BUILDING CODE REQUIREMENTS FOR BRICK VENEER IN SEISMIC AREAS

J. Gregg BORCHELT
Vice President
Brick Industry Association
Reston, Virginia
United States of America
borchelt@bia.org

ABSTRACT

This paper describes anchored brick veneer as used in the United States of America and provides an explanation of the model building codes in use there. The prescriptive requirements as found in the model building codes used in the USA are included. The seismic design provisions for anchored brick veneer in model building codes, including those in the residential code, are explained. Performance of veneers and related structural elements under seismic loading is explained.

KEYWORDS

brick, building code, performance, seismic requirements, veneer

INTRODUCTION

Brick veneer is a popular form of exterior wall cladding in all parts of the United States of America. Though used primarily in residential construction, it is also used extensively in retail, manufacturing, institutional and office buildings. Applications range from single story homes to high-rise structures. The majority of brick is used in the eastern United States, a location that has not historically incorporated seismic activity in design of buildings.

Building code requirements for brick veneer evolved empirically, with minor changes coming about as designers examined the performance of brick veneer. These changes include brick
veneer requirements for performance related to seismic forces. The Federal Government’s mandate to reduce property loss and deaths due to seismic events had a significant effect on the use of brick veneer in the residential market. This mandate increased seismic loads and changed the design and construction requirements for all materials, including limits on the height of brick veneer over wood frame backing. The brick and masonry industries have responded to these restrictions with analytical studies and resulting changes to the requirements for brick veneer and wood frame.

BACKGROUND ON BRICK VENEER

**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.

**Backing:** The wall or surface to which the veneer is secured

These definitions of veneer and backing taken from the 2000 International Building Code, or slight modifications, are found in the model building codes used in the United States. These definitions present several conditions that imply how all veneer materials, including brick, are treated with respect to design and performance. First, the veneer is not intended to resist loads; it is nonstructural. Loads imposed on the veneer are simply transferred to other structural materials designed to resist these loads. This backing resists these loads and transfers them to the structural frame. The exterior surface may be any of a variety of materials, each with specific requirements for thickness and attachment. The prescriptive requirements for attachment are often based on intuition, not engineering. Typically there is a provision in the code that the entire wall assembly must provide a weather-resistant barrier.

When the facing is masonry, it is known as masonry veneer. When the facing is brick it is known as brick veneer. Reasons for using brick include the variety of colors, sizes and textures available and the durability and low maintenance of brickwork. Brick veneer is of one of two types: adhered or anchored. In adhered veneer the brick is attached to the backing by the adhesive force of glue or a cement-based material to a continuous surface on the backing. Adhered brick veneer is not frequently used. Anchored brick veneer (Figure 1) is attached to the backing by a series of regularly spaced steel ties or anchors. There is an air space between the inside surface of the veneer and the outside surface of the backing. The airspace, along with flashing and weep holes, reduce water penetration into the building.

This paper covers only anchored brick veneer, the more widely used type of masonry veneer. Similar elements of veneer construction as found in the various model building codes are covered in the following subsections.

**Brick and Mortar**

Brick must meet the requirements of American Society for Testing and Materials Standards C 216 or C 652. These standards are for facing and hollow brick, respectively. They contain requirements for freeze-thaw durability and appearance. Brick units used in anchored veneer are required by model building codes to be at least 54 mm (2 7/8 in.) or 50 mm (2 in.) thick.
Actual brick thicknesses of 76 mm (3 in.), 90 mm (3-½ in.), and 95 mm (3 5/8 in.) are typically used.

Mortar must conform to the requirements of ASTM C 270. This standard includes a wide variety of permitted cementitious materials and sand. Mortar is specified by proportions of materials or by properties of laboratory tested mortar. Lower strength cementitious materials and mortar types are prohibited from use in the higher seismic areas by model codes. Mortar Type N is typically used with brick veneer.

![Diagram of Anchored Brick Veneer](image)

**Figure 1. Anchored Brick Veneer.**

**Anchors**

The anchors specified in each of the model codes are similar. They are of steel and may be:
- corrugated sheet of 0.76 mm (No. 22 gauge) by 22 mm (7/8 in.),
- sheet metal of 1.5 mm (0.06 in.) by 22 mm (7/8 in.), or
- wire of minimum MW11 (No. 9 gauge).

