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REINFORCED CONCRETE MASONRY

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INTRODUCTION

Structural elements constructed of reinforced concrete masonry effectively resist applied loads through the combined tensile strength of reinforcement and the compressive strength of masonry. The benefits of incorporating reinforcement are improved ductility, structural integrity, and greater resistance to flexural and shear stresses. Walls, columns, pilasters, and beams can be designed to resist dead, live, wind, seismic, and lateral earth pressure loads using the combined capabilities of masonry and reinforcement.

Reinforced concrete masonry walls are used extensively in most structural applications—warehouses, institutional buildings, retaining walls, shear walls and loadbearing walls in multistory hotel and apartments. They provide an economical system of construction, particularly when high lateral load resistance is required.

MATERIALS

Materials used for reinforced masonry—units, mortar, grout, and steel reinforcement, are governed by specifications that are referenced in building codes. Applicable specifications for these materials are listed in Table 1.

Table 1—Standard Material Specifications

Concrete Masonry Units	
ASTM C 90	Loadbearing Concrete Masonry Units
UBC 21-4	Hollow and Solid Loadbearing Concrete Masonry Units
Mortar	
ASTM C 270	Mortar for Unit Masonry
UBC 21-15	Mortar for Unit Masonry
Grout	
ASTM C 476	Grout for Masonry
UBC 21-14	Grout for Masonry
Aggregates	
ASTM C 144	Aggregate for Masonry Mortar
ASTM C 404	Aggregates for Masonry Grout
Reinforcement	
ASTM A 82	Steel Wire, Plain
ASTM A 615	Deformed and Plain Billet-Steel Bars
ASTM A 616	Rail-Steel Deformed and Plain Bars
ASTM A 617	Axle-Steel Deformed and Plain Bars
ASTM A 706	Low-Alloy Steel Deformed Bars
ASTM A 767	Galvanized Steel Bars
ASTM A 775	Epoxy-Coated Reinforcing Steel Bars
ASTM A 951	Masonry Joint Reinforcement
UBC 21-10	Joint Reinforcement for Masonry

Units—Reinforced concrete masonry is constructed of hollow units, solid units, or a combination of both. Single wythe walls are constructed of hollow units with vertical reinforcement and grout placed in designated cores of the block. Horizontal reinforcement, such as reinforcing bars grouted into bond beams, or joint reinforcement placed in mortar joints, is also often used. Multi-wythe walls are built with either hollow or solid units with grout and reinforcement in the space between wythes.

Units must be laid up so that the vertical spaces to be grouted provide a continuous, unobstructed opening Some projects require reinforcement to be in place before masonry work is begun. These requirements have resulted in the development of open-end block shapes which are designed to be placed around the reinforcement. Some of these shapes are illustrated in Figure 1.

Mortar—Ingredients for masonry mortar are governed by applicable product specifications. Mortar types are generally specified to comply with ASTM C 270 (ref. 5). Mortar is governed by either of two alternative specifications:

1. the proportion specification prescribes the parts by volume of each ingredient required to provide a specific mortar type
2. the property specification allows approved materials to be mixed in controlled percentages as long as the resultant laboratory prepared mortar meets prescribed compressive strength, water retention, and air content requirements.

Mortar Types M, S, and N are permitted for construction of reinforced concrete masonry. Building codes require the use of Type S or M mortar in Seismic Performance Categories D and E, and in seismic zones 3 and 4 (refs. 2, 7, respectively).

Grout—Ingredients for grout used in masonry construction include cementitious materials, aggregates, and hydrated lime. ASTM specifications contain requirements for proportions for each of these ingredients. However, it is typical practice to specify compressive strength based on design requirements rather than specifying proportions of each ingredient.

When grout is placed in a masonry wall, water is absorbed into the masonry units, reducing the volume of grout. The effects of grout volume loss may be minimized by reconsolidation before the grout starts to set. Expansive grout admixtures are sometimes recommended in addition to consolidation and reconsolidation to reduce voids in the grout. These materials are added at the job site, and cause the grout to expand slightly after placement, which compensates for volume reduction due to loss of water.

