The Performance of Weather-Resistant Barriers in Stucco Assemblies

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Abstract

This paper will focus on the performance of traditional three-coat cement plaster with two layers of Grade-D 60-minute paper. The speaker will discuss observations of moisture movement through the plaster, building paper, and plywood/OSB sheathing into the interior. Plaster performance was judged through nail pullout strength testing (ASTM D1037). The results were mapped to determine the level of damage and loss of structural strength. Rilem tube tests were conducted to determine the porosity, moisture absorption, humidity levels, and interior and exterior temperatures. The presenter will demonstrate how to better design plaster mix and use drain mats and rainscreens to prevent wood rot and damage.

Speaker

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Introduction

The most consistent feedback I get from all cement plaster contractors and plaster institutes is that the “proven” methods of applying weather-resistant barriers, lath, and plaster have been working for almost a century, so why change it? The fact of the matter is that while not much has changed in the plaster industry, the building “assembly” has changed completely.

When lath and building paper were first introduced as building materials—albeit at different times—their application was over open framing with wood space boards acting as the lath. Later construction included line wire over wood studs to support building paper, and lath installed with furring nails. Wall cavities did not contain insulation or incorporate air barriers. In contrast, today’s buildings incorporate airtight construction, full exterior sheathing (like plywood or gypsum), stud bays filled with insulation and interior paper-backed sheetrock, and interiors finished with vapor-impermeable materials (like vinyl wallpaper). Furthermore, when cement plaster or stucco was first popularized, it was used in single-family one- and two-story residential structures. Today we find cement plaster often used in high-rise construction, commercial buildings, public and institutional buildings, and large multifamily structures. These larger commercial structures often have little or no roof overhang, so they are less protected from direct rain and experience much higher wind pressures. Shingling, lapping flexible flashings, and building paper with fin or flange-style windows have given way to finless punched windows, storefronts, and curtainwalls. We often see architects integrating traditional cement plaster with barrier-type metal panels and other traditional siding. Further complicating matters, the International Building Code (IBC) is moving to have continuous insulation behind claddings without first testing wall assemblies that have truly continuous insulation to determine how to secure lath over continuous insulation and their moisture removal viability behind traditional cement plaster or stucco.

We all learn from failures, and in that sense, I have been extraordinarily lucky. Over the past ten years, I have been fortunate enough to study failed cement plaster assemblies in millions of square feet of large commercial-type structures ranging from multifamily buildings to office spaces, education facilities, and residential structures.

This paper will focus on what we can learn from these forensic studies, understanding the forces at play that can cause assembly failure and how to avoid failures, and will conclude with how to modify the standard building assembly to perform successfully with commercial-type applications.

Background

To understand the evolution of the cement plaster system, we have to start at the beginning. We will start with “open-stud” construction (Figure 1), as it was the most widely used construction method in the western United States 50 years ago and continues to be used in many states. Historically, contractors have used Portland cement plaster or stucco as the outer covering for most construction projects because it is easy to apply and use, has good water-resistive properties, is durable and fire-resistant, and can be modified for color and finish relatively easily. For more than 100 years, it has been touted as the product of choice.

A century ago, buildings were made using lath and plaster construction with a layer of boards covered with cementitious plaster over building studs. This typical assembly did not use building paper, and under wet conditions, it would allow some level of water to soak through the wood lath and collect in the wall cavity. The lath held the plaster in place, and when the plaster dried, it was a strong, durable assembly with open space between studs and did not have any insulation in the stud bay. The lack of insulation in the wall cavity allowed it to dry quickly during dry spells or dry to the warm interiors. Interior walls were often constructed similarly with gypsum-based plaster on wood lath. Heat from the interior or exterior surfaces would dry the moisture and readily permeate it out of the wall to either the interior or exterior. While humidity can build up over 90% inside walls during wet cycles, it did not result in mold or rot due to the lack of organic paper-faced sheetrock, old-growth wood framing, and constant air movement.

“Sackett Board” was invented in 1894 in the UK, and in 1910, the United States
Gypsum Corporation bought the Sackett Plaster Board Company and wrapped the gypsum plaster board with paper-based facings instead of the felt sheathing; they called the product “sheetrock.” As construction boomed in the ’40s and ’50s, drywall was easier to install, could be mass-produced, added a measure of fire safety, and reduced the process from a weeklong application to a one- or two-day project. Consequently, cement plaster cladding incorporated closed cavity construction in lieu of the traditional open-stud wall assembly.