Anchors come in a variety of configurations (Figures 2 and 3). Corrosion resistance is achieved with zinc or epoxy coatings or the use of stainless steel. Play in two piece adjustable anchors is limited to 1.6 mm (1/16 in).

![Typical Unit Veneer Anchors](image)

**Figure 2. Typical Unit Veneer Anchors.**
Backings

The structural backing used with brick veneer may be a continuous surface such as concrete masonry or concrete, or it may be steel or wood framing (studs) with an exterior sheathing. Wood studs are most often used in residential construction. Most backings with sheathing also require a weather-resistant barrier on its exterior.

Construction of Brick Veneer

The backing is in place before bricklaying begins. This is true even if the backing is masonry. In the United States a separate construction trade will complete non-masonry backings. This includes attaching all or at least one part of the anchors. Components of the wall system, such as door and window frames, a weather-resistant barrier and flashing, are installed prior to brick being laid.

Brickwork is laid to a line, with full bed and head joints required with solid brick and face shell bedding required with hollow brick (Figures 4 and 5). The air space between the brickwork and the backing is to be kept clear of mortar droppings and debris.

Proper installation of anchors is, of course, necessary. The anchor must be embedded into the mortar joint in order to develop its strength. Wire anchors must have at least 25 mm (1 in.) of cover to each face of the brickwork. Plate anchors must penetrate at least one-half of the veneer thickness. Size and type of connection of the anchor to the backing must meet the requirements of the building code and be installed in accordance with the anchor manufacturer’s recommendations. Obviously nails and screws must be attached to the studs, not the sheathing.
BUILDING CODE REQUIREMENTS FOR ANCHORED VENEER

Building Codes in the United States

There is no government mandated building code in the United States of America. Rather, building codes are adopted into law at the local level by a state, a county, or a city. These governmental jurisdictions typically adopt a model code with local amendments. Model codes are prepared by a modified consensus process, with code officials determining the content and changes.

Model building codes contain the following primary parts:
- Administrative issues that relate to adoption, building use and occupancy;
- Fire-resistive construction and fire protection;
- Accessibility and environmental control;
- Structural design loads, tests, and inspection;
- Soils and foundations;
- Material specific requirements for structural design and construction;
- Electrical, mechanical, plumbing, and conveying systems.

The original content of these primary parts comes from a variety of sources. The first three of these parts are typically prepared by model building code writing groups. Organizations representing design professionals, typically the American Society of Civil Engineers, write the standards that relate to structural design loads, tests, and inspection and the part on soils and foundations. As would be expected, organizations representing the various material groups write the standards that include the requirements for those materials. Organizations representing design professionals also write the standards for electrical, mechanical, plumbing, and conveying systems. These standards are written under a consensus system and are adopted by reference with modifications by the model building codes.

Changes to these codes are accepted on a cyclic basis. Changes come about as a result of changes in the referenced standards and changes introduced by an individual or organization.
Recently the federal government has been active in supporting changes to model codes, specifically with respect to seismic performance. These changes are presented at the code hearings where the proponent and opponents express their views. Final action is taken by the code officials who are members of the model code organization. At this time, a new edition of most model codes is approved on a three year cycle. Amendments are accepted once during that three year cycle.

**Model Building Codes**

There has been a significant change in model building codes in effect in the United States in recent years. Three model code organizations, that each promulgated a separate model building code used with regional preference, have merged into the International Code Council. Thus three model building codes and a common residential code have been replaced with a single code for one- and two-family dwellings, the International Residential Code [1], and one for other structures, the International Building Code [2]. A second model building code, the National Fire Prevention Association 5000 has just been approved. This group also uses the International Residential Code.

Both of these model building codes refer to the *Building Code Requirements for Masonry Structures* [3]. This document is written by the Masonry Standards Joint Committee and covers all masonry construction. It is a “joint” effort of the American Concrete Institute, the American Society of Civil Engineers, and The Masonry Society. This will be referred to as the MSJC Code in this paper. The MSJC Code includes requirements for structural masonry and veneer.

The veneer sections of model building codes provide for two means of compliance: a design using engineering principles or a set of prescriptive materials and practices that have proven to result in veneer that performs properly. Almost all veneer is designed using the prescriptive requirements. The following sections provide background on the current prescriptive requirements for anchored veneer, with emphasis on those related to seismic performance.

