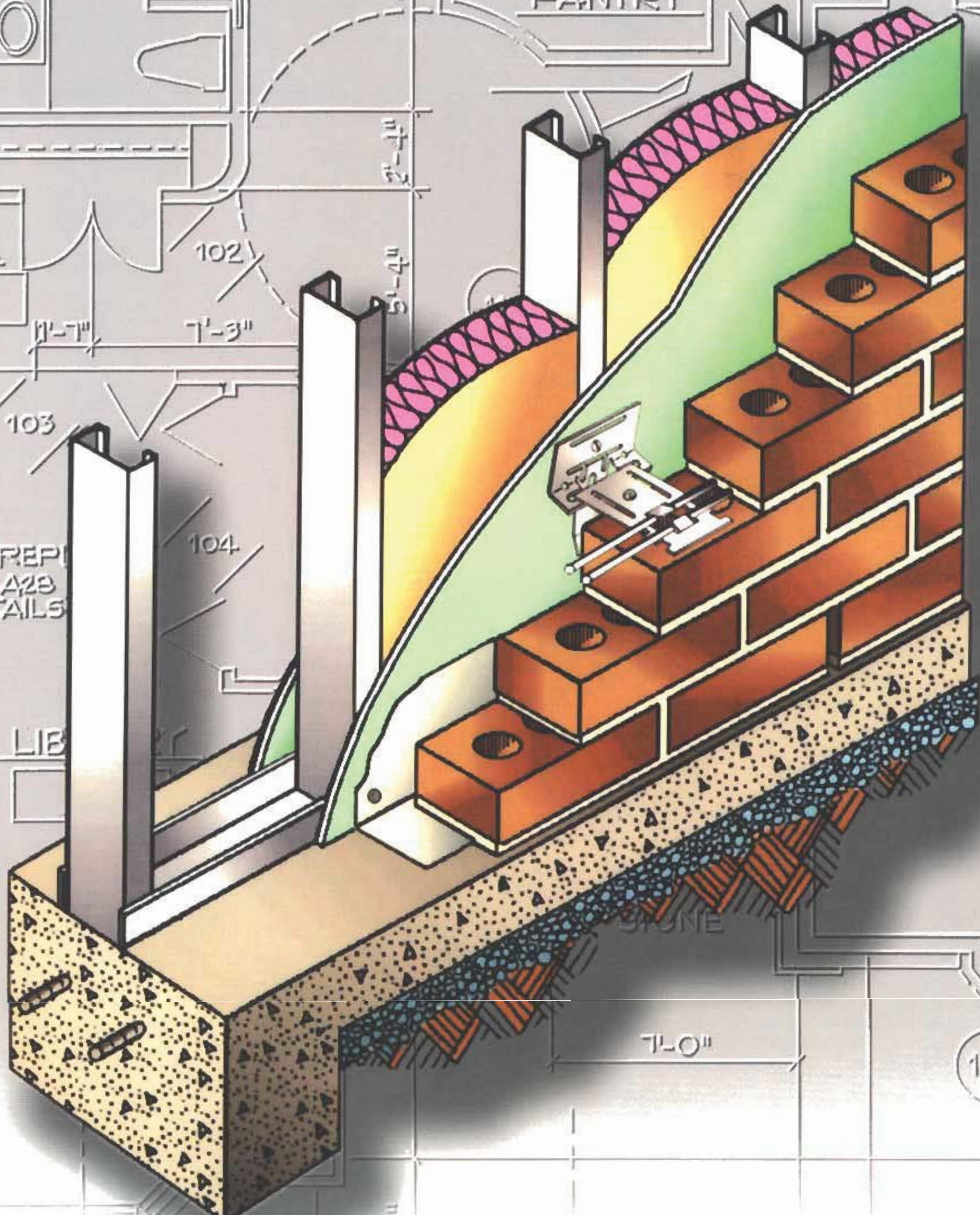
DESIGN GUIDE FOR ANCHORED BRICK VENEER OVER STEEL STUDS



prepared for

Western States Clay Products Association

by

KPFF Consulting Engineers

DESIGN GUIDE FOR ANCHORED BRICK VENEER

OVER STEEL STUD SYSTEMS

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INTRODUCTION

Brick masonry veneer with a steel stud backing was first used in the late 1960's. Since then, the system has proven to be a cost-effective alternative for the more traditional brick veneer with concrete masonry or wood stud backing. Its rapid acceptance, however, has preceded the development of adequate design and construction standards. There are many examples of successful BV/SS projects. Others, however, have not performed to expectations. This BV/SS design guide incorporates what has been learned from an evaluation of past system performances, both good and bad.

Currently, there is no generally accepted single design and construction procedure for brick veneer with a steel stud backing. A recent article warns of an unacceptable risk of failure [1]. Conflicting opinions state that the evolution of the BV/SS system is largely correcting the early problems [2], [3] & [4]. Yet, industry design recommendations are not always consistent[1]. This guide seeks to address these inconsistencies and present a rational procedure for the successful design and construction of BV/SS systems.

Someone experienced with brick masonry or steel stud construction should easily understand this guide. It is an expansion of the prescriptive requirements of the 2003 International Building Code Uniform Building Code, Chapter 14 and the Building Code Requirements for Masonry Structures, (ACI 530-02/ASCE 5-02/TMS 402-02). It begins with a description of the BV/SS system including concepts of exterior walls and their performance, various common wall configurations and a discussion of each wall component. Common design criteria are presented and discussed followed by information on testing and wall construction.

There are two levels of performance presented. The basis for distinguishing between levels is the anticipated system life. The first level, Level 1, is for institutional buildings with a long design life. The second level, Level 2, is for commercial buildings with an average design life.

The reader familiar with BV/SS systems may find that the design recommendations here differ from current practice in some regions. Design and construction practice will vary from location to location and the recommendations contained herein are not intended to transcend local experience and sound engineering judgment.

1.1 PURPOSE

The purpose of this document is to provide the architect, structural engineer and owner with a guide for the design of brick veneer with a steel stud backing.

1.2 BV/SS DEFINITION

The Brick Institute of America defines a veneer wall as:

"A wall having a facing of masonry units, or other weather-resisting, non-combustible materials, securely attached to the backing, but not so bonded as to intentionally exert common action under load"

and:

"A brick veneer wall consists of an exterior wythe of brick isolated from the backup by a minimum prescribed air space and attached to the backup with corrosion-resistant metal ties."

[1] An example is the design deflection limitation on the backing wall. Metal stud manufacturers recommend L/360. The Brick Industry Association recommends L/600

The International Masonry Institute defines a veneer as:

"A single facing wythe of masonry units or similar materials securely attached to a wall for the purpose of providing ornamentation, protection, insulation, etc. but not so bonded or attached as to be considered as exerting common reaction under load."

The 2003 International Building Code, Section 1402 defines a veneer as:

"VENEER. A facing attached to a wall for the purpose of providing ornamentation, protection or insulation, but not counted as adding strength to the wall."

"Anchored Masonry Veneer. Veneer secured with approved mechanical fastener to an approved backing."

When the facing is brick and the backing is steel studs, the veneer is classified as brick masonry veneer with a steel stud backing, (BV/SS). Figure 1.1 shows a typical brick veneer on steel stud installation.

Normally, the ties of the veneer are flexible for in-plane horizontal and vertical movement and rigid perpendicular to the wall face. Thus, the veneer and the backing are isolated and do not behave identically under load ("exert common action under load"). While the displacements perpendicular to the wall are typically the same (stiff axial tie), the vertical flexibility provided by the tie allows for differences in the response to vertical loading.

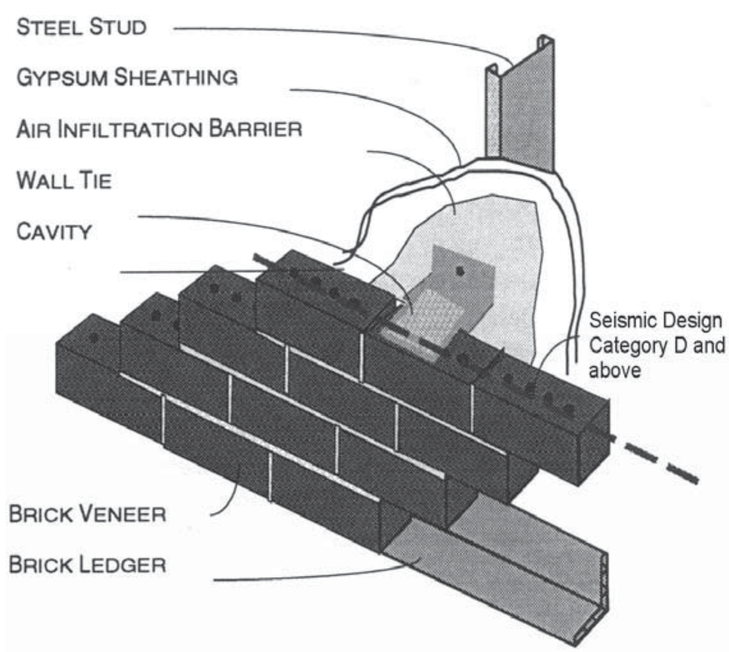


Figure 1-1 The Brick Veneer Over Steel Stud System

1.3 BV/SS ALTERNATIVES

Before selecting the BV/SS system, the designer should consider other alternatives. One often-overlooked alternative is “load bearing brick” systems consisting of reinforced hollow structural brick. These systems have proven to have high load capacity and often are more economical than separate steel or concrete load bearing with brick veneer infill. Many one-story schools have been constructed using load-bearing brick walls [5].

Another system is called structural brick veneer; see the “Design Guide for Structural Brick Veneer” [6]. This is a combination of the veneer concepts to be described in this document and structural brick described in "Notes on the Selection, Design and Construction of Reinforced Hollow Clay Masonry" [5]. The structural brick veneer system may have significant advantages where geometry of the wall is complex and speed of construction is an important part of the decision criteria. Structural brick veneer systems can also be panelized and installed in a manner similar to precast concrete walls.

BV/SS with rigid shear ties [7], or a grouted cavity have also been successfully used. The design of these systems is beyond the scope of this guide.

2.0 SYSTEM DEFINITION

2.1 CONCEPT

The design of the BV/SS system is developed around several basic performance assumptions. These assumptions are as follows:

1. Brick veneer is nonstructural.

2. Brick veneer will be allowed to crack under service wind and seismic loading. Crack widths will be controlled to between 0.02 and 0.04 inches by limiting steel stud deflections to L/360 for service loads.

3. The BV/SS system provides two planes of weather protection to accomplish the code service requirements.

4. The exterior brick veneer acts as the primary barrier (open rain screen).

5. The interior flashed cavity acts as the secondary barrier (drainage wall) for weather resistance.

6. Tie forces are computed for three conditions and designed for the maximum lateral force.

   Uncracked brick veneer, with brick veneer and steel studs sharing lateral load.

   Cracked brick veneer, with steel studs supporting all lateral load.

   Ties support an ultimate tributary lateral load of two times the brick veneer weight.

7. The steel stud backing is designed to support full lateral load.

2.1.1 Nonstructural

The BV/SS system is nonstructural. The term nonstructural characterizes the BV/SS system as isolated from the building structural frame and secondary members. This means that the veneer does not support the building or provide any assistance to the stability of the building as a whole. It carries no load other than itself.

Complete isolation is difficult to obtain. Buildings move. They move due to the effects of gravity, heating and cooling, moisture and wind or seismic loading. When a building moves, the nonstructural veneer must not become locked between building elements. Inadequate attention to the design or construction details for the isolation of the system from the rest of the building is a common cause for unacceptable performance.

Brick veneer and its connections must be of sufficient strength to transfer wind, earthquake, and dead loads to the structural frame. The masonry wythe must have sufficient flexural strength to transfer lateral loads to the wall ties. As the tie spacing increases, the strength of the masonry needs to increase. The ties must be of sufficient strength to transfer lateral load to the backing, which in turn, transfers lateral load to the building structural frame. The dead load of the veneer must be transferred within the masonry wythe to the ledger or foundation support. The ledger and its supports must be of sufficient strength to transfer the dead load to the building structural frame or foundation.

2.1.2 Design for Leakage

It should be assumed that all masonry might leak and allow water to penetrate. Masonry leaks more through the mortar and brick interface than through the masonry unit itself. If the mortar and brick interface is cracked, leakage may increase. After the masonry has cracked, the flexibility of the structural backing is the primary determinant of the crack size.

The most common design question asked about the BV/SS system is "What deflection limitation applies to the steel studs?" Various recommendations are available ranging between L/175 and L/2000[2].

The answer to this key question depends upon how much leakage the system can handle and at what point the cracking becomes aesthetically objectionable.

The answer depends on many factors:

1. Building location (regional or local weather).
2. Amount of corrosion protection provided.
3. Design life of the building.
4. Design of the air barrier (Rainscreen).
5. Tensile strength of the masonry.
6. Flashing system.
7. Stiffness of the building frame.
8. Quality of the masonry and workmanship.
9. The building maintenance program to be used.

Many of these factors and others will be discussed in this design guide.

In the absence of extra ordinary emphasis on performance, the deflection limit of L/360 is recommended. This limitation was chosen to limit brick veneer crack widths to between 0.02 to 0.04 inches (0.50mm to 1.0mm) [8]. This relationship is arrived at strictly from a geometric perspective. A deflection limit of L/360 for 3 5/8 inch thick brick will result in an outside crack width of 0.04028 inches. This crack width will be smaller with decreasing brick thickness and correspondingly larger with increasing brick thickness. The crack width at the center of the brick veneer will be one-half these values. This is illustrated in Figure 2.1.

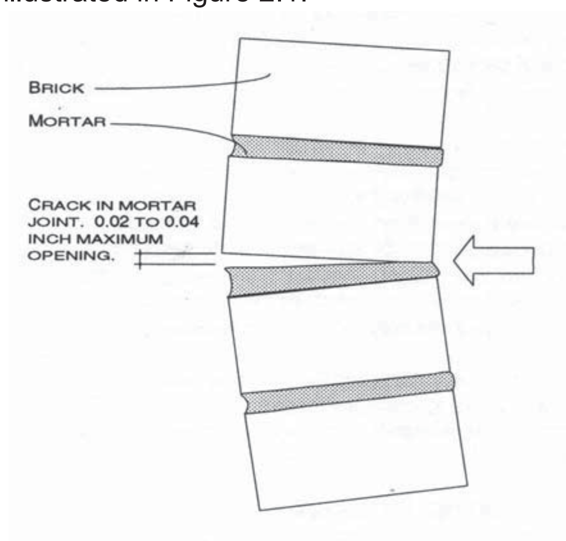


Figure 2-1 Illustration of Cracked Brick Veneer

[2] L/175 is a typical value for non-masonry exterior envelope design. L/2000 is generally believed to be of sufficient stiffness to prevent cracking of the veneer at service load

The wind or earthquake loading at which cracking occurs is instantaneous and reversible. When the loading is removed, the cracks will close and will not likely be visually discernable.

