Understanding the Common Causes of Condensation

Recognizing Water Vapor

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Karim P. Allana, PE, RRC, RWC

- **Education:** B.S., Civil Engineering, Santa Clara University
- **Registration:** P.E., Civil Engineering, California, Washington, Nevada, and Hawaii
- **Certification:** Registered Roof Consultant (RRC), Roof Consultants Institute, and Registered Waterproofing Consultant (RWC)
- **Overview:**
  - CEO and Senior Principal at Allana Buick & Bers.
  - Former Turner Construction Employee (Project Engineering and Superintendent)
  - Over 37 years experience providing superior technical standards in all aspects of building technology and energy efficiency.
  - Principal consultant in forensic investigations of building assemblies, failure analysis, evaluation and design of building infrastructure and building envelope evaluation and design.
  - Expert in all aspects of building envelope technology.
  - Completed numerous new construction, addition, rehabilitation, remodel and modernization projects for public and private sector clients.
  - Specialization in siding, roofing, cement plaster, wood, water intrusion damage, window assemblies, storefronts, below grade waterproofing, energy efficiency, solar engineering and complex building envelope and mechanical assemblies.

ABBAE Firm Overview

- Allana Buick & Bers (ABBAE) is an Architectural Engineering firm specializing in Building Envelope Systems
- ABBAE is one of the 5 largest building envelope consultants in the country
- ABBAE has over 33 years of experience & over 12,500 projects
- ABBAE is also a leading Forensic Defect firm with hundreds of forensic projects (litigation)
- Locations – 16 offices across California, Nevada, North Carolina, Oklahoma, Oregon, Texas, Virginia, Washington, Colorado and Hawaii

Staff & In-House Expertise

- Licensed Professional Engineers – Civil, Structural, and Mechanical
- Registered Architects
- Building Enclosure Commissioning Process Providers (BECxPs)
- Registered Building Envelope Consultant (RBEC)
- Registered Roofing Consultants (RRCs)
- Registered Waterproofing Consultants (RWCs)
- Registered Exterior Wall Consultant (REWCs)
- Registered Roof Observers (RROs)
- Certified Exterior Insulation and Finish System (EIFS) inspectors
- Curtain Wall Specialists
- ICC Certified Building Inspectors
- Quality Assurance Monitors
- Water Testing Experts
- Leak Investigation and Diagnosis Experts
- Infrared Imaging and Nuclear Moisture Scanning Experts

ABBAE Building Expertise

- Building Envelope Systems
  - Roofing Systems
    - High-Slope/Low-Slope Roofs
    - Green/Garden Roofs
    - Drainage Systems
    - Pedestrian Plazas
  - Exterior Wall Systems
    - Wall Cladding/Siding/GFRC/pre-cast
    - EIFS/cement plaster/stucco
    - Sheet Metal Flashings
  - Windows and Glazing Systems
    - Punched Windows
    - Curtain Wall/Window Wall Systems
    - Sliding Glass Doors
    - Skylights

- Building Envelope Systems (cont'd)
  - Roofing & Waterproofing Systems
    - Deck/Balcony/Lanai Waterproofing
    - Podium Waterproofing
    - Pool/Spa Deck Waterproofing
    - Above-Grade/Below-Grade Waterproofing
    - All types of low and steep sloped roofing
  - Commissioning BECx
    - OPR/BOD/Commissioning Plan
- Mechanical/HVAC Systems
  - HVAC design
  - Plumbing systems
  - Commissioning and testing

ABBAE Core Services

- Consulting and third-party peer review services
- Engineer of record for building envelope systems
- Contract administration services
- Inspection services (usually direct with owner)
- Air and water performance testing
- Mock-up design, observation, and testing
- Building assessments and forensic investigations
- Litigation support and expert witness services
- Educational seminars with AIA credits

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.

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

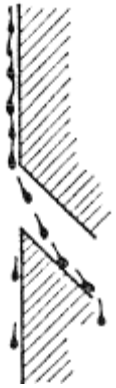
Three Key Elements of Wall Leaks:

- Water.
- Opening in Wall.
- Forces which drive water through the opening.

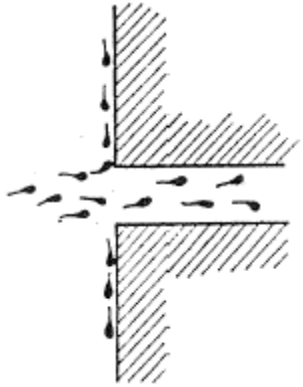
Wall Design

Typical Forces in Nature that Cause Water Intrusion Through Wall Assemblies

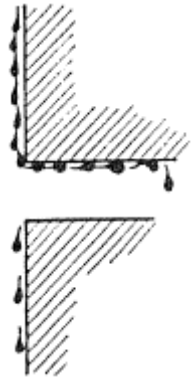
Air Currents



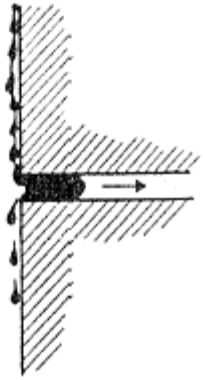
Gravity



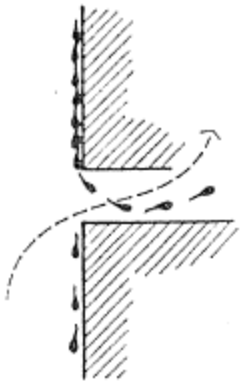
Kinetic Energy

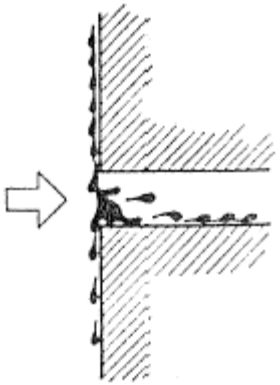


Surface Tension



Capillary Action



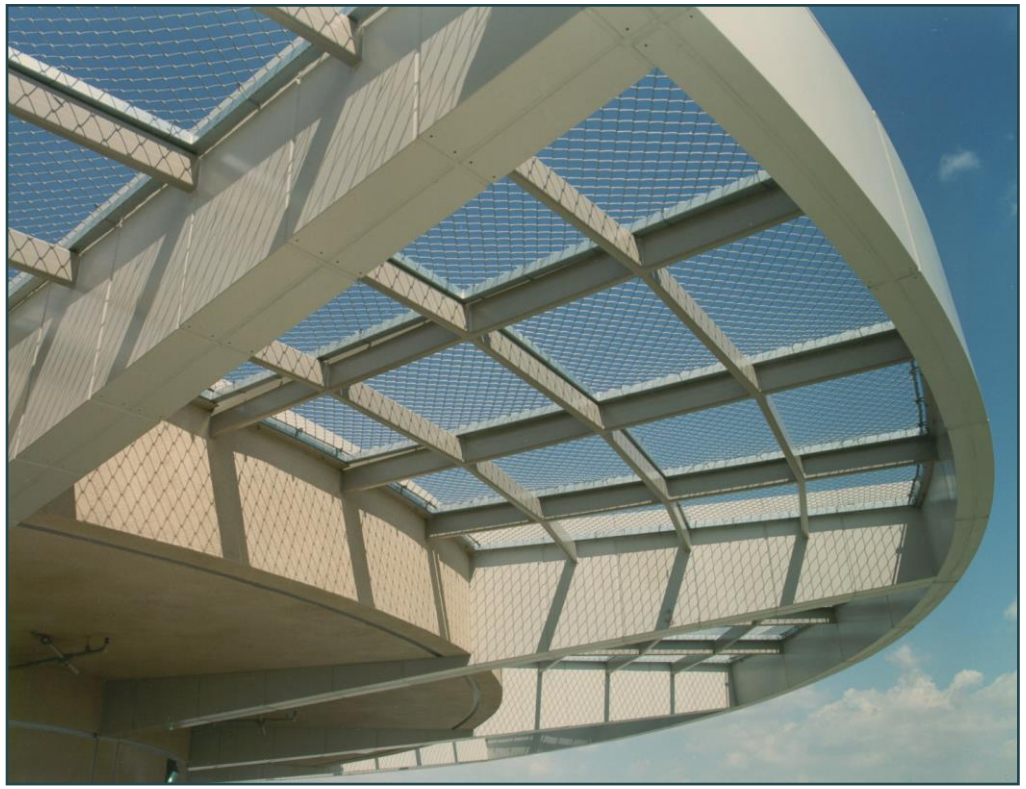


Pressure Differential

Wall Design

Philosophy Behind Barrier Wall Systems :

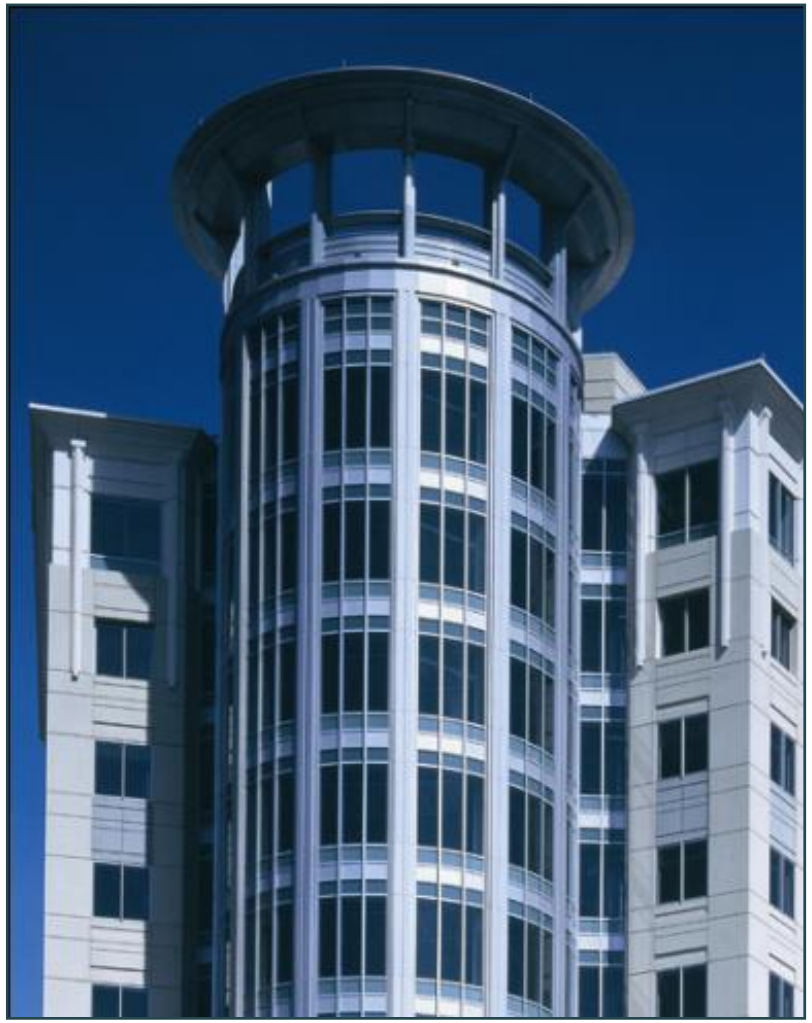
- We can’t do anything about the water!
- We can’t do anything about the forces that drive water through the opening!
- **We are going to seal every opening!!!**



