

## V-9. Masonry Curtain Walls on Tall Buildings

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### ABSTRACT

*Masonry curtain wall on tall buildings must be designed to resist wind load and differential movement in order to perform properly. Anchored veneer walls are explained. Design considerations include wind load transfer and reactions, support of the wall, differential movement and resistance to water penetration. Flexible anchorage of the veneer to its back-up is necessary. Recommended spacing of veneer ties is given. Steel stud back-up should match the flexural rigidity of the veneer. Allowable flexural tensile stresses for masonry walls are tabulated. Veneer ties and flexible anchors are shown. Shelf angles used to support the outer wythe must be adjusted as the masonry is placed, with a soft joint under the shelf angle. Differential movement from material properties, loads and temperature variations requires flexible connections to the frame. Expansion joint location and spacing is explained. Filled mortar joints with a tooled finish aid in water penetration resistance. Flashing and weep holes are required to prevent water from entering the building.*

The advantages of unit masonry construction have contributed to its use as a facing material as its importance as a load bearing material declined with the advent of frame structures. Recent studies have proven the economic benefits of masonry curtain walls<sup>9</sup>. Although a prime element in the appearance of the building, the design and detailing of a masonry curtain wall is often neglected by both the engineer and architect<sup>12,14</sup>. There is a need for education of architects and engineers in the design and use of this construction. Considerations must be given to the properties and type of the masonry unit and mortar, back-up material and the structural frame<sup>12,14,16</sup>.

### WALL TYPES

#### Curtain Walls

Curtain walls are generally accepted as carrying no loads other than their own weight. They must be designed to withstand wind load perpendicular to the plane of the wall and transfer the reactions to the structural frame. The wall is supported at regular intervals along the height of the structure on buildings over 100 ft. (30.5m)<sup>8</sup>.

Two types of walls with a masonry exterior are built to enclose tall buildings. Each is further subdivided. Figure 1 shows the most prevalent types.

#### Veneer Walls

These walls consist of a masonry facing or veneer, usually brick, attached to a back-up material of masonry, reinforced concrete or steel stud construction. Several methods are used to anchor the veneer to the back-up, each incorporates a flexible metal tie treated for corrosion resistance. A 1 in. (25.4mm) air space is detailed between the inside surface of the veneer and the outside of the sheathing or continuous back-up<sup>3</sup>.

#### Masonry Walls

The second construction is all masonry with one or more wythes acting together to resist the wind load. A variety of wall types are available and this may lead to

some confusion. The following methods for construction of masonry walls are available:

1. Single wythe construction of plain or reinforced masonry.
2. Cavity walls—Two or more wythes of masonry are bonded together by corrosion resistant metal ties and separated by a continuous air space, usually 2 in. (50.8mm) to 4½ in. (114mm) wide. The air space can be left open or filled with insulation. The metal ties are either individual steel wire ties or continuous joint reinforcement. Model building standards detail the size and spacing of the ties<sup>1,4,5</sup>. Several excellent papers on the properties and use of cavity walls are available<sup>2,6,13</sup>. Masonry bonded cavity walls, once popular, are no longer recommended for use on tall buildings.
3. Metal tied, solid walls—Two or more wythes of masonry are tied together by corrosion resistant ties and have the longitudinal vertical joint between them filled with mortar or grout. The metal tie requirements are the same in most standards as for cavity walls<sup>1,4,5</sup>. The joint between wythes is often reduced to ¾ in. (19.0mm). Different types of masonry units are often used for different wythes.

### DESIGN CONSIDERATIONS

There are four areas of concern for the designer when considering masonry curtain walls on tall buildings:

1. providing lateral load resistance,
2. supporting the weight of the wall,
3. differential movement between the curtain wall and frame,
4. maintaining a dry interior.

Some questions may best be solved by the architect, others by the engineer, but all must be considered.

