Chapter 11

MASONRY STRUCTURE DESIGN REQUIREMENTS

11.1 GENERAL:

11.1.1 Scope: The design and construction of reinforced and plain (unreinforced) masonry *components* and systems and the materials used therein shall comply with the requirements of this chapter.

11.1.2 Reference Documents: The designation and title of documents cited in this chapter are listed in this section.

ACI 318	American Concrete Institute (ACI), *Building Code Requirements for Structural Concrete*, excluding Appendix A, 1999
ACI 530	American Concrete Institute (ACI), Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402, 1999
ACI 530.1	American Concrete Institute (ACI), *Specifications for Masonry Structures*, ACI 530.1/ASCE 6/TMS 602, 1999

Compliance with specific provisions of ACI 530 is mandatory where required by this chapter.

11.1.3 Definitions:

Anchor: Metal rod, wire, bolt, or strap that secures masonry to its structural support.

Area:

Gross Cross-Sectional Area: The area delineated by the out-to-out specified dimensions of masonry in the plane under consideration.

Net Cross-Sectional Area: The area of masonry units, grout, and mortar crossed by the plane under consideration based on out-to-out specified dimensions.

Bed Joint: The horizontal layer of mortar on which a masonry unit is laid.

Backing: The *wall* surface to which *veneer* is secured. The backing can be concrete, masonry, steel framing, or wood framing.

Cleanout: An opening to the bottom of a grout space of sufficient size and spacing to allow removal of debris.

Collar Joint: Vertical longitudinal joint between wythes of masonry or between masonry wythe and back-up construction which is permitted to be filled with mortar or grout.

Column: An isolated vertical member whose horizontal dimension measured at right angles to the thickness does not exceed three times its thickness and whose height is at least three times its thickness.

Composite Masonry: Multiwythe the masonry members acting with composite action.

Connector: A mechanical device (including anchors, *wall* ties, and fasteners) for joining two or more pieces, parts, or members.

Cover: Distance between surface of reinforcing bar and edge of member.

Detailed Plain Masonry Shear Wall: A masonry *shear wall* designed to resist lateral forces neglecting stresses in reinforcement and designed in accordance with Sec. 11.10.2.

Dimension:

> **Actual Dimension:** The measured dimension of a designated item (e.g., a designated masonry unit or *wall*).
>
> **Nominal Dimension:** The specified dimension plus an allowance for the joints with which the units are to be laid. Nominal dimensions are usually given in whole numbers. Thickness is given first, followed by height and then length.
>
> **Specified Dimension:** The dimension specified for the manufacture or construction of masonry, masonry units, *joints*, or any other *component* of a *structure*.

Effective Height: For braced members, the effective height is the clear height between lateral supports and is used for calculating the slenderness ratio. The effective height for unbraced members is calculated in accordance with engineering mechanics.

Effective Period: Fundamental period of the structure based on cracked stiffness.

Glass Unit Masonry: Nonload-bearing masonry composed of glass units bonded by mortar.

Head Joint: Vertical mortar joint between masonry units within the wythe at the time the masonry units are laid.

Intermediate Reinforced Masonry Shear Wall: A masonry *shear wall* designed to resist lateral forces considering stresses in reinforcement and designed in accordance with Sec. 11.10.4.

Masonry Unit:

> **Hollow Masonry Unit:** A masonry unit whose net cross-sectional area in every plane parallel to the bearing surface is less than 75 percent of the gross cross-sectional area in the same plane.
>
> **Solid Masonry Unit:** A masonry unit whose net cross-sectional area in every plane parallel to the bearing surface is 75 percent or more of the gross cross-sectional area in the same plane.

Ordinary Plain Masonry Shear Wall: A masonry *shear wall* designed to resist lateral forces neglecting stresses in reinforcement and designed in accordance with Sec. 11.10.1.

Ordinary Reinforced Masonry Shear Wall: A masonry *shear wall* designed to resist lateral forces considering stresses in reinforcement and designed in accordance with Sec. 11.10.3.

Plain Masonry: Masonry in which the tensile resistance of the masonry is taken into consideration and the effects of stresses in reinforcement are neglected.

Plastic Hinge: The zone in a structural member in which the yield moment is anticipated to be exceeded under loading combinations that include earthquake.

Reinforced Masonry: Masonry construction in which reinforcement acts in conjunction with the masonry to resist forces.

Running Bond: The placement of masonry units such that head *joints* in successive courses are horizontally offset at least one-quarter the unit length.

Special Reinforced Masonry Shear Wall: A masonry *shear wall* designed to resist lateral forces considering stresses in reinforcement and designed in accordance with Sec. 11.10.5.

Specified: Required by *construction documents.*

Specified Compressive Strength of Masonry, f'_m: Required compressive strength (expressed as force per unit of net cross-sectional area) of the masonry. Whenever the quantity f'_m is under the radical sign, the square root of numerical value only is intended and the result has units of pounds per square inch (MPa).

Stack Bond: Stack bond is other than running bond. Usually, the placement of units is such that the head *joints* in successive courses are aligned vertically.

Stirrup: Shear reinforcement in a beam or flexural member.

Strength:

Design Strength: *Nominal strength* multiplied by a strength reduction factor.

Nominal Strength: *Strength* of a member or cross section calculated in accordance with these provisions before application of any strength reduction factors.

Required Strength: *Strength* of a member or cross section required to resist factored loads.

Tie:

Lateral Tie: Loop of reinforcing bar or wire enclosing longitudinal reinforcement.

Wall Tie: A connector that joins wythes of masonry *walls* together.

Veneer:

Masonry Veneer: A masonry wythe that provides the exterior finish of a *wall* system and transfers out-of-plane load directly to a backing but that is not considered to add load-resisting capacity to the *wall* system.

Anchored Veneer: Masonry *veneer* secured to and supported laterally by the backing through anchors and supported vertically by the foundation or other structural support.

Adhered Veneer: Masonry *veneer* secured to and supported by the backing through adhesion.

Wall: A vertical element with a horizontal length at least three times its thickness.

Wall Frame: A moment resisting frame of masonry beams and masonry columns within a plane with special reinforcement details and connections that provides resistance to lateral and *gravity loads*.

Wythe: A continuous vertical section of a *wall*, one masonry unit in thickness.

11.1.4 Notations:

A_b = cross-sectional area of an anchor bolt, in.^{2} (mm^2).

A_n = net cross-sectional area of masonry, 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_s = cross-sectional area of reinforcement, in.^{2} (mm^2).

A_v = cross-sectional area of shear reinforcement, in.^{2} (mm)^2

a = length of compressive stress block, in. (mm).

B_a = design axial strength of an anchor bolt, lb (N).

B_v = design shear strength of an anchor bolt, lb (N).

b_a = factored axial force on an anchor bolt, lb (N).

b_v = factored shear force on an anchor bolt, lb (N).

b_w = web width, in. (mm).

C_d = deflection amplification factor as given in Table 5.2.2.

c = distance from the fiber of maximum compressive strain to the neutral axis, in. (mm).

d_b = diameter of reinforcement, in. (mm).

d_{bb} = diameter of the largest beam longitudinal reinforcing bar passing through, or anchored in, the wall frame beam-*column* intersection, in. (mm).

d_{bp} = diameter of the largest *column* (pier) longitudinal reinforcing bar passing through, or anchored in, the wall frame beam-column intersection, in. (mm).

d_v = length of member in direction of shear force, in. (mm).

E_m = modulus of elasticity of masonry, psi (MPa).

E_s = modulus of elasticity of reinforcement, psi (MPa).

E_v = modulus of rigidity of masonry, psi (MPa).

f_g = specified compressive *strength* of grout, psi (MPa).

$f_m^{/}$ = specified compressive *strength* of masonry at the age of 28 days, unless a different age is specified, psi (MPa).

f_r = modulus of rupture of masonry, psi (MPa).

f_y = specified yield *strength* of the reinforcement or the anchor bolt as applicable, psi (MPa).

h = effective height of a *column*, pilaster or *wall*, in. (mm).

h_n = height of *structure* above the *base* level to level *n*, ft. (m).

h_b = beam depth in the plane of the *wall frame*, in. (mm).

h_c = cross-sectional dimension of grouted core of wall frame member measured center to center of confining reinforcement, in. (mm).

h_p = pier depth in the plane of the wall frame, in. (mm).

I_{cr} = moment of inertia of the cracked section, in.^{4} (mm^4).

I_{eff} = effective moment of inertia, in.^{4} (mm^4).

I_n = moment of inertia of the net cross-sectional area of a member, in.^{4} (mm^4).

L_c = length of coupling beam between coupled *shear walls*, in. (mm).

l_b = effective embedment length of anchor bolt, in. (mm).

l_{be} = anchor bolt edge distance, in. (mm).

l_d = development length, in. (mm).

l_{dh} = equivalent development length for a standard hook, in. (mm).

l_{ld} = minimum lap splice length, in. (mm).

M = moment on a masonry section due to unfactored load, in.-lb (N-mm).

