TECHNICAL NOTES on Brick Construction
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Technical Notes 42 - Empirical Design of Brick Masonry
November 1991

Abstract: This *Technical Notes* provides requirements for the empirical design of masonry structures. These requirements are based on past proven performance. The provisions are taken from ACI 530-92/ASCE 5-92, "Building Code Requirements for Masonry Structures", Chapter 9. Subjects discussed pertaining to ACI 530/ASCE 5 are: lateral stability; allowable stresses; lateral support; thickness of masonry; bonding; anchorage and miscellaneous requirements. Seismic considerations and material requirements are also included.

Key Words: brick, building codes, design standards, empirical design, masonry, stresses.

INTRODUCTION

Empirical design is a procedure for sizing and proportioning masonry elements to form an entire structure or parts of a structure. Empirical design does not require a rational analysis. It is based on rules of thumb and formulas developed over many years of experience. This design method has been used successfully for many decades.

Empirical design is generally used for buildings of a small scale nature. The basic premise is that masonry walls are incorporated into two directions of the building along with floor and roof systems for lateral support.

Chapter 9 of ACI 530-92/ASCE 5-92 is devoted solely to empirical design procedures. The provisions of earlier empirical standards have been modified to reflect contemporary construction materials and methods. Many requirements remain the same as earlier standards but new restrictions have been added to reflect recent developments.

The current model building codes contain requirements for empirical design of masonry. Until the development of ACI 530/ASCE 5, most of the model building code empirical design procedures were based on the ANSI A41.1 (R1970) document which has been discontinued.

It is the purpose of this *Technical Notes* to review many of the pertinent design and construction requirements included in Chapter 9 of ACI 530/ASCE 5. In this *Technical Notes,* sections of ACI 530/ASCE 5 referenced are given in parenthesis.

SCOPE (9.1)

Chapter 9 of ACI 530/ASCE 5 covers empirical design criteria which can be used for masonry components and masonry buildings in lieu of the design requirements in Chapters 5, 6, 7 and 8. Chapters 5 through 8 contain a rational design for masonry based on the working stress method. The scope of Chapter 9 has three basic restrictions that have not been incorporated in other previous empirical procedures: 1) buildings cannot be located in Seismic Zones 3 and 4 as defined in ASCE 7-88, "Minimum Design Loads for Buildings and Other Structures" (formerly referred to as ANSI A58.1); 2) lateral load forces, i.e. wind loads, are restricted to a maximum of 25 psf (1.2 kPa) as referenced in ASCE 7; 3) buildings relying on masonry walls for lateral load resistance cannot exceed 35 ft (10.7 mm) in height.

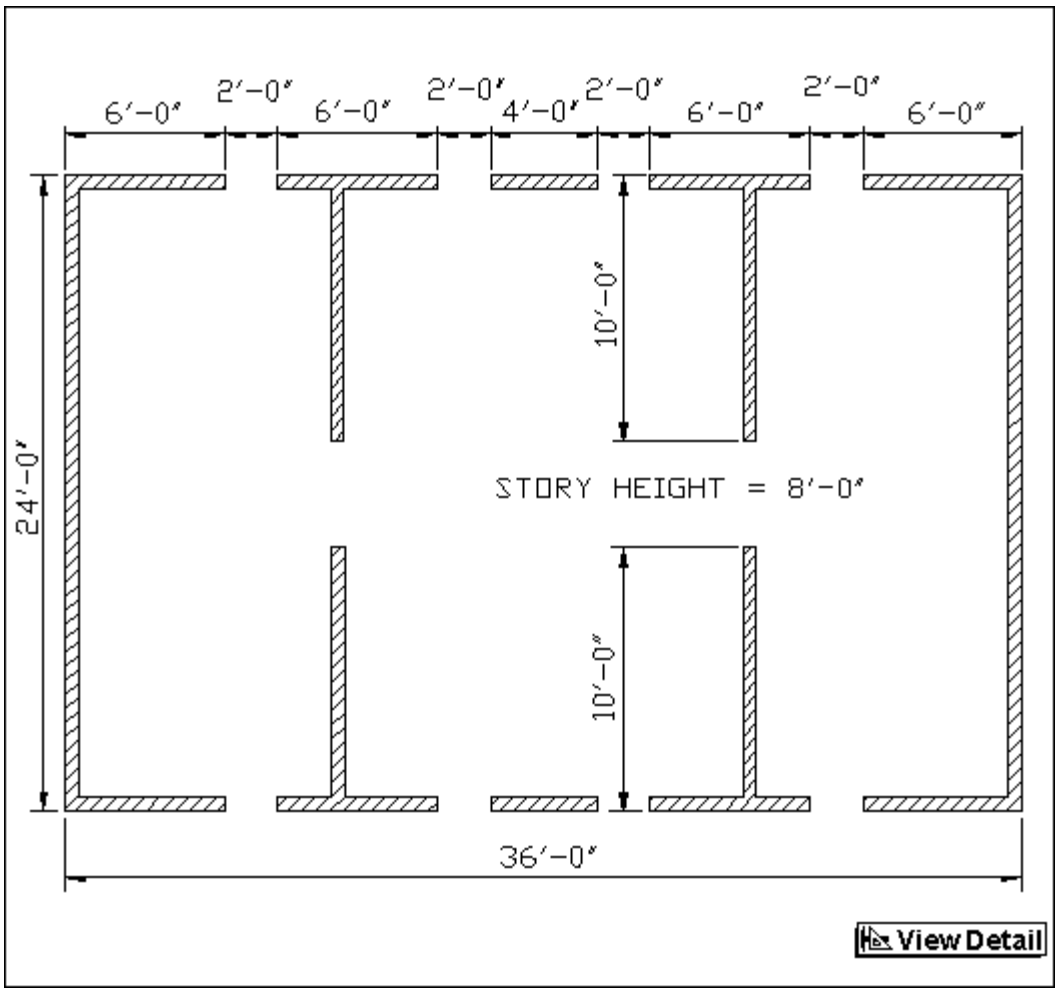
Chapter 9 permits empirical design of masonry elements not acting as a portion of the lateral force resisting system even though the main lateral force resisting system is rationally designed by other chapters contained in ACI 530/ASCE 5. Further, Chapter 9 can be used to design masonry elements in frame structures.