2.1.3 Rainscreen

The BV/SS system performance depends to a large extent on the prevention of water leakage through the system. Preventing leakage of the BV/SS system is basically the same as for other curtain wall systems.

Leakage occurs because of the presence of rainwater on the wall. Rain flows in sheets in all directions, concentrating at discontinuities such as joints. Lateral movement is greatest near the windward corners. Movement upward is greatest near the top of the building. With taller buildings there is a greater accumulation of rainwater flow, with flow concentrating at surface irregularities. Greater distances between irregularities will result in larger flows.

Figure 2.2 diagrams the six forces known to move water through openings. Each of these forces needs to be considered in the design of the BV/SS system.

The control of the gravity force can be accomplished by proper flashing or other means to avoid water penetration downward. It is also good practice to eliminate horizontal surfaces (such as sills, raked joints, and ledgers) where water can accumulate and pond.

Kinetic energy (motion) can be controlled by the elimination of any direct path into the area to be kept dry. When a path exists, such as a weep hole, sufficient extension of the vertical flashing needs to be provided to dissipate the kinetic energy with gravity.

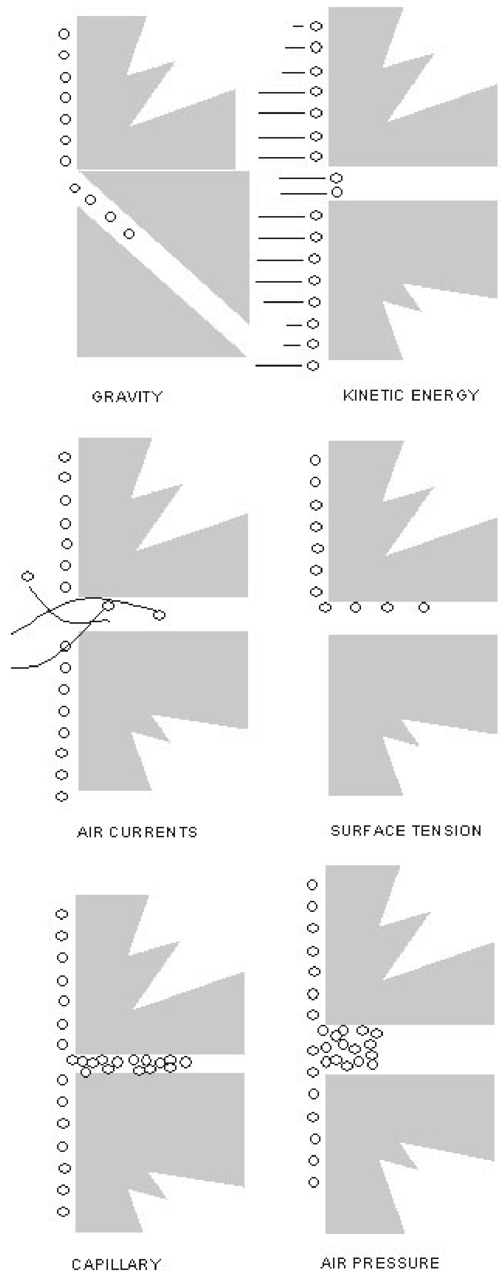


Figure 2-2 Forces Acting to Move Water Through an Opening

The movement of water by surface tension is normally controlled with drips.

Capillary action occurs when a space separating two wetted surfaces is small, such as a crack between the brick and mortar. To eliminate water movement by capillary action an air gap, such as the cavity behind the wythe of brick, is introduced as a stop to prevent water from migrating into the building.

Air currents and differential pressure are the two forces that typically cause most water intrusion problems. They are also the forces that can be controlled by the rainscreen or pressure equalization concept.

The rainscreen is the outer skin or surface of the wall or element that is exposed to the weather. The term screen is used since the outer skin itself is assumed to have openings. In the BV/SS case, the outer screen is the brick wythe. The weep holes at the base of the wall and vents at the top of the wall all help to allow for cavity pressure equalization. In order to have pressure equalization, an inner air barrier is also required. The inner air barrier does not need to be perfect. Precise values are not available, but it is generally accepted that a ten-to-one ratio between the rainscreen openings and the openings in the air barrier provides satisfactory results. For all practical purposes, this means that in the BV/SS system, the backup wall needs to be nearly a complete air barrier. Additionally, vertical and horizontal barriers in the air space can aid in cavity pressurization by channeling air flow.

It is important that the air barrier not only resists the flow of air, but also resists air pressure. To accomplish pressure equalization, the cavity must be pressurized. A simple unsupported nonstructural film will not work if it does not have the strength to resist the air pressure.

In summary, for leakage to occur three elements are necessary. There must be water, there must be an opening in the wall and there must be a force to move the water through the opening. Elimination of any one of the three will prevent leakage. The rainscreen principle focuses on the elimination of the third source for leakage, the force.

In practice, the successful control of water leakage requires a compromise between all three causes of leakage. Keeping water off the wall is obvious, but the elimination of openings and the requirement for openings for pressure equalization appears contradictory. In practice it is not. The weep hole opening is designed to allow for air movement into the cavity while flashing prevents water infiltration while accommodating drainage from the cavity.

2.1.4 Secondary Defense

Rainscreens are designed to resist water intrusion due to air currents and pressure differentials. However, as has been mentioned, there are other causes for water penetration through the veneer. For this reason, the BV/SS system should be designed not only as a rainscreen, but also as a drainage wall. In this strategy, it is assumed that water enters the cavity. The wall is then detailed so as to divert this water from the cavity back to the exterior surface of the wall system. The principal components of a drainage wall are the cavity, the weep holes and the flashing.

2.2 CONFIGURATION

Brick veneer buildings can be configured in limitless ways. The number of different forms is controlled only by the designer's imagination. These configurations can be classified in three distinct arrangements: solid wall, punched windows, and strip windows. These arrangements are illustrated in Figure 2.3.

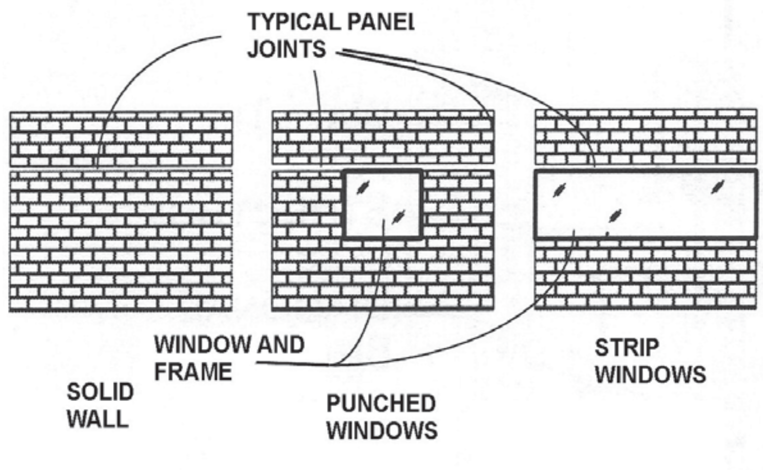


Figure 2-3 Typical Configurations

In any of these arrangements, steel studs can effectively and efficiently provide for necessary structural support of the brick veneer and its backing.

In concept, two different steel stud-framing schemes can be used to support the brick veneer. The first, commonly called the spandrel system, is designated herein as a Type 1 system. The second system is a floor-to-floor system and is designated as Type 2.

2.2.1 The Type 1 Spandrel System

The Type 1, or spandrel system, is the more versatile of the two systems identified. This system has been successfully employed in all three BV/SS configurations shown in Figure 2.3.

In this system, steel studs are hung from the slab edge or spandrel beam. Placement of the stud and slab edge connector allows for adjustments necessary to accommodate normal building frame construction tolerances. Intermittent horizontal braces are provided below the spandrel beam, to stabilize the steel stud framing and resist lateral wind and seismic loads. This is illustrated in Figures 2.4 and 2.5.

A ledger is welded to the studs to provide vertical support for the brick veneer and can be fabricated from angles, plates or other miscellaneous steel sections. The ledger can be placed at any location, but is most commonly found at the head of the window and defines the location of vertical separation necessary between floors. This is illustrated in Figures 2.4 and 2.6.

Brick gravity loads are transferred directly from the ledger angle to steel studs through bending and shear. The load is transferred from the steel studs to the building frame through the slab edge connection. Any resultant eccentricities are resisted in the slab edge connection alone or in combination with the bracing. Bracing can be either horizontal or diagonal. When using diagonal bracing, consideration should be given to the magnitude of vertical floor deflections, which will impose lateral wall movements. Also, any potential interference with mechanical systems should be considered. This is illustrated in Figure 2.5.

Out-of-plane wind and seismic loads are transmitted from the brick to the steel stud backing through the brick ties. A recent study shows that before initial brick cracking, most of the lateral out-of-plane loads are carried in the brick veneer and are transferred to the backing at the ties nearest the stud supports [9]. When the lateral loads are sufficient to exceed the modulus of rupture of the veneer, the mortar joint will crack. Lateral loads are then transferred to the steel stud primarily through the ties nearest the crack and the stud support points.

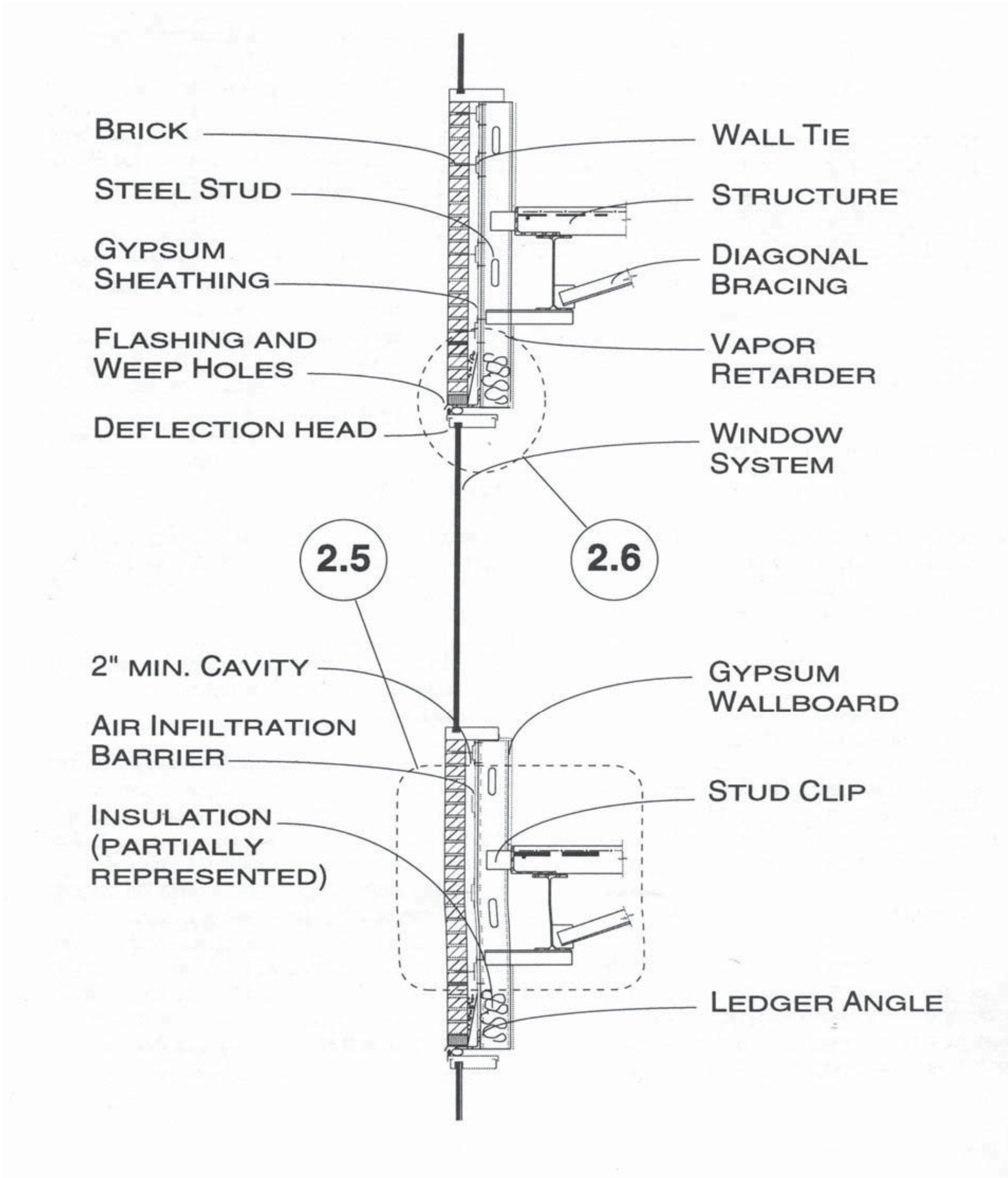


Figure 2-4 Wall Section - Type 1 System

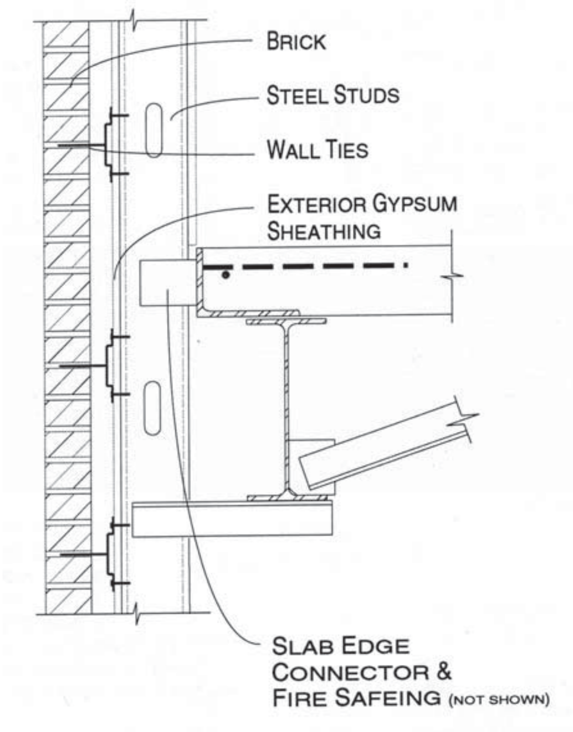


Figure 2-5 Floor Anchor - Type 1 System

In-plane seismic loads are transferred from the brick into the ledger. From the ledger, the loads are either transferred to floor supports through diagonals in the plane of the steel stud framing or to the horizontal braces through bending in the studs and braces.

Parapets can be incorporated in the Type 1 system by cantilevering the steel studs above the roof level structure. The parapet must be capped and flashed to protect the system from water intrusion.

2.2.2 The Type 2 Floor To Floor System

The Type 2, or floor-to-floor system, works for a solid wall or for a wall with "punched" or individual window openings. The Type 2 system is illustrated in Figure 2.7.

