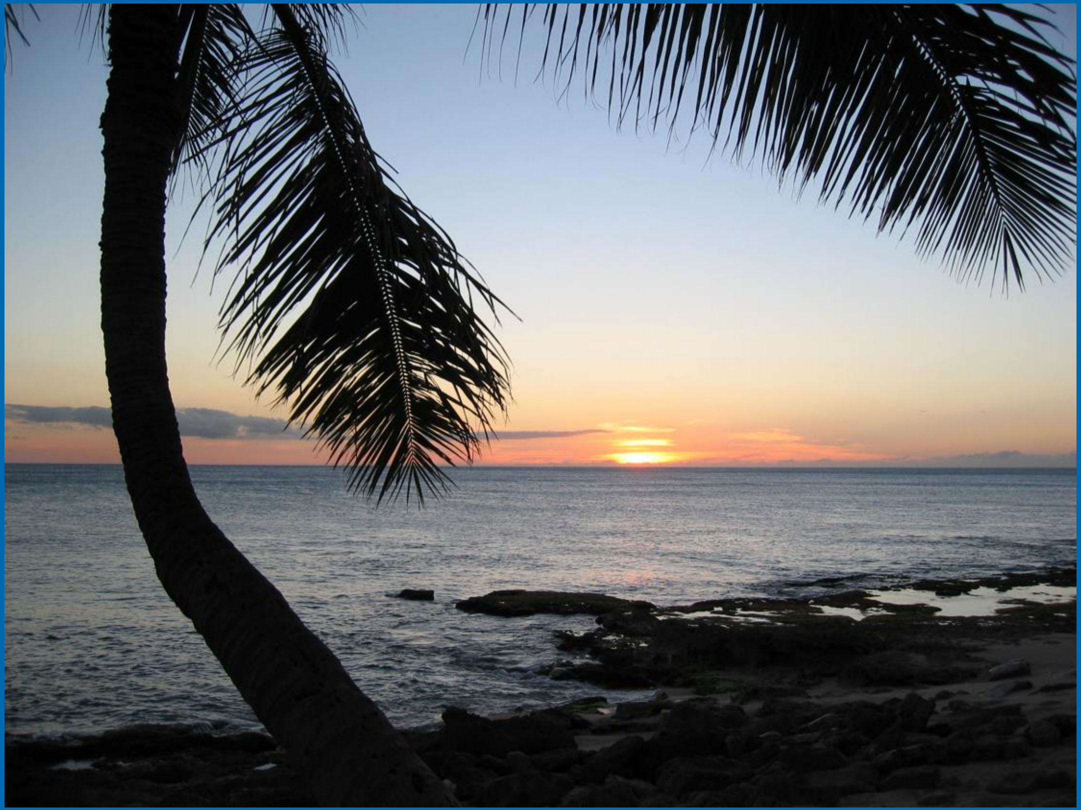
CSI February Meeting



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Allana Buick & Bers, Inc.

Design of Exterior Wall Assemblies

By

Karim P. Allana, PE, RRC, RWC

CSI Las Vegas

KARIM ALLANA, P.E., RRC, RWC

- EDUCATION: B.S., Civil Engineering, Santa Clara University, 1983
- REGISTRATION: P.E., Civil Engineering, California, 1987
- P.E., Civil Engineering, Nevada

  P.E., Civil Engineering, Hawaii

- CERTIFICATION: Registered Roof Consultant (RRC), Roof Consultants Institute
- Registered Waterproofing Consultant (RWC), Roof Consultants Institute
- OVERVIEW:
  - Over 20 years experience providing technical standards in building envelope technology.
  - Expert Witness in Construction Defect Litigation
  - Principal consultant in design of building envelope, roofing and waterproofing systems, forensic investigations of building assemblies and failure analysis.
  - Expert in all aspects of building envelope technology.
  - Specialization in cement plaster, other siding types, roofing, wood, water intrusion damage, window assemblies, storefronts, below grade waterproofing, and complex assemblies.
  - Completed over 1300 projects: new construction, addition, rehabilitation, remodel and modernization projects for public and private sector clients.

OVERVIEW

- Review of Exterior Wall Assemblies
  - Barrier Wall Systems
  - Rain Screen Principle
  - Drainable Wall Assemblies
  - Cement Plaster
  - EIFS

OVERVIEW

- Address the effects of moisture movement in wall assemblies
  - Principles of water phases, relative humidity, condensation, vapor retarders and vapor pressure
  - Examples of condensation caused by vapor transmission through interior and exterior walls, indoor showers, pools and spas
- Calculations for moisture diffusion through cement plaster wall assembly.
- EIFS Bullnose failure study

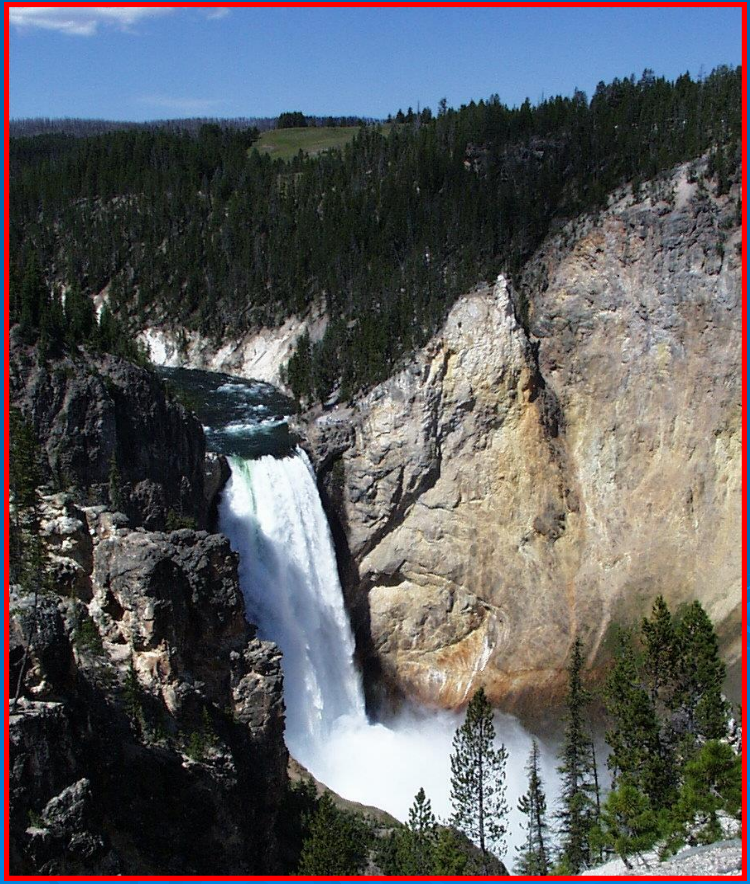
OVERVIEW

- Material Selection for Exterior Wall
  - Selection of Sustainable Materials
  - Materials less prone to mold and water damage
  - Selection of Vapor Retarders
  - Selection of Sealants for Exterior Wall

Wall Design

Three Key Elements of a Wall Leaks:

- Water
- Opening in Wall
- Forces to drive water through the opening



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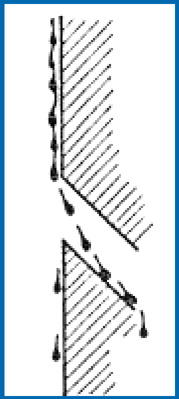
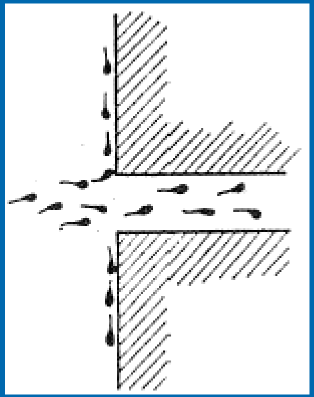
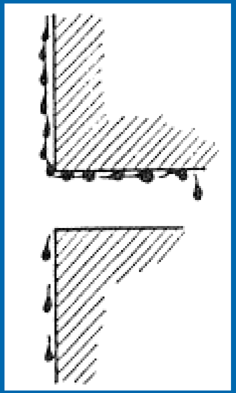
Typical Forces in Nature that Cause Water Intrusion Through Wall Assemblies