DESIGN

Consideration of lateral stability and lateral support are of prime importance in empirical design. Compressive stresses, thickness of masonry, bonding and anchorage requirements are incorporated in this design methodology.

Lateral Stability (9.3)

Shear walls are necessary when lateral support is provided by masonry construction. Shear walls must be provided in two directions, parallel and perpendicular to the assumed direction of the lateral load resisted. The minimum cumulative length of shear walls in any one direction must be at least 40 percent of the long dimension of the building. Portions of walls with openings cannot be included when determining the cumulative length of shear walls. BIA recommends that the cumulative length of shear walls include only wall lengths greater than or equal to one-half the story height of the building. Bearing walls are permitted to serve as shear walls. Shear walls must be a minimum nominal thickness of 8 in. (200 mm). Figure 1 provides an example calculation to determine the cumulative shear wall length.



MINIMUM CUMULATIVE LENGTH OF SHEAR WALLS = 0.4 X LONG DIMENSION

MINIMUM CUMULATIVE LENGTH = 0.4 X 36 FT = 14.4 FT

X-DIRECTION = 2 (6 + 6 + 6 + 6) = 48 FT > 14.4 FT OK

Y-DIRECTION = 2 (24 + 10 +10) = 88 FT > 14.4 FT OK

Cumulative Length of Shear Walls

FIG. 1

Shear wall spacing requirements are based on the type of floor or roof construction used in the building under consideration. When using stiffer elements such as cast-in-place concrete floors, the shear wall spacings are greater. Table 1 provides the maximum ratio of shear wall spacing to shear wall length based on the type of floor or roof construction.

Allowable Stresses (9.4)

Allowable compressive stresses permitted in Chapter 9 are given in Table 2. Compressive stress calculations are based on gross area, not minimum net area as is the case in the rational analysis chapters of ACI 530/ASCE 5. Gross area is based on the actual dimensions of the masonry unit under consideration. When multi-wythe walls are used in construction, the allowable stress taken from Table 2 should be based on the weakest combination of the unit and mortar used for each wythe.

The allowable stresses in Table 2 are considered as allowable average stresses, not maximum fiber stresses. These allowable stresses only pertain to vertically applied loads reasonably centered on the wall. Any influence of an eccentrically applied load is limited by the minimum wall thickness and maximum lateral support requirements.