Steel Reinforcement—The two principal types of reinforcement used in reinforced masonry are deformed steel bars and horizontal wire joint reinforcement. Standards for the most commonly used types of reinforcement are listed in Table 1.

Table 2—Tolerances For Placement of Reinforcement

Placement of reinforcement	
Flexural members	$\pm$ 1/2 in. (13 mm) for $d \leq$ 8 in. (203 mm)
	$\pm$ 1 in. (25 mm) for $d >$ 8 in. (203 mm) but $\leq$ 24 in. (610mm)
	$\pm$ 1 1/4 in. (32 mm) for $d >$ 24 in. (610 mm)
Walls (vertical bars)	$\pm$ 2 in. (51 mm) along the length of the wall
Clear spacing between bars and face of unit	
Fine grout	$\geq$ 1/4 in. (6.4 mm)
Coarse grout	$\geq$ 1/2 in. (13 mm)
Minimum cover joint reinforcement	
Exposed to weather or earth	$\geq$ 5/8 in. (16 mm)
Not exposed to weather or earth	$\geq$ 1/2 in. (13 mm)

CONSTRUCTION

Placement of hollow units for reinforced concrete masonry construction requires the following considerations:

- Vertical cores to be grouted are constructed so that a continuous, unobstructed opening of approved dimensions is maintained for proper placement of reinforcement and grout.
- Care should be taken to minimize mortar protrusions into the spaces to be grouted.
- When hollow unit walls are not fully grouted, mortar is placed on those cross webs adjacent to the cores to be grouted, to confine grout to specified locations.
- Vertical reinforcement is secured in its proper location by the use of bar positioners or by tying vertical and horizontal bars together.
- Metal lath, or other suitable material, is used in partially grouted masonry below bond beam courses to confine grout to specified locations.

Placement of steel reinforcement in its specified location is critical to the performance of reinforced masonry. The flexural resistance of reinforced masonry is based on the element's effective depth, *d*, which is the distance from the compressive face of the masonry to the centerline location of the tensile reinforcement.

Building codes contain allowable tolerances for placement of reinforcement in walls and flexural elements, and tolerances for the distance between vertical bars along the length of a wall. A summary of tolerance requirements is contained in Table 2.

In addition to allowable tolerances, codes prescribe requirements for lap splicing and minimum permissible space between reinforcement and adjacent masonry units for fine and coarse grouts to ensure that grout completely surrounds and bonds to the reinforcement.

Low Lift Grouting—Methods of placing grout in concrete masonry elements are high lift and low lift grouting. The construction sequence of low lift grouting is as follows:

- Build the masonry to scaffold height, placing horizontal reinforcement as the wall is laid up. Low lift grouting procedures limit the maximum height of masonry to 5 ft (1.5 m) prior to grouting (ref. 2). When a grout pour coincides with a bond beam course, an additional course of masonry should be placed above the bond beam to permit grouting the bond beam in one operation. The grout pour should then extend a minimum of 1/2 in. (13 mm) above the bond beam course.
- Place vertical reinforcement where required, ensuring that cavities containing reinforcement have a continuous unobstructed cross section complying with Table 3.
- Place grout of fluid consistency in those cavities which contain properly positioned reinforcing bars and all other cavities required to be grouted.
- Consolidate the grout with a vibrator (grout pours 12 in. (305 mm) or less may be consolidated using a puddling stick).
- Repeat the operation at the next higher level. Low lift grouting requires no special concrete block shapes or special equipment.

Methods of delivering grout to the wall include hand bucketing, pumping, or the use of a concrete bucket with a spout to direct the grout into the cores, whichever is most advantageous to the contractor. Complete consolidation of grout is accomplished by vibrating or puddling each lift, while penetrating into the previous lift.