#### Lateral Load Resistance, Veneer Walls

In order to resist wind pressure, the veneer must span between the wall ties and resist the resulting bending moment by the flexural tensile stress. Calculations show

that a tie spacing of 24 in. (610mm) with a 3 in. (76.2mm) thick brick and a 40 psf (1916 N/m<sup>2</sup>) wind load results in a flexural tensile stress of 10.7 psi (73.6 N/m<sup>2</sup>), well under the recommended allowable. Thus, mortar type can be selected on the basis of economy and Type N, American Society for Testing and Materials (ASTM) C270, Specification for Mortar for Unit Masonry, is recommended. In areas of high wind and on cavity walls, Type S mortar should be used.

The wind load is transferred to the back-up through metal ties. Since the only vertical load the masonry veneer should resist is its own weight, a flexible tie is required. Such a tie transfers only direct tension and compression, not shear or flexure. This permits differential movement between the veneer and the back-up. A wide variety of metal ties exist, several styles are depicted in Figure 2<sup>3,11</sup>. Each should be treated for corrosion resistance and have at least a 2 in. (51mm) embedment in the mortar.

The choice of the tie will depend on the combination of masonry unit size and the type of back-up. Rectangular or Z ties of 9 gage wire or joint reinforcement with tab ties are often used with masonry back-up if the bed joints align. Adjustable metal ties are also used with masonry back-up when the bed joints do not occur at the same height. Dovetail anchors with corrugated extensions are used with concrete back-up walls. These are 16 gage minimum, 1 in. (25.4mm) wide. When masonry veneer is attached to steel studs, metal wire ties should be used. The wire should be 9 gage and the ties attached to the stud with sheet metal screws.

Current recommendations for tie spacing for brick veneer on high-rise buildings, regardless of the type of tie or back-up are<sup>3</sup>:

- 1 tie for each 2½ sq. ft. (0.25 sq.m),
- 24 in. (0.6m) maximum spacing, vertical or horizontal.

The vertical spacing of ties near the floor/frame location must be carefully noted. It is easy to exceed the maximum spacing since the back-up material is not continuous. Any cantilevered section of veneer should be kept to a minimum length.

The back-up material in combination with the veneer must resist the wind load. Steel studs with sheathing applied to both surfaces are often used as back-up. Unfortunately, most stud manufacturer's recommendations for stud size and spacing are based solely on steel stress and stud buckling. Since the masonry veneer is much more rigid than the studs the brick veneer carries the majority of the load until cracks develop in the bed joints. Limiting the deflection of the studs to a maximum of the span length divided by 600 will reduce this problem.

Walls with masonry back-up resist the wind load by flexural tensile stress in the masonry. Normally built of light-weight concrete masonry units, the allowable stresses for the various mortar types are found in building standards<sup>4,5</sup>. Table 1 summarizes these values. Most engineers are familiar with the design process for reinforced concrete. Dovetail slots are cast into concrete in vertical lines to provide flexible attachment of the veneer.

## Lateral Load Resistance, Masonry Walls

Wind loads are resisted by either flexural tensile stress in the masonry or reinforcing steel grouted into the wall. Table 1 summarizes the allowable flexural tensile stresses for commonly used masonry and mortar combinations<sup>4,5</sup>. Although empirical requirements exist for the design of non-loadbearing masonry walls they are not recommended for use on tall buildings.

Reinforced masonry walls are designed by the pertinent building code:

- Reference (5) for reinforced solid brick,
- Reference (1) for reinforced hollow brick,
- Reference (4) for reinforced concrete masonry.

The provisions for partially reinforced masonry in each of these codes provide the most economical design since there is no minimum amount of steel required.

## Lateral Load Resistance, Reactions

The reactions from wind load must be transferred to the structural frame. In most highrise construction the column spacing is sufficiently greater than the floor to floor height so the masonry will span in this shorter direction. Thus, anchorage at the floor and spandrel beam will be required. Anchorage to the column will not be necessary unless a plate analysis is used.

When the back-up material or at least one wythe of masonry is built on the floor there is sufficient friction between the floor slab and masonry to provide load transfer. Metal studs are anchored in a special runner which is normally screwed to the floor and spandrel beam. These attachments must be sufficient to resist the horizontal reaction.