TABLE 2
Allowable Compressive Stresses

Construction; compressive strength of unit gross area, psi	Allowable compressive stresses,[1, 2] gross cross-sectional area, psi	
	Type M or S mortar	Type N mortar
Solid masonry of brick and other solid units of clay or shale; sand-lime or concrete brick:		
8000 or greater	350	300
4500	225	200
2500	160	140
1500	115	100
Grouted masonry, of clay or shale; sand-lime or concrete:		
4500 or greater	225	200
2500	160	140
1500	115	100
Solid masonry of solid concrete masonry units:		
3000 or greater	225	200
2000	160	140
1200	115	100
Masonry of hollow load bearing units:		
2000 or greater	140	120
1500	115	100
1000	75	70
700	60	55
Hollow walls (non-composite masonry bonded[3])		
Solid units:		
2500 or greater	160	140
1500	115	100
Hollow units	75	70
Stone ashlar masonry:		
Granite	720	640
Limestone or marble	450	400
Sandstone or cast stone	360	320
Rubble stone masonry		
Coarse, rough or random	120	100

[1]Linear interpolation for determining allowable stresses for masonry units having compressive strengths which are intermediate between those given in the table is permitted

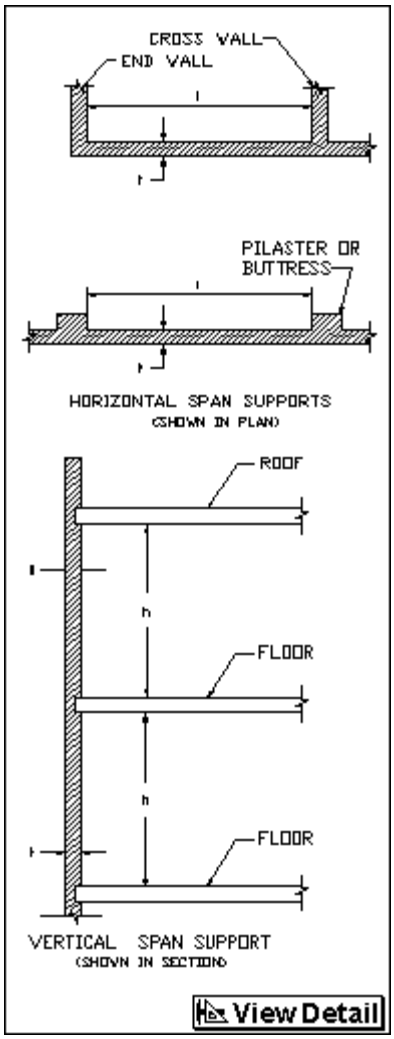
[2] 1 psi = 6.9 kPa

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

Lateral Support (9.5)

Chapter 9 contains arbitrary limits on the ratios of wall thickness to distance between lateral supports. These limits provide controls on the flexural tension stresses within the wall and limit possible buckling under compressive stresses. Maximum h/t or l/t ratios and minimum thickness used for determining distance between lateral supports are consistent with past masonry standards. Definitions for height (h), length (l) and thickness (t) for use in the allowable lateral support ratios are as follows: h = the vertical distance or height between lateral supports; l = the horizontal distance or length between lateral supports: and t = the nominal thickness of the masonry wall under consideration. ACI 530/ASCE 5 does not provide guidance for computing the thickness of masonry bonded hollow walls or cavity walls bonded with metal ties. BIA suggests that the value for thickness be the sum of the nominal thicknesses of the inner and outer wythes.

Masonry walls should be laterally supported in either the horizontal or vertical direction at intervals not exceeding those given in Table 3. Lateral support should be provided by cross walls, pilasters, buttresses or structural frame members when the limiting distance is taken horizontally. Floors, roofs or structural frame members should be used when the limiting distance is taken vertically (see Fig. 2).



Lateral Support Requirements

FIG. 2

Cantilever type walls also have a minimum lateral support criteria. The h/t ratio for cantilever walls should not exceed 6 for solid masonry walls nor 4 for hollow masonry walls.

Thickness of Masonry (9.6)

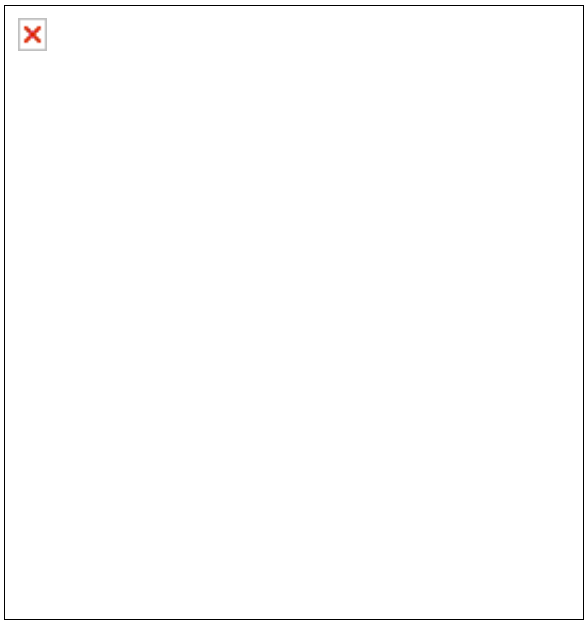
Empirical design requirements pertaining to the thickness of bearing walls and foundation walls are found in Section 9.6. Masonry walls must conform to thickness requirements as well as lateral support and allowable stress requirements. Thicknesses given are nominal dimensions. These requirements are more conservative than empirical design criteria in previous masonry standards.