A grout lift should not terminate at a mortar bed joint nor where horizontal reinforcing bars are placed. A grout key between lifts, located at least 1/2 in. (13 mm) below the mortar joint, ensures adequate shear transfer. One course may be laid above the lift height to obtain proper grout coverage of horizontal reinforcing, and the grout poured to a height approximately 1/2 in. (13 mm) above the bed joint. The final lift is poured to the top of the wall.

High Lift Grouting—On larger projects, grouting is often delayed until walls are built to story height or to the full height of the wall. Grout is then placed into the wall in several succeeding 5 ft (1.5 m) maximum lifts. This procedure is referred to as high lift grouting.

There are several advantages of high lift grouting on larger projects. Vertical steel can be placed after the wall is erected; its location can be checked by the inspector; and the grout can be transit-mixed and placed by a grout pump or concrete bucket within a relatively short time. Cleanout openings of sufficient size for removal of mortar droppings and other debris must be provided at the bottom of all vertical cavities containing reinforcement.

Horizontal reinforcing bars are positioned as the wall is

Table 3—Grout Space Requirements

Specified grout type	Maximum grout pour height, ft (m)	Minimum grout[a] space dimensions for grouting cells of hollow units in. x in. (mm x mm)
Fine	1 (0.3)	1½ x 2 (38 x 51)
Fine	5 (1.5)	2 x 3 (51 x 76)[b]
Fine	12 (3.7)	2½ x 3 (64 x 76)[c]
Fine	24 (7.3)	3 x 3 (76 x 76)
Coarse	1 (0.3)	1½ x 3 (38 x 76)
Coarse	5 (1.5)	2½ x 3 (64 x 76)
Coarse	12 (3.7)	3 x 3 (76 x 76)
Coarse	24 (7.3)	3 x 4 (76 x 102)

[a] Grout space dimension is the clear dimension between any masonry protrusion and shall be increased by the diameters of the horizontal bars within the cross section of the grout space.
[b] UBC (ref. 7) requires 1½ x 2 (38 x 51)
[c] UBC (ref. 7) requires 1¾ x 3 (44 x 76)

erected. Vertical bars may be installed prior to laying masonry or may be inserted from the top of the wall after the masonry is placed to story height. Vertical bars should be held in position at intervals not exceeding 200 bar diameters (ref. 7).

When design requirements result in a large amount of closely spaced vertical steel reinforcement, or when reinforcement is required to be in place prior to installation of the masonry units, a variation of the vertical steel placement may be employed. The vertical bars can be secured in their proper position at the foundation or base of the wall before units are laid up. Instead of threading hollow units down over the vertical rods, open-ended units are typically used, enabling the mason to lay the block around the steel reinforcement as the wall is being erected. These units are manufactured with one or both end webs removed, resulting in an "A" or "H" shape, as illustrated in Figure 1.

Mortar protrusion larger than ½ in. (13 mm) must be removed prior to grouting (ref. 2). All reinforcing, bolts, other embedded items, and cleanout closures must be securely in place before grouting is started. The grouting operation should be continuously inspected.

STRUCTURAL DESIGN

Engineered reinforced concrete masonry is designed either by the allowable stress design method or by the strength design method. Engineered masonry, in which design loads are determined and masonry members are proportioned to resist those loads in accordance with engineering principles of mechanics, is most frequently analyzed by the allowable stress method. This method is considered a conservative approach to design; however, it does not predict material performance and behavior if masonry is stressed beyond allowable limits.

The limit states design method evaluates member capacity (strength limit state) as well as member deformation under service loads (deformation limit state). Limit states design has particular advantages in providing for loads which are unpredictable, such as seismic loads or hurricane wind loads. Strength design of masonry is recognized by the Uniform Building Code (ref. 7).

Reinforced masonry design relies on reinforcement to resist tension, hence the tensile strength of masonry units, mortar and grout are neglected. By contrast, unreinforced masonry design considers the tensile strength of masonry in resisting design loads. The advantages of reinforced masonry include significantly higher flexural strength and ductility as well as greater reliability. Improved ductility of reinforced masonry is also a function of reinforcement, which continues to elongate well beyond the design level, allowing deformation beyond design levels without loss of strength. These deformations allow overloads to be redistributed to other members, thus improving structural performance when actual loads exceed design load levels.