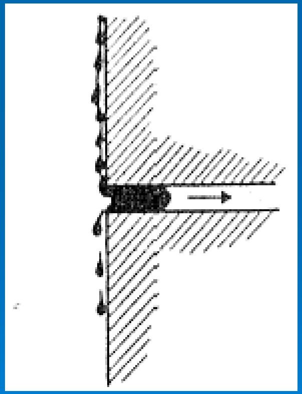
Gravity



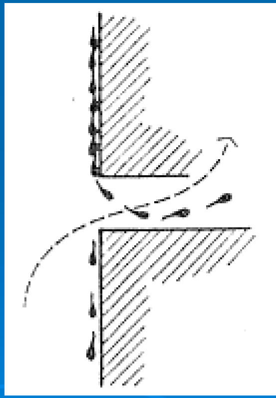
Kinetic Energy



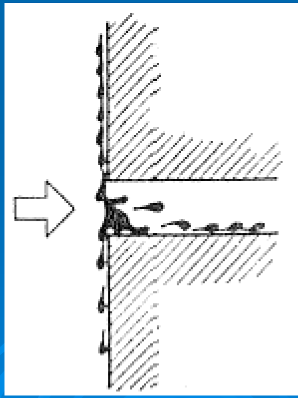
Surface Tension



Capillary Action



- Air Currents



Pressure Differential

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Wall Design

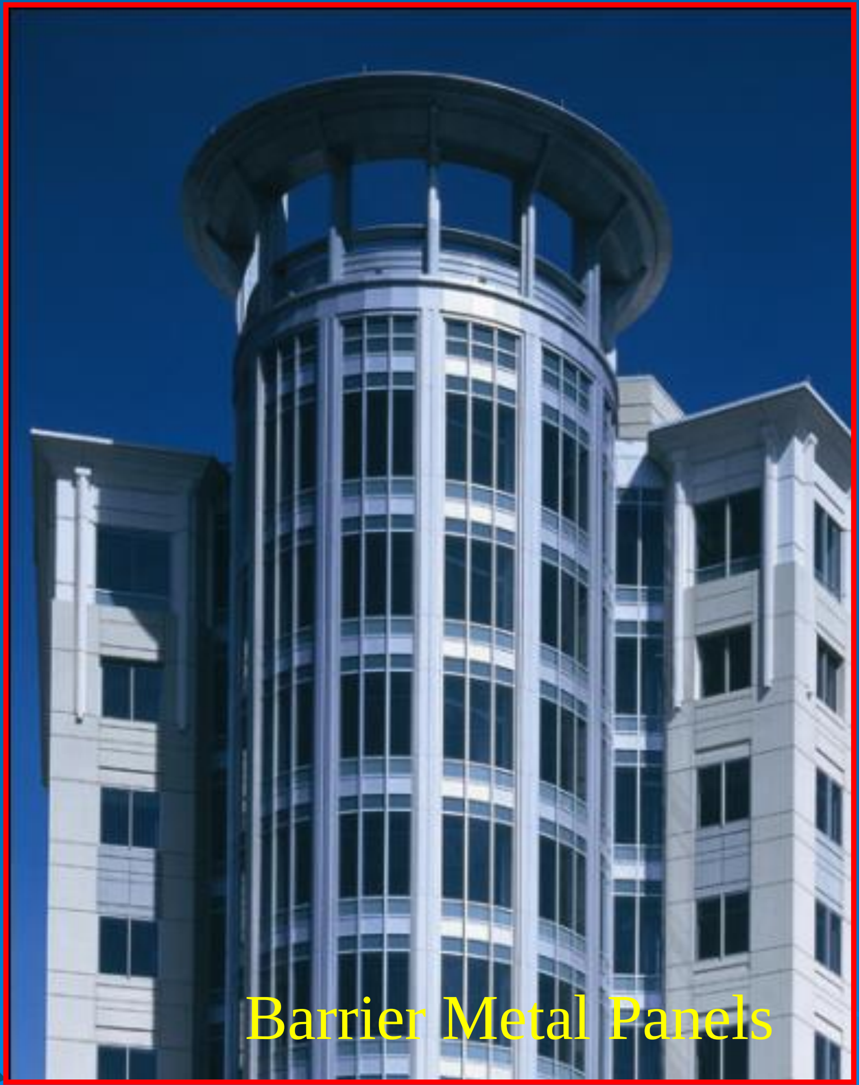
Philosophy Behind Barrier Wall Systems
:

- We can’t do anything about the water!
- We can’t do anything about the forces that drive water through the opening!
- <u>We are going to seal every opening!!!</u>

BARRIER WALL ASSEMLIES

- When exterior skin/mass is designed to be the only water barrier.
- Examples:
  - Traditional Exterior Insulation & Finish (EIFS)
  - Mass Masonry Walls
  - Certain types of Curtain Wall
  - Cast in Place (CIP) Concrete Wall

Barrier Wall Systems



Traditional EIFS is a Barrier Wall

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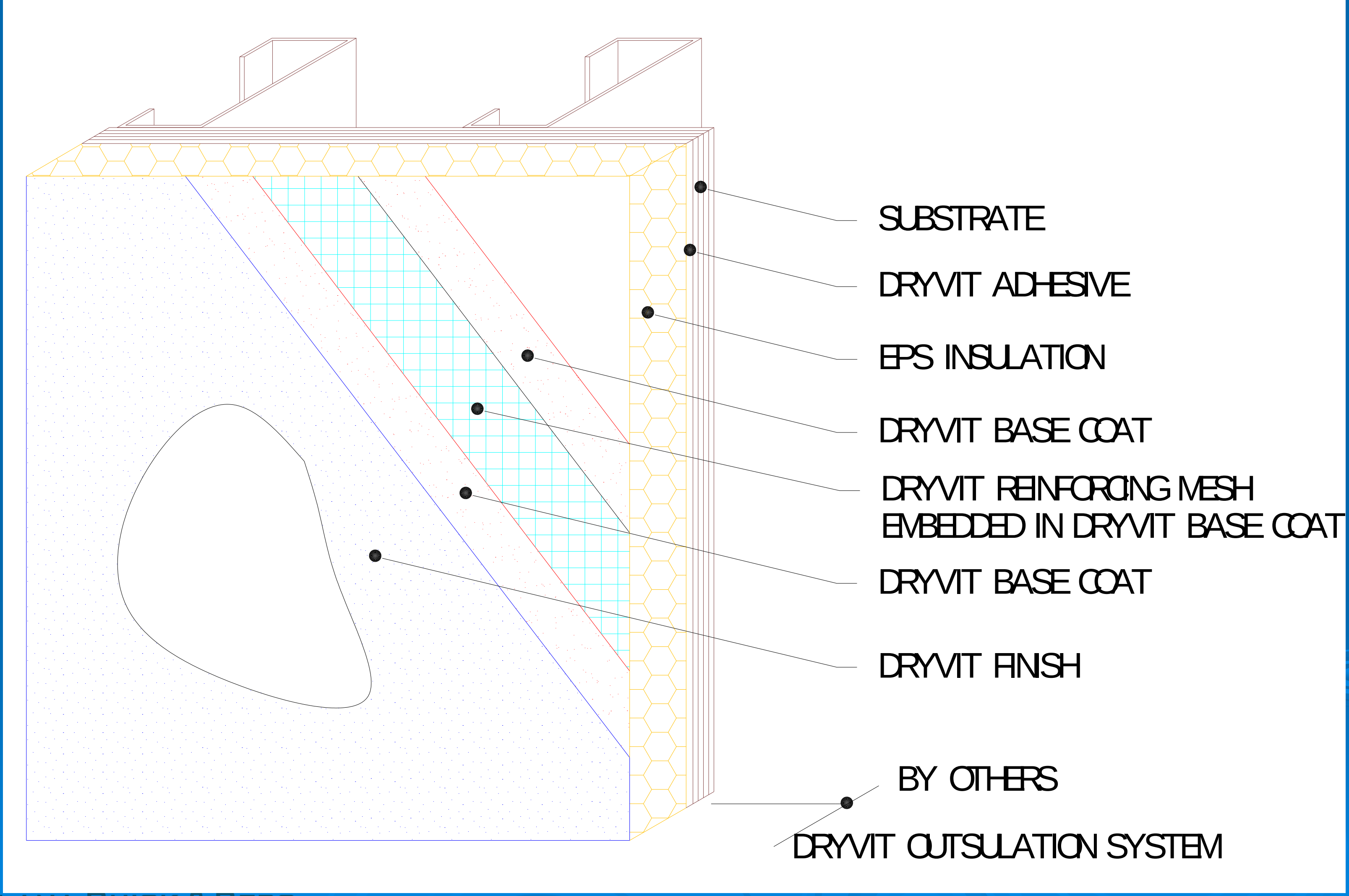
EIFS

➢ BARRIER WALL SYSTEM



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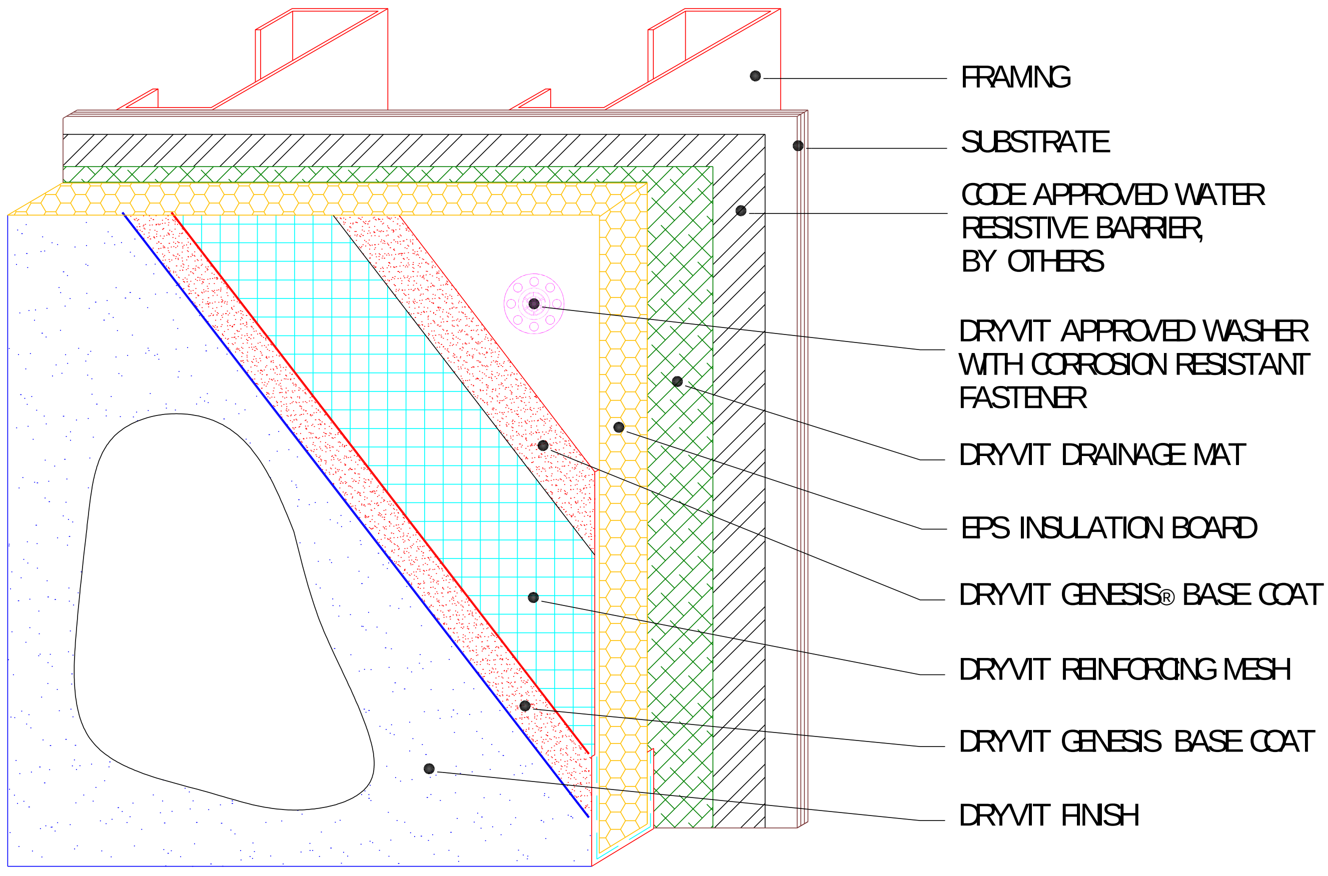
EIFS Wall, Perimeter Sealants are Critical for Preventing Water Intrusion in Barrier Wall

