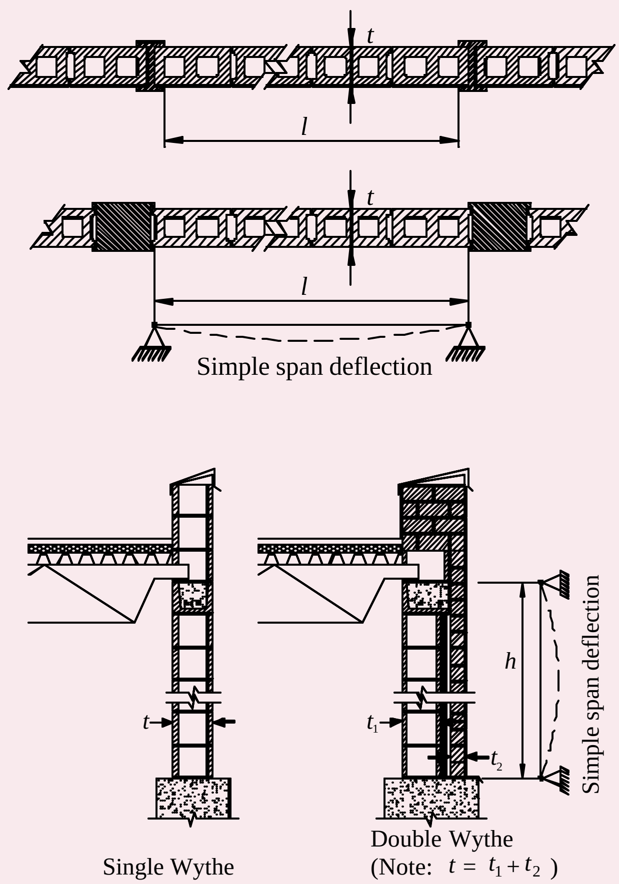


Figure 1—Lateral Support of Empirically Designed Concrete Masonry Walls
Figures used by permission (ref. 2).

Table 1—Wall Lateral Support Requirements (ref. 1)

Construction	Maximum wall length-to thickness or height-to thickness ratio[a]
Bearing walls	
Solid or solid grouted	20
All other	18
Nonbearing walls	
Exterior	18
Interior	36
Cantilever Walls[b]	
Solid	6
Hollow	4
Parapets (8-in. (203-mm) thick min.)[b]	3

[a] Ratios are determined using nominal dimensions. For multiwythe walls where wythes are bonded by masonry headers, the thickness is the nominal wall thickness. When multiwythe walls are bonded by metal wall ties, the thickness is taken as the sum of the wythe thicknesses.

[b] The ratios are maximum height-to-thickness ratios and do not limit wall length.

Table 2—Maximum Wall Spans, ft (m)

Wall thickness, in. (mm)	6 (152)	8 (203)	10 (254)	12 (305)
Bearing walls				
Solid or solid grouted	10 (3.0)[a]	13.3 (4.1)	16.6 (5.1)	20 (6.1)
All other	9 (2.7)[a]	12 (3.7)	15 (4.5)	18 (5.5)
Nonbearing walls				
Exterior	9 (2.7)	12 (3.7)	15 (4.5)	18 (5.5)
Interior	18 (5.5)	24 (7.3)	30 (9.1)	36 (11)
Cantilever Walls[b]				
Solid	3 (0.9)	4 (1.2)	5 (1.5)	6 (1.8)
Hollow	2 (0.6)	2.6 (0.8)	3.3 (1.0)	4 (1.2)
Parapets [b]	1.5 (0.5)	2 (0.6)	2.5 (0.8)	3 (0.9)

[a] 6-in. (152-mm) thick bearing walls are limited to one story in height.

[b] For these cases, spans are maximum wall heights.