**Federal Mandate to Reduce Earthquake Damage**

The United States government established a mandate to reduce the effects of earthquakes on buildings. The National Earthquake Hazard Reduction Program (NEHRP) began in 1977 and addresses both the design loads associated with earthquakes and the resistance to them provided by building materials and elements. This program has developed recommended provisions [4] for seismic design which are taken to the model building codes for adoption.

These provisions cover all material types. Provisions for anchored veneer refer to the MSJC Code. Thus there is nearly consistency in application of seismic requirements for anchored veneer in the model building codes. There is an inconsistency because of the differences between the International Residential Code and the International Building Code. These will be explained in more detail as the content of the codes is discussed.

**First Seismic Requirements for Veneer**

Prescriptive requirements for anchored veneer first included seismic provisions in the 1982 edition of the Uniform Building Code [5]. These requirements apply to anchored veneer made
with masonry units of 127 mm (5 in.) maximum thickness that is anchored directly to structural masonry, concrete, or studs. Seismic requirements are underlined:

1. Anchored veneer shall be supported on footings, foundations or other noncombustible support.
2. Where anchored veneer is applied more than 7.6 m (25 ft) above adjacent ground elevation, it shall be supported by noncombustible, corrosion-resistant, structural framing having horizontal supports spaced not over 3.7 m (12 ft) vertically above the 7.6 m (25 ft) height.
3. Noncombustible, noncorrosive lintels and noncombustible supports shall be provided over all openings where the veneer unit is not self-spanning. The deflections of all structural lintels and horizontal supports shall not exceed \( \frac{1}{500} \) of the span under full load of the veneer.
4. Anchors shall be corrosion resistant, and if made of sheet metal, shall have a minimum size of 0.76 mm (No. 22 gauge) by 25.4 mm (1 in.) or, if made of wire, shall be a minimum of MW11 (No. 9 gauge).
5. Anchor ties must be spaced to support not more than 0.19 m\(^2\) (2 ft\(^2\)) of wall area but not more than 0.61 m (24 in.) on center horizontally.
6. In Seismic Zones No. 3 and No. 4 anchor ties shall be provided to horizontal joint reinforcement wire of MW11 (No. 9 gauge) or equivalent.
7. The joint reinforcement shall be continuous with butt splices between ties permitted.
8. When used over stud construction, the studs shall be spaced at a maximum of 406 mm (16 in.) on centers.

Seismic Zones 3 and 4 were the highest of four zones in effect at that time.

A subsequent modification to these requirements, made in 1991, required that the joint reinforcement be mechanically attached to the veneer anchors and that butt splices in the reinforcement were permitted between the anchors.

**Masonry Standards Joint Committee Code [3]**

Requirements for anchored veneer were introduced into the *Building Code Requirements for Masonry Structures* the 1995 edition. These came from a compilation of veneer requirements in the previous three model building codes. Thus, the UBC requirements were used as the basis for seismic provisions. The MSJC Code is included by reference in the International Building Code.

Key prescriptive provisions from MSJC 1995 Code and subsequent editions through 2002 for anchored veneer are:

- **6.2.2.1** Prescriptive requirements for anchored masonry veneer shall not be used in areas where the basic wind speed exceeds 110 mph (177 km/hr) as given in ASCE 7.
- **6.2.2.3** *Vertical support of anchored masonry veneer*
- **6.2.2.3.1** The weight of anchored veneer shall be supported vertically on concrete or masonry foundations or other noncombustible structural supports, except as permitted in Sections 6.2.2.3.1.1, 6.2.2.3.1.4, and 6.2.2.3.1.5.
6.2.2.3.1.1 Anchored veneer is permitted to be supported vertically by preservative-treated wood foundations. The height of veneer supported by wood foundations shall not exceed 18 ft (5.49 m) above the support.

6.2.2.3.1.2 Anchored veneer with a backing of wood framing shall not exceed the height above the noncombustible foundation given in Table 6.2.2.3.1.

6.2.2.3.1.3 If anchored veneer with a backing of cold-formed steel framing exceeds the height above the noncombustible foundation given in Table 6.2.2.3.1, the weight of the veneer shall be supported by noncombustible construction for each story above the height limit given in Table 6.2.2.3.1.

<table>
<thead>
<tr>
<th>Table 6.2.2.3.1 - Height limit from foundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height at plate, ft (m)</td>
</tr>
<tr>
<td>30 (9.14)</td>
</tr>
</tbody>
</table>

6.2.2.3.1.4 When anchored veneer is used as an interior finish on wood framing, it shall have a weight of 40 lb/ft² (1915 Pa) or less and be installed in conformance with the provisions of this Chapter.