M_a = maximum moment in member due to the applied loading for which deflection is computed, in.-lb (N-mm).

M_{cr} = cracking moment strength of the masonry, in.-lb (N-mm).

M_d = design moment strength, in.-lb (N-mm).

M_u = required flexural strength due to factored loads, in.-lb (N-mm).

M_1, M_2 = nominal moment strength at the ends of the coupling beam, in.-lb (N-mm).

N_v = force acting normal to shear surface, lb (N).

P = axial force on a masonry section due to unfactored loads, lb (N).

P_n = nominal axial load strength, lb (N).

P_u = required axial strength due to factored loads, lb (N).

r = radius of gyration, in. (mm).

S = section modulus based on net cross-sectional area of a *wall*, in.^{3} (mm^3).

s = spacing of lateral reinforcement in wall frame members, in. (mm).

t = specified *wall* thickness dimension or least lateral dimension of a column, in. (mm).

V = shear on a masonry section due to unfactored loads, lb (N).

V_g = unfactored shear force due to gravity loads, lb (N).

V_m = shear strength provided by masonry, lb (N).

V_n = nominal shear strength, lb (N).

V_s = shear strength provided by shear reinforcement, lb (N).

V_u = required shear strength due to factored loads, lb (N).

$)$ = design story drift as determined in Sec. 5.3.7.1, in. (mm).

$)_a$ = allowable story drift as specified in Sec. 5.2.8, in. (mm).

$*_{max}$ = the maximum displacement at level x, in. (mm).

D = ratio of the area of reinforcement to the net cross-sectional area of masonry in a plane perpendicular to the reinforcement.

D_b = reinforcement ratio producing balanced strain conditions.

$,_{mu}$ = maximum usable compressive strain of masonry, in./in. (mm/mm).

N = strength reduction factor.

11.2 CONSTRUCTION REQUIREMENTS:

11.2.1 General: Masonry shall be constructed in accordance with the requirements of ACI 530.1. Materials shall conform to the requirements of the standards referenced in ACI 530.1.

11.2.2 Quality Assurance: Inspection and testing of masonry materials and construction shall comply with the requirements of Chapter 3.

11.3 GENERAL REQUIREMENTS:

11.3.1 Scope: Masonry *structures* and *components* of masonry *structures* shall be designed in accordance with the requirements of reinforced masonry design, plain (unreinforced) masonry design, empirical design or design for architectural *components* of masonry subject to the limitations of this section. All masonry walls, unless isolated on three sides from in-plane motion from the basic structural system, shall be designed as shear walls. For design of glass-unit masonry and masonry veneer, see Sec. 11.12

11.3.2 Empirical Masonry Design: The requirements of Chapter 5 of ACI 530.1 shall apply to the empirical design of masonry.

11.3.3 Plain (Unreinforced) Masonry Design:

11.3.3.1: In the design of plain (unreinforced) masonry members, the flexural tensile strength of masonry units, mortar and grout in resisting design loads shall be permitted.

11.3.3.2: In the design of plain masonry members, stresses in reinforcement shall not be considered effective in resisting design loads.

11.3.3.3: Plain masonry members shall be designed to remain uncracked.

11.3.4 Reinforced Masonry Design: In the design of reinforced masonry members, stresses in reinforcement shall be considered effective in resisting design loads.

11.3.5 Seismic Design Category A: *Structures* assigned to *Seismic Design Category* A shall comply with either the requirements of Sec. 11.3.2 (empirical masonry design), Sec. 11.3.3 (plain masonry design), or Sec. 11.3.4 (reinforced masonry design).

11.3.6 Seismic Design Category B: *Structures* assigned to *Seismic Design Category* B shall conform to all the requirements for *Seismic Design Category* A and the lateral-force-resisting system shall be designed in accordance with Sec. 11.3.3 or Sec. 11.3.4.

11.3.7 Seismic Design Category C: *Structures* assigned to *Seismic Design Category* C shall conform to the requirements for *Seismic Design Category* B and to the additional requirements of this section.

11.3.7.1 Material Requirements: Structural clay load-bearing wall tile shall not be used as part of the basic structural system.

11.3.7.2 Masonry Shear Walls: Masonry *shear walls* shall comply with the requirements for *detailed plain masonry shear walls* (Sec. 11.10.2), *intermediate reinforced masonry shear walls* (Sec. 11.10.4), or *special reinforced masonry shear walls* (Sec. 11.10.5).

11.3.7.3 Minimum Wall Reinforcement: Vertical reinforcement of at least 0.20 in.^{2} (129 mm^2) in cross-sectional area shall be provided continuously from support to support at each corner, at each side of each opening, at the ends of walls, and at a maximum spacing of 4 feet (1219 mm) apart horizontally throughout the walls. Horizontal reinforcement not less than 0.20 in.^{2} (129 mm^2) in cross section shall be provided as follows:

a. At the bottom and top of wall openings extending not less than 24 in. (610 mm) nor less than 40 bar diameters past the opening,

b. Continuously at structurally connected roof and floor levels and at the top of walls,

c. At the bottom of load-bearing walls or in the top of foundations when doweled to the wall, and

d. At maximum spacing of 120 in. (3048 mm) unless uniformly distributed joint reinforcement is provided.

Reinforcement at the top and bottom of openings, when used in determining the maximum spacing specified in Item d above, shall be continuous in the wall.

11.3.7.4 Stack Bond Construction: Where stack bond is used, the minimum horizontal reinforcement shall be 0.0007 times the gross cross-sectional area of the wall. This requirement shall be satisfied with uniformly distributed joint reinforcement or with horizontal reinforcement spaced not over 48 in. (1219 mm) and fully embedded in grout or mortar.

11.3.7.5 Multiple Wythe Walls Not Acting Compositely: At least one wythe of a cavity *wall* shall be reinforced masonry designed in accordance with Sec. 11.3.4. The other wythe shall be reinforced with a minimum of one W1.7 wire per 4-in. (102 mm) nominal wythe thickness and spaced at intervals not exceeding 16 in. (406 mm). The wythes shall be tied in accordance with ACI 530, Sec. 5.8.3.2.

11.3.7.6 Walls Separated from the Basic Structural System: Masonry *walls*, laterally supported perpendicular to their own plane but otherwise structurally isolated on three sides from the basic structural system, shall have minimum horizontal reinforcement of 0.0007 times the gross cross-sectional area of the *wall*. This requirement shall be satisfied with uniformly distributed joint reinforcement or with horizontal reinforcement spaced not over 48 in. (1219 mm) and fully embedded in grout or mortar. Architectural *components* of masonry shall be exempt from this reinforcement requirement.

11.3.7.7 Connections to Masonry Columns: Structural members framing into or supported by masonry columns shall be anchored thereto. Anchor bolts located in the tops of columns shall be set entirely within the reinforcing cage composed of column bars and lateral ties. A minimum of two No. 4 (13 mm) lateral ties shall be provided in the top 5 inches (127 mm) of the column.

11.3.8 Seismic Design Category D: *Structures* assigned to *Seismic Design Category* D shall conform to all of the requirements for *Seismic Design Category* C and the additional requirements of this section.

11.3.8.1 Material Requirements: Neither Type N mortar nor masonry cement shall be used as part of the basic structural system.

11.3.8.2 Masonry Shear Walls: Masonry *shear walls* shall comply with the requirements for *special reinforced masonry shear walls* (Sec. 11.10.5)

11.3.8.3 Minimum Wall Reinforcement: All walls shall be reinforced with both vertical and horizontal reinforcement. The sum of the areas of horizontal and vertical reinforcement shall be at least 0.002 times the gross cross-sectional area of the wall and the minimum area of reinforcement in each direction shall not be less than 0.0007 times the gross cross-sectional area of the wall. The spacing of reinforcement shall not exceed 48 in. (1219 mm). Except for joint reinforcement, the bar size shall not be less than a No. 3 (10-mm diameter). Reinforcement shall be continuous around wall corners and through intersections, unless the intersecting walls are separated. Only horizontal reinforcement that is continuous in the wall or element shall be included in computing the area of horizontal reinforcement. Reinforcement spliced in accordance with Sec. 11.4.5.6 shall be considered as continuous reinforcement. Architectural *components* of masonry shall be exempt from this reinforcement requirement.

11.3.8.4 Stack Bond Construction: Where masonry is laid in stack bond, the minimum amount of horizontal reinforcement shall be 0.0015 times the gross cross-sectional area of the wall. If open-end units are used and grouted solid, the minimum amount of horizontal reinforcement shall be 0.0007 times the gross cross-sectional area of the wall. The maximum spacing of horizontal reinforcement shall not exceed 24 in. (610 mm). Architectural *components* of masonry shall be exempt from these requirements.

11.3.8.5 Minimum Wall Thickness: The nominal thickness of masonry bearing *walls* shall not be less than 6 in. (152 mm). Nominal 4-in. (102 mm) thick load-bearing reinforced hollow clay unit masonry *walls* with a maximum unsupported height or length to thickness ratio of 27 are permitted to be used provided the net area unit strength exceeds 8,000 psi (55 MPa), units are laid in *running bond*, bar sizes do not exceed No. 4 (13 mm) with not more than two bars or one splice in a cell, and joints are not raked.