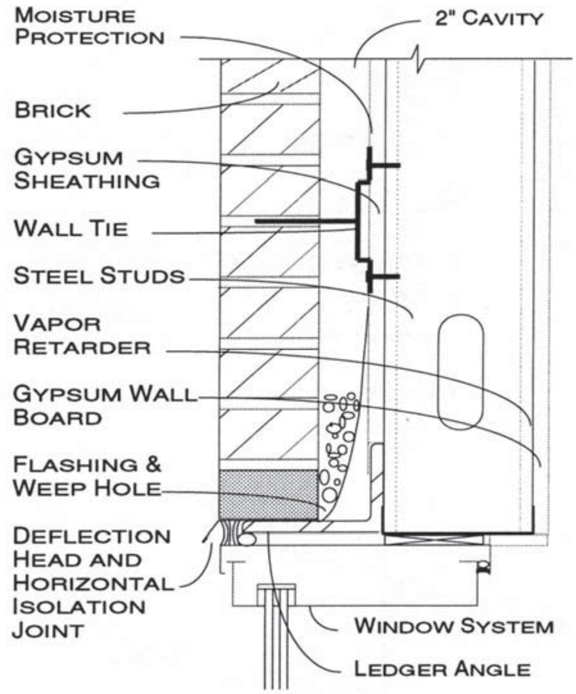


Figure 2-6 Wall Section - Type 2 System

In this system the steel studs fit in a runner or track that is anchored to the floor and spans to a deflection head anchored to the underside of the floor above. Building frame construction tolerance is accommodated in the placement of the steel studs and ledger angles. The ledger is anchored directly to the edge of the floor slab or spandrel beam. Like the Type 1 system, a joint is provided below the ledger and defines the location of vertical separation between floors. Brick gravity loads and in-plane lateral seismic loads are transferred directly from the ledger into the building frame by friction. It is recommended that not less than two-thirds of the brick bear on the support [10]. See Figure 2.8

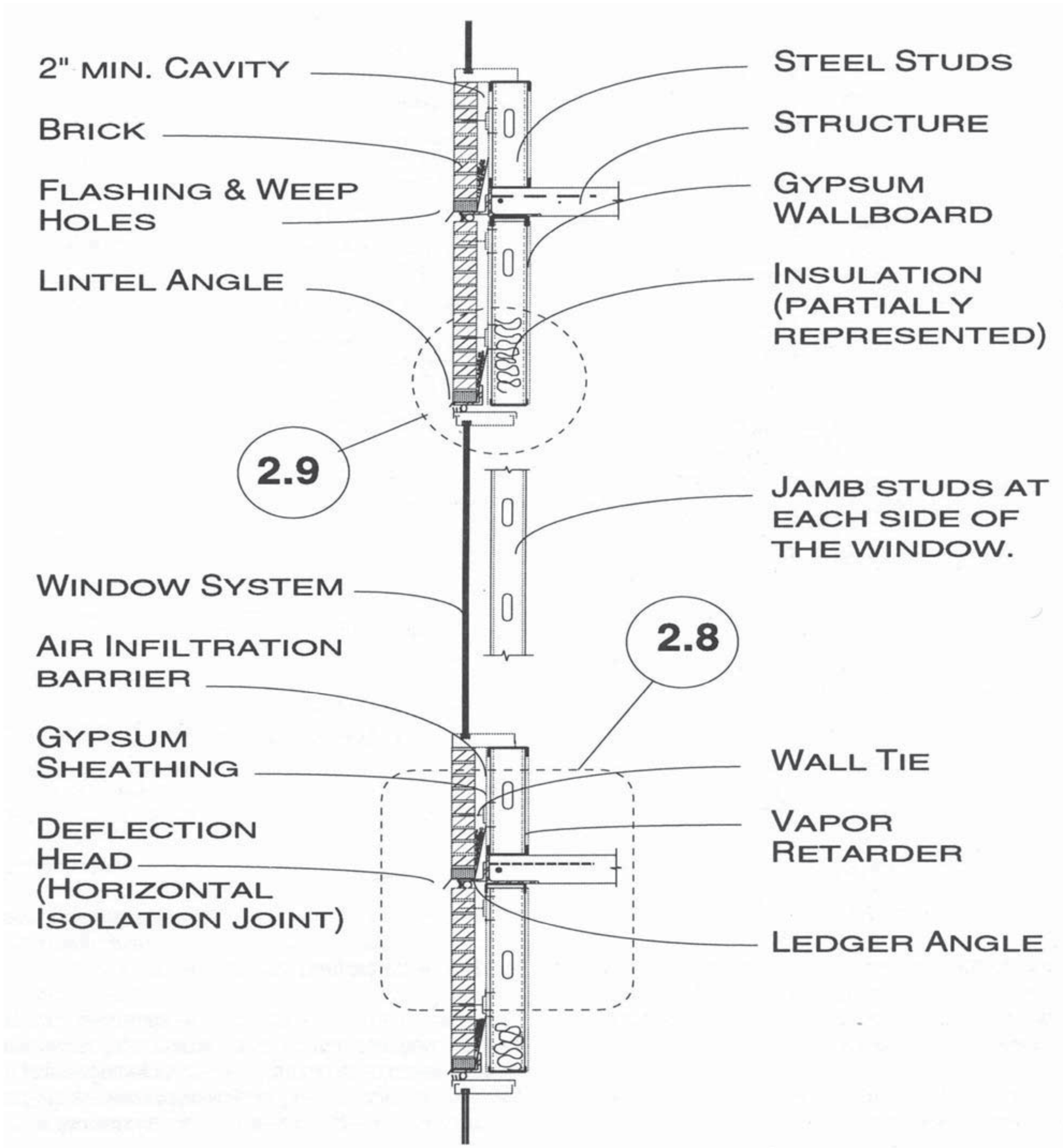


Figure 2-7 Brick Veneer Ledger - Type 2 System

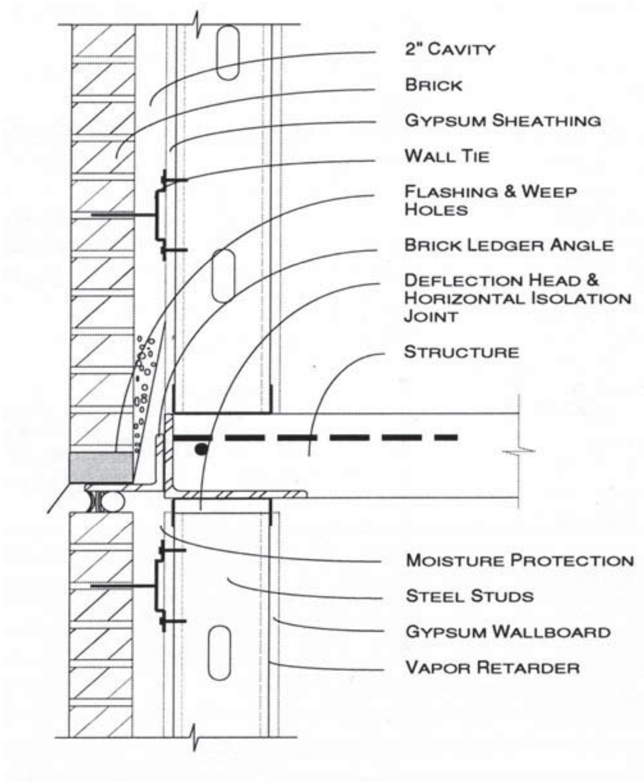


Figure 2-8 Brick Ledger - Type 2 System

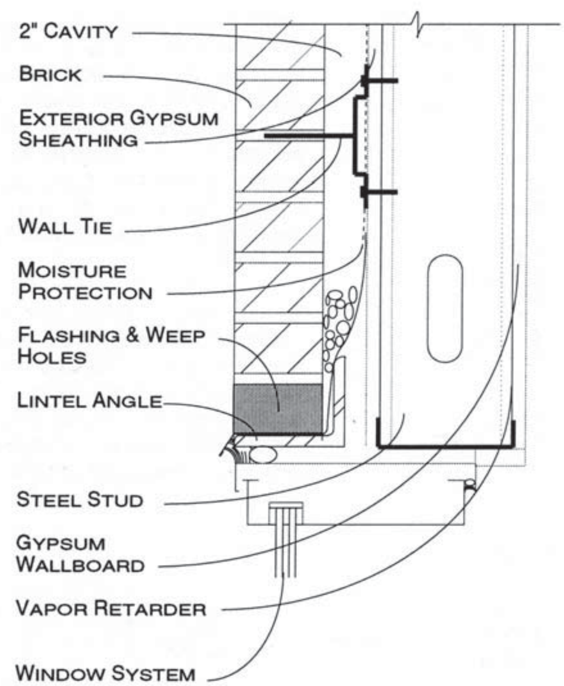


Figure 2-9 Brick Lintel - Type 2 System

Where openings are required, a brick lintel angle should provide the support necessary to span the opening. A lintel angle differs from a ledger in that it is normally not attached to the steel studs or building frame, but rests on the brick on either side of the opening as illustrated in Figure 2.9 and Figure 2.10.

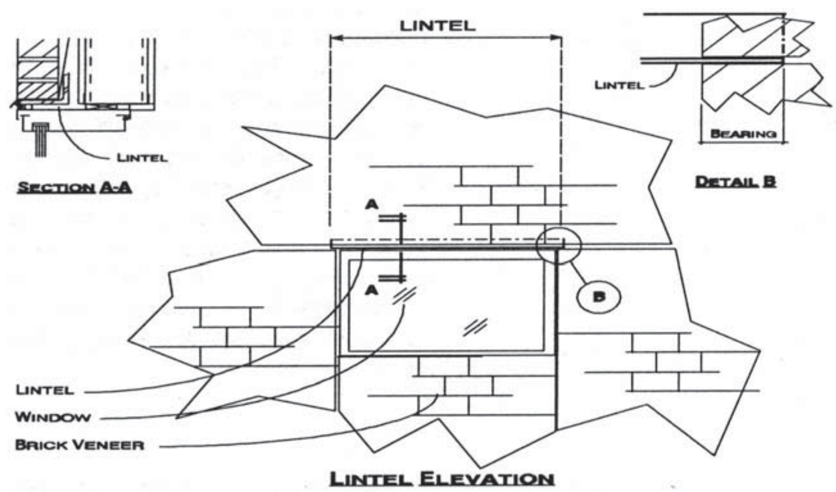


Figure 2-10 Elevation of a Lintel - Type 2 System

Out-of-plane lateral wind and seismic loads are transferred to the steel stud backing in the same manner as the Type 1 system. Supplemental steel studs will frequently be necessary at the edges of window openings in the brick veneer to support the additional tributary wind loads.

Parapets generally are not constructed with the Type 2 system since it is difficult to effectively pass the studs by the roof structure. A parapet can be constructed by either using the Type 1 system configuration at the roof or by providing a reinforced brick or concrete block backing system.

The detail at the foundation for either the Type 1 or Type 2 system is illustrated in Figure 2.11

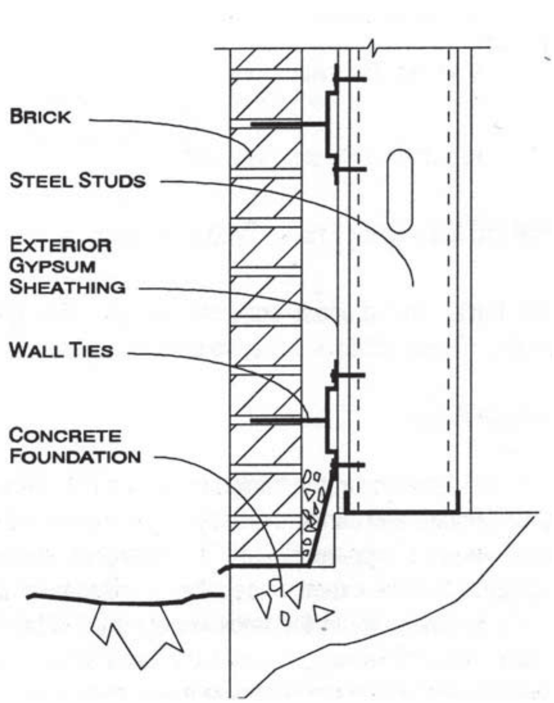


Figure 2-11 Brick Veneer Foundation Detail

2.2.3 Architectural Variations

There are many architectural variations that can be incorporated into these two systems. Some of the more common include relief in the brick surface; sloping brick window sills; sloping or horizontal brick soffits; mixing concrete masonry or tile with brick; and precast concrete window sills and heads. These variations require special attention.

Surface Relief

Relief or variations in the brick surface are not difficult to incorporate and can add greatly to the appeal of the brick veneer's appearance. The designer should recognize that the extent of the relief or offset must not create instability in the brick veneer as it is being constructed. This is as true at the base where the brick is being set on the ledger as it is at the top of the wall. It is recommended that not less than two-thirds of the brick bear on the support [9]. If eccentricities develop up the wall, the resultant lateral forces must be carried in the masonry ties. Caution must be exercised if this condition occurs. If the wall is laid up, and the mortar has not adequately cured, the ties may not be sufficiently anchored into the mortar joints to prevent collapse. The resulting instability will result in increased construction difficulty and cost. Additionally, the designer should recognize that the brick tie's compressive capacity will be reduced with an increasing cavity width.

Brick Sills

Sloped sills are a common accent in brick construction. Small slopes created from special brick shapes can be readily incorporated into the veneer wall. Larger more dramatically sloped sills require more care to design and construct.

Where the width of the slope does not allow the weight of the brick veneer to be fully supported on a lintel or ledger, then an alternative support must be provided. Continuous support for gravity loads should be provided for unreinforced veneer. An example is shown in Figure 2.12.

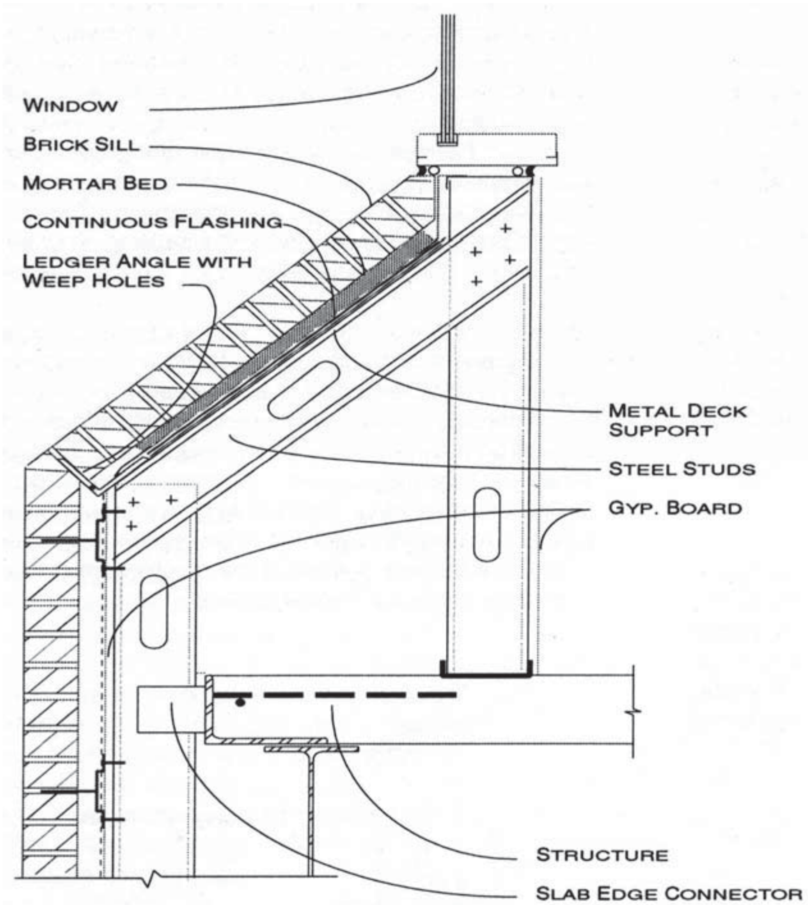


Figure 2-12 Sloping Brick Sill - Type 1 System

An alternative is to reinforce the brick, but a discussion of this is beyond the scope of this document [6]. In either choice, the surface below the sill needs to be fully flashed and often expansion joints should be provided at either end of the sloped sill.

