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The Importance of Destructive Testing for Identifying Concealed Resultant Structural Damage

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ABSTRACT

Defects in a building's water-resistive barrier (WRB) and veneer drainage systems are in direct conflict with modern building codes, industry standards, and manufacturers' instructions and create avenues for water intrusion and/or the accumulation of moisture within the building envelope system. The effects of the damage resulting from these defects are not always readily apparent and are often concealed in the form of deterioration of the structural sheathing and framing systems. Moisture intrusion through the building envelope and deficient discharge of the moisture from the veneer drainage system may result in moisture distress to the structural framing over time, ranging from latent to severe and unsafe conditions. The authors have investigated hundreds of water intrusion cases and have found over the course of these investigations that evidence of the moisture intrusion and damage to the structural systems may not be revealed by distress at the interior finishes or manifested at the exterior façade. The lack of reliable correlation between exterior and interior distress and framing deterioration necessitates the removal of exterior finishes to determine the condition of the structural framing. This paper is case study-driven and provides examples of both positive and negative correlation between visible interior and exterior distress and the extent of underlying structural damage observed through destructive testing.

INTRODUCTION

Defects within the building envelope that permit moisture, either cyclical or prolonged, to accumulate adjacent to structural framing can cause damage to the framing. The exterior finishes of the building often do not betray underlying structural damage, allowing long-term moisture intrusion to go unnoticed. This paper will focus on non-barrier veneer systems requiring a drainage plane behind the veneer, such as brick, stone, stucco, and exterior insulation and finish systems (EIFS). The lack of consistent and definitive correlation between exterior finish distress and water damage to the structural framing creates the need for destructive testing to determine the extent of damage, if any, at a particular building.

Possible structural damage resulting from long-term exposure to moisture includes biodegradation in wood sheathing and framing, corrosion in metal framing, and subsequent loss of structural capacity. The degree of resultant damage is dependent on several factors, creating unique evaluation conditions for each building or property. Most notably, climate conditions and defects in the water-resistive barrier (WRB) and veneer drainage systems contribute to resultant structural damage. For instance, with equivalent workmanship, damage in an arid climate might remain latent for a longer period of time than a similar construction located in a subtropical climate.

BUILDING ENVELOPE DEFICIENCIES

Deficiencies in the building envelope can result from one or more improper conditions and are commonly concealed by the exterior veneer finishes. The continuity of the WRB and drainage plane for veneer systems is critical in protecting structural framing from water damage and interior moisture distress.

Modern building codes include minimum requirements to prevent water infiltration through the building envelope. For example, the International Building Code (IBC) published by the International Code Council (ICC) dedicates a chapter to the exterior wall, providing guidance for the weather resistive exterior wall envelope, including the WRB and flashing components. The IBC also references industry standards, primarily the American Society for Testing and Materials (ASTM), in the exterior wall provisions. ASTM publications include installation standards for windows, doors, and skylights (ASTM E2112) and IBC referenced material standards for the WRB (ASTM D226).

Additionally, the IBC includes provisions for the installation of exterior plaster (stucco), which includes weep requirements, referencing ASTM C926 for installation guidelines, and increased WRB specifications, such as providing two layers of building paper. The installation of one layer of building wrap at stucco veneer increases the permeability of the exterior wall envelope and, therefore, the susceptibility of moisture intrusion to the framing. The IBC includes performance requirements, material requirements, and installation requirements to protect the structural framing and interior finishes from water intrusion and subsequent damage.

The primary component of the building envelope is the WRB, which wraps the exterior of the structure. The WRB is interrupted at fenestrations, such as doors and windows, balconies, and, in some instances, material transitions. Proper installation and detailing of the WRB creates a drainage plane that directs water to the exterior of the veneer system and prevents water migration to the structural framing systems or interior.

To connect the WRB to other elements of the building envelope, appropriate and compatible flashing is required. According to modern building codes, flashing is required to divert water to the exterior (ICC). When not installed properly, or when omitted entirely, flashing allows water to migrate behind the WRB and damage the structural framing components over time. Water follows the path of least resistance, which can be to the interior at areas of inadequate flashing.