Barrier Wall Assemblies

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

Barrier Wall Systems



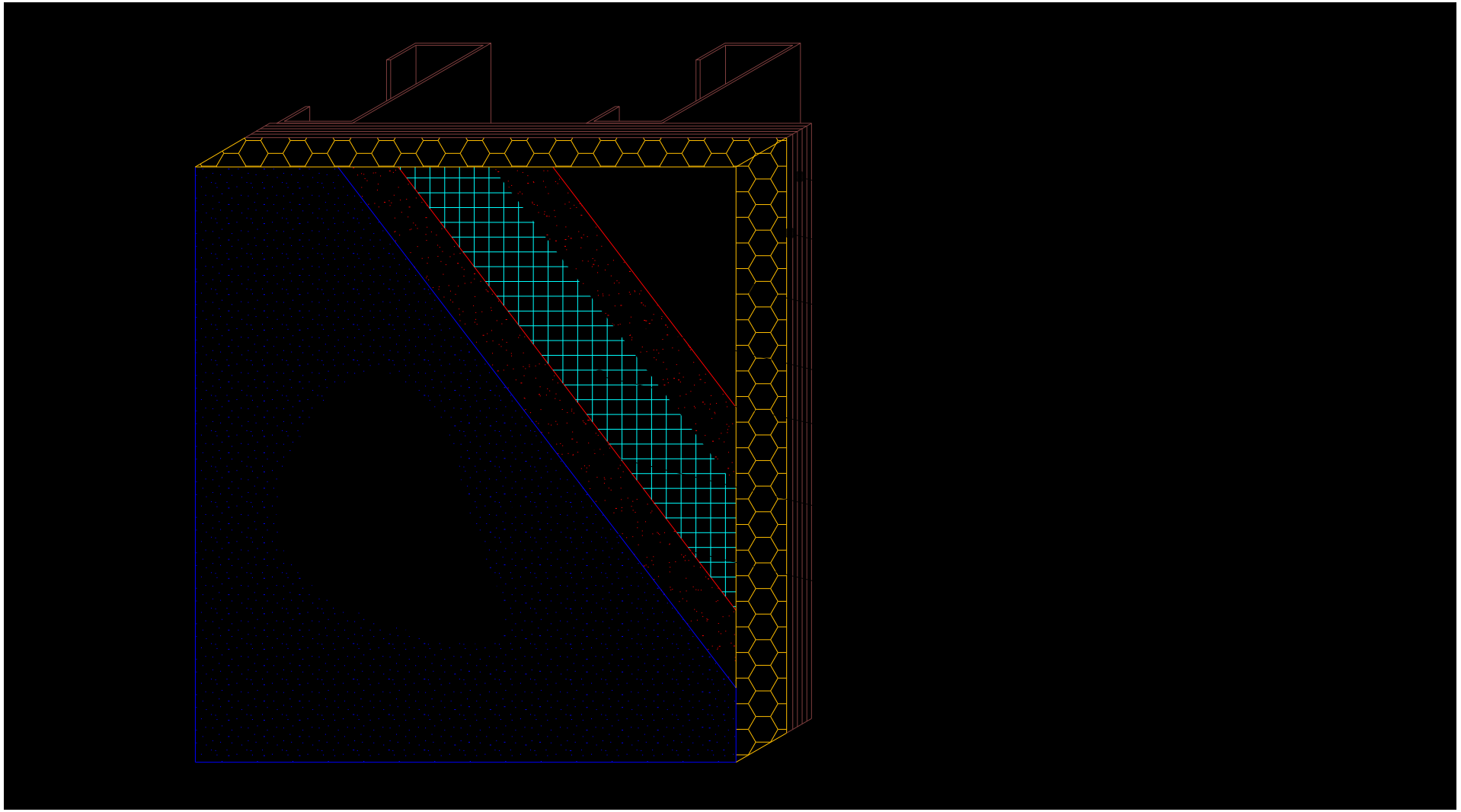
Barrier Metal Panels

Pre-cast Concrete

Traditional EIFS is a Barrier Wall

CHA-AL05795

EIFS Barrier Wall System

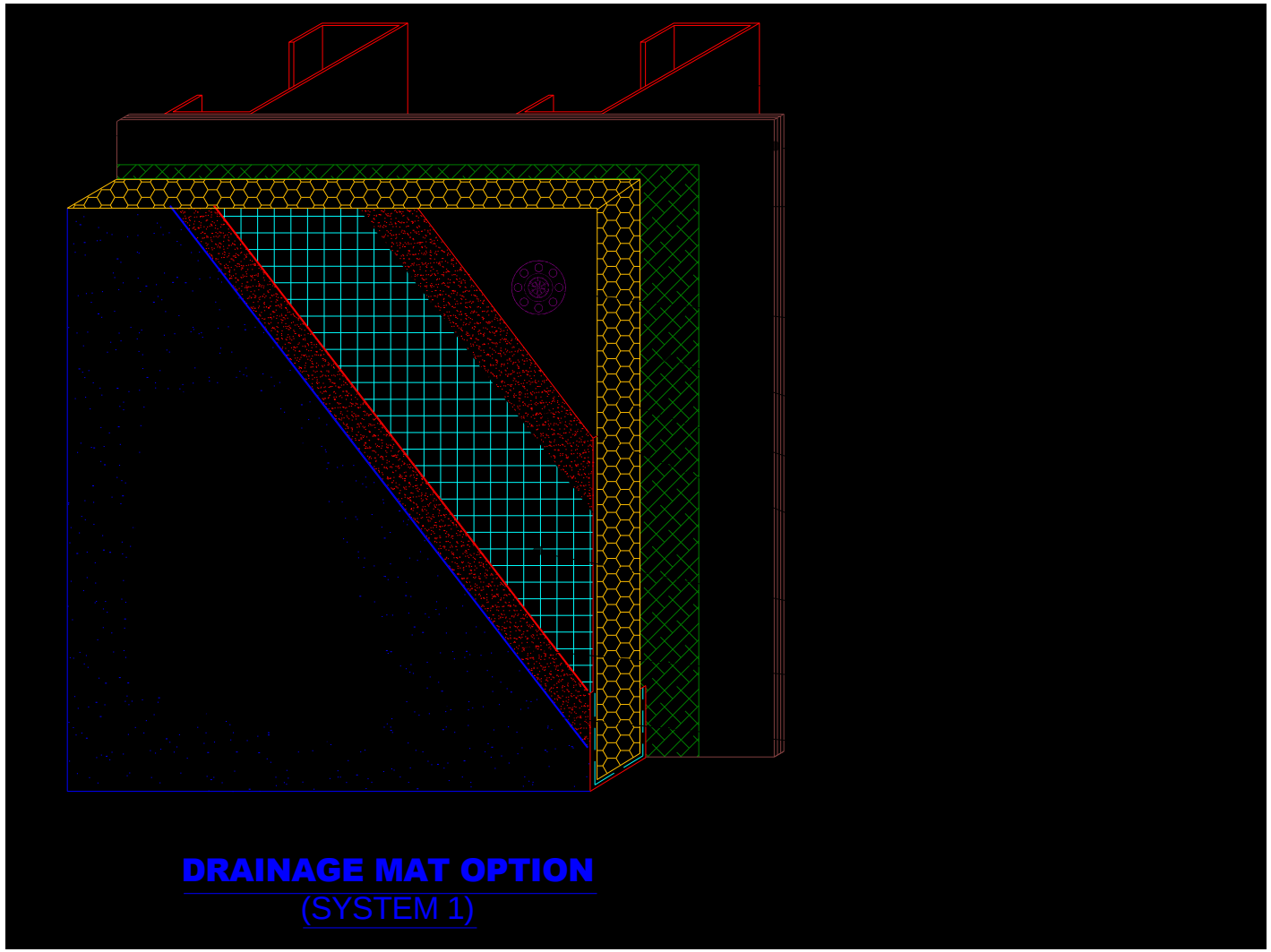


EIFS Barrier Wall System

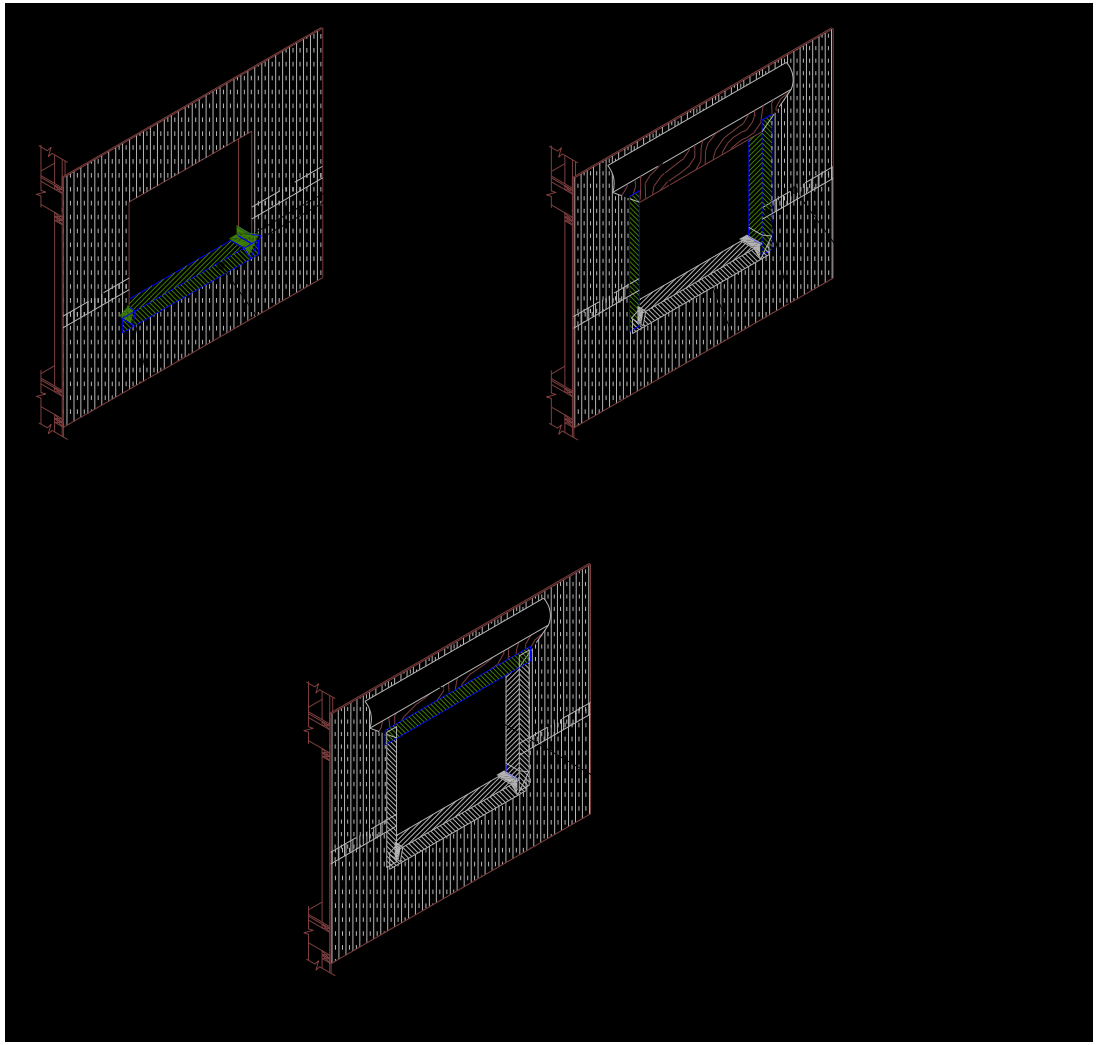
EIFS Wall, Perimeter Sealants are Critical for Preventing Water Intrusion in Barrier Wall