The curtain wall must also be anchored at the top. Many walls are detailed with the interior wythe of masonry laid tight under the spandrel beam, a mortar joint between the top of the last course and the bottom of the beam<sup>7</sup>. Others indicate a soft joint at this location<sup>2,8</sup>. Clay masonry products increase in size due to long term moisture expansion. Concrete masonry units shrink. Steel frames are more dimensionally stable than concrete which shrink and creep under load. Both types of frames undergo elastic deformation. Thus, soft joints are best and should be used between the top of masonry walls and the structural frame. Dovetail slots on the bottom of concrete beams or floors, with anchors in the head joint, or plates welded to the bottom flange of steel spandrel beams on each side of the interior wythe of masonry will provide lateral resistance while allowing vertical movement.

## Supporting the Wall

In highrise construction the weight of the wall is usually transferred to the structural frame at each floor. In some cases the floor slab is exposed and there is no problem supporting the wall. A continuous skin of masonry or horizontal bands between glazing requires a shelf angle to carry the exterior wythe of brick.



The shelf angle should be designed to resist excessive deflection and rotation due to the weight of the masonry. Deflection should be limited to the distance between supports divided by 600, with a maximum of 1/16 in. (1.6mm)<sup>8</sup>. Deflection and rotation of the spandrel beam which ultimately carries the weight must also be considered. Kickers or compression struts from the shelf angle to the floor or joists may be required.

Attachment of the shelf angle to the structural frame should allow as much adjustment as possible. This is especially critical when the masonry is continuous from floor to floor and with concrete frames. Differences in frame alignment must be accommodated. Shims between the shelf angle and frame should cover the full height of the angle. The failure to accomplish these items has recently been treated<sup>13,14,15</sup>. Several shelf angle details are shown in Figure 3.

### Differential Movement

The existence of differential movement between the building frame and exterior masonry has been widely recognized<sup>7,8,10,17</sup>. The following factors must be considered:

- elastic deformation,
- shrinkage in concrete and concrete masonry,
- creep,
- thermal movement,
- moisture expansion of clay masonry.

All of these are covered in detail in the previous references. The recommendations of each are:

- flexible anchorage,
- soft joints under shelf angles,
- expansion joints in the outer wythe.

Flexible anchorage, discussed in the section on lateral load resistance of veneer walls, also applies to all connections between the outer wythe of masonry and the building frame. Both tension and compression are resisted while movements in the plane of the wall are permitted. Various combinations of 1/4 in. (6.3mm) rod in loops and hooks, dovetail anchors and notched steel plates are used to fabricate these connections. Examples are depicted in Figure 4.

Soft joints under shelf angles prevent a common occurrence in masonry curtain wall construction, spalling of the unit above and below the shelf angle. An open joint or compressible filler immediately below the shelf angle allows movement. The edge of this joint should be filled with a sealant instead of mortar. The joint thickness should be based on total expected movement from all sources<sup>10,17</sup>.

Expansion joints in brick masonry accommodate thermal movement of the exterior wythe. They are constructed in straight lines with a water stop or compressible filler, and the outer edge filled with a sealant. Mortar is omitted and the width is determined by expected movement and caulking performance. Expansion joints are normally spaced less than 50 ft. (15.2m) apart, at offsets and

junctions in the building and at or near corners. The facade can be broken into discreet rectangular segments which have the same combination of materials and climatological exposure<sup>10</sup>.

### Maintaining a Dry Interior

A single wythe of masonry is not a moisture barrier and provisions must be made to remove water which penetrates the outer wythe of masonry curtain walls. The air space found in veneer and cavity wall construction keeps water from penetrating the entire wall. Waterproof sheathing on metal studs and commercially available "waterproof" coatings on the inner wythe of concrete or masonry back-up can be used. More important is the proper location of flashing and weep holes.

