Technical Notes 17L - Four Inch RBM Curtain and Panel Walls
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INTRODUCTION

Building Code Requirements for Engineered Brick Masonry, SCPI (BIA), August, 1969 defines a curtain wall as "an exterior non-loadbearing wall not wholly supported at each story. Such walls may be anchored to columns, spandrel beams, floors or bearing walls, but not necessarily built between structural elements." It further defines a panel wall as "an exterior non-loadbearing wall wholly supported at each story". Curtain walls must be capable of supporting their own weight for the height of the wall. Panel walls are required to be self-supporting between stories. Both walls resist lateral forces such as wind pressures and must transfer these forces to adjacent structural members. This *Technical Notes* presents the design and construction of 4-in. brick masonry curtain and panel walls which are considered to span horizontally in resisting lateral forces.

Recent structural research and rational design methods have greatly aided the design of 4-in. brick walls. However, exterior brick walls, 4 1/2 in. thick, were used prior to 1900 in the Church of St. Jean de Montmarte, Paris, France. Designed by M. A. deBoudot, these walls were reinforced with vertical wires through holes in the brick and horizontal wires in the mortar joints. One wall has an unsupported length of 29 ft 6 in. for the full height of 115 ft. Another wall is approximately 38 ft high with an unsupported length of 65 ft. The walls discussed herein differ from those designed by deBoudot in that they have a nominal thickness of 4 in. and contain only horizontal reinforcement.

In the United States, one of the first buildings to be constructed with 4-in. reinforced brick masonry walls was completed in June, 1932. This building, a compressor house, was constructed at Wood River, Illinois, in the refinery of the Standard Oil Company (Indiana). All the walls and columns of this building were of reinforced brick masonry. The walls, with the exception of two bays, were nominally 4 in. thick. The wall height was 18 ft 6 in. with a (column) spacing of 15 ft 4 in. The horizontal mortar joint above the first course of brick was reinforced with two 3/8-in. round bars, placed about 1/2 in. from each face of the wall. Above this, the reinforcement was placed in every third horizontal mortar joint, at a vertical spacing of about 9 5/8 in.

Two more recent examples of the 4-in. curtain wall located in the Denver, Colorado area are the Lakewood Brick Company building (Fig. 1) and the Kistler Printing Plant (Fig. 2). The Lakewood walls are 22 ft high and span continuously across steel and masonry composite columns spaced 20 ft on centers. The horizontal reinforcement varied from two No. 2 bars every second course at points of maximum moment to two No. 2 bars every fourth course at points of minimum moment. The Kistler Plant has similar spans, heights, and construction.

FIG. 1

FIG. 2

The application of the 4-in. wall in commercial and industrial buildings utilizes the many intrinsic properties normally found in brick masonry. Brick presents a pleasing appearance without the problem of maintenance. Four-inch walls built with face brick exhibit the following physical properties without insulation or plastering:

1. U value of 0.76 BTU per sq ft per hr per deg F.

2. Sound transmission class of 45.

3. Fire resistance rating of 1 hr.

4. Average weight of 40 psf.

Structural properties of 4-in. brick walls without reinforcement may be found in *Research Report No 9,* "Compressive, Transverse, and Racking Strength Tests of Four-Inch Brick Walls," SCPI, August' 1965.

DESIGN CONSIDERATIONS

Major factors to be considered in the design of 4-in. curtain or panel walls are (1) Structural, (2) Moisture Control, (3) Differential Movement, and (4) Special Considerations. The walls presented herein are designed in accordance with the SCPI Standard, *Building Code Requirements for Engineered Brick Masonry, August, 1969,* and the materials used should conform to the requirements for reinforced brick masonry as contained in this Standard.

Structural. Since the 4-in. walls do not meet the requirements specified in the SCPI Standard for reinforced walls, they are designed as "partially reinforced", see Section 4.7.1 1. The horizontal reinforcement in the wall resists the tensile stresses resulting from lateral pressures as the wall spans horizontally between structural elements such as columns, pilasters or cross walls.

