TECHNICAL NOTES on Brick Construction
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Technical Notes 3B - Brick Masonry Section Properties
May 1993

Abstract: This *Technical Notes* is a design aid for the *Building Code Requirements for Masonry Structures* (ACI 530/ASCE 5/TMS 402-92) and *Specifications for Masonry Structures* (ACI 530.1/ASCE 6/TMS 602-92). Section properties of brick masonry units, steel reinforcement and brick masonry assemblages are given to simplify the design process. Section properties are used to calculate stresses and to determine the allowable stresses given in the ACI 530/ASCE 5/TMS 402-92 Code.

Key Words: brick, dimensions, section properties, steel reinforcement.

INTRODUCTION

An assemblage's geometry determines its ability to resist loads. Section properties are properties of a masonry assemblage which are based solely on its geometry. Section properties are used in design and analysis of brick masonry structural elements. Section properties are used to determine allowable stresses which may be applied to brick masonry elements, as well as to calculate an element's stress under applied loads. Because brick is a small building unit, it may be used to construct assemblages of nearly any configuration. While this is a benefit of construction with brick masonry, it can make design tedious because each masonry assemblage will have unique section properties. To simplify the design process, this *Technical Notes* presents the section properties of brick units, steel reinforcement and typical brick masonry assemblages. The section properties are based on specified dimensions of the units and assemblages.

This *Technical Notes* is a design aid for the *Building Code Requirements for Masonry Structures* (ACI 530/ASCE 5/TMS 402-92) and the *Specifications for Masonry Structures* (ACI 530.1/ASCE 6/TMS 602-92). These documents, which are promulgated by the Masonry Standards Joint Committee (MSJC), will be referred to as the MSJC Code and the MSJC Specifications, respectively. References are made to the MSJC Code and Specifications to indicate where each section property applies. Other *Technical Notes* in this series provide an overview of the MSJC Code and Specifications and material properties of brick masonry.

NOTATION

Following are notations used in the text, figure and tables in this *Technical Notes*. Where applicable, notations are the same as used in the MSJC Code and Specifications.

A_n Net cross-sectional area of masonry, in.^{2} (mm^2)

A_s Area of steel, in.^{2} (mm^2)

b Width of section, in. (mm)

b_{flange} Width of flange, in. (mm)

b_{web} Width of web, in. (mm)

d Distance from extreme compression fiber ot the centroid of tension reinforcement, in. (mm)

E_m Elastic modulus of masonry, psi (MPa)

E_s Elastic modulus of steel, psi (MPa)

I   Moment of inertia, in.^{4} (m^4)

j   Ratio of distance between centroid of flexural compressive forces and centroid of tensile forces to depth

k   Ratio of distance between compression face and neutral axis to distance between compression face and centroid of tensile forces

n   Elastic moduli ratio, E_s/E_m

Q   First moment about the neutral axis of a section of that portion of the cross section lying between the neutral axis and extreme fiber, in.^{3} (m^3)

r   Radius of gyration, in. (mm)

S   Section modulus, in.^{3} (m^3)

SECTION PROPERTIES OF CONSTITUENT MATERIALS

The constituent materials of units, mortar, grout and reinforcement combine to form brick masonry assemblages. The section properties of each constituent material may be required in the design process. The section properties of clay and shale masonry units are the basis for the section properties of the total brick masonry assemblage. The section properties of steel reinforcement are used to determine the size and spacing of reinforcement within a brick masonry assemblage.

TABLE 1

BIA Standard Nomenclature for Brick Sizes

Unit Name	Unit Dimensions		
	Width, in. (mm)	Height, in. (mm)	Length, in. (mm)
Modular	3 1/2 - 3 5/8 (89 - 92)	2 1/4 (57)	7 1/2 - 7 5/8 (190 - 194)
Standard	3 1/2 - 3 5/8 (89 - 92)	2 1/4 (57)	8 (203)
Engineer Modular	3 1/2 - 3 5/8 (89 - 92)	2 3/4 - 2 13/16 (70 - 71)	7 1/2 - 7 5/8 (190 - 194)
Engineer Standard	3 1/2 - 3 5/8 (89 - 92)	2 3/4 - 2 13/16 (70 - 71)	8 (203)
Closure Modular	3 1/2 - 3 5/8 (89 - 92)	3 1/2 - 3 5/8 (89 - 92)	7 1/2 - 7 5/8 (190 - 194)
Closure Standard	3 1/2 - 3 5/8 (89 - 92)	3 1/2 - 3 5/8 (89 - 92)	8 (203)
Roman	3 1/2 - 3 5/8 (89 - 92)	1 5/8 (41)	11 1/2 - 11 5/8 (292 - 295)
Norman	3 1/2 - 3 5/8 (89 - 92)	2 1/4 (57)	11 1/2 - 11 5/8 (292 - 295)
Engineer Norman	3 1/2 - 3 5/8 (89 - 92)	2 3/4 - 2 13/16 (70 - 71)	11 1/2 - 11 5/8 (292 - 295)
Utility	3 1/2 - 3 5/8 (89 - 92)	3 1/2 - 3 5/8 (89 - 92)	11 1/2 - 11 5/8 (292 - 295)
King Size	3 (76)	2 5/8 - 2 3/4 (67 - 70)	9 1/2 - 9 5/8 (241 - 244)
Queen Size	3 (76)	2 3/4 (70)	7 5/8 - 8 (194 - 203)