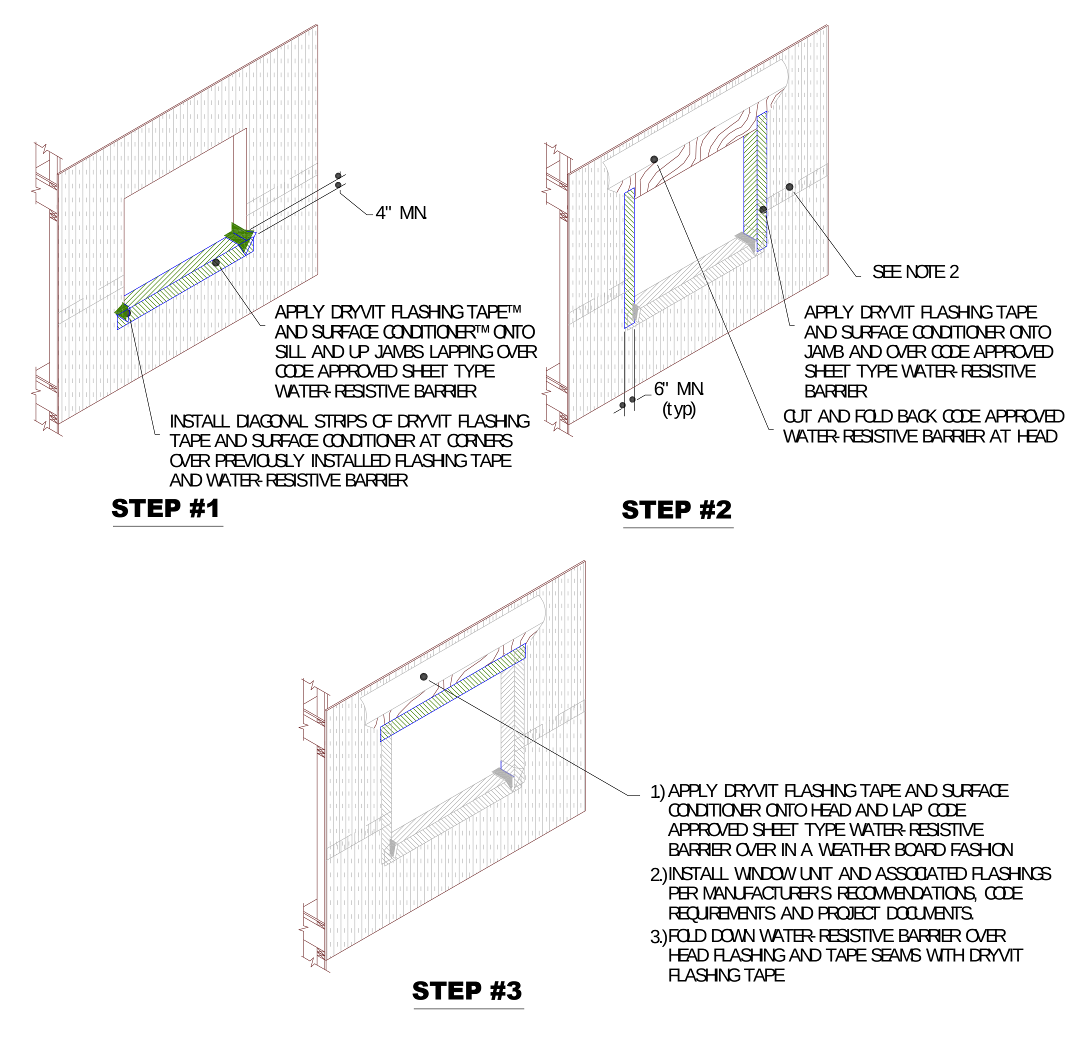
1/8” to 3/32” thick EIFS lamina consisting of polymer modified cement and fiberglass is the “Water Barrier”

EIFS Moisture Drained System



DRAINAGE MAT OPTION
(SYSTEM 1)

EIFS Moisture Drained Window



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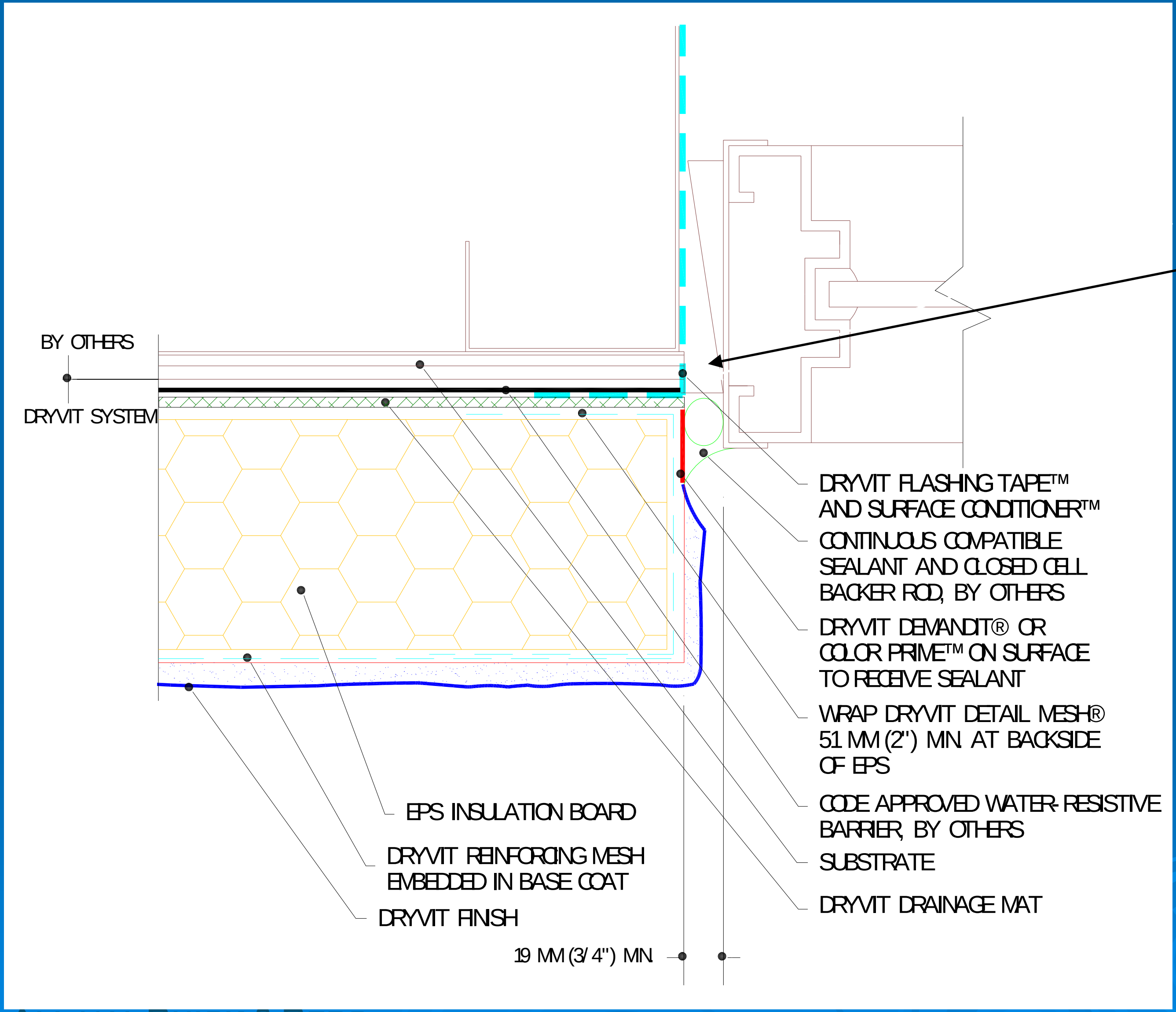
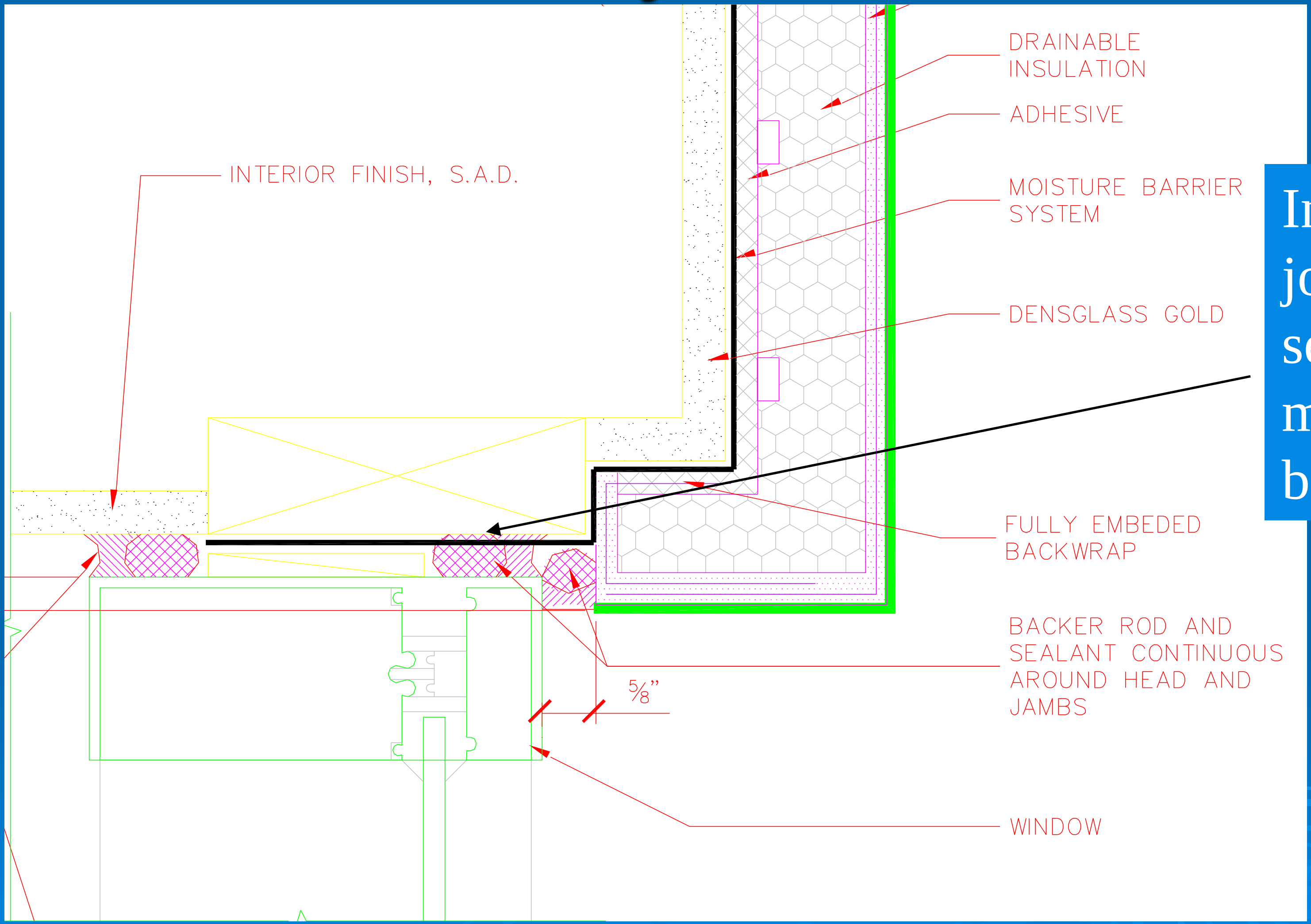
EIFS Moisture Drained Window Jamb