Since the lateral load due to wind can be either pressure or suction, the wall must be designed to resist the assumed lateral load acting in either direction. The maximum moment in the wall is used to calculate the required area of reinforcement, and to provide for stress reversals. This area of reinforcement is required in each wall face. It is recommended that the maximum area of reinforcement be provided throughout the length of the wall. This arrangement will provide more reinforcement than needed in portions of the wall near supports where the moment is less than maximum. However, the savings in fabrication and placement time will, in most cases, offset the added expense of the excess steel. Steel reinforcement should be lapped a minimum of 16 in. to insure the development of the tensile stresses without exceeding the allowable bond stresses. Bond and shear stresses should also be checked at points of maximum shear which would normally occur at the supports.

However, due to the large span-to-depth ratios employed, the bending stresses usually govern.

Where openings such as windows or doors occur, the effective section of the wall is, of course, reduced. This reduced section will affect not only the required area of reinforcement and strength of masonry but by reducing the stiffness of the wall will also affect the distribution of lateral loads in continuous walls. Since the tables contained herein are based on solid walls, walls with openings must be investigated by the designer.

Figure 3 shows a typical application of a 4-in. curtain wall under construction. Care must be taken to assure proper placement of the reinforcement during construction. The bars may be spread apart or pushed together as successive brick are laid and pressed into position. Ladder or truss-type joint reinforcement provides two longitudinal bars connected by cross wires, thus aiding proper positioning and reducing the time and effort involved in placement.

Care should be taken by the mason to insure that the reinforcement has mortar coverage both top and bottom as well as proper horizontal placement within the wall. The reinforcement should not be laid directly on top of the brick. Proper vertical placement can be attained by supporting reinforcement wires on small pads of mortar placed prior to full bedjoint mortar placement.

The proposed usage of the building will determine the permissible deflection for the 4-in. brick wall. For the loads and spans presented in Table 2, the maximum calculated horizontal deflection is on the order of L/200 for simply supported walls. The actual maximum deflection will generally be less due to the restraint which may exist at the top and bottom of the wall.

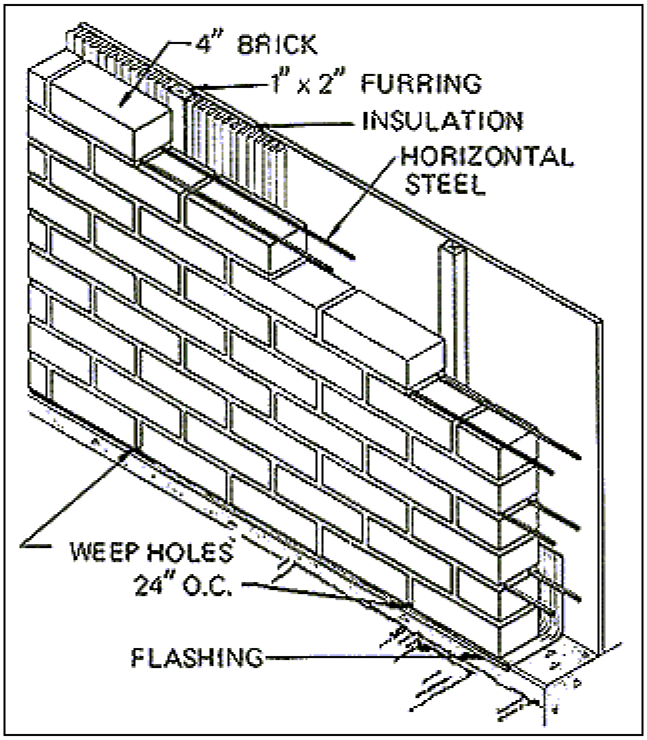
The general formula for the maximum deflection due to a uniformly distributed load on a simply supported beam is:

$$\Delta\ max = \frac{5wL^4}{384EI}$$

FIG. 3

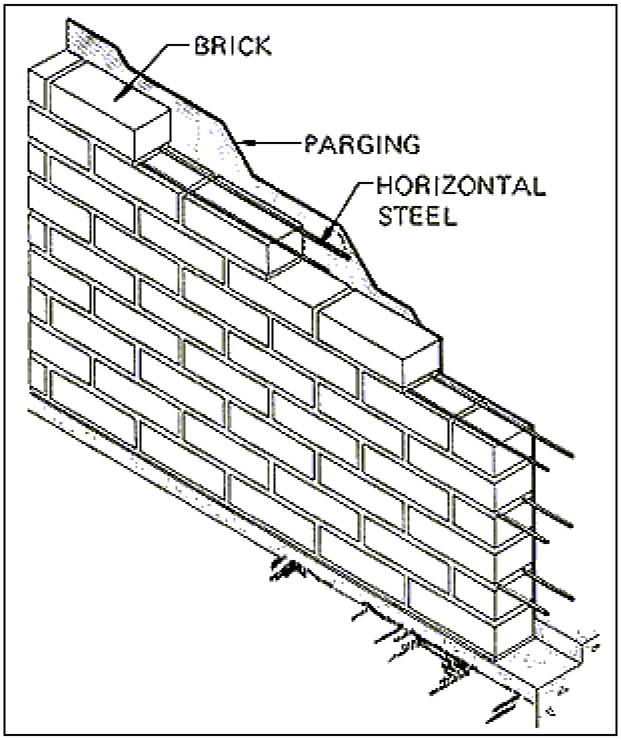
The "Progress Report of the ASCE on Reinforced Masonry Design and Practice", *Journal of the Structural Division, Proceedings of the ASCE,* Vol. 87, No. ST8, December, 1961, contains the following recommendation: "When checking for deflection, it is recommended that the moment of inertia of the masonry cross section be computed neglecting the effect of the reinforcement, and then use the standard deflection formulae for flexural members "

Moisture Control. The control of moisture through the 4-in. wall should be considered by the designer. Heavy rains driven by high winds may result in water penetrating the wall. If this is objectionable, one method of handling the problem is to provide drainage space on the inside of the wall to permit the water to flow to the flashing at the base and to be conducted back to the outside through weep holes. Drainage wall types (Fig. 4) employ this principle. A second method is to provide a water barrier (parging) to the inside of the wall. Barrier wall types (Fig. 5) employ this principle. It is recommended that, where a maximum resistance to rain penetration is desired in areas of severe exposure, drainage wall type designs be used. Barrier wall types may be sufficient in areas of moderate exposure.



