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Stucco Detailing for Buildings With Unique Geometry

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Abstract

Portland cement plaster (stucco) supported by metal lath relies on a properly installed weather-resistive barrier and drainage plane and properly installed through-wall flashings to manage water and prevent moisture intrusion from occurring into the wall assembly and the building interior. Unusual geometric features in building façades present unique challenges that often affect the performance of the building enclosure. These problematic features may include sloping walls as well as diagonally set fenestration, wall accessories, horizontal soffits, shelf conditions, and other projections. The information presented will assist designers and builders in avoiding the potential for water intrusion in buildings due to inappropriate detailing.

Speakers

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Stucco Detailing for Buildings With Unique Geometry

ABSTRACT

Portland cement plaster (stucco) supported by metal lath relies on a properly installed weather-resistive barrier (WRB) and drainage plane and properly installed through-wall flashings to manage water and prevent moisture intrusion from occurring into the wall assembly and the building interior. The behavior of water within the drainage plane in stucco supported by metal lath is relatively predictable in most installations. However, unusual geometric features in building façades present unique challenges that often affect the performance of the building enclosure. These problematic features may include sloping walls, as well as diagonally set fenestration, wall accessories, horizontal soffits, shelf conditions, and other projections.

The information presented, which is based on the authors' experience investigating these issues in real-world installations, will provide participants with an understanding of how unusual geometric features can affect the behavior of water within the stucco drainage plane and will assist designers and builders in avoiding the potential for water intrusion in buildings due to inappropriate detailing.

INTRODUCTION

Over the past 20 years, the authors have performed water leakage investigations on hundreds of buildings throughout the U.S. that were clad with Portland cement plaster stucco. The construction of the buildings under investigation has included stucco applied to solid bases, such as concrete or concrete masonry units (i.e., directly applied stucco), and stucco applied to metal plaster bases (metal lath).

For water leakage issues in stucco systems, it is important to understand how the stucco cladding resists water penetration. For directly applied stucco, the stucco is applied directly to the substrate; there is no WRB behind the stucco. Therefore, for these structures, the stucco relies on proper installation and possibly a coating to resist water infiltration. Proper installation requires proper bond between the stucco and the stucco accessories.

There are a number of conditions that commonly affect the bond between various layers in the stucco or between the stucco and the substrate. These conditions include:

- Variances between the allowable construction tolerances provided by the American Concrete Institute (ACI) for formed concrete surfaces and the tolerances for solid substrates to receive stucco provided in ASTM C926, *Standard Specification for Application of Portland Cement-Based Plaster*
- Poor surface preparation
- Poor placement of stucco
- Use of build-out materials
- Improper installation of stucco accessories
- Incompatible substrates

Any of these conditions or a combination of these conditions can result in delamination of the stucco. When delaminations occur in the stucco, the stucco becomes unsupported within the delaminated regions, limiting the ability of the stucco to transfer thermal or wind loads to building structure and frequently resulting in cracking of the stucco. Once cracking forms, water can migrate through the stucco and possibly into the building.

For stucco that is supported by metal lath, the primary method of resisting water penetration through the stucco cladding is at the exterior face of the assembly. However, water should be expected to penetrate the stucco, either by absorption through the stucco, through cracks or separations within the stucco system, or failed sealants at stucco terminations. Therefore, stucco systems supported by metal lath provide a drainage system consisting of a WRB and flashings to collect and drain incidental water that penetrates the exterior surface back to the exterior of the building and prevent the water from reaching the interior of the building. Reducing the avenues that enable water to penetrate the stucco by proper design and installation of these drainage components is critical to the success of stucco applied to metal lath.

While the behavior of water within the drainage plane in stucco supported by metal lath is relatively predictable in most installations, the authors often observe several common mistakes that are made during the design and construction enabling water leakage to occur. These mistakes, coupled with other conditions present when dealing with façades that have unusual geometric features, present unique challenges that often affect the performance of the building enclosure. Therefore, the focus of this paper is to discuss the typical performance characteristics of a stucco-clad wall supported by metal lath, common issues that result in water leakage, and the unique challenges related to unusual geometric features in building façades.

TYPICAL PERFORMANCE CHARACTERISTICS OF CLADDING COMPRISED OF STUCCO SUPPORTED BY METAL LATH

Cladding systems consisting of stucco supported by metal lath generally consist of one-coat, two-coat, or three-coat systems ranging from 3/8 to 7/8 in. thick. The stucco is keyed into lath that is placed over a WRB and exterior sheathing, which is attached mechanically to metal or wood studs. In addition to the metal lath and WRB, a successful stucco system includes stucco accessories (control joints, prefabricated reveal joints, expansion joints, etc.) through-wall flashings, and flashing around penetrations and sealant joints. For stucco supported by metal lath to perform successfully and properly manage incidental water that penetrates the stucco, all of these parts must be designed and installed properly. Following is a discussion of common design and construction defects that we have observed in stucco wall systems supported by metal lath that often result in water leakage. We also discuss methods of installation and design detailing that have been successfully used to avoid these common mistakes in a traditional stucco cladding system supported by metal lath.

Weather-Resistive Barriers (WRBs)

The International Building Code (IBC) requires that a minimum of one layer of #15 asphalt felt, complying with ASTM D226 for Type 1 felt, or other approved materials be installed as the water-resistive barrier for exterior veneers, including stucco. For wood-based sheathing, the IBC requires that a minimum of two layers of Grade B building paper be installed. The code requires each layer to be installed independently so that each layer provides a separate continuous drainage plane and in a manner so that any flashing allows water to drain.

Today, a wide range of WRBs is available, from loose-laid sheet products such as felt paper and building wraps, to fluid-applied and fully adhered membranes. In our experience, a single layer of #15 asphalt felt is generally not adequate to resist water penetration when the exterior wall has window openings and other pipe penetrations or when the exterior sheathing consists of gypsum sheathing. At these conditions, the authors typically see poor integration of flashings around windows and other penetrations, which often result in water leakage. We have also observed instances where the stucco bonds to some loose-laid sheet products. Therefore, we typically recommend a loose-laid sheet product or a fluid-applied membrane that can be wrapped into the openings, followed by a sacrificial layer of felt paper. If installed correctly, the sacrificial layer of felt paper adds to the water-tightness of the wall assembly and helps create a clear drainage plane between the felt paper and the underlying loose-laid sheet product or fluid-applied membrane.