Clay and Shale Masonry Units

Clay and shale masonry units are manufactured in a number of sizes and shapes. Clay and shale masonry units are classified as either solid units or hollow units. Solid units may contain up to 25 percent void area as a percentage of the gross cross-sectional area of the unit. Hollow units are classified as H40V for units with a total void area greater than 25 percent and less than 40 percent of the gross cross-sectional area, or H60V for units with a total void area greater than 40 percent and less than 60 percent of the gross cross-sectional area. The number and size of voids vary with unit size and manufacturing equipment.

The range of sizes of clay and shale masonry units is given in Table 1. The names given for unit sizes in Table 1 were established by consensus of United States brick manufacturers and are standard terminology for the brick industry. Further information on masonry unit sizes and coursing of brickwork can be found in the *Technical Notes* 10 series on estimating brickwork.

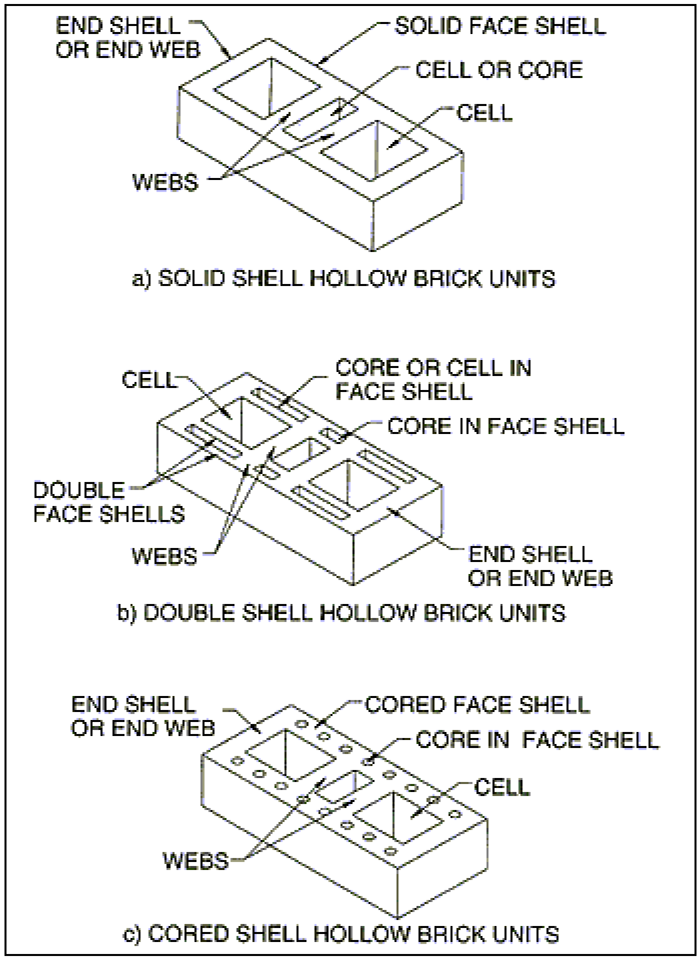
One criteria for unit selection may be accommodation of reinforcement within the unit itself. Placement of steel reinforcement within the cores or cells of hollow units or solid cored units is permitted by the MSJC Code and Specifications. A core is a void area less than or equal to 1 1/2 in.^{2} (970 mm^2). A cell is a void area which is larger than 1 1/2 in.^{2} (970 mm^2). When placing reinforcement within a unit, adequate space for grouting must be provided. Specifically, MSJC Code Section 8.3.5 requires that the minimum distance between the steel reinforcement and the surrounding masonry unit be 1/4 in. (6 mm) when fine grout is used and 1/2 in. (13 mm) when coarse grout is used.