Drainage Type Wall

FIG. 4

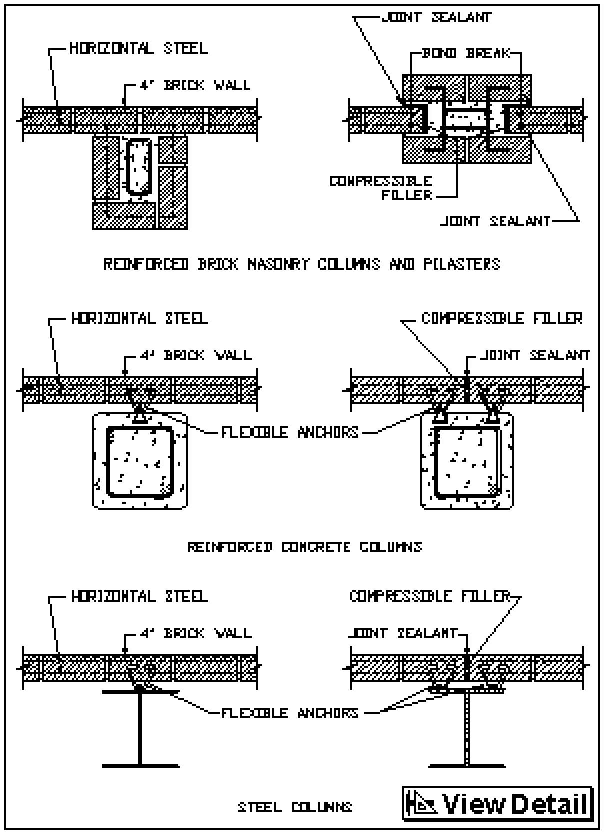


Barrier Type Wall

FIG. 5

Differential Movement. When masonry walls are used to enclose a structural frame building, consideration must be given to the method of anchoring the walls to the framing elements in a manner which will permit each to move relative to the other. The frame and the enclosing walls differ in their reactions to moisture in the magnitude of thermal movements. These and other causes for differential movement are discussed in greater detail in *Technical Notes* 18.

No single recommendation on the positioning and spacing of expansion joints can be applicable to all structures. Each building design should be analyzed to determine the potential movements and provisions should be made to relieve excessive stress which might be expected to result from such movement. Generally, expansion joints may be located at or near corners, offsets, junctures and openings. Since 4-in. walls are considered to span horizontally, expansion joints where required must be located at vertical supports. The maximum recommended spacing for expansion joints for these 4-in. walls is 100 ft for a straight wall without openings. However, conditions may require expansion joints as close together as 40 ft. Typical 4-in. wall details relating to expansion joints and methods of anchoring are shown in Fig. 6. Table 1 presents the maximum vertical spacing of No. 6 gage, galvanized wire anchors at the wall-to-support connections. The load distribution per anchor was assumed to be 600 lb. Maximum spacing was limited to 24 in.



Typical Four Inch Wall Details

FIG. 6

TABLE 1
Maximum Vertical Spacing of Wall Anchors (Inch)[a][b][c][d]

Wind Pressure psf	Horizontal Wall Span (ft)								
	10	12	14	16	18	20	22	24	26
15	24	24	24	24	24	24	22	20	18
20	24	24	24	22	20	18	16	15	
25	24	24	20	18	16	14			
30	24	20	17	15	13				

(a) No. 6 gage galvanized wire anchors.

(b) Load distribution assumed to be 600 lb per anchor

(c) Maximum vertical spacing limited to 24 in.

(d) Spacing is for an interior support of a continuous wall. Spacing at an end support is 24 in.

Special Considerations. There are special design possibilities which the designer of structures incorporating 4-in. reinforced walls may desire to consider. One such consideration is to design the wall as a plate supported on three or four sides. Another consideration is to utilize the loadbearing capabilities of the 4-in. wall. The SCPI Standard may be used to design the wall to carry vertical loads in addition to lateral loads.

The reinforced wall itself may be considered to act as a lintel over openings in the wall such as provided for windows and doors. The wall reinforcement should be checked to determine if it is adequate for the particular opening. Where the normal wall reinforcement is insufficient, supplemental steel should be added. Assuming a lintel to carry only the dead load of the wall for a height equal to one-half the opening span, a 4-in. brick masonry lintel, with an ultimate strength (f'_m) of 2200 psi, an effective depth of 36 in. and two No 2 bars, will span an opening of 12 ft 6 in. This is neglecting other reinforcement which is in the wall above the opening. Therefore, depending on the actual wall and opening layout, wider openings may be spanned. *Technical Notes* 17B provides additional information on reinforced brick masonry lintels.