6.2.2.3.1.5 Exterior masonry veneer having an installed weight of 40 psf (195 kg/m²) or less and height of no more than 12 ft (3.7 m) is permitted to be supported on wood construction. A vertical movement joint in the masonry veneer shall be used to isolate the veneer supported by wood construction from that supported by the foundation. Masonry shall be designed and constructed so that masonry is not in direct contact with wood. The horizontally spanning element supporting the masonry veneer shall be designed so that deflection due to dead plus live loads does not exceed l/600 nor 0.3 in. (7.6 mm).

6.2.2.3.2 When anchored veneer is supported by floor construction, the floor shall be designed to limit deflection as required in Section 1.10.1.

6.2.2.3.3 Provide noncombustible lintels or supports attached to noncombustible framing over all openings where the anchored veneer is not self-supporting. The deflection of such lintels or supports shall conform to the requirements of Section 1.10.1.

6.2.2.9 Veneer laid in other than running bond Anchored veneer laid in other than running bond shall have joint reinforcement of at least one wire, of size W1.7 (MW11), spaced at a maximum of 18 in. (457 mm) on center vertically.

There are specific requirements for anchors to be used with anchored brick veneer. Veneer anchors are identified by steel item used to fabricate them. These include corrugated sheet metal, sheet metal, wire, and joint reinforcement. Anchors are further identified as single or adjustable (two-piece) anchors. Adjustable anchors must not disengage and there is a limit of clearance between parts of 1.6 mm (1/16 in.). Pintle anchors must have two legs of wire size MW1.8 (W2.8) and an offset not exceeding 31.8 mm (1¼ in.).

These classifications determine the frequency requirements. Table 1 summarizes the area of veneer required for typical ties. Anchors are spaced at a maximum of 813 mm (32 in.)
horizontally and 457 mm (18 in.) vertically. Additional anchors are placed around openings larger that 406 mm (16 in.) in either direction. The MSJC Code includes specific requirements for placing the anchor in the mortar joints.

### Table 1. Veneer Anchor Frequency Requirements, MSJC Code

<table>
<thead>
<tr>
<th>Anchor Type</th>
<th>Area of Veneer per Anchor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Square Meters</td>
</tr>
<tr>
<td>Corrugated Sheet, Single Piece</td>
<td>0.25</td>
</tr>
<tr>
<td>Flat Plate, Single Piece</td>
<td>0.33</td>
</tr>
<tr>
<td>Wire, MW 11 (W1.7) and smaller, Single Piece</td>
<td>0.25</td>
</tr>
<tr>
<td>Wire, larger than MW 11 (W1.7), Single Piece</td>
<td>0.33</td>
</tr>
<tr>
<td>Two Piece Adjustable</td>
<td>0.25</td>
</tr>
</tbody>
</table>

The type of backing used with the brick veneer determines a number of related wall components. Anchor type is one of these items. Corrugated anchors are permitted only with wood backing. Thus, wood stud backing permits any anchor type. Steel stud and concrete backing require adjustable anchors. Masonry backing can accept wire or adjustable anchors or joint reinforcement. The minimum and maximum air space dimensions between the inside face of the brick and the outside face of the backing or sheathing are set.

Seismic requirements

Specific criteria for seismic conditions are introduced and are cumulative with increasing seismic activity. The four Seismic Zones used in the previous codes were updated to five Seismic Design Categories (SDC). The building’s Seismic Design Category is established by the use of the building and severity of the design earthquake ground motion at the site. Alphabetical designations for SDC begin at A and end with F as the highest.

Seismic Design Categories A and B

There are no specific seismic requirements.

Seismic Design Category C

6.2.2.10.1.2 Isolate the sides and top of anchored veneer from the structural so that vertical and lateral seismic forces resisted by the structure are not imparted to the veneer.

Seismic Design Category D

6.2.2.10.2.2 Support the weight of anchored veneer for each story independent of other stories.
6.2.2.10.2.3 Reduce the maximum wall area supported by each anchor to 75% of that required for the specific tie used. Maximum horizontal and vertical spacing are unchanged.

6.2.2.10.2.4 Provide continuous, single-wire joint reinforcement of minimum wire size MW11 (W1.7) at a maximum spacing of 457 mm (18 in.) on center vertically.