Manufacturer's standard Detail is Missing Secondary Seal to Water Resistive Barrier

Drainable EIFS Window Jamb With Secondary Sealant Joint

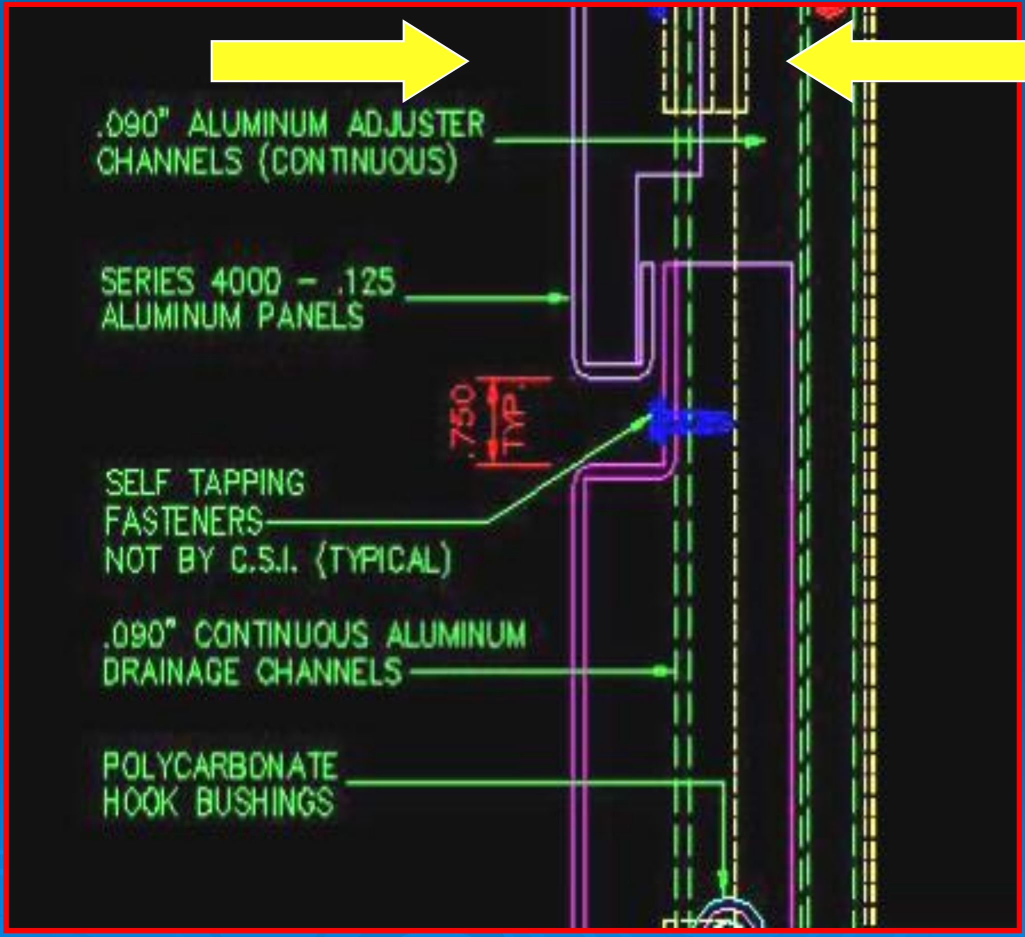


Inside sealant joint to seal secondary moisture barrier

Rainscreen Wall

- **Back Ventilated**
- **Rainscreen Wall**

- In a Back Ventilated System the joints are open. Therefore, the pressure on the back side of the panel system is essentially the same as it is on the outside.



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BUILDING AREAS SUSCEPTIBLE TO CONDENSATION

- Compact roof assemblies, i.e., no attic – flat roofs or cathedral ceilings
- Exterior wall assemblies with large temperature difference between outside and inside
- Interior wall assemblies with humidity and temperature difference

Effects of Moisture Movement in Wall Assemblies

- Address the Principles of water phases, relative humidity, condensation, vapor retarders and vapor pressure
  - Common modes of water movement through cement plaster and modes of drying.
  - Examples of condensation caused by vapor transmission through exterior walls

Relevant Terminology:

- WATER PHASES
- RELATIVE HUMIDITY
- CONDENSATION
- WATER VAPOR TRASMISSION
- PERMEANCE/PERMEABILITY
- VAPOR PRESSURE
- DIFFUSION

RELATIVE HUMIDITY

- The amount of water in its gaseous phase that can be contained within a given volume of air is a function of the air's temperature:
  - *Warm air holds more moisture than cold air!!*
- Relative humidity is expressed as a percentage: 100% humidity means that the air is saturated at that temperature

DIFFUSION/PERMEABILITY

- Diffusion is the transmission of water vapor through a material
- Some materials allow diffusion to occur more rapidly than others
- A material’s ability to allow diffusion of water vapor is measured by “permeability” and “permeance”

PERMEABILITY

- Permeability is based on a given thickness range of material.
  - Unit of measure = Perm.inch
  - Example, Permeability of concrete = 3.2 perm.in
  - Permeance of 6” thick concrete slab = 3.2 perm.in/6” = .53 perm

Figure 5

Typical Water Vapor Permeance and Permeability Values[1,2]		
Material	Permeance (perm)	Permeability (perm•in)
Common roof membrane materials:		
Asphalt (hot applied, 2 lbs/100 ft²)	0.5	
Asphalt (hot applied, 3.5 lbs/100 ft²)	0.1	
Built-up membrane (hot applied)	0.0	
No. 15 asphalt felt	1.0	
No. 15 tarred felt	1.0	
Roll roofing (saturated and coated)	0.05	
Common insulation materials:		
Expanded polystyrene insulation		2.0 - 5.8
Extruded polystyrene insulation		1.2
Plastic and metal films and foils:		
Aluminum foil (1 mil)	0.0	
Kraft paper and asphalt laminated, reinforced	0.3	
Polyethylene sheet (4 mil)	0.08	
Polyethylene sheet (6 mil)	0.06	
Other common construction materials:		
Brick masonry (4 in. thick)	0.8	
Concrete (1:2:4 mix)		3.2
Concrete block (with cores, 8 in. thick)	2.4	
Gypsum wall board (plain, ³/₈ in. thick)	50	
Hardboard (standard, ⅛ in. thick)	11	
Metal roof deck (not considering laps and joints)	0.0	
Plaster on metal lath	15	
Plaster on wood lath	11	
Plywood (Douglas fir, exterior glue, ¼ in. thick)	0.7	
Plywood (Douglas fir, interior glue, ¼ in. thick)	1.9	
Wood, sugar pine		0.4 - 5.4

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Case Study #1 (COOLING CLIMATE) EXAMPLE OF CONDENSATION IN HOTEL PARTY WALL

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Case Study # 1

- Honolulu, Hawaii hotel
- Air leakage through failed sealant joint between lanai door and exterior wall
- Condensation between hotel party walls
- Calculate how much condensation (gallons) of water accumulates on the wall in 1 week time span.

