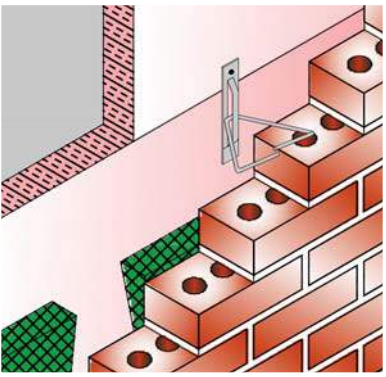
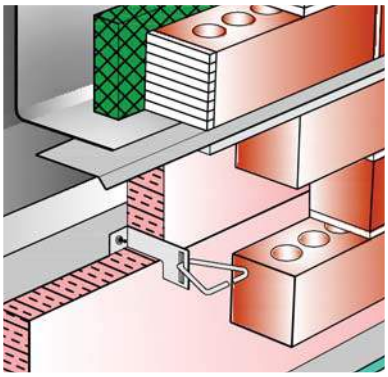
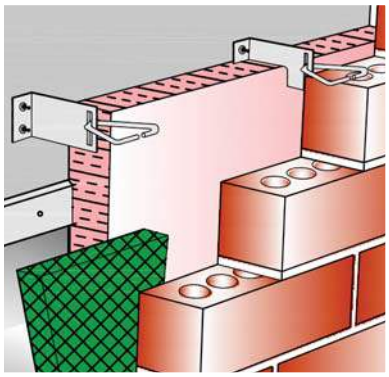
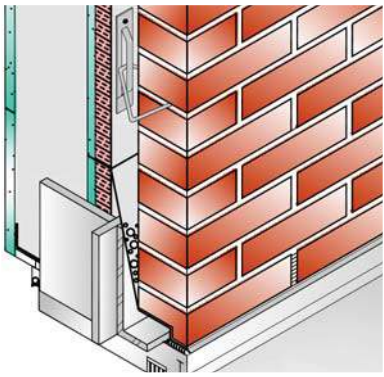
DESIGN GUIDE FOR

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

Prepared for:

Western States Clay Products Association
www.wscpa.us

Submitted by:

KPFF Consulting Engineers
1601 5th Ave. Suite 1600
Seattle, WA 98101

Third Edition

May 2021

ACKNOWLEDGEMENTS

This report and design guide was sponsored by the Western States Clay Products Association and written by KPFF Consulting Engineers. The lead author was John M. Hochwalt, the Director of Engineering for the Seattle Structural Group of KPFF.

This work was coordinated through the Brick Veneer Steel Stud Task Group of the Technical Committee of Western States Clay Products Association. This Task Group consists of Jeff Elder, Steven Judd, John Chrysler, John Tawresey and John Hochwalt.

John G. Tawresey, KPFF Consulting Engineers prepared the 2004 Second Edition.

Jefferson W. Asher III, John G. Tawresey, Edwin T. Dean and Mr. Craig Baltimore, KPFF Consulting Engineers prepared the First Edition.

The material presented in this publication, including technical and engineering data, figures, drawings and tables are for general information only. It should not under any circumstances be relied upon for specific applications of the Brick Veneer Over Steel Stud System without independent evaluation by a licensed design professional familiar with its specific use and application. Anyone making use of this material does so at their own risk and assumes any and all liability resulting from such use.

TABLE OF CONTENTS

DESCRIPTION **Page**

LIST OF FIGURES/ILLUSTRATIONS

DESCRIPTION **Page**

1.0 INTRODUCTION

Brick masonry veneer with a steel stud backing (BV/SS) 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.

While the design of these systems has matured considerably since the last edition of this guide, there is still no generally accepted single design and construction procedure for brick veneer with a steel stud backing. Both the masonry industry and the cold formed framing industry have published guidelines and recommendations for designers, but these design recommendations are not always consistent and do not address issues critical to designers in the western states such as seismic performance. In addition, changes to the energy codes are also placing new requirements on these walls that effect their design and detailing. This guide seeks to address these inconsistencies and gaps in published guidance and present a rational and comprehensive 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 2018 International Building Code, Chapter 14 and the Building Code Requirements for Masonry Structures, (TMS 402-16), Chapter 12. 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 prolonged 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 Industry Association 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".

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 2018 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.

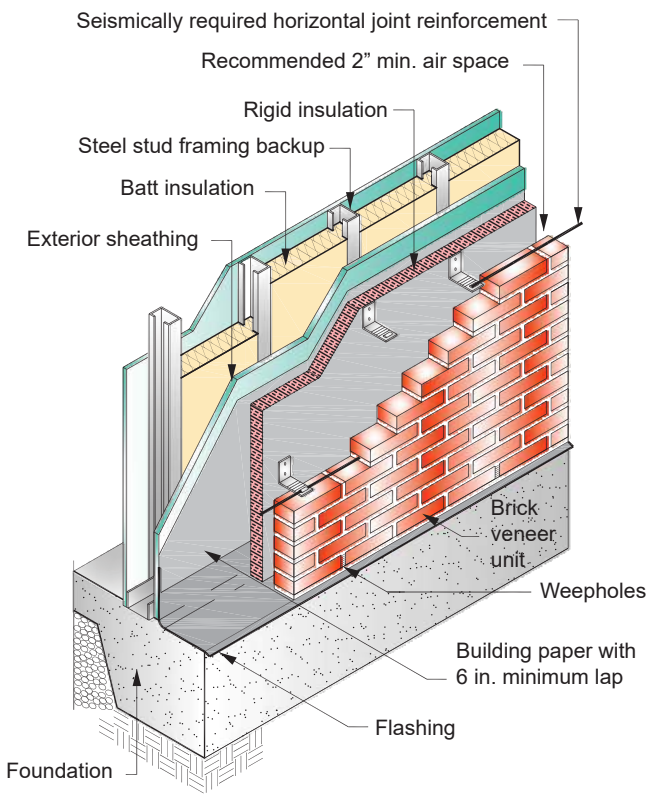


Figure 1-1 The Brick Veneer Over Steel Stud System.

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

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 (Structural Clay Units, SCU). These SCU systems have proven to have high load capacity and often are more economical than providing a separate steel stud backing with brick veneer. Many schools, maintenance facilities, fire stations and apartments have been constructed using load-bearing brick walls [32].

Another system is called structural brick veneer; see the "Design Guide for Structural Brick Veneer" [33]. This is a combination of the veneer concepts to be described in this document and structural brick concepts described in "Notes on the Selection, Design and Construction of Reinforced Hollow Clay Masonry" [32]. 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.

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 bed joints will be allowed to crack under service wind and seismic loading. Crack widths will be controlled to not exceed 0.04 inches to limit the ingress of water.
3. The BV/SS system provides two planes of weather protection to accomplish the code service requirements.
   - The exterior brick veneer acts as the primary barrier.
   - The interior flashed cavity acts as the secondary barrier (drainage wall) for weather resistance.
4. Anchor spacing is based on the prescriptive requirements of TMS 402, or on an engineered design that considers the distribution of anchor forces, which is primarily dependent on the stiffness of the backing, the anchor stiffness, and the degree of cracking in the veneer.
5. The steel stud backing is designed to support full lateral load perpendicular to the wall, without any consideration of the strength or stiffness of the veneer.

2.1.1 NONSTRUCTURAL

The BV/SS system is nonstructural. The term nonstructural characterizes the BV/SS system as isolated from the primary building structural frame and secondary structural 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 dead load other than itself, and transmits any out of plane loads to the structure via the steel stud backing and connections.

Complete isolation is difficult to obtain. Buildings move. They move due to the effects of gravity, foundation settlements, heating and cooling, moisture and wind and 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, and, in the extreme, hazards to the public.

Brick veneer and its connections must be of sufficient strength to transfer wind, seismic, and dead loads to the structural frame. The masonry wythe must have sufficient flexural strength to transfer lateral loads to the wall anchors. As the anchor spacing increases, the strength of the masonry needs to increase. The anchors must be of sufficient strength to transfer out of plane lateral loads 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 a ledger or foundation support. The ledger and its supports must be of sufficient strength and durability to transfer the dead load to the building structural frame or foundation for the life of the building.

2.1.2 DESIGN FOR LEAKAGE

It should be assumed that all veneer masonry might leak and allow water to penetrate the cavity. Masonry leaks more through the mortar-brick interface than through the masonry unit itself.

For this reason, the type of mortar is important in brick veneer. Most commonly recommended for brick veneer are Type N, Portland lime mortars as

they have high bond strength to resist deflection, and shrink less which minimizes hairline cracks in head and bed joints. Additional information on mortar can be found in Section 2.4.9.2.

If the mortar-brick interface is cracked, leakage may increase. Once 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?" A corollary question is "What load is used for checking deflection?"

The question of what loading should be used for deflection checks can be particularly confusing as ASCE 7 and the International Building Code provide several load levels that could be used for this purpose.

One of the most common loads encountered are ultimate loads, which are determined using the IBC load combinations for strength design. These loads have been determined to have a very low probability of occurrence during the life of the building, such that a structure designed to have adequate strength and stability to resist those loads would have a low probability of collapse during its life. Typically, the probability of the load occurring during the life of the structure is 5 to 10%. For environmental loads like wind or seismic, this would correspond to an event expected to happen only every 500 to 1000 years.

The other most commonly encountered type of loads are those determined using the IBC load combinations for allowable stress design. The loads are commonly referred to as service loads or allowable stress design (ASD) level loads; because they are the maximum load the structure would be expected to experience in service. For environmental loads like wind or seismic, this would correspond to an event expected to happen only every 50 to 100 years.

The term "service loads" also refers to more frequently occurring loads that are used in performing serviceability checks. One example of this is found in IBC Table 1604.3. That table provides deflection limits for various structural components. There is a footnote that states that when checking deflections due to wind loads that 42% of the ultimate wind load corresponding to a wind expected to occur once every 10 years.

BV/SS would be classified as "with other brittle finishes" in IBC Table 1604.3, thus mandating that the deflection not exceed $l/240$ when subjected to a 10-year wind load. This is the deflection limit used to proportion the prescriptive stud designs found in the IBC, IRC and AISI S230. This limit is not recommended for BV/SS designs, however, as it will result in excessive crack widths.

Industry standards, however, recommend that steel studs supporting brick veneer be designed to more stringent criteria than required by the IBC. For example, both BIA Technical Notes 28B and AISI CF03-1 recommend a $l/600$ deflection. BIA states that this should be evaluated under "service" wind loads which is understood to be the ASD level loads. In contrast, AISI states that this deflection limit should be evaluated using 70% of the service level loads, which is consistent with the IBC approach as the service level wind loads are 60% of the ultimate wind loads.

If we normalize all of these recommendations to a 10-year service level wind load, we find that the resulting limits are:

- IBC $l/240$ (not recommended)
- AISI $l/600$
- BIA $l/860$

Given the extreme variation in published deflection limits for steel studs supporting brick veneers, it is highly desirable to establish a rational basis for establishing a deflection limit.

Such a rational basis can be established by determining the maximum width of crack that can be accepted in the veneer. The permissible crack width 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.
5. Bond 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.

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

In the absence of extraordinary emphasis on performance, it is recommended that the crack width not exceed 0.04 inches (1.0 mm) under a wind load expected to occur once in ten years [8]. Assuming that the crack occurs at midheight, that the veneer is $3^5/_8$" thick, and that the veneer behaves as a rigid body above and below the crack, geometry can be used to show that a crack width of 0.04" corresponds to a deflection of the veneer equal to $l/360$.

If the intent is to limit the veneer displacement to $l/360$, the steel studs will need to be designed to a tighter limit because the anchors that connect the veneer to the studs allow additional movement before engaging the studs. These anchors will be discussed in detail in Section 2.4.11 of this document. For this discussion, it can be assumed that there may be $^1/_8$" of additional movement due to the anchors. As a result, it is recommended that the deflection of the steel studs not exceed $l/360$ less $^1/_8$ inch.

Using this criterion for steel stud deflection will result in varying crack widths depending on the thickness of the brick. The crack width will be smaller than 0.04" 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.

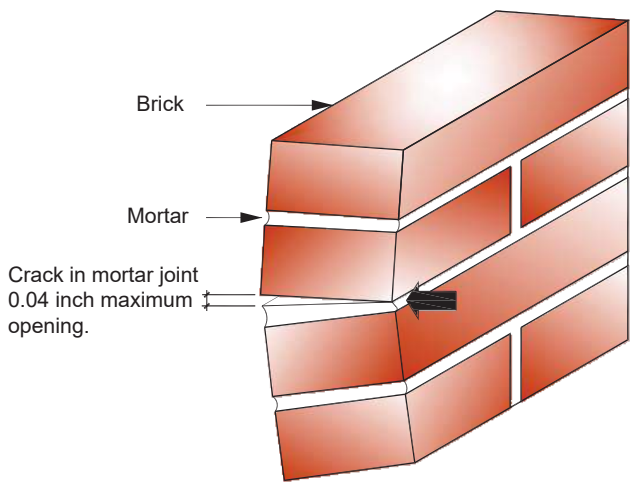


Figure 2-1 Illustration of Cracked Brick Veneer.

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.

Lastly, there may be criteria other than control of crack width in the veneer that may influence the permissible deflection of the backing. For example, when the backing is especially tall, it may be appropriate to limit the deflection to some absolute number to avoid adjoining materials having to accommodate excessively large movements. For example, if the backing

in a ballroom is 30-feet tall, the proposed deflection limit would allow 7/8" of movement in a 10-year wind event, which might be difficult to accommodate in adjoining construction.

2.1.3 RAINSCREEN

The BV/SS system performance depends to a large extent on the prevention of water leakage through the system and a properly designed and functioning weep and vent 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, including upwards, concentrating at discontinuities such as joints, offsets, steps, flashings and copings. Lateral movement of wind driven rain 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 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 prevent penetration or to redirect moisture movement. It is also good practice to eliminate horizontal surfaces (such as sills, raked joints, offsets, 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 weephole, sufficient extension of the vertical flashing needs to be provided to dissipate the kinetic energy with gravity.

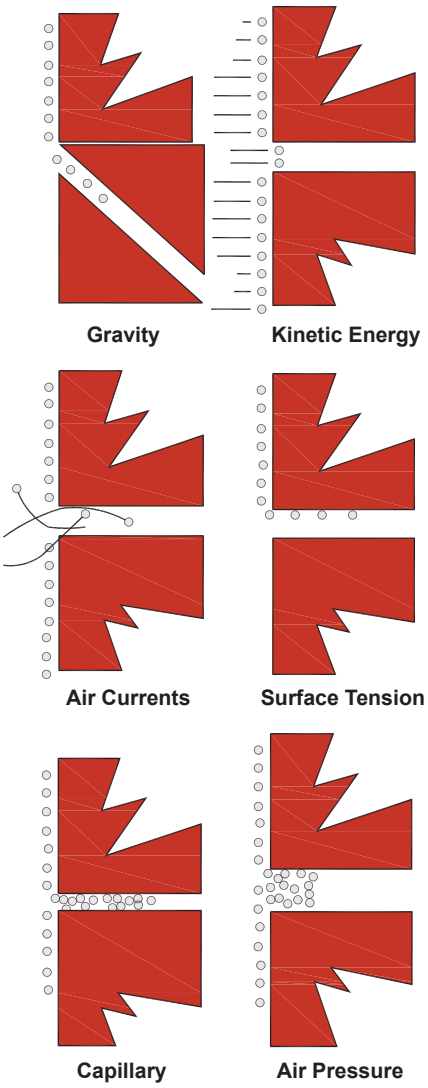


Figure 2-2 Forces Acting to Move Water Through an Opening.

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.

A rainscreen assembly includes the following components:

- Water shedding surface (WSS)
- Vented and drained air space
- Water-resistive barrier (WRB)
- Means of drainage
- Air barrier (AB)

The water shedding surface is the outer skin or surface of the wall or element that is exposed to the weather. The system is described as a rainscreen because the WSS is assumed to have openings. In the BV/SS case, the WSS is the brick wythe. The weepholes 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.

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, and should be backed with some rigid material, which may be difficult at movement joints.

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, and more specifically the force due to differential air pressure.

In practice, the successful control of water leakage requires consideration of all three factors contributing to leakage. Keeping water off the wall is obviously beneficial, but the elimination of openings and the requirement for openings for pressure equalization appears contradictory. In practice it is not. The weephole opening is designed to allow for air movement into the cavity whereas flashing prevents water infiltration while accommodating drainage from the cavity.

2.1.4 SECONDARY DEFENSES

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 weepholes and the flashing.

The final layer of defense against water entering the building is a Weather Resistive Barrier (WRB). The WRB prevents water from exiting the cavity to the inside of the building.

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 (or ribbon) windows. These arrangements are illustrated in Figure 2-3.

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

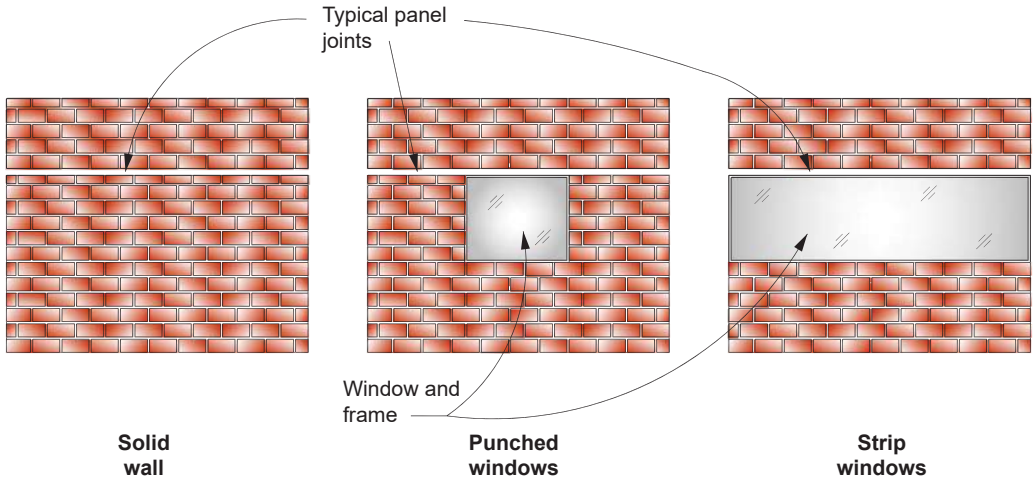


Figure 2-3 Typical Configurations.

In concept, two different steel stud-framing schemes can be used to support the brick veneer. These are described below.

2.2.1 THE BYPASS SYSTEM

The bypass 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 run past (bypass) the edge of slab. The studs are supported by the slab edge or spandrel beam, or by being supported by miscellaneous steel suspended from the floor framing. Placement of the stud and slab edge connector allows for adjustments necessary to accommodate normal building frame construction tolerances. Intermittent horizontal or diagonal braces may be 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.

If miscellaneous steel is provided to support the studs, it can be designed to be suspended from the spandrel beam, or to span from column to column. In either case, it also needs to be detailed to allow it to be adjusted to accommodate the building frame tolerances.

A ledger provides vertical support for the brick veneer and can be fabricated from angles, plates or other miscellaneous steel sections. There are also proprietary ledgers available, which are primarily used to improve the energy performance of the wall. 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 and lateral movement separation necessary between floors. This is illustrated in Figures 2-4, 2-6 and 2-7.

If miscellaneous steel is being provided to support the studs, the ledger can be attached directly to that steel as shown in Figure 2-7. Otherwise, the ledger can be supported from the steel studs as shown in Figure 2-6.