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

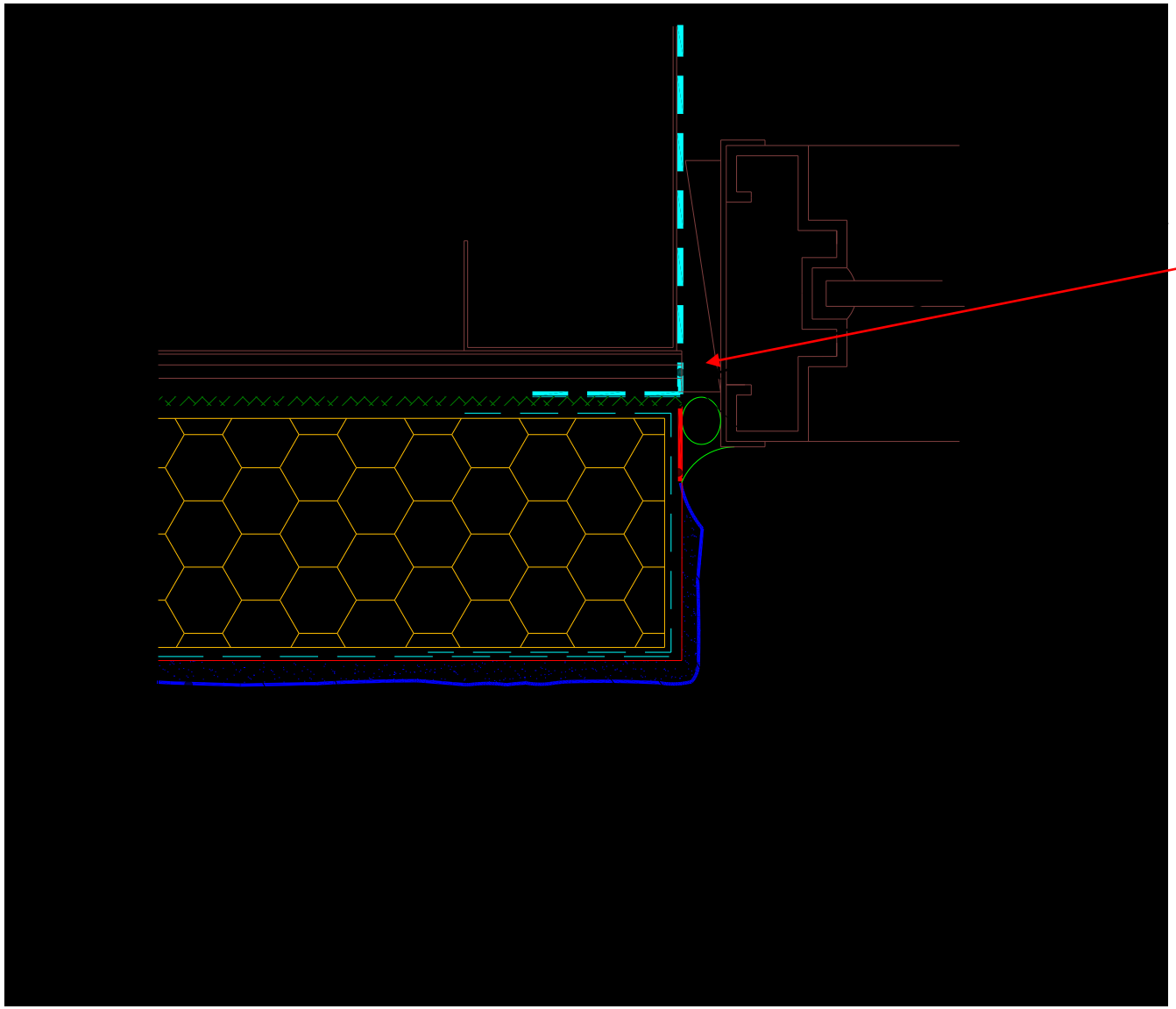
EIFS Moisture Drained System



EIFS Moisture Drained Window



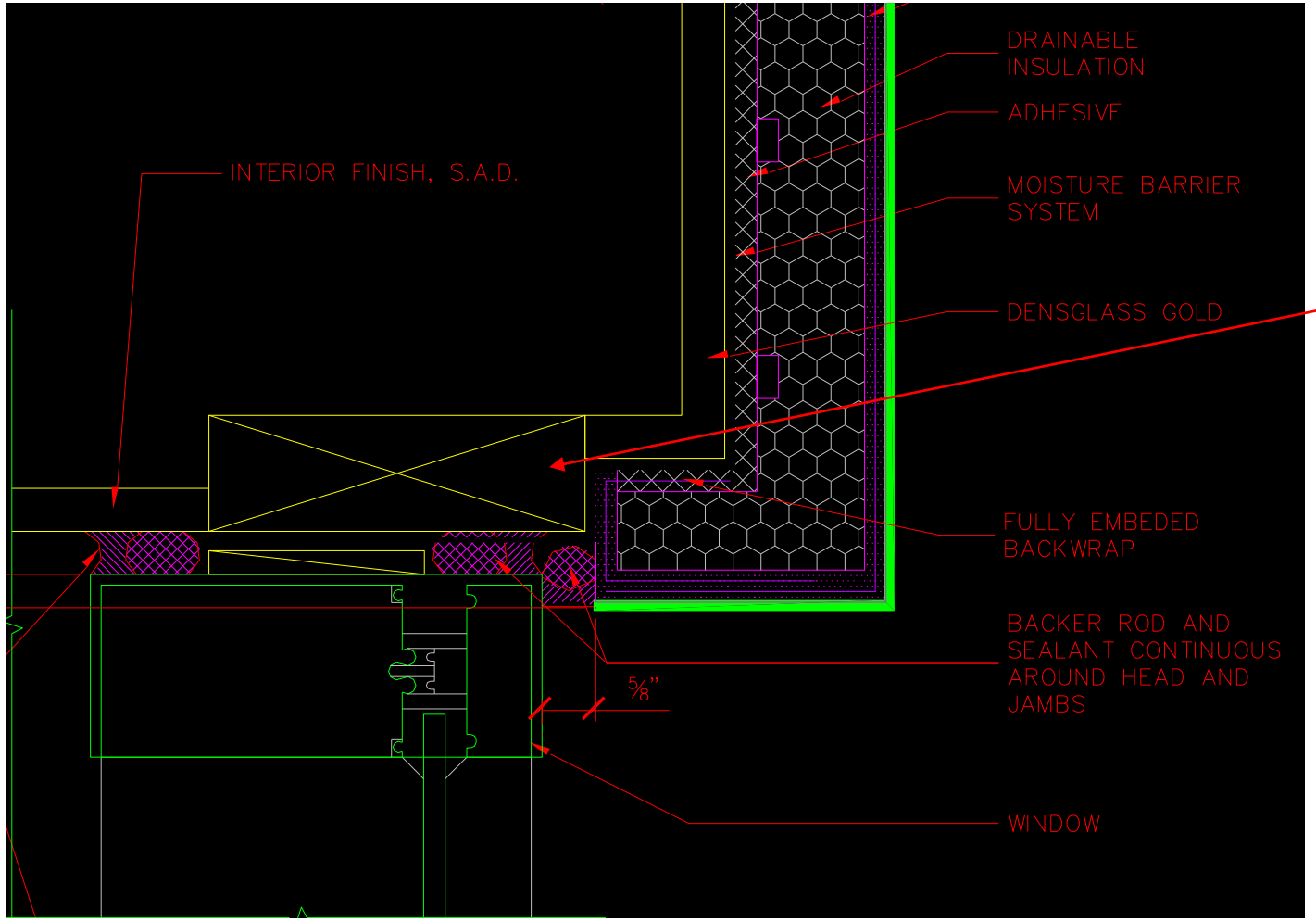
EIFS Moisture Drained Window Jamb



Manufacturer's standard detail is missing secondary seal to water resistive barrier.

EIFS Moisture Drained Window Jamb

Drainable EIFS Window Jamb With Secondary Sealant Joint



Inside sealant joint to seal secondary moisture barrier.

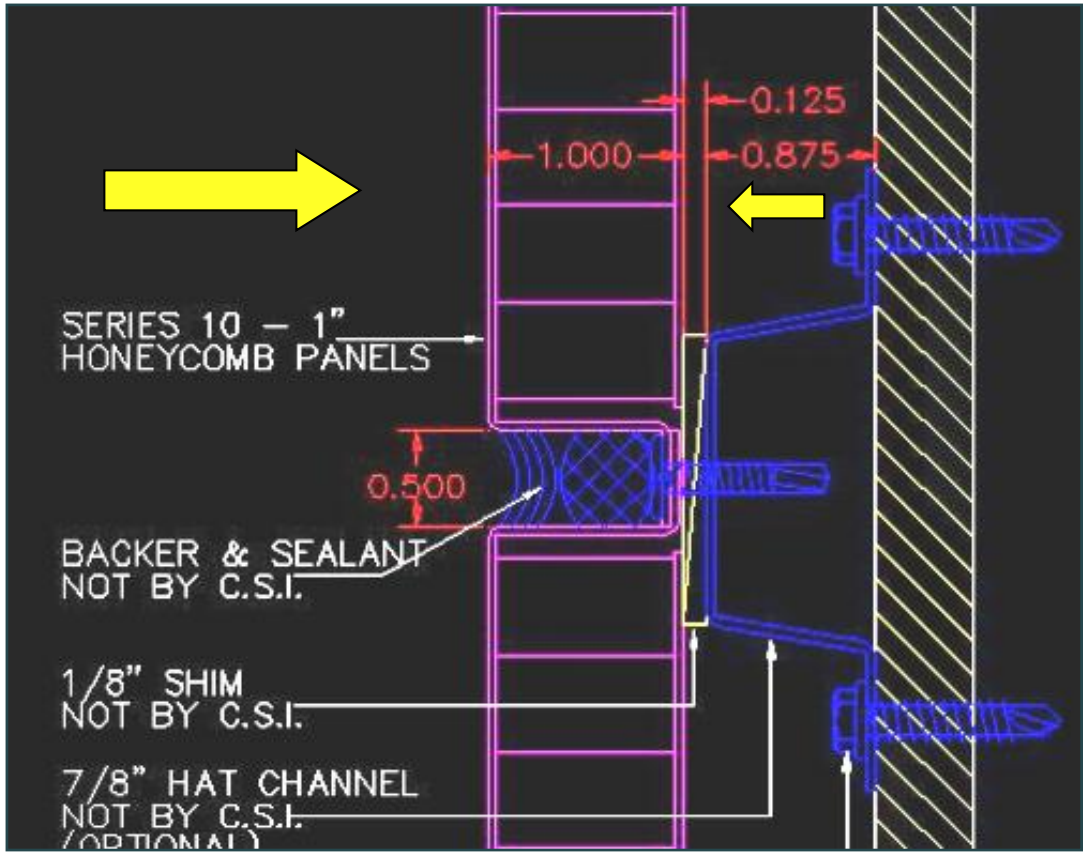
Wall Design

Philosophy Behind Back Ventilated Rainscreen Systems:

- Counteract the driving force behind water intrusion, i.e. Pressure Differential.
- Equalize the pressure between the outside skin and inside face of panel.
- Cavity behind the panel or masonry with vents to equalize pressure.