Reliability of reinforced masonry is due to the predictable tensile strength of steel reinforcement and compressive strength of masonry, which results in a predictable strength of reinforced masonry elements.

DESIGN LOADS

Allowable stress design is based on service level loads, which are typical load levels expected to occur when the structure is in use, and members are proportioned using conservative allowable stresses (see Table 4). Strength design of masonry is based on a realistic evaluation of member strength subjected to factored loads which have a low probability of being exceeded during the life of the structure. Minimum design loads for allowable stress design (service loads) and for strength design (factored loads) are included in *Minimum Design Loads for Buildings and Other Structures* (ref. 3).

ALLOWABLE STRESS DESIGN

Allowable stress design principles and assumptions for reinforced concrete masonry are:

- Members are proportioned to satisfy applicable conditions of equilibrium and compatibility of strains within the range of allowable stresses when subjected to design service loads.
- Strain in the reinforcement, masonry units, mortar, and grout is directly proportional to the distance from the neutral axis. Therefore, plane sections before bending remain plane after bending.
- The tensile strength of masonry units, mortar and grout, is neglected.
- Reinforced concrete masonry is a homogeneous, isotropic material. Reinforcement is perfectly bonded to masonry.
- Stress is linearly proportional to strain within the working stress range.

Flexure

Flexural compression and tension stresses are determined in accordance with accepted allowable stress design principles. This results in a triangular distribution of compressive stress from zero at the neutral axis to a maximum at the extreme compression fiber. Tensile stress in reinforcement is based on the strain in the steel multiplied by its modulus of elasticity. Strain in reinforcement increases linearly in proportion to the distance from the neutral axis to the centroid of reinforcement. Flexural members are proportioned such that the maximum calculated tensile and compressive stresses are within allowable stress limits. Increased flexural strength due to compression in reinforcement located on the compression side of the neutral axis is typically neglected unless it is confined by lateral ties to prevent buckling of the reinforcement.

Axial Compression

Axial loads acting through the neutral axis of a member are distributed over the net cross-sectional area of masonry. The compressive resistance of reinforcement is neglected unless the reinforcement is confined by lateral ties in accordance with the provisions for columns to prevent buckling of the reinforcement. Masonry members are proportioned such that the maximum axial compressive stress does not exceed the allowable axial compressive stress. The allowable axial compressive stress is based on the compressive strength of masonry, a slenderness coefficient, and an allowable stress coefficient.

Combined Axial Compression and Flexure

Most loading conditions result in a combination of axial load and flexure acting on the reinforced masonry member. Superimposing the stresses resulting from axial compression and flexural compression produces the combined stress. Members are proportioned such that the maximum combined stress does not exceed the allowable stress.

Shear

Shear acting on flexural members, shear walls, or reinforced masonry columns is resisted by the masonry or by reinforcement.

Where the masonry is designed to resist shear, the shear force is distributed over an area equal to the effective width of the member multiplied by the length of wall between the centroid of tension reinforcement and the location of the resultant compressive force.

The member is proportioned such that the maximum shear stress is limited to the allowable stress value or, alternatively, shear reinforcement is provided to resist the entire shear force. The required shear reinforcement is provided parallel to the direction of the shear force and distributed over a distance equal to the effective depth of the member. This reinforcement orientation provides shear resistance across a potential 45° diagonal tension crack in the masonry.

STRENGTH DESIGN

Strength design principles and assumptions for reinforced concrete masonry are:

- The strength of members is based on satisfying the applicable conditions of equilibrium and compatibility of strains when subjected to factored design loads.
- Strain in the reinforcement, masonry units, mortar, and grout is directly proportional to the distance from the neutral axis. Therefore, plane sections before bending remain plane after bending.
- The tensile strength of masonry units, mortar, and grout is neglected.
- Reinforced concrete masonry is a homogeneous, isotropic material. Reinforcement is perfectly bonded to the masonry.
- Masonry compressive stress distribution and masonry strain is assumed to be rectangular and uniformly distributed over an equivalent compression zone, bounded by the compression face of the masonry, with a depth of 0.85c (see Figure 3).
- The maximum usable strain at the extreme compression fiber of the masonry is limited to 0.003.