In either case, a stand-off can be used to make the connection from the miscellaneous steel or studs to the ledger angle. The use of a stand-

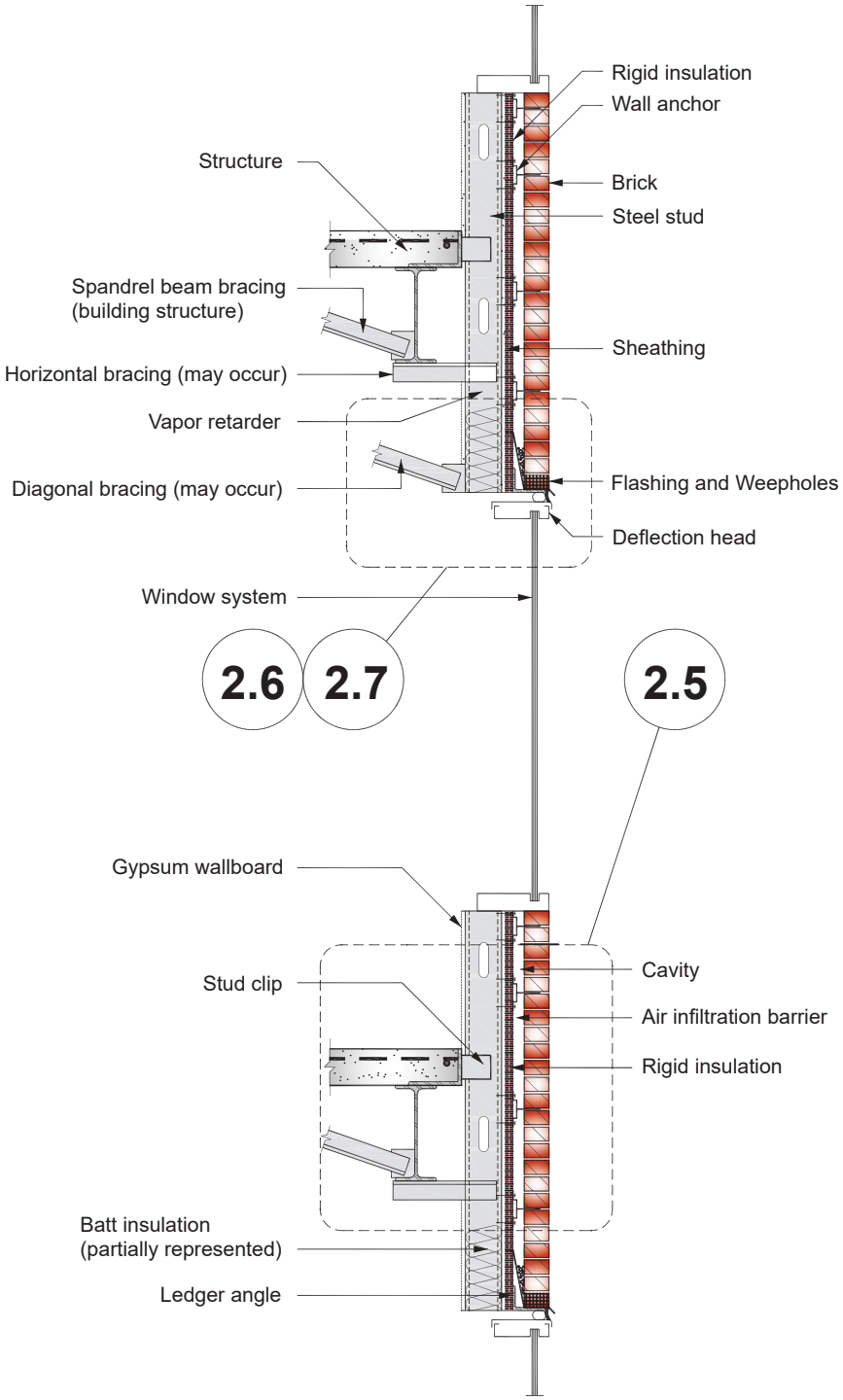


Figure 2-4 Wall Section – Bypass System.

off reduces the area of steel passing through the insulation, improving the energy performance. In these figures, the stand-off is illustrated as a WT. Other shapes could also be used. The ledger can be attached to the flange of the WT by either welding or by providing welded headed studs on the stand-off so that the ledger angle can be bolted to it.

Where the stand-off is attached to the studs, it is possible to weld the stand-off to the studs, which should be done in accordance with AWS D1.3.

As an alternative to welding, AISI CF03 recommends screwing the stand-off to the studs. The detailing of the ledger connections will need to consider the thermal performance of the wall as is discussed later in this document.

Where the ledger is attached to the studs, the 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 connection of the studs to the slab edge or spandrel beam. The eccentricy of the veneer weight relative to the supporting structure is typically resisted by a force couple between the slab edge connection and the bracing.

If miscellaneous steel is not present, bracing is required to resist lateral loads and can be either horizontal or diagonal as shown in Figure 2-4. When using diagonal bracing, consideration should be given to the magnitude of vertical floor deflections, which will impose lateral wall movements and induce additional loads into the stud framing system which need to be accounted for in design. Also, any potential interference with mechanical systems should be considered. This is illustrated in Figure 2-4.

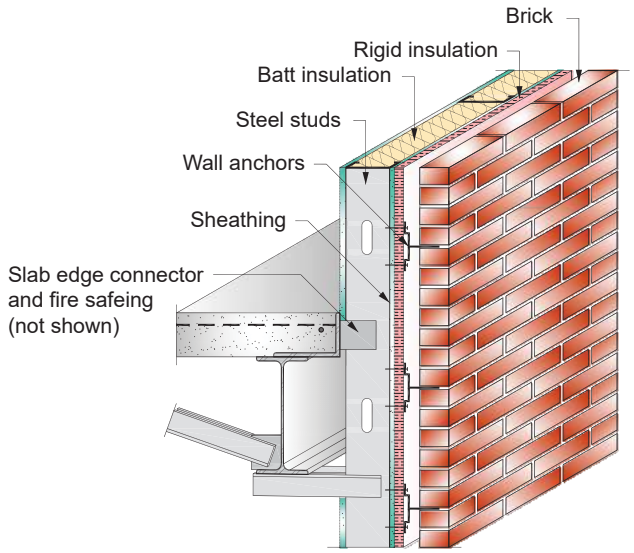


Figure 2-5 Floor Anchor – Bypass System.

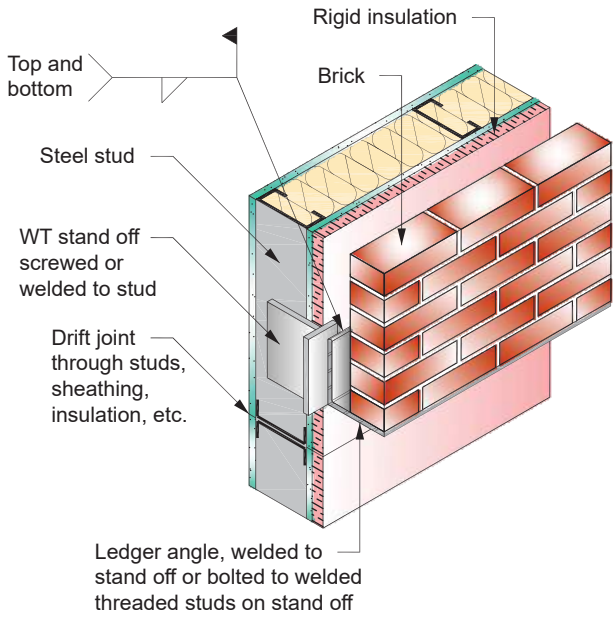


Figure 2-6 Ledger Support to Steel Studs.

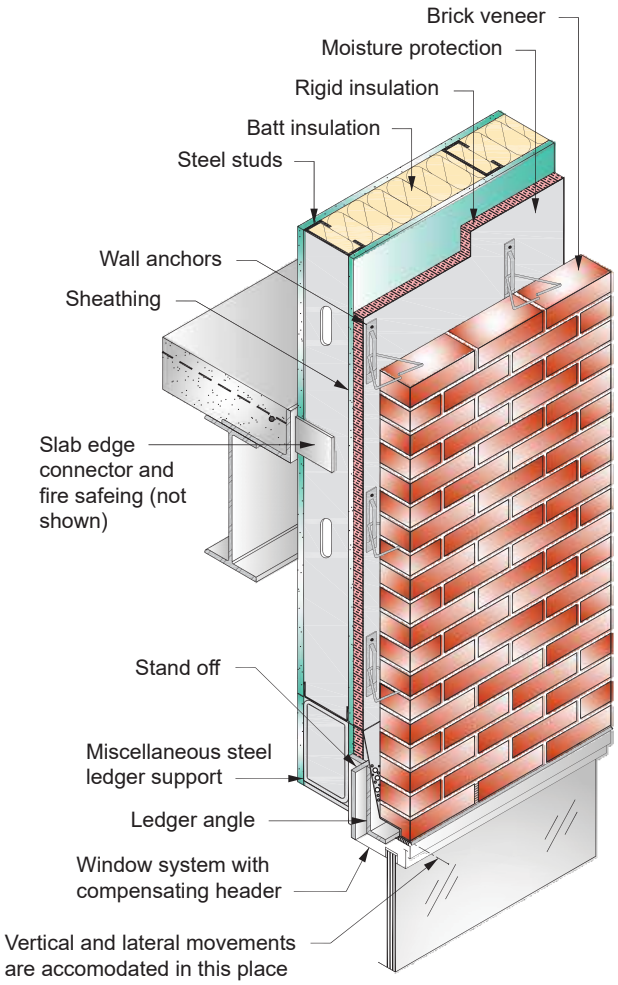


Figure 2-7 Ledger Supported by Miscellaneous Steel.

Out-of-plane wind and seismic loads are transmitted from the brick to the steel stud backing through the brick anchors. Studies have shown 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 anchors nearest the stud supports. When the lateral loads are sufficient to exceed the modulus of rupture of the veneer assembly, the mortar joint will crack. Out-of-plane loads are then transferred to the steel stud primarily through the anchors nearest the crack and the stud support points. For these reasons the determination of anchor forces is more complicated than simply considering the tributary area associated with an individual anchor.

The limited research that has been done on the in-plane behavior of veneers [26] suggests that the in-plane behavior of veneers is generally good, which is supported by the historical performance of veneers in earthquakes.

Where failures have occurred, they have been in the out-of-plane direction. As a result, this Guide focuses on design for out-of-plane effects.

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 INFILL SYSTEM

The infill system works for a solid wall or for a wall with “punched” or individual window openings. The infill system is illustrated in Figure 2-8.

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. This means that the through wall joint that accommodates deflection and building drift must be very close to the underside of the structure.

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. The ledger angle connection must be adjustable in all directions to accommodate construction tolerances in the building structure. In the out-of-plane direction this can be accomplished with shims as shown on Figure 2-9.

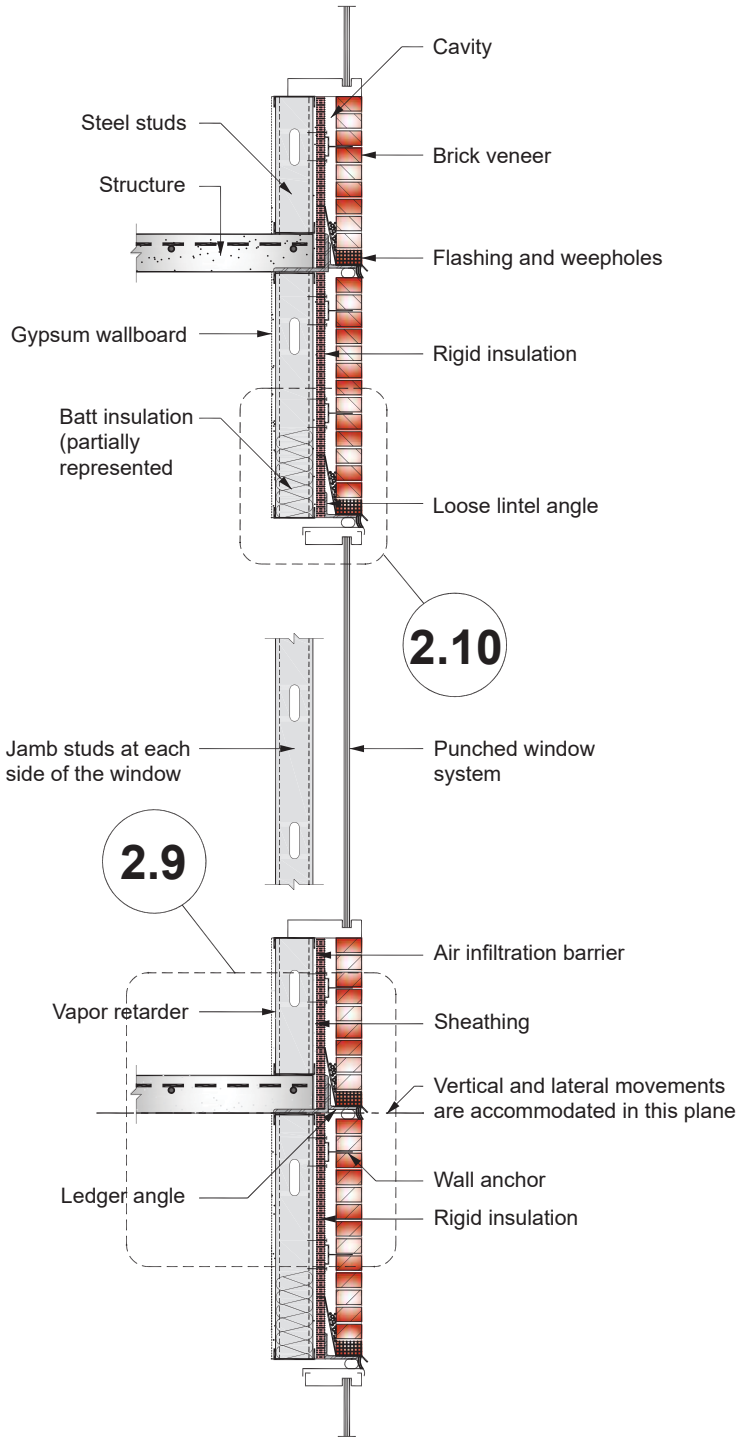


Figure 2-8 Brick Veneer Ledger – Infill System.

Like the bypass system, a joint is provided below the ledger and defines the location of vertical and lateral movement separation between floors. Brick gravity loads and in-plane lateral seismic loads are transferred directly from the ledger into the building frame by the slab edge connection. It is recommended that at least two-thirds of the brick bear on the support [16].

Where openings are required, a loose lintel angle should provide the support necessary to span the opening. A loose 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 2-10 and Figure 2-11. This keeps the weight of the veneer in the veneer and eliminates the potential for differential movements at these locations.

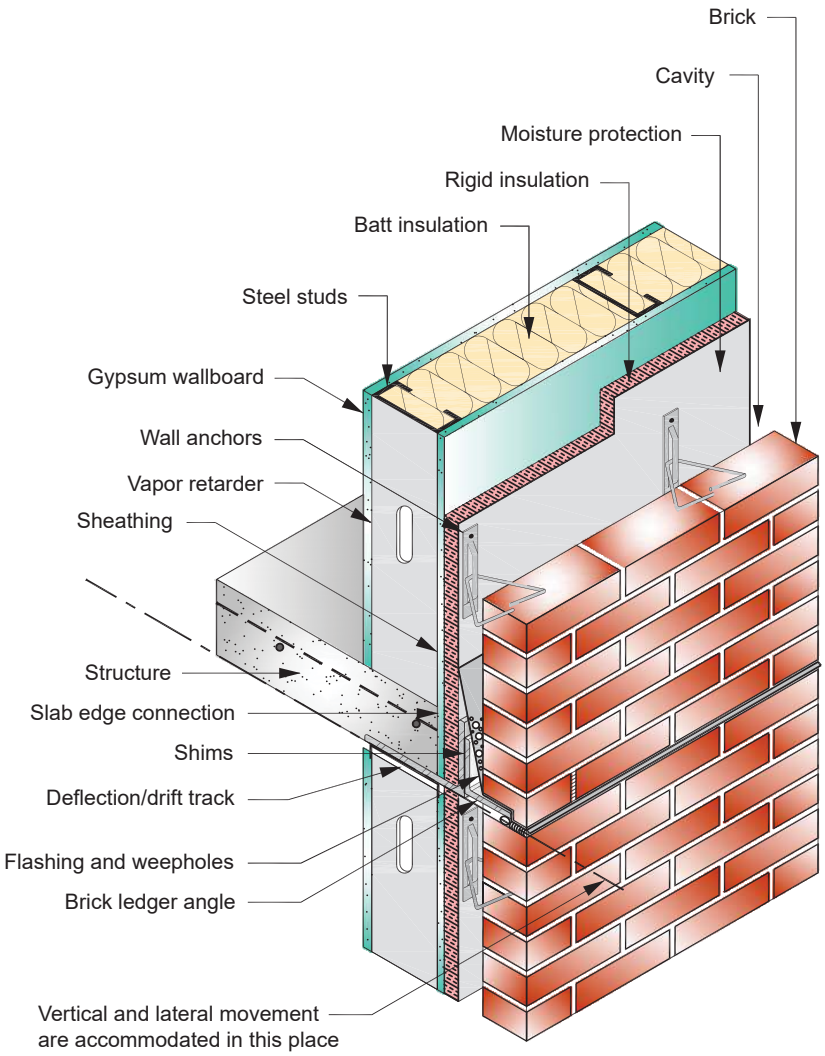


Figure 2-9 Brick Ledger – Infill System.

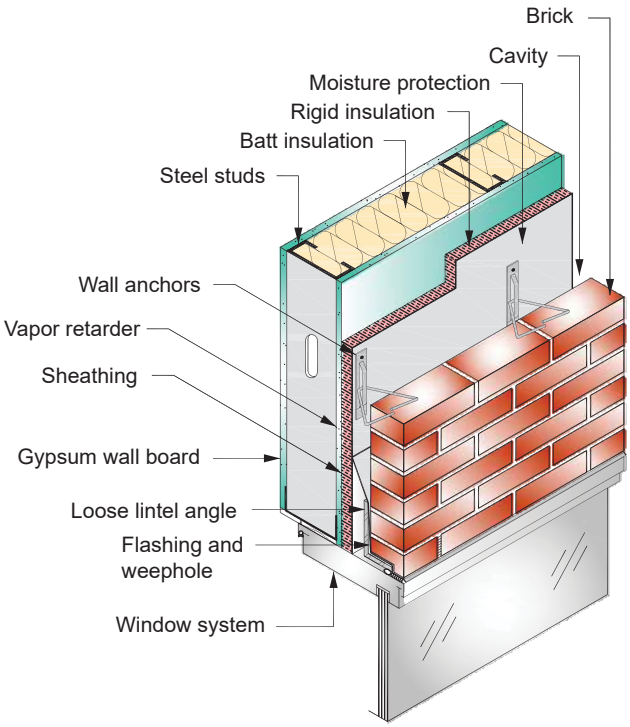


Figure 2-10 Brick Lintel – Infill System.

If it is preferable to see masonry at the head of the window instead of a loose lintel, there are at least two ways that can be achieved – by construction of load bearing brick lintels or by use of proprietary lintels.

An example of a load-bearing brick lintel is shown in Figure 2-12. Due to the limited cover available in these conditions, it is typically desirable to use stainless steel reinforcing bars, or more readily available stainless steel threaded rods. These would typically be designed using the reinforced masonry provisions of TMS 402.

Other materials, such as precast concrete can also be used to support masonry over openings. These are typically designed in accordance with ACI 318, and, like the other lintel types, bear on the masonry veneer at the jambs. They are mortared into place to transfer out-of-plane shear loads, or have their own connectors to the backing.