In certain instances, the cross-sectional area of masonry units may need to be determined. For example, the compressive strength of a masonry prism is determined based on the unit's gross cross-sectional area when the prism is constructed of solid units or fully grouted hollow units, and on the unit's net cross-sectional area when the prism is constructed of hollow units. For solid units which contain cores, the gross cross-sectional area is used as the net cross-sectional area. Unit cross-sectional area may be determined in accordance with ASTM C 67 Methods of Sampling and Testing Brick and Structural Clay Tile.

The shell and web thickness of hollow units may need to be determined because hollow unit brick masonry walls are typically face-shell bedded, while columns, pilasters and the first course of walls must be fully bedded. Minimum thickness requirements for shells and webs of hollow units are established by ASTM C 652 Specification for Hollow Brick (Hollow Masonry Units Made From Clay or Shale). These limits are given in Table 2. Many manufacturers exceed the minimum thickness requirements given in Table 2, so it is advisable to request actual unit dimensions for design purposes.

TABLE 2

Hollow Unit Section Properties



Nominal width of units, in. (mm)	Minimum solid face shell thickness, in. (mm)	Minimum cored or double face shell thickness[1], in. (mm)	Minimum end shell or end web thickness[2], in. (mm)
3 & 4 (75&100)	3/4 (19)	-	3/4 (19)
6 (150)	1 (25)	1 1/2 (38)	1 (25)
8 (200)	1 1/4 (32)	1 1/2 (38)	1 (25)
10 (250)	1 3/8 (35)	1 5/8 (41)	1 1/8 (30)
12 (300)	1 1/2 (38)	2 (50)	1 1/8 (30)

[1]Cores greater than 1 in.2 (650 mm2) in cored shells shall be not less than 1/2 in. (13 mm) from any edge. Cores not greater than 1 in.2 (650 mm2) in shells cored not more than 35% shall be not less than 3/8 in. (10 mm) from any edge.

[2]The thickness of webs shall not be less than 1/2 in. (13 mm) between cells, 3/8 in. (10 mm) between cells and cores or 1/4 in. (6 mm) between cores.

Steel Reinforcement

Steel reinforcement for brick masonry assemblages consists of bars and wires. Reinforcing bars are placed in grouted cavities, pockets, cores, cells or bond beams of brick masonry walls, columns, pilasters and beams. Steel wire reinforcement is placed in brick masonry mortar joints to reinforce individual assemblages or to tie structural elements together, such as the wythes of a multi-wythe wall. Common bar and wire section properties are given in Table 3. The sizes of reinforcement listed in Table 3 are those permitted by the MSJC Code. The cross-sectional area of reinforcement is used in MSJC Code Eq. 7-10 to determine the spacing of shear reinforcement. The diameter of reinforcement is used to establish placement limits and minimum reinforcement development length requirements given in Chapter 8 of the MSJC Code.

TABLE 3
Steel Reinforcement Sizes

Reinforcement Type	Designation	Diameter, in. (mm)	Area, in.^{2} (mm^2)
Bars	No. 3	0.375 (10)	0.110 (71)
	No. 4	0.500 (13)	0.196 (126)
	No. 5	0.625 (16)	0.307 (198)
	No. 6	0.750 (19)	0.442 (285)
	No. 7	0.875 (22)	0.601 (388)
	No. 8	1.000 (25)	0.785 (506)
	No. 9	1.128 (29)	1.000 (645)
	No.10	1.270 (32)	1.267 (817)
	No.11	1.410 (36)	1.561 (1007)
Wires	W1.1 (11 gage)	0.121 (3.1)	0.011 (7)
	W1.7 (9 gage)	0.148 (3.8)	0.017 (11)
	W2.1 (8 gage)	0.162 (4.1)	0.021 (14)
	W2.8 (3/16 in.)	0.188 (4.8)	0.028 (18)
	W4.9 (1/4 in.)	0.250 (6.4)	0.049 (32)