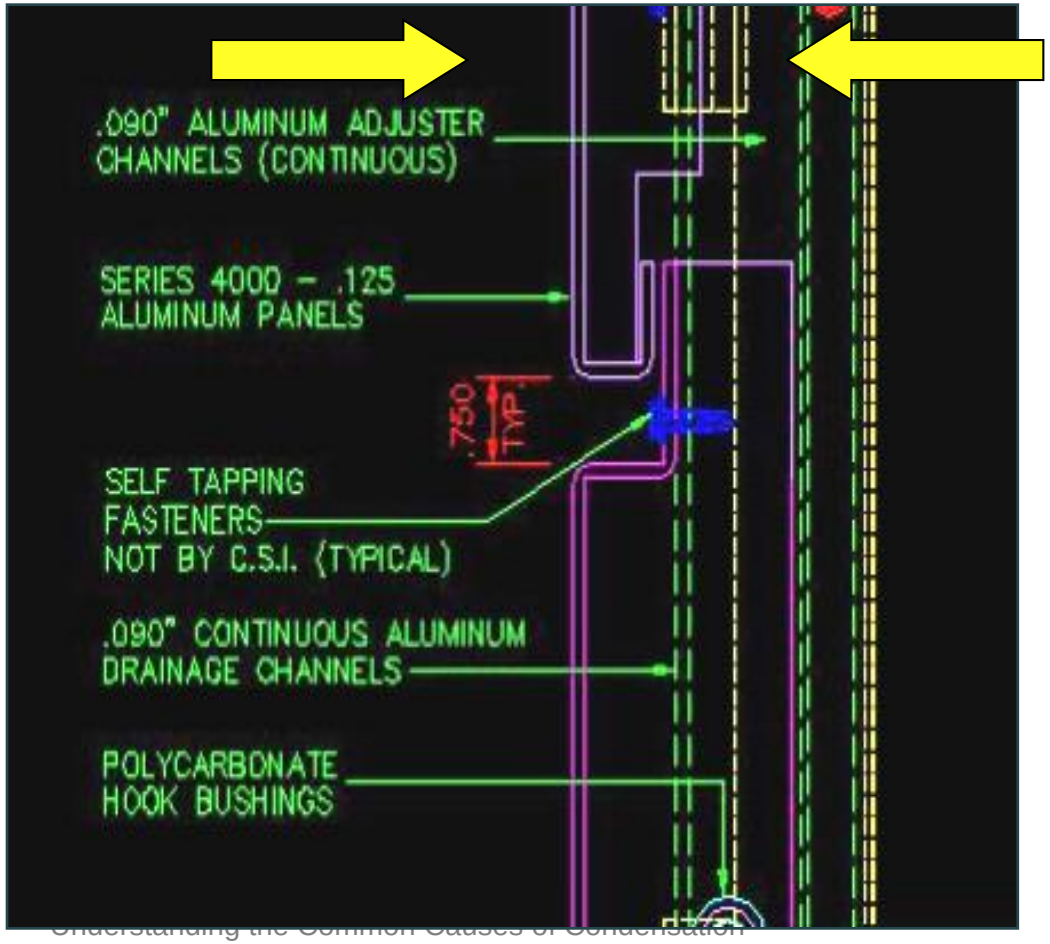
Pressure Differential

- Cavity Wall
  - Pressure is greater on the outside of the wall because it is completely sealed!



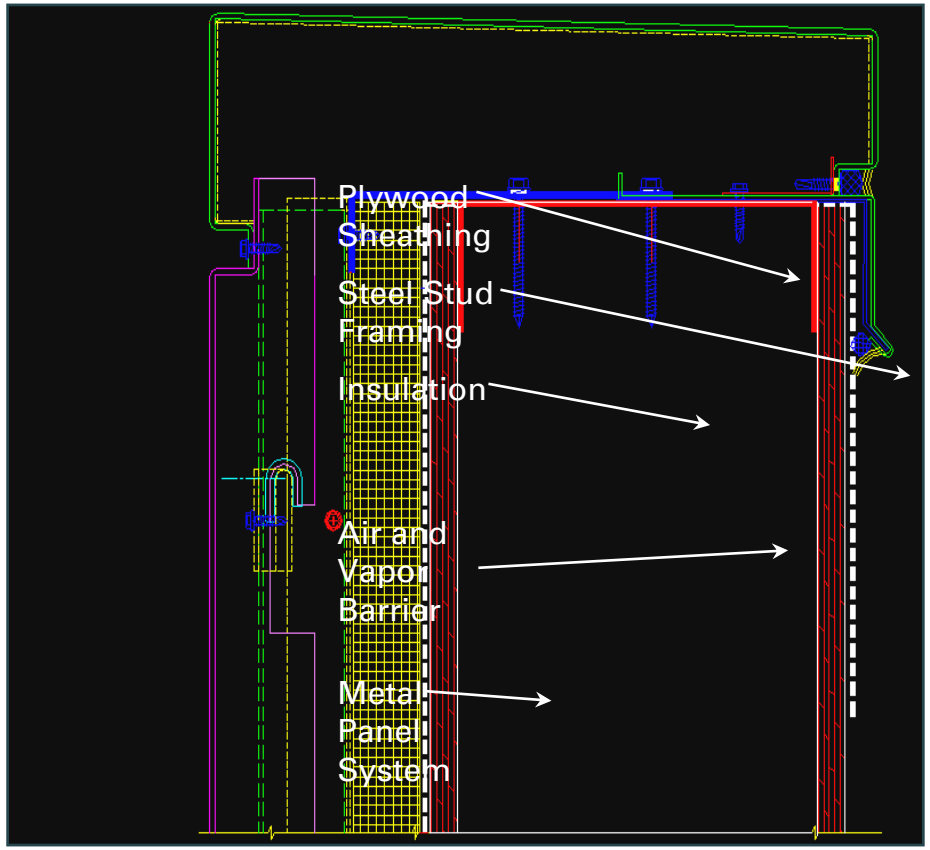
Pressure Differential

- **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.**



Wall Design

- **Back Ventilated**
- **Rainscreen Wall**
  - The air barrier behind the panels is a vapor barrier. The design professional needs to take this into consideration when designing a back ventilated rainscreen system.

