PERFORMANCE OF WEATHER RESISTANT BARRIERS IN STUCCO ASSEMBLY

by

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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 resistive 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 completely changed.

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 air-tight 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 wall paper). Furthermore, when cement plaster or stucco was first popularized, it was used in single-family 1- and 2-story residential structures; today we find cement plaster often used in high-rise construction, commercial buildings, public and institutional buildings and large multi-family 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 fin-less punched windows, storefronts and curtain walls. 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, 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 10 years, I have been fortunate enough to study failed cement plaster assemblies in millions of square feet of large commercial type structures ranging from multi-family buildings, to office spaces, education facilities, and residential structures.

This presentation will focus on what we can learn from these forensic studies, understanding the forces at play that can cause assembly failure, 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 resistive, and can be modified for color and finish relatively easily. For more than 100 years, it has been touted as the product of choice.

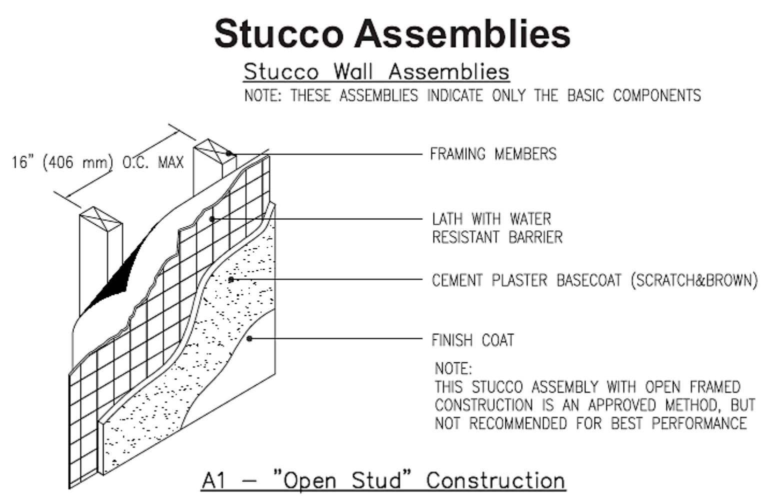


Figure 1: "Open Stud" Construction Components

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 to +90% inside walls during wet cycles, it did not result in mold or rot due to the lack of organic paper faced sheet rock, 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 International Building Code (IBC) establishes standards for the construction industry that addressed Fire Codes, structural performance, weather and water resistive construction, setting life safety criteria, accessibility standards, and establishing 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 used for reinforcing instead of wood lath. Original felt papers (15 and 30 lbs. 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 resistive, breathable paper, likely as a reaction to condensation issues, which was the next significant change in the 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 takes 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 non-combustible 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 by using 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 set of problems – 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 moves through these assemblies.

Poor performance of the traditional stucco assemblies is giving way to rain screen 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.

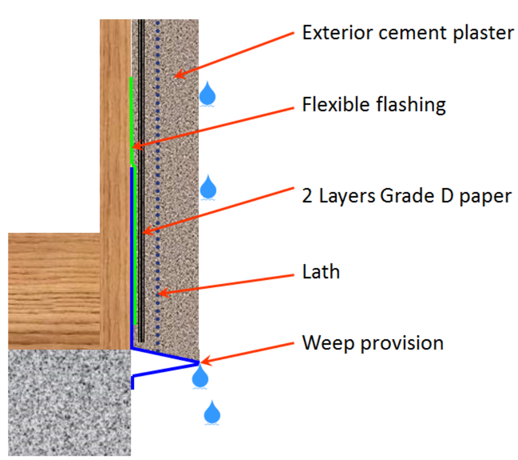


Figure 2: Stucco or Cement Plaster, Moisture Drained System

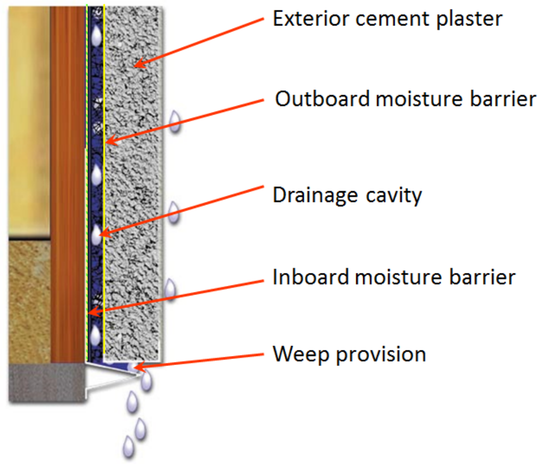


Figure 3: Rain-Screen Moisture Management System

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, sheathing, and cause metal flashings to rust and 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 because the exterior surfaces are meant to keep water from entering the wall system, the permeability of many siding materials including stucco, allow 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 figure below.