Bearing Walls. The minimum thickness of masonry bearing walls more than one story in height must be 8 in. (200 mm). Bearing walls of one story buildings may be reduced to 6 in. (150 mm). The height to thickness limitation in Table 3 requires a wall of 6 in. (150 mm) in thickness to have a maximum height of 10 ft (3.1 m)

Specific provisions are incorporated due to a change in wall thickness between floor levels or floor and roof levels. If a change in wall thickness between floors or between floor and roof levels is desired, the greater wall thickness must

extend to the lower support level. Wall thicknesses may be changed to meet fire, sound or thermal requirements. Where walls of hollow masonry units or masonry bonded hollow walls are decreased in thickness, a course or courses of solid masonry should be constructed between the thicker wall below and the thinner wall above. Special units or construction are permitted to be used as long as the loads from face shells or wythes of masonry above are transmitted to the wall system below.

Foundation Walls. Foundation walls have empirical thickness requirements which are shown in Table 4. Foundation walls must be constructed of either Type M or S mortar. The height of unbalanced fill (height of finished ground above the basement floor or inside ground level) and the height of the wall between lateral supports must not exceed 8 ft (2.4 m), and the equivalent fluid weight of unbalanced fill must not exceed 30 pcf (480.5 kg/m3). Most well-drained sand and gravel backfills have an equivalent fluid weight of less than 30 pcf (480.5 kg/m3). When these conditions are not met, foundation walls must be designed in accordance with Chapters 5 and 6 or 5 and 7 of ACI 530/ASCE 5.



[1]1 in = 25.4 mm

[2]1 ft = 0.3048

Parapets. Parapets are required to have a minimum thickness of at least 8 in. (200 mm). Their height cannot exceed three timed their thickness.

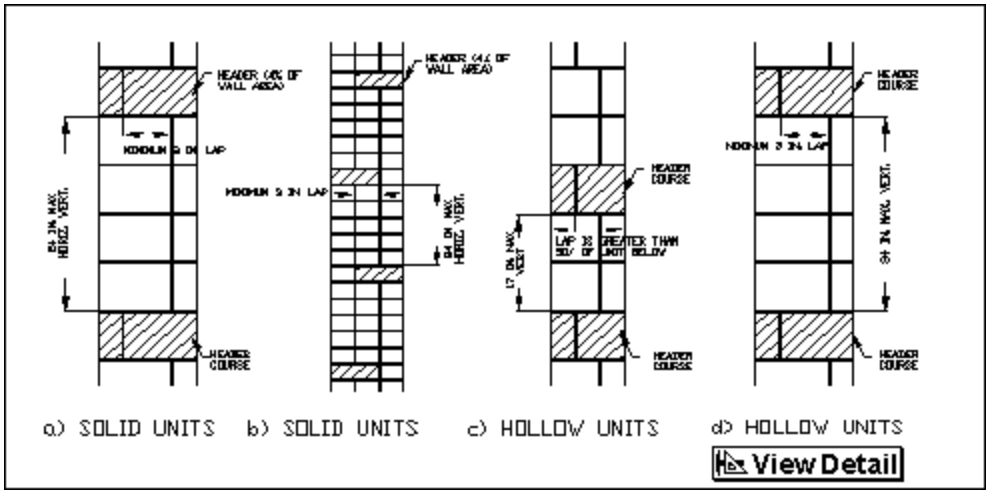
Bonding (9.7)

Multi-wythe masonry walls may be bonded together by either masonry headers or metal wall ties. Limitations on the area and spacing of masonry headers or metal ties for both solid and hollow units are contained in Chapter 9 of the code.

Masonry headers are typically used when bonding barrier type walls (walls of solid units built without air spaces) or hollow walls composed of solid masonry units. Metal ties can be used for barrier type walls (with grouted collar joints) and drainage type walls (a clear air space between wythes of masonry).

The necessary requirements for bonding multi-wythe walls with masonry headers is shown in Fig. 3. Masonry headers of solid units must comprise not less than 4 percent of wall surface area and extend at least 3 in. (75 mm) into each wythe.

The distance between adjacent full-length headers should not exceed 24 in. (610 mm) horizontally or vertically along the wall surface.