Table 3—Allowable Compressive Stress for Empirical Design of Masonry (ref. 1)

Gross area compressive strength of unit, psi (MPa)	Allowable compressive stresses based on gross cross-sectional area, psi (MPa)[a] Type M or S mortar	Type N mortar
Solid concrete brick:		
8000 (55) or greater	350 (2.41)	300 (2.07)
4500 (31)	225 (1.55)	200 (1.38)
2500 (17)	160 (1.10)	140 (0.97)
1500 (10)	115 (0.79)	100 (0.69)
Grouted concrete masonry:		
4500 (31) or greater	225 (1.55)	200 (1.38)
2500 (17)	160 (1.10)	140 (0.97)
1500 (10)	115 (0.79)	100 (0.69)
Solid concrete masonry units:		
3000 (21) or greater	225 (1.55)	200 (1.38)
2000 (14)	160 (1.10)	140 (0.97)
1200 (8.3)	115 (0.79)	100 (0.69)
Hollow concrete masonry units:		
2000 (14) or greater	140 (0.97)	120 (0.83)
1500 (10)	115 (0.79)	100 (0.69)
1000 (6.9)	75 (0.52)	70 (0.48)
700 (4.8)	60 (0.41)	55 (0.38)
Hollow walls (noncomposite masonry bonded[b])		
solid units:		
2500 (17) or greater	160 (1.10)	140 (0.97)
1500 (10)	115 (0.79)	100 (0.69)
hollow units	75 (0.52)	70 (0.48)

[a] Linear interpolation for intermediate values of compressive strength is permitted.

[b] Where floor and roof loads are carried on one wythe, the gross cross-sectional area is that of the wythe under load; if both wythes are loaded, the gross cross-sectional area is that of the wall minus the area of the cavity between the wythes. Walls bonded with metal ties shall be considered as noncomposite walls unless collar joints are filled with mortar or grout.

DESIGN PROVISIONS

Minimum Wall Thickness

Buildings that rely on empirically designed masonry walls for lateral load resistance are permitted up to 35 ft (10.7 m) in height.

Empirically designed bearing walls of one story buildings must be at least 6 in. (152 mm) thick and must be at least 8 in. (203 mm) thick for buildings more than one story high.

Lateral Support

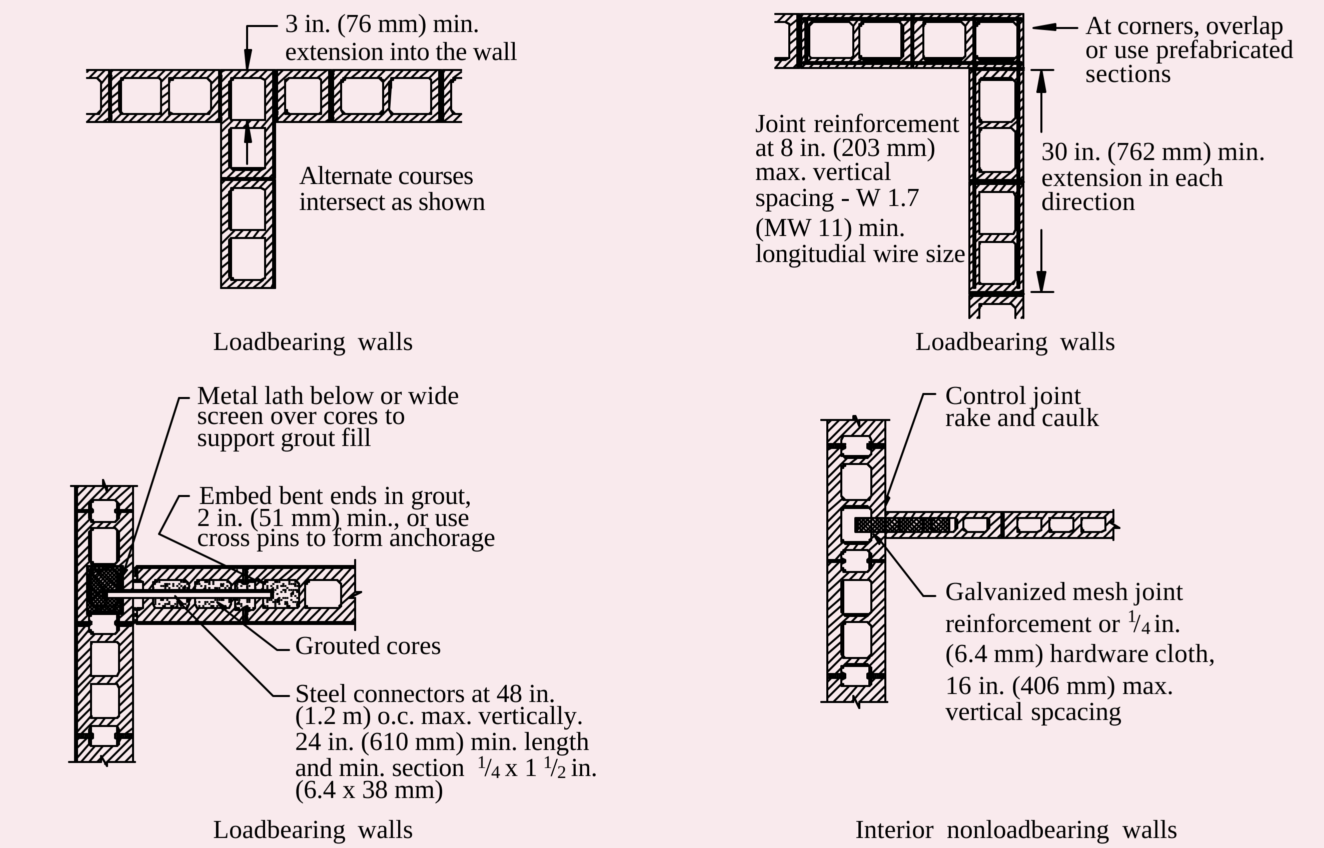
Lateral support for walls can be provided in the horizontal direction by cross walls, pilasters, buttresses, and structural frame members, or in the vertical direction by floor diaphragms, roof diaphragms, and structural frame members, as illustrated in Figure 1. For empirically designed walls, such support must be provided at the maximum intervals given in Tables 1 and 2.