Condensation between hotel party walls

Moisture intrusion through air leakage at exterior side of party wall

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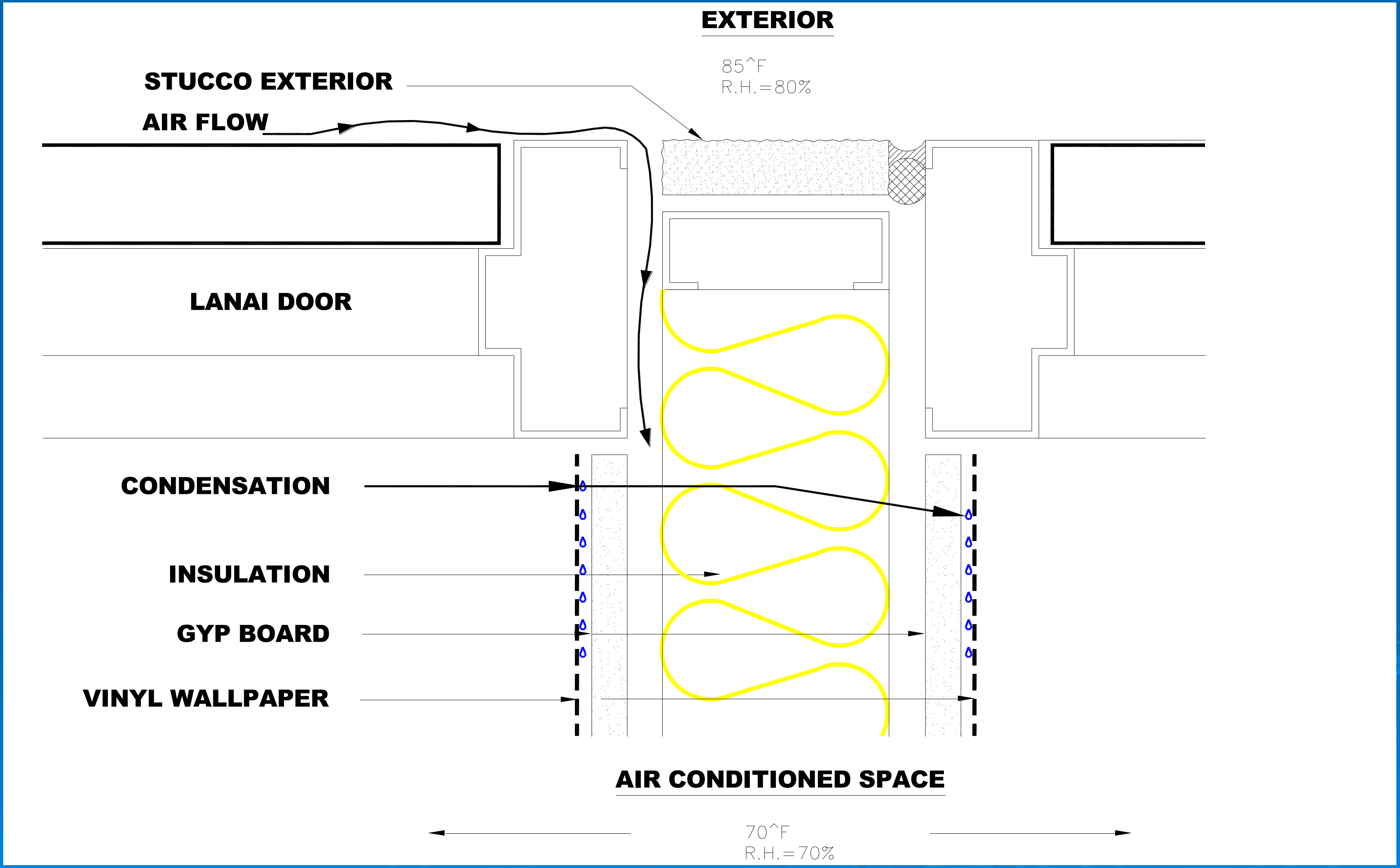
Case Study # 1, Hawaii Hotel interior wall, condensation due to air leakage



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Case Study # 1: Moisture trapped in a shared wall cavity.

Gaps near an exterior door allow warm humid air to flow into a wall cavity in a Hawaii Hotel (see Figure 10). The affected wall area 10'x8'. Outside temperature and relative humidity are 85F and 80% respectively. The inside temperature and relative humidity are 70F and 70% respectively. Assume condensation forms at the back side of the low perm vinyl wallpaper coating. How much water can collect over a 1 week period?

Case Study # 2: Conclusion.

VT= 80 ft^2 x 168 hr x 0.4523 in.Hg x 50 perm

= 304,389 grains of water

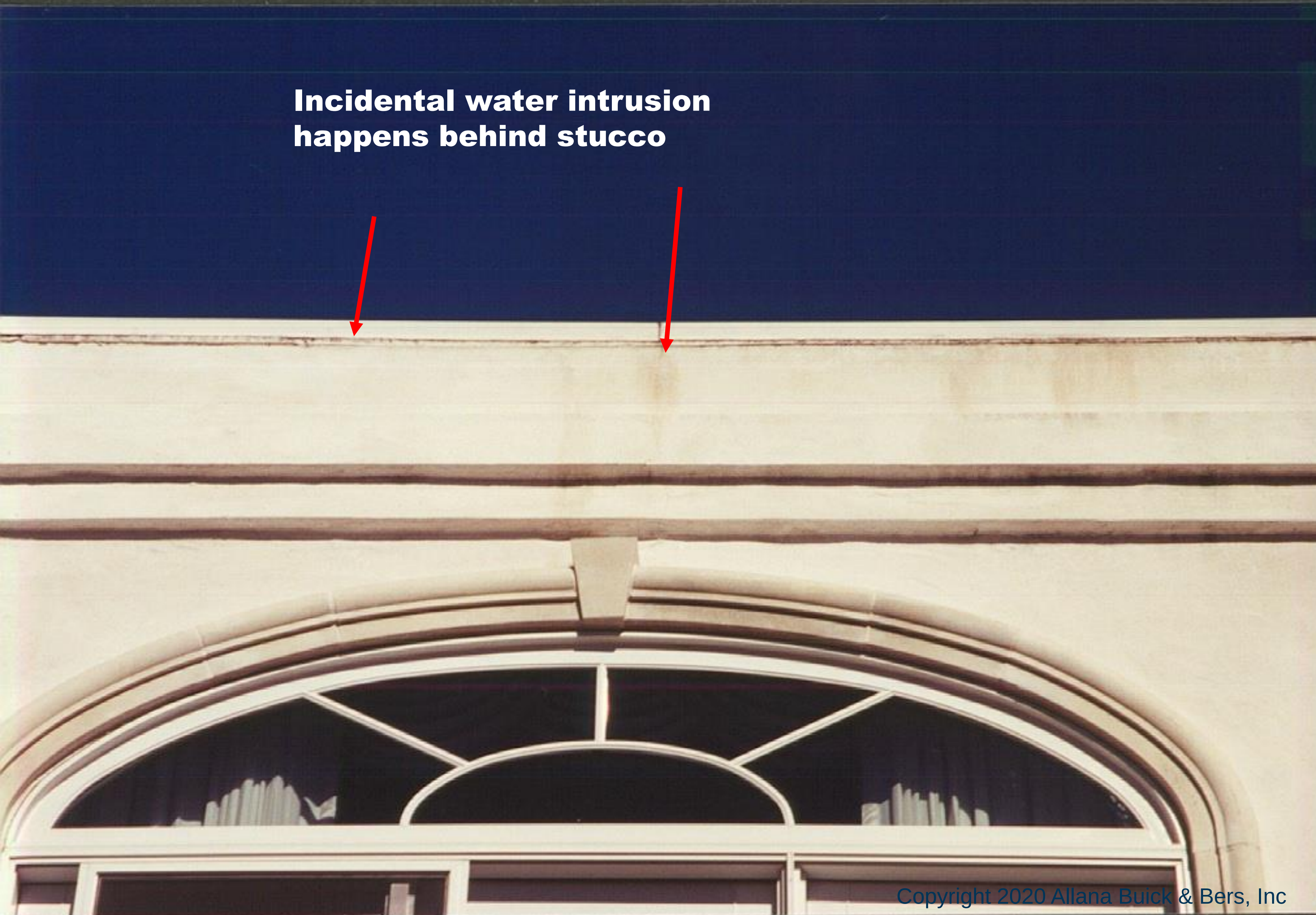
= 43.5 pounds of water

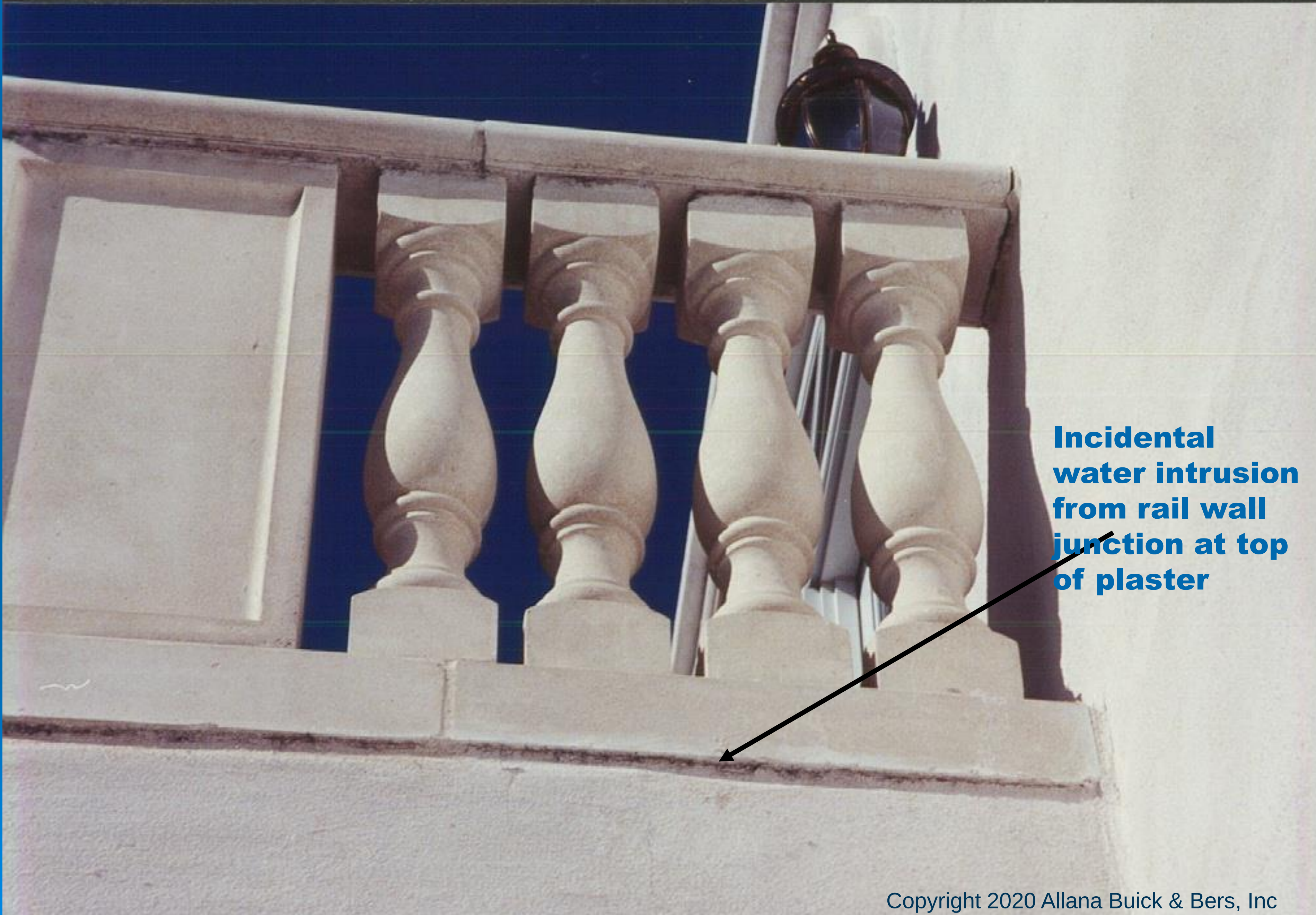
= 5.24 gallons of water (in 1 week)