As construction became more widespread, governments became more involved in the process and began to standardize requirements for buildings and their construction. The Uniform Building Code (UBC), and now the International Building Code (IBC), established standards for the construction industry that addressed fire codes, structural performance, weather- and water-resistive construction, as well as establishing life safety criteria, accessibility standards, and other construction and design standards. As new regulations are developed, they apply to new construction primarily, but if you make changes or renovate an older building, you may be subject to compliance with all the new regulations established since the original construction date. For us, this update requirement has created new challenges for the industry. Green buildings are more energy efficient, better insulated, more airtight, and enclosed with wood or gypsum sheathing. As the industry itself pushes forward to make these changes for energy, fire, and structural reasons, how these assemblies manage water and moisture has changed, sometimes taking on unintended consequences and not performing as intended.

In the 1940s, asphalt-coated “felt” was often used under exterior siding, and cement plaster with poultry netting was used for reinforcing instead of wood lath. Original felt papers (15- and 30-lb. organic felts) used behind exterior cement plaster were more “water-resistant” but less permeable. I imagine this construction may have caused some condensation, but it would have self-dried due to a lack of insulation that allowed the free flow of heat and air through the walls. In 1964, the establishment of UU-B-790 (a federal specification) required minimum water-resistance rates that correspond to a permeance rating of about 5 perms for water-resistive barriers.

In 1968, the code (UU-B-790a) started requiring “Grade-D” type paper as a weather-resistant, breathable paper, likely as a reaction to condensation issues, which was the next significant change in exterior stucco and siding. This breathable Grade-D type paper with a minimum 15 minutes of water resistance would allow more moisture to flow into the wall cavity, but again, the moisture dried steadily due to higher permeability and the lack of insulation being crowded into the wall cavities. The addition of various types of batt insulation was another change to the hygrothermal performance of the wall assembly, and the time it took to dry out the wall cavity increased. Depending on the interior use of paper-faced gypsum boards and the level of incidental water intrusion through the exterior wall, some assemblies would undoubtedly have developed some level of mold growth and rot as a result of the fully insulated, closed-cavity exterior wall construction.

Full plywood or OSB-type exterior sheathing was the next significant shift in siding/stucco substrates. Dry plywood-type sheathing has a permeability ranging from 0.5 to 1.5 perms—technically a vapor retarder. However, when plywood and OSB get damp (moisture content in excess of 20%), the permeability increases to over 20 perms, making them much more permeable. Gypsum-based sheathing boards are often used in construction of noncombustible types of sheathing product to reduce and retard fires. Interior wall and exterior sheathing boards are highly permeable, in excess of 30 perms, and can readily move moisture across the sheathing.

As buildings have become more energy-efficient with the use of insulation that reduces heat flow, moisture barriers that reduce air and water movement, and solid sheathing to improve structural and fire-resistive building performance, we have also created a new challenge: how to remove the moisture that gets trapped inside a wall cavity.

A common assembly with 60-minute Grade-D paper over full exterior gypsum sheathing, plywood, or OSB sheathing is very sensitive to the level of “incidental” water that passes through the stucco. While fluid-applied weather-resistive barriers and
polymetric housewraps have become more popular in the past decade and are considered more cutting-edge, they also have similarly high permeability ranging from 15 perms to over 70 perms. In order to understand weather-resistive barrier performance and how walls behave with full sheathing and insulation, it is important to understand how water and moisture move through these assemblies.

Poor performance of traditional stucco assemblies is giving way to rainscreen-type assemblies (Figures 2 and 3) with wall drainage boards or furring strips to improve the wall’s ability to remove water as well as introduce airflow to dry these assemblies. Manufacturers have introduced better-designed building paper to improve drainage and not deteriorate under repeated wet and dry cycles.

To ensure a building’s sheathing and structural components are not impacted by normal wet/dry cycles, it is vital to the long-term performance and integrity of wall systems to remove any incidental or excess moisture. The damaging effect of repeated wet/dry cycles can eventually result in degradation of organic building paper and sheathing and cause metal flashings to rust, as well as nails to rust, lose strength, or back out. Additionally, excess moisture retained within a wall can promote biological growth such as mold and mildew.