Another common deficiency in the building envelope that results in water damage to the structural framing is not providing provisions for the exterior wall envelope to "weep" or drain to the exterior.

While the WRB and flashing are hidden by exterior finishes, the weeping provisions should be visible without removing finishes. Weep holes in stone veneer, weep screed in stucco veneer, and base flashing are important components in directing water to the exterior of a building. Water that penetrates the exterior finishes is intended to drain back to the exterior to prevent extended moisture exposure to the veneer system components. Many WRB materials are not intended to be waterproof when subjected to contact with saturated materials for an extended period of time and will break down over time due to retained moisture in the veneer system. Common areas where water accumulates due to improperly functioning weeping provisions includes the heads of windows and doors, at the base of the walls, and at soffit to fascia transitions at balconies and terraces.

CASE STUDIES

Visible exterior and interior conditions are not always indicative of underlying structural framing deterioration. Due to the concealed nature of the flashing and WRB, the only component of the drainage plane that is typically visible is the weeping system. Additionally, moisture staining at interior finishes may not be symptomatic of the severity of distress to the structural framing. Therefore, the diagnostic capabilities of exterior and interior observations tend to be limited. Non-destructive moisture surveys of interior and exterior finishes can be performed to identify areas requiring additional destructive testing. Moisture survey testing methods include infrared thermal imaging and moisture meters, which use electrical conductance and impedance principles to determine comparative moisture levels by creating a low-frequency, alternating electric field between electrodes placed on a specific material surface. Destructive testing is often necessary to verify moisture survey data, evaluate the exterior wall construction, workmanship, and framing conditions at a building and to determine the extent of damage, if applicable.

The case studies discussed herein are forensic evaluations of multi-family properties in Texas that presented interior or exterior distress requiring further investigation. The finish distress at these structures was not proportional to the observed resultant damage to the wood sheathing and structural framing.

Mid-Rise Condominium Complex

This four-story condominium building located in southeast Texas was constructed circa 2008. The wood-framed condominium structure was supported on a two-level reinforced concrete parking garage ("podium" construction). The exterior finishes consisted of stucco veneer and cementitious siding. Each condominium unit had a balcony supported by wood-framed columns clad with stucco veneer. The fascia and soffit of the balconies were clad in stucco, and the balconies had a concrete walking surface. The balcony framing was concealed by the architectural finishes.

A cursory evaluation of the exterior indicated cracking, staining, and signs of potential moisture-related distress. Suspected organic growth was noted between the stucco veneer and EIFS banding surrounding the windows. The finishing of the stucco did not indicate signs of degradation. During interior inspections of the units, a portion of the individual condominium units had moisture staining at the jambs and heads of the windows (**Figure 1**).

Figure 1: Moisture staining adjacent to window jamb

The interior moisture staining at the jambs and heads of windows was consistent with water infiltration around the window openings, potentially related to building envelope deficiencies. To determine the cause of moisture intrusion, portions of the stucco veneer were removed around windows. Destructive testing revealed improper flashing and WRB integration at building envelope transitions. The flashing and WRB were not shingle-lapped and permitted water to flow behind the WRB to the sheathing and structural framing. The wood sheathing and framing was deteriorated at and around the windows (**Figure 2**). The stucco veneer did not exhibit staining, fractures, or deterioration consistent with the extent of degradation of the underlying wood framing (**Figure 3**). Large areas of stucco were removed, revealing advanced deterioration of the sheathing and structural framing related to the building envelope deficiencies at the window openings.

Figure 2: Deteriorated wood framing below a window

Figure 3: Moisture streaking below EIFS banding with no fracturing of the stucco

At the balconies, the stucco veneer terminated in contact with the concrete topping slab, therefore, no weeping provisions were constructed at the stucco veneer in violation with industry standards (**Figure 4**). The soffit and fascia interface also lacked weeping provisions (**Figure 5**).