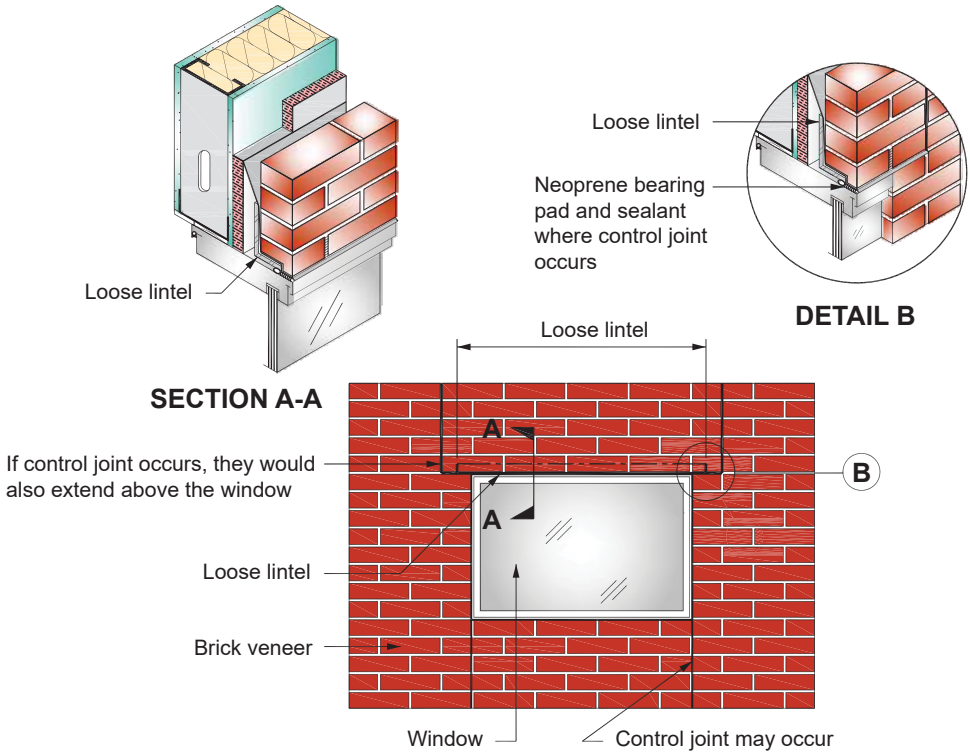


Figure 2-11 Elevation of a Loose Lintel – Infill System.

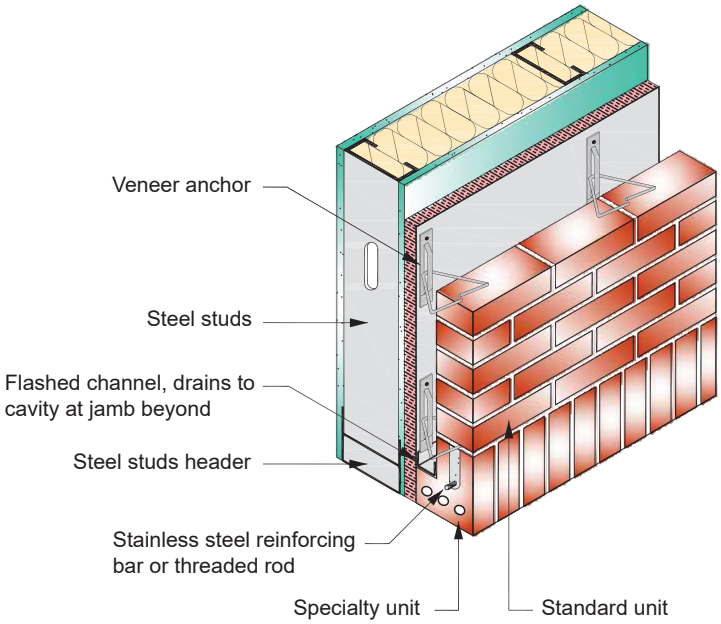


Figure 2-12 Section of a Brick Lintel.

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

Parapets can be challenging to construct with the infill system since it is difficult to cantilever the studs from the roof structure. There are several options available and which are illustrated in Figure 2-13:

- **A:** Lower the ledger angle to below the roof framing and use the bypass system configuration at the roof.
- **B:** Cantilever a reinforced brick or concrete block backing wall from the structure. This works best if there is concrete on the roof for embedment of the wall dowels, although it is also possible to weld reinforcing dowels to steel roof framing.
- **C:** Provide diagonal braces on the inside of the parapet. The roofing can be sloped up on top of these braces so that the braces are within the building envelope.
- **D:** Use a proprietary connector that has been designed and tested for the base of cantilevered stud walls.

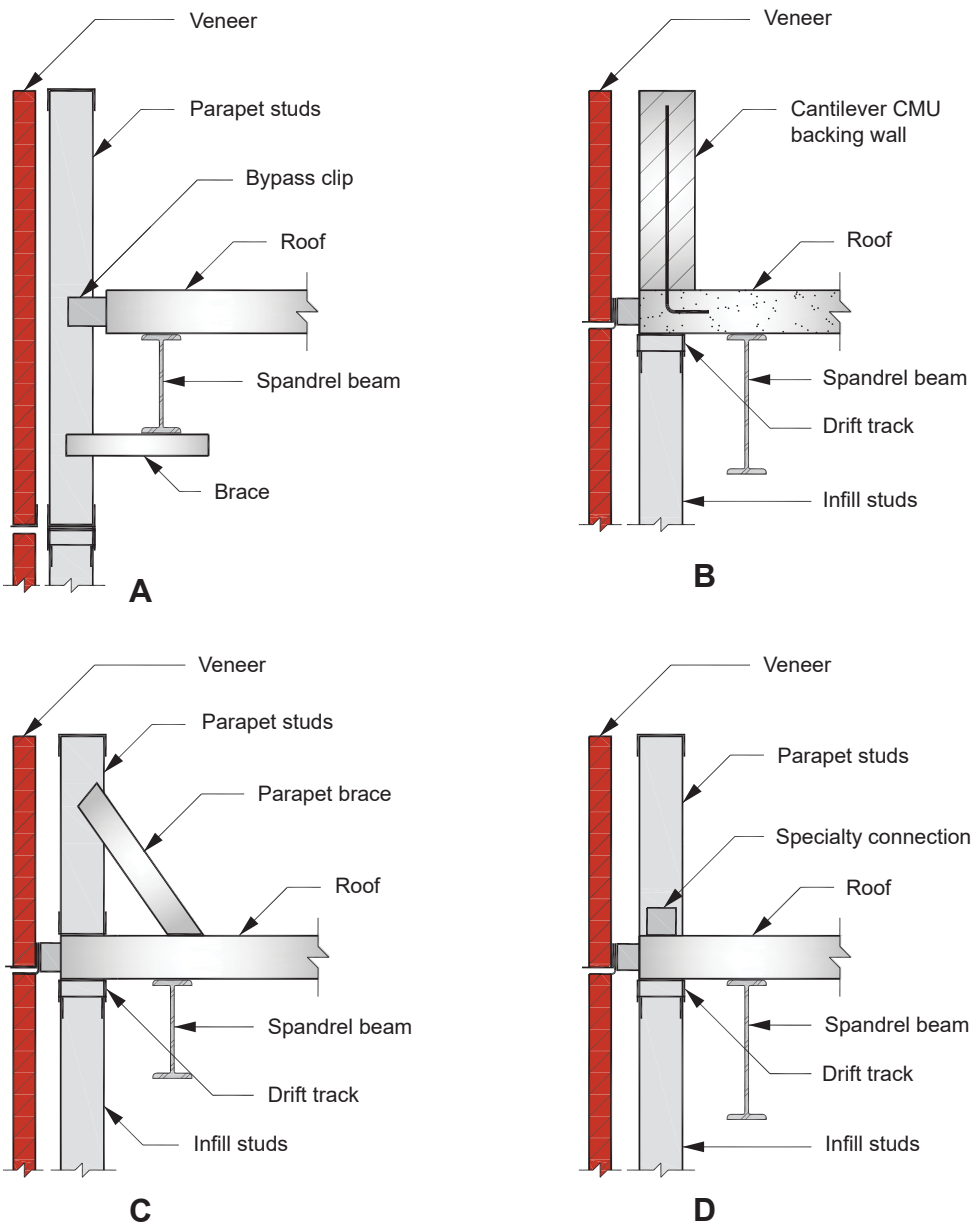


Figure 2-13 Infill Framing Parapet Options.

The detail at the foundation for either the bypass or infill system is illustrated in Figure 2-14.

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 or horizontal brick soffits where allowed; mixing concrete masonry or tile with brick; and precast concrete window sills and heads. These variations require special attention.

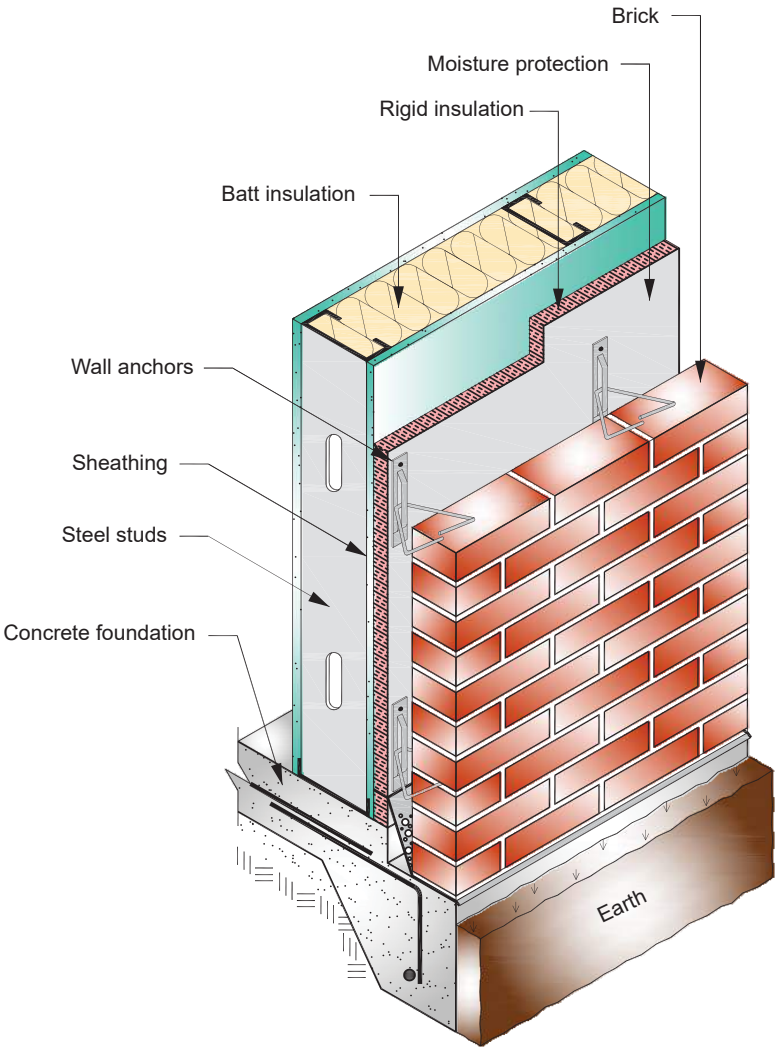


Figure 2-14 Brick Veneer Foundation Detail.

2.2.3.1 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. If eccentricities develop up the wall, the resultant lateral forces must be carried in the masonry anchors and this force must be considered in addition to the wind and seismic forces. Caution must be exercised if this condition occurs. If the wall is laid up, and the mortar has not adequately cured, the anchors 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 compressive capacity of the veneer anchor may be reduced with an increasing cavity width.

In addition to ensuring that surface relief does not create a stability issue with the veneer, consideration should be given to the effect of the relief on the management of water in the wall. For example, if the relief creates a horizontal ledge, water may collect on the ledge and migrate into the wall through the adjacent mortar joint. Similarly, ledges within the cavity can redirect the flow of water back out of the wall in unintended locations which can result in water being retained within the wall for a longer period of time and increased efflorescence.

2.2.3.2 BRICK SOFFITS

When permitted, suspended brick soffits are similar to the masonry lintels discussed above and can be constructed using similar solutions – reinforced masonry elements and proprietary hardware. The primary difference is that the soffit will typically be suspended from the structure above, rather being supported by adjacent vertical veneers. Consideration will also need to be given to bracing the panels to the structure above for in-plane seismic loads and displacements.

Such approaches would likely also address the concerns that some jurisdictions have about the seismic hazard of masonry veneers suspended in an overhead condition. These concerns have led some jurisdictions to prohibit the use of anchored veneers in overhead conditions. Those jurisdictions which currently have explicit prohibitions on overhead masonry include the California Division of the State Architect (which oversees schools and other state facilities) and the California Office of Statewide Health Planning and Development (which oversees hospitals).

Reinforced panels as described would be designed using Sections 8.3 or 9.3 of TMS 402 and as such would not be classified as an anchored veneer. Moreover the reinforcing would provide a level of integrity comparable to a precast concrete panel. Similar arguments could be made when proprietary systems are used as they also provide direct, mechanical support of the masonry with continuous steel elements for integrity.

2.2.3.3 MIXING CONCRETE MASONRY WITH BRICK

Another architectural variation is to combine concrete masonry or cast stone elements 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, these materials 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 the materials made with Portland cement will expand and contract due to moisture changes over time. Both will expand and contract with temperature.

Where the band is only a single course high, it is not recommended to isolate the band from the surrounding masonry and cracking of the head joints should be anticipated. Under typical conditions, these cracks are expected to be narrow, perhaps in the range of .01” to .02”. If this cracking is objectionable, these could be addressed by providing sealant over a raked mortar joint, or tuck pointing the joint after the majority of the permanent volume change movements have occurred.

Where the band is two or more courses high, it is possible to mitigate potential cracking by isolating the band from the clay masonry. This

can be done be placing a bond breaker in the bed joint above and below the concrete masonry band. The band is stabilized in the out-of-plane direction by providing a line of veneer anchors within the band.

Control joints should be considered within the concrete masonry bands based on aspect ratios and local performance.

The clay masonry above and below the band should also be stabilized by placing veneer anchors in the first bed joint beyond the bed joints with bond breaker. See Figure 2-15, adapted from BIA Technical Note 18A for an illustration of this condition.

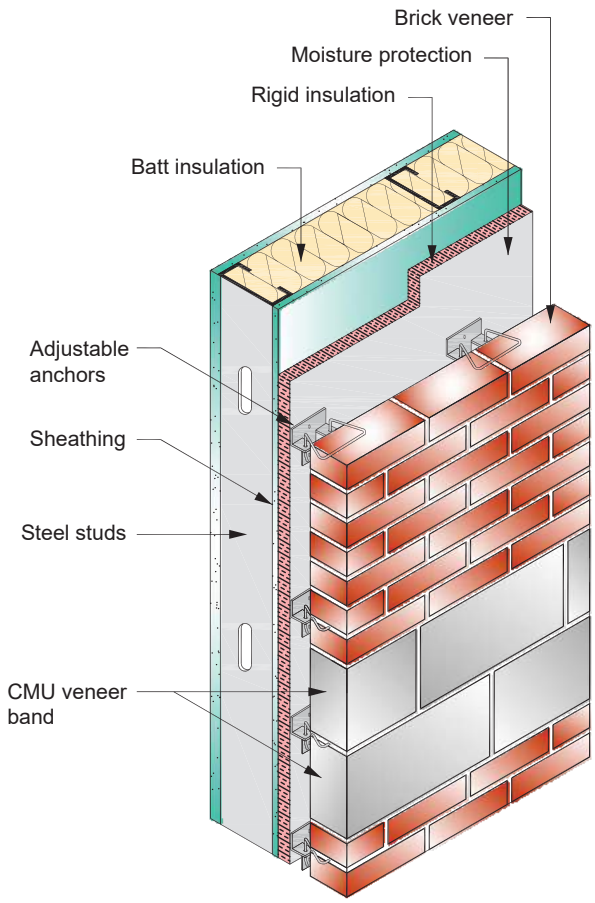


Figure 2-15 Concrete Masonry Band.

2.2.3.4 MIXING PRECAST CONCRETE WITH BRICK

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, and may encounter volume change issues similar to those discussed above for concrete masonry and cast stone bands.

One way to mitigate the expansion and contraction of these larger precast concrete elements is to provide soft joints with caulking and backer rods in the head joints instead of mortar.

2.3 PERFORMANCE

The design life and performance are important qualitative terms that define the things that designers envision. Buildings will not last forever. The owner and designer(s) 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(s). Buildings of this type might include many public, religious, or institutional buildings. Specifically, these are buildings where the additional costs

associated with higher performance and quality are judged to be necessary in meeting the overall project requirements.

Level 2 is intended to signify a level of performance and quality and design life consistent with a code compliant design. 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 anchor and its attachment 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 steel studs may be beneficial due to the potential reduction in crack width, and as a result, reducing the amount of water allowed through the veneer.

2.4 COMPONENTS

The BV/SS system consists of many 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, and is organized starting at the inside of the wall assembly and working towards the exterior of the wall assembly. For a more in depth discussion of the nonstructural components of the wall assembly, the National Masonry Systems Guide is recommended.

2.4.1 VAPOR RETARDER

A vapor retarder limits the transmission of water vapor through the BV/SS system. The vapor retarder is not always required, but when it does occur, it is commonly placed on the interior or “warm in winter” side of the steel stud wall.

A vapor retarder commonly contains points where minor leakage can occur, such as electrical outlets or joints at structural members, but in general these points of minor leakage do not compromise its overall function.

Code requirements for the vapor retarder are found in IBC Section 1404.3. The IBC recognizes several different types of vapor retarders that can be used depending on the project conditions. These include vapor retarders that are part of the insulation backing, certain paints applied on the surface of the gypsum wallboard or a separate polyethylene or aluminum foil sheet. See illustration in Figure 2-16 for a common configuration.

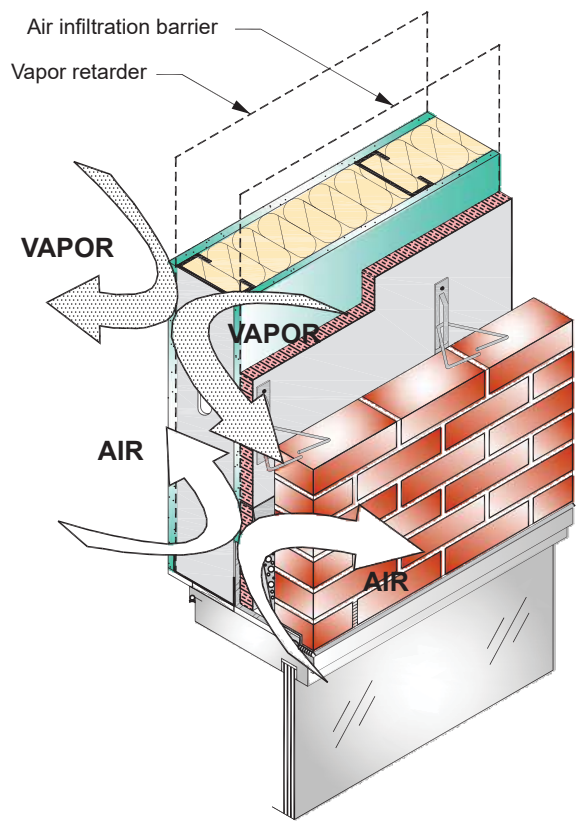


Figure 2-16 Vapor Retarder Illustration.

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.

2.4.2 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 www.ssma.com, the Steel Stud Manufacturing Association.

The minimum thickness of the stud material should be determined as required to meet strength and deflection requirements as well as to provide adequate material for welding and for screw anchorage. BIA Technical Note 28B recommends a minimum thickness of 0.043 in. (43 mil; 18 gage) to provide sufficient engagement of the brick anchor fasteners. If the TMS 402 prescriptive tie design is being used, that thickness becomes mandatory.