Note that the span limitations apply to only one direction; that is, the span in one direction may be unlimited as long as the span in the other direction meets the requirements of Tables 1 or 2.

Allowable Stresses

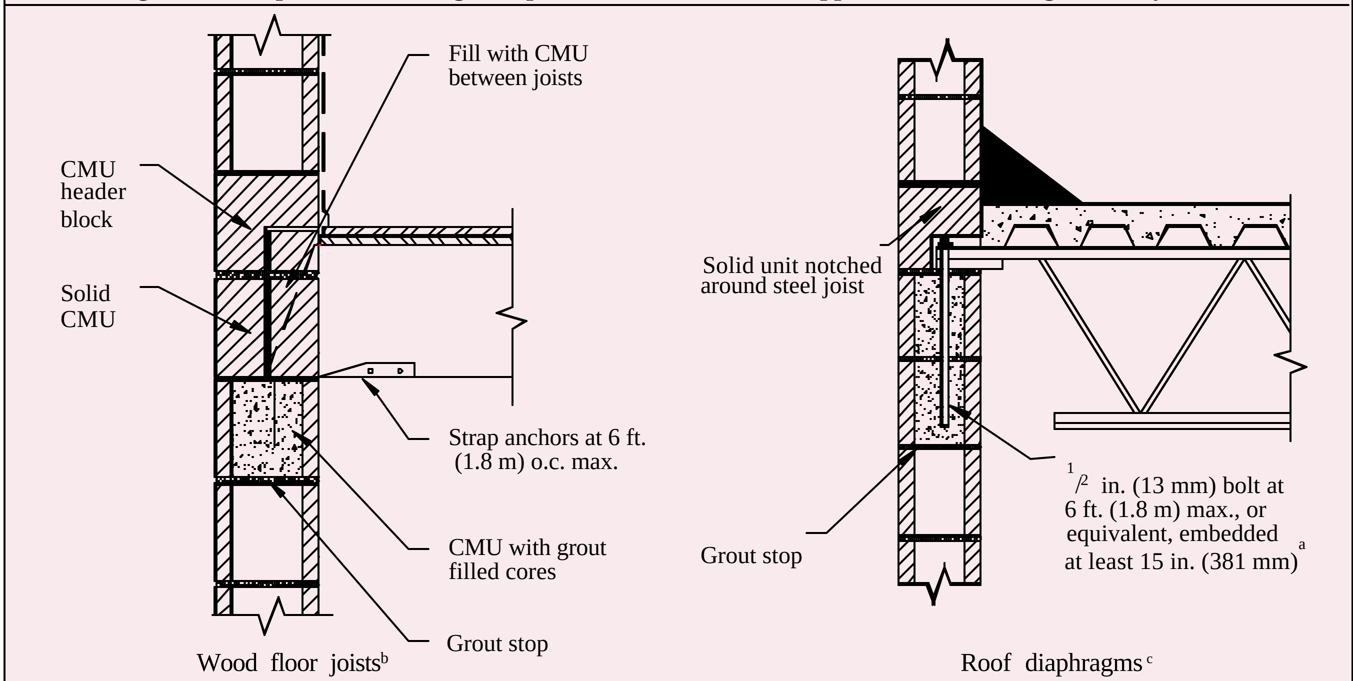
Allowable stresses in empirically designed masonry due to building code prescribed vertical (gravity) dead and live loads (excluding wind or seismic) are given in Table 3. Calculated compressive stresses for both single and multiwythe walls are determined by dividing the design load by the gross cross-sectional area of the wall, excluding areas of openings, chases or recesses. The area is based on the specified dimensions of masonry, rather than on nominal dimensions. In multiwythe walls, the allowable stress is determined by the weakest combination of units and mortar shown in Table 3.