11.3.8.6 Minimum Column Reinforcement: Lateral ties in columns shall be spaced not more than 8 in. (203 mm) on center for the full height of the column. Lateral ties shall be embedded in grout and shall be No. 3 (10 mm) or larger.

11.3.8.7 Minimum Column Dimension: The nominal dimensions of a masonry column shall not be less than 12 in. (305 mm).

11.3.8.8: Separation Joints: Where concrete abuts structural masonry and the joint between the materials is not designed as a separation joint, the concrete shall be roughened so that the average height of aggregate exposure is 1/8 in. (3 mm) and shall be bonded to the masonry in accordance with these requirements as if it were masonry. Vertical joints not intended to act as separation joints shall be crossed by horizontal reinforcement as required by Sec. 11.3.8.3.

11.3.9 Seismic Design Categories E and F: *Structures* assigned to *Seismic Design Categories* E and F shall conform to the requirements of *Seismic Design Category* D and to the additional requirements and limitations of this section.

11.3.9.1 Material Requirements: Construction procedures or admixtures shall be used to minimize shrinkage of grout and to maximize bond between reinforcement, grout, and units.

11.3.9.2 Masonry Shear Walls: Masonry shear walls shall comply with the requirements for *special reinforced masonry shear walls* (Sec. 11.10.5).

11.3.9.3 Stack Bond Construction: Masonry laid in stack bond shall conform to the following requirements:

11.3.9.3.1: For masonry that is not part of the basic structural system, the minimum ratio of horizontal reinforcement shall be 0.0015 and the maximum spacing of horizontal reinforcement shall be 24 in. (610 mm). For masonry that is part of the basic structural system, the minimum ratio of horizontal reinforcement shall be 0.0025 and the maximum spacing of horizontal reinforcement shall be 16 in. (406 mm). For the purpose of calculating this ratio, joint reinforcement shall not be considered.

11.3.9.3.2: Reinforced hollow unit construction shall be grouted solid and all *head joints* shall be made solid by the use of open end units.

11.3.10 Properties of Materials:

11.3.10.1 Steel Reinforcement Modulus of Elasticity: Unless otherwise determined by test, steel reinforcement modulus of elasticity, E_s, shall be taken to be 29,000,000 psi (200,000 MPa).

11.3.10.2 Masonry Modulus of Elasticity: The modulus of elasticity of masonry. E_m, shall be determined in accordance with Eq. 11.3.10.2 or shall be based on the modulus of elasticity determined by prism test and taken between 0.05 and 0.33 times the masonry prism strength:

$$E_m = 750 f'_m \tag{11.3.10.2}$$

where E_m = modulus of elasticity of masonry (psi) and f'_m = *specified compressive strength of masonry*, psi. The metric equivalent of Eq. 11.3.10.2 is the same except that E_m and f'_m are in MPa.

11.3.10.3: The modulus of rigidity of masonry, E_v, shall be taken equal to 0.4 times the modulus of elasticity of masonry, E_m.

11.3.10.4 Masonry Compressive Strength:

11.3.10.4.1: The specified compressive strength of masonry, f'_m, shall equal or exceed 1,500 psi (10 MPa).

11.3.10.4.2: The value of f'_m used to determine *nominal strength* values in this chapter shall not exceed 4,000 psi (28 MPa) for concrete masonry and shall not exceed 6,000 psi (41 MPa) for clay masonry.

11.3.10.5 Modulus of Rupture:

11.3.10.5.1 Out-of-Plane Bending: The modulus of rupture, f_r, for masonry elements subjected to out-of-plane bending shall be taken from Table 11.3.10.5.1.

TABLE 11.3.10.5.1 Modulus of Rupture for Out-of-Plane Bending (f_r)

Masonry type	Mortar types, psi (MPa)			
	Portland cement/lime		Masonry cement and air-entrained Portland cement/lime	
	M or S	N	M or S	N
Normal to bed *joints*				
Solid units	80 (0.55)	60 (0.41)	48 (0.33)	30 (0.21)
Hollow units[a]				
Ungrouted	50 (0.34)	38 (0.26)	30 (0.21)	18 (0.12)
Fully grouted	136 (0.94)	116 (0.80)	82 (0.57)	52 (0.36)
Parallel to bed *joints* in running bond				
Solid units	160 (1.10)	120 (0.83)	96 (0.66)	60 (0.41)
Hollow units				
Ungrouted and partially grouted	100 (0.69)	76 (0.52)	60 (0.41)	38 (0.26)
Fully grouted (running bond masonry)	160 (1.10)	120 (0.83)	96 (0.66)	60 (0.41)
Parallel to bed *joints* in stack bond:	0	0	0	0

[a] For partially grouted masonry, modulus of rupture values shall be determined on the basis of linear interpolation between hollow units that are fully grouted and hollow units that are ungrouted based on amount (percentage) of grouting.

11.3.10.5.2 In-Plane Bending: The modulus of rupture, f_r, for masonry elements subjected to in-plane forces shall be taken as 250 psi (1.7MPa). For grouted *stack bond* masonry, tension parallel to the bed *joints* for in-plane bending shall be assumed to be resisted only by the continuous grout core section.

11.3.10.6 Reinforcement Strength: Masonry design shall be based on a reinforcement strength equal to the specified yield strength of reinforcement, f_y, that shall not exceed 60,000 psi (400 MPa).

11.3.11 Section Properties:

11.3.11.1: Member strength shall be computed using section properties based on the minimum net bedded and grouted cores cross-sectional area of the member under consideration.

11.3.11.2: Section properties shall be based on specified dimensions.

11.3.12 Headed and Bent-Bar Anchor Bolts: All bolts shall be grouted in place with at least 1 in. (25 mm) grout between the bolt and masonry, except that 1/4-inch (6.4 mm) bolts may be placed in bed joints that are at least 1/2 in. (12.7 mm) in thickness.

11.3.12.1: The design axial strength, $B_{a,}$ for headed *anchor* bolts embedded in masonry shall be the lesser of Eq. 11.3.12.1-1 (strength governed by masonry breakout) or Eq. 11.3.12.1-2 (strength governed by steel):

$$B_a = A_b f_y \tag{11.3.12.1-2}$$

$$B_a = 4 \quad A_p \sqrt{f_m^{/}} \tag{11.3.12.1-1}$$

where:

B_a = design axial strength of the headed anchor bolt, lb;

N = strength reduction factor where N = 0.5 for Eq. 11.3.12.1-1 and N = 0.9 for Eq. 11.3.12.1-2;

A_p = projected area on the masonry surface of a right circular cone, in.^{2};

A_b = effective tensile stress area of the headed anchor bolt, in.^{2};

$f_m^{/}$ = specified compressive strength of the masonry, psi; and

f_y = specified yield strength of the headed anchor bolt, psi.

The metric equivalent of Eq. 11.3.12.1-1 is $B_a = (0.33 A_p \sqrt{f_m^{/}})$ where B_a is in N, A_p is in mm^2, and $f_m^{/}$ is in MPa. The metric equivalent of Eq. 11.3.12.1-2 is the same except that B_a is in N, A_b is in mm^2, and f_y is in MPa.

11.3.12.1.1: The area A_p in Eq. 11.3.12.1-1 shall be the lesser of Eq. 11.3.12.1.1-1 or Eq. 11.3.12.1.1-2:

$$A_p = R_b^2 \tag{11.3.12.1.1-1}$$

$$A_p = R_{be}^2 \tag{11.3.12.1.1-2}$$

where:

A_p = projected area on the masonry surface of a right circular cone, in.^{2};

l_b = effective embedment length of the headed anchor bolt, in.; and

l_{be} = *anchor* bolt edge distance, in..

The metric equivalents of Eq. 11.3.12.1.1-1 and Eq. 11.3.12.1.1-2 are the same except that A_p is in mm^2 and l_b and l_{be} are in mm.

Where the projected areas, A_p, of adjacent headed anchor bolts overlap, the projected area, A_p, of each bolt shall be reduced by one-half of the overlapping area. That portion of the projected area falling in an open cell or core shall be deducted from the value of A_p calculated using Eq. 11.3.12.1.1-1 or Eq. 11.3.12.1.1-2, whichever is less.

11.3.12.1.2: The effective embedment length of a headed bolt, l_b , shall be the length of embedment measured perpendicular from the surface of the masonry to the head of the *anchor* bolt.

11.3.12.1.3: The minimum effective embedment length of headed anchor bolts resisting axial forces shall be 4 bolt diameters or 2 in. (51 mm), whichever is greater.