SECTION PROPERTIES OF BRICK MASONRY ASSEMBLAGES

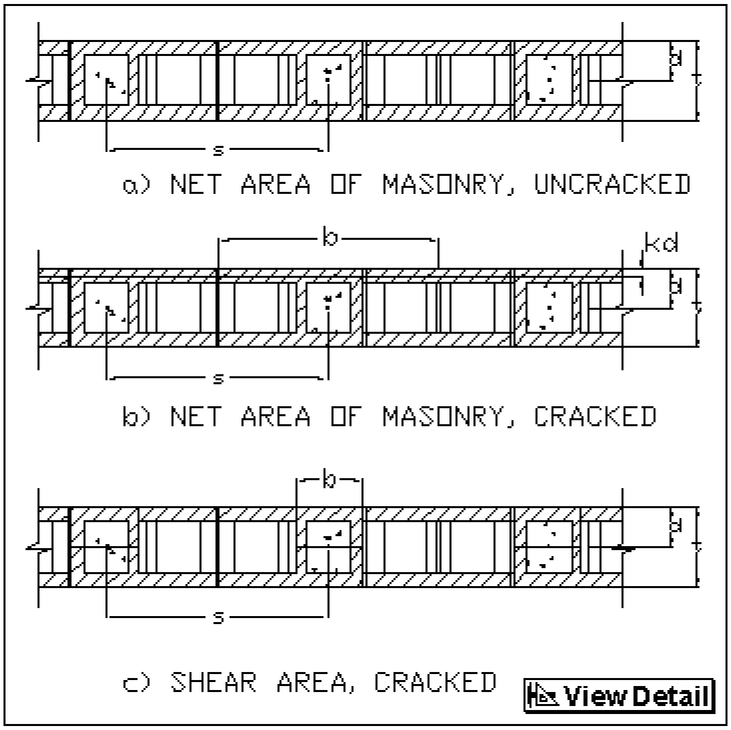
The section properties of the assemblage of the constituent materials, along with the strength of the materials, will determine the magnitude of loads the assemblage can resist. Consider the section properties required in the design of brick masonry assemblages following the MSJC Code. The width of the brick masonry assemblage, b, is used in MSJC Code Eqs. 6-7 and 7-3 and the effective depth of reinforcement, d, is used in MSJC Code Eqs. 7-3, 7-5, 7-8 and 7-10. Moment of inertia, I, is used in MSJC Code Eqs. 6-6 and 6-7. Radius of gyration, r, is used in MSJC Code Eqs. 6-3, 6-4, 6-6, 7-1 and 7-2 to determine allowable compressive stresses and axial load. The first moment of area, Q, is used in MSJC Code Eq. 6-7 to determine the shear stress in an unreinforced masonry element. The dimensionless quantities k and j are used to determine a cracked, reinforced masonry element's compressive stress and the allowable shear stress given in MSJC Code Eq. 7-3. The quantities k and j are functions of the area of reinforcement, A_s, and the moduli ratio, n. The moduli ratio, n, is the ratio of the modulus of elasticity of steel, E_s, to the modulus of elasticity of masonry, E_m.

Following is a discussion of the section properties of typical brick masonry assemblages. Tables 4 through 7 provide section properties of these assemblages based on the dimensions indicated, which are based on the least specified brick unit dimensions given in Tables 1 and 2. The MSJC Code requires that the computation of stresses be based on the minimum net cross-sectional area of the element under consideration, A_n. For ungrouted, hollow brick units laid with face-shell bedding, the minimum net cross-sectional area is the mortar bedded area. The computation of stiffness of a brick masonry element may be based on the average net cross-sectional area of the element. The average cross-sectional area is permitted for stiffness computations, because the distribution of material within an element may be non-uniform. Examples of structural elements which have a non-uniform distribution of materials include partially grouted or ungrouted hollow unit masonry walls.

Walls

Brick masonry walls may be constructed of a single wythe (one unit in thickness) or multiple wythes and can be reinforced or unreinforced. Brick masonry walls may be loaded perpendicular to the plane of the wall or in the plane of the wall. Out-of-plane loads may be caused by wind or earth pressures or by earthquake induced ground motions. In-plane loads may be the dead weight of the structure, live loads or the result of the transfer of out-of-plane loads through wall connections.

Section properties used in the MSJC Code's design equations for unreinforced masonry walls are I, r and Q. Section properties used in the MSJC Code's design equations for reinforced masonry walls are j, b and d. Additional section properties used to compute applied stresses are A_n, S and k. Effective areas for partially grouted, hollow unit masonry walls are illustrated in Figure 1. Shading indicates net uncracked area, net cracked area and shear area for a cracked cross section. For all illustrations in this *Technical Notes*, cross-hatching indicates mortar bedded areas. In Figure 1(b), the effective width, b, is taken as the least of s, 6t and 72 in. (1.8 m). In Figure 1(c), the effective width, b, is taken as the width of the grout space plus the thicknesses of the adjacent web and end web.