Figure 4: Stucco veneer in contact with concrete topping slab

Figure 5: Lack of weeping provisions at soffit transition

Due to the lack of weeping provisions observed at the balcony-to-wall intersections and visual evidence of organic growth, portions of the stucco veneer adjacent to the balconies, including at the supporting columns, were removed. Removal of the stucco surrounding the structural wood columns, particularly at the balcony bearing condition, revealed severe structural framing deterioration and unsafe conditions. The backside of the WRB for the opposite side of the column was visible through the portion of removed stucco, indicating an absence of competent framing (**Figure 6**). The structural wood framing exhibited a complete loss in structural capacity and was deteriorated to the point that it would crumble with the slightest contact.

The stucco did not have a pattern of deterioration or fracturing indicative of the advanced degree of structural framing deterioration revealed during testing. At the unit interiors, staining adjacent to the balconies was not a pervasive concern for the building occupants. The stucco-clad columns were not abutted to an interior space and, therefore, there was no interior distress which would alert occupants of the structurally deficient conditions exposed during the destructive testing.

The destructive testing at the balcony columns revealed complete deterioration of the structural wood framing, resulting in an unsafe cantilevered condition at the balconies. To determine the extent of distress due to this defect, stucco was removed at several additional balconies. In addition to distress at the columns, the wood sheathing and framing at the fascia edges of the balconies and at the balcony and wall interface were deteriorated. The advanced deterioration of the structural framing and sheathing revealed through destructive testing constituted a life-safety concern, requiring temporary shoring and the restriction of access to the balconies (**Figure 7**).

Figure 6: Deterioration of the structural wood framing at balcony column

Figure 7: Deterioration of the structural wood framing at balcony column and temporary framing

The structural distress and life-safety issues at the condominium building resulted directly from building envelope deficiencies. The pattern of moisture staining at the balconies indicated that water accumulated at the balcony and wall interface and that the walking surface was not able to properly drain to the exterior. Additionally, the structural wood framing was in the direct path of water migration and was not properly protected by the building envelope.

Determination of the full extent of the framing damage required destructive testing in large sections adjacent to building transitions and fenestrations throughout the building. The building repair protocol required a complete removal of the veneer system and repair of the extensive structural damage.

Multi-Building Condominium Complex

This multi-building condominium complex located in North Texas was constructed in phases beginning circa 2003. The wood-framed buildings were clad in stucco veneer, adhered stone veneer, and composite siding. The buildings had different architectural components, particularly at the balconies. Some buildings were constructed with large, expansive balconies supported by columns, and other balconies were framed between the walls of adjacent units. Based on areas of interior moisture staining around windows installed in the adhered stone veneer, portions of the exterior finishes were removed to evaluate the flashing and WRB conditions.

The building envelope lacked a proper WRB. Areas of wood deterioration were discovered at the heads, jambs, and sills of windows throughout the property. At some locations, the sheathing deterioration adjacent to the windows was severe enough for the sheathing to delaminate during removal of the finishes and had evidence of deterioration at the adjacent framing (**Figure 8**).

The adhered stone veneer did not exhibit moisture staining. Finishes were removed at the balcony and wall interface in an area of adhered stone veneer to evaluate the flashing conditions. The drainage path was interrupted at the balcony material transition and did not divert water to the exterior. The wood sheathing at the balcony and wall interface was deteriorated (**Figure 9**).

Figure 8: Deterioration of the sheathing at the head and jamb of a window

Figure 9: Deterioration of the sheathing at the balcony and wall interface

Stucco-clad wood columns supported balcony framing in multiple locations throughout the property. The stucco surrounding these columns presented fracturing in a pattern consistent with the wood framing deflecting downward or crushing (**Figure 10**). In addition to the stucco fractures at the columns, streak staining was located below the balcony topping slab and edge flashing. The underside of the balconies was fractured and moisture-stained (**Figure 11**). Due to the potentially compromised bearing condition and the stucco distress at the balcony, destructive testing of the stucco veneer at the columns and balconies was performed to further assess the framing.

Figure 9: Fractured stucco at a column pedestal

Figure 10: Fractured stucco at a balcony soffit

Initial finish removal exposed a deteriorated wood beam at the balcony fascia and adjacent to the bearing condition of a column. The framing deterioration was consistent with the fracture patterns at the stucco veneer. Similar to the conditions at the window and at the balcony-to-wall interface, the WRB at the balcony perimeter was inadequate with only one layer of material (**Figure 12**).