11.3.12.2: The design axial strength, B_a,, for bent-bar anchor bolts (J- or L-bolts) embedded in masonry shall be the least of Eq. 11.3.12.2-1 (strength governed by masonry breakout), Eq. 11.3.12.2-2 (strength governed by steel), or Eq. 11.3.12.2-3 (strength governed by anchor pullout):

$$B_a = 4 \quad A_p \sqrt{f'_m} \qquad (11.3.12.2\text{-}1)$$

$$B_a = \quad A_b f_y \qquad (11.3.12.2\text{-}2)$$

$$B_a = 1.5 \quad f'_m e d_b + 200 \quad (l_b + e + d_b) d_b \qquad (11.3.12.2\text{-}3)$$

where:

B_a = design axial strength of the bent-bar anchor bolt, lb;

N = strength reduction factor where N = 0.5 for Eq. 11.3.12.2-1, N = 0.9 for Eq. 11.3.12.2-2, and N = 0.65 for Eq. 11.3.12.2-3;

A_p = projected area on the masonry surface of a right circular cone, in.^{2};

A_b = effective tensile stress area of the bent-bar anchor bolt, in.^{2};

e = projected leg extension of bent-bar anchor bolt, measured from inside edge of *anchor* at bend to farthest point of anchor in the plane of the hook, in.; shall not be taken larger than $2d_b$ for use in Eq. 11.3.12.2-3.

d_b = nominal diameter of bent-bar anchor bolt, in.

l_b = effective embedment length of bent-bar anchor bolt, in.

f'_m = specified compressive strength of the masonry, psi;

f_y = specified yield strength of the bent-bar anchor bolt, psi.

The metric equivalent of Eq. 11.3.12.2-1 is:

$$B_a = 0.33 \quad A_p\sqrt{f'_m}$$

where B_a is in N, A_p is in mm^2, and f'_m is in MPa. The metric equivalent of Eq. 11.3.12.2-2 is the same except that B_a is in N, A_b is in mm^2, and f_y is in MPa. The metric equivalent of Eq. 11.3.12.2-3 is:

$$B_a = 1.5 \quad f'_m e d_b + 2.05 \quad (l_b + e + d_b) d_b$$

where B_a is in N, e and d_b are in mm, and f'_m is in MPa.

The second term in Eq. 11.3.12.2-3 shall be included only if continuous special inspection is provided during placement per Sec. 11.3.5.2.

11.3.12.2.1: The area A_p in Eq. 11.3.12.2-1 shall be the lesser of Eq.11.3.12.2.1-1 or Eq. 11.3.12.2.1-2:

$$A_p = l_b^2 \qquad (11.3.12.2.1\text{-}1)$$

$$A_p = l_{be}^2 \qquad (11.3.12.2.1\text{-}2)$$

where:

A_p = projected area on the masonry surface of a right circular cone, in.^{2};

l_b = effective embedment length of the bent-bar anchor bolt, in.; and

l_{be} = anchor bolt edge distance, in..

The metric equivalents of Eq. 11.3.12.2.1-1 and Eq. 11.3.12.2.1-2 are the same except that A_p is in mm^2 and l_b and l_{be} are in mm.

Where the projected areas, A_p, of adjacent bent-bar anchor bolts overlap, the projected area, A_p, of each bolt shall be reduced by one-half of the overlapping area. That portion of the projected area falling in an open cell or core shall be deducted from the value of A_p calculated using Eq. 11.3.12.2.1-1 or Eq. 11.3.12.2.1-2, whichever is less.

11.3.12.2.2: The effective embedment of a bent-bar anchor bolt, l_b , shall be the length of embedment measured perpendicular from the surface of the masonry to the bearing surface of the bent end, minus one anchor bolt diameter.

11.3.12.2.3: The minimum effective embedment length of bent-bar anchor bolts resisting axial forces shall be 4 bolt diameters or 2 in. (51 mm), whichever is greater.

11.3.12.3: Where the anchor bolt edge distance, l_{be}, equals or exceeds 12 bolt diameters, the design shear strength, B_v, shall be the lesser of the values given by Eq. 11.3.12.3-1 (strength governed by masonry) or Eq. 11.3.12.3-2 (strength governed by steel):

$$B_v = 1750 \sqrt[4]{f'_m A_b} \qquad (11.3.12.3\text{-}1)$$

$$B_v = 0.6 \quad A_b f_y \qquad (11.3.12.3\text{-}2)$$

where:

N = strength reduction factor where N = 0.5 for Eq. 11.3.12.3-1 and N = 0.9 for Eq. 11.3.12.3-2;

A_b = effective tensile stress area of the anchor bolt, in.^{2};

f'_m = specified compressive strength of the masonry, psi, and

f_y = specified yield strength of anchor bolt as applicable, psi.

The metric equivalent of Eq. 11.3.12.3-1 is $B_v = 5350 \sqrt[4]{f'_m A_b}$ where A_b is in mm^2 and f'_m and f_y are in MPa. The metric equivalent of Eq. 11.3.12.3-2 is the same as that above except that A_b is in mm^2 and f_y is in MPa.

Where the anchor bolt edge distance, l_{be}, is less than 12 bolt diameters, the value of B_v in Eq. 11.3.12.3-1 shall be reduced by linear interpolation to zero at an l_{be} distance of 1 in. (25 mm).

11.3.12.4: Anchor bolts subjected to combined shear and tension shall be designed to satisfy Eq. 11.3.12.4:

$$\frac{b_a}{B_a} + \frac{b_v}{B_v} \leq 1 \qquad (11.3.12.4)$$

where:

b_a = design axial force on the anchor bolt, lb (N);

B_a = design axial strength of the anchor bolt, lb (N);

b_v = design shear force on the anchor bolt, lb (N); and

B_v = design shear strength of the anchor bolt, lb (N).

11.4 DETAILS OF REINFORCEMENT:

11.4.1 General:

11.4.1.1: Details of reinforcement shall be shown on the contract documents.

11.4.1.2: Reinforcing bars shall be embedded in grout.

11.4.2 Size of Reinforcement:

11.4.2.1: Reinforcing bars used in masonry shall not be larger than a No. 9 bar (29 mm diameter). The bar diameter shall not exceed one-eighth of the nominal *wall* thickness and shall not exceed one-quarter of the least clear dimension of the cell, course, or collar joint in which it is placed. The area of reinforcing bars placed in a cell, or in a course, of hollow unit construction shall not exceed 4 percent of the cell area.

11.4.2.2: Longitudinal and cross wire joint reinforcement shall be a minimum W1.1 (0.011 mm^2) and shall not exceed one-half the joint thickness.

11.4.3 Placement Limits for Reinforcement:

11.4.3.1: The clear distance between parallel reinforcing bars shall not be less than the nominal diameter of the bars nor less than 1 in. (25 mm).

11.4.3.2: In columns and pilasters, the clear distance between vertical reinforcing bars shall not be less than one and one-half times the nominal bar diameter, nor less than 1-1/2 in. (38 mm).

11.4.3.3: The clear distance limitations between reinforcing bars also shall apply to the clear distance between a contact lap splice and adjacent splices or bars.

11.4.3.4: Reinforcing bars shall not be bundled.

11.4.4 Cover for Reinforcement:

11.4.4.1: Reinforcing bars shall have a minimum thickness of masonry and grout cover not less than 2-1/2 d_b nor less than the following:

a. Where the masonry face is exposed to earth or weather, 2 in. (51 mm) for bars larger than No. 5 (16 mm) and 1-1/2 in. (38 mm) for No. 5 (16 mm) bar or smaller.

b. Where the masonry is not exposed to earth or weather, 1-1/2 in. (38 mm).

11.4.4.2: The minimum grout thickness between reinforcing bars and masonry units shall be 1/4 in. (6 mm) for fine grout or 1/2 in. (12 mm) for coarse grout.

11.4.4.3: Longitudinal wires of joint reinforcement shall be fully embedded in mortar or grout with a minimum cover of 1/2 in. (13 mm) when exposed to earth or weather and 3/8 in. (10 mm) when not exposed to earth or weather. Joint reinforcement in masonry exposed to earth or weather shall be corrosion resistant or protected from corrosion by coating.

11.4.4.4: *Wall* ties, anchors, and inserts, except anchor bolts not exposed to the weather or moisture, shall be protected from corrosion.

11.4.5 Development of Reinforcement:

11.4.5.1 General: The calculated tension or compression in the reinforcement where masonry reinforcement is anchored in concrete shall be developed in the concrete by embedment length, hook or mechanical device, or a combination thereof. Hooks shall be used only to develop bars in tension.

11.4.5.2 Development of Reinforcing Bars and Wires in Tension: The development length, l_d, of reinforcing bars and wire shall be determined by Eq. 11.4.5.2 but shall not be less than 12 in. (305 mm) for bars and 6 in. (152 mm) for wire:

$$l_d = \left(\frac{1}{f}\right)\left(\frac{0.13 d_b^2 f_y g}{K\sqrt{f'_m}}\right) \qquad (11.4.5.2)$$

where:

l_d = development length, in.;

f = strength reduction factor as given in Table 11.5.3;

d_b = diameter of the reinforcement, in.;

K = the least of the clear spacing between adjacent reinforcement, the cover of masonry and grout to the reinforcement, or 5 times d_b, in.;

f'_m = specified compressive strength of masonry, psi;

f_y = specified yield strength of the reinforcement, psi; and

= 1.0 for No. 3 through No. 5 reinforcing bars,

1.4 for No. 6 through No. 7 reinforcing bars, or

1.5 for No. 8 through No. 9 reinforcing bars.