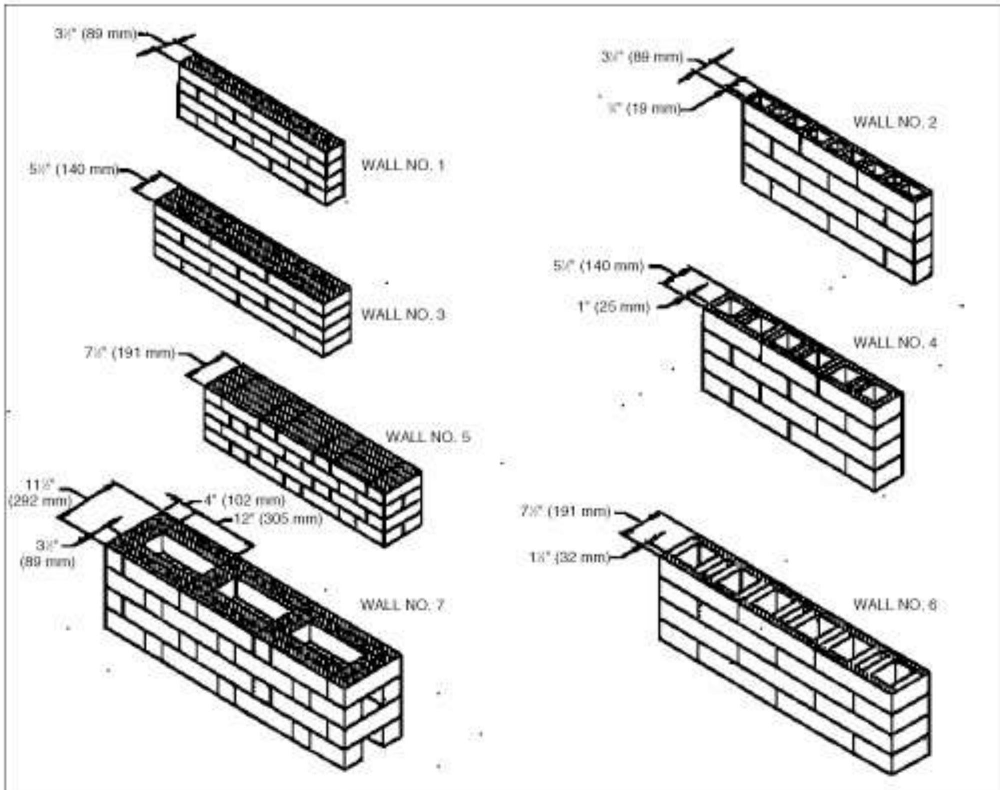
Effective Areas for Partially Grouted, Hollow Unit Masonry Walls

FIG. 1

Section properties for typical ungrouted and grouted brick masonry walls are given in Tables 4 and 5, respectively. The quantities k and j are not provided in this *Technical Notes* because they are dependent upon the quantity of reinforcement provided, the elastic moduli of the masonry and the steel and the loading conditions. The elastic moduli of the masonry and the steel will determine the moduli ratio, n. The moduli ratio is used to determine the state of stress in the steel and the masonry under loads. The loading conditions may be a combination of out-of-plane and in-plane loads. Walls which are subject to flexural and axial loads must be designed considering the interaction of axial load and bending moment, which may be accomplished by the use of a moment-load interaction diagram. The method of development of a moment-load interaction diagram is beyond the scope of this *Technical Notes*.

TABLE 4

Ungrouted Wall Section Properties[1]