Through-Wall Flashings and Flashings Around Penetrations

The IBC also requires flashing to be installed in veneer claddings such as stucco. Code Section 1405.4 states that flashings shall be installed to prevent moisture from entering the wall system and also that all moisture that enters the wall system is redirected to the exterior. Section 1405.4 also requires flashing be installed around door and window assemblies; penetrations and terminations of exterior wall assemblies; and exterior wall intersections with roofs, chimneys, porches, decks, etc.

ASTM C1063 (Section 7.11.5) requires a foundation weep screed to be installed at the bottom of all steel-and wood-framed exterior walls. ASTM C926 (Appendix A2, Design Considerations, Section A2.2.2) recommends that a drip screed and through-wall flashings or weep holes or other effective means to drain away any water that may get behind stucco be installed at the bottom of exterior walls supported by a floor or a foundation. Installation of a means to permit water to exit the drainage plane is critical to the success of a stucco wall system. Although these items are frequently specified, detailing is often inadequate to ensure proper installation, frequently leading to water leakage into buildings. In addition, designers often fail to adequately detail and specify flashings where the stucco cladding is interrupted above grade. We have investigated numerous buildings that lack appropriate flashings, particularly at balcony locations. The lack of flashings at these locations enables water that penetrates the stucco to enter the building and often causes significant issues.

In our experience, designers typically specify through-wall flashings at the head of the windows, as required by the building code. This flashing typically terminates above the window jambs and does not extend beyond the jambs. Formed end dams are not normally installed in stucco construction, primarily due to the propensity for cracking at the end dam locations. This method of flashing design and installation creates several difficulties regarding integration of the flashings with the WRB and the windows and in ensuring the integrity of these systems. Small holes often occur at the interfaces of these materials, enabling water to bypass the flashings and WRB and penetrate the building. One way to resolve these concerns is to install sealant on the through-wall flashing when an accessory casing bead (J-mold) is installed above the flashing in an effort to create a sealant end dam. However, in our experience, the placement of the sealant is often not watertight or fails prematurely, and water continues to bypass these sealant end dams. Our recommendation is to install continuous flashing around the building at the elevation of the window heads. The authors have successfully employed this method in major stucco repair and reclad projects on a variety of facilities.

The lack of flashings around pipe penetrations and other small penetrations are also common causes of problems in stucco claddings. These conditions are frequently not detailed and are often constructed with only a sealant joint between the stucco or stucco accessory and the penetration. Therefore, water traveling down the backside of the stucco can enter the interior through the open space between the exte-

Figure 1 – Water leakage at screw installed through sheathing (with sheathing removed for clarity).

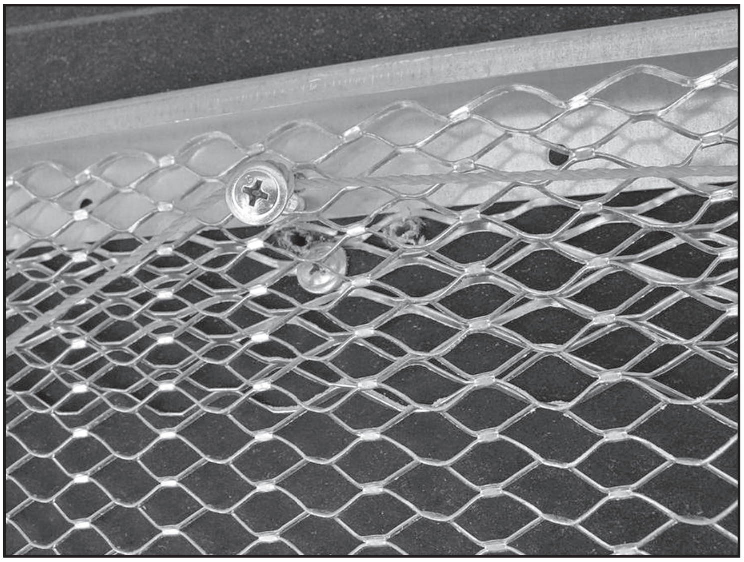

Figure 2 – View of unsealed screw hole.

rior sheathing and the penetration. To remedy this condition, we recommend installing a boot (similar to a roof pipe penetration) or waterproofing the penetration with self-adhered flashings in conjunction with the WRB. Several WRB manufactures have preformed flashings for these conditions.

Metal Lath Attachment

When installing attachments for metal plaster bases to wood framing members or to metal framing members, ASTM C1063, Sections 7.10.2.5; and 7.10.3.3 require the fasteners to be installed into the framing member such that the fasteners pass through the lath, but do not deform the rib. Section 7.10.2.2 states that 6d nails, 1-in. roofing nails, or 1-in. wire staples shall be installed flush with the lath and into the wood-framing member. Although some sheathing materials can provide adequate capacity to resist required lateral loads, water infiltration often results when fasteners are not installed in the framing members. During leakage investigations, the authors have frequently witnessed water leakage through the exterior wall system at locations where fasteners are attached only to the exterior sheathing and not the framing members (*Figure 1*).

Another common condition that we have observed is water leakage through unsealed screw holes. This occurs when the installer misses the framing member, backs the screw out, and fails to seal the penetration (*Figure 2*). This condition typically arises because the installer of the lath is not the same installer of the exterior sheathing or the WRB. Once the WRB is installed, the installer of the lath cannot readily determine the location of the framing members. Therefore, to ensure that the lath installer is able to locate the framing members, it is very important for the general contractor to coordinate between the subcontractors and locate the studs on the WRB as it is installed so that chalk lines can be placed to highlight their locations (*Figure 3*). If an anchor misses a stud during the installation of the lath, the anchor should be removed; the lath and weather barrier should be cut to expose the unsealed penetration in the sheathing so that it can be sealed. Once the penetration in the sheathing is sealed, the WRB should be repaired and the lath should be retied.