The metric equivalent of Eq. 11.4.5.2 is

$$l_d = \left(\frac{1}{f}\right)\left(\frac{1.57 d_b^2 f_y g}{K\sqrt{f_m^{'}}}\right) \qquad (11.4.5.2\text{-}1)$$

where l_d, K, and d_b are in mm and f_y and f'_m are in MPa.

11.4.5.3 Standard Hooks:

11.4.5.3.1: The term standard hook as used in the *Provisions* shall mean one of the following:

11.4.5.3.1.1: A 180-degree turn plus extension of at least 4 bar diameters but not less than 2-1/2 in. (64 mm) at free end of bar.

11.4.5.3.1.2: A 90-degree turn plus extension of at least 12 bar diameters at free end of bar.

11.4.5.3.1.3: For *stirrup* and tie anchorage only, either a 135-degree or a 180-degree turn plus an extension of at least 6 bar diameters at the free end of the bar.

11.4.5.3.2: The equivalent embedment length for standard hooks in tension, l_{dh}, shall be as follows:

$$l_{dh} = 13 d_b \qquad (11.4.5.3.2)$$

where d_b = diameter of the reinforcement, in. The metric equivalent of Eq. 11.4.5.3.2 is the same except that d_b is in mm.

11.4.5.3.3: The effect of hooks for bars in compression shall be neglected in design computations.

11.4.5.4 Minimum Bend Diameter for Reinforcing Bars:

11.4.5.4.1: The diameter of bend measured on the inside of the bar, other than for *stirrups* and ties, shall not be less than values specified in Table 11.4.5.4.1.

TABLE 11.4.5.4.1 Minimum Diameters of Bend

Bar Size	Grade	Minimum Bend
No. 3 (10 mm) through No. 7 (22 mm)	40	5 bar diameters
No. 3 (10 mm) through No. 8 (25 mm)	50 or 60	6 bar diameters
No. 9 (29 mm)	50 or 60	8 bar diameters

11.4.5.5 Development of Shear Reinforcement:

11.4.5.5.1: Shear reinforcement shall extend the depth of the member less cover distances.

11.4.5.5.2: The ends of single leg or U-stirrups shall be anchored by one of the following means:

a. A standard hook plus an effective embedment of 0.5 times the development length, l_d. The effective embedment of a *stirrup* leg shall be taken as the distance between the mid-depth of the member and the start of the hook (point of tangency).

b. For No. 5 (16 mm) bar and D31 wire and smaller, bending around longitudinal reinforcement through at least 135 degrees plus an embedment of $l_d/3$. The $l_d/3$ embedment of a *stirrup* leg shall be taken as the distance between mid-depth of the member and the start of the hook (point of tangency).

c. Between the anchored ends, each bend in the continuous portion of a transverse U-stirrup shall enclose a longitudinal bar.

11.4.5.5.3: Except at wall intersections, the end of a reinforcing bar needed to satisfy shear strength requirements in accordance with Sec. 11.7.3.3 shall be bent around the edge vertical reinforcing bar with a 180-degree hook. At *wall* intersections, reinforcing bars used as shear reinforcement shall be bent around the edge vertical bar with a 90-degree standard hook and shall extend horizontally into the intersecting *wall*.

11.4.5.6 Splices of Reinforcement: Lap splices, welded splices, or mechanical connections shall be in accordance with the provisions of this section.

11.4.5.6.1 Lap Splices: Lap splices shall not be used in plastic hinge zones. The length of the plastic hinge zone shall be taken as at least 0.15 times the distance between the point of zero moment and the point of maximum moment.

11.4.5.6.1.1: The minimum length of lap, l_{ld}, for bars in tension or compression shall be equal to the development length, l_d, as determined by Eq. 11.4.5.2 but shall not be less than 12 in. (305 mm) for bars and 6 in (152 mm) for wire.

11.4.5.6.1.2: Bars spliced by non-contact lap splices shall not be spaced transversely farther apart than one-fifth the required length of lap or more than 8 in. (203 mm).

11.4.5.6.2 Welded Splices: A welded splice shall be capable of developing in tension 125 percent of the specified yield strength, f_y, of the bar. Welded splices shall only be permitted for ASTM A706 steel reinforcement. Welded splices shall not be permitted in plastic hinge zones of intermediate or special reinforced walls or special moment frames of masonry.

11.4.5.6.3 Mechanical Splices: Mechanical splices shall be classified as Type 1 or Type 2 according to Sec. 21.2.6.1 of ACI 318.

Type 1 mechanical splices shall not be used within a plastic hinge zone or within a beam-column joint of intermediate or special reinforced masonry shear walls or special moment frames. Type 2 mechanical splices shall be permitted in any location within a member.

11.5 STRENGTH AND DEFORMATION REQUIREMENTS:

11.5.1 General: Masonry *structures* and masonry members shall be designed to have strength at all sections at least equal to the *required strength* calculated for the factored loads in such combinations as are stipulated in these provisions.

11.5.2 Required Strength: The *required strength* shall be determined in accordance with Chapters 5 and 6.

11.5.3 Design Strength: *Design strength* provided by a member and its connections to other members and its cross sections in terms of flexure, axial load, and shear shall be taken as the *nominal strength* multiplied by a strength reduction factor, N, as specified in Table 11.5.3.

TABLE 11.5.3 Strength Reduction Factor N

Axial load, flexure, and combinations of axial load and flexure	Reinforced masonry Plain masonry	N = 0.85 N = 0.60
Shear	Reinforced masonry	N = 0.80
Shear	Plain masonry	N = 0.80
Reinforcement development length and splices		N = 0.80
Anchor bolt strength as governed by steel		N = 0.90
Anchor bolt strength as governed by masonry		N = 0.50
Bearing		N = 0.60

11.5.4 Deformation Requirements:

11.5.4.1: Masonry *structures* shall be designed so the design story drift, $)$, does not exceed the allowable story drift, $)_a$, obtained from Table 5.2.8.

11.5.4.1.1: Cantilever *shear walls* shall be proportioned such that the maximum displacement, $*_{max}$, at Level n does not exceed $0.01h_n$.

11.5.4.2: Deflection calculations for plain masonry members shall be based on uncracked section properties.

11.5.4.3: Deflection calculations for reinforced masonry members shall be based on an effective moment of inertia in accordance with the following:

$$I_{eff} = I_n \left(\frac{M_{cr}}{M_a} \right)^3 + I_{cr} \left[1 - \left(\frac{M_{cr}}{M_a} \right)^3 \right] \leq I_n \qquad (11.5.4.3)$$

where:

M_{cr}	=	Sf_r ,
M_{cr}	=	cracking moment strength of the masonry, in.-lb;
M_a	=	maximum moment in the member at the stage deflection is computed, in.-lb;
I_{cr}	=	moment of inertia of the cracked section, in.^{4};
I_n	=	moment of inertia of the net cross-sectional area of the member, in.^{4};
S	=	uncracked section modulus of the *wall*, in.^{3}; and
f_r	=	modulus of rupture of masonry, psi.

The metric equivalent of Eq. 11.5.4.3 is the same except that M_{cr} and M_a are in (N-mm), I_{cr} and I_n are in mm^4, S is in mm^3, and f_r is in MPa.

11.5.4.4: The calculated deflection shall be multiplied by C_d for determining drift.

11.6 FLEXURE AND AXIAL LOADS:

11.6.1 Scope: This section shall apply to the design of masonry members subject to flexure or axial loads or to combined flexure and axial loads.

11.6.2 Design Requirements of Reinforced Masonry Members:

11.6.2.1: Strength design of members for flexure and axial loads shall be in accordance with principles of engineering mechanics and in accordance with the following design assumptions:

a. Strain in reinforcement and masonry shall be assumed directly proportional to the distance from the neutral axis, except for deep flexural members with overall depth to clear span ratio greater than 2/5 for continuous span members and 4/5 for simple span members where a nonlinear distribution of strain shall be considered.

b. Maximum usable strain, ε_{mu}, at the extreme masonry compression fiber shall be assumed equal to 0.0025 in./in. for concrete masonry and 0.0035 in./in. for clay-unit masonry.

c. Stress in reinforcement below the *specified* yield strength, f_y, shall be taken as the modulus of elasticity, E_s, times the steel strain. For strains greater than those corresponding to the *specified* yield strength, f_y, the stress in the reinforcement shall be considered independent of strain and equal to the *specified* yield strength, f_y,

d. Tensile strength of masonry shall be neglected in calculating the flexural strength of a *reinforced masonry* cross section.

e. Flexural compression in masonry shall be assumed to be an equivalent rectangular stress block. Masonry stress of 0.80 times the *specified* compressive strength, $f_m^{/}$ shall be assumed to be uniformly distributed over an equivalent compression zone bounded by edges of the cross section and a straight line located parallel to the neutral axis at a distance $a = 0.80c$ from the fiber of maximum compressive strain. For out of plane bending, the width of the equivalent stress block shall not be taken greater than 6 times the nominal thickness of the masonry wall or the spacing between reinforcement, whichever is less. For in-plane bending of flanged walls, the same dimension shall apply.