Brick Soffits

Brick soffits offer problems similar to those of a sill. Support for gravity loads should be provided to the extent that the veneer is not self-spanning.

Mixing Concrete Masonry With Brick

Another architectural variation is to combine concrete masonry with brick veneer. This commonly takes the form of banding, either horizontal or vertical, or as an accent pattern of some form. In either arrangement, concrete masonry can be directly incorporated into the brick veneer without modification to the steel stud backing. When using horizontal brick and concrete masonry bands, the designers must recognize the opposing behavior of the two materials and detail accordingly with movement joints and joint reinforcement. Brick masonry will expand while concrete masonry will contract due to moisture changes over time. Both will expand and contract with temperature.

Precast Concrete

Precast concrete windowsills and heads, as well as accents, can be successfully coordinated into a BV/SS system. Where the precast elements are small, they can be integrated into the brick veneer with little or no modifications to the backing. Large components may require a separate support and anchorage system.

2.3 PERFORMANCE

The design life and performance are important qualitative terms that define the things that designer's design. Buildings will not last forever. The owner and designer should establish a reasonable design life and performance level for every project. This requires consideration of the economic factors associated with the selection of materials, maintenance, and factors of safety.

In one respect, minimum performance level is set by the building code, however, there are aspects of a BV/SS system performance that are not explicitly covered by the building code and require judgment. Therefore, it is convenient to define two distinct levels of expected performance:

Level 1 is intended to signify a high level of quality and long or extensive design life. The actual length of time used for the design life would be established or set by the owner and designer. Buildings of this type might include many public or institutional buildings. Specifically, these are buildings where the additional costs associated with higher quality are judged to be necessary in meeting the overall project requirements.

Level 2 is intended to signify a good level of quality and an average design life. Buildings of this type might include: general office, industrial, and residential buildings. These are buildings where it is decided that the additional cost of Level 1 quality is not economically justified or necessary.

The primary difference in design life is obtained by increasing the quality of the brick tie and its anchorage to the backup wall, improving the weather resistance of the backup wall surface and expanding on the amount of inspection and testing. Increasing the stiffness of the backing may be beneficial in that the amount of water allowed through cracks in the veneer would be reduced.

2.4 COMPONENTS

The BV/SS system consists of several components that must be specified and detailed. Each component should be carefully considered during design and its suitability and appropriateness judged. The following discussion should help in this process.

2.4.1 Steel Studs

Steel stud selection is largely dictated by stiffness criteria. Steel studs are typically cold-formed. More information about steel studs can be found at http:// ssma.com, the Steel Stud Manufacturing Association. Steel thickness should be a minimum of 18 gauge. This minimum gauge is required to provide adequate material for welding and for screw anchorage. Steel studs are commonly specified in 14, 16, and 18-gauge material. The studs must be galvanized and should be galvanized to a minimum of G60 in accordance with ASTM A 525 (G90 if a higher level is decided). Steel stud spacing selected for design should be compatible with the sheathing module for ease of construction. The sheathing will generally brace the studs against flexural-torsional buckling.

In the unusual case where sheathing is not used, the studs will require adequate bracing to prevent flexural-torsional buckling. Complete steel stud design procedures are available from the 2001 edition of the "North American Specification for the Design of Cold-Formed Steel Structural Members"

2.4.2 Exterior Sheathing

Wall sheathing requirements will vary with the quality level desired for the project and the climate at the project location. There are many options and systems available. The wall sheathing consists of an air infiltration barrier and green board gypsum sheathing, the most common, or other supporting board. There are many products available. Often cement boards are used in high performance systems. The cement board is considered more resistant to moisture and more importantly, more reliable for sealing between panel joints. Plywood sheathing is not often used. Rigid insulation may also be used on this surface, in lieu of or, in addition to insulation in the steel stud cavity.

The wall sheathing is a significant barrier to moisture. A high level of moisture protection on this surface will promote a long design life. This can be achieved with special surface treatments. The wall sheathing should be either 1/2" or 5/8" thick (exterior) gypsum sheathing, or other board fastened with corrosion-resistant screws. Joints between sheets in high-level systems should be sealed. The entire sheathed surface should be covered with a damp proofing material. As defined in ASTM D 1079a, damp proofing is "... the treatment of a surface or structure to resist the passage of water without hydrostatic pressure." Either using a fluid-applied elastomeric membrane or a cold-emulsion bituminous damp proofing can achieve damp proofing. The material that is selected should be formulated to allow for adequate water vapor transmission. This is to prevent entrapment of moisture vapor within the stud cavity. The damp proofing material may not adequately bridge the joints between the gypsum sheathing. This is why it may be required that the joints be sealed to allow the damp proofing to span the joints.

Alternatively, it may be satisfactory for some projects to increase the moisture resistance of sheathing behind the wall tie only. A building paper, such as 15 lb. felt, would be used over the entire wall surface. At the wall tie locations, the weather resistance of the wall would be enhanced by the application of an area of flexible sheet flashing. This would be material set in mastic, composed of plastic or synthetic-rubber that would seal the wall surface at the point where the tie anchorage penetrates the sheathing. This would be an example of a Level 2 installation.

For a more common application, the wall sheathing recommended is also 1/2" or 5/8" (exterior) grade gypsum sheathing fastened with corrosion-resistant screws. In lieu of covering the surface with a damp proofing material, a building paper may be adequate. This has commonly been a 15 lb felt without special consideration of the tie locations.

Alternative materials are available that could also provide an air infiltration barrier, depending on local practice. The material that is selected should allow for adequate water vapor transmission.

2.4.3 Vapor Retarder

A vapor retarder will function to limit moisture diffusion through the BV/SS system. The vapor retarder is commonly placed on the interior or "warm in winter" side of the steel stud wall, but its location may vary depending on local practice and the configuration of wall insulation used. A vapor retarder commonly contains points where minor leakage can occur, such as electrical outlets or joints at structural members, but in general these systems still function adequately. The vapor retarder can be provided as a part of the insulation backing, on the surface of the gypsum wallboard or as a separate polyethylene sheet. See illustration in Figure 2.13 for a common configuration.

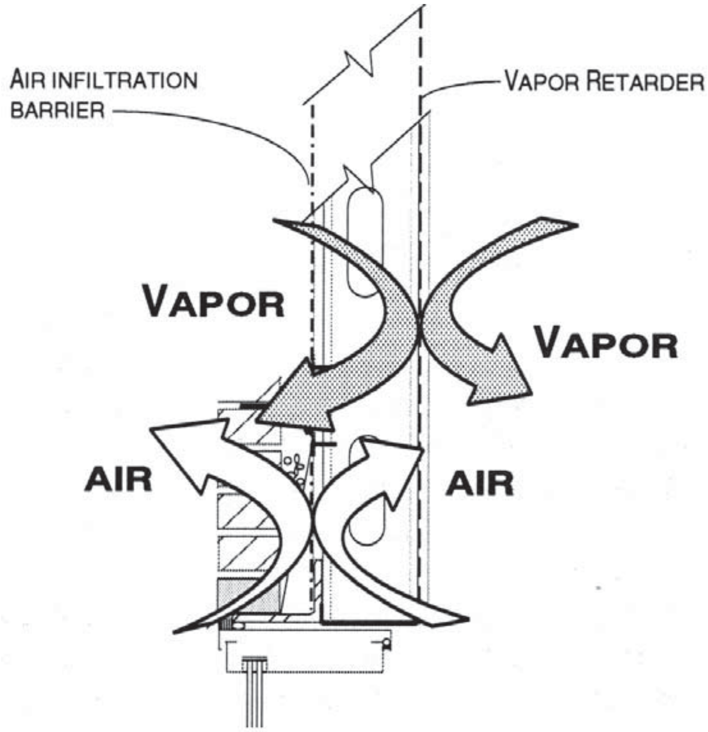


Figure 2-13 Vapor Retarder Illustration

Air pressure from wind infiltration, fan pressurization, and stack effect may be sufficient to dislodge inadequately supported vapor retarders allowing for significant vapor leakage.

To be effective for use with the BV/SS system, vapor retarders must be constructed so that they:

1. Impede the exfiltration of moisture at the "warm in winter" side of the insulation;

2. Prevent vapor leakage; and,

3. Withstand peak differential interior air pressures.

Gypsum wallboard, or other types of board, provides a rigid support for the vapor retarder, and itself resists air flow.

2.4.4 Cavity

The cavity or air space between the brick and the positive water barrier at the exterior steel stud wall should not be less than two inches wide. Smaller cavities are permitted but often do not function well. The cavity acts to provide a buffer for wind-driven rain and allows water that penetrates the brick veneer to migrate down the inside brick face without migrating across the cavity space. Except for brick ties and flashing, the cavity should be kept clear of any obstructions that might allow water to bridge across. Mortar droppings should be prevented from falling into the cavity. When mortar droppings do enter the cavity, they should be removed. Cavity spaces can be wider, but this will reduce the capacity of the brick ties. Construction tolerance on the cavity width should be limited to ± 1/2".

2.4.5 Flashing/Weep Holes

Continuous flashing is necessary for the removal of water that enters the cavity space. Flashing material for the BV/SS system can be provided with the same materials commonly used in other types of brick wall construction. Flashing should be placed at any location where the cavity is interrupted, such as where the masonry is bearing on steel or concrete. This typically occurs at locations such as brick ledgers, lintels, windows, and sills. End dams should be provided to prevent water migration around windows or other obstructions. Full head joint weep holes (the entire head joint is left open) should be provided above the flashing or ledger to drain water back out through the brick veneer. Were a rainscreen concept is used, some have used open head joints below the flashing or ledger to aid in pressure equalization of the cavity (See discussion in Section 2.1.3). If this is done, extra care and inspection is required to insure that the air barrier is nearly complete (no air infiltration). If it is not, the wall will likely leak as a path is now available for water to drip from the ledge and be force into the wall by any number of mechanisms. Pea gravel, proprietary meshes or screens above the flashing will help to prevent mortar droppings from clogging weep holes. Weep holes should be spaced no more than 24 inches apart. Open head joint weep holes are recommended. Weep tubes and cotton wicks many times fail to function when they become clogged or damaged. Screens in open head joint weeps can be used to deter insect infestations. The flashing and weep system is illustrated in Figure 2.14

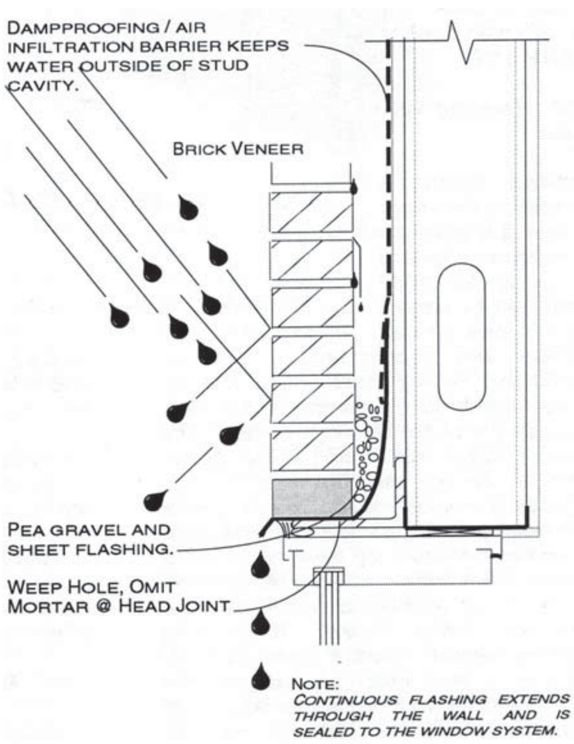


Figure 2-14 Flashing/Weep Holes Illustration

It is important that the flashing extend through the wall in order for it to function. Flashing stopped within the wall increases the chance for leaks, and likely will not function. Two commonly accepted details are provided in Figure 2.15.

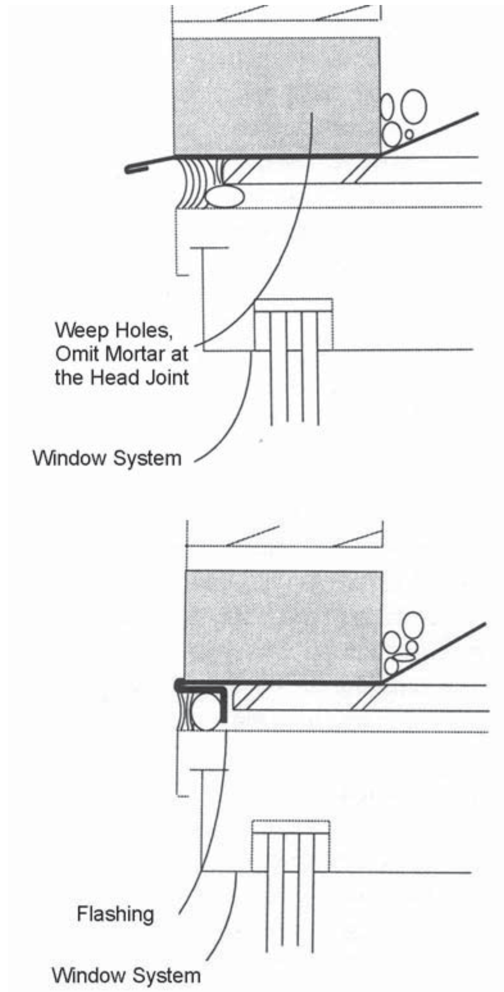


Figure 2-15 Two Flashing Details

The performance of the flashing is critical to the successful function of the wall. The quality of the flashing system will strongly influence the design life of the wall.

2.4.6 Masonry

Generally, brick is selected for its color, texture, and size and most commonly is an ASTM C 216 Facing Brick. Alternatively, the brick may be an ASTM C 652 Hollow Brick. Face brick comes in three different types based on factors affecting appearance.

1. Type FBS, Face Brick Standard: General use in exposed masonry.

2. Type FBX, Face Brick Extra: General use in exposed masonry with a high degree of mechanical perfection, and minimum permissible variation in size.