In addition, the commentary to *Building Code Require-*



Note: Other metal ties, joint reinforcement or anchors may be used provided they are spaced to provide an equivalent area of anchorage.

Figure 2—Empirical Anchorage Requirements for Lateral Support of Intersecting Masonry Walls



Notes:

[a] As an alternative, the bolts can be hooked or welded to at least 0.2 in.^{2} (129 mm^2) of bond beam reinforcement placed not less than 6 in. (152 mm) from the top of the wall.

[b] Wood joists anchored to parallel masonry walls require metal straps which extend over and under the joists and which are secured to at least three joists. Anchors must be spaced at a maximum of 6 ft (1.8 m). Blocking is required between joists at each strap anchor.

[c] Steel floor joists which bear on and are anchored to masonry walls require 3/8 in. (9.5 mm) reinforcing bars spaced a maximum of 6 ft (1.8 m) on center, or equivalent anchorage. Where joists are parallel to the wall, anchors must be located at joist cross bridging.

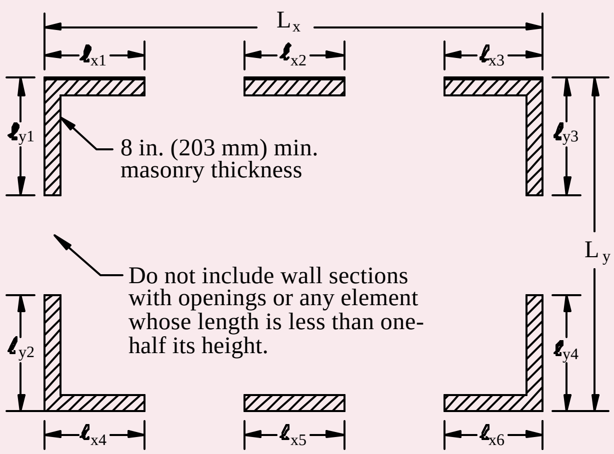
Figure 3—Empirical Anchorage Requirements for Floor and Roof Diaphragms

ments for Masonry Structures (ref. 1) contains additional guidance for concentrated loads. According to the commentary, when concentrated loads act on empirically designed masonry, the course immediately under the point of bearing should be a solid unit or be filled solid with mortar or grout. Further, when the concentrated load acts on the full wall thickness, the allowable stresses under the load may be increased by 25 percent. The allowable stresses may be increased by 50 percent when concentrated loads act on concentrically placed bearing plates that are greater than one-half but less than the full area.

Anchorage for Lateral Support

Where empirically designed masonry walls depend on cross walls, roof diaphragms, floor diaphragms, or structural frames for lateral support, it is essential that the walls be properly anchored so that the imposed loads can be transmitted from the wall to the supporting element. Minimum anchorage requirements for intersecting walls and for floor and roof diaphragms are shown in Figures 2 and 3, respectively.

Masonry walls are required to be anchored to structural frames that provide lateral support by ½ in. (13 mm) diameter bolts spaced at a maximum of 4 ft (1.2 m), or with other bolts and spacings that provide equivalent anchorage. The bolts must be embedded a minimum of 4 in. (102 mm) into the masonry.