In addition to unsealed penetrations, we often observe that the anchors for the metal lath are installed in such a manner that the lath is deformed. This is the result of nails, screws, and staples that are over-driven. When lath is deformed, the lath is restrained from moving, which can result in the stucco cracking. The deformed lath can also compress the WRB, which obstructs the drainage plane (*Figure 4*). When using screws to attach the lath, the installers should use guides on their screw guns to control the depth of the screw.

Attachment of Accessories

Stucco accessories are made of either vinyl or metal. The flanges on the vinyl accessories are primarily solid, with small-diameter holes that allow for connection between the accessory and the lath. The flanges for the metal accessories are solid and also have small-diameter holes in the flange (fewer than vinyl accessories), but also have metal lath that extends off of the solid portion of the flange. For proper installation of the stucco accessories, the metal lath must be attached to the accessory. The authors believe that proper installation consists of installing the accessory so that it is not restrained to the wall. If the accessory is restrained and not able to move, cracking and separations can occur in the stucco. Therefore, for vinyl accessories, we recommend that the lath is wire-tied to the accessory through the holes present in the flange of the accessory. For the metal accessories, we recommend that the lath is either wire-tied to the accessory or

Figure 3 – View of chalk lines illustrating locations of studs and floor slab.

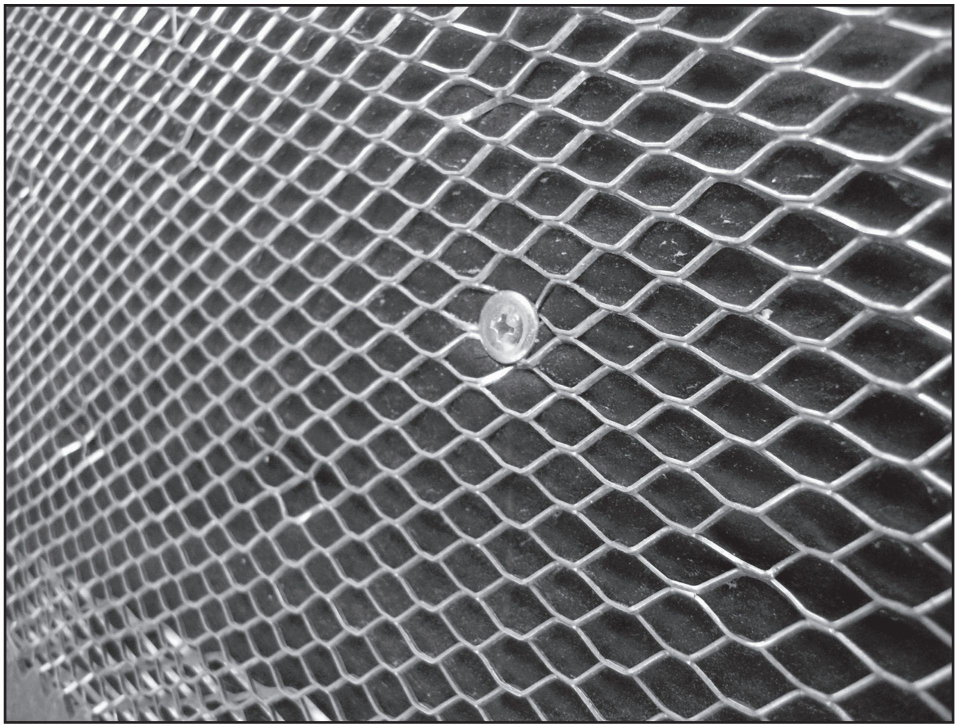

Figure 4 – View of over-drilled screw deforming lath.

mechanically attached through the lath portion of the accessory. The mechanical attachment should be installed so that it does not depress the metal lath. If the metal lath is depressed, then the accessory will be restrained from movement.

During construction, contractors often install the accessories first, followed by the lath. Mechanical anchors are often installed through the small holes in the solid portions of the flanges, followed by additional anchors used to connect the lath to the accessory. This installation method frequently restrains the accessory as well as obstructs the drainage plane (*Figure 5*).

In a few instances, the authors have known designers to specify and installers to apply sealant behind the flange of the accessory. In addition to the sealant, a mechanical fastener is commonly installed through the flange. This has typically been observed around openings such as windows and at pipe penetrations in lieu of proper flashing. In these cases, a separation often forms between the stucco and the accessory because excess sealant interferes with the key of the stucco to the accessory, resulting in water leakage through the opening.

Horizontal Shelf Conditions

Horizontal shelf conditions, such as tops of walls and recessed windowsills, often allow excessive water to enter the stucco drainage cavity. The water enters through cracks or through absorption. Cracking is common at recessed window openings and tops of walls due to improper length-to-width ratios of the stucco panels in these locations. The length-to-width ratio often exceeds the 2½ to 1 required by ASTM C926, Section 7.11.4.2. Once the water is behind the stucco, it can collect on the surface of the WRB and potentially leak into the building at laps and fasteners.

ASTM C926 recognizes this condition, and in Section A2, Design Considerations (Section A2.1.1), it states that sufficient slope shall be provided to prevent water, snow, or ice from accumulating or standing on horizontal surfaces.

In addition to providing adequate slope as required by ASTM C926, we typically recommend metal flashing be installed over the horizontal surfaces. In addition, limiting the fasteners on horizontal surfaces and wrapping the horizontal surface with self-adhered flashing helps to protect the fastener penetrations and laps in loose-laid sheet WRBs.