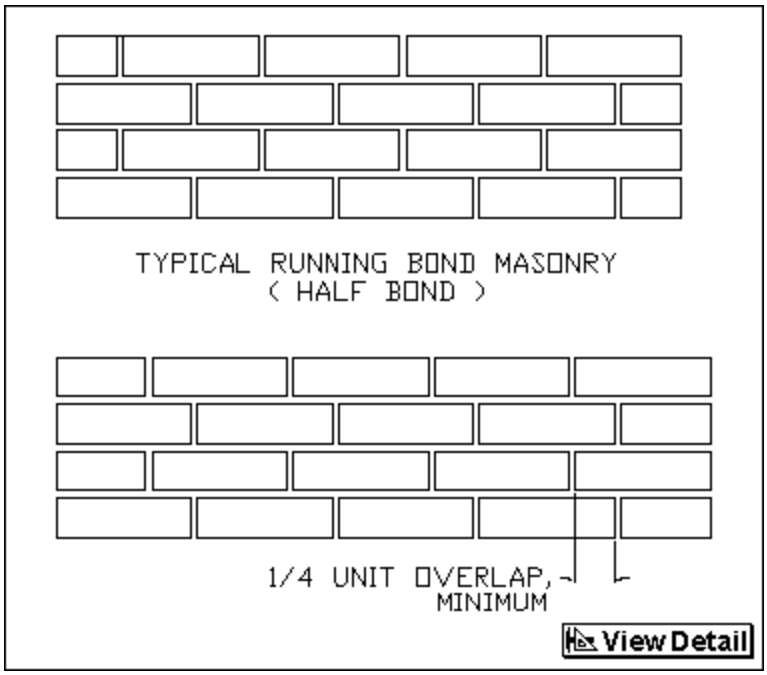
Multi-Wythe Bond With Masonry Headers

FIG. 3

Two options exist when bonding multi-wythe walls with metal ties, the use of unit metal ties and the use of prefabricated horizontal joint reinforcement. When using unit metal ties, such as Z-ties or rectangular ties (box ties), one tie must be provided for each 4 1/2 ft^2 (0.42 m^2) of wall area. Ties should be at least 3/16 in. (4.76 mm) in diameter and be corrosion resistant. The maximum vertical distance between ties should not exceed 24 in. (610 mm), and the maximum horizontal distance should not exceed 36 in. (914 mm). Z-ties may not be used with hollow masonry units. Additional metal ties should be provided at all openings, spaced not more than 3 ft (0.91 m) apart around the perimeter and within 12 in. (300 mm) of the opening. These provisions are similar to those for cavity wall construction.

When bonding multi-wythe walls with horizontal joint reinforcement, there should be one crosswire metal tie for each 2 2/3 ft^2 (0.25 m^2) of wall area. The vertical spacing should not exceed 16 in. (400 mm). Crosswires should not be smaller than No. 9 gage wire (W 1.7) and be corrosion resistant.

Pattern Bond. Masonry walls can be laid in either running or stack bond. Running bond is defined by each wythe of masonry head joints in successive courses being offset by at least one-quarter the unit length (see Fig. 4). It is considered stack bond if the longitudinal bond is offset less than one-quarter the unit length, and horizontal joint reinforcement or bond beams with a maximum spacing of 4 ft (1.2 m) vertically with a minimum area of steel equal to 0.0003 times the vertical cross-sectional area of the wall must be provided.



Typical Foundation Details

FIG. 4

Anchorage (9.8)

Masonry elements must be anchored to various components of the building which provide lateral support when using empirical design. Anchorage must occur at intersecting walls, at floors and roofs which adjoin masonry walls and where masonry walls abut structural framing. Anchorage requirements for masonry walls contained in ACI 530/ASCE 5 are as follows:

"9.8.2 Intersecting walls - Masonry walls depending upon one another for lateral support shall be anchored or bonded at locations where they meet or intersect by one of the following methods:

9.8.2.1 Fifty percent of the units at the intersection shall be laid in an overlapping masonry bonding pattern, with alternate units having a bearing of not less than 3 in. (75 mm) on the unit below.

9.8.2.2 Walls should be anchored by steel connectors having a minimum section of 1/4 in. (6.4 mm) by 1 1/2 in. (38.1 mm) with ends bent up at least 2 in. (50 mm) or with cross pins to form anchorage. Such anchors shall be at least 24 in. (600 mm) long and the maximum spacing shall be 4 ft (1.22 m).

9.8.2.3 Walls shall be anchored by joint reinforcement spaced at a maximum distance of 8 in. (200 mm). Longitudinal rods of such reinforcement shall be at least 9 gage (W 1. 7) and shall extend at least 30 in. (762 mm) in each direction at the intersection.