The studs must be galvanized and should be galvanized to a minimum of G60 in accordance with ASTM A653. A G90 coating is also available and it provides a 50% increase in galvanizing thickness. Specification of the G90 coating is uncommon, but may be appropriate in especially corrosive environments or where an enhanced service life is desired. Steel stud spacing selected for design should be compatible with the sheathing module, the sheathing span capacity, and the desired anchor spacing for ease of construction. Generally, this will result in a stud spacing of 16 or 24 inches. 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 in AISI S100 "North American Specification for the Design of Cold-Formed Steel Structural Members." AISI S211 "North American Standard for Cold-Formed Steel Framing – Wall Stud Design" and AISI CF03 "Steel Stud Brick Veneer Design Guide" are other useful references for stud design.

2.4.3 STUD CAVITY INSULATION

There are two locations where insulation can be placed in the wall assembly to achieve the required thermal performance – the cavity between the steel studs and the cavity between the exterior sheathing and the veneer.

The decision about the type(s), amount and location of the insulation will depend on the climatic conditions and project requirements, and code compliance.

When insulation is placed in the stud cavity, low density batt insulation is most common. According to the *Masonry Systems Guide*, up to R-15 can be achieved in the cavity space between $3^5/_8$" studs and R-21 in the cavity space between 6" studs.

When insulation is placed in the cavity, care should be conducted in locating the dewpoint such that moisture condensation does not occur within the stud space. This is especially critical when vapor retarders are installed as they may trap moisture in the stud cavity reducing insulation effects and increasing corrosion potential of the studs and reduction of wall anchorage.

2.4.4 EXTERIOR SHEATHING

Wall sheathing requirements will vary with the quality level desired for the project and the climate at the project location. Silicone impregnated, glass fiber mesh faced gypsum sheathing (exterior rated gypsum board) is the most common, type of exterior sheathing. The wall sheathing should be either $^1/_2$" or $^5/_8$" thick (exterior) gypsum sheathing, or other board, fastened with corrosion-resistant screws.

2.4.5 AIR AND WATER BARRIER

The function of the air barrier is to control the flow of air through the wall assembly. Controlling the flow of air has several beneficial effects on wall performance as it limits the flow of heat, the migration of water vapor, and the penetration of rain through the wall assembly. To successfully perform these functions, the air barrier needs to be continuous and needs to be able to withstand the pressure differentials that it will experience, similar to the discussion of vapor retarders above.

The function of the water resistive barrier is to stop the migration of liquid water through the wall.

There are a number of products that can be used to perform one of both of these functions. One common approach is to use a single product that performs both functions, and which is applied to the exterior sheathing. These products are available in both a liquid applied and self-adhered sheet form.

2.4.6 EXTERIOR INSULATION

The most effective location for the insulation is outside of the stud and sheathing. This helps move the dewpoint into the moisture controlled cavity. Insulation is placed in the space between the exterior sheathing and the veneer and is generally secured to the sheathing or studs. Some veneer anchors perform this as a secondary function.

When the WRB is placed directly on the exterior sheathing, this insulation will be exposed to water and need to remain effective and not deteriorate under those conditions. One type of insulation suitable for this condition is semi-rigid mineral fiber board insulation.

Rigid insulations, such as polystyrene or polyisocyanurate can also be used. These act as vapor retarders, which may influence the distribution of insulation within the wall.

2.4.7 AIR SPACE

The air space between the brick and exterior sheathing or cavity insulation, if present, is required by TMS 402 Section 12.2.2.7.5 to be a minimum of one inch wide. The air space provides a buffer for wind-driven rain and allows water that penetrates the brick veneer to flow down the inside brick face without migrating across the air space. Except for brick anchors and flashing, the air space should be kept clear of any obstructions that might allow water to bridge across the cavity. Mortar droppings should be prevented from falling into the air space. There are commercially available mortar diverting materials available to assist in achieving this. When mortar droppings do enter the air space, they should be removed, or troweled against the inside face of the units, so that the air space is unimpeded. It is recommended that the quality control program verify that the air space does not get filled with mortar droppings.

2.4.8 FLASHING/WEEPHOLES

Continuous flashing is necessary for the removal of water that enters the cavity space. 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.

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.

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 shown in Figure 2-17.

End dams should be provided to prevent water migration around windows or other obstructions.

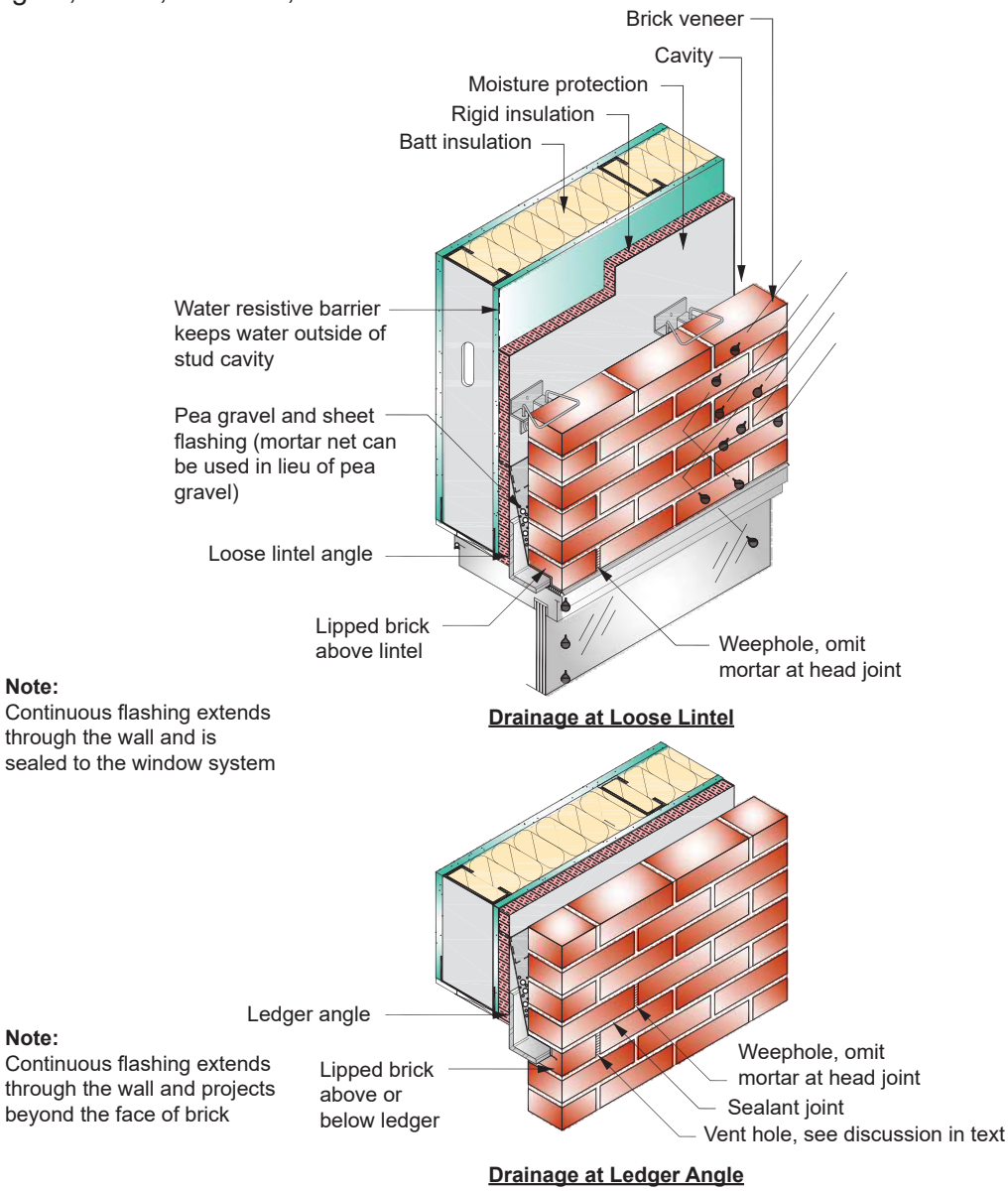


Figure 2-17 Flashing/Weepholes Illustration.

Full head joint weepholes (where the entire height and depth of the head joint is left open or filled with a product that allows drainage) should be provided above the flashing or ledger to drain water back out through the brick veneer. Weep tubes are not recommended as many times they 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 2-17

Pea gravel, proprietary meshes or screens above the flashing will help to prevent mortar droppings from clogging weepholes. Weepholes should be spaced no more than 24 inches apart.

Where 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 assure 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 forced into the wall by any number of mechanisms.

2.4.9 MASONRY

2.4.9.1 MASONRY UNITS

Generally, brick is selected for its color, texture, and size and most commonly is an ASTM C216 Facing Brick. Alternatively, the brick may be an ASTM C652 Hollow Brick, or more rarely ASTM C62 Solid Brick. Face brick comes in three different types based on factors affecting appearance.

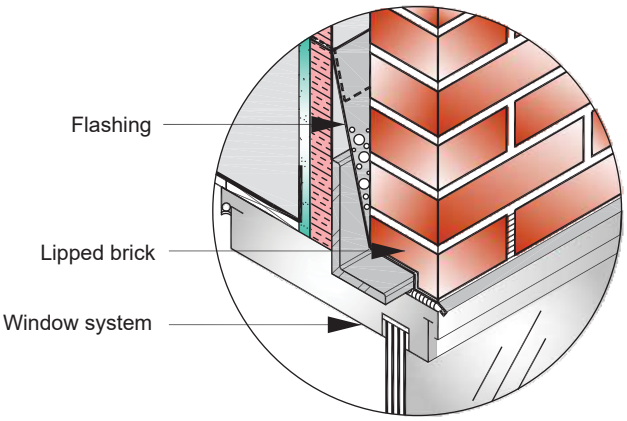


Figure 2-18 Flashing Detail.

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 such as coating, surface textures and/or tumbling.

Face brick also comes in two grades:

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

Brick grade identifies the implied relative durability of the brick. Selection of an appropriate grade of brick is determined by the climatology of the project site. ASTM C216 contains a diagram of weathering indexes for the United States. Grade SW brick is satisfactory in all climates.

There is a wide variety of ways in which units can be laid to achieve pattern and texture. An important distinction for this guide is whether the bond pattern is considered to be “laid in running bond” or “not laid in running bond.” As defined by

TMS 402 Section 2.2, masonry is considered to be laid in running bond when the head joints in successive courses are offset from each other by at least one-quarter of the length of the units. If units are not laid in running bond, there is a requirement to provide joint reinforcing as is discussed in Section 2.4.9.3 below.

2.4.9.2 MORTAR

Mortar should be either Type N or Type S, with Type N being more commonly specified for veneer applications.

Currently, the more reliable mortars contain Portland cement, hydrated lime, sand, and water and, sometimes, certain admixtures. Type S mortar exhibits higher flexural bond strength but is more expensive due to higher cement content.

The higher lime content of Type N mortars are more workable and easier to clean. A benefit of lime mortars is that hydrated lime reacts with carbon dioxide in the atmosphere to produce limestone, which results in autogenous healing of hairline cracks and improved durability of the wall.

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 2-19.

Raked joints are often specified for their appearance, but raking results in a horizontal ledge where water may collect, and the geometry of the joint promotes higher absorption through wicking. These effects can result in increased water migration into the wall and greater potential for efflorescence. If raked joints are desired, the effect may be achieved by a "'deep V". Simple raked joints must be tooled after raking.

Mortar can also be colored through the addition of pigments. These pigments are typically inert and have small effect on the mortar properties.

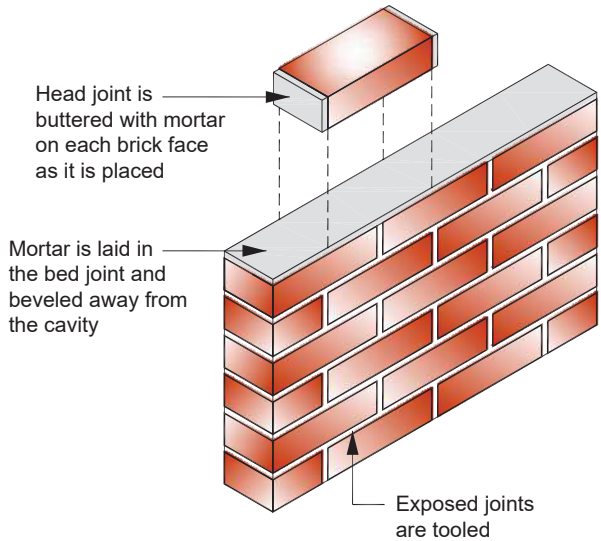


Figure 2-19 Mortar Joint Construction Illustration.

2.4.9.3 JOINT REINFORCING

Lastly, there are two situations where it may be required to provide single wire joint reinforcing in the mortar joint.

The first situation arises when the masonry units are laid in other than running bond. In that event, joint reinforcing is required by TMS 402 Section 12.2.2.10 which reads as follows:

Anchored veneer not laid in running bond shall have joint reinforcement of at least one wire, of size W1.7, spaced at a maximum of 18 in. on center vertically.

The reason for requiring the joint reinforcing is that the veneer needs to be able to span laterally between anchors. When the head joints are aligned (or nearly so), there is the potential for cracking at the head joints; the joint reinforcing is

intended to ensure that the continuity of the wall is maintained across the head joints.

It is recommended that the joint reinforcing be placed in different bed joints than the anchors to avoid conflicts between the anchors and the bed joints, and because there is some evidence that the presence of joint reinforcing at the same location as the anchors may reduce the anchor capacity.

The second situation arises if the building is in Seismic Design Category C or higher and compliance with ASCE 7 Chapter 14 is required. This would be unusual, because when the IBC adopts ASCE for Seismic Design in Section 1613.1, one of the noted exceptions is that compliance with Chapter 14 is not required.

ASCE 7 Section 14.4.6.1 reads as follows:

Provide continuous single wire joint reinforcement of wire size W1.7 at a maximum spacing of 18 in. on center vertically. Mechanically attach anchors to the joint reinforcement with clips or hooks.

Shake table testing of joint reinforcement in veneer [26] has shown that performance with wire reinforcement is no better than, and may be worse than, performance of veneers without the wire. For that reason joint reinforcing is not recommended as a strategy to achieve enhanced performance.

Lastly, there is one condition where the designer may elect to use joint reinforcing, which is when clay and concrete masonry units are used in the wall such that the head joints between concrete units may be subject to tension strains. In these cases, joint reinforcing in the bed joints of the concrete units may help to ensure that the head joint cracking is controlled and kept tight. This is discussed in more detail in Section 2.2.3.3.

When joint reinforcement is used, it should be either hot dip galvanized, epoxy coated or stainless steel as required by TMS 402 Section 6.1.4.2.

2.4.10 LEDGERS/LINTELS

Ledgers and lintels are generally ASTM A36 structural steel angle or bent plate. The code requires that ledgers and lintels be non-combustible and that they be supported by non-combustible construction. Furthermore, the code requires that they be 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, and eventually spalling of the masonry. The use of 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 or designed to accommodate differential movement created by temperature changes and building movements. It is preferable that the joints in the ledger angle align with joints in the veneer that the thermal movements can occur at the same place for both materials. 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 in accordance with ASTM A780. Typical attachments of ledgers to structure are discussed in the bypass and infill system descriptions above.

In order to achieve the required energy performance, it is sometimes necessary to provide stand-offs to allow the cavity insulation to pass between the ledger angle and the wall

sheathing. This allows for a continuous layer of insulation and reduces thermal bridging by reducing the area of steel passing through the insulation. These stand-offs can be constructed with steel tee sections as shown in Figures 2-6 and 2-7, angles, tube steel or other steel components.

Loose lintel angle requirements are similar to those of the ledger angle. Unlike ledgers, loose lintels are not fastened to the backing but are built into the veneer to span openings. As an alternate to steel angles, reinforced masonry or precast concrete lintels can be used.

Ledgers and lintels need to be designed to a vertical deflection limit of $l/600$ in accordance with TMS 402 Section 12.2.2.3.3. Additionally, the structural design of the ledger or lintel should consider minor axis bending of the leg supporting the masonry, and torsion as appropriate. This normally requires the ledger to have a thickness greater than $^3/_8$ inch.

There are several options for the vertical spacing of ledgers.

Often the easiest solution for design and detailing is to provide ledgers at each story as this isolates the BV/SS from movements of the structural frame. This is currently required in seismic design Category E and above by TMS 402 Section 12.2.2.11.3.2.

Economy and energy performance is sometimes improved by providing the lintels at every other floor, or even every third floor. When this is done, the detailing must consider the relative movements between the veneer and the structure, both vertically and laterally. If the wall is detailed such that the relative movement occurs between the veneer and the backing, elements such as windows which are connected to the backing but extend into the plane of the veneer will also need to detailed for the relative movements.

If the prescriptive wall design provisions are used, ledgers must be provided above the initial 30-foot height and at each story above that in accordance with TMS 402 Section 12.2.2.7.1. The 30-foot height to the first ledger was developed for wood framing. The 30-foot limit was originally 12 feet, then 25 feet, and finally 30 feet, all intended to avoid problems due to wood shrinkage in the platform type of wood construction.

This shrinkage does not occur with steel stud framing. Thus, larger distances (heights) between ledgers can be successfully built using the alternate design provisions of TMS 402 Section 12.2.1. However, as discussed above, the accommodation of differential in-plane movements between the BV/SS and the structure is the primary challenge, especially if the structure has a flexible lateral system such as a moment frame which can result in the design story drift due to seismic loads being as high as 2.5%, or in excess of 4-inches for typical story heights.

2.4.11 BRICK ANCHORS

Brick anchors and their attachment are important components of the BV/SS system. Adjustable anchors are required for prescriptively designed veneers attached to steel studs and are typically used for engineered veneers as well. As a result, this section solely discusses adjustable veneer anchors.

There are a number of acceptable anchors for use in the BV/SS system. Two-piece adjustable brick anchors are the most common. Two typical types are shown in Figure 2-20.

They consist of an element embedded in the mortar bed joint and a connecting bracket attached to the steel stud with fasteners. Where embedded element is fabricated from wire, it is referred to as a “pintle”. There are also anchors

where the embedded element is fabricated from sheet steel.

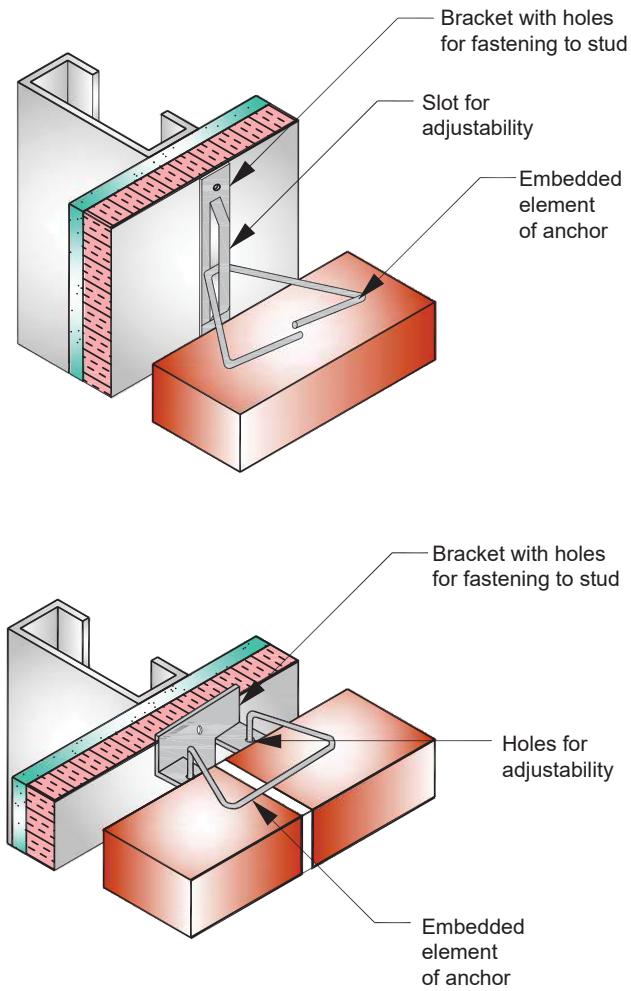


Figure 2-20 Typical Wall Anchors.