UNUSUAL GEOMETRY AND ITS EFFECT ON THE BEHAVIOR OF WATER WITHIN THE DRAINAGE PLANE

As we have described, the behavior of water within the drainage plane in stucco supported by metal lath is relatively predictable when applied to assemblies and details that are consistent with current recommended industry standards and practice. In some cases, alternative detailing that varies somewhat from these standards and practice—including those often referred to as "local custom" details commonly employed

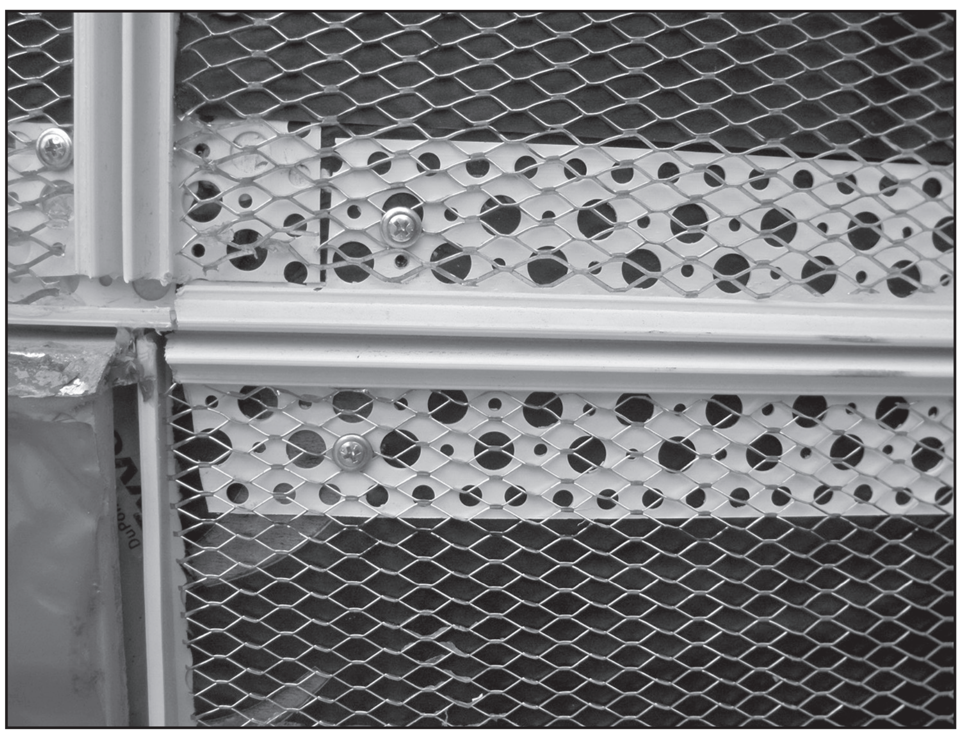

Figure 5 – View of screw attachment between lath and vinyl accessory.

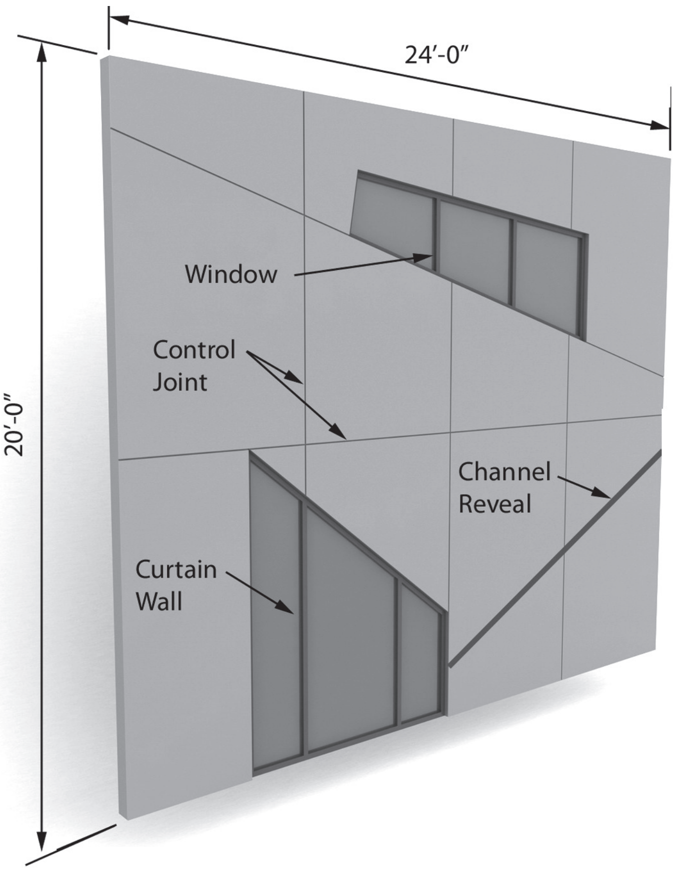

Figure 6 – Three-dimensional drawing of mock-up.

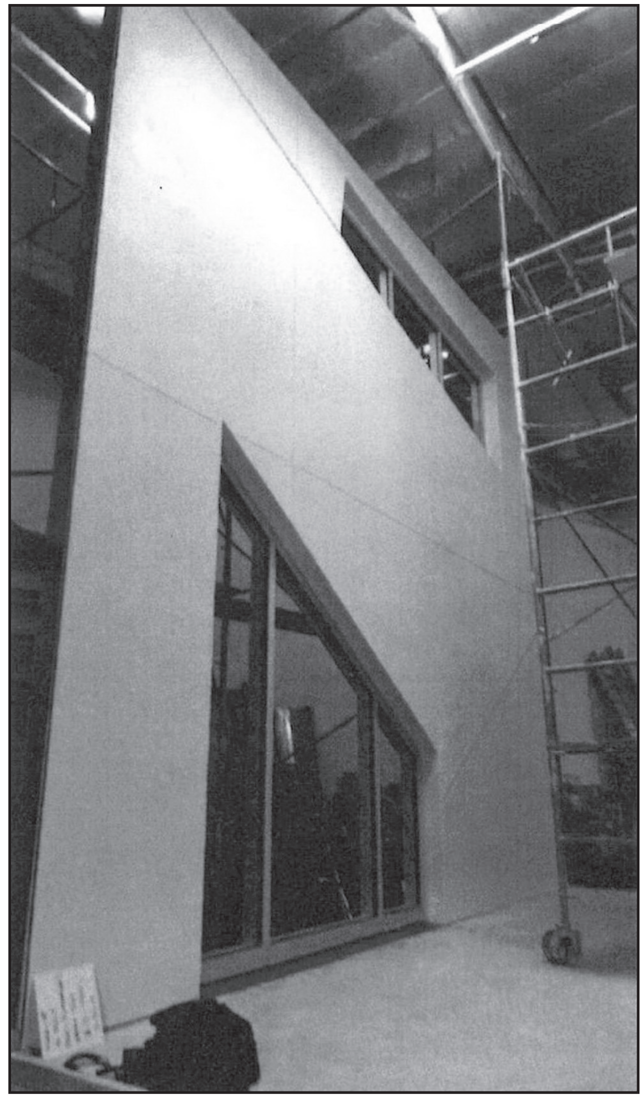

Figure 7 – Photograph of actual laboratory mock-up.

in specific climate regions—can often adequately manage water within the drainage plane. However, unusual geometric features in building façades present unique challenges that can significantly affect the behavior of water in these assemblies.