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 non-thermally broken aluminum window frames. Where cabinets, bedside tables and beds press against exterior walls, elevated moisture levels in the gypsum wallboard leads to mold growth on the interior surface of the sheetrock. Tightly packed closets up against exterior walls that do not have air circulation can cause clothes, books and shoes to get moldy.

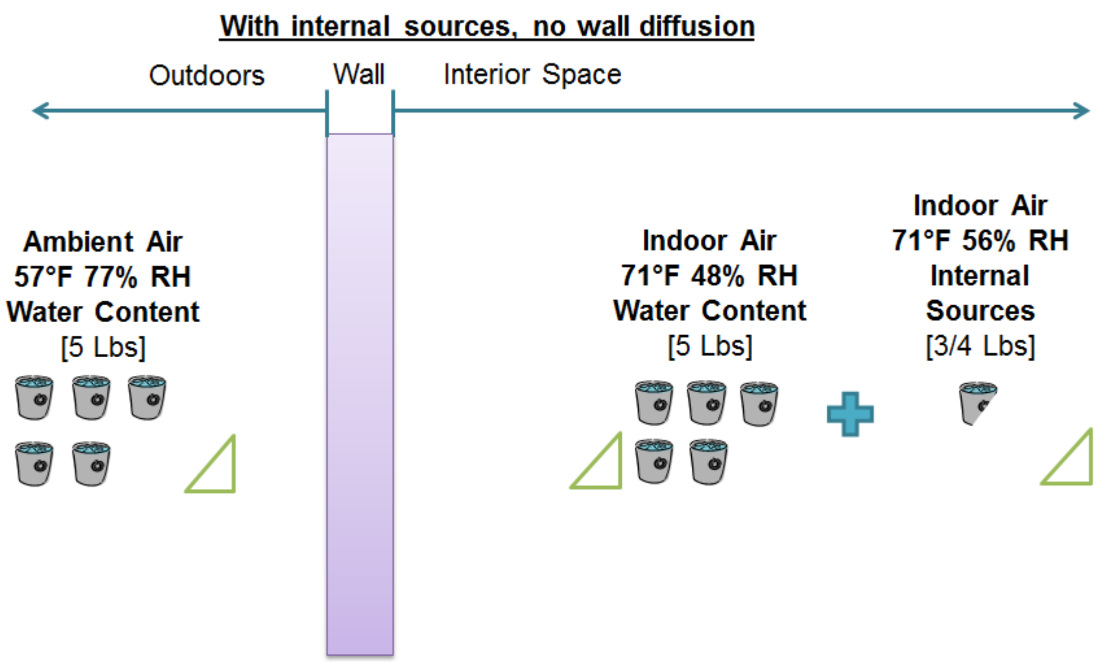


Figure 4A: Moisture Diffusion Study Results – With occupant Internal Loads

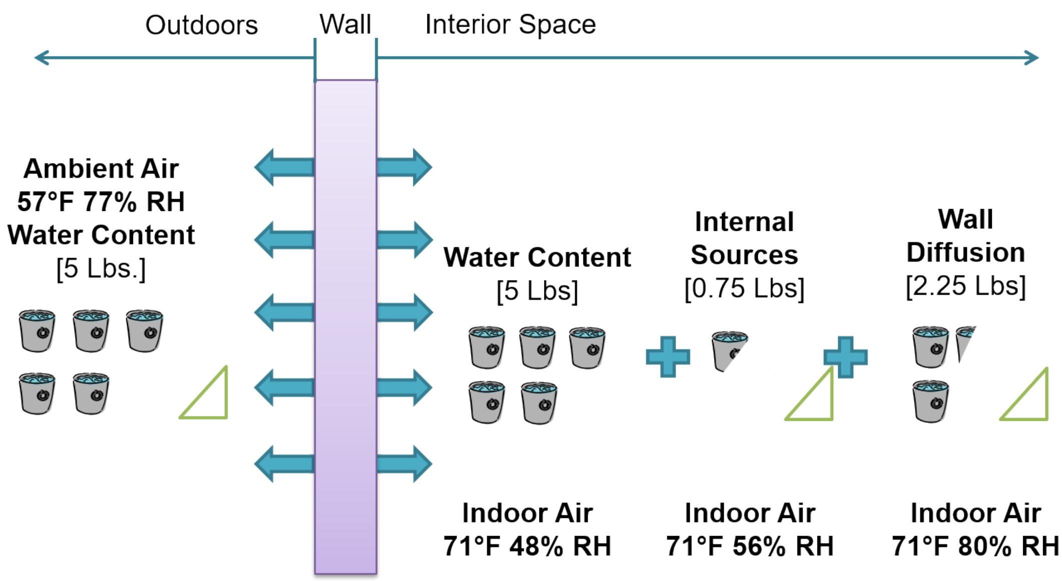


Figure 4B: Moisture Diffusion Study Results – With Internal Sources & Wall Diffusion Due to Excessive Cracking and Defects

Interior weather resistive elements such as Grade D paper or Water Resistive Barriers (WRB) work in tandem with the exterior skin to manage and keep out "incidental" water. The level of moisture movement to the inside and wood rot or metal rusting damage caused by such moisture movement is directly proportionate to the increase in humidity level inside occupied 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 sheeting 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.