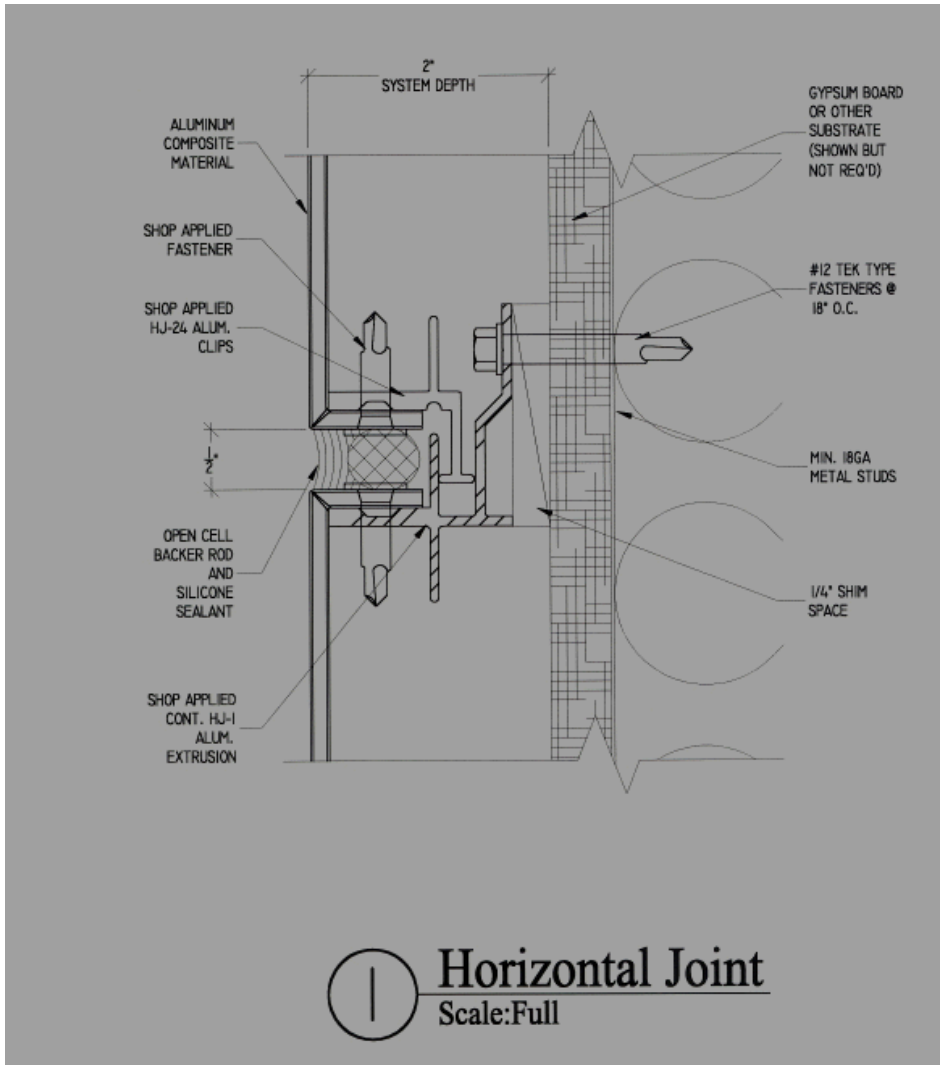


Austin-Bergstrom International Airport, TX

Open Joint Rainscreen System in
Aluminum Plate Kynar Finish

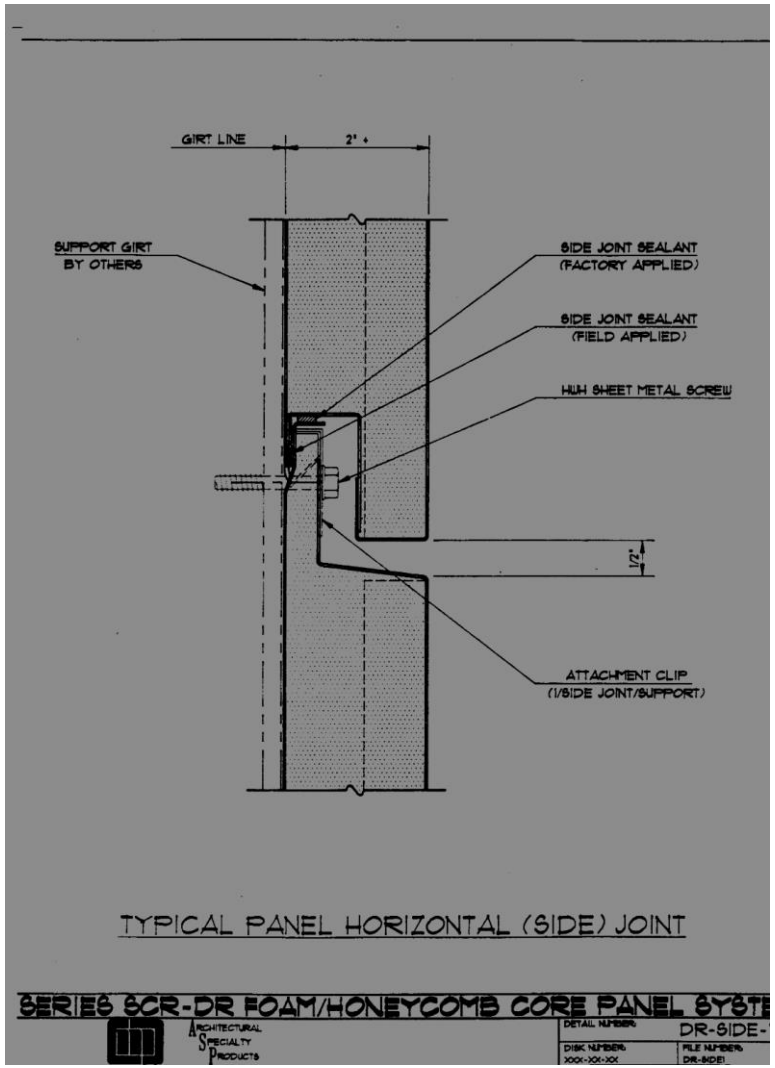
What kind of Back Panel?

- Barrier or Rainscreen Wall?
- Sequential Installation?



What kind of Metal Panel?

- Barrier or Rainscreen Wall?
- Sequential Installation?



EIFS Case Study

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Case Study: EIFS Bull Nose, Pleasanton CA

4- Story Office Building Pleasanton, CA

CHA-AL05795

Dryvit Outsulation is a Barrier System

- There are 3 basic types of the Dryvit EIFS system

- All Exterior Insulation & Finish Systems (EIFS) consist of a 1/16” cementious layer reinforced with a fiberglass mesh (lamina). The lamina is top coated with an acrylic texture and color coat. The thin layer of cement is the primary waterproofing for al EIFS systems.
- Dryvit Outsulation system (as installed on 5050 Hopyard) is a barrier system, i.e. this 1/16” layer is the only waterproofing on the exterior wall. No felt, no other means to weatherproof the building.
- Dryvit Outsulation Plus & Infinity Systems; in addition to the lamina, there is a waterproofing coating behind the EPS foam in both of these upgrade systems. This additional waterproofing membrane, if properly installed and drained can be an effective “secondary” barrier to water entry.

Typical Crack in EIFS Bull Nose

CHA-AL04351

Patterns of Cracking in Bull Nose

- There were two distinct patterns 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 at inside Corner

DEFECT: Lack of expansion joint at inside corners

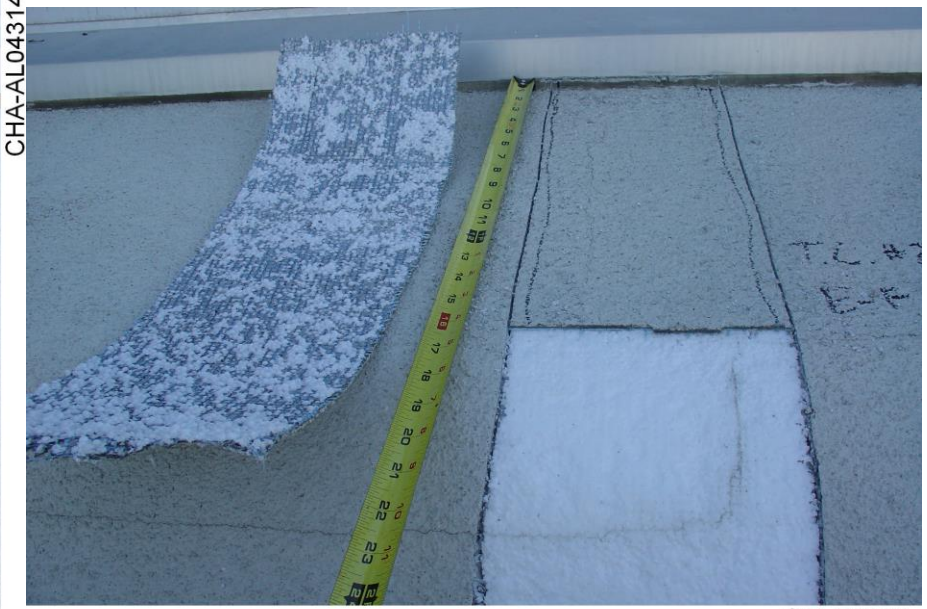
CHA-AL04435

Vertical Crack in the Field

CHA-AL03186

Multiple Cracks, Horizontal and Vertical

CHA-AL04314



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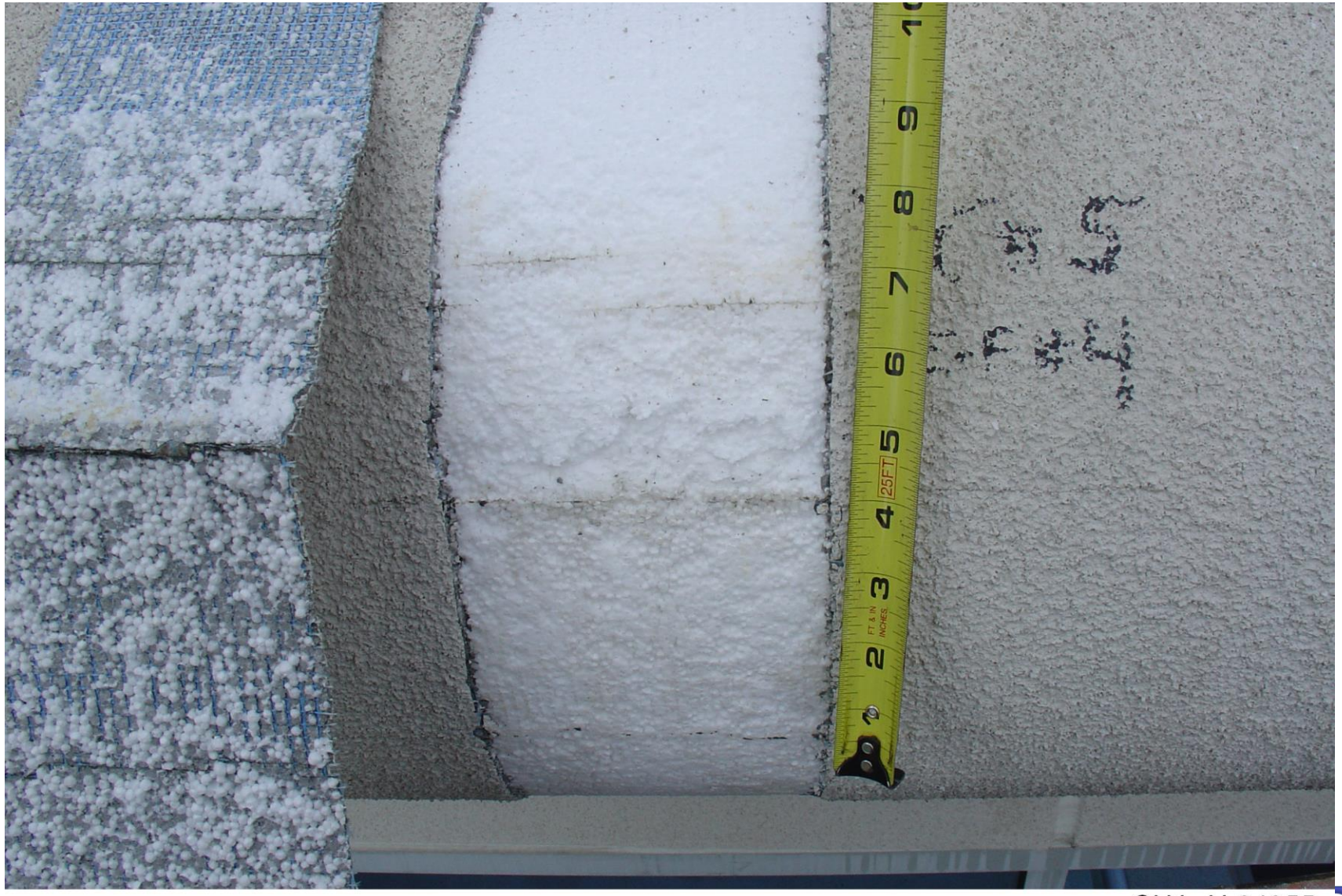
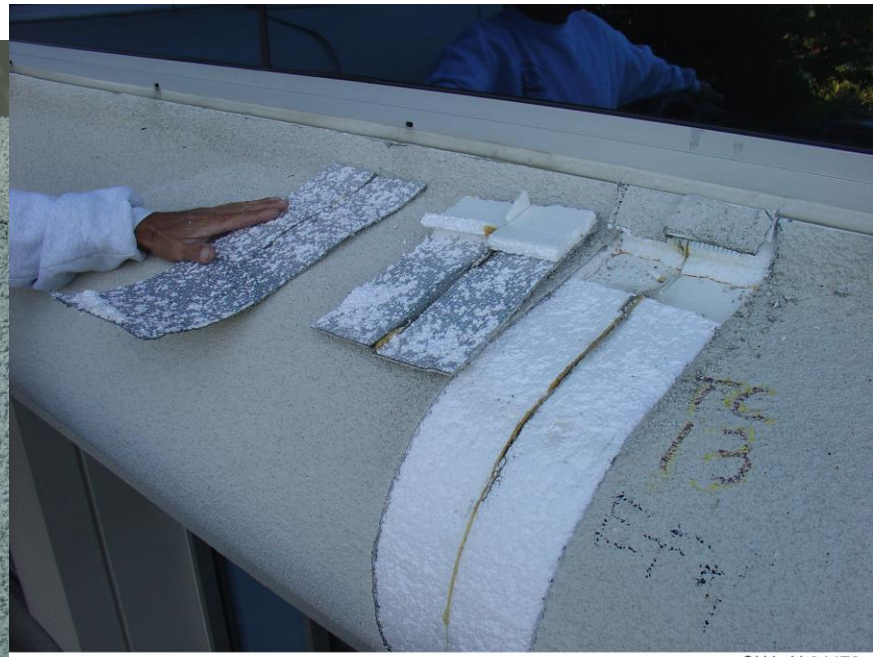
Typical Horizontal Crack Pattern