3. Type FBA, Face Brick Architectural: Brick manufactured to achieve distinct architectural effects.

Face brick also comes in two grades:

1. Grade MW: Moderate Weathering.
2. Grade SW: Severe Weathering.

Brick grade identifies the durability of the brick. Selection of an appropriate grade of brick is determined by the climatology of the project site. ASTM C 216 contains a diagram of weathering indexes for the United States. Grade SW brick is satisfactory in all climates.

Mortar should be either Type N or Type S. Currently, the more reliable mortars contain portland cement, hydrated lime, sand, and water and certain admixtures. Type S mortar exhibits higher flexural bond strength but either type is appropriate for the BV/SS application.

The durability of the wall is highly influenced by the quality of the mortar joints. Care should be taken to ensure that dense exposed joints are achieved. Joints should be tooled to a concave or "V" finish to densify the mortar surface, provide good weathering resistance and compress the mortar to the brick, see Figure 2.16.

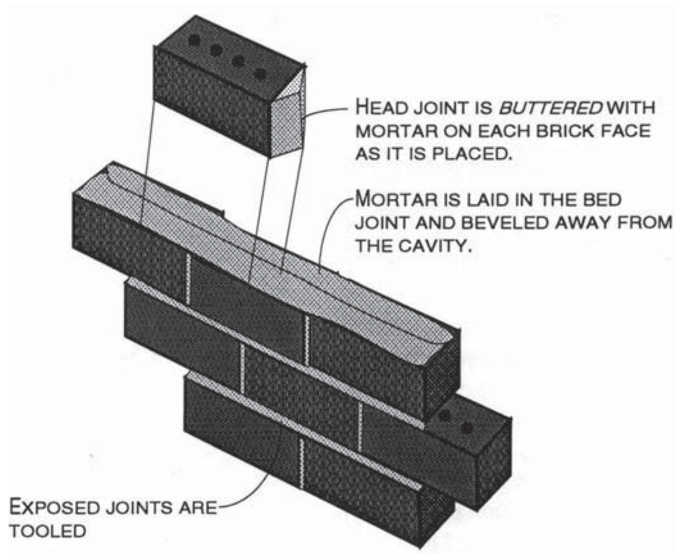


Figure 2-16 Mortar Joint Construction Illustration

If raked joints are desired, the effect may be achieved by a "'deep V". Simple raked joints must be tooled after raking.

2.4.7 Ledgers/Lintels

Ledgers and lintels are generally ASTM A 36 structural steel angle or bent plate. The code requires that ledgers and lintels be non-combustible and non-corrosive and therefore should be hot-dip galvanized. Ledgers and lintels that are not protected can possibly corrode and stain the brick surface as they degrade. The use of 300 series stainless steel is generally not necessary and may be subject to galvanic corrosion if placed in contact with galvanized steel.

Ledgers should provide continuous support for the brick veneer. Ledgers should be detailed with 1/4" to 1/2" open butt joints at eight to twelve feet on center. A compressible filler material can be placed in the joint to ensure that it does not fill with mortar. These joints will allow for expansion of the ledger angle and allow the ledgers to be conveniently galvanized in a single dipping operation. Damage to galvanized coatings by welding or other field installation practices should be repaired using cold galvanizing compounds. Ledgers should be welded to the steel studs in the Type 1 system and can be either welded or bolted to the building frame in the Type 2 system. Lintel angle requirements are similar to those of the ledger angle. Unlike ledgers, lintels are not generally fastened to the backing but are built into the veneer to span openings.

Ledgers need to be designed to a vertical deflection limit of L/600 in accordance with ACI 530-02/ASCE 5-02/TMS 402-02 Section 6.2.2.3.3. Additionally, the structural design of the ledger should consider minor axis bending of the leg supporting the masonry. This normally requires the ledger to have a thickness greater than 3/8 inch.

Ledgers provided at each story improve the isolation of the BV/SS from movements of the structural frame. This is currently required in seismic design Category D and above by ACI 530-02/ASCE 5-02/TMS 402-02 Section 6.2.2.10.2.2. This requirement has been removed in the most recent code and the designer may find this important for buildings of two and three stories. By code, ledgers should be provided above the initial 30-foot height and should not be spaced more than 12-feet on center vertically there after, unless special design techniques are used. Special design techniques would include details to accommodate movement and meet strength requirements. The 30' and 12' ledger spacing requirements were developed for wood framing. The 12' dimension was intended to be for early wood study story heights. The 30' was originally 12', then 25', and then 30' and was to accommodate the early platform type of wood construction. This common type of construction introduced wood in side grain bearing which is susceptible to large compression deflection (shrinkage).

For example, two 2" thick top plates plus a 12" thickness for a joist plus a 3" thickness for plate and sheathing would give almost 2' of wood to shrink and could result in over 1/2" of settlement (shrinkage) per level. Two stories would give an inch of differential long-term settlement between the wood and the masonry. This would likely cause distress of the anchors.

This shrinkage does not occur with steel stud framing. In fact, steel studs or steel columns are considered to be "special construction" designed to prevent differential deflection. Thus, larger distances (heights) between ledgers can be successfully built with proper design.

2.4.8 Brick Ties

Brick ties and their attachment are important components of the BV/SS system. Brick tie performance is characterized by many factors including:

Adjustability.

Adjustability in the vertical direction is important for ease of construction and to isolate in-plane brick veneer movements from the backing. With care, ties may be attached at coursing modules.

Tolerance and freeplay.

In and out movement of the tie should be less than 1/16 inch.

Strength.

Ties need to possess the axial strength required to meet design requirements.

Stiffness.

A reasonable range is 2000 to 6000 pounds per inch of deflection.

Positive Anchorage.

The tie is typically screwed or bolted to the steel stud backing. In Seismic Design Category D and above, ties must engage the #9 gauge wire spaced not more than 18 inches on center vertically. The wire is not reinforcement of the veneer. It is for increasing the strength and ductility of the connection of the tie to the veneer. Thus, the wire does not have to be continuous or lapped like wall reinforcement.

Corrosion-resistant/Non-corrosive.

Ties should be either hot-dip galvanized or 300 series stainless steel.

Test Rated.

Ties must have their capacities and other characteristics established from comprehensive testing programs.

There are a number of acceptable ties for use in the BV/SS system. Two-piece adjustable brick ties are the most common. Two typical types are shown in Figure 2.17.

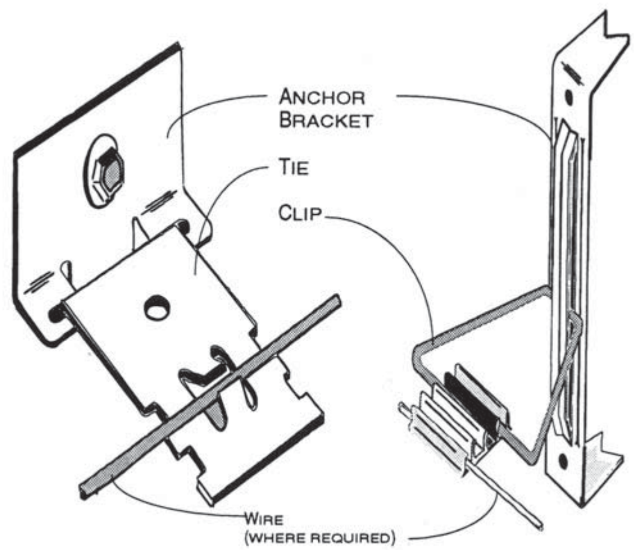


Figure 2-17 Typical Wall Tie Anchors

They consist of an anchor embedded in the masonry and an anchor bracket attached to the steel stud. The amount of adjustability varies with the manufacturer, but should be sufficient to allow for consistent placement in the field. In Seismic Design Category D and above, the anchor must engage or enclose a horizontal joint reinforcing wire of No. 9 gauge or equivalent. The anchor should extend into the middle third of the brick joint to provide for a positive anchorage. The size of the anchor specified should be compatible with the cavity width, including rigid insulation if present. The unbraced length of the anchor, within the cavity, should be kept less than KL/r = 200. Where "K" is taken as 1.0, "L" is the unbraced length of the tie and "r" is the tie's radius of gyration. For a wire, the radius of gyration is .25 x the diameter of the wire resulting in a maximum unsupported length of 50 wire diameters.

The attachment of the anchor bracket to the steel studs has been one of the more controversial aspects of the BV/SS system, [1], [2], [3] and as a result, has been subject to a great deal of discussion. The attachment is commonly made with a metal fastener, as shown in Figure 2.18.

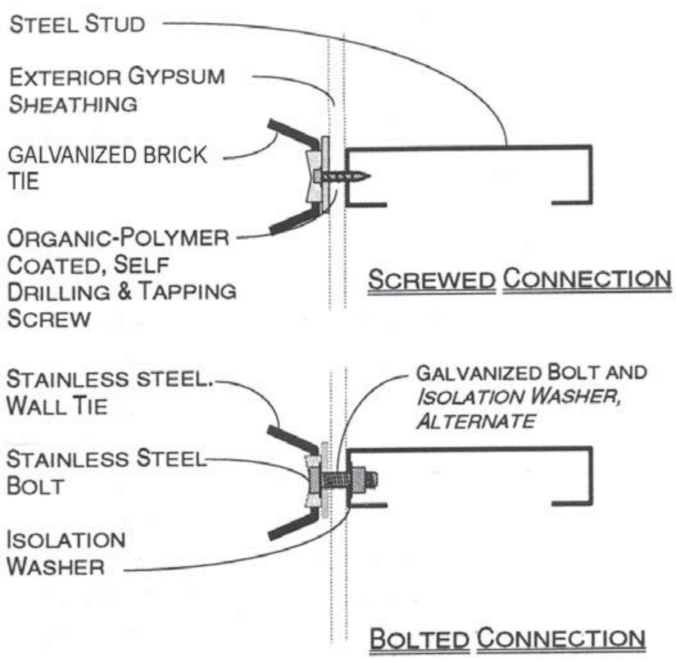


Figure 2-18 Wall Tie Fasteners

Brick tie forces are transferred by tension in the fastener and compression in the gypsum sheathing[3], into the steel stud backing. The ultimate compressive strength of gypsum board may be considered to be 350 to 400 psi [11]. Fastener strength can be found from the manufacturer. Strength, however, may not be as critical as the corrosion protection provided for the fastener. It is important that the fastener be as corrosion-resistant as practical.

The corrosion of metals is a very complex process. Scientific understanding of the corrosion process is supported by a fairly comprehensive set of theoretical concepts, many of which are not fully clarified or entirely agreed upon by the scientific community [12]. Two types of corrosion significant to the BV/SS system are:

1. General Corrosion -Oxygen Type

2. Galvanic Corrosion-Hydrogen Type

General corrosion occurs in plain and low alloy steels, containing less than 13% chromium in neutral water and humid atmospheres. This type of corrosion is commonly referred to as oxidation. General corrosion would be combated by either using 300 series stainless steel (17% chromium) or with a protective coating of zinc or an organic polymer.

Galvanic corrosion is a hydrogen type of electrochemical corrosion where metals of different electric potential, electro-conductively linked, deteriorate as the material with lower electrical potential (anode) sacrifices electrons to the material of higher electrical potential (cathode). In other words, when dissimilar materials are placed in contact with each other in the presence of moisture, galvanic corrosion can occur. Table No. 1 prepared by AISI identifies the potential for galvanic corrosion for various combinations of base metals and fasteners.

Based on the AISI guidelines, care must be taken with stainless steel so that it is not placed in direct contact with galvanized steel. If stainless steel and galvanized steel are not isolated from each other, the galva-

[3]Some ties have protruding legs that allow compressive forces to be transferred directly to the steel stud.

nized steel may be markedly corroded and subject to deterioration.

Alternatively, the electric potential difference between materials may not be the most significant determinant of the probability of galvanic corrosion. The "... decisive quantity is the corrosion current density, the size of the corrosion current relative to the anode surface", this according to a report published on corrosion problems in roofing and siding [12]. This report suggests that the galvanic corrosion associated with stainless steel fasteners in galvanized steel studs is not significant because the current density of the fasteners relative to the galvanized steel studs is low.

Table No. 1

Guidelines for Selection of Fasteners Based on Galvanic Action`

Base Metal	Fastener Metal					
	Zinc and Galvanized Steel	Aluminum and Aluminum Alloys	Steel and Cast Iron	Brasses, Copper, Bronzes, Monel	Martensitic Stainless Type 410	Austenitic Stainless Type 300
Zinc and Galvanized Steel	A	B	B	C	C	C
Aluminum and Aluminum Alloys	A	A	B	C	Not Recommended	B
Steel and Cast Iron	AD	A	A	C	C	B
Terne (Lead-Tin) Plated Steel Sheets	ADE	AE	AE	C	C	B
Brasses, Copper, Bronzes, Monel	ADE	AE	AE	A	A	B
Ferritic Stainless Steel (Type 400)	ADE	AE	AE	A	A	A
Austenitic Stainless Steel (Type 300)	ADE	AE	AE	AE	A	A

Source: American Iron and Steel Institute Committee of Stainless Steel Producers April 1977
Shaded boxes identify material commonly considered in BVSS applications

Key:
A. The corrosion of the base metal is not increased by the fastener.
B. The corrosion of the base metal is marginally increased by the fastener.
C. The corrosion of the base metal may be markedly increased by the fastener material.
D. The plating on the fastener is rapidly consumed, leaving the bare fastener metal.
E. The corrosion of the fastener is increased by the base metal.
Note: Surface treatment and environment can change activity.

For higher levels of protection against corrosion, it is suggested that stainless steel wall ties be provided. This might be employed in a Level 1 or institutional grade building. 300 series stainless steel bolts with an isolation[4] washer at the connection to the (galvanized) steel stud can be used to fasten the anchor bracket. Alternatively, if galvanized steel bolts are used an isolation washer should be provided at the anchor bracket. Additionally, stainless steel joint reinforcing should be provided where a stainless steel tie is placed in contact with it.

Galvanized ties, fastened with self-drilling self-tapping steel screws, should be adequate for the Level 2, commercial grade building or other installations requiring average levels of corrosion protection. The screws should be carefully specified. Self-drilling, self-tapping screws need to have a hardened tip to provide the cutting action necessary for the drilling and tapping operations. Hardened steels, however, can be subject to stress corrosion cracking and hydrogen embrittlement at very low stresses. Softer more ductile steels are not generally as susceptible to stress corrosion cracking and hydrogen embrittlement because instead of cracking, the material is more likely to yield and redistribute the internal stress. Consequently, the specified fastener should be a composite: a hardened tip for drilling and tapping, and a ductile shank for clamping. Treating the screw with an organic-polymer coating can provide high corrosion resistance. This coating will generally perform much better than zinc.

[4] An isolation washer may not be required if the electric potential difference between the materials is considered to be insignificant.

2.4.9 Vertical Expansion Joints

Vertical expansion joints need to be provided at various strategic locations in the BV/SS wall system. Expansion joint placement is dictated by several factors, including:

1. Climate
2. Configuration
3. Temperature
4. Structural Support
5. Materials

The Brick Industry Association Technical Note 18A, Differential Movement - Expansion Joints, contains a valuable discussion on the many considerations involved in expansion joint placement. Additionally, section 3.2.2 of this report discusses vertical joint sizing requirements.