11.6.2.2: For structures designed using an *R* value greater than 1.5, the ratio of reinforcement, *D*, shall not exceed the lesser ratio as calculated with either of the following two critical strain conditions:

a. For walls subjected to in-plane forces, for columns, and for beams, the critical strain condition corresponds to a strain in the extreme tension reinforcement equal to 5 times the strain associated with the reinforcement yield stress, f_y.

b. For walls subjected to out-of-plane forces, the critical strain condition corresponds to a strain in the extreme tension reinforcement equal to 1.3 times the strain associated with the reinforcement yield stress, f_y.

For both cases, the strain in the extreme compression fiber shall be assumed to be either 0.0035 for clay masonry or 0.0025 for concrete masonry.

The calculation of the maximum reinforcement ratio shall include unfactored gravity axial loads. The stress in the tension reinforcement shall be assumed to be 1.25 f_y. Tension in the masonry shall be neglected. The strength of the compressive zone shall be calculated as 80 percent of $f!_m$ times 80 percent of the area of the compressive zone. Stress in reinforcement in the compression zone shall be based on a linear strain distribution.

For structures designed using an *R* value less than or equal to 1.5, the ratio of reinforcement, *D,* shall not exceed the ratio as calculated with the following critical strain condition:

The critical strain condition corresponds to a strain in the extreme tension reinforcement equal to 2 times the strain associated with the reinforcement yield stress, f_y. The strain in the extreme compression fiber shall be assumed to be either 0.0035 for clay masonry or 0.0025 for concrete masonry.

The calculation of the maximum reinforcement ratio shall include unfactored gravity axial loads. The stress in the tension reinforcement shall be calculated by multiplying the strain by the modulus of elasticity of the reinforcement, but need not be taken greater than 1.25 f_y. Tension in the masonry shall be neglected. The strength of the compressive zone shall be calculated using an triangular stress block whose maximum value is the strain in the extreme compression fiber of the masonry, times the modulus of elasticity of the masonry. Stress in reinforcement in the compression zone shall be based on a linear strain distribution.

11.6.2.3: Members subject to compressive axial load shall be designed for the maximum moment that can accompany the axial load. The required moment, M_u, shall include the moment induced by relative lateral displacements.

11.6.3 Design of Plain (Unreinforced) Masonry Members:

11.6.3.1: Strength design of members for flexure and axial load shall be in accordance with principles of engineering mechanics .

11.6.3.2: Strain in masonry shall be assumed directly proportional to the distance from the neutral axis.

11.6.3.3: Flexural tension in masonry shall be assumed directly proportional to strain.

11.6.3.4: Flexural compressive stress in combination with axial compressive stress in masonry shall be assumed directly proportional to strain. Maximum compressive stress shall not exceed $0.85 f_m^{/}$.

11.6.3.5: Design axial load strength shall be in accordance with Eq. 11.6.3.5-1 or Eq. 11.6.3.5-2:

$$’_n = A_n f_m^{/} \left[1 - \left(\frac{h}{140r} \right)^2 \right] \text{ for } h/r < \qquad (11.6.3.5\text{-}1)$$

$$P_n = A_n f_m^{/} \left(\frac{70r}{h} \right)^2 \text{ for } h/r \ \$ \ 99 \qquad (11.6.3.5\text{-}2)$$

where:

N	=	strength reduction factor per Table 11.5.3;
A_n	=	*net cross-sectional area* of the masonry, in.^{2};
$f_m^{/}$	=	*specified* compressive strength of the masonry, psi;
h	=	*effective height* of the *wall* between points of support, in. and
r	=	radius of gyration, inches.

The metric equivalents for Eq. 11.6.3.5-1 and Eq. 11.6.3.5-2 are the same except that A_n is in mm^2, $f_m^{/}$ is in MPa, and h and r are in mm..

11.7 SHEAR:

11.7.1 Scope: Provisions of this section shall apply for design of members subject to shear.

11.7.2 Shear Strength:

11.7.2.1: Design of cross sections subjected to shear shall be based on:

$$V_u \;\#\quad V_n \tag{11.7.2.1}$$

where:

V_u	=	required shear strength due to factored loads, lb;
N	=	strength reduction factor per Table 11.5.3; and
V_n	=	nominal shear strength, lb.

The metric equivalent of Eq. 11.7.2.1 is the same except that V_u and V_n are in N.

11.7.2.2: The design shear strength, NV_n , shall exceed the shear corresponding to the development of 1.25 times the nominal flexural strength of the member, except that the nominal shear strength need not exceed 2.5 times V_u.

11.7.3 Design of Reinforced Masonry Members:

11.7.3.1: Nominal shear strength, V_n, shall be computed as follows:

$$V_n = V_m + V_s \tag{11.7.3.1-1}$$

where:

V_n	=	nominal shear strength, lb;
V_m	=	nominal shear strength provided by masonry, lb; and
V_s	=	shear strength provided by reinforcement, lb.

The metric equivalent for Eq. 11.7.3.1-1 is the same except that V_n, V_m, and V_s are in N.

$$V_n(\max) = 6\sqrt{f'_m}\,A_n \tag{11.7.3.1-2}$$

For M/Vd_v < 0.25:

For M/Vd_v < 1.00:

$$V_n(\max) = 4\sqrt{f'_m}\,A_n \tag{11.7.3.1-3}$$

where:

$V_n(max)$	=	maximum nominal shear strength, lb;
A_n	=	net cross-sectional area of the masonry, in.^{2};
f'_m	=	specified compressive strength of the masonry, psi;
M	=	moment on the masonry section due to unfactored design loads, in.-lb;
V	=	shear on the masonry section due to unfactored loads, lb; and
d_v	=	length of member in direction of shear force, inches.

Values of M/Vd_v between 0.25 and 1.0 may be interpolated.

The metric equivalent of Eq. 11.7.3.1-2 is $V_{m(max)} = 0.5\sqrt{f'_m}A_n$ and the metric equivalent of Eq. 11.7.3.1-3 is $V_m(max) = 0.33\sqrt{f'_m}A_n$ where $V_n\,(max)$ is in N, A_n is in mm^2, f'_m is in MPa, M is in N-mm, and d is in mm.

11.7.3.2: Shear strength, V_m, provided by masonry shall be as follows:

$$V_m = \left[4.0 - 1.75\left(\frac{M}{Vd}\right)\right]A_n\sqrt{f'_m} + 0.25P \qquad (11.7.3.2)$$

where M/Vd_v need not be taken greater than 1.0 and

V_m	=	shear strength provided by masonry, lb;
M	=	moment on the masonry section due to unfactored design loads, in.-lb;
V	=	shear on the masonry section due to unfactored loads, psi;
d_v	=	length of member in direction of shear force , in.;
A_n	=	net cross-sectional area of the masonry, in.^{2};
f'_m	=	specified compressive strength of the masonry, psi; and
P	=	axial load on the masonry section due to unfactored design loads, lb.

The metric equivalent of Eq. 11.7.3.2 is $V_m = 0.083\left[4.0 - 1.75\left(\frac{M}{Vd}\right)\right]A_n\sqrt{f'_m} + 0.25P$ where V_m and P are in N, M is in N-mm, f'_m is in MPa, d is in mm, and A_n is in mm^2.

11.7.3.3: Nominal shear strength, V_s, provided by reinforcement shall be as follows:

$$V_s = 0.5\left(\frac{A_v}{s}\right)f_y d_v \quad (11.7.3.3)$$

where:

A_v = area of shear reinforcement, in.^{2} (mm^2);

d_v = length of member in direction of shear force, in. (mm);

s = spacing of shear reinforcement, in. (mm); and

f_y = specified yield strength of the reinforcement or the anchor bolt as applicable, psi (MPa).

The metric equivalent of Eq. 11.7.3.3 is the same.

11.7.4 Design of Plain (Unreinforced) Masonry Members:

11.7.4.1: Nominal shear strength, V_n, shall be the least of the following:

a. 1.50 $\sqrt{f'_m}A_n$, lb (the metric equivalent is 0.375 $\sqrt{f'_m}A_n$, where f'_m is in MPa and A_n is in mm^2);

b. $120A_n$, lb (the metric equivalent is $0.83A_n$, N, where A_n is in mm^2);

c. $37 A_n + 0.3 N_v$ for *running bond* masonry not grouted solid, lb (the metric equivalent is $0.26A_n + 0.3N_v$ where A_n is in mm^2 and N_v is in N);

$37 A_n + 0.3 N_v$ for *stack bond* masonry with open end units grouted solid, lb (the metric equivalent is $0.26A_n + 0.3N_v$ when A_n is in mm^2 and N_v is in N);

$60 A_n + 0.3 N_v$ for *running bond* masonry grouted solid, lb (the metric equivalent is $0.414A_n + 0.3N_v$ when A_n is in mm^2 and N_v is in N); and

$15 A_n$ for *stack bond* masonry with other than open end units grouted solid, lb (the metric equivalent is $0.103A_n$ when A_n is in mm^2

where:

f'_m = *specified* compressive strength of the masonry, psi;

A_n = *net cross-sectional area* of the masonry, in.^{2}; and

N_v = force acting normal to shear surface, lb.