Water diffusing through the weather resistive 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 rain screen construction, water does not free flow down to the weeps or “air” dry. Much of the water entering the system on to the WRB intrudes into the interior space.

> *“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.”*
>
> Thomas K. Butt
> Journal of ASTM International
> November/December 2005

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.

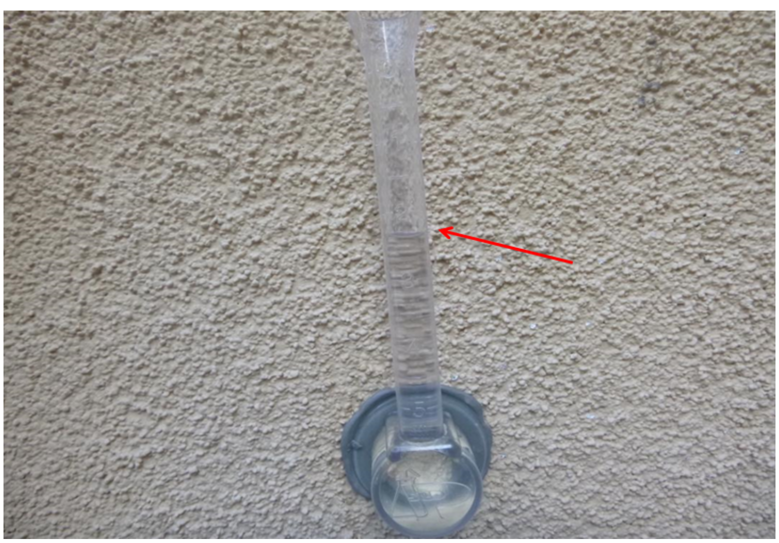


Figure 5: Rilem Tube Level Dropped in 15 Minutes

These tools work with a variety of materials and coatings and the results are repeatable and reliable. Cement plaster, 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 great relative scale to measure absorption. In cement plaster assemblies, we find that absorption rates can vary greatly in a 20-minute test, ranging from 0" 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 exterior face of the plywood/OSB to 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 multi-family 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).

Figure 6A: Damage – South Elevation – Partial

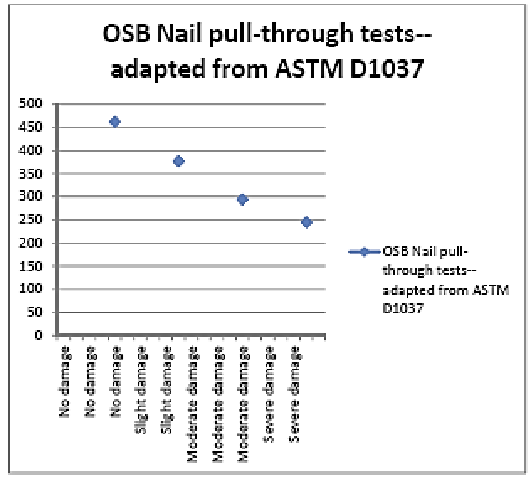
Figure 6B: North Elevation - Partial

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 gives 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 pull out strength between slight, moderate and severely damaged areas.

Figure 6C: ASTM D-1037 Nail Pull Tests – Loss of Strength

Test #	Sample Location	Condition	Result (lb.)	Average for condition (lb.)
11	#2307 #1	No damage	525.6	
12	#2307 #1	No damage	419.7	
13	#2307 #1	No damage	535.2	
14	#2307 #1	No damage	391.2	
15	#2307 #1	No damage	440.5	462.4
16	#2304 #4	Slight damage	274.6	
17	#2304 #4	Slight damage	308.1	
18	#2310 #5	Slight damage	401.1	
19	#2310 #5	Slight damage	429.8	
20	#2310 #5	Slight damage	472.7	377.3
21	#2308 #3	Moderate damage	254.7	
22	#2308 #3	Moderate damage	368.0	
23	#2207 #2	Moderate damage	383.6	
24	#2207 #2	Moderate damage	202.4	
25	#2207 #2	Moderate damage	264.6	294.7
26	#2201 #1	Severe damage	164.7	
27	#2201 #1	Severe damage	267.3	
28	#1104	Severe damage	258.7	
29	#2306 #6	Severe damage	309.8	
30	#2306 #6	Severe damage	224.8	245.1