As a general rule, vertical expansion (movement) joints should be provided at the following locations:

1. At or near wall corners
2. At wall discontinuities
3. At changes in height
4. At changes in thickness
5. Adjacent to large openings
6. Adjacent to dissimilar materials
7. At abutments to other building elements
8. At a maximum spacing of thirty feet on center

Vertical expansion joints should also be provided at other locations where the brick might crack.

2.4.10 Window Anchorage

Windows can be anchored to either the brick veneer or the steel stud backing but should not be anchored to both. Anchoring to both would create problems because differential in-plane movement would cause the system to bind at the window anchorages. In other words, anchoring to both would short-circuit the isolation that is being achieved with adjustable brick ties.

2.4.11 Sealants

Sealants provide the first line of protection against rain intrusion into the system. Placement of sealants should be done in strict conformance with the manufacturer's recommendations and using workers highly experienced in their application.

Joints should be properly prepared, cleaned with solvent, primed for adhesion and backed with a backer rod, see Figure 2.19.

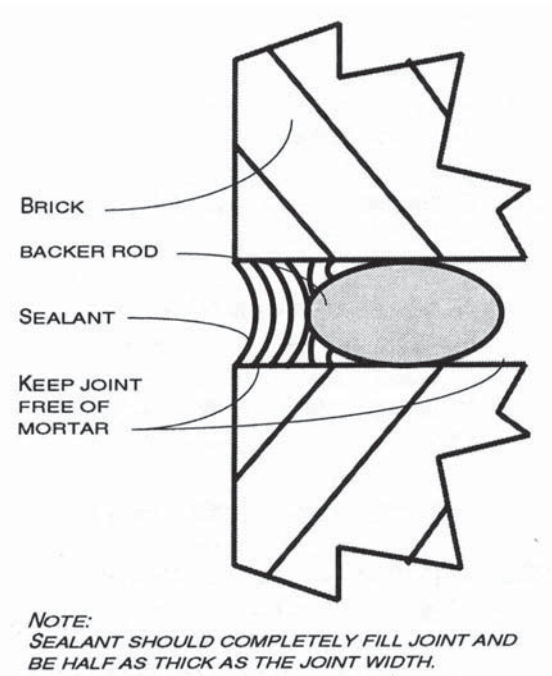


Figure 2-19 Vertical Expansion Joint Detail

Sealant compatibility tests (peel test) conforming to ASTM C 794 should be conducted for each type of brick unit used and for all other materials in direct contact with the sealant. The compatibility tests should also be conducted on treated (sealed) brick, unless the treatment is to be done after sealing. The compatibility tests are important. It is not uncommon to have no bond between some brick and sealant combinations.

2.4.12 Cleaning and Sealing

Cleaning of masonry is a well-established technology. The Brick Industry Association has two Technical Notes that provide excellent information. Technical Notes 20, Cleaning Brick Masonry, describes the various accepted methods for initial cleaning and cleaning for subsequent masonry staining. Technical Notes 23, Efflorescence, Causes and Mechanisms, Part I, addresses the subject of efflorescence.

Sealing or water repellent treatments of brick masonry are more controversial. The application of water repellents is common in the northwest and other areas, but has not been recommended by the Brick Industry Association. Water repellents are effective in reducing water passage through the masonry. It is generally agreed that the repellent helps stop capillary movement of water through the wall, thus reducing the quantities to be handled by the secondary water control system.

The Brick Industry Association and others are concerned with the effect the water repellent has on the appearance and durability of the brick. Water and salts, if trapped within the masonry, may cause cryptoflorescence, freeze-thaw damage and spalling. Water repellents must allow the masonry to breath by not significantly altering vapor transmission through the brick. BIA Technical Notes 7E, Colorless Coatings for Brick Masonry, is a good reference for further discussion of this issue.

3.0 DESIGN CRITERIA AND PERFORMANCE

3.1 LOADS

Loads on the brick veneer over steel stud system primarily consist of dead load, wind load, and seismic forces. The veneer itself should support no load other than its own weight. In normal practice it may also support the weight of window systems, and possibly some ornamentations. The backup system (steel studs and building frame) must be designed to support any additional vertical and lateral load imposed by the veneer.

Design wind forces can be calculated from the code for elements and components of structures.

Design seismic forces are also calculated from the procedures contained in the code for elements of structures and nonstructural components. In general, the main part of the veneer including the masonry, ties and backup system is designed to resist the imposed seismic forces elastically (without much ductility). The R_p in the ASCE 7 - 2002 is 2.5 reflecting some system and material ductility, but not much. The design of the connection “fasteners connecting the system” has an R_p of 1.0 and an a_p of 1.25. This is essentially an elastic response to the seismic loading.

3.2 MOVEMENT

Buildings and their components, while seemingly static, are subjected to a variety of dynamic movements. These movements result from either external forces applied to the building, such as wind, earthquake, or live load or are the result of internal changes to the building's materials such as shrinkage, creep, and thermal effects. Successful design requires that these movements be recognized and incorporated into the design details.

3.2.1 Building Frame

Building frame movements must be accommodated by the BV/SS system. Vertical frame movements result from differential deflections on spandrel beams due to different loadings and stiffness. In concrete buildings, creep and shrinkage is a consideration as well. In some buildings, elastic shortening of columns will contribute significantly to vertical movement.

Spandrel beams or any members supporting brick veneer should, by code, be designed to deflect not more than 1/600 of their span under full dead load of the veneer, creep, and live load. It is likely that deflection greater than 1/2000 of the span will result in masonry cracking. Vertical cracks in brick spandrels may be problematic. Stiffness greater than the code minimum or vertical joints should be used to control this type of cracking if that is desired.

It should be recognized that camber does not limit deflection and is <u>not</u> a part of the veneer, creep, and live load deflection limitation. The veneer weight is applied gradually as the brick is being laid. Where camber compensates for deflection due to the veneer's weight and the deflection is something more than the 1/2000 of the span, then it is possible that cracking will be induced in the wall before its completion.

Wind and seismic loading generally cause lateral frame movements. Creep and shrinkage in buildings with prestressed concrete floors and thermal movements in buildings without controlled environments may also be significant. Temperature movement in building frames is generally a concern in open structures such as parking garages. Other building types may also experience significant thermal movements if construction activities span large seasonal variations in temperature. In any event engineering judgment should be used to account for temperature movements in the building frame.

Creep and shrinkage in prestressed concrete buildings may be significant where prestressing forces are high or building floor plates are large. The Post-Tensioning Manual and PCI Design Handbook both contain procedures for calculating creep and shrinkage movement.

Both wind and seismic drift will vary greatly depending on such things as type of building frame, building size, shape and weight. The minimum drift criteria set by code accounts for several factors, including the variability of actual loads and stiffness and the larger drifts that will occur due to inelastic deformations associated with major earthquakes. The BV/SS connections and panel joints should be designed to accommodate the required building frame movement.

Sources of movement have been summarized in Table No. 2.

Table No. 2

Movement Type	Structural System	Source of Movement	Limitations	Recommended Values	Typical Values	Isolation Method
Vertical Floors	Steel or concrete	Differential application of live load	L/600	<0.60 inch	1/4″	Compensation channel at the window head
						Soft joint under the ledger angle
	Concrete	Shrinkage with drying	(2)	(3)	1/16″	Allow the concrete to dry and cure before installing the veneer
		Creep	(2)	(3)	(3)	Provide vertical control joints every 20 to 30 feet
Vertical Columns	Steel	Differential elastic shortening	(2)	(3)	(3)	Only applies to high-rise buildings where the veneer is installed prior to finishing the building frame
	Concrete	Shrinkage	(2)	(3)	1/16″	Allow the concrete to dry and cure before installing the veneer
		Creep	(2)	(3)	1/16″	Compensation channel at the window head
						Soft joint under the ledger angle
Lateral	Frame of steel or concrete	Wind	(2)	.0025H	3/8″	Usually absorbed elastically in the system
		Seismic	Per analysis Minimum ½″	Depends on occupancy	21/2 TO 3″	Compensation channel at the window head
						Soft joint under the ledger angle
	Shear Wall	Wind	(2)	.0025H	1/8″	Usually absorbed elastically in the system
		Seismic	Per analysis Minimum ½"	Depends on occupancy	1/4 TO 1/2 ″	Compensation channel at the window head
						Soft joint under the ledger angle

Notes:

1. For the Type 1 system, deflection of the ledger may cause cracking of the brick veneer due to the veneer's own weight.
2. No known values.
3. Depends on the structure.

3.2.2 Seismic Performance

General

The BV/SS system is considered nonstructural. This is an important distinction for establishing the seismic performance requirements.

Seismic performance of the BV/SS system is a complex subject since under certain levels of seismic shaking, damage can occur to the veneer and its backing. There are currently several organizations preparing standards for seismic design. The National Earthquake Hazards Reduction Program (NEHRP-2000) divides the performance of structures into four levels:

1. Operational: “Structures meeting this level when responding to an earthquake are expected to experience only negligible damage to their structural systems and minor damage to nonstructural systems” (the BV/SS system). “Repairs if necessary can be conducted at the convenience of the owner.” “The risk to life is negligible.”
2. Immediate occupancy: “Structures meeting this level are expected to sustain more damage to non-structural systems” (the BV/SS system). “Exterior nonstructural wall elements and roof elements continue to provide a weather barrier, and are otherwise serviceable” (although they may be damaged).
3. Life safety: “Significant structural and nonstructural damage has occurred.” “Nonstructural elements of the structure, while secured and not presenting falling hazards, are severely damaged and can not function” (the BV/SS system).
4. Collapse prevention: “The structure has sustained nearly complete damage. Nonstructural elements of the structure have experienced substantial damage and may have become dislodged creating falling hazards” (the BV/SS system).

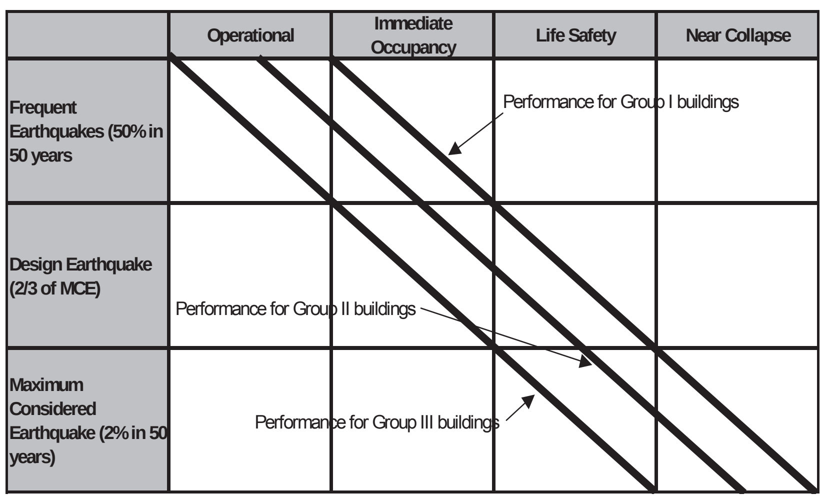
The NEHRP provisions also distinguish between building uses by assigning each structure a Seismic Use Group.

Group III are essential facilities requiring post-earthquake use.

Group II are facilities with a large number of occupants.

Group I are all other facilities.

Combining the performance classification with the occupancy distinction results in the following chart describing expected seismic performance.



The building code is not specific about the seismic performance of curtain wall and brick veneer. Judgment is required on the part of the engineer to develop appropriate seismic criteria based on the project performance objective. For example, failure of the brick veneer over the firehouse door during a major earthquake is not acceptable. Whereas, complete separation of a brick veneer from the frame on a suburban office building with surrounding planters may be acceptable.

Building Code Requirements for Masonry Structures, (ACI 530-02/ASCE 5-02/TMS 402-02) requires anchored brick veneer in “Seismic Design Category” C and above to have “isolation of the sides and top anchored veneer from the structure so that vertical and lateral seismic forces resisted by the structure are not imparted to the veneer”. If this criteria is applied for the Maximum Considered Earthquake event, then isolation of the veneer becomes very difficult if not impossible. A more rational approach is to isolate for less movement and accept some damage in accordance with the NEHRP criteria.

Building Code Requirements for Masonry Structures, (ACI 530-02/ASCE 5-02/TMS 402-02) requires anchored brick veneer in “Seismic Design Category” D and above to “support the weight of anchored veneer for each story independent of other stories”. This requirement has been removed from the –05 MSJC document.

ASCE 7–02 Section 9.6.1.3 provides the seismic loads for the design of the veneer. The seismic forces on the veneer and the body of the connections are assumed to have some ductility. An R_p of 2.5 is tabulated. The fasteners of the connecting system are assumed to have no ductility and are required to be designed elastically, R_p of 1.25.

Corners

Building corners are especially vulnerable to damage from story drift due to wind or seismic loading. Consequently, they should receive extra attention in design. Because corners in the Spandrel System behave differently from corners in the Floor-to-Floor system, each is discussed separately.

Spandrel System

In the Spandrel System, each panel is only connected to a single floor. These panels and their corners are consequently isolated from interstory drift. Care should be taken, however, to ensure that the windows are properly detailed for the drift.

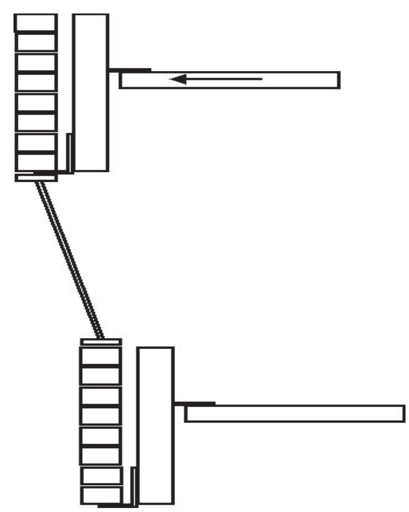


Figure 3-1 Spandrel System Drift

Floor-to-Floor System

Because they are tied to two floors, corners in the Floor-to-Floor system must receive special attention. When detailing these corners, the designer should consider the following recommendations:

Place isolation joints at all corners.

When a single panel has ties in two orthogonal directions, the panel will “lock” when subjected to story drift. A panel locked in this manner may suffer serious damage when subjected to even very modest story drifts.

Align the isolation joint at the corners with the most flexible axis of the building.

The masonry cladding is isolated from seismic drifts acting parallel to the direction of the isolation joint. However, for building drifts acting perpendicular to the joint, the cladding is only isolated until the caulking joint becomes substantially compressed and begins to transmit forces to the adjacent panel. Orienting the joint so that only the smaller story drifts associated with the stiffest axis of the building act across the isolation joint can minimize this problem.