11.8 SPECIAL REQUIREMENTS FOR BEAMS:

11.8.1: The spacing between lateral supports shall be determined by the requirements for out of-plane loading but shall not exceed 32 times the least width of beam.

11.8.2: The effects of lateral eccentricity of load shall be taken into account in determining spacing of lateral supports.

11.8.3: The minimum positive reinforcement ratio r in a beam shall not be less than $120/f_y$ (the metric equivalent is $0.83/f_y$ where f_y is in MPa) except that this minimum positive steel reinforcement ratio need not be satisfied if the area of reinforcement provided is one third greater than that required by analysis for *gravity loads* and the *Seismic Design Category* is A, B, or C.

Where a concrete floor provides a flange and where the beam web is in tension, the ratio, D, shall be computed using the web width.

11.8.4 Deep Flexural Members:

11.8.4.1: Flexural members with overall depth to clear span ratios greater than 2/5 for continuous spans or 4/5 for simple spans shall be designed as deep flexural members taking into account nonlinear distribution of strain and lateral buckling.

11.8.4.2: Minimum flexural tension reinforcement shall conform to Sec. 11.8.3.

11.8.4.3: Uniformly distributed horizontal and vertical reinforcement shall be provided throughout the length and depth of deep flexural members such that the reinforcement ratios in both directions are at least 0.001. Distributed flexural reinforcement is to be included in the determination of the actual reinforcement ratios.

11.9 SPECIAL REQUIREMENTS FOR COLUMNS:

11.9.1: Area of longitudinal reinforcement for *columns* shall be not less than 0.005 or more than 0.04 times cross-sectional area of the *column*.

11.9.2: There shall be a minimum of four longitudinal bars in *columns*.

11.9.3: Lateral ties shall be provided to resist shear and shall comply with the following:

a. Lateral ties shall be at least 1/4 in. (6 mm) in diameter.

b. Vertical spacing of lateral ties shall not exceed 16 longitudinal bar diameters, 48 lateral tie diameters, nor the least cross sectional dimension of the column.

c. Lateral ties shall be arranged such that every corner and alternate longitudinal bar shall have lateral support provided by the corner of a lateral tie with an included angle of not more than 135 degrees and no bar shall be farther than 6 in. (152 mm) clear on each side along the lateral tie from such a laterally supported bar. Lateral ties shall be placed in either a mortar joint or grout. Where longitudinal bars are located around the perimeter of a circle, a complete circular lateral tie is permitted. Minimum lap length for circular ties shall be 84 tie diameters.

d. Lateral ties shall be located vertically not more than one-half lateral tie spacing above the top of footing or slab in any story and shall be spaced as provided herein to not more than one-half a lateral tie spacing below the lowest horizontal reinforcement in beam, girder, slab or drop panel above.

e. Where beams or brackets frame into a column from four directions, lateral ties may be terminated not more than 3 in. (76 mm) below lowest reinforcement in the shallowest of such beams or brackets.

11.10 SPECIAL REQUIREMENTS FOR SHEAR WALLS:

11.10.1 Ordinary Plain Masonry Shear Walls: The design of *ordinary plain masonry shear walls* shall be in accordance with Sec. 11.3.2 or Sec. 11.3.3. No reinforcement is required to resist seismic forces.

11.10.2 Detailed Plain Masonry Shear Walls: The design of *detailed plain masonry shear walls* shall be in accordance with Sec. 11.3.3. *Detailed plain masonry shear walls* shall have minimum amounts of reinforcement as prescribed in Sec. 11.3.7.3 and 11.3.7.4.

11.10.3 Ordinary Reinforced Masonry Shear Walls: The design of *ordinary reinforced masonry shear walls* shall be in accordance with Sec. 11.3.4. No prescriptive seismic reinforcement is required for *ordinary reinforced masonry shear walls*

11.10.4 Intermediate Reinforced Masonry Shear Walls: The design of *intermediate reinforced masonry shear walls* shall be in accordance with Sec. 11.3.4. *Intermediate reinforced masonry shear walls* shall have minimum amounts of reinforcement as prescribed in Sec. 11.3.7.3 and 11.3.7.4.

11.10.5 Special Reinforced Masonry Shear Walls: *Special reinforced masonry shear walls* shall meet the requirements for *intermediate reinforced masonry shear walls* (Sec. 11.10.4) in addition to the requirements of this section.

The design of *special reinforced masonry shear walls* shall be in accordance with Sec. 11.3.4. *Special reinforced masonry shear walls* shall comply with material requirements of Sec. 11.3.8, minimum reinforcement requirements of Sec. 11.3.8.3 and 11.3.8.4, and minimum thickness requirements of Sec. 11.3.8.5. In addition, *special reinforced masonry shear walls* shall be reinforced and constructed as required in this section.

11.10.5.1 Vertical Reinforcement: The maximum spacing of vertical reinforcement in an *special reinforced masonry shear wall* shall be the smaller of::

a. One-third the length of the wall,

b. One-third the height of the wall, or

c. 48 in. (1219 mm).

11.10.5.2 Horizontal Reinforcement: Reinforcement required to resist in-plane shear in a *special reinforced masonry shear wall* shall be placed horizontally, shall be uniformly distributed, and shall be embedded in grout. The maximum spacing of horizontal reinforcement shall be the smaller of:

a. One-third the length of the wall,

b. One-third the height of the wall,

c. 48 in. (1219 mm), or

d. 24 in. (610 mm) for stack bond masonry.

11.10.5.3 Shear Keys: The surface of concrete upon which a *special reinforced masonry shear wall* is constructed shall have a minimum surface roughness of 1/8 in. (3.0 mm). Keys with the following minimum requirements shall be placed at the base of *special reinforced masonry shear walls* when the calculated strain in vertical reinforcement exceeds the yield strain under load combinations that include seismic forces based on a *R* factor equal to 1.5:

a. The width of the keys shall be at least equal to the width of the grout space

b. The depth of the keys shall be at least 1.5 in. (40 mm),

c. The length of the key shall be at least 6 in. (152 mm),

d. The spacing between keys shall be at least equal to the length of the key,

e. The cumulative length of all keys shall be at least 20 percent of the length of the shear wall,

f. A minimum of one key shall be placed within 16 in. (406 mm) of each end of a shear wall, and

g. Each key and the grout space above each key in the first course of masonry shall be grouted solid.

11.10.6: Flanged Shear Walls:

11.10.6.1: *Wall* intersections shall be considered effective in transferring shear when either conditions (a) or (b) and condition (c) as noted below are met:

a. The face shells of hollow masonry units are removed and the intersection is fully grouted.

b. Solid units are laid in running bond and 50 percent of the masonry units at the intersection are interlocked.

c. Reinforcement from one intersecting *wall* continues past the intersection a distance not less than 40 bar diameters or 24 in. (600 mm).

11.10.6.2: The width of flange considered effective in compression on each side of the web shall be taken equal to 6 times the thickness of the web or shall be equal to the actual flange on either side of the web *wall*, whichever is less.

11.10.6.3: The width of flange considered effective in tension on each side of the web shall be taken equal to 3/4 of the *wall* height or shall be equal to the actual flange on either side of the web *wall*, whichever is less.

11.10.7 Coupled Shear Walls:

11.10.7.1 Design of Coupled Shear Walls: Structural members that provide coupling between *shear walls* shall be designed to reach their moment or shear *nominal strength* before either *shear wall* reaches its moment or shear *nominal strength.* Analysis of coupled *shear walls* shall conform to accepted principles of mechanics.

11.10.7.2 Shear Strength of Coupling Beams: The design shear strength, ϕV_n, of the coupling beams shall exceed the shear calculated as follows:

$$\phi V_n \geq \frac{1.25(M_1 + M_2)}{L_c} + 1.4V_g \qquad (11.10.7.2)$$

where:

ϕV_n	=	shear strength, lb (N);
M_1 and M_2	=	nominal moment strength at the ends of the beam, lb-in. (N-mm);
L_c	=	length of the beam between the *shear walls*, in. (mm); and
V_g	=	unfactored shear force due to gravity loads, lb (N).

The metric equivalent of Eq. 11.10.7.2 is the same except that V_n and V_g are in N, M_1 and M_2 are in N-mm, and L is in mm.

The calculation of the nominal flexural moment shall include the reinforcement in reinforced concrete roof and floor system. The width of the reinforced concrete used for calculations of reinforcement shall be six times the floor or roof slab thickness.

11.11 SPECIAL MOMENT FRAMES OF MASONRY:

11.11.1 Calculation of Required Strength: The calculation of required strength of the members shall be in accordance with principles of engineering mechanics and shall consider the effects of the relative stiffness degradation of the beams and columns.