9.8.2.4 Interior non-loadbearing walls shall be anchored at their intersection, at vertical intervals of not more than 16 in. (400 mm) with joint reinforcement or 1/4 in. (6.4 mm) mesh galvanized hardware cloth.

9.8.2.5 Other metal ties, joint reinforcement or anchors, if used, shall be spaced to provide equivalent area of

anchorage to that required by this section.

9.8.3 Floor and roof anchorage - Floor and roof diaphragms providing lateral support to masonry shall be connected to the masonry by one of the following methods:

9.8.3.1 Wood floor joists bearing on masonry walls shall be anchored to the wall at intervals not to exceed 6 ft (1.8 m) by metal strap anchors. Joists parallel to the wall shall be anchored with metal straps spaced not more than 6 ft (1.8 m) on centers extending over or under and secured to at least 3 joists. Blocking shall be provided between joists at each strap anchor.

9.8.3.2 Steel floor joists shall be anchored to masonry walls with 3/8 in. (9.5 mm) round bars, or their equivalent, spaced not more than 6 ft (1.8 m) on center. Where joists are parallel to the wall, anchors shall be located at joists cross bridging.

9.8.3.3 Roof structures shall be anchored to masonry walls with 1/2 in. (12.7 mm) bolts 6 ft (1.8 m) on center or their equivalent. Bolts shall extend and be embedded at least 15 in. (381 mm) into the masonry, or be hooked or welded to not less than 0.20 in^2 (129 $mm2$) of bond beam reinforcement placed not less than 6 in. (150 mm) from the top of the wall.

9.8.4 Walls adjoining structural framing - Where walls are dependent upon the structural frame for lateral support they shall be anchored to the structural members with metal anchors or otherwise keyed to the structural members. Metal anchors shall consist of 1/2 in. (12. 7 mm) bolts spaced at 4 ft (1.2 m) on center embedded 4 in. (100 mm) into the masonry, or their equivalent area. "

Miscellaneous Requirements (9.9)

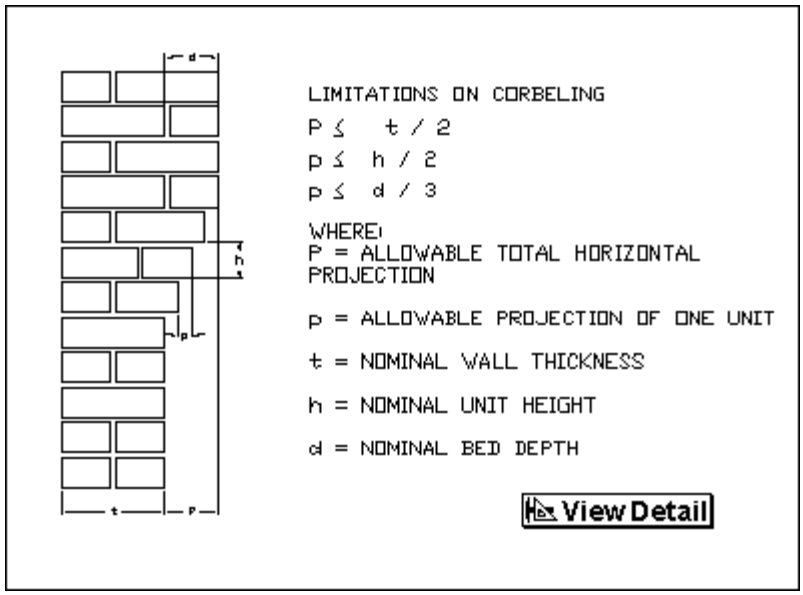
General limitations for masonry structures such as masonry over chases and recesses, lintels over openings, noncombustible supports for masonry walls and corbeling have empirical requirements for proper design and construction.

Chases and recesses in masonry walls are sometimes used for visual effects or to receive pipes, conduits or ducts. When chases or recesses are wider than 12 in. (300 mm), the masonry above the chase must be supported by noncombustible lintels, which could be steel angle lintels or reinforced brick masonry lintels.

The design of lintels must be in accordance with Section 5.6 which stipulates that the deflection of lintels due to vertical loads should not exceed the span divided by 600 nor 0.3 in. (7.6 mm) when supporting unreinforced masonry. Minimum bearing for lintels is 4 in. (100 mm) on each end of the masonry opening.

Masonry is not permitted to be supported by combustible construction, i.e. wood. Even though wood construction may meet the deflection requirements for lintels, this restriction is a fire safety requirement.

Corbeling limitations are the same as those required by the model building codes used throughout the country. The maximum corbeled projection beyond the plane of the wall should not be more than one-half of the wall thickness or one-half the wythe thickness for hollow walls. The maximum projection of any single course of masonry should not exceed one-half the unit height or one-third the unit thickness. Solid units are required for corbeled courses of Masonry. Figure 5 illustrates these criteria for corbeling masonry.