Flashing should be placed on a thin bed of mortar, with another thin bed on top to prevent punctures. There must obviously be a height differential from the outside to inside, with a 4 in. (102mm) minimum. The ends of flashing must be turned up. Weep holes must be located immediately above the flashing, spaced at 24 in. (610mm) intervals, and kept open to function properly. Flashing should be located at the wall base, above shelf angles, at opening sills and heads, projections, recesses, and roof intersections.

Several choices by the designer can greatly reduce problems with water penetration. Adequate bond between the mortar and masonry unit is essential. Many factors influence this property and attention should be paid to absorption of masonry units, mortar ingredients and its water content. Raked joints lead to more problems than concave or V tooled joints. Complete filling of all mortar joints and proper installation of flashing and weep holes is necessary.

### CONCLUSIONS

Masonry curtain walls will continue to be used on tall buildings for economic and esthetic reasons. The design and detailing of these walls should be undertaken with cooperation between the architect and engineer to ensure that all facets are covered. Since various materials are involved the designers should be cognizant of the properties of each.

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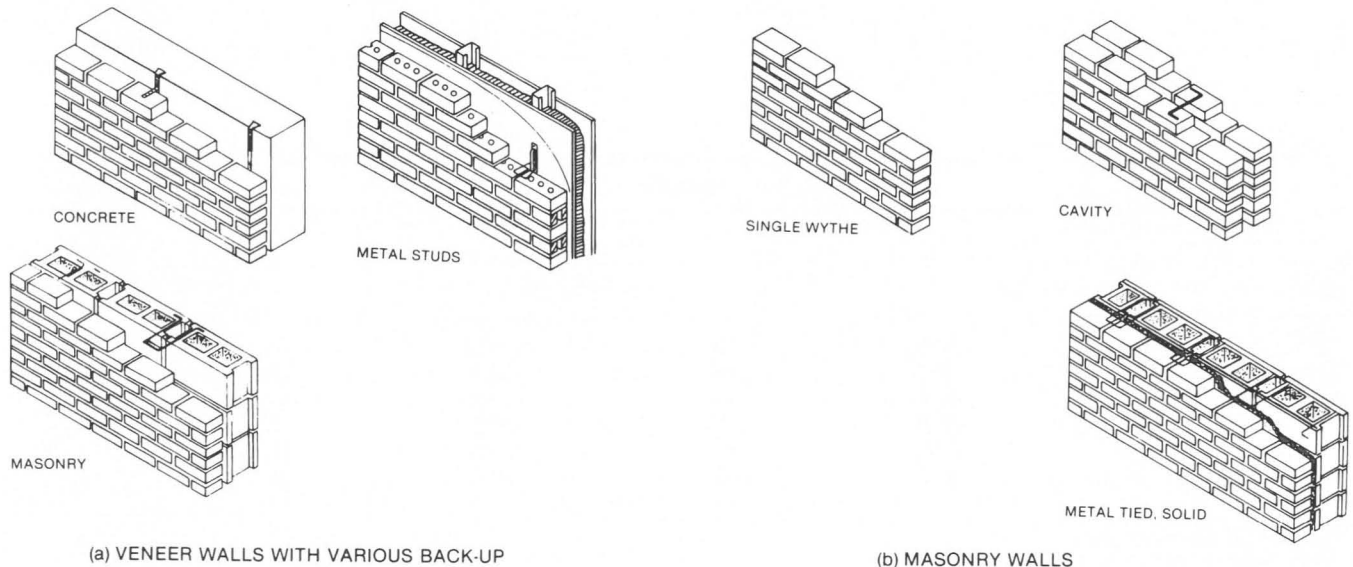