Flexure

Research (ref. 6) has confirmed the accuracy of using the rectangular stress block model for calculating flexural strength of masonry. The required moment strength, M_u, is limited to the nominal moment strength, $M_n = A_s f_y(d\text{-}a/2)$, multiplied by the strength reduction factor for flexure, $\phi = 0.8$ (refs. 7, 8).

To ensure ductile behavior, the maximum reinforcement is limited to 50% of the reinforcement which produces

Table 4—Allowable Stresses[a] for Reinforced Concrete Masonry

Compression

Axial $P_a = (0.25 f'_m A_n + 0.65 A_{st} F_s)[1-(h/140r)^2]$, where $h/r \leq 99$

$P_a = (0.25 f'_m A_n + 0.65 A_{st} F_s)(70r/h)^2$, where $h/r > 99$

Flexural .... $F_b = 1/3\, f'_m$[b]

Shear

Where reinforcement is not provided to resist the entire shear:

Flexural members .... $F_v = (f'_m)^{0.5}$, 50 psi max. (0.3 MPa)

Shear walls

$M/Vd < 1$ .... $F_v = 1/3[4-(M/Vd)](f'_m)^{0.5}$ [80-45(M/Vd)] psi max.

$M/Vd \geq 1$ ..... $F_v = (f'_m)^{0.5}$ 35 psi max. (0.2 MPa)

Where reinforcement is provided to resist all the calculated shear:

Flexural members .... $F_v = 3.0(f'_m)^{0.5}$, 150 psi max. (1.0 MPa)

Shear walls

$M/Vd < 1$ .... $F_v = 1/2[4-(M/Vd)](f'_m)^{0.5}$ [120-45(M/Vd)] psi max.

$M/Vd \geq 1$ ... $F_v = 1.5(f'_m)^{0.5}$, 75 psi max. (0.5 MPa)

Steel Reinforcement

Tension

Grade 40 .... F_s = 20,000 psi (138 MPa)

Grade 60 .... F_s = 24,000 psi (165 MPa)

Joint reinforcement .... F_s = 30,000 psi (207 MPa)

Compression .... $F_s = 0.4 f_y$, 24,000 psi max (165 MPa)

[a] refs. 1, 2, 4, 7

[b] UBC (ref. 7) limits F_b to 2,000 psi (13.8 MPa) max.