Exterior Cement Plaster

- Moisture Drained Wall System (not pressure equalized)
- Common Modes of Water Intrusion
- Mechanism for water weeping and drying
- Stucco Design Philosophy
  - Design as a Barrier Wall
  - Design as a conventional Drainable Wall

Incidental water intrusion happens behind stucco




Incidental water intrusion from rail wall junction at top of plaster


Minor stains from rail wall junction

This innocent looking Incidental water caused a lot of damage!


'00 8 7

Stucco leak from top of rail wall


WINDOWS ISSUES
Cracks and
sealant failure
around window

Case Study # 2, Stucco Leak in wall. Study of slow diffusion

Few visible signs of distress

Relatively benign looking vinyl wall paper

Removal of a small area displayed evidence of some real problems

Case Study # 2, Slow diffusion due to vapor barrier on the inside face of wall

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Mold and rot in the wall cavity

Case Study # 2, slow diffusion in wall can cause a lot of damage from leaks

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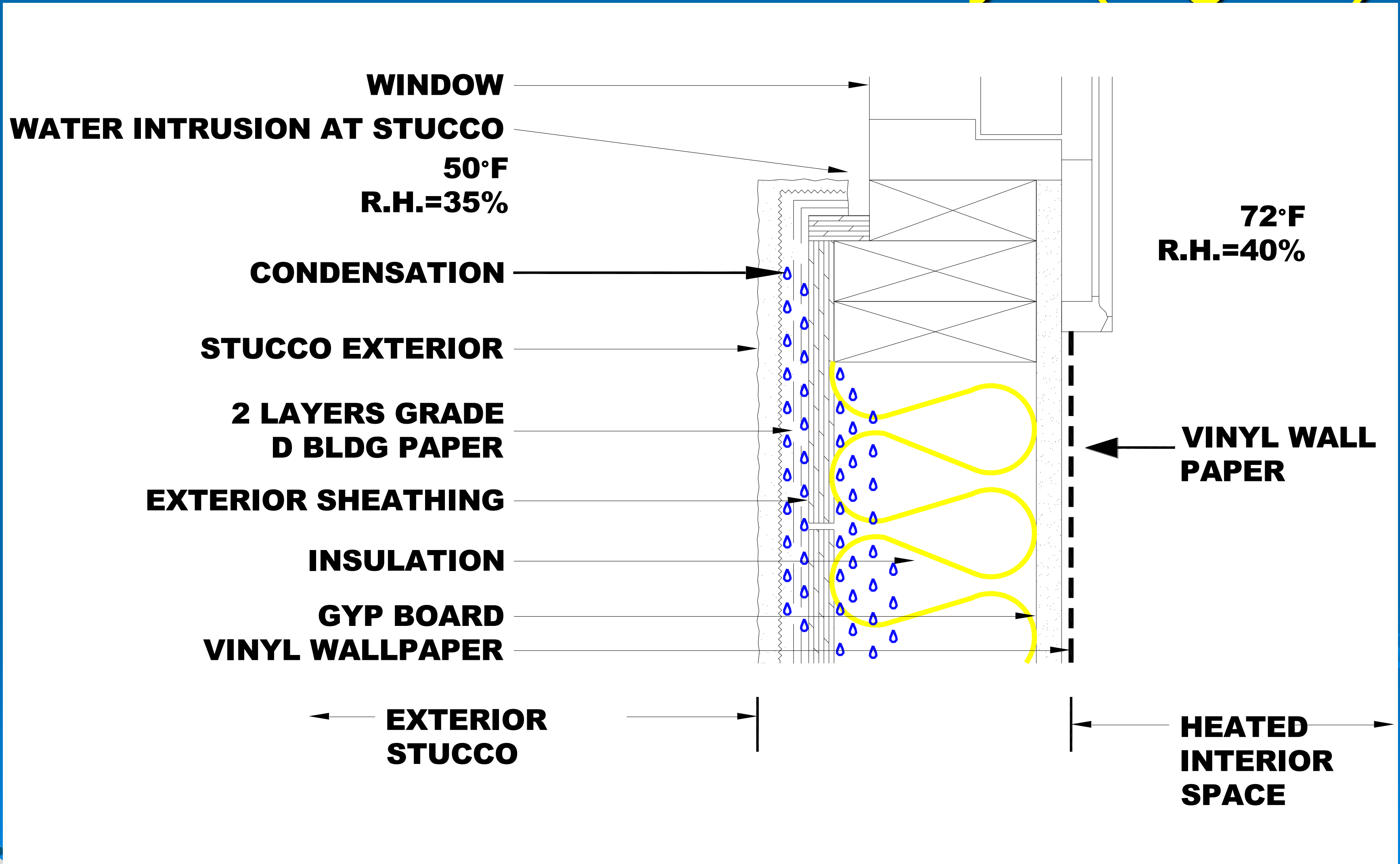
Case Study # 2: Moisture trapped in different layers of a wall assembly, how long before it dries?.

During the rainy season, water collects in a wall due to a window leak in the locations shown (see Figure 13). The affected area is 100 ft^2. Outside temperature and relative humidity are 50F and 35% respectively. The inside temperature and relative humidity are 72F and 40% respectively. Under these conditions, moisture will flow from inside to outside. <u>How much time will it take for the water to leave the assembly in each of the locations?</u> <u>Each location has 1 gallon of water intrusion.</u>

Case Study # 2, Diffusion. How long does it take for water to dry? (Fig 13)



Case Study # 2: How long does it take for 0.1 Gallon of water to dry if trapped between paper & stucco?

Location 1- Moisture over the building paper:
From the pressure distribution,

$$\Delta P = 0.13315 - 0.12690 = 0.0066 \text{ in. Hg}$$

The effective Z value only takes into account the stucco since moisture will be driven out from inside the building/wall assembly.

$Z = 1/15 \text{ perm}^{-1}$

Permeance = 15 perm

Case Study # 2: How long does it take for 0.1 Gallon of water to dry if trapped between paper & stucco?

Therefore, converting gallons into grains (1/10 gallon = 5809 grains):

T = 5,809 gr/(100ft2 x 0.0066 in.Hg x 15 perm)
= 587 hours
= 24 days

Simmilarly: How long does it take for 0.1 Gallon of water to dry if trapped between OSB and paper?

T = 5,809 gr/(100ft2 x 0.0438 in.Hg x 2.143 perm)
= 619 hours
= 26 days

Case Study # 2: How long does it take for 1 Gallon of water to dry if trapped between Insulation and OSB?

Location 3- Over the insulation:

From the pressure distribution,

$$\Delta P = 0.21763 - 0.12690 = 0.0907 \text{ in. Hg}$$

Find the effective Z value:

$Z = 1/15 + 1/5 + 1/5 + 1/2 = 0.96667$ perm^{-1}

Permeance = $1/Z = 1.034$ perm

Case Study # 2: How long does it take for 1 Gallon of water to dry if trapped between Insulation and OSB?.

T = 58094 gr/(100ft2 x 0.0907 in.Hg x 1.034 perm)
= 6190 hours
= 264 days

The rate of diffusion changed due to plywood/OSB which is a vapor retarder.

STUCCO LESSONS

- Old stucco system with just Grade “D” building paper and no consideration for managing excess water does not work.
- Acceptable tolerance for incidental water intrusion needs to be greatly reduced.
- Design should consider building cement plaster more as a “barrier” system.
- Alternatively, provide a layer of “water management” system such as rain screen or pressure equalized behind the cement plaster finish.