Figure 1. Typical Curtain Wall Construction

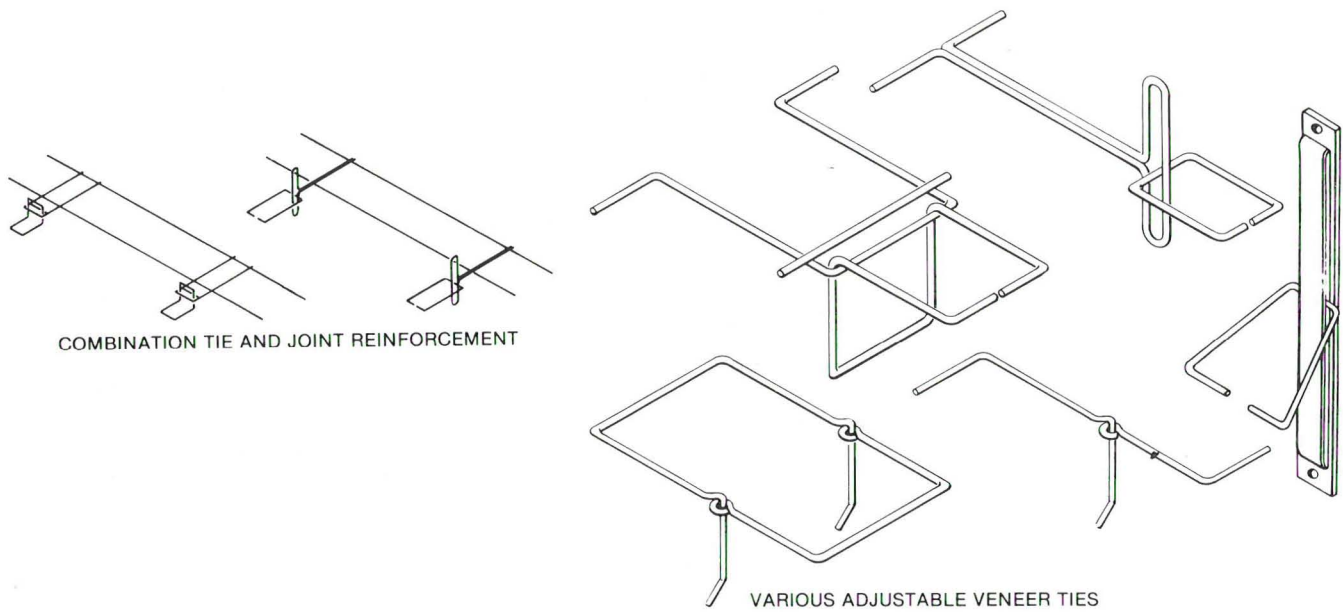


Figure 2. Various Metal Veneer Ties

**TABLE 1—Allowable Flexural Tensile Stress in Masonry, pounds per square inch (newtons per square meter)**

Mortar Type <sup>a</sup>	Masonry Unit					
	Brick <sup>b</sup>		Hollow Concrete <sup>c</sup>		Solid Concrete	
M <sup>d</sup>	36	(248)	23	(159)	39	(269)
M <sup>e</sup>	72	(497)	46	(317)	78	(538)
S <sup>d</sup>	36	(248)	23	(159)	39	(269)
S <sup>e</sup>	72	(497)	46	(317)	78	(538)
N <sup>d</sup>	28	(193)	16	(110)	27	(186)
N <sup>e</sup>	56	(386)	32	(221)	54	(373)