In x-direction,

cumulative shear wall length = $l_{x1} + l_{x2} + ... + l_{xn}$

In y-direction,

cumulative shear wall length = $l_{y1} + l_{y2} + ... + l_{yn}$

In each direction, cumulative shear wall length must exceed the larger of $0.4L_x$ and $0.4L_y$

Figure 4—Empirically Designed Shear Wall Requirements

Table 4—Shear Wall Diaphragm Length-to-Width Ratios (ref. 1)

Floor or roof construction	Maximum length-to-width ratio of diaphragm panel
Cast-in-place concrete	5:1
Precast concrete	4:1
Metal deck with concrete fill	3:1
Metal deck with no fill	2:1
Wood diaphragm	2:1

Shear Walls

Where the structure depends on masonry walls for lateral stability against wind or earthquake forces, shear walls must be provided parallel to the direction of the lateral forces as well as in a perpendicular plane, for stability.

Requirements for empirically designed masonry shear walls are shown in Figure 4.

Shear wall spacing is determined empirically by the length-to-width aspect ratio of the diaphragms that transfer lateral forces to the shear walls, as listed in Table 4. In addition, roofs must be designed and constructed in a manner such that they will not impose thrust perpendicular to the shear walls to which they are attached.

The height of empirically designed shear walls is not permitted to exceed 35 ft (10.7 m). The minimum nominal thickness of shear walls is 8 in. (203 mm).

Bonding of Multiwythe Walls

Wythes of multiwythe masonry walls are required to be bonded together. Bonding can be achieved using masonry headers, metal wall ties, or prefabricated joint reinforcement, as illustrated in Figure 5. Various empirical requirements for each of these bonding methods are given below.

Bonding of solid unit walls with masonry headers. Where masonry headers are used to bond wythes of solid masonry construction, at least 4 percent of the wall surface of each face must be composed of headers, which must extend at least 3 in. (76 mm) into the backing. The distance between adjacent full-length headers may not exceed 24 in. (610 mm) in either the horizontal or vertical direction. In walls where a single header does not extend through the wall, headers from opposite sides must overlap at least 3 in. (76 mm), or headers from opposite sides must be covered with another header course which overlaps the header below by at least 3 in. (76 mm).

Bonding of hollow unit walls with masonry headers. Where two or more hollow units are used to make up the thickness of a wall, the stretcher courses must be bonded at vertical intervals not exceeding 34 in. (864 mm) by lapping at least 3 in. (76 mm) over the unit below, or by lapping at vertical intervals not exceeding 17 in. (432 mm) with units which are at least 50 percent greater in thickness than the units below.

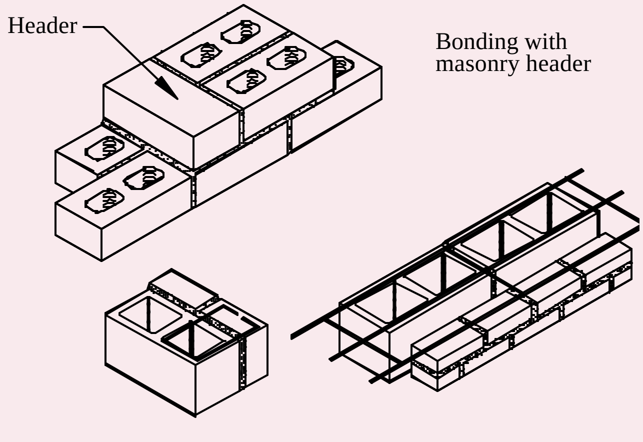


Figure 5—Types of Bonding

Bonding with metal wall ties.
Wire size W2.8 (MW18) wall ties, or metal wire of equivalent stiffness, may be used to bond wythes. Each $4^1/_2$ ft^2 (0.42 m^2) of wall surface must have at least one tie. Ties must be spaced a maximum of 24 in. (610 mm) vertically and 36 in. (914 mm) horizontally. Hollow masonry walls must use rectangular wall ties for bonding. In other walls, ends of ties must be bent to 90^o angles to provide hooks no less than 2 in. (51 mm) long. Additional bonding ties are required at all openings, and must be spaced a maximum of 3 ft (914 mm) apart around the perimeter and located within 12 in. (305 mm) of the opening. Wall ties cannot include drips.