DESIGN TABLES

Design Assumptions. As presented herein, the 4-in. curtain wall is analogous to a one-way reinforced slab. In preparing the tables, a width of cross section "b" of 12 in. was selected. The effective depth "d" was assumed as 2 3/4 in. (Fig. 7). This dimension is based on the minimum thickness for a 4-in. nominal wall (3 1/2 in.) and the requirement by the SCPI Standard for shut-in. mortar coverage for bars or wire to in. or less in diameter embedded in the horizontal mortar joints. In order for the effective depth assumptions to remain as stated, raked joints could not be used. If raked joints are desired on 4-in. reinforced curtain walls, the effective depth must be reduced by the amount of raking of the joint and steel must be placed to maintain a minimum 5/8-in. coverage. It is not recommended that raked joints be used on 4-in. curtain walls for the above reason. Additional assumptions are as follows:

1. For stresses due to wind, the allowable stresses in brick masonry and reinforcing steel are increased by 1/3.

2. A brick masonry compressive strength (f'_m) of 2200 psi resulting in an allowable brick masonry stress (f_m) equal to 0.32 (f'_m) (1.33) or 936 psi.

3. An allowable steel stress (f_s) equal to 20,000 (1.33) or 26,600 psi.

4. Only type M or type S portland cement-lime mortars are to be used.

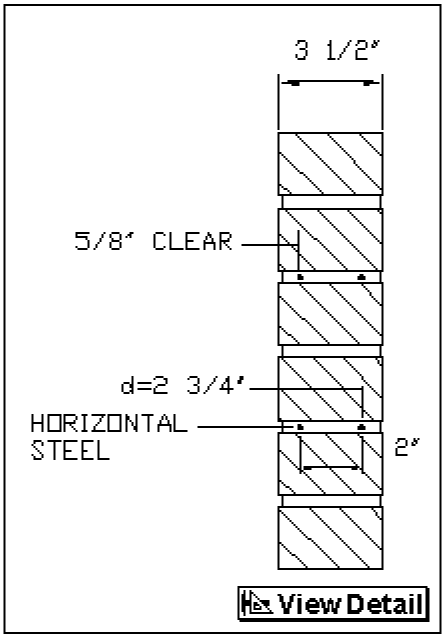
5. Architectural or engineering inspection is provided during construction. A 1/3 reduction in the allowable stresses is required if this inspection is not provided.

6. In a simple span or two continuous spans, the maximum shear is equal to 0.625 wL and the maximum moment is equal to 0.125 wL^2.

7. In three or more continuous spans, the maximum shear is equal to 0.60 wL and the maximum moment is equal to 0.10 wL^2.

8. Coursing is assumed to be three brick masonry courses per 8 in. of wall height.

9. Four-inch walls are solid without openings.



Section Through Four Inch Brick Wall

FIG. 7

Use of Tables. Table 2 provides the reinforcement requirements for various support conditions, span lengths and wind pressures. The steel areas tabulated are for one face of the wall. An equal amount must be provided in the opposite face. It should be noted that an expansion joint interrupts the continuity of the wall. The condition at the joint will therefore be one of simple support.

TABLE 2
Required Area of Reinforcement Per Vertical Foot For Each Face of Wall (Square Inch Per Foot)[a]

Span (ft)	Simple Span or Two Continuous Spans - Wind Pressure (psf) 15	20	25	30	Three or More Continuous Spans - Wind Pressure (psf) 15	20	25	30
10	0.035	0.047	0.059	0.070	0.028	0.038	0.047	0.056
12	0.051	0.068	0.084	0.101	0.041	0.054	0.068	0.081
14	0.069	0.092	0.115	0.138	0.055	0.074	0.092	0.110
16	0.090	0.120	0.150	0.180	0.072	0.096	0.120	0.144
18	0.114	0.152	0.190		0.091	0.122	0.152	0.182
20	0.141	0.188			0.113	0.150	0.188	
22	0.170				0.136	0.182		
24	0.203				0.162	0.216		
26					0.190			

(a) See Design Assumptions

Table 3 gives the area of reinforcement as provided by various steel sizes and vertical spacings for one wall face. After the required area is selected from Table 2, the bar size and spacing which provides an area of reinforcement equal to or greater than what is required may be selected from Table 3.