As is true in most situations, water within the drainage plane of stucco supported by metal lath tends to follow the path of least resistance. Where unusual geometry occurs in this type of cladding, the path of least resistance at some conditions may be significantly altered, circumventing the traditional flow of water in the assembly. These conditions may include certain types of diagonal control or expansion joints, diagonal door and window heads and jambs, diagonal soffits and recesses at door/window heads, diagonal weeps and drip flashings, diagonal shelf conditions (including recessed window sills), diagonal architectural reveal channels, and diagonal casing accessories.

In a recent litigation case, SGH provided expert opinion related to the effects of diagonal accessory installations in a project that was experiencing significant water intrusion. While there were other factors that contributed to the water intrusion, many of the sources of the building enclosure failures were, in our opinion, related to the unusual geometric conditions outlined in this paper. Due to limitations established by the terms of the litigation case, the specific project and owner are not identified, and photographs of the actual project could not be used. Figures used in this document include graphic recreations of the conditions encountered during our investigation and photographs of laboratory mock-ups constructed for testing during the litigation case.

For most conditions identified in this document, the laboratory mock-up was constructed to replicate both as-designed and as-constructed conditions. This allowed for independent consideration of both construction errors and design issues. The mock-up specimen—shown as a three-dimensional drawing in *Figure 6* and photographically in *Figure 7*—included many of the unusual geometric conditions encountered at the project; however, it was not an exact reproduction of any specific portion of the actual project.

Water testing was performed on the mock-up in the laboratory using the procedures outlined in ASTM E2128, including the use of the calibrated spray rack, but without a pressure differential between interior and exterior conditions (*Figure 8*).

Control and Expansion Joints

Control joints are intended to control shrinkage and other minor movement cracks in the stucco and are not designed to weep water to the exterior from the drainage plane. However, when horizontal control joints are installed in a manner that secures the joint flanges tightly against the WRB—such as is the case with mechanically attached joints with solid flanges—the flow of water downward within the drainage plane becomes obstructed, and trapped water may even-

Figure 8 – Water testing of laboratory mock-up.

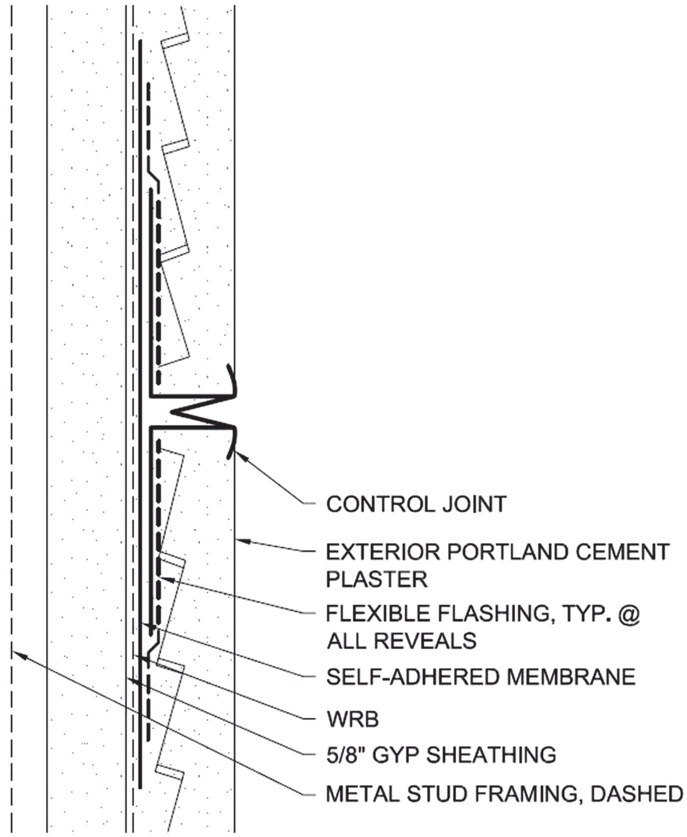

Figure 9 – Detail of as-designed control joint.

tually find its way out of the assembly by slowly seeping between the stucco and control joint material, with the help of gravity.

When these types of control joints are installed in a diagonal manner, however, that same force of gravity creates an altered path of least resistance for water to travel along within the assembly. Where the joint installation obstructs the downward vertical movement of the water, the drainage plane cavity itself provides a clearer and unobstructed path compared to the small gap between the plaster and the control joint accessory, allowing water to flow diagonally downward along the top of the joint within the drainage plane. As the water flows diagonally, it joins with more water flowing down toward the control joint, accumulates, and gains in volume until it intersects another obstruction such as a similarly installed vertical control joint, or until it encounters a weep or other escape mechanism. Where an obstruction interrupts the diagonal flow, a dam effect can cause an increased accumulation of water that may overwhelm the drainage plane, allowing water to penetrate the WRB at vertical and sometimes even horizontal laps.

At the example project in the litigation case, the as-designed condition at diagonal control joints included solid-flange "double-J" accessories, mechanically attached through a layer of self-adhered flashing membrane and sheathing to double studs at vertical framing members and to solid backing at horizontal or diagonal conditions (*Figure 9*).