Bonding with prefabricated joint reinforcement.
Where adjacent wythes of masonry are bonded with prefabricated joint reinforcement, there shall be at least one cross wire serving as a tie for each $2^2/_3$ ft^2 (0.25 m^2) of wall area. The joint reinforcement must be spaced 24 in. (610 mm) or closer vertically. Cross wires on prefabricated joint reinforcement shall not be smaller than wire size W1.7 (MW11) and shall be without drips. The longitudinal wires must be embedded in the mortar.

Miscellaneous Empirical Requirements

Chases and Recesses
Masonry directly above chases or recesses wider than 12 in. (305 mm) must be supported on lintels.

Lintels
Lintels are designed as reinforced beams, according to Section 2.3.3.4 of *Building Code Requirements for Masonry Structures* (ref. 1). End bearing must be at least 4 in. (102 mm), although 8 in. (203 mm) is typical.

Support on Wood
Empirically designed masonry is not permitted to be supported by wood girders or other forms of wood construction, due to expected deformations in wood from deflection and moisture, causing distress in the masonry, and due to potential safety implications in the event of fire.

Corbelling
Only solid masonry units may be used for corbelling. For solid walls, the corbelled masonry can project beyond the face of the wall up to one-half of the wall thickness, as long as the opposite side of the wall remains in its same plane. For hollow walls, the corbelled projection cannot exceed one-half the wythe thickness. The maximum projection of an individual masonry unit must be either one-half the height of the unit or one-third its thickness at right angles to the wall, whichever is less.

EMPIRICALLY DESIGNED PARTITION WALLS

In many cases, the building structure is designed using traditional engineered methods, such as strength design or allowable stress design, but the interior non-loadbearing masonry walls are empirically designed. In these cases, the partition walls are supported according to the provisions listed in Tables 1 and 2, but it is important that the support conditions provide isolation between the partition walls and the building's structural elements to prevent the building loads from being transferred into the partition. The anchor, or other support, must provide the required lateral support for the partition wall while also allowing for differential movement. This is in contrast to the "*Anchorage for Lateral Support*" section, which details anchorage requirements to help ensure adequate load transfer between the building structure and the loadbearing masonry wall.

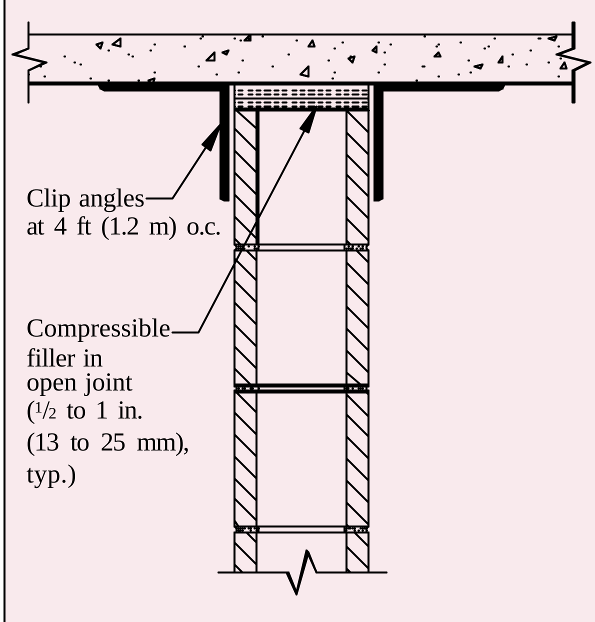


Figure 6—Example of Support for Empirically Designed Masonry Partition Wall

Figure 6 shows an example of such a support, using clip angles. C channels or adjustable anchors could be used as well. The gap at the top of the wall should be between $^1/_2$ and 1 in. (13 and 25 mm), or as required to accommodate the anticipated deflection. The gap is filled with compressible filler, mineral wool or a fire-rated material, if required. Fire walls may also require a sealant to be applied at the bottom of the clip angles. This joint should not be filled with mortar, as it may allow load transfer between the structure and the partition wall.

REFERENCES

1. *Building Code Requirements for Masonry Structures*, ACI 530/ASCE 5/TMS 402. Reported by the Masonry Standards Joint Committee, 2002.
2. *Masonry Designer's Guide*. American Concrete Institute, Council for Masonry Research, and The Masonry Society, 1999.
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