Seismic Design Categories E and F

6.2.2.10.3.2 Provide vertical expansion joints at all returns and corners.

6.2.2.10.3.3 Mechanically attach anchors to the joint reinforcement with clips or hooks. (Figure 6)

As indicated in the Commentary to the MSJC Code [3], these requirements are to provide added flexibility to the veneer. The Commentary states:

6.2.2.10 Requirements in seismic areas — These requirements provide several cumulative effects to improve veneer performance under seismic load. Many of them are based on similar requirements found in Chapter 30 of the Uniform Building Code6.14. The isolation from the structure reduces accidental loading and permits larger building deflections to occur without veneer damage. Support at each floor articulates the veneer and reduces the size of potentially damaged areas. An increased number of anchors increases veneer stability and reduces the possibility of falling debris. Joint reinforcement provides ductility and post-cracking strength. Added expansion joints further articulate the veneer, permit greater building deflection without veneer damage and limit stress development in the veneer.

Modifications to these seismic requirements were introduced in the 2005 edition. The following changes have been made:

1. The requirement to support the weight of the veneer for each story independent of other stories was removed from Seismic Design Category D and implemented in SDC E and F.
2. The requirement for continuous, single wire joint reinforcement was removed from Seismic Design Category D and implemented in SDC E and F.

Both of these changes were based on engineering investigations. Further explanation is given in the section, veneer performance under seismic loads.
This separate building code for one-and two-family dwellings is more prescriptive to its overall philosophy to design and construction. It covers limited types of buildings, as the name implies. The smaller scope of this charge, and the desire to limit the amount of engineering input, results in the inclusion of derived design tables for wood and steel stud construction. One significant change is to divide SDC D into two subzones, D₁ and D₂, separated at a Short Period Design Spectral Response Acceleration of 0.83g.

The IRC also includes specific prescriptive requirements for anchored veneer. It does not reference the MSJC for veneer requirements. The prescriptive requirements for anchored veneer, with relation to the MSJC code requirements, are:

1. Requirements for a weather-resistant envelope, including a weather-resistive barrier, drainage means, and flashing.
2. Minimum nominal thickness of brick veneer of 50 mm (2 in.).
3. Anchor materials and types are MW11 wire and corrugated sheet metal of the same size as in the MSJC Code.
4. Veneer anchors frequency is one anchor per 0.0.302 m² (3.25 ft²) for all anchor types.
5. Maximum spacing for anchors is 601 mm (25 in.) horizontally.
6. Backing types are the same and have the same permitted anchors and air space dimensions as in the MSJC Code.
7. Anchored brick veneer with wood or cold-formed backing is limited to a maximum thickness of 127 mm (5 in.).
8. Support of veneer on wood of cold-formed frame is permitted, with detailing requirements for support on wood.
9. Sizes and spans for steel and reinforced masonry lintels are given.
Cumulative seismic requirements are:

Seismic Design Categories A and B
Exterior masonry veneer with a backing of wood or cold-formed steel framing shall not exceed 9.14 m (30 ft) in height above the noncombustible foundation, with an additional 2.35 m (8 ft.) permitted for ends.

Seismic Design Category C
In other than the topmost story, the length of bracing shall be 1.5 times the length otherwise required.

Seismic Design Category D₁ and D₂
1. Exterior masonry veneer with a backing of wood or cold-formed steel framing shall be limited to the first story above grade.
2. Each tie shall support not more than 0.186 m² (2 ft²) of wall area.
3. Veneer ties shall be mechanically attached to horizontal joint reinforcement wire a minimum of MW11 (9 gage). The horizontal joint reinforcement shall be continuous in the veneer bed joint, with lab splices permitted between the veneer tie spacing.

The seismic performance of wood stud construction is not well understood and many combinations of wall sheathing and nailing schedules are possible. Since veneer is not intended to resist loads, the seismic load from the weight of the veneer is applied to the wood stud shear walls. Conservative assumptions with respect to the strength of the shear walls indicated that typical wood frame construction in SDC C could not resist the resulting seismic force from brick veneer more than 2.35 m (30 ft) in height. In SDC D, the limit was one story. This change was coupled with an increase in the seismic activity in the central and eastern United States. The result was that a significant portion of the market for anchored brick veneer was threatened.