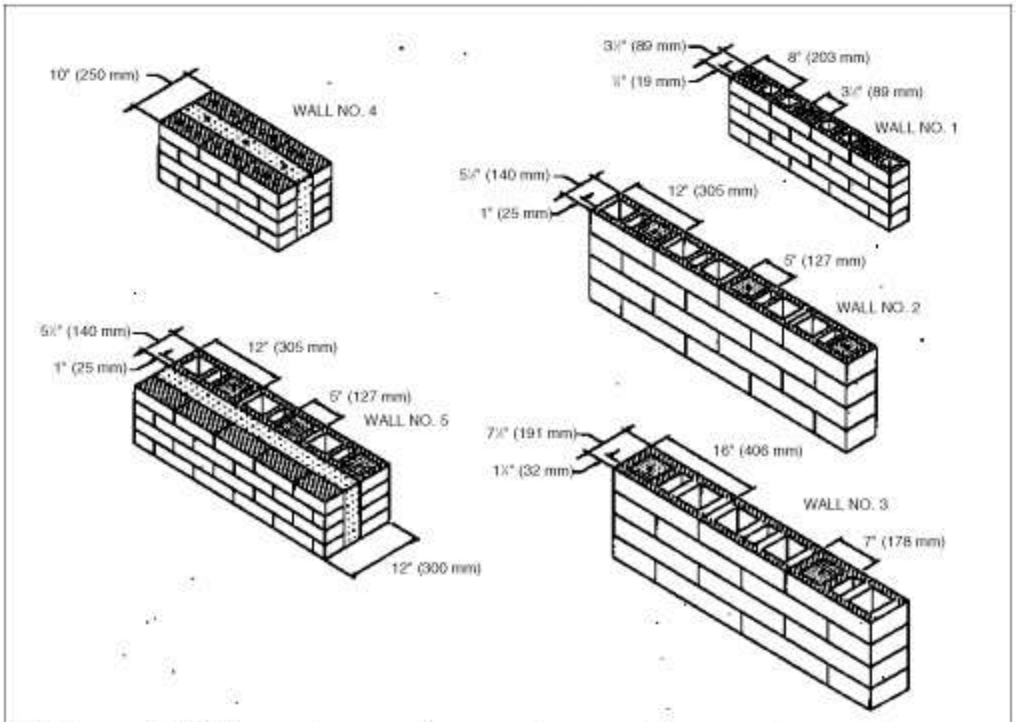
Wall No.	A_n, in.^{2} (mm^2)	I, in.^{4} (x10^{-6} m^4)	S, in.^{3} (x10^{-6} m^3)	r, in. (mm)	Q, in.^{3} (x10^{-6} m^3)
1	42 (27 100)	42.9 (1.79)	24.5 (40.1)	1.01 (25.7)	18.4 (30.2)
2[2]	18 (11 600)	34.9 (1.45)	19.9 (32.6)	1.39 (35.3)	12.4 (20.3)
3	66 (42 600)	166.4 (6.93)	60.5 (99.1)	1.59 (40.4)	45.4 (74.4)
4[2]	24 (15 500)	123.5 (5.14)	44.9 (73.6)	2.27 (57.7)	27.0 (44.2)
5	90 (58 100)	421.9 (17.6)	112.5 (184)	2.17 (55.1)	84.4 (138)
6[2]	30 (19 400)	296.9 (12.4)	79.2 (130)	3.15 (80.0)	46.9 (76.9)
7	100 (64 500)	1 456.3 (60.6)	253.3 (415)	3.82 (97.0)	176.9 (290)

[1]Per foot (305 mm) of wall.

[2]Section properties are based on minimum solid face shell thickness (see Table 2) and face shell bedding.

TABLE 5

Grouted Wall Section Properties[1]



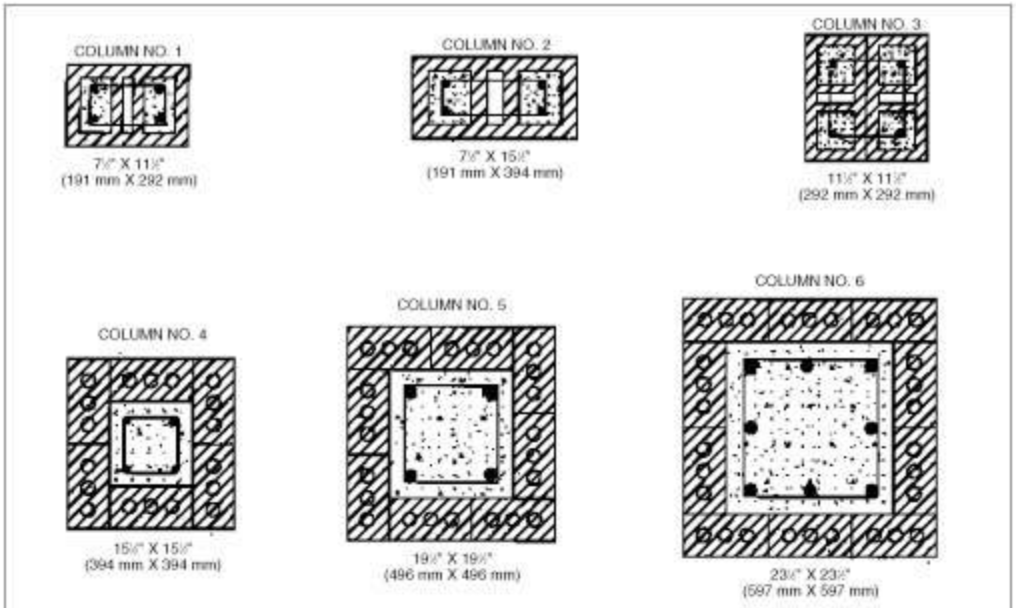
Wall No.	Cell Grout Spacing, in. (mm)	A_n[1] in.^{2} (m^2)	I[1] in.^{4} (x10^{-5} m^4)	r[1] in. (mm)
1	8 (200)	28.5 (18 400)	38.4 (1.60)	1.16 (29.5)
	12 (300)	25.0 (16 100)	37.2 (1.55)	1.22 (31.0)
	16 (410)	23.3 (15 000)	36.6 (1.52)	1.26 (32.0)
	24 (610)	21.5 (13 900)	36.0 (1.50)	1.30 (33.0)
	32 (810)	20.6 (13 300)	35.8 (1.49)	1.32 (33.5)
	48 (1 200)	19.8 (12 800)	35.5 (1.48)	1.34 (34.0)
2	12 (300)	41.5 (26 800)	141 (5.87)	1.85 (47.0)
	24 (610)	32.8 (21 200)	132 (5.49)	2.01 (51.1)
	36 (910)	29.8 (19 200)	129 (5.37)	2.08 (52.8)
	48 (1 200)	28.4 (18 300)	128 (5.33)	2.12 (53.8)
3	16 (410)	56.3 (36 300)	352 (14.7)	2.50 (63.5)
	24 (610)	47.5 (30 600)	333 (13.9)	2.65 (67.3)
	32 (810)	43.1 (27 800)	324 (13.5)	2.74 (69.6)
	48 (1 200)	38.8 (25 000)	315 (13.1)	2.85 (72.4)
4	fully grouted	120 (77 400)	1 000 (41.6)	2.89 (73.4)
5	12 (300)	120 (77 400)	1 390 (57.9)	3.41 (86.6)
	24 (610)	111 (71 600)	1 240 (51.6)	3.34 (84.8)
	36 (910)	108 (69 700)	1 180 (49.1)	3.31 (84.1)
	48 (1 200)	106 (68 400)	1 150 (47.9)	3.29 (83.6)