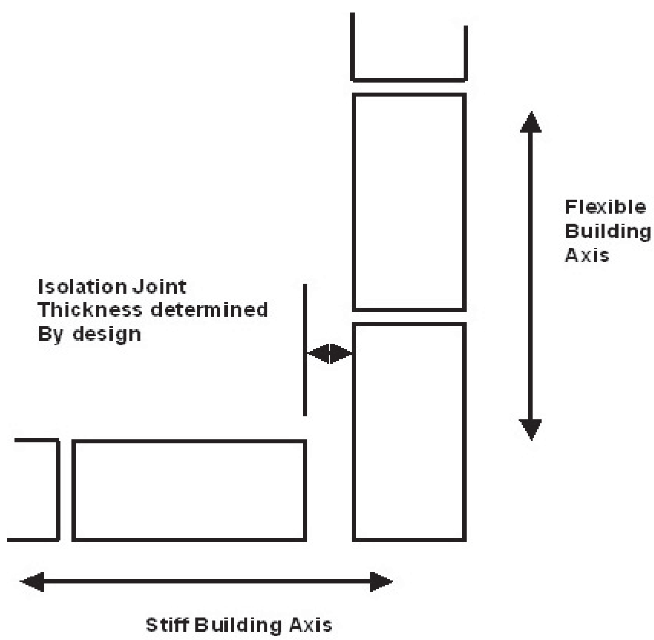


Figure 3-2 Corner Isolation Joint, Floor-to-Floor System

Rationally determine design drifts for corner isolation joints.

Ideally, the corner isolation joint would be designed for the full inelastic story drift associated with the building. However, because of aesthetic considerations and due to the large drifts associated with many modern buildings, this may not always be feasible. When this is the case, joints can be sized for some percentage of the inelastic drift or, as a minimum, for the drifts associated with wind loading. As this decision impacts both the aesthetics of the building and its seismic performance, it may be appropriate to discuss the various alternatives and their implications with the building owner.

Anticipate Corner Damage

When joints are not designed for the full inelastic story drift, these panels may be damaged during a severe seismic or wind event. While it is not a foregone conclusion that this damage will translate to masonry materials falling from the building, it is advisable that these corners be positioned on the building in such a fashion as to minimize any potential safety hazard.

3.2.3 Brick Veneer Movements

Thermal and moisture movements in the brick veneer can be estimated from the following equation, provided in BIA Technical Notes 18A Differential Movement-Expansion Joints:

$$\Delta = \left[0.0005 + 4\,x10^{-6}\left(T_{max} - T_{min}\right)\right]L$$

Where:

Δ = Total expansion of the wall (inches).

T_{max} = Maximum mean wall temperature in degrees Fahrenheit.

T_{min} = Minimum mean wall temperature in degrees Fahrenheit.

L = Length of brick veneer wall (inches).

Vertical expansion joints need to be provided at a spacing to accommodate the estimated expansion calculated. Generally, vertical joints are spaced not more than 30 feet apart, based on the desire to keep the joints in the veneer small. It is also important for the designer to recognize that most joint sealant is only approximately 50% compressible.

For example, if the desired sealant joint is 1/2" and the difference between the maximum and minimum mean wall temperature is 100^{o} F, then the maximum joint spacing would be calculated:

$$L = \frac{.5x0.5}{0.0005 + 4x10^{-6}x100} = 278" \text{ or } 23'$$

Horizontal expansion joints are required below the ledger angle, as illustrated in Figure 3.3. The joint size is influenced by many factors, including:

1. Deflection of the support structure;

2. Deflection/rotation of the horizontal leg of the ledger;

3. Vertical thermal/moisture expansion of the veneer; and

4. Deflection of the ledger between anchorages.

The joint size should be a minimum of twice the calculated amount to meet the limitations of the compressibility of the sealant. As a minimum, it is recommended that the joint not be less than 3/8". Sometimes much of the deflection can be allowed for in the window system. This is particularly true in strip window systems. The deflection is commonly accommodated with a deflection (or compensation) channel at the head of the window. The deflection capacity of the channel can be sized as required.

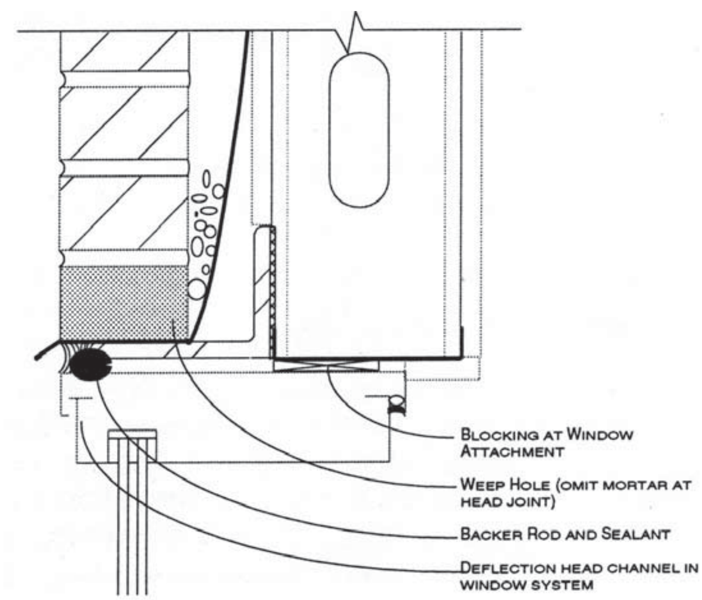


Figure 3-3 Head Joint Illustration - Type 1 System

3.3 STRUCTURAL DESIGN

A licensed engineer should provide structural design of the BV/SS system. This would generally be the building engineer (Engineer-of-Record), a specialty-consulting engineer or an engineer working for the contractor. In any event, a licensed design professional familiar with the requirements of a BV/SS system should provide for the design. Many problems found today in BV/SS systems can be traced to inadequate design.

To successfully design a BV/SS system the following assumptions can be relied upon as a rational [13]:

The brick veneer over steel stud system should be designed to meet the requirements of ACI 530-02/ASCE 5-02/TMS 402-02, Chapter 6 Veneer, with the modifications as noted herein. Additionally, the building code for the local jurisdiction should be met. The following will generally equal or exceed the building code.

1. The brick veneer is a nonstructural component.

2. The BV/SS system's structural performance when subjected to earthquake ground motion should conform to the criteria outlined in Section 3.2.2 of this document.

3. Brick veneer should be expected to crack under service wind and seismic loading.

4. Maximum tie demands should be determined using the design requirements of Section 3.3.1 of this document. Once the maximum tie demands are established, ties should be selected that have ultimate capacities that meet the following requirements:

   For wall ties with an elastic stiffness (K_{Tie}) less than or equal to 2 kips/inch, the ultimate capacity should be 1.25 times the maximum calculated demand;

   For wall ties with an elastic stiffness (K_{Tie}) greater than 2 kips/inch, the ultimate capacity should be 2.0 times the maximum calculated demand.

   The ultimate capacity of the wall tie may be governed by the axial capacity of the wall tie itself, either in tension or compression, or by the capacity of the anchorage of the wall tie to the masonry, or by the capacity of the attachment of the tie to the steel stud. Wall ties should be detailed with mechanical attachments to the masonry to provide the required strength, assuming that the masonry has cracked. Wall tie suppliers should provide the designers with test data that verifies compliance with these requirements. Wall tie free-play shall be limited to 1/16 of an inch.

5. Steel stud size and spacing should be selected to limit deflection to a maximum of L/360.

6. Wall ties, wall tie attachments, and steel studs should be of corrosion-resistant materials. The cavity wall system should be designed assuming that water will intrude into the cavity. Drainage of the water out of the cavity must be provided for.

Spot bedding of wall ties is not recommended

Filling the cavity with mortar is a different system than BV/SS and is beyond the scope of this publication. A system that fills the cavity has recently successfully been used and may have many advantages over the BV/SS system.

In-plane seismic load transfer between the brick veneer and the supporting ledger angle is commonly accomplished by using the friction that exists at this interface.

A positive attachment can be made, using lugs or plates, to anchor the brick veneer to the ledger angle. This arrangement, however, could be problematic for the performance of the composite system. Large differential thermal and moisture movements exist between the brick veneer and the ledger angle and must be accommodated. Anchorage of the brick veneer to the ledger angle would likely introduce cracks in the veneer at the anchorage locations, and make the system more difficult to flash.

For the BV/SS system it is generally desirable not to anchor the brick to the ledger angle and instead to rely on friction.

Rational Design

As an alternative to the prescriptive method of ACI 530-02/ASCE 5-02/TMS 402-02, Chapter 6 Veneer, a more detailed rational analysis of the BV/SS system may be performed, which incorporates the spatial distribution and stiffness of all veneer system components. The results of the detailed analysis may be used to establish required wall tie capacities, wall tie spacing, and steel stud sizes and spacing.

A detailed rational analysis of the BV/SS system would preclude the need to conform to the prescriptive requirements of the Standard. Such an analysis would include consideration of the following:

An accurate representation of the stiffness and spatial distribution of all veneer components, including masonry, metal studs, masonry ties, and attachment elements;

A step-by-step characterization of the change in system stiffness associated with crack propagation in the masonry; and an appropriate representation of the wind and/or seismic loading to which the BV/SS system would be subjected.

Typically, this could be accomplished with the use of a detailed finite element model of the BV/SS system [9]. While it is recognized that the utilization of such a detailed model would be beyond the scope of the typical design services provided on BV/SS projects, there are some potential construction cost savings associated with a "rational design" approach. These cost savings may be of a net benefit to an owner in certain circumstances. Specifically, metal stud sizes and gauges, brick tie sizes and spacing, and metal stud attachments all can be potentially optimized using a "rational design" approach. A large or particularly complex BV/SS project may benefit from such a design approach.

3.3.1 Design Procedure

The example that follows applies to the Type 2, floor-to-floor case. The procedure for the Type 1, spandrel condition is the same except for appropriate modifications to account for the different support conditions. This procedure was developed in the Report on Behavior and Design of Anchored Brick Veneer/Metal Stud Systems prepared by Ron Mayes and Jeff Asher [13].

1. Calculate metal stud size and spacing required based on serviceability limit state:

$$I_{req} = \frac{5W_{design}l_{max}^4}{384E\Delta_{max}}$$

Where:

E = Modulus of elasticity of steel stud.

W_{Design} = Total static design load on brick veneer, wind or seismic.

I_{RQD} = Required moment of inertia.

L_{max} = Maximum steel stud span.

Δ_{max} = Maximum out-of-plane assume allowable deflection of brick veneer system.

$$\Delta_{max} = \frac{L_{max}}{360}$$

(NOTE: Stud stress is generally not critical for typical building geometries and loadings)

2. Calculate maximum demand on ties by the following:

a. Calculate static out-of-plane load at which first cracking occurs in the brick:

$$W_{cr} = \frac{8M_{cr}}{L^2_{max}}$$

Where:

$M_{CR} = f_r$ x S (cracking moment)

f_r = 180 psi [14]

S = Section modulus

b. Calculate total static out-of-plane load that will result in cracking:

$$W_{total} = W_{cr} \, x \, \frac{[EI]_{brick} + [EI]_{studs}}{[EI]_{brick}}$$

c. Compare W_{Total} to W_{Design} and calculate maximum tie force (T_{Max}):

If $W_{Total} \leq W_{Design}$, then the veneer has cracked and;

$$T_{max} = \frac{W_{cr} L_{max}}{2}$$

If $W_{Total} > W_{Design}$ then the veneer has not cracked then;

$$T_{t\,max} = W_{design} \, x \, \frac{[EI]_{brick}}{[EI]_{brick} + [EI]_{stud}} \, x \, \frac{L_{max}}{2}$$

3. Choose tie manufacturer whose brick tie has an ultimate capacity:

$T_{Capacity} \geq 1.25 \text{ x } T_{Design}$ (Where, $K_{Tie} \leq 2$ Kips/Inch) [13]

$T_{Capacity} \geq 2.0 \text{ x } T_{Design}$ (Where, $K_{Tie} > 2$ Kips/Inch) [13]

Where capacity and stiffness are verified by appropriate test data.

4. Design shelf angle and attachment for vertical load.

5. Design metal stud attachments for demand based on W_{Design} assuming studs take 100% of the out-of-plane load.

3.3.2 Example Design Calculation

System:

3-1/2" brick veneer
f'm = 2,500 psi
E = 1,875 ksi

6" x 18 gauge steel studs at 16" o.c.
I = 2.23 in^4
S = 0.74 in^3

Brick ties spaced at 16" o.c. horizontal and 18" o.c. vertically (2.0 sf)

12'-0" story height.

Loads:

Dead weight (brick veneer): 35 psf vertical

Wind load: 35 psf lateral

Seismic load:

The International Building Code requires veneer to be designed in accordance with ASCE 7. Additionally, requirements of Building Code Requirements for Masonry Structures, (ACI 530-02/ASCE 5-02/TMS 402-02) need to be met.

Assume the following values for seismic forces apply:

Veneer = 11psf
Connection Body = 15 psf
Fasteners = 44 psf

Wind load governs.

W_{Design} = 35 psf

Except for fastener design.

W_{Design} = 44 psf

Verify Steel Stud Size and Spacing:

$$I_{req} = \frac{5W_{design}L^4}{384E\Delta_{max}}$$

$$\Delta_{max} = \frac{L}{360} = \frac{12x12}{360} = 0.40"$$

$$I_{req} = \frac{5x(0.035x16/12)x(12x12)^4}{384x12x29000x0.40}$$

$$I_{req} = 1.88 inches^4 \le 2.23 inches^4 \text{ ok}$$

6" x 18 gauge studs at 16" o.c. have adequate strength

$$S_{req} = \frac{W_{design}L^2}{8F_b}$$

Assume members are laterally braced

$$F_b = F_y\Omega_t = \frac{33{,}000}{1.67} = 19{,}760 \text{ psi}$$

Where Ω_t is the AISI factor of safety for bending.

$$F_b = 19{,}760 \text{ psi}$$

$$S_{req} = \frac{(0.305x16/2)x(12x12)^2}{8x12x19.8}$$

$$S_{req} = 0.51 inches^3 \le 0.74 inches^3 \text{ ok}$$

6" x 18 gauge studs at 16" o.c. have adequate strength

Calculate maximum tie force:

Cracking Load

$$W_{cr} = \frac{8M_{cr}}{L^2}$$

$$M_{cr} = f_r xS = 180x\frac{12x3.5^2}{6}$$

$$M_{cr} = 4{,}410 \text{ in} - \text{lb} = 368 \text{ ft} - \text{lb}$$

$$W_{cr} = \frac{8x368}{12^2} = 20.4 \text{ psf}$$

$$(EI)_{brick} = 1{,}875 x \frac{12x3.5^3}{12}$$

$$(EI)_{brick} = 80{,}391\ kip - in^2$$

$$(EI)_{studs} = 29{,}000x2.23x\frac{12}{16}$$

$$(EI)_{studs} = 48{,}503\ kip - in^2$$

$$\frac{(EI)_{brick} + (EI)_{studs}}{(EI)_{studs}} = 1.60$$

$$W_{total} = 1.60xW_{cr} = 1.60x20.4$$

$$W_{total} = 32.7\ psf \le W_{design} = 35\ psf$$

The Brick will crack

$$T_{max} = W_{cr}x\frac{L}{2}x\frac{16}{12} = 20.4x\frac{12}{2}x\frac{16}{12} = 163\ lbs$$

Cracked Brick

$$T_{max} = W_{design}x\left(\frac{1}{2}\right)x\left(\frac{L}{2}\right)x\left(\frac{16}{12}\right)$$

$$= 35x\left(\frac{1}{2}\right)x\left(\frac{12}{2}\right)x\left(\frac{16}{12}\right) = 140\ lb$$

Specific Tie Capacity

Assume tie stiffness of 2,000 lbs/inch

$$T_{capcaity} = 1.25xT_{max} = 1.25x163$$

$$T_{capcaity} = 204\ lbs$$

Specify a minimum tie strength of 204 lbs or change tie spacing to reduce load and re-calculate.