TABLE 3
Area of Reinforcement Per Face of Wall
(Square Inches Per Vertical Foot)[(a)]

Reinforcement Per Face	Spacing of Reinforcement							
	Every Course	Every 2nd Course	Every 3rd Course	Every 4th Course	Every 5th Course	Every 6th Course	Every 7th Course	Every 8th Course
1 - # 2 bar	0.225	0.112	0.075	0.056	0.045	0.037	0.032	0.028
1 - 3/16-in. wire	0.124	0.062	0.041	0.031				
1 - # 9 gage wire	0.077	0.039	0.026					

(a) Based upon three brick courses per 8 in. of height.

In conjunction with the use of Table 2, a minimum value of 2200 psi for the compressive strength of brick masonry (f'_m) is required. Lesser values of f'_m may be employed if the designer calculates the actual strength of masonry required by his design. Table 4 can be used in selecting unit strength and mortar type as determined by the calculated stresses

TABLE 4
Assumed Compressive Strength of Brick Masonry [(a)]

Compressive Strength of Units, psi	Assumed Compressive Strength[(b)] of Brick Masonry, f'_m, psi	
	Type M Mortar	Type S Mortar
14,000 plus	4600	3900
12,000	4000	3400
10,000	3400	2900
8,000	2800	2400
6,000	2200	1900
4,000	1600	1400
2,000	1000	900

(a) Taken from Table 2, Building Code Requirements for Engineered Brick Masonry, SCPI (BIA), August, 1969.

(b) See Design Assumptions.

Design Example

Given: Three continuous 20-ft spans

Wind = 25 psf

f'_m = 2200 psi

$f_m = 0.32(f'_m)(1.33) = 936$ psi

$f_s = 20{,}000(1.33) = 26{,}600$ psi

$$V_m = 0.70\sqrt{f'm}(1.33) = 44 psi$$

Required: A_s

1. Design by calculation:

$V_{(max)}$ 0.60 wL = 0.60(25)(20) = 300 lb

$M_{(max)}$ 0.10 wL^2 = 0.10(25)$(20)^2$ = 12,000 in. -lb

$$A_s = \frac{M}{f_s jd} = \frac{12{,}000}{26{,}600(7/8)(2.75)} = 0.1875 sq\ in.$$

Select one No. 2 bar (each face, every course):

A_s (each face) = 0.225 sq in. (Table 3)

$$p = \frac{A_s}{bd} = \frac{0.225}{12(2.75)} = 0.0068\ sq\ in.$$

$$E_m = 1000f'm = 2.2(10^6) sq\ in.$$

$$n = \frac{E_s}{E_m} = \frac{29(10^6)}{2.2(10^6)} = 13.2\ sq\ in.$$

$$\begin{aligned} k &= -pn + \sqrt{2pn + (pn)^2} \\ &= -0.090 + \sqrt{0.180 + 0.008} \\ &= -0.090 + 0.434 = 0.344 \end{aligned}$$

$$j = 1 - k/3 = 1 - 0.115 = 0.885$$

Check masonry stress (f_m):

$$f_m = \frac{2M}{jkbd^2} = \frac{2(12{,}000)}{0.885(0.344)(12)(2.75)^2} = 870 psi < 936 psi,\quad ok.$$

Check steel stress (f_s):

$$f_s = \frac{M}{A_s jd} = \frac{12,000}{0.225(0.885)(2.75)} = 22,000\,psi < 26,6000\,psi, \quad ok.$$

Check shear at interior support:

$$v = \frac{V}{bd} = \frac{300}{12(2.75)} = 9.1\,psi < 33(1.33)\,psi, \quad ok.$$

Check bond:

$$\sum_o = 4\frac{1}{2}(0.786) = 3.54\ in.$$

$$u = \frac{V}{\sum_o jd} = \frac{300}{3.54(0.0885)(2.75)} = 35\,psi < 80(1.33)\,psi, \quad ok.$$

2. Selection from Table 2:

$A_s = 0.188\ in.^2$ per face

Selection from Table 3:

One No. 2 bar in each wall face every course.