The fasteners attaching the anchors to the studs penetrate through the air barrier, water resistive barrier, and the exterior sheathing, where these components occur, before engaging the flange or the web of the stud. The embedded element should extend into the middle third of the bed joint, nor less than $1^1/_2$ inch to provide for a positive anchorage. The size of the anchor specified should be compatible with the cavity width, including rigid insulation if present.

Tension forces are typically transferred from the veneer anchor to the steel stud by a self-drilling fastener screwed through the sheathing and into the stud. These fasteners are discussed in the following section.

Compression forces are transferred by a variety of mechanisms, depending on the design of the anchor. Some anchors have a robust fastener that can resist both tension and compression forces. Others rely on the brick anchor bearing in compression on the sheathing, which in turn bears onto the steel stud backing. The sheathing needs to be strong enough to resist the compression forces; the ultimate compressive strength of gypsum board may be considered to be 350 to 400 psi [19]. Where the sheathing is not strong enough, or the anchor is to be mounted at the face of the rigid insulation, anchors are available with prongs that penetrate through the weaker materials and bear directly against the steel stud.

Minimum requirements for adjustable anchors used in prescriptive designs are established by TMS 402 Section 12.2.2.5.5. Adjustable brick anchor performance is characterized by many factors including:

2.4.11.1 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, anchors may be attached at coursing modules.

Anchors are typically adjustable by $1^1/_4$" which is the maximum permitted by TMS 402 for pintle anchors used in prescriptive designs and which corresponds to about half the height of a typical clay unit, so that no matter where the anchor is positioned vertically, it can be adjusted to engage a bed joint.

2.4.11.2 MAXIMUM CLEARANCE

TMS 402 requires that the clearance provided to allow the free movement of the adjustable portion of the anchor should not exceed $^{1}/_{16}$ inch.

2.4.11.3 STRENGTH

When the space between the inside of the veneer and the backing is not greater than $4^{5}/_{8}$", TMS 402 requires that pintle anchors have one or more legs of wire size W2.8. If two legs or more legs of wire size W2.8 are provided, the space between the inside of the veneer and the backing is permitted to be up to $6^{5}/_{8}$". Larger spaces require an engineered design.

When an engineered design is performed, ties need to possess the axial strength required to meet design requirements.

2.4.11.4 STIFFNESS

The stiffness of the anchor is a very important property as it has a strong influence on the interaction of the veneer and the steel studs. The stiffer the anchor is, the closer the deformations of the brick veneer are forced to match the deformations of the steel studs. Generally, this results in higher tie forces.

The situation is complicated by the fact that the stiffness (and strength) of adjustable anchors varies depending on the as-built position of the adjustable portion of the anchor. Fortunately, stiffness and strength tend to be correlated, so that when the anchor is in the position where it is stiffest and it is attracting the most load, it is also in its strongest position.

For anchor design, it is commonly assumed that the anchor is at the midpoint of its adjustability with strength and stiffness measured at that location.

A recent study [21] reviewed available test data for veneer anchors and proposed generic properties for two types of adjustable veneer anchors as shown in Table 2-1.

Table 2-1. Generic Adjustable Anchor Strength and Stiffness Values

Anchor Type	Diagram	Design Load[1] (lb)	Allowable Load[2] (lb)	Stiffness (lb/in.)
Slotted		330	200	3000
Two-leg pintle		210	125	2500

[1]For use with ultimate loads

[2]For use with service loads

2.4.11.5 POSITIVE ANCHORAGE

The anchor is typically screwed to the steel stud backing. As noted above, this may require penetrating the air barrier, the water resistive barrier, and the exterior sheathing.

When a prescriptive design is provided and the space between the inside of the veneer and the backing exceeds $4^{5}/_{8}$", there are a number of additional requirements for the anchorage to the backing which can be found in TMS 402, Section 12.2.2.5.5.5.2.

2.4.11.6 CORROSION-RESISTANT/NON-CORROSIVE

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

For higher levels of protection against corrosion, it is suggested that stainless steel wall anchors be provided. This might be employed in a Level 1 or institutional grade building.

Galvanized anchors, 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.

Stainless steel is $^1/_3$ as thermally conductive as carbon steel and may be advantageous in walls where energy performance is a key criterion.

Another option when energy performance is important is to use anchors fabricated with components that provide a thermal break. These components are often plastic and are not addressed by the prescriptive provisions of TMS 402. As a result, an engineered design may be required to demonstrate code compliance. See Figure 2-21 for an example of a anchor with a thermal break.

2.4.11.7 TEST RATED

For engineered designs. anchors must have their capacities and other characteristics established from comprehensive testing programs. Unfortunately, there is not an accepted standard for the testing of veneer anchors, and the degree of transparency about the details of the testing varies between manufacturers. Frequently, only the anchor components are tested; the testing does not consider pull out of the anchor from the mortar joint or pull-out of the fastener from the stud. The latter capacity can be determined from AISI S100, but the former can only be determined from available testing. The limited testing that is available suggests an ultimate capacity of at least 600 pounds for a typical triangular shaped pintle properly embedded in the mortar joint [20]. Since this usually exceeds the capacity of the

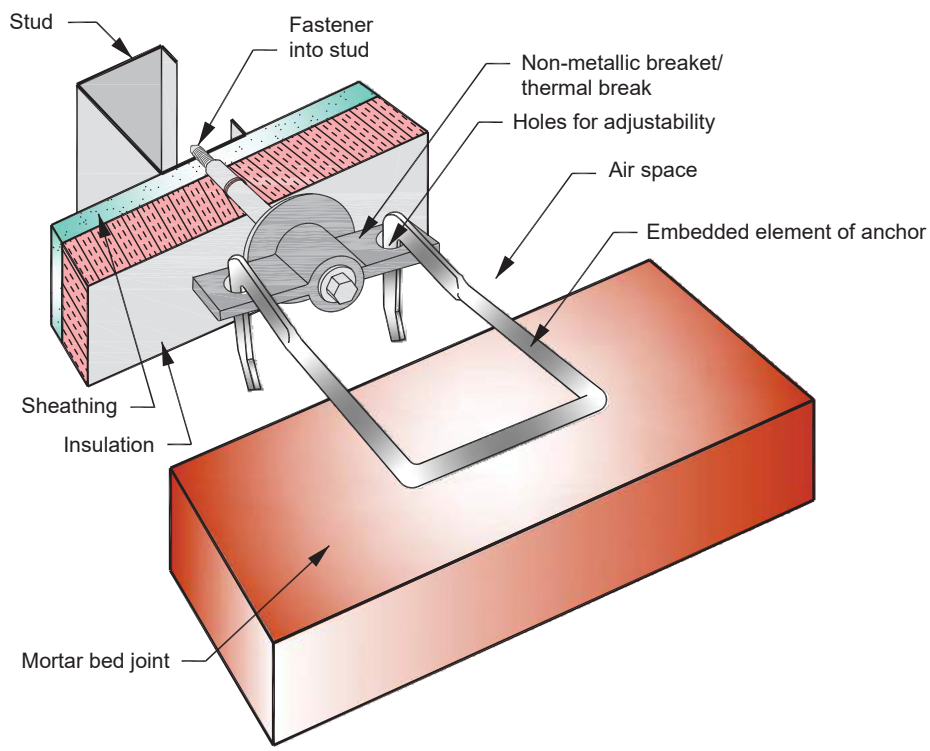


Figure 2-21 Wall Anchor with Thermal Break.

anchor itself, this limit state does not usually control the design.

2.4.11.8 FASTENERS

The screws used to fasten the brick anchors to the steel studs should be specified to comply with ASTM C1513 or to have been qualified through testing using an acceptance criterion established by a reputable evaluation service such as the ICC Evaluation Service. The latter is typically a more stringent requirement.

It is important that these fasteners be qualified to meet one of these standards because 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. There are a variety of ways that manufacturers accomplish this, such as heat treating the cutting point of the screw differently from the shaft, or by fusing one material for the tip of the screw to a different material for the shaft of the screw.

Hydrogen embrittlement and hydrogen assisted corrosion stress cracking occur in hardened steels when a source of hydrogen is available. Sources of hydrogen may be found in the coating itself such as when fasteners are zinc electroplated, or due to galvanic corrosion. The latter can be mitigated by baking the fasteners after coating to drive off the hydrogen.

The fastener must be corrosion-resistant. This can be accomplished by use of stainless steel or by protection with a coating. A variety of coatings are available which include both electrodeposited metallic coatings (typically zinc) and proprietary organic-polymer coatings. The performance of the coatings can be compared through the results of corrosion testing, although it should be noted that the testing does not typically consider damage to the coating that may occur during installation of the screw.

The potential for galvanic corrosion must also be considered as part of the fastener selection. Galvanic corrosion is a 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. Since zinc has a much lower electric potential than stainless steel there is a potential for significant corrosion of the zinc to occur when the two metals are placed in contact with one another.

The electric potential difference between materials is not, however, the sole determinant of the probability or rate of galvanic corrosion. The relative surface areas of the anode and cathode are also important. When the cathode has a much large surface area than the anode, corrosion will be more likely and will happen more rapidly. The converse is also true – due to the small surface area of the (cathodic) stainless steel screws to the (anodic) galvanized stud corrosion of the base metal would occur slowly.

When assessing the corrosion risk of bimetallic screws (mild steel tip with stainless steel threads, for example), the engineer need not focus on the drill point material, as that is not in permanent contact with the stud.

Proper installation of self-drilling/self-tapping screws is to have 3 full threads exposed from the back-side of the assembly. These 3 threads have reduced profiles due to the self-tapping process.

Table 2.2 – Galvanic Corrosion

Base Metal	Fastener Material				
	Zinc (Galvanized)	Aluminum	Mild Steel	Copper	Stainless Steel
Zinc	–	L	L	L	L
Aluminum	M	–	L	L	L
Mild Steel	H	M	–	L	L
Copper	H	H	M	–	L
Stainless Steel	H	H	H	M	–

Notes:
1. Table assumes that the surface area of the base metal is large relative to the fasteners.
2. "L" indicates galvanic corrosion of the fasteners is not expected. Little galvanic corrosion of the base metal is expected.
3. "–" indicates that the fastener material and the base metal are the same; galvanic corrosion is not expected.
4. "M" indicates that a moderate amount of galvanic corrosion of the fasteners may occur. Galvanic corrosion of the base metal is not expected.
5. "H" indicates that a high amount of galvanic corrosion of the fasteners may occur. Galvanic corrosion of the base metal is not expected.

2.4.12 EXPANSION JOINTS

As noted previously, clay masonry tends to expand over time in the presence of water. For this reason, expansion joints need to be provided in the veneer to accommodate those movements. As discussed below, these joints may perform additional functions.

2.4.12.1 HORIZONTAL JOINTS

Horizontal joints need to be provided below each ledger or shelf angle. These joints accommodate vertical expansion of the brick, vertical movements of the building structure due to live loads and lateral movements of the building structure due to wind and seismic loads.

The spacing of these joints are governed by code requirements and detailing considerations, which are discussed in Section 2.4.10 on ledgers and lintels.

The height of the joint must be sufficiently large to accommodate the combination of the expected veneer and building movements, within the limitations of the sealant used within the joints. Since code level seismic movements can be quite large, it is usually acceptable to have sealant failure in extreme seismic events; this should be confirmed with the Owner for buildings where a higher level of seismic performance is intended. At a minimum, the joint and sealant should be designed to accommodate service level seismic movements and code level wind movements without failure.

Structural Movements are discussed in Section 3.2.3, Brick Veneer Movements are discussed in Section 3.2.5, and the Movement Capabilities of Sealants are discussed in Section 2.4.14.

Vertical offsets of horizontal joints should be avoided. If they cannot be avoided, the vertical joint that occurs at the offset, will need to accommodate interstory drifts due to wind and seismic loads, as the veneer of one side of the vertical joint will be supported on a different level than the veneer at the other side of the joint. This can result in joints becoming quite large and aesthetically objectionable.

2.4.12.2 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 Gradient
4. Structural Support
5. Materials

The Brick Industry Association Technical Note 18A, Accommodating Expansion of Brickwork, contains a valuable discussion on the many considerations involved in expansion joint placement. Additionally, Section 3.2.2 of this document 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
9. At or near changes in backing stiffness

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

2.4.13 WINDOW ANCHORAGE AND CLEARANCE

It is generally preferable to anchor windows to the steel stud backing as the window will need to be tied into the air/water barrier on the sheathing to create a weather tight assembly. In no case should the window be anchored to both studs and the brick. 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 sides would short-circuit the isolation that is being achieved with adjustable brick anchors.

In fact, to ensure that the adjustable veneer anchors function as intended, sufficient clearance should be provided between the brick and the window to allow the movement to occur without distressing the sealant joints. When ledgers are provided every floor and the veneer and studs are supported by common elements, these differential movements are small. The effects become much more significant when ledgers are not provided at every floor.

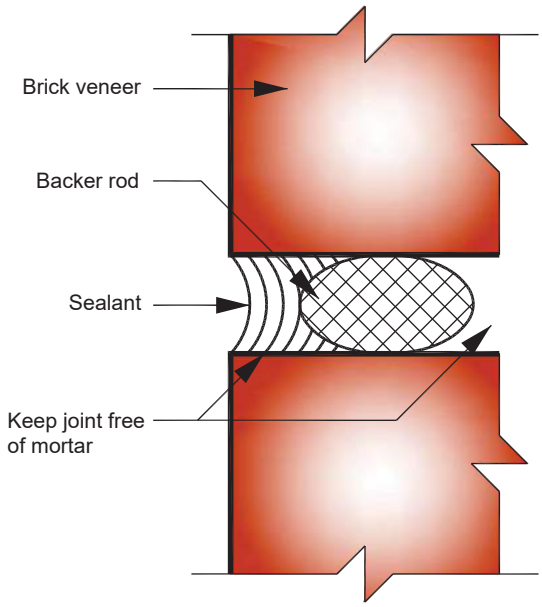
2.4.14 SEALANTS

Sealants provide the first line of protection against rain intrusion into the system. Installation 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 (as necessary based on bond strength testing) and backed with a backer rod, see Figure 2.22. The backer rod serves several functions – it:

- ensures the proper thickness of the sealant
- creates the desirable hourglass shape of the sealant
- acts as a bond breaker so that the sealant is only adhered on two sides.

All of these are important for the sealant to achieve the intended movement capacity.



Note:
Sealant should be completely fill joint
and be half as thick as the joint width

Figure 2-22 Vertical Expansion Joint Detail.

Sealant compatibility tests (peel test) conforming to ASTM C794 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 common to have no bond between some brick and sealant combinations.

2.4.15 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 Brickwork, describes the various accepted methods for initial cleaning and cleaning for subsequent masonry staining. Technical Notes 23A, Efflorescence, Causes and Mechanisms, addresses the subject of efflorescence.

Some manufacturers also make specific recommendations for cleaners to be used on their products. Check with the manufacturer before proceeding with any cleaning activities.

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 the passage of water in liquid form 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 6A, Colorless Coatings for Brick Masonry, is a good reference for further discussion of this issue.

3.0 DESIGN CRITERIA AND PERFORMANCE

3.1 ENERGY

While the aesthetic value and weather protection performance of the BV/SS system is well understood, the energy performance is less well understood. The energy code provides both prescriptive and performance based ways to demonstrate the compliance of the building envelope with the energy requirements.

Of particular interest is the treatment of potential thermal bridges such as the brick ties and ledger angles. These elements act as thermal bridges because they are exposed to the exterior environment at the veneer but are also connected to the steel studs on the inside of the building. As a result heat can be transmitted between the interior of the building and the exterior environment, or vice versa.

There are ways that these thermal bridging effects can be mitigated. These include:

- Minimizing the material crossing the thermal barrier (insulation). For example, the brick anchors can be engineered to maximize the spacing between anchors, or ledger angles can be supported with standoffs.
- Minimizing the thermal conductivity of the materials crossing the thermal barrier. Brick anchors can be constructed of stainless steel, or have a plastic, ceramic, or dense fabric thermal break as part of their assembly. Similarly, stainless steel ledger angles can be used, or the ledger can be bolted to the structure with a thermal break installed between the ledger angle and the structure.

Additional guidance and strategies for achieving compliance with the energy code requirements can be found in the *Masonry Systems Guide*.

3.1.1 PRESCRIPTIVE R / U VALUES

In the prescriptive approach to energy design, the code prescribes the energy performance that the exterior wall must meet. This is the most commonly used approach and is based on an assumed static condition; it does not recognize the benefit from the mass of the veneer mitigating the effects of temperature swings. This approach also makes an implicit judgement about the best balance between thermal performance of the exterior envelope and the energy efficiency of the building mechanical and electrical systems.

One of the key definitions of this approach is that of continuous insulation. This is the continuous plane of rigid insulation that is placed on the outside of the sheathing. The International Energy Conservation Code defines this as “Insulating material that is continuous across all structural members without thermal bridges other than fasteners and service openings. It is installed on the interior or exterior or is integral with any opaque surface of the building envelope.” Brick anchors are generally understood to be fasteners and thus are permitted under this provision. Similarly, ledger angles installed using standoffs are generally understood to be in compliance with the continuous insulation provision.

Not all energy codes, however, treat continuous insulation in the same fashion. The Washington State Energy Code, for example has a footnote in the R Value table that states “For roof, wall or floor assemblies where the proposed assembly would not be continuous insulation, an alternate nominal R-value compliance option for assemblies with isolated metal penetrations of otherwise continuous insulation is . . .” What follows is a table that defines additional amounts of insulation that are required to compensate for

the metal penetrations. If the area of penetrations is less than .04% of the wall area, there is no penalty. In no case, is the area of metal penetrations allowed to exceed 0.12%. For some context, the percentage area of penetrations to the wall area for some typical conditions are as follows:

- $^1/_2$" thick continuous horizontal ledger angle spaced at 12 feet on center vertically: 0.35%.
- $^1/_2$" x 6" standoff for the support of a ledger angle are used at 48" on center horizontally and 12 feet on center vertically: 0.043%.
- Slot type adjustable anchors at 16" on center each way, with (2) prongs and (2) #10 screws: 0.22%.
- Adjustable anchors at 16" on center each way, with a $^1/_4$" diameter barrel passing through the insulation: .019%.

This demonstrates compliance with the Washington Energy Code R/U factor provisions is possible, but requires thoughtful detailing and anchor selection.

A problem with this approach is that it treats all metals as the same, whereas stainless steel is only $^1/_3$ as conductive as galvanized steel. Presumably brick anchors with thermal breaks would not be required to be counted as a metal penetration, although that might be dependent on the authority having jurisdiction.

3.1.2 NON-PRESCRIPTIVE ENVELOPE TRADE-OFF METHOD

This method allows one to increase the insulation is certain areas, while decreasing the insulation in other areas in order to maintaining the same net overall energy use for the building.

For example: increasing the insulation in the roof may allow one to reduce or eliminate the insulation in all or some of the walls.

3.1.3 NON-PRESCRIPTIVE ENERGY COST BUDGET METHOD

As an alternate to the prescriptive approaches, an energy model of the complete building can be constructed in accordance with ASHRAE 90.1, to demonstrate that the overall energy use (cost) of the building is no greater than that of the same building, if it was designed comply with the prescriptive requirements. This allows rational tradeoffs to be made between the building envelope and building systems.

3.1.4 NON-PRESCRIPTIVE PERFORMANCE RATING METHOD

This is another alternate to the prescriptive approaches, which also uses an energy model of the complete building, constructed in accordance with ASHRAE 90.1. This method is most commonly used when the energy performance is intended to be better than the code minimum. This method allows a wider range of energy saving strategies to be used in assessing building performance such as, building mass, building orientation, natural ventilation and daylighting.