**TRADITIONAL MOISTURE MANAGEMENT**

Today we are building elaborate, complex structures that utilize all sorts of technology to provide us comfort and protection, while at the same time being efficient and safe. Keeping moisture or rain out of an inner wall space has been going on for decades, but the manner in which the building envelope has evolved has taken us to new dimensions in design and construction. All of this advancement continues to evolve with new and better products, techniques, and skills.

Just as the exterior surfaces are meant to keep water from entering the wall system, the permeability of many siding materials—including stucco—allows water and moisture from rain, fog, or dew to intrude. In West Coast climates like California and Washington, during rain events the interior is not only much drier, but the temperatures are often higher than the exterior, which promotes drying to the interior (Figures 4A and 4B). Permeance rates of damp or wet materials such as wood sheathing can be much higher, which leads to moisture movement inwards where humidity is lower and where most of the drying occurs. Cracks or other wall defects can raise this level even higher as shown in the figures.

As water found inside the wall permeates through exterior assemblies and dries to the inside, it raises interior humidity levels, often causing condensation on the inside surfaces of nonthermally broken
Water diffusing through the weather-resistant barrier raises moisture levels in the OSB or plywood to above 20%, promoting wood decay and the rusting of nails and staples. Humidity rates in the wall cavity can often exceed 90%, promoting biologic growth in paper-faced gypsum boards.

Without drainage mat or rainscreen construction, water does not flow down freely to the weeps or “air” dry. Much of the water entering the system onto the WRB intrudes into the interior space.

The solution to improving the performance of the wall assembly is dependent on two primary factors:

- Reducing the level of incidental water on the WRB
- Improving drainage and drying behind the siding/stucco

It is commonly believed that incidental water landing on the WRB will easily drain down the weeps and flow out of the assembly, but that is not entirely true. Trace amounts of water trapped behind siding material can move laterally within the assembly. When left standing, it permeates the assembly, leaving it hanging like a wet blanket. Moisture gradually works its way through the WRB and solid sheathing if present and dries to the inside. High levels of moisture permeating through the sheathing finds its way into the wall cavity, raising humidity levels not only in the wall cavity, but also in the interior living space, causing damage.

The decades of the 1980s and 1990s saw an increase in construction failures and defect litigation related to water-induced damage to frame buildings with notable hotspots in such places as California, British Columbia, and North Carolina. In the last three years, mold became the focus of attention. Although there are a myriad of reasons for the apparent increase in water-related building damage, the increased air-tightness of buildings to achieve energy conservation is generally accepted as a major contributing factor. The historic ability of wall components wetted by precipitation or condensed water vapor to dry through air movement is no longer as effective as it was before the advent of energy-efficient new construction.

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Therefore, as we have become more energy-efficient using wall insulation and impermeable moisture barriers that reduce air and water movement, we have also created a new set of problems: how to remove moisture that becomes trapped within a wall cavity. Rilem tubes (Figure 5) enable the assessment of water absorption properties of walls or other substrates. Higher absorption of the cement plaster or cement board-type siding can greatly increase the moisture permeation through the wall.

These tools work with a variety of materials and coatings, and the results are repeatable and reliable. Cement plaster and fiber cement siding and/or materials are unique, and their use in combination with coatings and paints can create different results, so each building should be tested independently to provide accurate and repeatable result measurements.

While there is no clear standard for absorption testing with a Rilem tube for many cladding materials, it does provide a greater relative scale to measure absorption. In cement plaster assemblies, we find that absorption rates can vary greatly in a 20-minute test, ranging from no loss to several inches. In many cases, we found that a traditional moisture-drained assembly without a drain mat or rainscreen (more porous assemblies) results in greater and uniform damage to the substrate and higher interior humidity levels.

Electronic moisture measurement devices that rely on transduction to measure the change in conductivity are used to measure moisture content of softer assemblies such as gypsum or wood sheathing. Levels of moisture in plywood sheathing can vary from the exterior face of the plywood/OSB to the interior face of plywood/OSB, depending on the cycle of wetting and drying. The amount of moisture in a building sheathing or wall cavity will vary with airflow, exterior and interior humidity, and temperature. Moisture meters—either surface or pin-type—are only qualitative measurement devices, measuring specific relative moisture levels, and not the relative humidity within an environment.

We had the opportunity to conduct an extensive study of dozens of large multifamily buildings and some large single-family homes with traditional building paper and either cement board siding or stucco. In both, siding types of assembly and stucco assembly, the siding/stucco was completely removed to expose the condition of the OSB or plywood or gypsum sheathing. While some of the damage to the sheathing was definitely due to leaks from wall penetrations or improperly flashed horizontal waterproofing systems, we surprisingly documented a lot of moisture movement and damage due to moisture soaking through the building.
paper and damaging the wood sheathing (Figures 6A and 6B).