Corbeling Limitations

FIG. 5

Seismic Considerations for Empirically Designed Masonry

Appendix A of ACI 530/ASCE 5 contains special requirements for masonry in seismic zones as specified in ASCE 7 (formerly ANSI A58.1). The provisions of Chapter 9 on empirical design of masonry may be used in Seismic Zones 0, 1 and 2, and are modified by Appendix A. Empirical design cannot be used in buildings located in Seismic Zones 3 and 4.

For Seismic Zones 0 and 1, all provisions of Chapter 9 apply without modification. There are no restrictions on materials or design methods since these areas of the country represent low seismic risk.

Masonry elements in Seismic Zone 2 must meet more stringent requirements. Connections are strengthened and minimum vertical and horizontal reinforcement is required in order to provide more ductility in the structure. All materials also are permitted to be used in the structure.

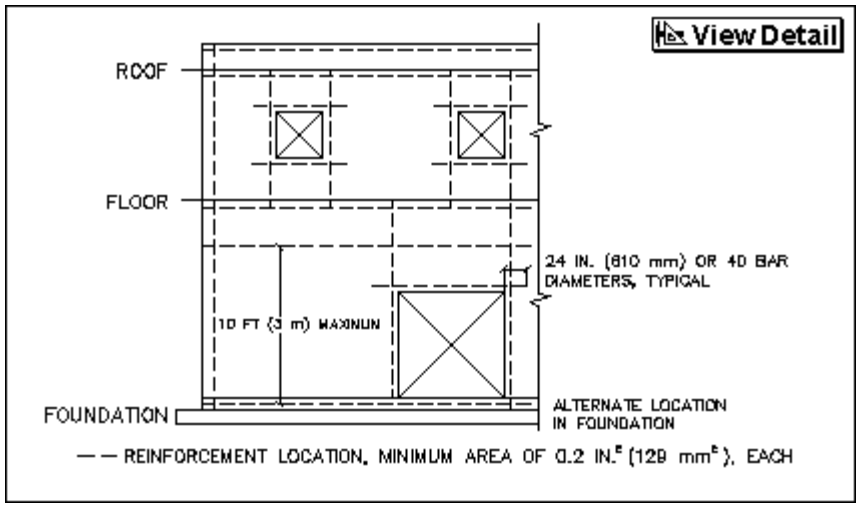
Seismic requirements for buildings or structures in Seismic Zone 2 as contained in Appendix A are as follows:

> *"A.3.5 Veneer and units not specifically intended for structural use shall not be designed to resist loads other than their own weight or their own shear loads.*
>
> *A.3.6 Masonry walls shall be anchored to all floors and roofs which provide lateral support for the walls. Such anchorage shall provide direct connection capable of resisting horizontal forces required in Section 5.2 or a minimum of 200 lb (90.9 kg) per lineal foot (meter) of wall, whichever is greater. Walls shall be designed to resist bending between anchors where anchor spacing exceeds 4 ft (1.2 m). Anchors in masonry walls shall be embedded in reinforced bond beams or reinforced vertical cells.*
>
> *A.3.7 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 #4 lateral ties shall be provided in the top 5 in. (127 mm) of the column. Welded or mechanical connections for reinforcing bars in tension shall develop 125 percent of the yield strength of the bars in*

tension.

A.3.8 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 and at the ends of walls. Horizontal reinforcement not less than 0.20* in.^{2} (129 mm^2) *in cross section area shall be provided: (1) at the bottom and top of wall openings and shall extend not less than 24 in. (610 mm) nor less than 40 bar diameters past the opening, (2) continuously at structurally connected roof and floor levels and at the top of walls, (3) at the bottom of the wall or in the top of the foundations when doweled to the wall, (4) at maximum spacing of 10 ft (3.1 m) unless uniformly distributed joint reinforcement is provided. Reinforcement at the top and bottom openings when used in determining the maximum spacing specified in Item No. (4) above shall be continuous in the wall. "*

Minimum reinforcement requirements are shown in Fig. 6.



Minimum Reinforcement Requirements for Seismic Zone 2

FIG. 6

"A.3.9 Where head joints in successive courses are horizontally offset less than one-quarter of the unit length, the minimum horizontal reinforcement shall be 0.0007 times the gross cross-sectional area of the wall. This reinforcement shall be satisfied with uniformly distributed joint reinforcement or with horizontal reinforcement spaced not over 4 ft (1.2 m) and fully embedded in grout or mortar "

MATERIALS AND CONSTRUCTION

General

The provisions of ACI 530.1-92/ASCE 6-92, "Specifications for Masonry Structures" have minimum material and

construction requirements for masonry structures designed in accordance with Chapter 9 empirical provisions. Masonry units, mortar, grout, reinforcement and accessories are included. This document should be referenced in the project specifications and can be modified as required for the particular project.