Lath was cut at the joints and nested over the control joint flanges. All fasteners in the control joint flanges, as well as all fasteners for the lath were sealed. Vertical joints were installed in a continuous manner, and horizontal or diagonal control joints were cut and sealed to the vertical joints in conformance with the manufacturer's installation instructions. During water testing of the as-designed construction in the mock-up at diagonal control joints, water was found to collect within the drainage plane where the diagonal joint intersected the vertical joint, overloading the drainage plane between the plaster and the WRB, increasing in depth within the assembly until (in some locations) eventually passing through the unsealed laps in the WRB.

Diagonal expansion joints that obstruct the free flow of water within the drainage plane present similar problems unless they also include separate weeps. The addition of weeps, however, may not provide complete relief from problems, as we will discuss later.

Channel reveals are popular with many designers and can be used to enhance visual accents. These channels are most commonly fabricated from extruded aluminum; however, some formed sheet metal channels are also available. These accessories typically utilize solid flanges and are usually mechanically attached to the building structure through the WRB. Similar to the conditions associated with mechanically fastened control joints, these installations can obstruct the free flow of water on the WRB to weep flashings, and channel reveals installed diagonally can present similar concerns as those identified for control and expansion joints.

In the laboratory mock-up test specimen, the as-designed construction for the channel reveal installation was replicated. This installation was similar to that for the control joints in that the solid flanges were mechanically attached to framing through a layer of self-adhered flashing membrane and sheathing, the lath was cut and nested into the channel flanges, and all fasteners were sealed. Unlike the control joints, however, the design required the channel reveals to be continuous and not interrupted by vertical joints. In addition, some conditions at the project included diagonal reveals terminating at recessed vertical window jambs, as shown in the mock-up depicted in Figure 6. During water testing of the as-designed mock-up, water was found to have collected along the top of the channel, growing in volume as it progressed down the diagonal. Where the channel intersected a window jamb, water intrusion occurred at the interface between the window head soffit (where the bulk of the drainage plane water was discharged from the channel) and the window frame, and also along the channel path beginning about 24 inches from the window. Deconstruction of the assembly showed that water was accumulating within the drainage plane and passing through laps in the WRB and also through fasteners, even though they were sealed at the WRB face (*Figure 10*).

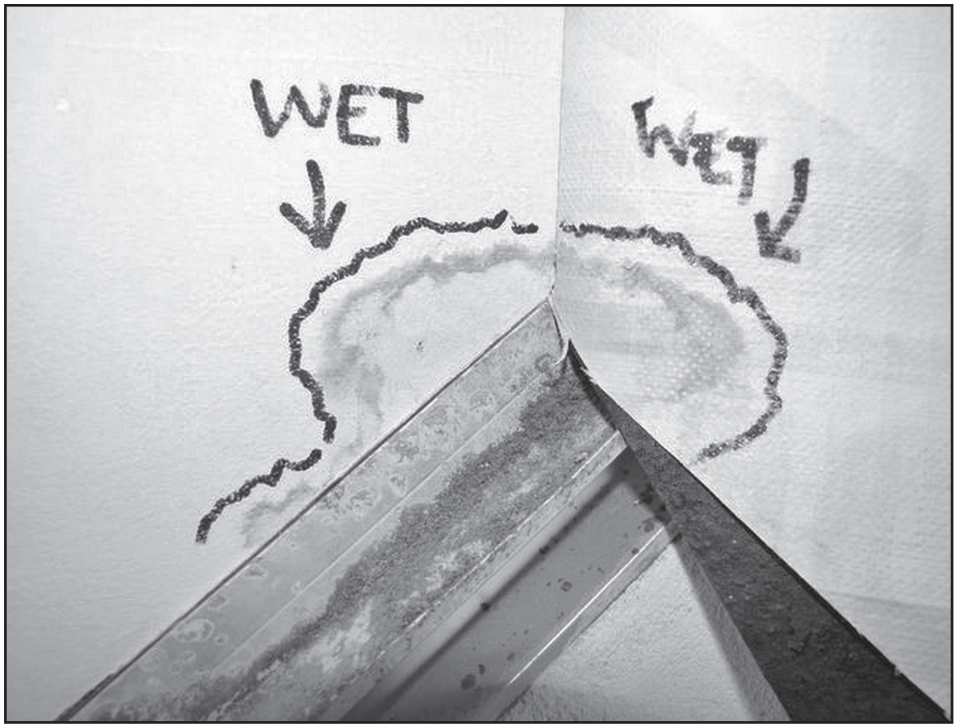

Figure 10 – Evidence of water penetration at diagonal aluminum channel.

Avoiding problems associated with diagonal control joints, expansion joints and channel reveals can be accomplished by using fabricated products in a manner consistent with that intended by the manufacturer. For assemblies requiring a drainage plane, ensure that control joints are installed over a continuous WRB and have expanded metal flanges wire-tied to lath that is discontinuous at joint locations and fully embedded in the plaster. This installation, which is consistent with ASTM C1063, will provide a free and unobstructed drainage plane. Weeps or drip flashings designed to evacuate water from the assembly should be provided at appropriate intervals; however, control joints should not be expected to weep water from the drainage plane.

Weeps and Drip Flashings

Weeps or drip flashings are critical to the drainage plane performance in a stucco assembly supported by metal lath. These accessories are generally used in a horizontal application, spaced at designated vertical intervals along a stucco wall, at transitions to horizontal soffit conditions, and at door and window head conditions. There are numerous products available that are designed, fabricated, tested, and marketed by the manufacturer to facilitate weeping of water from the drainage plane. These products generally perform best when installed in horizontal applications, and their performance may be adversely affected by installations having unusual geometry. At diagonal installations, the concept of the path of least resistance again alters the behavior of the water within the drainage plane. Where drip flashings are not provided at diagonal soffit and recessed door- or window-head conditions, water follows the path of least resistance and tends to wrap from the vertical wall drainage plane into the horizontal/diagonal soffit portion of the assembly. The water then flows downward along the horizontal/diagonal drainage plane, accumulating in volume as more water enters the assembly with no adequate path to weep from the assembly (*Figure 11*).