LESSONS LEARNT FROM INCIDENTIAL WATER IN STUCCO

- Construction methods have significantly changed. Buildings are built much more air tight.
- A lot of attention has been given to air barriers to control movement of moisture laden air.
- Air barriers also impede the “drying” out effect in walls. Diffusion is not enough to dry out walls.
- Construction labor is less skilled today

LESSONS LEARNT FROM INCIDENTIAL WATER IN STUCCO

- When designing wall assemblies, consider the following:
  - Be less reliant on building paper and “permeable” coatings.
  - Design walls to be more “barrier” assemblies or as rain screen assemblies.
  - Ventilate whenever possible.
  - Consider vapor retarders in all climates
  - Limit use of vinyl wall paper in exterior wall assemblies

Case Study # 2
EIFS Bull Nose

- **EIFS Bull Nose Failure**
- **Design Issues**
- **Thermal Modeling**
- **Lesson Learned**

Case Study # 2, EIFS Bull Nose Failure EIFS Barrier System

CHA-AL05795

4- Story Office Building

Pleasanton, CA

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Rather Large EIFS Bull Nose

CHA-AL04351

Patterns of Cracking in Bull Nose

- There were two distinct pattern of cracking in the bull nose:
  - Horizontal cracks; always located between the flat and curved parts of the bull nose, on top or bottom of the bull nose. Horizontal cracks also located in the center of the bull nose curved shape.
  - Vertical cracks; Randomly located throughout the building and almost always present at the inside corner, at a jog in the exterior wall.
  - Few other cracks fell outside of this pattern where in the same locations there were both vertical and horizontal cracks

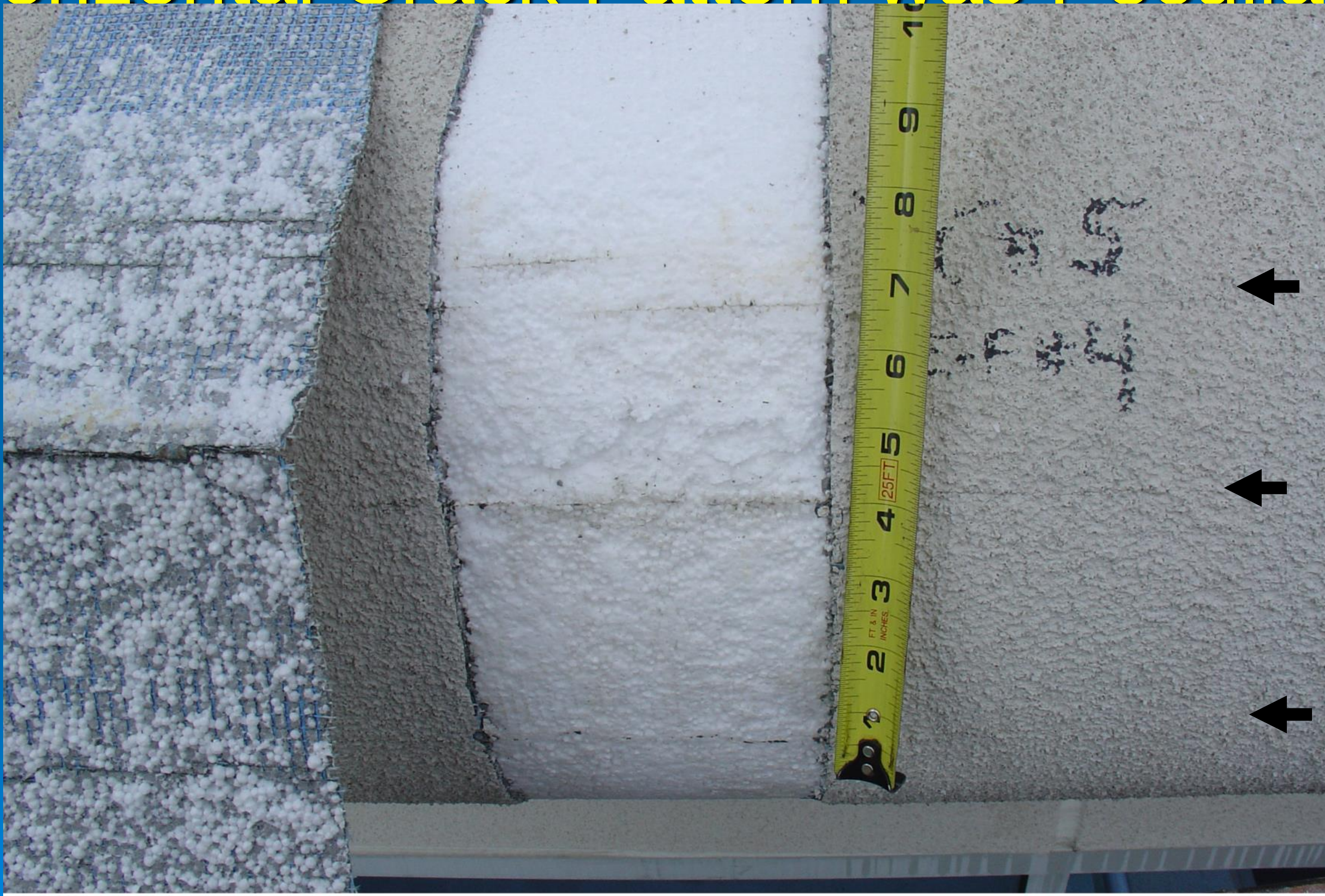
Vertical Crack in the Field


CHA-AL03186

Reasons for Vertical Cracks

- Generally, vertical cracks were caused by “gaps” in EPS insulation. Gaps create areas where the cementious base coat collects and creates a discontinuity for thermal movement, causing a split

Horizontal Crack Pattern was Peculiar



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DESTRUCTIVE TESTING

Test Cut #2– East Elevation – 3rd floor line EIFS Bullnose

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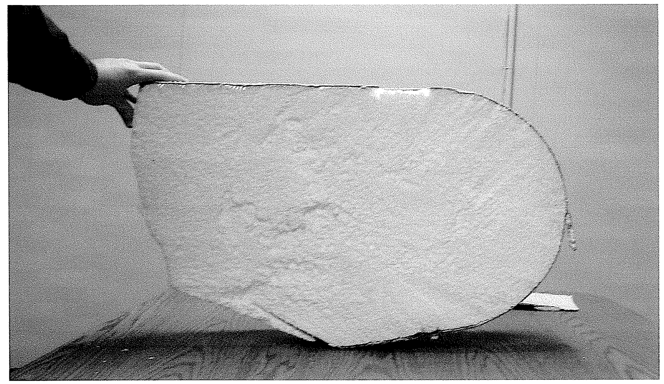
FORENSIC ANALYSIS OF HORIZONTAL CRACKS

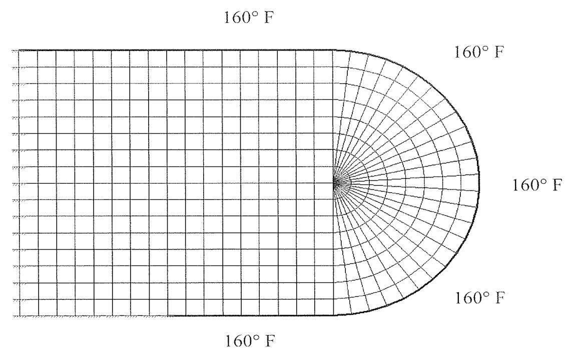
- In order to develop a suitable, sustainable, repair for this building, we analyzed the mode of failure.
- The horizontal crack pattern in the EIFS finish at the nose of the bull nose was unusual and distinct.
- Our structural engineering team performed thermal modeling of the bull nose panels to see what kind of forces we could develop.
- We also performed visual analysis of the lamina construction to ascertain the method of construction, rasping of the foam and embedment of mesh in the base coat.
- We looked at the numerous samples that we had gathered to see if there was a pattern.

THERMAL ANALYSIS WITH RISA 2D SOFTWARE

5050 Hopyard Preliminary Finite Element Analysis of EIFS bullnose assembly.



5050 Hopyard EIFS bull-nose specimen



2D Finite Element Model of EIFS bull-nose Specimen: Model is subjected to a uniform thermal load of 160 F. Elements are 4 node quadrilaterals and are assigned the