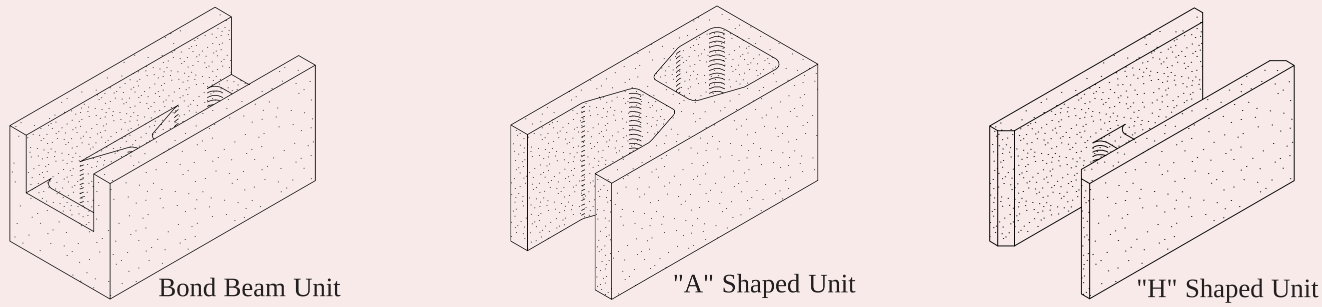

Figure 1—Block Shapes For Reinforced Construction

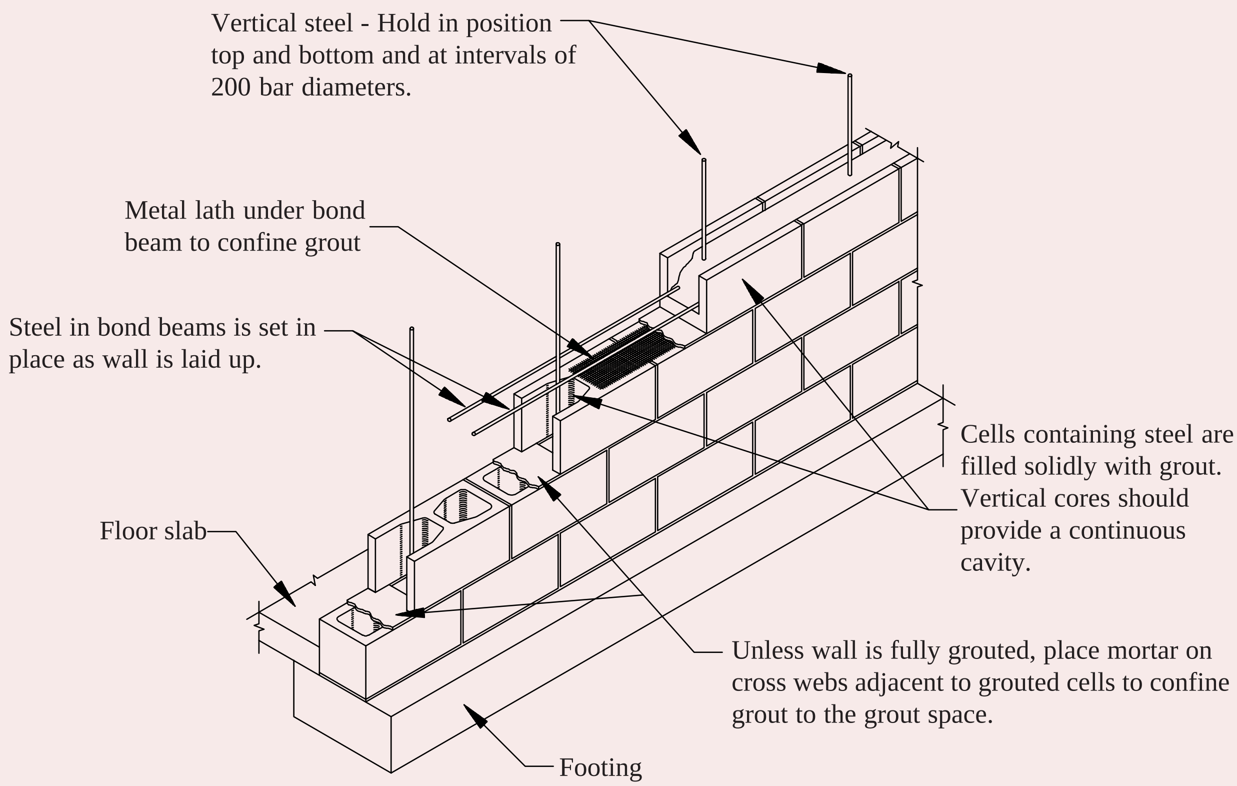

Figure 2—Reinforced Concrete Masonry Construction

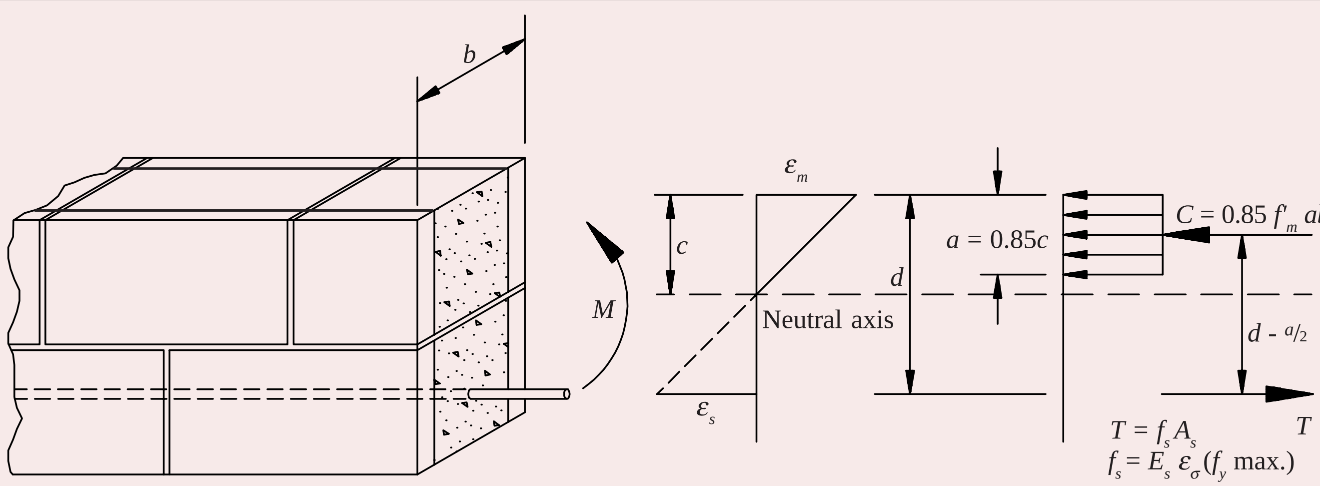

Figure 3—Equivalent Stress Block Model for Strength Design of Reinforced Concrete Masonry

balanced strain conditions, ρ_{bal} (ref. 7). Balanced conditions occur when reinforcement reaches its specified yield strength at the same time that masonry reaches its maximum usable compressive strain of 0.003. This limit on reinforcement ensures the steel yields at strength level loads.

In addition to complying with flexural strength requirements, members should also be designed to have adequate stiffness to limit deflections or any deformations that may adversely affect strength or serviceability of a structure.

Other Load Effects

Axial compression, shear, and other load effects must be checked to ensure design strengths and permissible limits are not exceeded. Code criteria covering these load effects vary, and the designer should reference the applicable code for these provisions.

NOTATIONS:

A_n net cross-sectional area of masonry, in.^{2} (mm^2)
A_{st} total area of laterally tied longitudinal reinforcing steel in a reinforced masonry column or pilaster, in.^{2} (mm^2)
A_v cross-sectional area of shear reinforcement, in.^{2} (mm^2)
a depth of equivalent rectangular stress block, in. (mm)