Depending on the elevation, we observed and documented damage to the wood sheathing and graphed it visually to depict damage. We realized that other than poking the sheathing with an awl, most experts were not using any scientific means for analyzing the damage to the sheathing. Surprisingly, even though the sheathing was discolored due to different levels of water damage, slight, moderate, and some severe areas passed the “awl” poke test.

To make the assessment process more scientific, we went on to create a testing protocol using ASTM D1037, which is a nail pull-through test (Figure 6C). The nail pull-through tests were more telling and representative of loss of structural value such as shear value. These types of tests can provide a detailed profile of force exerted over time and give a more realistic assessment of the loss in structural capacity (Figure 6D). Using the standard measurements, we were able to demonstrate a significant difference in nail pullout strength between slight, moderate, and severely damaged areas.

Although a building envelope may be designed to prevent moisture and water intrusion into the interior spaces, care must be taken to prevent damage to the wall framing and allowing unintended humidity inside. Construction itself may allow a measurable amount of moisture absorption and diffusion to occur over an extended time period. Unintended and higher levels of moisture diffusing through the assembly can lead to not only decay and loss of strength in materials, it can cause mold on interior surfaces due to elevated humidity levels. The question is, how do we deal with the incidental levels...
Understanding Incidental Water Penetration

The typical source of incidental water intrusion is the perimeter of windows, reveals, control joints, wall penetrations, inside and outside corners of buildings, joints in siding panels, and small 1/64-in. shrinkage cracks.

Typical sources of unintended water intrusion include open or unsealed sealant joints, cracks 1/32 in. or larger, shrinkage cracks around reveals, and control and expansion joints. The typical source of excessive water behind stucco and other siding are items such as water run-off from horizontal waterproofed elements (roofs or balcony decks and walkways) directing water behind the stucco assembly. Water managed on “horizontal waterproofing” elements should never be drained onto WRB.

Traditional Grade-D 60 papers wrinkle as a result of being left exposed to moisture and sun during installation. Wrinkling of the paper can sometimes promote drainage but often obstructs water flow and creates pockets for water to collect. Stucco also tends to adhere to traditional paper, effectively cutting off the water flow on top of the paper. In those instances, water will penetrate to the second layer of paper, if present. Since traditional weather-resistant barriers like building paper depend on water shedding, any buildup of water can lead to lateral migration of water at the laps in the paper. While fluid-applied barriers do not have laps, and therefore, water cannot effectively get behind them, water standing on highly permeable fluid-applied barriers can permeate behind the barrier just the same.

Tightly fastened horizontal control joints, expansion joints, or reveals create water cut-offs, and water tends to collect above them. Generally, we see fastener rusting and moderate to severe damage both above and below horizontal control/reveal joints. Unsealed joints in control, expansion, and reveal joints, as well as screeds and corners, can be a source of unintended water on WRB. Applying flexible flashings behind these joints, reveals, and screeds—both on the horizontal and on the vertical—helps mitigate some of the damage. Examples of this type of assembly and the results of damage are in Figures 7 and 8.

Standing or trapped water behind the siding or stucco can create a hydrostatic head. Under hydrostatic head, water can penetrate through fasteners, absorb through the WRB, and permeate right through to the interior. In the absence of a drainage mat or rainscreen, I see no advantage of WRB that has a permeability of greater than 10.

Another common element that allows unintended moisture is the porosity of the cement stucco material. Where we measured high levels of water penetrations using a Rilem tube test, we also observed high levels of sheathing damage. Synthetic siding or stucco that is porous is another source of unintended water/moisture on the WRB (Figures 9A and 9B). We have observed the “uniform”-type damage in many projects clad with cement board siding. Cement board siding can be just as porous, if not more so, than cement plaster. Top edges of lap siding can create a lip where water can accumulate. Joints in the lap siding, corners, trim, and around window and other openings allow similar, if not more, water intrusion as cement plaster.