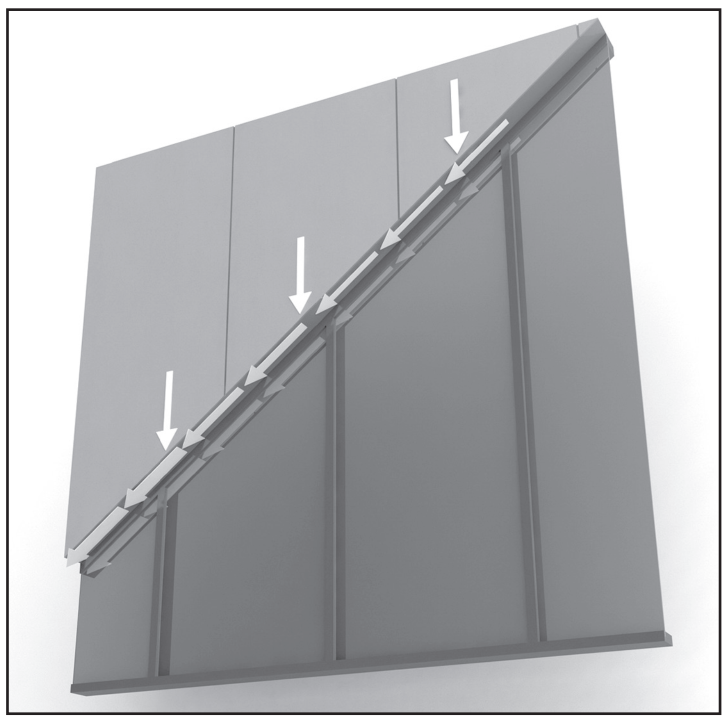

Figure 11 – Diagram showing path of water within the drainage plane at diagonal recessed window head without drip flashing.

This water accumulation can exceed the capacity of the drainage plane, causing the water to fill the cavity and leak through the laps in the WRB or through-flashings at adjacent assemblies. Large quantities of water that reach the end of the diagonal run may exceed the capacity of the flashings, if provided, at the termination.

Where diagonal drip flashings or weeps are provided, some water will weep out; however, some water flowing in the drainage plane tends to travel along the path of least resistance, remaining within the drainage plane and flowing along the diagonal head rather than weeping out at the flashings. This water again accumulates and can exceed the capacity of the drainage plane, potentially causing the water to fill the cavity and leak through the laps in the WRB or through-flashings at adjacent assemblies (although to a lesser extent, compared to assemblies without drip/weep flashing). This condition is commonly encountered where steep-slope roofing intersects a vertical stucco assembly extending upward. In these cases, where water is expected to flow within the drainage plane along a diagonal path, "kick-out" flashings have traditionally been used to evacuate water from the assembly.

Potential problems related to weeps and drip flashings in stucco assemblies with diagonal accessories and terminations can be mitigated following some basic principles. In tall stucco wall assemblies, provide weeps or drip flashings at appropriate vertical intervals. The intervals may vary depending on region, climate, and other factors; however, it is generally recommended that weeps be provided at each floor line, or at every 20 ft., whichever is less. Drip flashings should be provided at the head condition for doors, windows, and other similar penetrations. Where possible, these weeps should be horizontal; however, where diagonal weeps or drip flashings are to be installed, kick-out flashings should be provided. At conditions where long diagonal drip flashing or weep runs occur, it may be necessary to provide multiple kick-out flashings spaced at intervals appropriate to the specific conditions. In addition, accessories that include a 45-degree termination, similar to typical foundation weep screeds, may improve performance compared to standard drips or casing beads, including perforated casings.

In the as-designed laboratory mock-up, weeps and drip flashings were not included at recessed window-head conditions; therefore, none of these conditions was tested on the mock-up during our investigation.

Horizontal Shelf Surfaces

Horizontal shelf conditions occur at a variety of locations, including tops of walls and recessed windowsills. These conditions pose an increased risk of water intrusion at any configuration; however, this risk is increased when the shelf slopes diagonally parallel to the plane of the wall. Rainwater falling on these shelf conditions can penetrate the stucco more easily through cracks and at inadequately sealed terminations to adjacent materials compared to vertical walls. While the substrate and WRB at shelf conditions should always slope to the vertical face below for drainage, aesthetic decisions often result in this slope being minimized. Water on diagonal shelves will follow the path of least resistance, often along the more steeply sloped diagonal direction rather than toward the vertical face. When water on the shelf WRB intersects an obstruction such as a vertical wall or jamb condition, the water may accumulate and exceed the capacity of the WRB, entering the assembly through laps in the WRB.

Diagonal shelf conditions occur at the example project in the form of recessed windowsills, and this condition was replicated in the as-designed mock-up. During the water testing, no evidence of water intrusion was encountered; however, our review of field water testing and investigative deconstruction documentation of these conditions at the actual building revealed that water was entering the wall cavities at laps in the building paper and at the sealant interface between the sill shelf and the window frame seal, mostly at the location where the sill intersects the recessed jamb. Due to space limitations, the as-designed mock-up presents smaller samples of the various conditions. In the actual project, the windowsills where water intrusion was identified extended as much as 45 ft. in length, which likely increased the accumulation of water compared to our mock-up, which may account for failure in the actual project, but not in the mock-up testing.

Where diagonal shelf conditions are installed, proper detailing can minimize risks. Shelves should be sloped toward the vertical face below as much as possible. At these critical conditions, the WRB should always be installed over a more-reliable water barrier such as a metal flashing, self-adhered flashing material, or both. Where the shelf WRB intersects an obstruction such as a vertical wall or jamb, a well-detailed flashing should be provided. This flashing should be fully sealed so that it does not rely on normal weather-laps to resist water intrusion. Always provide well-detailed sealant installations at the interface between the diagonal shelf and adjacent materials, especially at the bottom termination.