a. ASTM C270, by proportions

b. With inspection of construction

c. Net area of mortar bed

d. Direction of stress normal to bed joint

e. Direction of stress parallel to bed joint, units in running bond

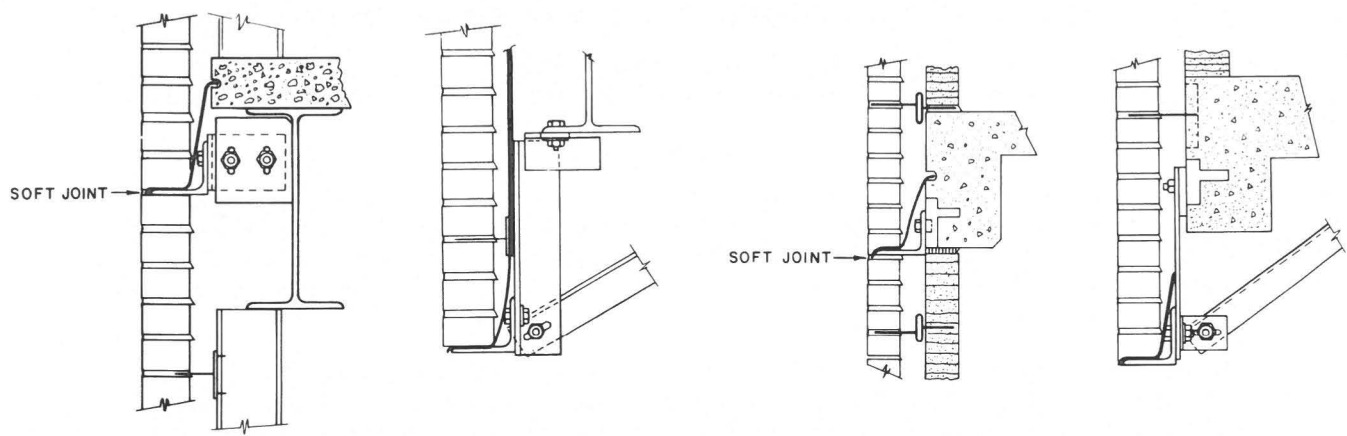


Figure 3. Shelf Angle Details

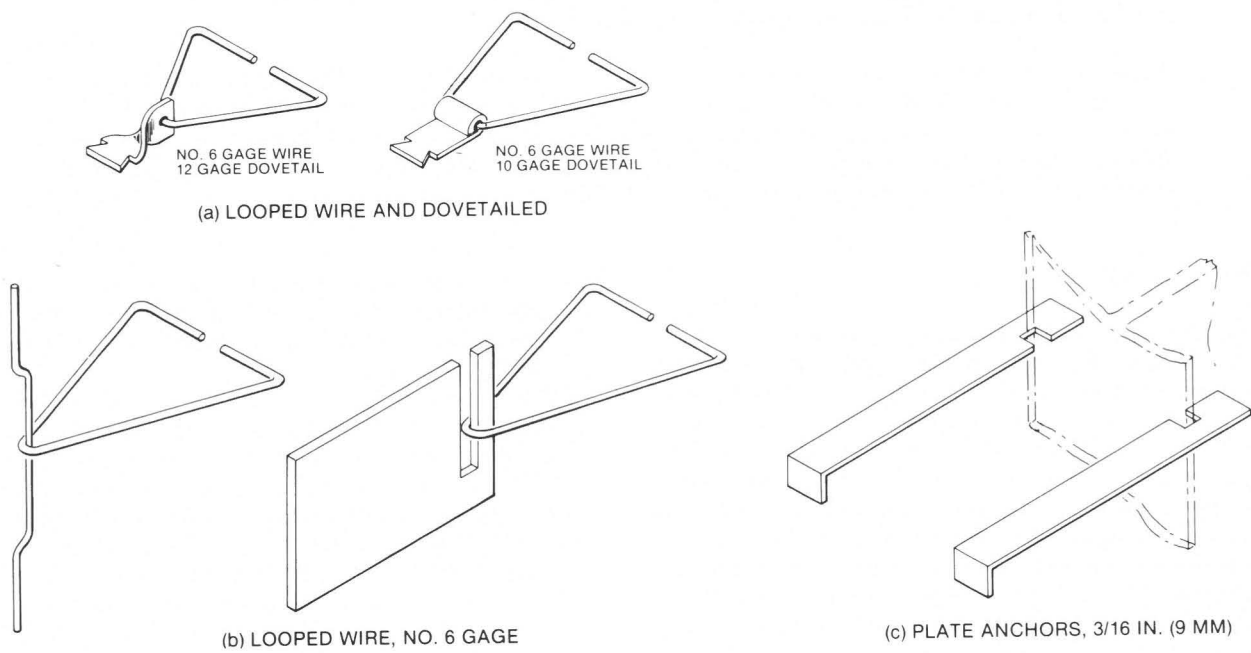


Figure 4. Flexible Metal Anchors