To determine the extent of distress and scope of repair at the balconies and columns, additional destructive testing was performed at similar conditions. The framing deterioration was found to be pervasive at the balconies (**Figure 13**). The severity of the section loss at the wood decking, wood-framed columns, and trusses necessitated temporary shoring at the balconies. In addition to deterioration of the framing and interior moisture staining, the resultant damage included compression of the weakened wood framing and interior finish distress attributable to superstructure movement.

Figure 11: One layer of WRB at deteriorated framing conditions

Figure 13: Balcony framing deterioration

The severity of the deterioration varied from building to building and condition to condition. At some buildings, the resultant structural framing distress was limited to wood sheathing deterioration with the framing still intact. At other buildings and conditions, the structural capacity of the wood framing was severely compromised and temporary shoring was required. The propagation of distress at this project varied based on exposure and age of construction, although similar building envelope deficiencies were noted throughout the buildings. The only way to assess the condition of the structural framing conditions, which revealed life-safety issues at multiple balconies, was through destructive removal of the veneer systems.

Comparison of Exterior Finish Distress and Resultant Damage

Often, the physical appearance of the exterior veneer instigates a forensic evaluation. However, the presence or absence of exterior finish distress has proven to be an unreliable indication of underlying building envelope deficiencies and subsequent resultant damage. The exterior veneer may exhibit staining or fracturing that alert owners and occupants of potential construction deficiencies. These multi-building condominium complexes, one located in Central Texas and the other in North Texas, exhibited degradation of the stucco veneer. The staining and fracturing of the stucco was pervasive throughout both properties.

North Texas Property

The North Texas property had stucco-clad soffit conditions throughout the buildings at balconies, garage openings, and planter boxes. The stucco soffits lacked weeping provisions and were fractured and stained (**Figure 14**). Due to the lack of a weeping mechanism, the soffit trapped and prevented water from draining.

Destructive testing revealed that only one layer of WRB was installed, although the building code required two layers. Portions of the cantilevered floor framing exhibited section loss due to the weeping and WRB deficiencies (**Figure 15**). At this complex, the exterior stucco veneer distress positively correlated to building envelope deficiencies and structural framing deterioration.

Figure 12: Soffit staining and lack of weeping provisions

Figure 15: Structural framing deterioration at the soffit condition and one layer of building wrap

Central Texas Property

The Central Texas property had mixed exterior finishes, including stucco veneer, and was wood-framed. The finish coat of the stucco was stained, generally adjacent to fenestrations (**Figure 16**). Destructive testing at the stucco revealed a competent and intact weather barrier, proper flashing, and no water distress to the wood sheathing (**Figure 17**). Despite the significant staining patterns at the stucco veneer, no correlating moisture distress was noted at the sheathing or structural framing. The condition of the framing could only be reliably determined by destructive testing.

Figure 13: Staining at stucco below a window

Figure 14: Proper flashing and drainage plane installation

CONCLUSIONS

The appearance of the exterior finishes may not be a reliable indication of underlying building envelope deficiencies and structural framing deterioration. Exterior finish distress, particularly to stucco, can be related to many factors, including the quality of the finish coat and staining from roof water runoff. Absent building envelope defects, such conditions would not be expected to damage the underlying structural framing. Destructive testing is required to evaluate and confirm the condition of the structural framing systems due to the hidden nature of the drainage plane and lack of reliable correlation between exterior and interior distress and framing deterioration. Some exterior conditions, including inadequate weeping and areas of water accumulation in proximity to the building envelope, create conditions conducive to framing deterioration due to prolonged contact with moisture. However, other factors, such as the WRB and flashing, should be evaluated to determine integrity of the building envelope, waterproofing performance, and compliance with applicable building codes, standards, and manufacturers' instructions. The evaluation of potential construction deficiencies at the building envelope is a multi-faceted endeavor and destructive testing is a critical component of the investigation to assess the extent of damage to the concealed structural framing systems.

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