3.2 STRUCTURAL

3.2.1 PRESCRIPTIVE VS. ENGINEERED

The building codes provide options that allow the construction of some or all of the BVSS system without structural engineering. For certain types of buildings, and with good detailing, this can result in economical, well performing designs.

The veneer and veneer anchors are most commonly provided on a prescriptive basis. TMS 402, Section 12.2.2 allows a wide range

of structures to use the prescriptive provisions unless the velocity pressure, q_z, exceeds 55 psf. Note that when the velocity pressure exceeds 40 psf, that the prescriptive method is limited to buildings with a height not exceeding 60 feet.

The building code also includes prescriptive designs for the steel studs for some residential structures. The two ways that buildings can qualify for the use of prescriptive designs are if the structure is eligible to be permitted using the International Residential Code or if the structure qualifies for prescriptive design by IBC Section 2211.1.2. In the latter case, the framing is provided in accordance with AISI 230 *Standard for Cold-Formed Steel Framing - Prescriptive Method For One- And Two-Family Dwellings*. It should be noted, however, that these prescriptive designs are based on a deflection limit of $l/240$, which is not recommended by this guide.

Engineered design is permitted for all buildings. The following sections discuss the relevant criteria.

3.2.2 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, wind pressures imposed directly on the units and seismic forces generated by its mass.

Other components of the façade that occur within the veneer, such as doors, louvers, and windows, are typically secured to and supported by the backup system. The backup system (steel studs and building frame) must be designed to support any vertical and lateral load imposed by these components. Similarly, if there are appurtenances on the face of the building such as canopies and sunshades, these should be anchored through the veneer and to the backing, and should not rely on the veneer for support.

Design wind forces can be calculated from the code using the provisions for components and cladding. In accordance with the commentary to ASCE 7 Section 26.2, the tributary area for the determination of the wind loads on the backing can be taken as $L^2/3$ where L is the span of the backing.

Design seismic forces are also calculated from the procedures contained in ASCE 7 for nonstructural components, using equations 13.3-1 through 13.3-3 and Table 13.5-1, and considering vertical earthquake effects per Section 13.3.1.2.

The relevant equations are as follows:

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)}\left(1 + 2\frac{z}{h}\right)$$

Where F_p need be no greater than:

$$F_p = 1.6 S_{DS} I_p W_p$$

And F_p shall be at least:

$$F_p = 0.3 S_{DS} I_p W_p$$

According to the commentary of ASCE 7, brick veneers are to be treated as veneers with low deformability outlined in Table 13.5-1, resulting in a_p of 1 and R_p of $1^1/_2$, and an Ω_0 of 2. At cantilevered parapets, we would recommend designing for an a_p of $2^1/_2$. While this is not required by ASCE 7, it is consistent with the amplification factor applied to other cantilevered components. These factors would apply to the veneer itself and the veneer anchors, including the fasteners attaching the anchors to the studs.

The studs should be treated as a nonstructural wall with an R_p of $2^1/_2$ and an Ω_0 of 2. The value of a_p varies depending on whether the studs are cantilevering (for example at a parapet) where $a_p = 2^1/_2$ or spanning between floor where $a_p = 1$.

The design of the fasteners within the stud wall is a source of potential confusion. While Table 13.5-1 includes "fasteners connecting the system" under the category of exterior nonstructural walls, the commentary describes these as being fasteners with low redundancy. This would not apply to screws used to attach cold formed metal framing components to each other. Those typically have both redundancy and reasonable ductility. In Seismic Design Category C and greater, fasteners attaching the steel studs to concrete may be more economically designed using the overstrength using Ω_0, rather than trying to ensure a ductile mechanism.

Table 3-1 Recommended Seismic Coefficients[1]

Component	a_p	R_p	Ω_0
Typical			
Veneer and anchors	1	$1^1/_2$	2
Studs	2	$2^1/_2$	2
Cantilevered Parapets			
Veneer and Anchors	$2^1/_2$	$1^1/_2$	2
Studs	$2^1/_2$	$2^1/_2$	2

[1] Based on ASCE 7 Table 13.5-1

3.2.3 STRUCTURAL MOVEMENTS

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, or are the result of external displacements such as those caused by foundation settlements. Successful design requires that these movements be recognized and incorporated into the design details.

3.2.3.1 BUILDING FRAME

VERTICAL MOVEMENTS

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 be designed to deflect not more than 1/600 of their span under full dead and live load. See TMS 402 Section 12.2.2.3.3. While the code does not mandate consideration of creep, it is recommended that creep effects be included when checking the deflections of concrete and composite structures.

The deflection limit should also be coordinated with the design of other elements within the plane of the veneer. It is possible that a more stringent deflection limit will be required to accommodate architectural detailing at conditions such as window heads.

It should be recognized that camber does not limit deflection and is not a part of the deflection limitation. The veneer weight is applied gradually as the brick is being laid. Where camber compensates for deflection due to the weight of the veneer and the deflection is something more than the 1/600 of the span, it is possible that cracking will be induced in the wall before its completion.

CANTILEVERED FLOORS

When the veneer is supported on cantilevered floors, consideration needs to be given to the possible upward deflection of the slab edge. This can occur if the back span is loaded and the cantilever is not loaded.

When multiple floors are cantilevered, it is theoretically possible have the cantilever loaded on one floor and the back span loaded on an adjacent floor, producing a large differential movement between floors. This condition is not explicitly addressed by the building code, so it is appropriate to apply engineering judgement in deciding whether to consider this condition.

LATERAL MOVEMENTS

Wind and seismic loading are the predominant cause of lateral building movements. Other possible causes of lateral movements include temperature changes, foundation settlements, creep and shrinkage.

Temperature movement in building frames is generally only a concern in structures with uncontrolled environments 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 judgement 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. Where this occurs, additional joints or wider joints may be required to accommodate these movements. 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, configuration and weight.

ASCE 7 establishes drift limits for the strength code-level seismic event and requires consideration of inelastic deformations when checking these limits. The inelastic deformations are determined by amplifying the drifts from the elastic analysis by the factor C_d, which accounts for the nonlinear behavior of the structure. Note that the minimum drift permitted to be used in the detailing of exterior walls is $^1/_2$" per ASCE 7 Section 13.5.3.

There are no code limits for building drifts due to wind load. The BV/SS connections and panel joints should be designed to accommodate the required building frame movement. It may be appropriate to detail wall components that can be easily replaced, such as sealant joints, to accommodate service level wind and seismic movements only.

Of particular note is the condition at building corners where horizontal movement in two orthogonal directions (for 90-degree corners) will occur and must be accommodated. Typical bi-directional (vertical and inplane lateral) deflection track detailing may fall well short of the necessary performance where two orthogonal walls adjoin. This is discussed in more detail further below in "Detailing for Seismic Performance – Corners".

Sources of movement and recommended limits have been summarized in Table No. 3-2.

3.2.4 SEISMIC PERFORMANCE

3.2.4.1 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 the system itself is complex and performs multiple functions. Depending on the level of seismic shaking, damage can occur to the veneer and its backing, which can compromise functional performance of the cladding system and adjacent elements to varying degrees.

Table 3-2

Movement Type	Structural System	Source of Movement	Code Limitation	Recommended Limitation	Typical Values	Isolation Method
Vertical Movement of Floors	Steel or concrete	Differential application of live load. Long term deflection of concrete.	*l*/600	< 0.60 inch	$^1/_2$"	Deflection track at the backup wall head
						Soft joint in the veneer under the ledger angle
	Concrete	Shrinkage with drying	None	(2)	$^1/_{16}$"	Allow the concrete to dry and cure before installing the veneer
		Creep	None	(2)	(2)	Provide vertical control joints every 20 to 30 feet
Vertical Movement of Columns	Steel	Differential elastic shortening	None	(2)	(2)	Only applies to high-rise buildings where the veneer is installed prior to finishing the building frame
	Concrete	Shrinkage	None	(2)	$^1/_{16}$"	Allow the concrete to dry and cure before installing the veneer
		Creep	None	(2)	$^1/_{16}$"	Deflection track at the backup wall head
						Soft joint in the veneer under the ledger angle
Building Lateral Movements	Frame of steel or concrete	Wind	None	0.0025H	$^3/_8$"	Usually absorbed elastically in the system
		Seismic	Varies. Depends on occupancy and structure type	Minimum $^1/_2$"	$2^1/_2$ To 3"	In-plane: Drift track at the backup wall head. Out-of-plane: Leaning of back-up and veneer
						Soft joint in the veneer under the ledger angle
	Shear wall	Wind	None	0.0025H	$^1/_8$"	Usually absorbed elastically in the system
		Seismic	Depends on occupancy and structure type	Minimum $^1/_2$"	$^1/_2$ To $^3/_4$"	In-plane: Drift track at the backup wall head. Out-of-Plane: Leaning of back-up veneer
						Soft joint in the veneer 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. Depends on the structure.

3.2.4.2 CODE LEVEL PERFORMANCE

The minimum level of seismic performance is code compliance, which simply means that the BV/SS is designed to meet the code requirements for strength and accommodation of movements, and no other measures are taken to address performance. Based on the commentary to ASCE 7 Section 13.1.3, the implied performance of a code compliant design of a BV/SS system would be as follows:

- Minor earthquakes: Minimal damage. BV/SS system retains functionality including the air/water barriers.
- Moderate earthquakes: Some damage. Functionality may be affected.
- Design earthquake: Major damage may include loss individual veneer units, but veneer should remains attached to the structure. Functionality may be lost.

This physical reality of code compliant performance is often poorly understood. It is recommended that seismic performance be discussed with the Owner at the appropriate time so that there is not a mismatch between their expectations and what is being provided. This is as true of the primary structure as it is of cladding systems.

For critical facilities – defined as Occupancy Category IV – the BV/SS is required to be designed for higher forces by using a component amplification factor of 1.5. It is intended that this will result in a higher level of performance, such that damage to the BV/SS system will not compromise the continued operation of the facility after the design level event.

3.2.4.3 ENHANCED PERFORMANCE

For projects where code compliant performance is not sufficient, it is possible to design the BV/SS system to achieve better performance. While written for existing buildings, ASCE 41 “Seismic Evaluation and Retrofit of Existing Buildings” provides the state-of-the art framework for achieving better performance through Performance Based Seismic Design (PBSD).

The basic framework in ASCE 41 is to establish a desired level of performance which is associated with a given level of ground shaking. ASCE 41 generally divides the performance of nonstructural components into three levels, although for cladding two of the performance levels are defined identically:

1. Operational Performance Level: “Negligible damage . . . No loss of function or weather tightness.”
2. Position Retention and Life Safety Performance Levels: “Distortion in connections and damage to cladding components, including loss of weathertightness and security. Overhead panels do not fall.”

The two levels of ground shaking considered by ASCE-41 are labeled as BSE-1N and BSE-2N, which correspond to the ASCE 7 design earthquake and maximum considered earthquake (MCE) respectively. A design team need not limit themselves to those levels of shaking, however. One could decide, for example, to design for the life safety performance level in a smaller earthquake that is expected to occur more frequently than the design earthquake.

For anchored veneers, ASCE 41 provides specific requirements to achieve these performance levels based on the level of shaking. Since ASCE 41 assumes the veneer is existing, the following requirements are suggested as an adaptation of the ASCE 41 provisions to new construction:

1) Operational Performance Level:

   a) Forces: Determine per ASCE 41 Section 13.4.3, using a component importance factor, I_p, of 1.5.

   b) Displacements: Determine per ASCE 41 Section 13.4.4. The back-up system is not permitted to yield under this drift, nor are the veneer or sealant joints permitted to be dislodged. If the inelastic (amplified) drift exceeds 2% (using a drift of at least $^1/_2$"), the adequacy of the back-up system to accommodate the drifts must be demonstrated by analysis or testing.

2) Position Retention and Life Safety Performance Levels:

   a) Forces: Determine per ASCE 41 Section 13.4.3, using a component importance factor, I_p, of 1.0.

   b) Displacements: Determine per ASCE 41 Section 13.4.4. For life safety, accessible sealant joints would be permitted to be dislodged. For position retention performance, the nonstructural functions of the BV/SS are not expected to be maintained. For example, the water resistive barrier could be damaged at the position retention performance level. If the inelastic (amplified) drift exceeds 2% (using a drift of at least $^1/_2$"), the adequacy of the back-up system to accommodate the drifts must be demonstrated by analysis or testing.

In applying these provisions, specifically with respect to the drift criteria at the operational performance level, it is important to meet the intent of the provision (to maintain operations) rather than read the provisions too literally. For example, the sealant joints within the veneer may not be necessary for the functionality of the BV/SS to be maintained since the system is designed and detailed assuming water will enter the cavity. On the other hand a sealant joint in the primary air/water barrier within the cavity would need to remain in position and functional.

3.2.4.4 CORNERS

Building corners are especially vulnerable to damage from story drift due to wind or seismic displacement. Consequently, they should receive extra attention in design.

The approach to corners starts with understanding the general strategy for accommodating building drifts. The two basic approached to framing the wall were described in Section 2.2 as the Bypass System and the Infill System. Within these, there are different options for how building drifts can be accommodated, which are illustrated in Figures 3-1 through 3-4.

BYPASS – SPANDREL SYSTEM

In this system there are continuous strip windows, which results in a horizontal band of brick at each floor which 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, which link the panels together, are properly detailed for the drift, which is concentrated within the height of the windows. See Figure 3-1.

BYPASS – LEANING SYSTEM

With this system, the studs associated with each floor are connected to the studs on the floors above and below. It is important that this be done in a way such that the stud system is statically determinant. This means that only one floor will be braced; on Figure 3-2 the roof is shown as being braced. Alternatively, the studs at the floor could have been braced. The statically determinant system allows the studs to lean back and forth to accommodate the story

drifts, without introducing secondary forces. If the system was made statically indeterminant, for example by having braces at both the roof and the floor, the system would not have the flexibility to accommodate the building drifts. The result would be poor performance and possibly failure of the wall.

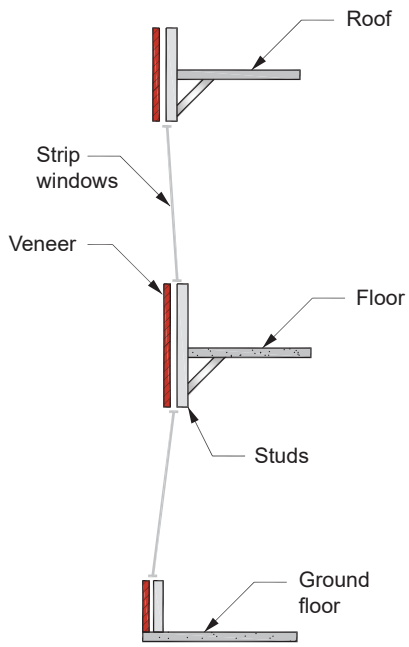


Figure 3-1 Bypass Spandrel System Drift.

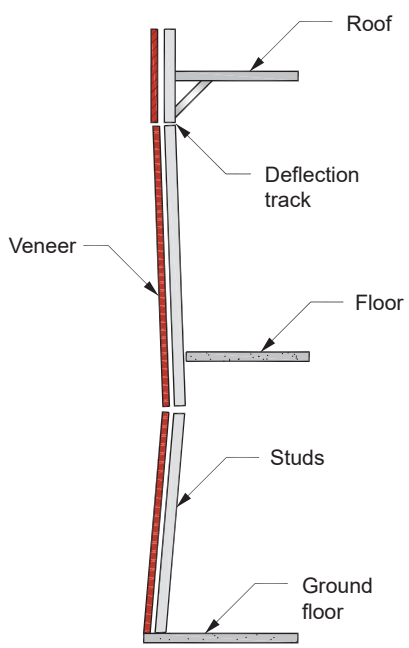


Figure 3-2 Bypass – Leaning System Drift.

The corners of this system will be challenging since the studs are connected to more than one floor.

BYPASS – INDEPENDENT SYSTEM

With this system, the studs are left unconnected at the movement joints; the studs at each floor are independent. This works well for corners, but requires that the sealant joints accommodate lateral displacement in all directions and the ground floor studs have to be cantilevered which can be difficult. This system is depicted in Figure 3-3.

It is possible to combine the leaning and independent systems. Most commonly this would be done by detailing the ground floor as a leaning system, but then detailing all the upper levels as independent from one another.

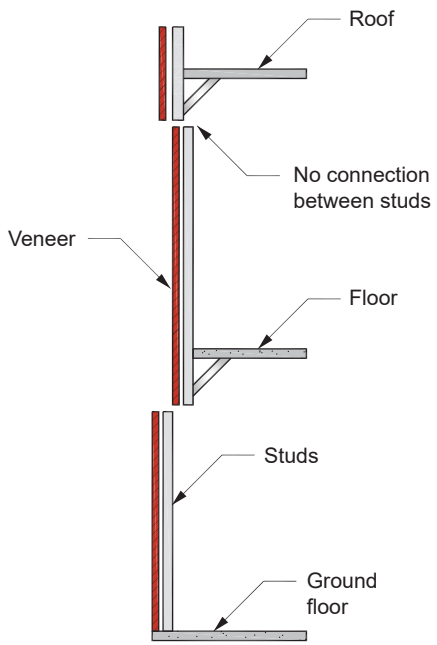


Figure 3-3 Bypass – Independent System Drift.

INFILL – LEANING SYSTEM

With the infill system, depicted in Figure 3-4, the only practical option is to use a leaning system, because an independent system would require cantilevering the studs at each floor. Because the brick veneer and backing are tied to two floors, corners in the Infill System, like the leaning Bypass System must receive special attention.

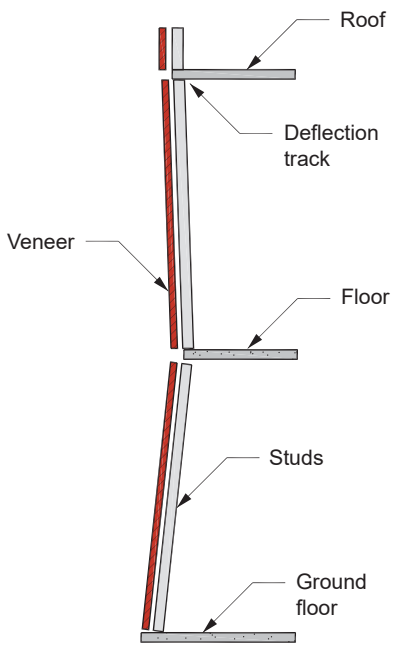


Figure 3-4 Infill – Leaning System Drift.

When detailing corners of the leaning systems, the designer has the following options to accommodate building drifts at the corner:

1. Isolation Joints

This strategy mitigates potential damage in the veneer by providing an isolation joints at all corners. When a single panel has connections 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. The conventional solution to mitigate this effect is to place an isolation joint at the corner.

The joint isolates the masonry cladding 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.

To avoid that effect, the joint would need to accommodate the full seismic drift; the joint may need to be quite large.

This will not, however, prevent the studs from locking, as the stud movements are constrained by the deflection / drift tracks. It is expected that stud backing at the corner will be damaged and could compromise the ability of the studs to keep the veneer on the building,

2. Optimize Joint Location

This is a refinement of Option 1, and is applicable when then building drift is much less in one direction than the other. In these buildings, orienting the joint so that only the smaller story drifts associated with the stiffest axis of the building act across the isolation joint can reduce the joint size.

Like Option 1, Option 2 does not address potential performance problems related to the studs.