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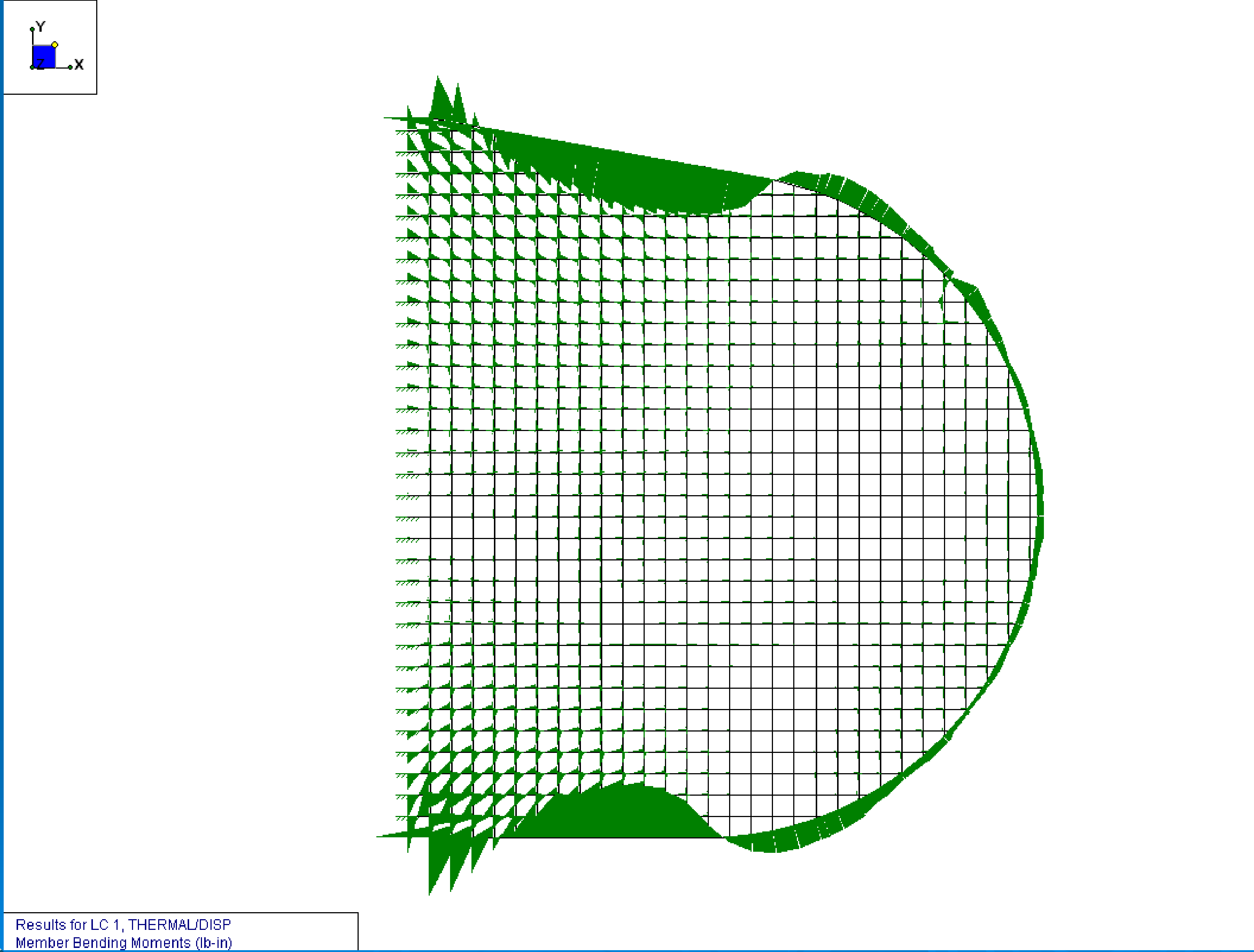
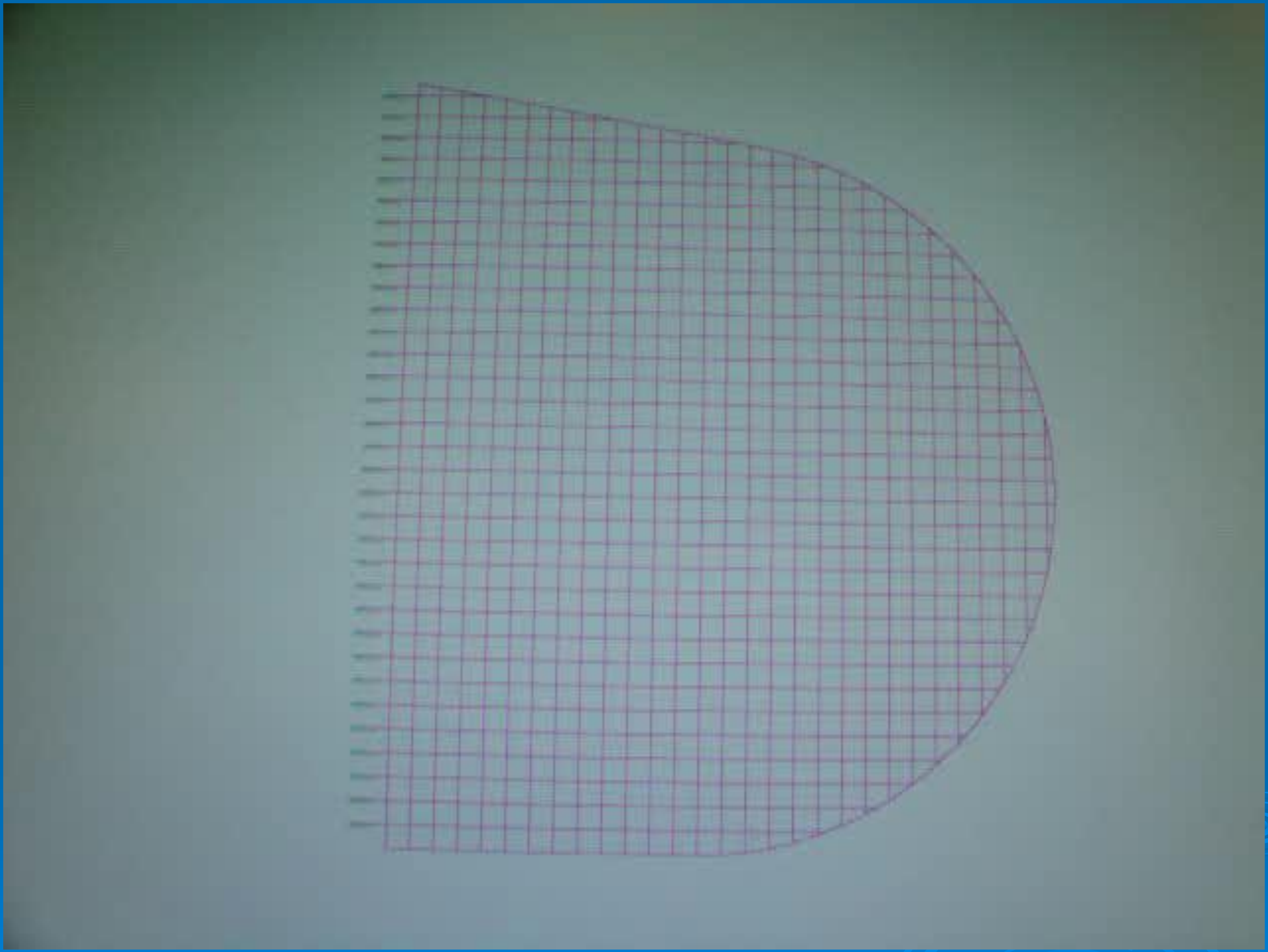


Moments (lb-in) for 50°F Decrease

THERMAL ANALYSIS (For Horizontal Cracks)

- All thermal stresses are concentrated at the shape change area
- Moment reverses at the shape change
- Maximum stress are at the curved portions of the bull nose
- Crack leads to water intrusion, UV and breakdown of the fiberglass mesh causing a split
- The lamina can withstand approximately 150 to 180 pounds of tension per linear inch, and our model shows there’s only 4-5 pounds of tension per linear inch, but there is still cracking



50°F Temperature Decrease (100°F to 50°F at 50x magnification)

FAILURE ANALYSIS EIFS BULL NOSE

- Lamina also undergoes bending, from deformed shape which ultimately caused the failure.
- If EIFS is modeled as a cementitious beam with compressive strength of 3,000 pounds per square inch (“psi”), the modulus of rupture, or “cracking stress” is 411 psi. ABB’s model showed that the maximum bending load of the lamina was .312 lb/in, which translates into 474 psi in the uncracked lamina section. Therefore, the maximum bending stress would exceed the “cracking stress” by 63 psi.

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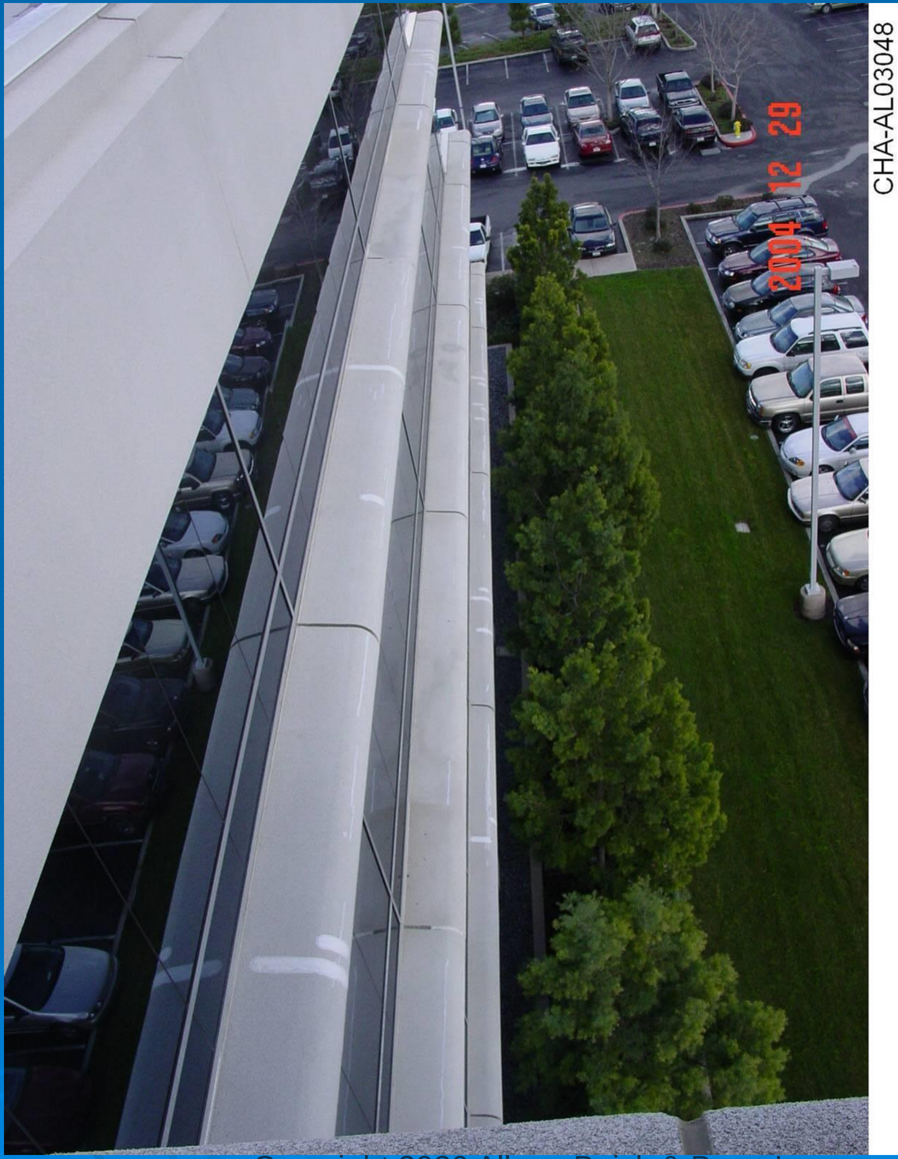
CAUSATION OF HORIZONTAL CRACKS

1. Size and geometry of the bull nose is producing concentrated stress where cracks are occurring.
2. Once lamina is cracked, it allows water intrusion.
3. UV and water degrade the exposed fiberglass mesh at a crack and cause it to split.
4. We explore ways of reducing the mass of the foam, to reduce thermal movement and stresses.



Thank You

Questions?