[1]Per foot (305 mm) of wall. Section properties are based on minimum solid face shell thickness (see Table2) and face shell bedding of hollow unit masonry.

Columns

Columns, as defined by the MSJC Code, are isolated elements whose horizontal dimension measured at a right angle from the thickness dimension does not exceed three times the thickness dimension and whose height is at least three times its thickness. Brick masonry columns are used to support large axial loads. Axial loads are typically due to the permanent weight of the structure and the transient floor or roof load which is tributary to the column. According to the MSJC Code, columns must be reinforced with a minimum of four reinforcing bars, and the area of reinforcement, A_s, must be at least 0.0025 but not more than 0.04 times the column's net cross-sectional area, A_n. The minimum nominal dimension of a column is 8 in. (200 mm) and the ratio of height to least lateral dimension must not exceed 25. These requirements will influence the brick masonry column cross section selected. Typical brick masonry column configurations and section properties are given in Table 6. Section properties are based on uncracked cross sections. Typically, a brick masonry column will be in compression and will not crack under loads. However, columns which are loaded by a eccentric axial load or a large lateral load may crack in flexure. A moment-load interaction diagram should be used to design and analyze such columns, considering the section properties of the cracked cross section. The method of development of a moment-load interaction diagram is beyond the scope of this *Technical Notes*.