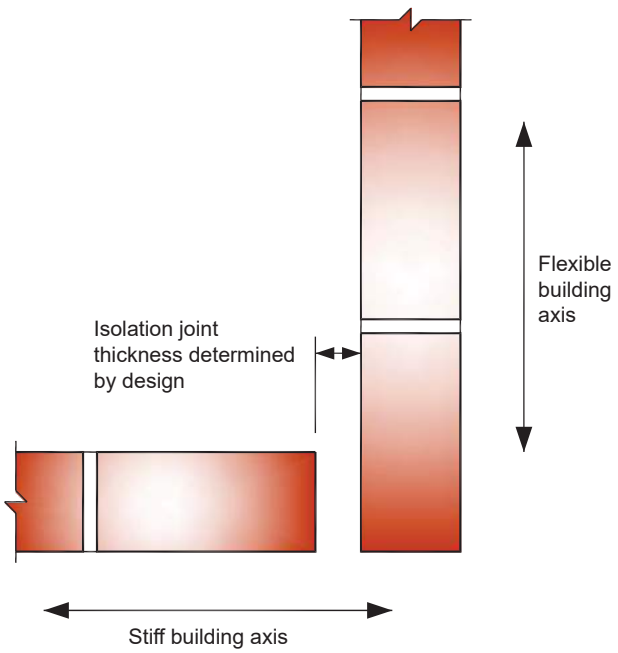


Figure 3-5 Corner Isolation Joint, Floor-to-Floor System.

3. Performance Based Drift Limits

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 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.

When joints are not designed to accommodate the full inelastic (amplified) story drift, the areas of wall nearest the corner 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. It is also possible to design shelves, awnings, or other horizontal projections at critical locations (above building egress doors) to catch any falling debris.

As the decision to use this option 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 and possibly the building official.

4. Sacrificial Joint Closures

Metal panels can be used to more aesthetically close an otherwise large joint. The joint is designed for elastic performance up to and including the elastic lateral displacement of the building. Beyond that limit, the metal can crush, or de-form, or detach on one side, or yield to accommodate the inelastic (amplified) drift without creating large load transfers across the joint, causing damage.

5. Warped Corner Detailing with Joints

It is possible to design the back-up stud framing in the corner areas of a building to accommodate large drifts utilizing small joints in the brick veneer by designing the back-up framing and veneer to warp in a defined zone immediately adjacent to the corner, on both sides of the corners. This approach is depicted in Figure 3-6. The spacing of the joints on either side of the corner is selected to limit the warping deformations as measured on the diagonal. The discussion in Section 2.1.2 may be useful in establishing an appropriate deformation limit for this condition.

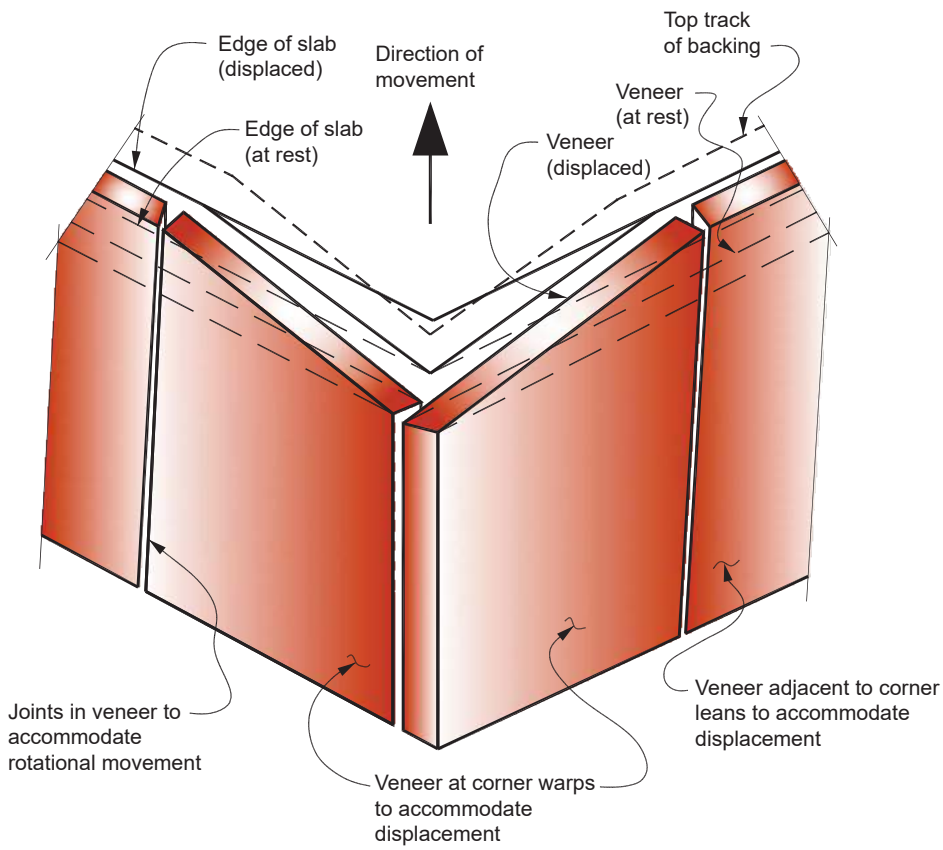


Figure 3-6 Warped Corner with Joints.

6. Warped Corner Detailing without Joints

As an alternate to placing isolation joints at the corner, it may be possible to eliminate the veneer anchors on both sides of the corner for some distance to allow the veneer to warp independently of the backing to accommodate building movements. The limited testing that has been done to validate this approach [29] suggests that eliminating anchors within four feet of the corner allowed the masonry to warp to accommodate around 0.4% drift without cracking.

This design would not meet the prescriptive anchor requirements of TMS 402; in addition to assessing the effect of warping on the veneer, the anchor forces would need to be determined through an analysis and the anchors designed accordingly. The approach discussed in Section 3.3.2 could be adapted for this condition.

Cracking of the veneer in the corner region where there are no anchors needs to be carefully assessed because of the potential loss of a larger section of masonry.

This approach may also mitigate some of risk that stud damage poses to the veneer performance, by disconnecting the portion of the backing that would be most heavily damaged from the veneer.

7. Freestanding Corner

With this approach, the backing transitions from a leaning system to an independent system at the corner. Since the independent framing is attached to only one floor, there is no locking at the corner. This approach is depicted in Figure 3-7.

This will require that a vertical joint be provided through the wall at the transition between the leaning framing and the independent framing. This joint will need to extend from the veneer all the way through to the interior wall sheathing. Since this joint only needs to accommodate shearing motion, it can be relatively small. In the veneer, this joint can be a typical vertical control joint.

For a bypass condition, the free standing condition can be easily achieved by cantilevering the backing from the lower floor as depicted in Figure 3-3. For the infill system a combination of in-plane bracing cantilevered studs, perhaps using proprietary connections, may be required.

3.2.5 BRICK VENEER MOVEMENTS

Thermal and moisture movements in the brick veneer can be estimated from the following equation, adapted from BIA Technical Notes 18 *Volume Changes – Analysis and Effects of Movement:*

$$\Delta = [k_e + k_f + k_t(T_{max} - T_{install})]L$$

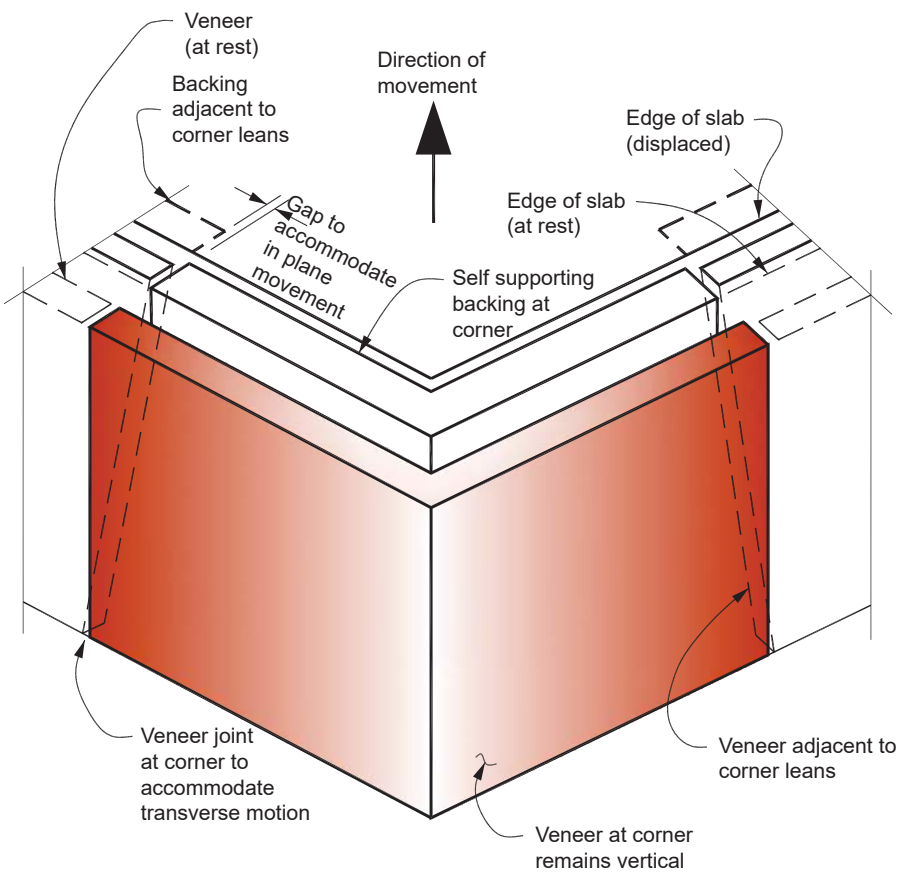


Figure 3-7 Freestanding Corner.

Where:

Δ = Total expansion of the wall (inches).

k_e = Coefficient of Moisture Expansion (5×10^{-4})

k_f = Coefficient of Freezing Expansion (where occurs, 2×10^{-4})

k_t = Coefficient of Thermal Expansion (4×10^{-6} /°F)

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

$T_{install}$ = Wall temperature in degrees Fahrenheit at time of installation.

L = Length of brick veneer wall (inches).

Since the freezing movements only occur when the brick is fully saturated and the temperature is 14° or lower, the freezing term can be omitted. If T_{max} minus $T_{install}$ is assumed to be not more than 100°, this equation can be simplified to:

$$\Delta = 0.0009L$$

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.

Brick veneer construction tolerances should also be considered when sizing the joint. If the dimensional tolerance of the width of the joint is +/-$^1/_8$" then the joint spacing should be reduced such that the maximum movement is $^3/_8$", not $^1/_2$".

For example, if the desired sealant joint is $^3/_4$" with a $^1/_8$" tolerance and the temperature gradient is 100°F, then the maximum joint spacing would be calculated:

$$L = \frac{0.50\left(\frac{3}{4} - \frac{1}{8}\right)}{0.0005 + 4 \times 10^{-6} \times 100} = 347"$$

This assumes the sealant is 50% compressible and results in a joint spacing of 30 feet.

Alternatively, if the desired joint spacing is known, the required joint width can be calculated. For example, if a joint spacing of 24' is desired, then the required joint width for a sealant with 50% compressibility would be:

$$t = \frac{0.0009(24)(12)}{0.50} + \frac{1}{8} = 0.64 \text{ inches}$$

Horizontal expansion joints are required below the ledger angle, as illustrated in Figure 3.8. The joint size is influenced by many factors, including:

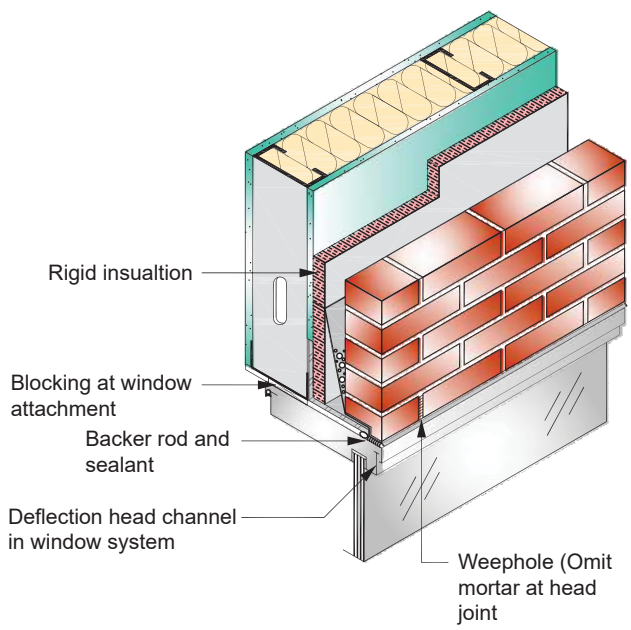


Figure 3-8 Head Joint Illustration – Bypass System.

The joint size is influenced by many factors, including:

1. Long and short term deflection of the support structure, including shrinkage and creep;

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 plus an amount to accommodate construction tolerance. 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. Coordination between the joint design (allowing for movement) and the window function (accommodating movement) must be addressed early in the design process.

The ability of the joint sealant to accommodate shearing movements may also influence the required joint geometry. The ability of the joint sealant to accommodate shearing movements is a function of its ability to be stretched as shown in Figure 3-9.

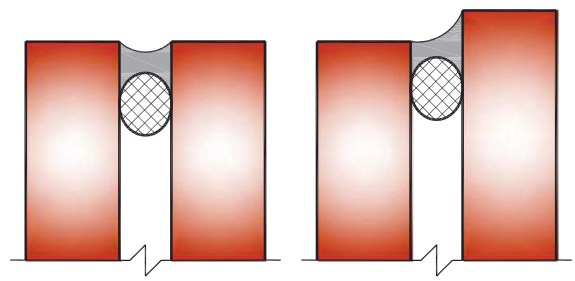


Figure 3-9 Shear Deformation of joint.

According to Dow Corning [18], if the extensibility, E, of the joint sealant is known, the required width of the joint to accommodate a given movement can be calculated as follows:

$$t_{joint} = \Delta \sqrt{\frac{1}{2E + E^2}}$$

Alternatively, if the joint width is known, the shear movement capacity of the joint can be calculated as follows:

$$\Delta = t_{joint} \sqrt{2E + E^2}$$

For example, if a joint is specified to be $^1/_2$" thick and filled with a sealant with 100% extensibility, the movement capacity is:

$$\Delta = \left(\frac{1}{2} - \frac{1}{8}\right) \sqrt{2(1.00) + (1.00)^2} = 0.6"$$

Lastly, it should be noted that in some situations, the combined effects of shear and tension/compression on the sealant may need to be considered.

3.3 STRUCTURAL DESIGN

The brick veneer over steel stud system should be designed to meet the requirements of TMS 402-16, Chapter 12 Veneer, with the modifications as noted below. Additionally, all requirements of the building code for the local jurisdiction should be met.

Unless the prescriptive provisions are being used, a licensed engineer should provide structural design of the BV/SS system. This would generally be the building engineer (Engineer-of-Record), a specialty structural engineer (SSR) 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.

Ideally all components of the BV/SS system that require structural design would be designed by a single structural engineer. Most commonly, however, some components are designed by the EOR (ledgers, possibly loose lintels), some by a specialty structural engineer (steel studs) and some prescriptively designed by the architect (brick veneer and brick anchors). This can result in inconsistencies in the design of the various components and a less than optimum design.

ANCHOR DESIGN

The design of the veneer anchors typically starts with the selection of an adjustable veneer anchor. If one of engineered methods will be used to determine the anchor spacing, the strength and stiffness of the veneer anchors will be required; this is typically determined from manufacturer testing.

Several methods exist for determining the required tie spacing:

- Prescriptive
- Tributary Area
- Rational Design

PRESCRIPTIVE DESIGN

With the prescriptive approach, adjustable anchors are provided at a spacing such that at least one anchor is provided for every 2.67 ft^2 of wall surface, with the additional requirement that the horizontal spacing not exceed 32 inches and the vertical spacing not exceeding 25 inches. If the building is in Seismic Design Category D or higher the maximum wall area per anchor is reduced to 2.00 ft^2. If the building is in a high wind area, that is if the velocity pressure q_z exceeds 40 psf but does not exceed 55 psf, the maximum wall area per anchor is reduced to 1.87 ft^2 and the maximum horizontal and vertical spacing is limited to 18 inches. Velocity pressures in excess of 55 psf require design by one of the following two methods.

Note that additional anchors are also required around openings per TMS 402, Section 12.2.2.5.6.4.

It also considered good practice to provide additional anchors close to the vertical joints in the wall, in the top bed joint below horizontal joints, and as close as possible to the ledger angle.

ALTERNATE DESIGN

TMS 402, Section 12.2.1 allows for the alternate, or engineered, design of the veneer, provided that three basic criteria are met:

- Loads shall be distributed through the veneer to the anchors and the backing using principles of mechanics.
- Out-of-plane deflection of the backing shall be limited to maintain veneer stability.

- The veneer is permitted to crack.

First, Hochwalt, Bennett et al [21] showed that the out-of-plane stability will be met if the steel stud stiffness complies with the following table based on the height of the wall, *h*, divided by the thickness of the veneer units, t_{sp}:

Table 3-3 Deemed to comply h/t_{sp} ratios to provide out-of-plane stability

Deflection of Backing		Maximum h/t_{sp} Ratio
Wind[1]	Seismic[2]	
Code Maximum[3]		67
h/360	*h*/150	100
h/420	*h*/175	117
h/480	*h*/200	133
h/540	*h*/225	150
h/600	*h*/250	167

[1] Under application of 0.42 times the strength level wind load. See footnote "*f*" to IBC Table 1604.3.
[2] Under application of the strength level seismic load.
[3] Per IBC Table 1604.3, the maximum permitted deflection for veneers under wind load is *l*/240.

The values in Table 3-3 were derived to limit the mid-height deflection of the wall under strength level loads such that the centroid of the wall weight remains within the wall section by a factor of safety of 1.5. See Figure 3-10.

It would be possible to exceed the limits in the table, provided that the brick anchors and the steel studs are designed by a second order analysis to provide a stabilizing force to the veneer. This should be rarely necessary.

Once the out-of-plane stability is addressed, there are two possible methods to determine required anchor forces. These approaches are described in more detail below.

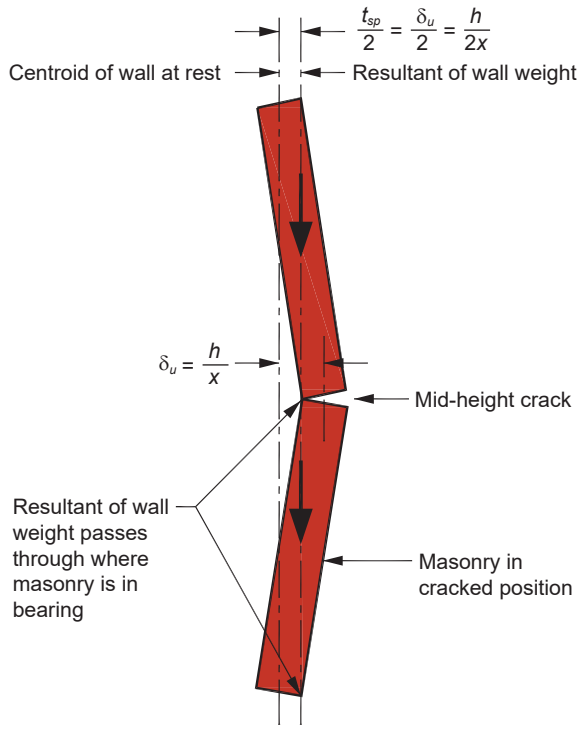


Figure 3-10 Veneer Stability Check.

TRIBUTARY AREA METHOD

A recent study [21] examined several different methods that have been proposed for the simplified determination of anchor forces where prescriptive design was not appropriate. These methods were generally based on the anchor force being based on a factor applied to the tributary area of the anchor or a factor applied to the tributary area of the supporting stud.

To examine the reliability of those methods, the authors performed a parametric study that considered variations in story height, backing stiffness, and anchor stiffness. In the study 144 pseudo nonlinear analyses were performed in accordance with the rational design procedure described below. This study only analyzed the Infill System; all walls were considered to be simply supported at the top and the bottom.