Reasons for Vertical Cracks (Defect)

- 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
- In some cases, vertical cracks resulted due to lack of mesh embedment



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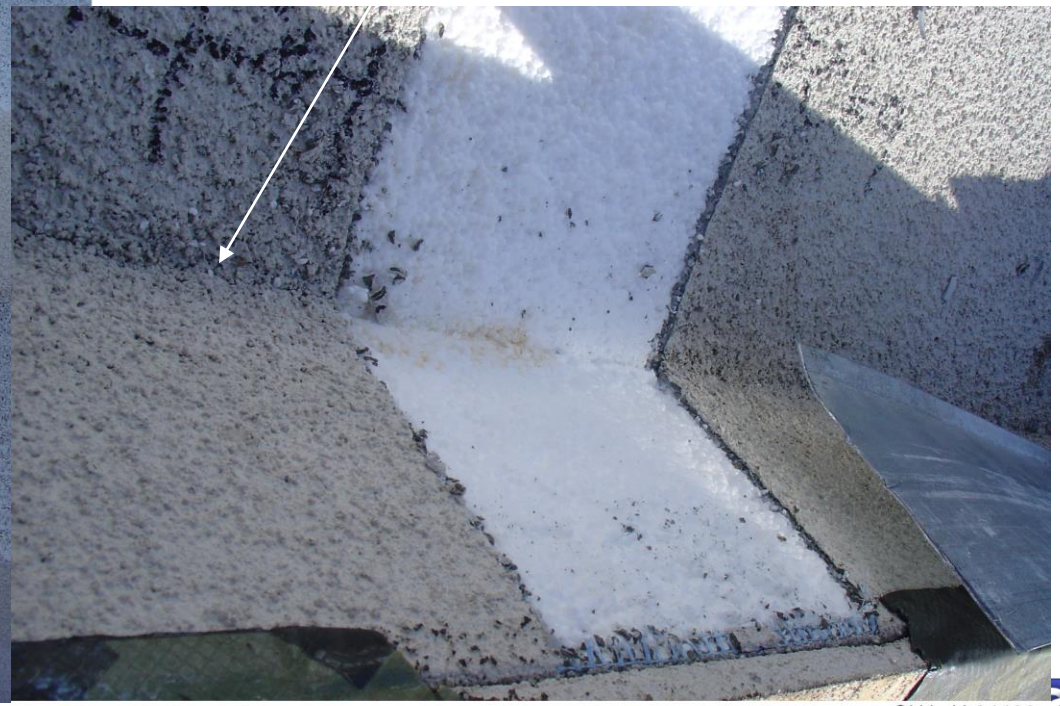
Cracks at Parapet Wall; Lack of Slope

Cracks and splits are caused due to lack for extra reinforcing mesh

Vertical Crack at inside corner

Horizontal Crack at inside corner. Notice water stains.



Cracks and leaks at Inside Corner of bull nose

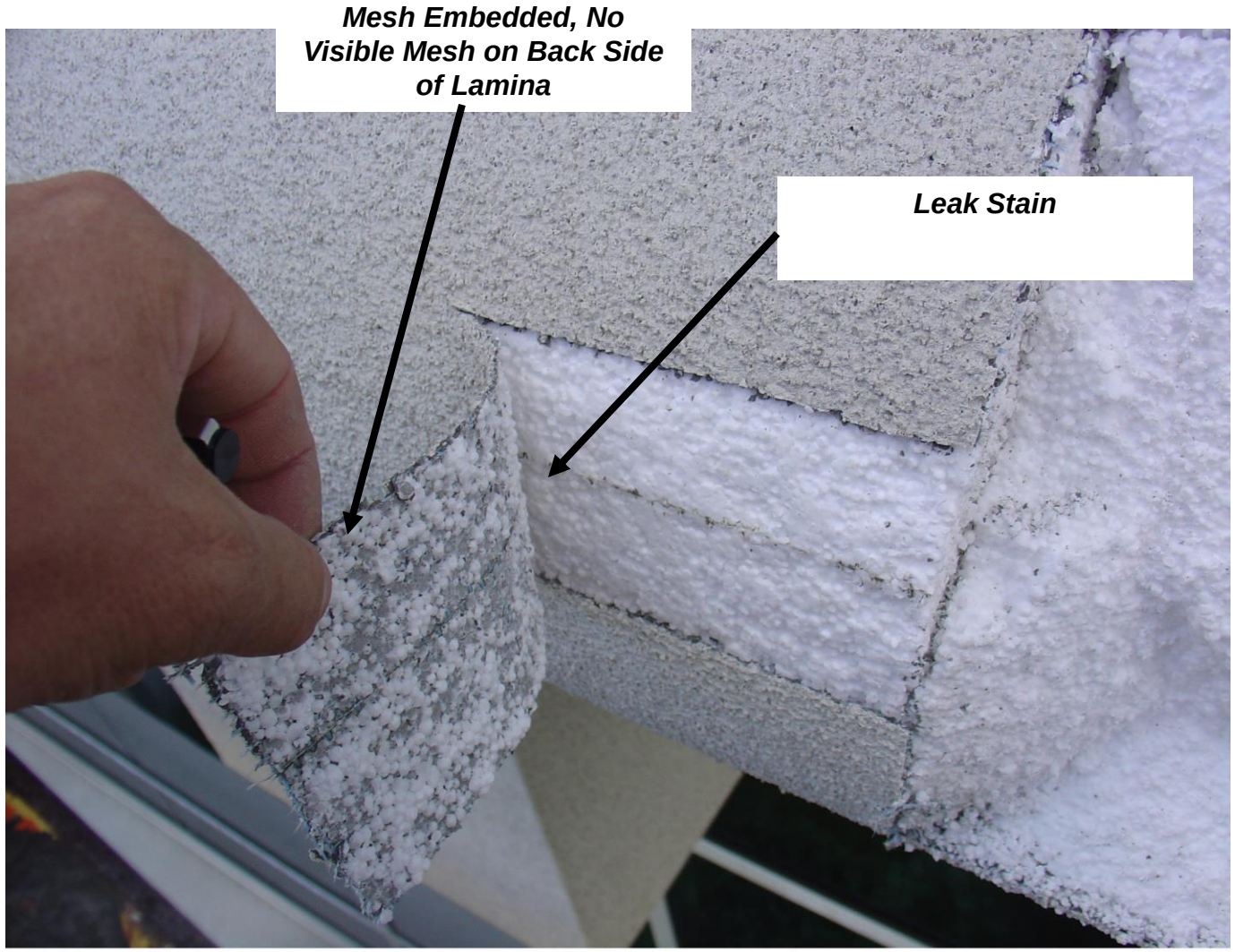
Leak Test Location #4 – Southeast Elevation – above 2nd floor

Test Cut # 2, East Elevation.

CHA-AL05261

AUGUST 2004 TESTING

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



Travel Path for Water Leak

- EIFS outsulation is a “barrier” system. The 1/16” Cementious skin is the only waterproofing barrier in the system. CRACKS = WATER INTRUSION & LEAKS
- Our testing showed that water leaks were occurring from both horizontal (longitudinal) and vertical (perpendicular) cracks in the lamina at the bull noses.
- In case of vertical cracks, there existed a gap between the foam and water was able to quickly and readily travel through the EIFS skin, and reach the interior sheathing or ceiling space.
- In case of the horizontal cracks, water traveled between the EIFS lamina and EPS (Expanded Polystyrene Foam), and very slowly moved around the bull nose and leaked to the interior space.

EIFS Defect: Lamina is not backwrapped

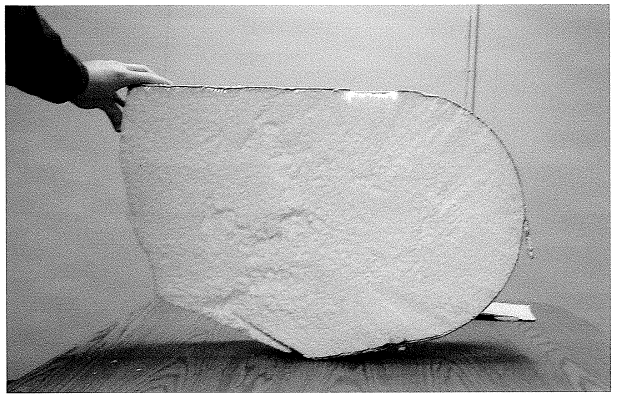
Test Cut #3– East Elevation – 4th floor line EIFS Bullnose. Required by Dryvit

Forensic Analysis of Horizontal Cracks

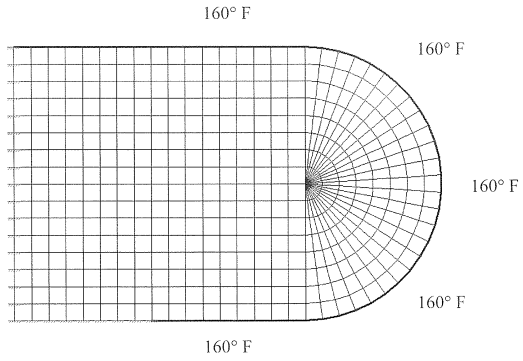
- In order to develop a suitable, sustainable, repair for this building, we analyzed the mode of failure.
- The horizontal crack pattern in the EIFS finish at the nose of the bull nose was unusual and distinct.
- Our structural engineering team performed thermal modeling of the bull nose panels to see 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