Casing Beads

Casings are typically used as a termination for stucco. Most standard casings for exterior stucco have a component defining the depth, which we will call the projection, of ¾ or ⅞ in. to match the thickness of the stucco. They also have a return at the face of the stucco, which typically measures ⅛ or ¼ in. Flanges may consist of expanded metal lath or solid metal. While expanded flanges wire-tied to lath and encased in the plaster provide the best opportunity for the stucco panel to move and resist cracking, in many areas of the country, casing accessories with mechanically attached solid flanges are commonly used. Having solid flanges, however, does not necessarily allow these accessories to perform as flashings for the purposes of sealing the stucco cladding to an adjacent assembly. When a sealant application is used and sealed to the return face of the casing, establishing a good seal is difficult, since the face of ⅛ to ¼ in. is often insufficient to accept the minimum sealant-joint depth required for adhesion. Casing beads used in a flashing application inherently include a reverse lap at joints, leading to potential leaks. Casings by their design cannot be "nested" within each other; therefore, they cannot be fully weather-lapped in vertical or diagonal applications. Typical joint conditions for casings include a cut in each piece allowing for the lap; however, this ensures that a portion of the lap will not be shingled in a weather-lapped manner. Problems with casing accessories in any orientation, including diagonal, can be avoided by incorporating a separate, properly lapped and sealed flashing. Allowance for movement in the stucco assembly can also be enhanced by using casing accessories with expanded flanges that can be wire-tied to the lath and encased in the plaster material.

At the example project from the litigation case, the designer's details showed no casing or termination accessory of any kind. The sealant was shown adhered to the window frame and to the face of the finished stucco, which is not part of the weather-resistive barrier assembly. The shop drawings of the window included a metal flashing or casing with a relatively large return (*Figure 10*); however, this was not further detailed or specified in the project documentation, and the actual installation included a standard casing with a ⅛-in. return. As constructed, the sealant was adhered to the finish coat of the stucco, engaging only ⅛ in. of metal at the best-case conditions, and in many case, no metal due to tolerance limitations. In the as-designed mock-up, which utilized the standard ⅛-in. casing return, water was also observed penetrating into the cavity of the windows through the laps on the projection of the casing.

Installation of WRB

In most cases, the installation of sheet-applied WRB materials is relatively straightforward. Manufacturers specify the required overlap dimensions at horizontal and vertical lap joints in the material. To achieve a reliable weather lap, the installation of the WRB progresses vertically from the low point to the high point, providing a shingle effect. In most cases, decisions regarding where the WRB installation starts and in which direction the installation proceeds are determined by the contractor, based on construction schedule-related issues; WRB decisions are not typically addressed by the designer.

For the most common installations, vertical lap joints can be lapped from right to left or from left to right with little consequence to the performance of the building enclosure. Where diagonal accessories affect the path of water within the drainage plane, however, the orientation of vertical lap joints can play a significant role in maintaining the water-resistance of the assembly. When the path of water within the drainage plane is diverted by a diagonal accessory and flows downward along the diagonal, WRB sheet materials that are installed beginning at the high point of the accessory and progress to the low point create a reverse lap that can allow water to penetrate the WRB. These conditions become even more problematic at recessed shelf and soffit conditions, since the reverse lap has a greater surface area exposed to water travelling along the diagonal drainage plane at the shelf or soffit.

An example of how the installation sequence of the WRB at diagonal accessories and other features must be carefully considered would be obvious at a trapezoidal window having head and sill conditions that slope on a diagonal in different directions. In cases such as this, the installation of the WRB above the window head must be installed from the left to the right, while the installation of the WRB below the sill must be installed from the right to the left.

While the use of self-adhered membrane flashings in these conditions can provide additional protection in sealing the open laps, the potential exists for accumulation of water within these assemblies to leak through inadequately sealed lap joints, and through sealant installations that were intended to shed water rather than to resist longer-term immersion.

While the design documents for the project did not address this reverse lap potential, for the purposes of fabricating the as-designed mock-up, we elected to provide a proper weather-lap. We do note, however, that our review of documentation from testing and destructive investigations at the actual building showed that these reverse laps did exist in the building and were a major source of water intrusion.

Managing the potential for water intrusion at diagonal accessories and lapping of the WRB requires the installer to have a thorough understanding of the behavior of water in the drainage plane at these conditions; however, in our experience, this is often not the case. While the installation sequencing will almost always be a contractor's "means-and-methods" decision, designers can also influence the installation by including specific installation instructions related to installing the WRB at diagonal accessories on the construction drawings and in the project manual.

CONCLUSION

Façades comprised of stucco supported by metal lath are popular throughout the United States and in many other parts of the world. These systems are relatively economical, durable, and require minimal maintenance, in addition to being aesthetically pleasing. A successful installation of this type of wall cladding requires an understanding of the ASTM standards developed to help designers and builders, which include ASTM C926 and ASTM C1063.

In this paper, we have described the basic performance characteristics of the drainage plane and how following the requirements of the ASTM standards can reduce the potential for water leaks in the building. For buildings that have unusual geometric features, however, those engaged in the design and construction of these assemblies must also have a more advanced understanding of how unusual geometry can alter the behavior of water within this drainage plane. We have described some of the unusual conditions we have encountered in our investigations, and have provided some suggestions for addressing these conditions in a manner that will minimize the potential for leaks. In addition to understanding and adhering to the requirements of the ASTM standards, designers and installers should follow some other basic principles, including:

- Use plaster accessories in the manner intended by the manufacturer. For example, do not expect control joints to perform as weeps or drip screeds.
- Provide weeps and drip screeds at appropriate intervals on walls, at the head condition of penetrations such as doors and windows, and at transitions from vertical walls to soffits.
- Do not install accessories in a manner that obstructs the vertical flow of water in the drainage plane, especially diagonal accessories, like mechanically attached control joints or channel reveals, unless effective weeps are also provided.
- Slope horizontal and/or diagonal shelf conditions to drain to the outside face of the wall.
- When installing stucco with diagonal accessories, follow the "path of least resistance," which may direct water diagonally; and provide active measures like kick-out flashings to evacuate water before excessive accumulation can occur.
- Install WRB materials with vertical joints weather-lapped in a manner that anticipates diagonal or horizontal movement of water when wrapped onto shelf or soffit conditions.

Ultimately, the success of these installations depends on all parties involved in the design and construction of stucco supported by metal lath having an adequate understanding of the behavior of water in the drainage plane, particularly where unusual geometry occurs.