Slight Damage	19% less nail pull out strength
Moderate Damage	36% less
Severe Damage	46-100% less

Figure 6D: Nail Pull Through Strength Test: ASTM D1037

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 cannot only lead to decay and loss of strength in materials, it can cause mold on interior surfaces due to elevated humidity levels. Question is how do we deal with the incidental levels of moisture? How do we design to prevent unintended levels of moisture? Moreover, how do we make it more fool proof to prevent against both?

UNDERSTANDING INCIDENTAL WATER PENETRATION

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

Typical sources of unintended water intrusion include open or unsealed sealant joints; cracks 1/32" or larger, shrinkage cracks around reveals; unsealed butt joints in reveals, corner molds, 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 to flow on top of the paper. In those instances, water will penetrate to the second layer of paper, if present. Since traditional weather resistive 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 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.

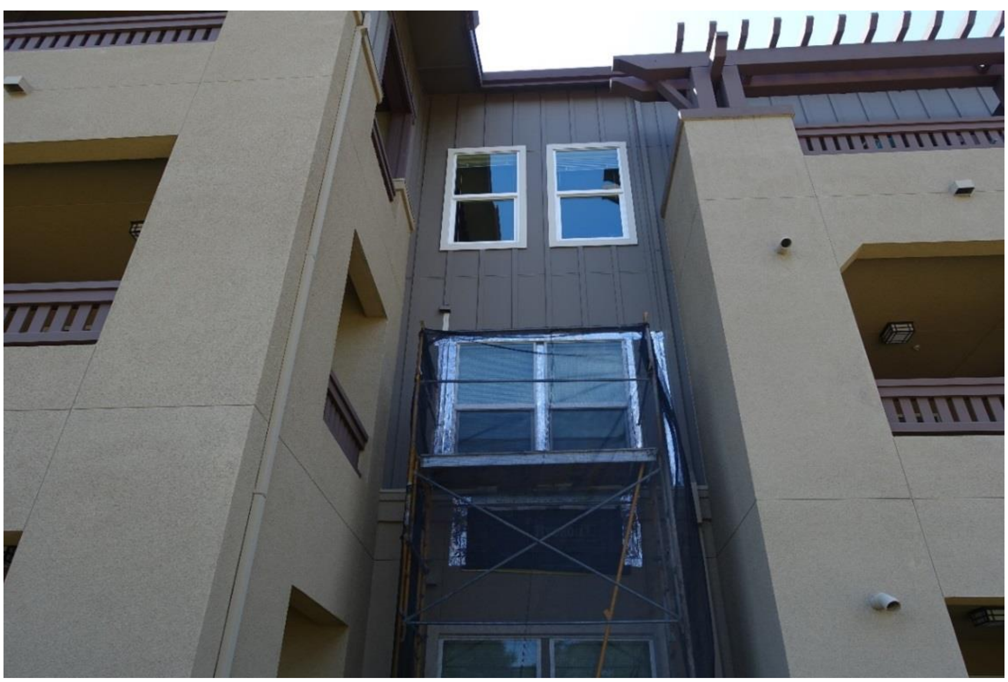


Figure 7: Traditional Fiber Cement Siding Assembly

Figure 8: Uniform Damage Behind Fiber Cement Siding

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.

Figure 9A: Control Joint Corner Unsealed

Figure 9B: Control Joint Impedes Water Drainage

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. The following measures will greatly reduce moisture intrusion: do not tolerate defective construction or unintended water, allow the building breathe 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 it un-impeded. Fluid applied WRB used in conjunction with traditional building paper can improve drainage. Use of engineered and tested weather resistive paper that has drainage groves or channels built-in have 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: Rain screens are typically created by installing drain mats or vertical furring strips behind siding or stucco. The air gap and cavity allows for effective drainage and promotes 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. Rain screen systems not only allow unimpeded drainage, they also create positive airflow and promote active drying. Effectively moving water off the weather resistive barrier and promoting air movement is the key getting better performance from the weather resistive barriers. This type of a system is much more fool proof against defective construction and unintended water behind the cladding. The system is designed prevent water from becoming a standing element.

Western “1-coat” type cement plaster system with 1” rigid insulation board is a rainscreen system. While the cement plaster system is actually two coats, it is only 1/2” 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 non-barrier 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 result of this tight assemblies construction is like having a "wet blanket" up against the exterior wall sheeting. While I have documented many such projects and its impacts with traditional 2-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 WRB's 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.