4.0 TESTING

Many different preconstruction mockup tests are available for evaluating the performance of the BV/SS system design and construction. Preconstruction mockup testing is not necessary for all projects, and because of the costs involved, are likely feasible only for large projects. Tests are generally conducted to evaluate air, water and structural performance.

4.1 AIR

When air infiltration tests are conducted on the building mockup, they should be performed in accordance with ASTM E 783, while those conducted in the laboratory should be performed in accordance with ASTM E 283. Air infiltration tests should normally be done before water penetration tests because water trapped in the brick veneer tends to reduce air leakage.

4.2 WATER

Water penetration tests for the brickwork should be performed in accordance with ASTM E 514, to measure the permeability of the constructed wall. Additional large-scale mockup tests are available using the procedures contained in AAMA 501.3, developed for testing aluminum curtain wall systems.

4.3 STRUCTURAL

Structural tests measure a system's performance under loading perpendicular to the surface and resulting deflection. This type of testing provides a means for accurately assessing the complex behavior of the BV/SS system. A standard test procedure, ASTM E 330, is available for testing exterior windows and curtain walls. Brick panel strength tests can be conducted in accordance with ASTM E 72.

5.0 SUBMITTALS

Two types of submittals are of concern for the BV/SS system. They are the design submittals and the material submittals.

5.1 DESIGN SUBMITTALS

The design submittal is necessary if the building designer, i.e. the Architect or the Engineer-of-Record, does not perform the design of the BV/SS. The design submittal would generally include calculations, plans, details, and specifications for the BV/SS system, all sealed by the design professional. These submittals provide the building designers the opportunity to confirm that the BV/SS system is well integrated into the building and that it conforms to the intent of the design requirements.

5.2 MATERIAL SUBMITTALS

Material submittals are important because they allow the designer to verify that the products specified for the project are being provided. This is particularly true for components specified on a performance basis. The material submittals would include such things as catalogue sheets, tests data, samples, performance data, certificates of conformance, welding certificates and most importantly a system mockup.

Ideally, the system mockup is separate from the building and can be moved to various locations on the site for viewing. As a cost saving measure, the mockup does not necessarily need to be separate from the building, but can be incorporated into the project. This is less desirable because it is more difficult to make comparisons when the mockup is not mobile, and secondly, important internal components are quickly concealed when the mockup is incorporated into the building.

The mock-up is valuable because it establishes limits on color, size variations, workmanship tolerances, joint sizes, method of laying, tooling, cleaning, effect of coatings, etc.

6.0 WARRANTIES

A one-year warranty on construction and materials is the minimum expected. Longer warranties may be appropriate for some projects.

7.0 PRODUCTS

Section 2.4 of this report discusses the various components of the BV/SS system. These components are addressed in a tabular format in Table No. 4 to simplify the selection of the BV/SS system components. Components representing the highest quality levels have been shaded. This list is not intended to be comprehensive. Other products may provide improved performance. But care should be exercised. Further, the products and manufacturers listed here are neither recommended nor endorsed. The suitability of all products and manufacturers should be verified prior to specifying their use.

TABLE No. 3	
BRICK VENEER OVER STEEL STUD COMPONENTS	
COMPONENT	SPECIFICATION$^{(1),(2)}$
7.1 Masonry 04200	
Material	Brick ASTM C 216 and C 652 (See BIA Tech Notes 9A)
Type	FBS, FBX or FBA; HBS, HBX, or HBA
Grade	MW or SW
Mortar	Type S, or Type N Portland Cement Lime Mortar (PCL)
Manufacturers	Castaic Brick Company (800-227-8242) Higgins Brick Company (310-540-1126) Interstate Brick (801-280-5200) McNear Brick and Block (415-453-7702) H.C. Muddox Company (916-645-3771) Mutual Materials Company (425-452-2300) Pacific Clay Brick Products (909-674-2131) Phoenix Brick Yard (602-258-7158) Summit Brick and Tile Company (719-542-8278)
7.2 Flashing 04200/7600	
Material	Sheet Metal Flashing Trim Flexible Sheet Flashing Laminated Composition Sheet Flashing
Manufacturers	As Desired
7.3 Wall Ties 04200	
Tie – Anchor Bracket Material (see Figure 2.17)	ASTM A 366 Steel Plate, Hot-Dip Galvanized (1.5 oz/ft^2)ASTM A 153 Class B2,
	ASTM A 167, 300 Series Stainless Steel Plate
Anchor Tie or Clip Material (see Figure 2.17)	ASTM A 366 Steel Plate, ASTM A 153, Class B2, Hot-Dip Galvanized (1.5 oz/ft^2) ASTM A 82 Steel Wire, ASTM A 153, Class B2, Hot-Dip Galvanized (1.5 oz/ft^2)
	ASTM A 167, 300 Series Stainless Steel Plate ASTM A 580, 300 Series Stainless Steel Wire

Notes:
Other products may be available and better suited for use depending on local practice and should be considered.
Shading indicates an institutional level system.

COMPONENT	SPECIFICATION(1),(2)
Manufacturers	D/A 213S Assembly (Dur-O-Wal, Inc.) DW-10 Series (Hohmann & Barnard, Inc.)
Masonry Reinforcement Wire Material	ASTM A 82 Steel Wire, ASTM A 153, Class B2, Hot-Dip Galvanized (1.5 oz/ft^2)
	ASTM A 580, 300 Series Stainless Steel Wire
Manufacturers	AA Wire Products Company Dur-O-Wal, Inc. Heckman Building Products, Inc. Hohmann & Bernard, Inc. National Wire Products Industries
Screw Fasteners	Self-drilling/self-tapping with mild shank and hardened tip and organic-polymer coating ASTM A 449
Manufacturer	Dril-Flex with Stalgard, Elco Industries, Inc.
Bolt Fasteners	ASTM A 307, Steel Bolt ASTM A 153, Class C, Hot-Dip Galvanized
	ASTM F 593, 300 Series Stainless Steel Bolt
Manufacturers	As Desired
7.4 Steel Studs 05400	
Material	Cold-Formed ASTM A 446 Sheet Steel
Finish	ASTM A 525 G90 Hot-Dip Galvanized
Gauge	18, 16, or 14 Note: Specify section properties
Spacing	16" o.c. normal
Manufacturers	As desired
7.5 Miscellaneous Steel 05500	
Material	ASTM A 36 Structural Shapes and Plates ASTM A 500 Tubes
Finish	ASTM A 123, Grade 65 (where exposed) Hot-Dip Galvanized (1.5 oz/ft^2)
Manufacturers	As Desired

Notes:
Other products may be available and better suited for use depending on local practice and should be considered.
Shading indicates an institutional level system.

COMPONENT	SPECIFICATION(1),(2)
7.6 Moisture Barrier 07100	
Material	No. 15 Felt Building Paper ASTM D 226, Type I
Manufacturers	As Desired
Dampproofing Material	Fluid-Applied Elastomeric Membrane Bituminous Membrane Cold-Applied Asphalt Emulsion, ASTM D 1227
	Polyethylene-sheet-backed Rubberized Asphalt Membrane
Coverage	Consult with manufacturer
Manufacturers	As Desired
	"Bituthene Ice and Water Shield," W.R. Grace & Company "Polyken 640 Underlayment Membrane," Polyken Technologies "Polyguard Deck Guard," Polyguard Products Inc. "Textroseal," Hohmann & Bernard Inc.
7.7 Vapor Barrier 07100	
Material	As Desired
Manufacturers	As Desired
7.8 Exterior Gypsum Sheathing 09200	
Material	ASTM C 79, GA-253 See Gypsum Association Handbook
Composition	Water resistant gypsum core and water repellant surfaces
Geometry	1/2" or 5/8" thick, 2' to 4' wide by 8' to 16' long Tongue and groove edges or lapping
Screws	Self-drilling, self-tapping, corrosion-resistant Phillips wafer head screws, #6 at 8" o.c. min
7.9 Interior Gypsum Wallboard 09200	
Material	ASTM C 36 GA-216
Geometry	1/2" or 5/8" thick 4' wide by 8' to 16' long
Screws	Self-drilling, self-tapping corrosion resistant Phillips wafer head screws, #6 @ 8" o.c. min
Manufacturers	As Desired
Notes: Other products may be available and better suited for use depending on local practice and should be considered. Shading indicates an institutional level system.	

8.0 Construction

The details of design take shape during construction of the BV/SS system. It is important that nothing be left to chance, and that the design intent is clearly communicated to the builders. While this is largely done through the design drawings and specifications, it should be reinforced with a preconstruction meeting, mockup review, testing, and inspection.

8.1 Inspection

The type and amount of construction inspection will vary from project to project. As a minimum, the inspectors should closely review the mockup panel. When a mockup is not used, the first section of wall constructed should be considered the test panel. Some important items to check are:

Masonry

1. Joints are properly tooled and well consolidated.
2. Care is taken to minimize mortar droppings.
3. Expansion joints are kept clean of mortar or other material.
4. Materials are adequately stored.
5. Correct mortar mix is being used.
6. Mortar joints are completely filled.
7. Weep holes are open and free draining.
8. Unfinished work is protected daily.

Brick Ties

1. Proper ties are being installed.
2. Anchor tie engages joint wire when required in high seismic regions.
3. Anchor bracket is fastened to steel stud framing, not sheathing alone.
4. Anchor tie and bracket connection is within manufacturers accepted adjustment.
5. Wall anchors are properly spaced.
6. Anchor embedment has sufficient embedment in the veneer (see Section 2.4.8).

Steel Studs

1. Size and spacing are correct.
2. Welds and other fastenings are adequate and galvanized.
3. Miscellaneous structural components are correctly installed.

Weather Protection

1. Sheathing is in place, correctly fastened, and holes repaired. This is the most common cause of poor system performance.
2. Flashing is correctly installed.
Coatings, where used, completely cover the surfaces intended.
3. Vapor retarder and air infiltration barrier is installed and adequately sealed.
4. Expansion joints are adequately caulked.
5. Brick surface is cleaned and sealed.

A written report should be made and provided to the designers for each day that an inspection is made. Any deficiencies that are uncovered should be reported to the builders and designers. Corrections to any deficiencies should be noted in subsequent reporting. At the completion of the project, the inspector and contractor should make a final report certifying compliance.

For Level 2 (commercial) buildings, a program of periodic inspection may be acceptable, while for Level 1 (institutional) buildings continuous inspection may be more appropriate.

In addition to the inspections, the designers should make periodic visits to review the general condition of BV/SS construction.

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10. Brick Industry Association, "Technical Notes on Brick Construction 28B", Page 3, February 1987
11. Gypsum Association, "Manufactured Housing Recommendations", GA-406-87
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13. Mayes, Dr. Ronald, and Asher, Jefferson, P.E., "Report on Behavior and Design of Anchored Brick Veneer/Metal Stud Systems," Pages 8 and 9, September 1989
14. Mayes, Dr. Ronald, and Asher, Jefferson, P.E., "Wind and Earthquake Forces on Brick Veneer with Steel Studs," Page 35, September 1989

10.0 STANDARDS

AMERICAN SOCIETY FOR TESTING AND MATERIALS

A 36 Specifications for Structural Steel
A 82 Specification for Steel Wire, Plain, for Concrete Reinforcement
A 123 Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
A 153 Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
A 167 Specification for Stainless and Heat-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip
A 307 Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength
A 366 Specification for Steel Sheet, Carbon, Cold-Rolled, Commercial Quality
A 449 Specification for Quenched and Tempered Steel Bolts and Studs
A 525 Specification for General Requirements for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process
A 580 Specification for Stainless and Heat-Resisting Steel Wire

C 55 Specification for Concrete Building Brick
C 79 Specification for Gypsum Sheathing Board
C 90 Specification for Hollow Load-Bearing Concrete Masonry Units
C 216 Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)
C 652 Specification for Porous Concrete Pipe
C 794 Test Method for Adhesion-in-Peel of Elastomeric Joint Sealants

D 226 Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing
D 227 Specification for Emulsified Asphalt Used as a Protective Coating for Roofing

E 72 Methods of Conducting Strength Tests of Panels for Building Construction
E 283 Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen
E 330 Test Method for Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference
E 514 Test Method for Water Penetration and Leakage Through Masonry
E 783 Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors

F 593 Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs

BRICK INDUSTRY ASSOCIATION TECHNICAL NOTES

7E Colorless Coatings for Brick Masonry
9A Manufacturing, Classification, and Selection of Brick
18A Design and Detailing of Movement Joints, Part 1
20 Cleaning Brick Masonry

23 Efflorescence, Causes and Mechanisms, Part 1

GYPSUM ASSOCIATION

GA-216 Application and Finishing of Gypsum Board
GA-253 Recommended Specifications for the Application of Gypsum Sheathing

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Masonry Advisory Council, Design Alert, #4, Masonry Institute Inc.

Masonry Advisory Council, Design Alert, #5, Masonry Institute Inc.

Masonry Advisory Council, Design Alert, #7, Masonry Institute Inc.

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12.0 CONSTRUCTION COSTS

The cost insert presents estimates for a representative Level 1 (Institutional) and Level 2 (Commercial) BV/SS system. Actual cost, of course, will vary depending on factors such as geographic location, market, and variations incorporated in the architectural quality and configuration of the brick work. The costs are broken down by major component, in place, in dollars per square foot of wall surface. The total cost estimates are developed on a through-the-wall basis from consultations with West Coast masonry subcontractors. Through-the-wall costs are a better measure for comparisons between alternative systems, than the costs of only portions of the system.

Again, the costs contained here are only a representative guide. More accurate cost estimates need to be developed on a project-specific basis.

NOTES

ALLIED ASSOCIATES AND WEB ADDRESSES

1	**Arizona Masonry Guild**	(www.masonryforlife.com)
2	**Masonry Advisory Council**	(www.maconline.org)
3	**Masonry Industry Promotion Group**	(www.masonrypromotion.com)
4	**Masonry Institute of America**	(www.masonryinstitute.org)
5	**Masonry Institute of Oregon**	(www.mioctio.org)
6	**Masonry Institute of Washington**	(www.masonryinstitute.com)
7	**Rocky Mountain Masonry Institute**	(www.rmmi.org)
8	**Southwestern Brick Institute**	(www.swbrick.com)
9	**Utah Masonry Council**	(www.utahmasonrycouncil.org)