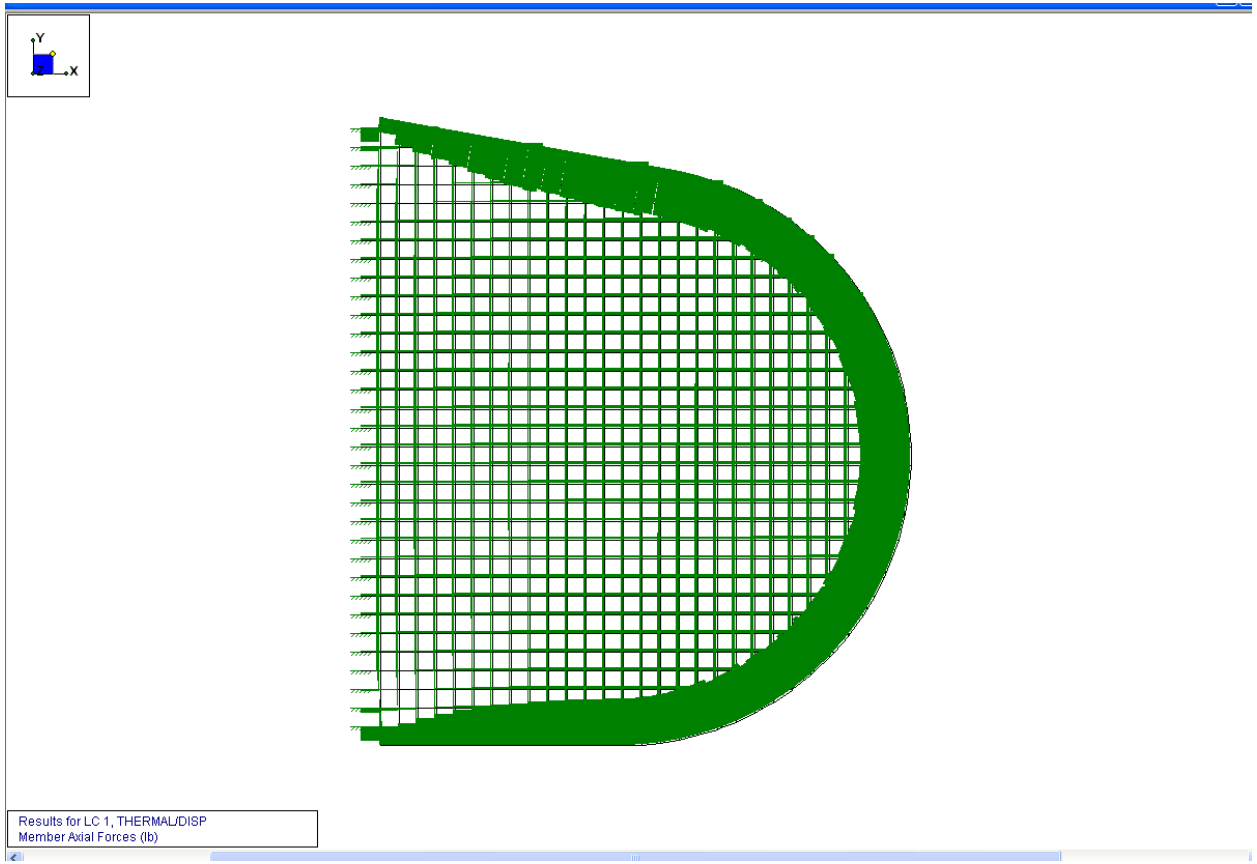
5050 Hopyard Preliminary Finite Element Analysis of EIFS bullnose assembly.



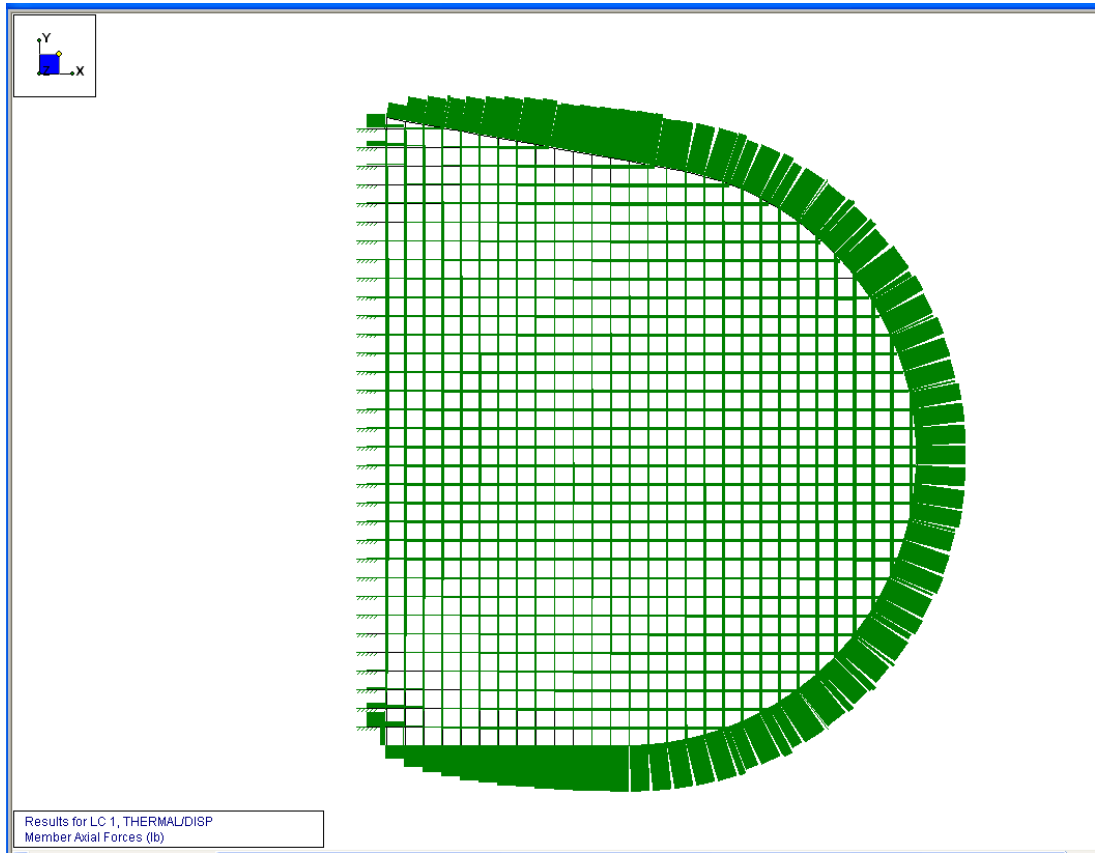
5050 Hopyard EIFS bull-nose specimen



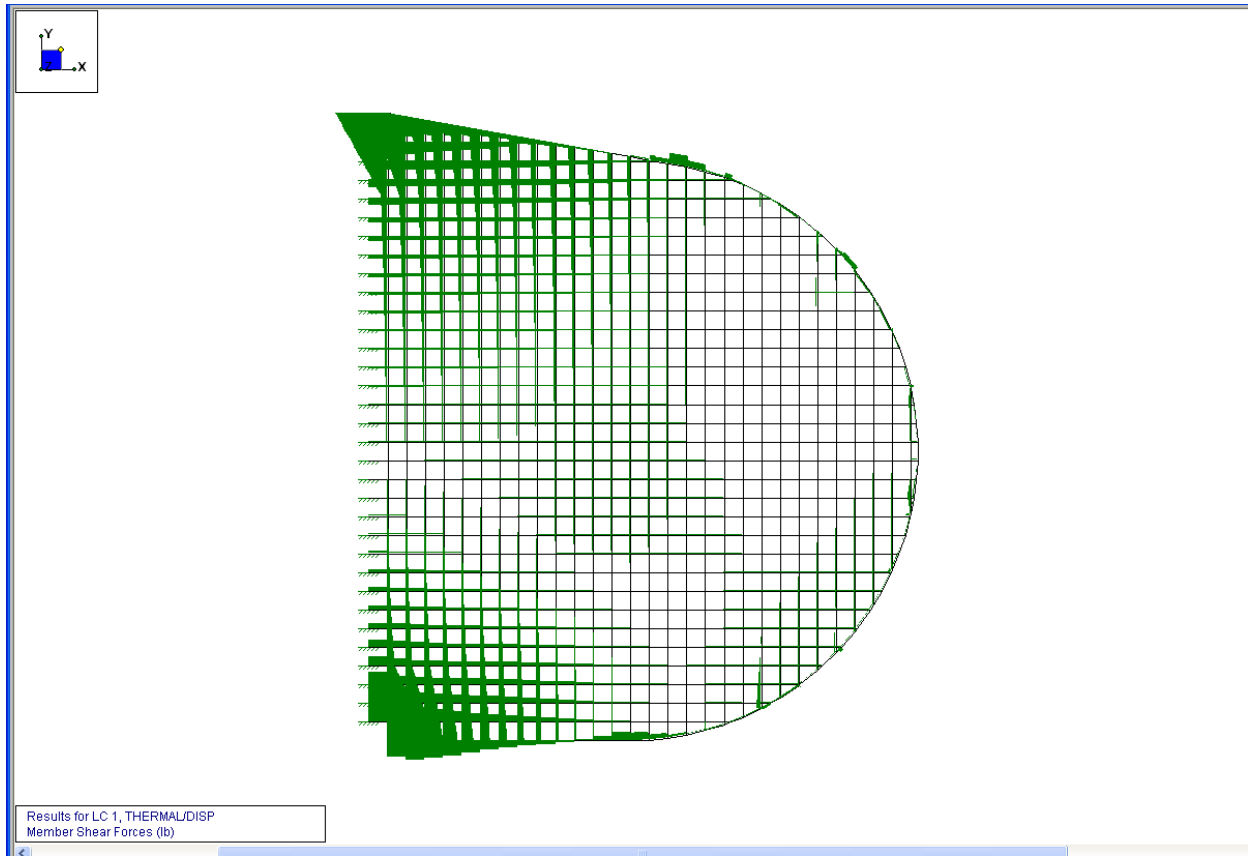
2D Finite Element Model of EIFS bull-nose Specimen: Model is subjected to a uniform thermal load of 160 F. Elements are 4 node quadrilaterals and are assigned the