The conclusion of the study was that the best prediction of the actual anchor force was based on the anchor tributary area as shown in Table 3-4:

Table 3-4 Tie Forces

Anchor Stiffness	Strength Level Force
$k_{anchor} \leq$ 2000 lb/in.	2.0 $p_u A_t$
2000 lb/in. < $k_{anchor} \leq$ 5000 lb/in.	2.5 $p_u A_t$
5000 lb/in. < $k_{anchor} \leq$ 8000 lb/in.	3.0 $p_u A_t$
k_{anchor} > 2000 lb/in.	4.0 $p_u A_t$

k_{anchor} = anchor stiffness; p_u = strength level out-of-plane load; A_t = tributary area of veneer anchor

RATIONAL DESIGN

As an alternative to the prescriptive method and the tributary area method, 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 anchor capacities, wall anchor 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 anchors, and attachment elements;
- A step-by-step characterization of the change in system stiffness associated with crack propagation in the masonry. This can be done manually by inserting hinges into the veneer at locations of crack formation, or by the creation of a true nonlinear element to represent the veneer behavior.
- An appropriate representation of the wind and/or seismic loading to which the BV/SS system would be subjected. Because of the nonlinear nature of the analysis it is essential that it be done with strength level forces.

Typically, this could be accomplished with the use of a detailed finite element model of the BV/SS system. 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 several reasons why the added effort may be beneficial to the project:

- Improved energy performance by using greater anchor spacings than would be permitted by prescriptive design.
- Exceeding other prescriptive limits such as the maximum distance from the inside of the brick to the backing, the maximum wind load. Rational design may achieve this more efficiently than the tributary area method.
- 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 anchor 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 ANCHOR DESIGN PROCEDURE – TRIBUTARY AREA METHOD

The Tributary Area Method should only be used with the Infill System. The following steps are suggested:

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

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

Where:

E = Modulus of elasticity of steel stud.

W_{Δ} = Load on brick veneer, wind or seismic, selected for consistency with Δ_{max}.

I_{req} = Required moment of inertia.

l_{max} = Maximum steel stud span.

Δ_{max} = Maximum allowable out-of-plane deflection of brick veneer system. It is recommended that this be checked using a 10 year wind load which is equal to 0.42 times the ultimate component and cladding load calculated in accordance with ASCE 7.

If based on span to depth limit:

$$\Delta_{max} = \frac{l_{max}}{360} - \frac{1}{8} \text{ inch}$$

If based on crack width:

$$\Delta_{max} = \frac{l_{max}}{4t_{sp}/t_{cr}} - \frac{1}{8} \text{ inch}$$

Where t_{sp} is the width of the masory units and t_{cr} is the acceptable crack width. If using a maximum crack width of 0.04”, this can also be expressed as:

$$\Delta_{max} = \frac{l_{max}}{100t_{sp}} - \frac{1}{8} \text{ inch}$$

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

2. Choose preferred veneer anchor or select the generic strength and stiffness properties that will be specified.
3. Calculate maximum tributary area the anchor can support by use of the tributary area method, based on the anchor stiffness and controlling wind or seismic load.
4. Select anchor spacing based on maximum allowable tributary area.
5. Design shelf angle and attachment for vertical load.
6. Design metal stud attachments for controlling wind or seismic load and assuming studs take 100% of the out-of-plane load.

3.3.2 ANCHOR DESIGN PROCEDURE – RATIONAL DESIGN

This method assumes that pseudo-nonlinear model will be developed to determine anchor forces. The pseudo-nonlinear model is a linear elastic model that in interatively modified by inserting hinges at locations where the analysis indicates that the masonry is cracked.

It is also possible to perform a true material nonlinear analysis, which would require developing a nonlinear element for the masonry.

The procedure described can be applied to both the Bypass System and the Infill System.

1. Calculate metal stud size and spacing required based on serviceability limit state as discussed for tributary area method above. Check the stud strength to resist design loads.
2. Choose preferred veneer anchor or select the generic strength and stiffness properties that will be specified.

3. Determine masonry properties based on available information. If the unit supplier can provide the unit strength, use TMS 602, Table 1 to determine f'_m, based on the specified mortar type. Once f'_m is known, the elastic modules, E_m, can be computed from TMS 402, Table 4.2.2. If the unit strength is unknown, it may be necessary to assume a range of f'_m in order to compute a range of E_m. The modulus of rupture, f_r, is determined from TMS 402, Table 9.1.9.2 based on the specified mortar type. It is also useful to compute the cracking moment for the width of the veneer that will be included in the model.
4. Construct an analytical model of the wall system. This will consist of linear elastic elements for steel studs and the veneers. The veneer anchors can be model as link elements with L/AE selected to provide a stiffness matching the anchor stiffness, or true spring elements can be used if they are supported by the analytical software. It will be necessary to assume an anchor spacing to create the model.
5. Apply ultimate loads to the model. We recommend applying all of the loads to the veneer.
6. Analyse the model. Identify the location in the veneer with the highest moment. If it exceeds the cracking moment, insert a hinge in the model at that location. Repeat this step until all the moments in the veneer are less than the cracking moment.
7. Identify the maximum anchor force. If it is less than the nominal capacity, the selected anchors and spacing are adequate. If the nominal anchor capacity is exceeded, there are several options:
   - Reduce the anchor spacing.
   - Use an anchor with a higher capacity. If the stiffness is different than the anchor analysed, it will be necessary to rerun the analysis.
   - Use a more flexible anchor.

   When the analysis needs to be redone, the model must first be returned to its original, uncracked state before restarting the process.
8. Design shelf angle and attachment for vertical load.
9. Design metal stud attachments for demands assuming studs take 100% of the out-of-plane load.

3.3.3 EXAMPLE DESIGN CALCULATION

System:

$3^1/_2$" brick veneer

Type N mortar cement mortar

f'_m = 2,500 psi

E = 1,750 ksi

600S137-43 steel studs at 16" o.c. From AISI Manual

I = 2.04 in.^{4}

M_{nxo} = 21.3 kip-in.

$\phi\ M_{nxo}$ = 0.9 x 21.3 kip-in. = 19.2 kip-in.

12'-0" story height.

Loads:

Dead weight (brick veneer): <u>35 psf</u> vertical (assume 10 psf per inch of brick thickness)

q_z = 28 psf

Component and cladding wind load: 45 psf
Building height not greater that 60 feet.

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*, (TMS 402-16) need to be met.

Assume the following values for seismic forces apply:

Seismic Design Category D

$S_{DS} = 1.0g$

We will check the seismic demands at the highest level of the building, where $z = h$, thus:

$$F_p = \frac{0.4a_pS_{DS}W_p}{\left(\frac{R_p}{I_p}\right)}\left(1 + 2\frac{z}{h}\right) = \frac{1.2a_pS_{DS}W_p}{\left(\frac{R_p}{I_p}\right)}$$

Since this is not a critical facility, $I_p = 1.0$. Since this is not a parapet, $a_p = 1$. For the veneer and the anchors, $R_p = 1^1/_2$, for the studs, $R_p = 2^1/_2$. Calculating the forces on the veneer and anchors we find:

$$F_p = \frac{1.2(1)(1)(35)}{\left(\frac{1.5}{1}\right)} = 28 \text{ psf}$$

Check the other limits

$F_p \leq 1.6S_{DS}I_pW_p = 1.6(1)(1)(35) = 56$ psf

This does not control.

$F_p \geq 0.3S_{DS}I_pW_p = 0.3(1)(1)(35) = 10.5$ psf

This does not control.

Since the seismic load is less than the wind load, the wind load governs.

$W_{Design} = 45$ psf

Verify Steel Stud Size and Spacing:

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

$$\Delta_{max} = \frac{l}{360} - \frac{1}{8} \text{ inch} = \frac{144}{360} - \frac{1}{8} \text{ inch} = 0.28''$$

Use the 10 year wind to check serviceability, W_{ser} = 0.42 x 45 = 19 psf.

$$I_{req} = \frac{5\left(0.019 \text{ x } \frac{16}{12}\frac{1}{12}\right)(12 \text{ x } 12)^4}{384 \text{ x } 29000 \text{ x } 0.28}$$

$I_{req} = 1.46 \text{ in.}^4 \leq 2.04 \text{ in.}^4$ OK

Check if 600S137-43 studs at 16" o.c. have adequate strength

$$M_u = \frac{w_uL^2}{8} = \frac{\left(0.045 \text{ x } \frac{16}{12}\frac{1}{12}\right)(12 \text{ x } 12)^2}{8}$$

$M_u = 13.0$ k-in. $\leq \phi M_{nxo}$

600S137-43 gauge studs at 16" o.c. have adequate strength

DETERMINE ANCHOR SPACING

PRESCRIPTIVE

For prescriptive design, Seismic Design Category D, maximum area per anchor is 2.67 × 0.75 = 2.00 ft^2 per TMS 402, Section 12.2.2.11.2.2. Wind pressure q_z = 32 psf does not control area per anchor.

Provide adjustable anchors spaced at 16” o.c. horizontal and 18” o.c. vertically (2.0 sf) provided that this works with the masonry module. Often these ties would be spaced at 16” o.c. both ways for compatibility with the masonry module.

TRIBUTARY AREA

For Tributary Area design, both generic adjustable anchor types in Table 2-1 have a stiffness between 2000 and 5000 k/in.; the anchor force will be $2.5p_uA_t$ per Table 3-4.

The slotted type has a design strength of 330 lbs, which results in a tributary area per anchor of:

$$A_t = \frac{330}{2.5(45)} = 2.93 \text{ ft}^2$$

Which would allow a 16” x 24” anchor spacing.

The two leg pintle type has a design strength of 210 lbs, which results in a tributary area per anchor of:

$$A_t = \frac{210}{2.5(45)} = 1.87 \text{ ft}^2$$

Which would require a 16” x 16” tie spacing.

RATIONAL DESIGN

For the rational design method, a pseudo-nonlinear model was created. The initial model assumed slotted anchors at a 24” anchor spacing with the first anchor at 12” above the base of the wall.

The modulus of rupture for the masonry is 100 psi per TMS 402, Table 9.1.9.2. The cracking moment is:

$$M_{cr} = Sf_r = \frac{bt^2 f_r}{6} = \frac{(16)3.5^2(100)}{6}$$

$$M_{cr} = 3{,}270 \text{ lbs – in.} = 3.27 \text{ k – in.}$$

In the initial elastic model, the maximum moment in the veneer occurred at midheight and exceeded the cracking moment, so a hinge was inserted at midheight.

After inserting the hinge at midheight, the model was rerun and the moments in the veneer were checked. The moments at the quarter points were still exceeding the cracking moment. A hinge was first inserted at the upper quarter point as the axial load is lower at that location, and then a hinge was inserted at the lower quarter point. With these three cracks, the moments in the veneer were below the cracking strength of the masonry and the analytical work was complete.

The peak anchor force was 198 lbs which was less than the design strength of both the slotted anchor and the two leg pintle anchor; either anchor could be spaced at 16” x 24”.

Next, we investigated spacing the anchors at 16” x 28”, with the first anchor located at 4” above the base of the wall. This also resulted in three cracks in the wall. The peak anchor force was 277 lbs which was less than the design strength of the slotted anchor. This anchor force was enough greater than the design strength of the two leg pintle that we did not deem it worth reanalyzing the wall with the slightly more flexible anchors.

Last, we investigated spacing the anchors at 16” x 32”, with the first anchor located at 8” above the base of the wall. This also resulted in three cracks in the wall. The peak anchor force was 231 lbs, less than the peak load when the anchors were spaced at 28”, due to the more widely spaced anchors resulting in more uniform loads. This was less than the design strength of the slotted anchor.

Summary of results:

	Design Anchor Spacing	
Method	**Slotted**	**2 Leg Pintle**
Prescriptive	16” x 18”	
Tributary Area	16” x 24”	16” x 16”
Rational Design	16” x 32”	16” x 24”

3.4 STRUCTURAL DETAILING

Once the structural design is complete, it must be incorporated into the contract drawings and specifications.

When conveying the anchor requirements, consideration should be given to providing not just the typical spacing of the anchors, but also requirements for the minimum spacing at wall boundaries, such as at control joints and around the perimeter of openings. Minimum requirements for prescriptive anchor designs are defined in TMS 402, Section 12.2.2.5.6.4 and in Section 12.2.2.12 for high wind areas.

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 E783, while those conducted in the laboratory should be performed in accordance with ASTM E283. 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 E514, to measure the permeability of the constructed wall. Additional large scale mockup tests are available using the procedures contained in ASTM C1601.

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 E330, is available for testing exterior windows and curtain walls. Brick panel strength tests can be conducted in accordance with ASTM E72.

Lateral displacement mock-up tests can also be performed to evaluate how the wall system responds to in-plane and perpendicular to plane horizontal movements. These are usually inclusive of a building corner to evaluate the bi-directional displacement performance.

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 (DEFERRED 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, but rather delegates the design responsibility through a performance specification. 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 and building officials 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, generally as a “first install” area. 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.

The mock-up should be left in place until the completion and acceptance of the work.

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. 3 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.

7.1.1.1 TABLE NO. 3	
7.1.1.2 BRICK VENEER OVER STEEL STUD COMPONENTS	
COMPONENT	**SPECIFICATION[(1),(2)]**
7.1 Masonry 04200	
Material	Brick ASTM C216, C62 and C652 (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	H.C Muddox Brick, www.hcmuddox.com
	Interstate Brick, www.interstatebrick.com
	McNear Brick & Block, www.mcnear.com
	Mutual Materials Company, www.mutualmaterials.com
	Pacific Clay Products Inc., www.pacificclay.com
	Summit Brick & Tile, www.summitbrick.com
7.3 Wall Ties 04200	
Anchor – Anchor Bracket Material (see Figure 2.17)	ASTM A366 Steel Plate, Hot-Dip Galvanized (1.5 oz/ft^2) ASTM A153 Class B2,
	ASTM A167, 300 Series Stainless Steel Plate
Anchor Anchor or Clip Material (see Figure 2.17)	ASTM A366 Steel Plate, ASTM A153, Class B2, Hot-Dip Galvanized (1.5 oz/ft^2) ASTM A82 Steel Wire, ASTM A153, Class B2, Hot-Dip Galvanized (1.5 oz/ft^2)
	ASTM A167, 300 Series Stainless Steel Plate ASTM A580, 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)]
Masonry Reinforcement Wire Material	ASTM A82 Steel Wire, ASTM A153, Class B2, Hot-Dip Galvanized (1.5 oz/ft^2)
	ASTM A580, 300 Series Stainless Steel Wire
Screw Fasteners	Self-drilling/self-tapping with mild shank and hardened tip and organic-polymer coating ASTM A449
7.4 Steel Studs 05400	
Material	Cold-Formed ASTM A446 Sheet Steel
Finish	ASTM A525 G60 Hot-Dip Galvanized
	ASTM A525 G90 Hot-Dip Galvanized
Gauge	18, 16, or 14 Note: Specify section properties
Special	16” o.c. normal
7.5 Miscellaneous Steel 05500	
Material	ASTM A36 Structural Shapes and Plates ASTM A500 Tubes
Finish	ASTM A123, Grade 65 (where exposed) Hot-Dip Galvanized (1.5 oz/ft^2)
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 strengthened with a mandatory 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. Weeps and vents are open and free draining.
8. Unfinished work is protected daily.

BRICK ANCHORS

1. Proper anchors are being installed.
2. Anchor tie engages joint wire when required.
3. Anchor bracket is fastened to steel stud framing, not sheathing alone.
4. Anchor anchor 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 2.4.11).
7. Screws are properly engaged in studs.

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 primed, as necessary, and 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.

9.0 REFERENCES

1. American Concrete Institute, ACI 318, “Building Code Requirements for Structural Concrete”, 2014.
2. American Iron and Steel Institute, AISI S100, “North American Specification for the Design of Cold-Formed Steel Structural Member”, 2016.
3. American Iron and Steel Institute, AISI 230, “Standard for Cold-Formed Steel Framing - Prescriptive Method For One- And Two-Family Dwellings”, 2015.
4. American Iron and Steel Institute, AISI CF03-1, “Steel Stud Brick Veneer Design Guide”, 2003.
5. American Society of Civil Engineers, ASCE 7, “Minimum Design Loads and Associated Criteria for Buildings and Other Structures”, 2016.
6. American Society of Civil Engineers, ASCE 41 “Seismic Evaluation and Retrofit of Existing Buildings”, 2017.
7. American Welding Society (AWS), AWS D1.3/D1.3M, “Structural Welding Code – Sheet Steel,” 2018.
8. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Standard 90.1, “Energy Standard for Buildings Except Low-Rise Residential Buildings ASHRAE 90.1”, 2019.
9. The Brick Industry Association, BIA 4, “Introduction to Energy Performance of Brick Masonry”, 2016.
10. The Brick Industry Association, BIA 6A, “Colorless Coatings for Brick Masonry”, 2008.
11. The Brick Industry Association, BIA 18, “Volume Changes – Analysis and Effects of Movement”, 2006.
12. The Brick Industry Association, BIA 18, “Accommodating Expansion of Brickwork”, 2006.
13. The Brick Industry Association, BIA 20, “Cleaning Brickwork”, 2018.
14. The Brick Industry Association, BIA 23A, “Efflorescence - Causes and Prevention”, 2006.
15. The Brick Industry Association, BIA 28B, “ Brick Veneer/Steel Stud Walls”,2005.
16. Clark, Charles; Fried, Cortney and Byrja, James, ASTM STP1612, “Addressing Maximum Design Deflection for Cold-Formed Steel Framing When Used as a Backing for Brick Veneer”, 2018.
17. Clark, Charles; Fried, Cortney and Byrja, James, ASTM STP1612, “History of Cold-Formed Steel Framing Used as a Backing for Brick Veneer”, 2018.
18. Dow Corning Americas, “Technical Manual”, 2017.
19. Gypsum Association, “Gypsum Board Typical Mechanical and Physical Properties “, GA-235-10, 2010.

20. Heckmann Building Products Inc, Test Data for POSITIE Brick Veneer Anchoring System, Undated.

21. Hochwalt, John; Bennett, Richard; Thompson, Jason; Dalrymple, Andy; clark, Charle and Trimble, Brian, “Proposed Changes to the TMS 402 Anchored Veneer Provisions”, 13th North American Masonry Conference, 2019.

22. International Code Council, “International Building Code”, 2018.

23. International Code Council, “International Energy Conservation Code”, 2018.

24. International Code Council, “International Residential Code”, 2018.

25. Masonry Institute of Washington (MIW), “National Masonry Systems Guide: Northwest Edition,” 2016.

26. Okail, Hussein, University of California San Diego, “Experimental and analytical investigation of the seismic performance of low-rise masonry veneer buildings”, PhD Thesis, 2010.

27. Post-Tensioning Institute, TAB.1-06, “Post-Tensioning Manual”, 2006.

28. Precast/Prestressed Concrete Institute, “PCI Design Handbook”MNL-120-17, 2017.

29. Tawresey, John and Twitchell, Kyle, “Warping of Brick Cladding Corners”, *Structure Magazine*, January, 2009, pages 20 and 21.

30. Sweeney, Steven C. and Morefield, Sean W., “Evaluation of Corrosion Resistant Reactive Vitreous Steel Fixtures for Masonry Walls”, National Association of Corrosion Engineers International, 2013.

31. The Masonry Society, TMS 402/602-16, “Building Code Requirements and Specification for Masonry Structures”, 2016.

32. Western States Clay Products Association, “Notes for the Selection, Design and Construction of Reinforced Hollow Clay Masonry”, 2002.

33. Western States Clay Products Association, “Design Guide for Structural Brick Veneer”, 2011.

10.0 CONSTRUCTION COSTS

The *Masonry Systems Guide* includes information on construction costs.

11.0 INDEX

A

B

C

D

E

F

H

I

J

L

M

N

P

R

S

T

V

W

NOTES

NOTES

NOTES

NOTES