Large quantities of water can soak through the stucco/siding material itself, depending on its level of porosity. Our measurements of high humidity levels in the interior living spaces of buildings with “cement board siding” were just as high as those we experienced in stucco assemblies, even though the materials are very different in manufacture and installation.
IMPROVING DRAINAGE AND DRYING

In the process of conducting forensic building studies, the reason for failures is most evident with moisture intrusion into the building where there is no avenue to remove that moisture or allow it to dry out. Once moisture infiltrates behind the tightly designed cladding with little or no air movement, problems are going to occur.

To alleviate such problems, there are a few measures that—when designing or constructing a building—can ensure that water intrusion is dealt with before it becomes an assembly failure. These will greatly reduce moisture intrusion, allow the building to last longer, and save owners from future, highly expensive (and often unnecessary) repairs due to water damage.

Improve Drainage. Furring horizontal control joints or reveals will allow water to travel behind them unimpeded. Fluid-applied WRB used in conjunction with traditional building paper can improve drainage. Use of engineered and tested weather-resistive paper that has drainage grooves or built-in channels has been proven in testing to improve drainage and drying. In certain dryer climates like southern California and Arizona, this level of improvement may be enough.

Improve Air Movement. Rainscreens are typically created by installing drain mats or vertical furring strips behind siding or stucco. The air gap and cavity allow for effective drainage and promote drying. In addition to an engineered drainage layer, through-the-wall flashings are typically installed at each floor to drain the water, equalize pressure, and promote airflow. Rainscreen systems not only allow unimpeded drainage, they also create positive airflow and promote active drying. Effectively moving water off the weather-resistant barrier and promoting air movement are the keys to getting better performance from the weather-resistant barriers. This type of a system is much more foolproof against defective construction and unintended water behind the cladding. The system is designed to prevent water from becoming a standing element.

Western “one-coat” type cement plaster systems with 1-in. rigid insulation board are rainscreen systems. While the cement plaster system is actually two coats, it is only ½ in. thick, and allows more incidental water behind it. The drainage channels in the ridged insulation effectively drain water away and allow the assembly to dry. Despite being half as thick as traditional cement plaster, it manages water on traditional WRB better than most other siding or traditional cement plaster material.
CONCLUSION

Today’s building envelopes are designed to be energy-efficient, technologically advanced, and to provide a safe, comfortable, and manageable environment. Though many of the current exterior cladding materials have been in use for over a hundred years, the wall assembly has changed, and the manner in which these cladding systems perform has changed. Siding and stucco directly applied over highly permeable weather-resistive barriers can cause a high level of damage, depending on the sources of incidental and unintended water penetration.

Since Grade-D WRB became a code requirement behind nonbarrier-type assemblies, a lot has changed. Traditional WRB do not have rainscreen-type cavities or drainage boards, and the cladding is built tight up against the WRB. With air barriers and insulation in the wall cavities, this tight assembly allows for very inefficient drying, mostly to the interior, and results in issues. The consequence of this tight assembly construction is like having a “wet blanket” up against the exterior wall sheathing. While I have documented many such projects and their impacts with traditional two layers of Grade-D building paper, I have not performed a similar study with fluid-applied WRB in a tight assembly. Traditional WRB can be saturated over time and has the capacity to hold water and permeate it through the sheathing.

In case of a cement plaster assembly with a primary fluid-applied WRB, often a layer of building paper is used to separate the plaster from the WRB. In an assembly that has a combination of fluid- and paper-based WRB, I believe that the amount of moisture permeation through the assembly will depend on the permeability of the fluid-applied barrier. Some of the available fluid-applied WRBs are much more permeable than 60-minute Grade-D papers; therefore, I do not believe that the fluid-applied WRB will fare better than two layers of Grade-D papers. I do believe that in a tight assembly, it is better to choose a lower permeability fluid-applied barrier.

In a case where stucco or siding is porous, consider penetrating sealers or elastomeric-type coating to reduce the water absorption through the skin. Provide functional sealant joints around openings to reduce incidental water. Design and install plaster with properly constructed control and expansion joints to reduce cracking.

The best solution is rainscreen-type assemblies. Rainscreen-type assemblies manage excess water and dry so efficiently that they are not dependent on the quality of the WRB. In such an assembly, high permeability WRB can perform well and will allow drying from the inside out just as effectively as from the outside. It is my opinion that rainscreen should be the standard of care in commercial high-rise type buildings. Rainscreen is already a standard of care in the Pacific Northwest areas, although not required by code. Rainscreens offer such amazing redundancy and are so forgiving that every building envelope consultant should make it their number-one recommendation. The problem with this assembly is the higher cost, which owners tend not to approve.