c distance from extreme compression fiber to neutral axis, in. (mm), a/0.85
d distance from extreme compression fiber to centroid of tension reinforcement, in. (mm)
d_b nominal diameter of reinforcement, in. (mm)
E_s modulus of elasticity of steel, psi (MPa)
F_a allowable compressive stress due to axial load only, psi (MPa)
F_b allowable compressive stress due to flexure only, psi (MPa)
F_s allowable tensile or compressive stress in reinforcement, psi (MPa)
F_v allowable shear stress in masonry, psi (MPa)
f'_m specified compressive strength of masonry, psi (MPa)
f_y specified yield stress of steel reinforcement, psi (MPa)
h effective height of column, wall, or pilaster, in. (mm)
M maximum moment occurring simultaneously with design shear force, V, at section under consideration, in.-lb (N·m)
M_n nominal moment strength of a cross section before application of strength reduction factors, in.-lb (N·m)
M_u required moment strength at a cross section to resist factored loads, in.-lb (N·m)
P_a allowable compressive force in reinforced masonry due to axial load, lb (N)
P_n nominal axial load strength, lb (N)
P_u factored axial load, lb (N)
r radius of gyration, in. (mm)
V design shear force, lb (N)
V_u factored shear, lb (N)
ε strain
ϕ strength reduction factor
ρ ratio of reinforcement area to gross masonry area, A_s/bd
ρ_{bal} reinforcement ratio producing balanced strain conditions

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