In an effort to reduce the effect of these seismic restrictions, the brick industry worked with the writers of wood industry provisions. The first result was to provide a strengthened wood shear wall system that was capable of resisting the seismic load from the veneer. Tie downs were required at the end of shear walls; a prescribed sheathing material and nailing schedule were added as seismic loads increased. These requirements were added to the International Residential Code in 2002 amendments to the 2000 edition. Further work for the 2003 edition of the NEHRP Provisions took a more realistic look at the performance of brick veneer. The fact that the veneer is capable of resisting loads was recognized and the limits on the permitted height of anchored masonry veneer were reduced.

This activity and other amendments have been adopted in the 2003 IRC as follows:

Anchored veneer tie frequency was reduced one anchor per 0.0.248 m² (2.67 ft²).
A maximum slope of roofs supporting masonry veneer was established at 7:12 without special construction. Roofs sloped up to 12:12 required steel stops on the supporting angles.

Seismic Design Category D₁ and D₂
The requirement for joint reinforcement was eliminated.
The permitted height of anchored veneer was increased to 6.10 m or 9.14 m (20 ft or 30 ft), plus 2.44 m (8 ft) in the gabled ends. These greater heights depend on veneer wythe thickness,
concrete or masonry backing for the lower 3.05 m (10 ft), and the presence of specific braced panels and hold down connectors.

VENEER PERFORMANCE UNDER SEISMIC LOADS

Perception

Media coverage of seismic events invariably includes images of fallen brick and the damage they cause. Photos of X-type cracking in masonry elements between windows and piles of masonry rubble on the sidewalks are often shown. There is seldom any explanation as to the type of element that failed or the age or the prior condition of the building. The impression is that masonry construction is not appropriate for use in seismically active areas. It is true that some existing brick masonry buildings, both bearing wall and veneer, are not adequate to resist potential seismic forces. However, there are design and construction procedures that will upgrade existing structures to satisfactory performance. Further, post-earthquake investigations have shown that current design and construction procedures for brick structures, including veneers, provide resistance to seismic forces [6, 7, 8, 9].

Load Generation and Resistance

Loads generated by earthquakes are caused by the inertia of the object subjected to ground shaking. The seismic load may occur in any direction, resulting from the direction of movement of the ground. For analytical purposes, seismic loads are typically assumed to be applied in the plane of the wall and perpendicular to the plane of the wall. The load in any element is directly proportional to weight of that element, and the load occurs with the element itself. This means that the basic assumption that veneer is not intended to resist loads is violated. Brick veneer is subject to seismic loads and it must be able to resist those loads and transfer them to the structural system of the building. Analytical studies have shown that anchored veneer does resist seismic loads and it contributes to the resistance of seismic loads [10].

Seismic loads due to the weight of the wall from in-plane movement are resisted by the brick veneer only. There must be sufficient masonry present to develop the necessary shear resistance without cracking, or it must be reinforced. Transfer of in-plane forces to the backing will depend on the type of veneer anchor used.

Loads perpendicular to the plane of the wall are resisted by both the veneer and the backing. These develop flexural tension in the masonry and it spans as a beam supported on elastic supports (the anchors). The anchors transfer those reactions perpendicular to the face of the masonry from the masonry to the backing. The strength of the brick veneer, the anchors, and the backing must be sufficient to withstand the loads.

Failure Mechanism

In-plane loads

In-plane loads in the veneer generate corresponding shear stress. Sliding may take place at the support since the presence of flashing provides a weakened plane. In-plane stresses may cause a
series of stepped or horizontal cracks in the veneer if the applied force is greater than the shear resistance of the masonry. X-type cracking is prevalent near and between openings due to load reversal. Tall, thin masonry elements may develop horizontal cracks in bed joints near the top and bottom of the elements. If the masonry elements are not strong enough and if the earthquake is severe, collapse of the veneer can occur [6, 7, 8, 9]. (Figure 7) Johnson and McGinley [11] have shown that there is typically sufficient masonry to develop the necessary shear resistance without cracking. Further, the corrugated steel anchors typically used in residential construction provide significant transfer of load, if needed, and do so with ductile behavior.