TABLE 6
Column Section Properties

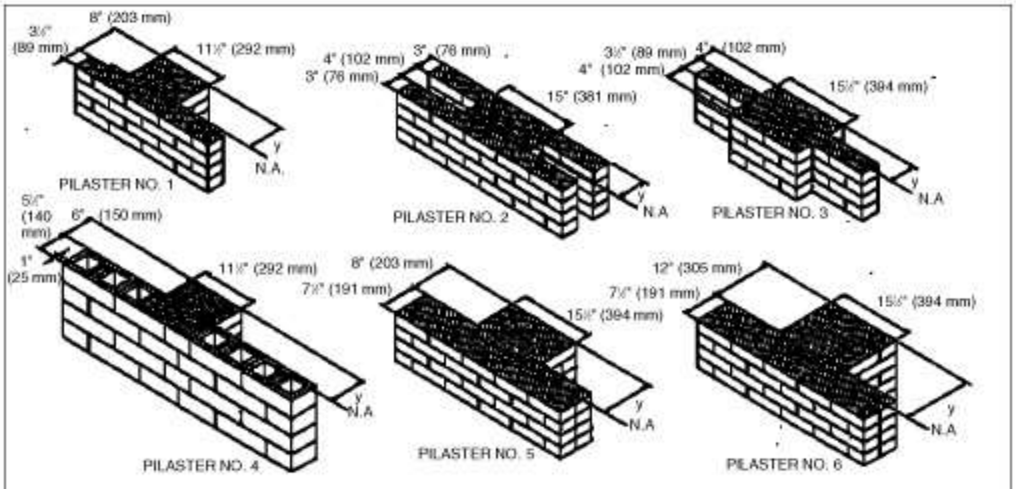


Column No.	A_n, in.^{2} (mm^2)	I_{min}, in.^{4} (x10^{-6} m^4)	r_{min}, in.(mm)	Q_{min}, in.^{3} (x10^{-6} m^3)	0.0025A_n, in.^{2} (mm^2)	0.04A_n, in.^{2} (mm^2)
1	86.3 (55 700)	404 (16.8)	2.16 (55.0)	80.9 (133)	0.27 (139)	3.45 (2 230)
2	116 (74 800)	545 (22.7)	2.17 (55.1)	109 (179)	0.29 (187)	4.64 (2 990)
3	132 (85 200)	1 460 (60.7)	3.32 (84.3)	190 (311)	0.33 (213)	5.28 (3 410)
4	240 (155 000)	4 810 (200)	4.48 (114)	465 (762)	0.60 (387)	9.60 (6 190)
5	380 (245 000)	12 000 (502)	5.63 (143)	927 (1 520)	0.95 (613)	15.2 (9 810)
6	552 (356 000)	25 400 (1060)	6.79 (172)	1620 (2 660)	1.38 (890)	22.1 (14 300)

Pilasters

A pilaster is simply an increase in the effective thickness of a wall at a specific location. To work together, the wall and the thickened section must be integrally constructed. MSJC Code Section 5.10 permits three methods of bonding a pilaster to create integral construction: 1) interlocking fifty percent of the masonry units, 2) toothing at 8 in. (200 mm) maximum offset and attachment with metal ties and 3) providing reinforced bond beams at a maximum spacing of 4 ft (1.2 m) on centers vertically. The length of the wall or flange that is considered to act integrally with the pilaster from each edge of the pilaster or web is the lesser of six times the thickness of the wall or the actual length of the wall. Typical brick masonry pilaster configurations and uncracked section properties are given in Table 7. As noted previously, cracked section properties such as k and j must be determined based on the amount of reinforcement, the moduli ratio and the loading conditions. Pilasters which are loaded both out-of-plane and in-plane must be designed considering the interaction of axial load and bending moment, which may be accomplished by the use of a moment-load interaction diagram. The method of development of a moment-load interaction diagram is beyond the scope of this *Technical Notes*.

TABLE 7
Pilaster Section Properties



Pilaster No.	b_{web}, in. (mm)	b_{flange}, in. (mm)	y, in. (mm)	A_n, in.^{2} (mm^2)	I, in.^{4} (x10^{-5} m^4)	r, in. (mm)
1	11.5 (292)	42.0 (1 070)	7.85 (199)	279 (180 000)	2 720 (113)	3.12 (79.3)
2	15.0 (381)	36.0 (9 14)	5.00 (127)	366 (236 000)	4 060 (169)	3.33 (84.6)
3	15.5 (394)	42.0 (1 070)	5.75 (146)	325 (210 000)	2 120 (88.0)	2.55 (64.8)
4[1]	11.5 (292)	66.0 (1 680)	7.24 (184)	264 (170 000)	2 730 (114)	3.22 (81.8)
5	15.5 (394)	90.0 (2 290)	10.7 (272)	915 (590 000)	10 800 (450)	3.44 (87.4)
6	15.5 (394)	90.0 (2 290)	13.9 (353)	977 (630 000)	20 300 (843)	4.55 (116)

[1]Section properties are based on minimum solid face shell thickness (see Table 2) face shell bedding of the flange and full bedding of the web.

Beams

Reinforced brick masonry beams may be used to span over wall openings such as windows and doors. Brick masonry beams provide a number of advantages over precast concrete or steel lintels. For example, brick masonry beams are a more efficient use of materials and produce a visually appealing brick masonry soffit. Some typical brick masonry beam configurations and their section properties are given in *Technical Notes* 17H and 17J.

SUMMARY

Section properties of brick masonry materials and assemblages are required whenever a rational design of brick masonry structural elements is developed following the criteria of the MSJC Code and Specifications. This *Technical Notes* provides a summary of section properties of brick masonry. Section properties of clay and shale masonry units, steel reinforcement and typical brick masonry assemblages are given.

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 herein must be used in conjunction with good technical judgment and a basic understanding of the properties of brick masonry. Final decisions on the use of the information contained in this *Technical Notes* are not within the purview of the Brick Institute of America and must rest with the project architect, engineer and owner.

REFERENCES

1. *Building Code Requirements for Masonry Structures and Commentary* (ACI 530/ASCE 5/TMS 402-92) and *Specifications for Masonry Structures and Commentary* (ACI 530.1/ASCE 6/TMS 602-92), American Concrete Institute, Detroit, MI, 1992.