11.11.2 Flexural Yielding: Flexural yielding shall be limited to the beams at the face of the *columns* and to the bottom of the columns at the base of the *structure*.

11.11.3 Reinforcement:

11.11.3.1: The nominal moment strength at any section along a member shall not be less than one-half of the higher moment strength provided at the two ends of the member.

11.11.3.2: Lap splices are permitted only within the center half of the member length.

11.11.3.3: Welded splices and mechanical connections may be used for splicing the reinforcement at any section provided not more than alternate longitudinal bars are spliced at a section and the distance between splices on alternate bars is at least 24 in. (610 mm) along the longitudinal axis.

11.11.3.4: Reinforcement shall have a specified yield strength of 60,000 psi (414 MPa). The actual yield strength shall not exceed 1.5 times the specified yield strength.

11.11.4 Wall Frame Beams:

11.11.4.1: Factored axial compression force on the beam shall not exceed 0.10 times the net cross-sectional area of the beam, A_n, times the specified compressive strength, f'_m.

11.11.4.2: Beams interconnecting vertical elements of the lateral-load-resisting system shall be limited to a reinforcement ratio of $0.15f'_m/f_y$ or that determined in accordance with Sec. 11.6.2.2. All reinforcement in the beam and adjacent to the beam in a reinforced concrete roof or floor system shall be used to calculate the reinforcement ratio.

11.11.4.3: Clear span for the beam shall not be less than 4 times its depth.

11.11.4.4: Nominal depth of the beam shall not be less than 4 units or 32 in. (813 mm), whichever is greater. The nominal depth to nominal width ratio shall not exceed 4.

11.11.4.5: Nominal width of the beams shall equal or exceed all of the following criteria:

a. 8 in. (203 mm),

b. Width required by Sec. 11.8.1, and

c. 1/26 of the clear span between *column* faces.

11.11.4.6: Longitudinal Reinforcement:

11.11.4.6.1: Longitudinal reinforcement shall not be spaced more than 8 in. (203 mm) on center.

11.11.4.6.2: Longitudinal reinforcement shall be uniformly distributed along the depth of the beam.

11.11.4.6.3: In lieu of the limitations of Sec. 11.8.3, the minimum reinforcement ratio shall be $130/f_y$ (the metric equivalent is $0.90/f_y$ where f_y is in MPa).

11.11.4.6.4: At any section of a beam, each masonry unit through the beam depth shall contain longitudinal reinforcement.

11.11.4.7 Transverse Reinforcement:

11.11.4.7.1: Transverse reinforcement shall be hooked around top and bottom longitudinal bars and shall be terminated with a standard 180-degree hook.

11.11.4.7.2: Within an end region extending one beam depth from *wall* frame column faces and at any region at which beam plastic hinges may form during seismic or wind loading, maximum spacing of transverse reinforcement shall not exceed one-fourth the nominal depth of the beam.

11.11.4.7.3: The maximum spacing of transverse reinforcement shall not exceed one-half the nominal depth of the beam or that required for shear strength.

11.11.4.7.4: Minimum transverse reinforcement ratio shall be 0.0015.

11.11.4.7.5: The first transverse bar shall not be more than 4 in. (102 mm) from the face of the pier.

11.11.5 Wall Frame Columns:

11.11.5.1: Factored axial compression force on the *wall* frame column shall not exceed 0.15 times the net cross-sectional area of the column, A_n, times the specified compressive strength, $f_m^{\prime}$. The compressive stress shall also be limited by the maximum reinforcement ratio.

11.11.5.2: *Nominal dimension* of the column parallel to the plane of the *wall* frame shall not be less than two full units or 32 in. (810 mm), whichever is greater.

11.11.5.3: *Nominal dimension* of the column perpendicular to the plane of the *wall* frame shall not be less than 8 in. (203 mm) or 1/14 of the clear height between beam faces.

11.11.5.4: The clear height-to-depth ratio of column members shall not exceed 5.

11.11.5.5 Longitudinal Reinforcement:

11.11.5.5.1: A minimum of 4 longitudinal bars shall be provided at all sections of every *wall* frame column member.

11.11.5.5.2: The flexural reinforcement shall be uniformly distributed across the member depth.

11.11.5.5.3: The nominal moment strength at any section along a member shall be not less than 1.6 times the cracking moment strength and the minimum reinforcement ratio shall be $130/f_y$ (the metric equivalent is $0.90/f_y$ where f_y is in MPa).

11.11.5.5.4: Vertical reinforcement in wall-frame columns shall be limited to a maximum reinforcement ratio equal to the lesser of $0.15 f_m^{\prime} / f_y$ or that determined in accordance with Sec. 11.6.2.2.

11.11.5.6 Transverse Reinforcement:

11.11.5.6.1: Transverse reinforcement shall be hooked around the extreme longitudinal bars and shall be terminated with a standard 180-degree hook.

11.11.5.6.2: The spacing of transverse reinforcement shall not exceed one-fourth the nominal dimension of the column parallel to the plane of the *wall* frame.

11.11.5.6.3: Minimum transverse reinforcement ratio shall be 0.0015.

11.11.6 Wall Frame Beam-Column Intersection:

11.11.6.1: Beam-column intersection dimensions in masonry wall frames shall be proportioned such that the wall frame column depth in the plane of the frame satisfies Eq. 11.11.6.1-1:

$$h_p > \frac{4{,}800\, d_{bb}}{\sqrt{f_g^{\prime}}} \qquad (11.12.6.1\text{-}1)$$

where:

h_p = pier depth in the plane of the wall frame, in.;

d_{bb} = diameter of the largest beam longitudinal reinforcing bar passing through, or anchored in, the wall frame beam-column intersection, in.; and

f'_g = specified compressive strength of grout, psi (shall not exceed 5,000 psi (34.5 MPa) for use in Eq. 11.11.7.1-1).

The metric equivalent of Eq. 11.11.6.1-1 is $h_p > \frac{400 d_{bb}}{\sqrt{f_g^{\prime}}}$ where h_p and d_{bb} are in mm and $f_g^{\prime}$ is in MPa.

Beam depth in the plane of the frame shall satisfy Eq. 11.11.6.1-2:

$$h_b > \frac{1800\, d_{bp}}{\sqrt{f_g^{\prime}}} \qquad (11.11.6.1\text{-}2)$$

where:

h_b = beam depth in the plane of the wall frame, in.;

d_{bp} = diameter of the largest *column* (pier) longitudinal reinforcing bar passing through, or anchored in, the wall frame beam-column intersection, in.; and

f'_g = specified compressive strength of grout, psi (shall not exceed 5,000 psi (34.2MPa) for use in Eq. 11.11.6.1-1).

The metric equivalent of Eq. 11.11.6.1-2 is $h_b > \frac{150 d_{bp}}{\sqrt{f_g'}}$ where h_b and d_{bp} are in mm and f_g' is in MPa.

Nominal shear strength of beam-column intersections shall exceed the shear occurring when wall frame beams develop their nominal flexural strength.

11.11.6.2: Beam longitudinal reinforcement terminating in a wall frame column shall be extended to the far face of the *column* and shall be anchored by a standard hook bent back into the wall frame column.

Special horizontal shear reinforcement crossing a potential diagonal beam *column* shear crack shall be provided such that:

$$A_s \ \$ \ \frac{0.5 V_n}{f_y} \tag{11.11.6.2}$$

where:

A_s = cross-sectional area of reinforcement in.^{2};

V_n = nominal shear strength, lb; and

f_y = *specified* yield strength of the reinforcement or the *anchor* bolt as applicable, psi.

The metric equivalent of Eq. 11.11.6.2 is the same except that A_s is in mm^2, V_n is in N, and f_y is in MPa.

Special horizontal shear reinforcement shall be anchored by a standard hook around the extreme wall frame column reinforcing bars.

Vertical shear forces may be considered to be carried by a combination of masonry shear-resisting mechanisms and truss mechanisms involving intermediate column reinforcing bars.

The nominal horizontal shear stress at the beam-*column* intersection shall not exceed the lesser of 350 psi (2.5 MPa) or $7\sqrt{f_m'}$ (the metric equivalent is $0.58\sqrt{f_m'}$ MPa).

11.12 GLASS-UNIT MASONRY AND MASONRY VENEER:

11.12.1 Design Lateral Forces and Displacements: Glass-unit masonry and masonry veneer shall be designed and detailed to resist the design lateral forces as described in Sec. 6.1 and 6.2.

11.12.2 Glass-Unit Masonry Design:

11.12.2.1: The requirements of Chapter 7 of ACI 530 shall apply to the design of *glass unit masonry*. The out-of-plane seismic strength shall be considered as the same as the strength to resist wind pressure as specified in Sec. 7.3 of ACI 530 .

11.12.3 Masonry Veneer Design:

11.12.3.1: The requirements of Chapter 6 of ACI 530 shall apply to the design of *masonry veneer*.

11.12.3.2: For *structures* in *Seismic Design Category E,* corrugated sheet metal anchors shall not be used.