Out-of plane loads

Since the brickwork, anchors and backing work together to resist out-of-plane loads, the resistance mechanism is quite complex. The brickwork has a high flexural rigidity compared to stud backing and initially resists the majority of the load. A crack will develop in a bed joint of the masonry if the wall construction is not sufficient to resist the load. The flexural tensile stress in the brick veneer reaches its maximum value just prior to cracking. At this state anchors nearest to rigid supports may reach their highest load. Immediately after the veneer cracks the portions of the backing away from the rigid supports receive a much higher load. Further, the loads in the anchors are reduced and are distributed more evenly [12]. After this initial crack the maximum flexural stress in the veneer perpendicular to the bed joints is now greatly reduced and may not reach cracking level again. Once a horizontal crack forms the veneer may now span horizontally, with the vertical studs acting as supports. McGinley, et al, [13] have shown that the veneer has sufficient strength to resist these resulting stresses parallel to the bed joints. Joint reinforcement is detrimental to out-of-plane loading. It reduces the tensile stress in the bed joints and may lead to early cracking and instability [14].

Increasing seismic loads can result in anchor failure, backing failure, or collapse of the veneer (Figure 8). Unbraced vertical sections of masonry can develop high flexural stresses in the veneer and high forces in the top level of anchors. Parapets and gables of veneer construction are susceptible to collapse if support is not provided at the top.
Combined Loads

The transition between in-plane and out-of-plane loading, which occurs at corners and returns, causes a unique situation. The veneer at these locations, if bonded around the return, is subject to loads of different magnitudes and types. Further, the resistance provided by the masonry may be substantially different on each elevation. Determination of the actual stress near returns is difficult. Cracking frequently occurs at the corners. Thus the need for expansion joints near returns [8].

Factors Influencing Failure

As implied in Failure Mechanisms, there are several contributing factors to any failure of brick veneer under seismic loading. The height, length, and thickness of the veneer element are certainly critical. They determine the load in the veneer wythe, the amount of material available to resist the load, and the level and type of stress generated. Thus the location of vertical expansion joints and of openings are of concern with respect to in-plane loads. Location of horizontal expansion joints must also be considered. If these are present the veneer can accept more building drift.

The type of brick and mortar used in the construction will also influence performance, but to a lesser degree. Resistance to in-plane load is determined by material properties. Higher brick compressive strength and higher mortar cement content increase masonry shear resistance. However, the increase is not directly proportional. The resistance to out-of-plane load perpendicular to the bed joints is relatively low regardless of material combinations when compared to stress generated.

The type of anchor selected has a great influence on the ability of the wall system to resist out-of-plane load. Stronger, more rigid anchors will reduce the load resisted by the brickwork. Weaker, more flexible anchors place greater demand on the brickwork in resisting out-of-plane loads. Resistance to pull-out from or push-through the mortar joint must be high. Anchors are
subject to poor performance due to improper installation (Figure 9) and to loss of strength due to corrosion [7, 8, 9].

The backing is important in its contribution to out-of-plane loading. Stiff backings, such as concrete or concrete masonry, share a greater part of load with the veneer than do more flexible backings such as wood or steel studs. Cracking in the veneer is reduced with a stiffer backing. A backing and structural system which permits larger deflection and has a high story drift will also result in larger deflection of the veneer. This will increase cracking, reduce stability of the veneer, and increase anchor loads.

![Figure 9. Failure due to pullout of nail from stud.](image)

The manner in which the weight of the veneer is supported is also important. Veneer supported at or near each floor level can undergo larger out-of-plane seismic movements. Collapse, if it occurs, is restricted to smaller areas when there is more frequent support of veneer weight. Support at locations above the foundation must be combined with a horizontal expansion joint under these intermediate supports. This joint provides space for movement from frame deflection and story drift to occur. This support at each floor is critical in frame structures and is easily achieved. Support above the foundation is virtually impossible with wood and steel stud structural systems. Bennett [15] reports no technical justification for the requirement to support anchored veneer at each floor level when these light weight backings also act as the structural system.

**SUMMARY**

Anchored masonry veneer continues to be a popular exterior cladding in the United States of America. The building code requirements for its use have progressed from those based on intuition and comparison of masonry cavity walls to those based on engineering analysis. Seismic performance criteria have evolved in a similar manner. Virtually all post-earthquake investigations show that the performance of brick veneer is determined more by the connection of the anchors to the backing and adherence to proper construction requirements than to the stresses developed in the anchored brick veneer. The need for inspection of construction, as required in
critical facilities, is evident. Adherence to the code required design and construction requirements will maintain confidence in the continued use of anchored brick veneer.

REFERENCES