Masonry Units

The products section permits the use of clay brick, concrete masonry units and stone masonry in empirically designed masonry structures. ASTM standards for clay or shale masonry covered by ACI 530.1/ASCE 6 are ASTM C 34, C 56, C 126, C 212, C 216 and C 652. Grade or class of the units to be used in construction are determined by exposure conditions and required durability. For further information on the manufacture, designation and selection of clay masonry units, see *Technical Notes* 9 Series.

Mortar and Grout

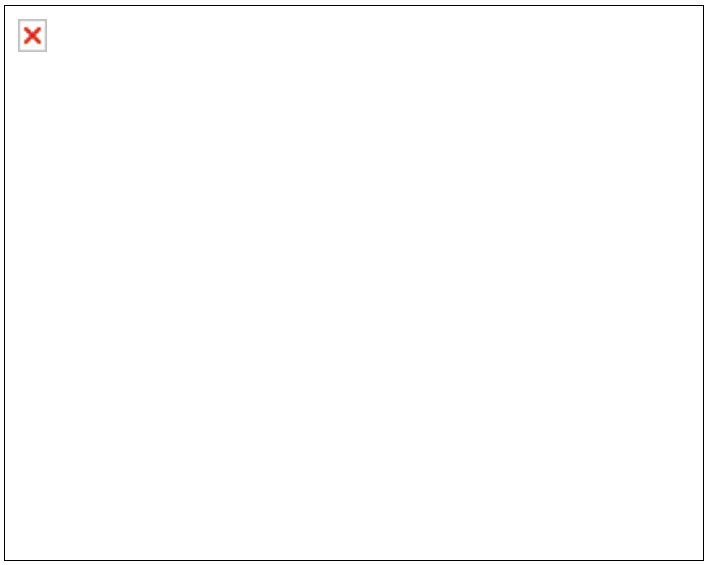
Mortar is required to conform to ASTM C 270 Mortar for Unit Masonry. When job site pigments are used to color mortar there are maximum percentages of color pigment by weight of the cement content which can be added. For portland cement-lime mortars, the maximum content of the coloring pigment is limited to 10 percent for mineral oxide pigments and 2 percent for carbon black. If masonry cements are used, the percentage by weight for color pigments are halved.

Grout is required to conform to ASTM C 476 Grout for Unit Masonry. This is a proportion specification for either fine or coarse grout used in construction.

Reinforcement and Accessories

ACI 530.1/ASCE 6 contains provisions for reinforcement and metal accessories. All reinforcement and metal accessories are required to be corrosion resistant. Procedures described represent current construction practices and are consistent with model building codes now in existence. Topics that are covered are ASTM standards for the materials, inspection, and detailing and placement of reinforcement and accessories which include tolerances.

Corrosion Resistance. Conventional corrosion protection methods attempt to protect metals embedded in masonry by isolating them with impervious coatings, by using metals that are corrosion resistant or by providing cathodic protection. ACI 530.1/ASCE 6 provides requirements for corrosion protection for carbon steel by galvanized coatings. The amount of galvanizing required increases with the severity in exposure of the masonry wall. Anchors, ties and joint reinforcement must meet minimum corrosion protection requirements. Table 5 shows the minimum corrosion protection requirements needed for metal accessories used in masonry walls.



Construction

Construction requirements within ACI 530.1/ASCE 6 cover the conventional construction practices used in projects that involve empirically designed masonry. The provisions are similar to those found in the model building codes. The basic premise under the construction requirements is to ensure proper placement of materials. Mortar joint filling depends on the type of unit used in construction. Solid units have full head and bed joints. Hollow units are laid with face shell bedding. Requirements include tolerances for erection, collar joints and placement of embedded items such as wall ties and reinforcement. Grout placement is also covered.

SUMMARY

This *Technical Notes* reviews empirical design procedures contained in ACI 530/ASCE 5. The discussion centers on the requirements which are needed by engineers and architects to fully understand the empirical design of masonry structures within the limits of Chapter 9.

The information and suggestions contained in this *Technical Notes* are based on the available data and the experience of the engineering staff of the Brick Institute of America. The information contained in this publication must be used with good technical judgment. Final decisions on the use of materials and suggestions contained herein are not within the purview of the Brick Institute of America and must rest with the project architect, engineer and owner.