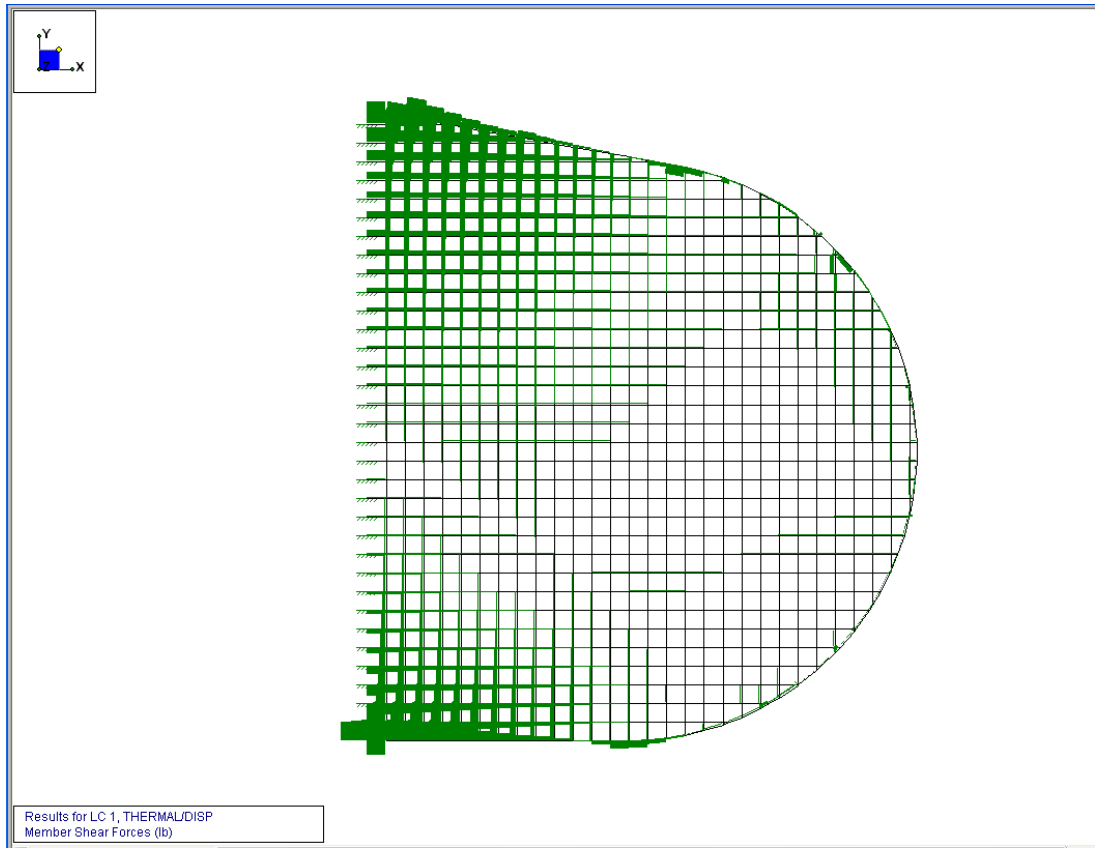
Axial Loads (lb) for 50°F Increase



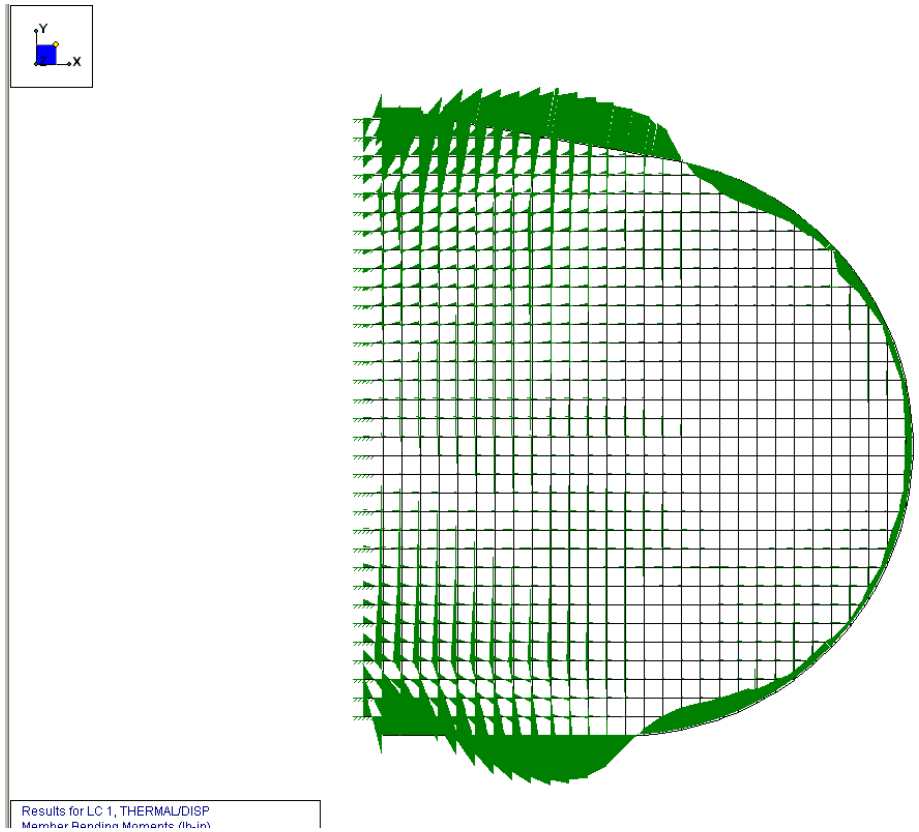
Axial Loads (lb) for 50°F Decrease



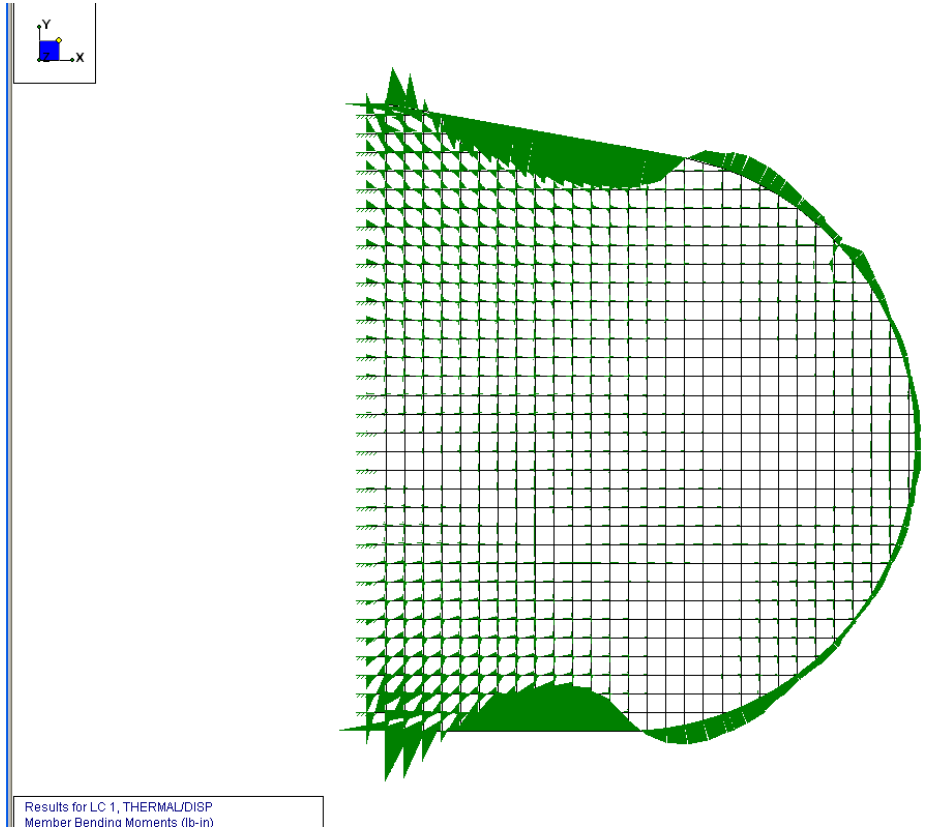
Shears (lb) for 50°F Increase



Shears (lb) for 50°F Decrease



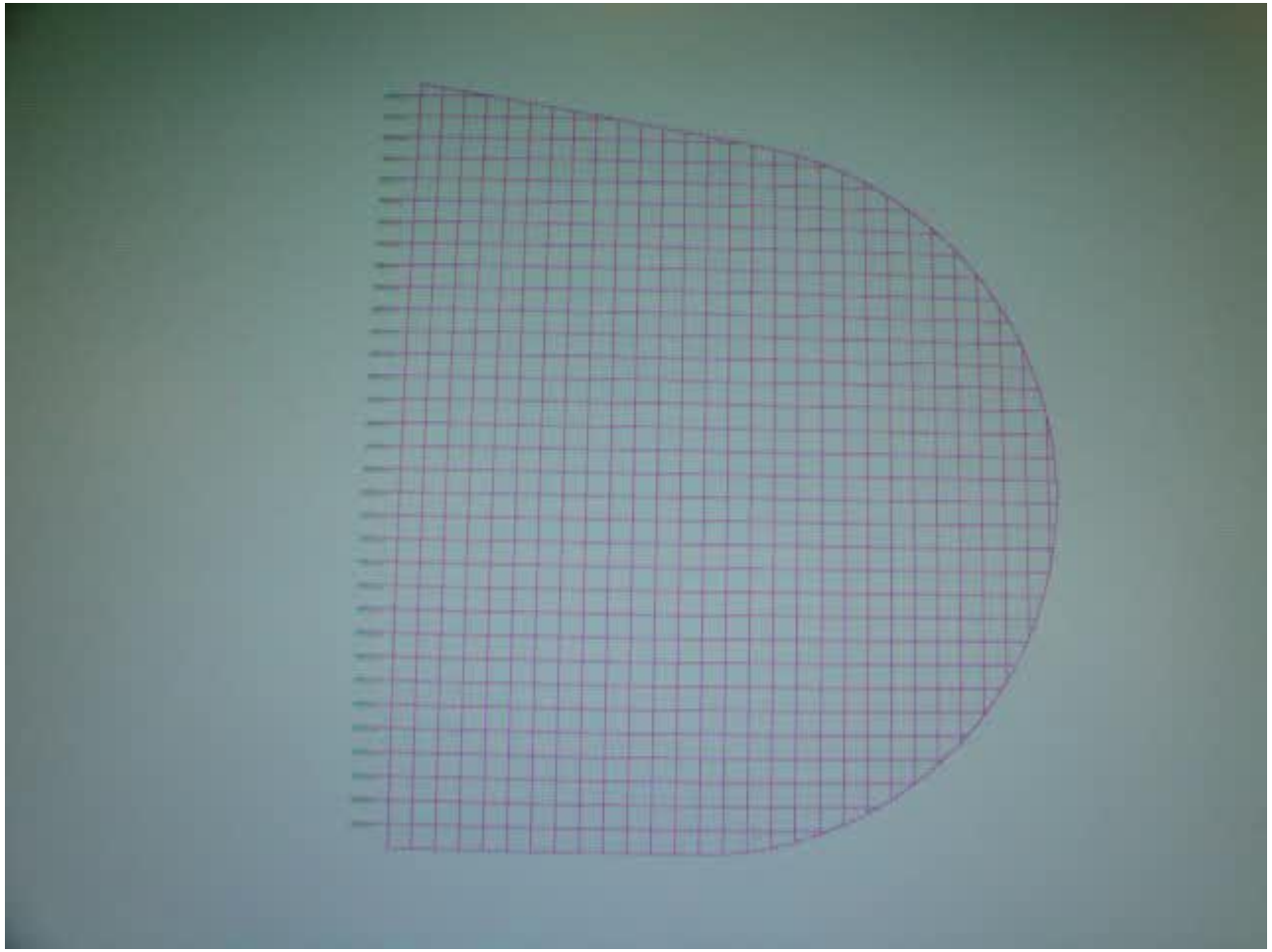
Moments (lb-in) for 50°F Increase



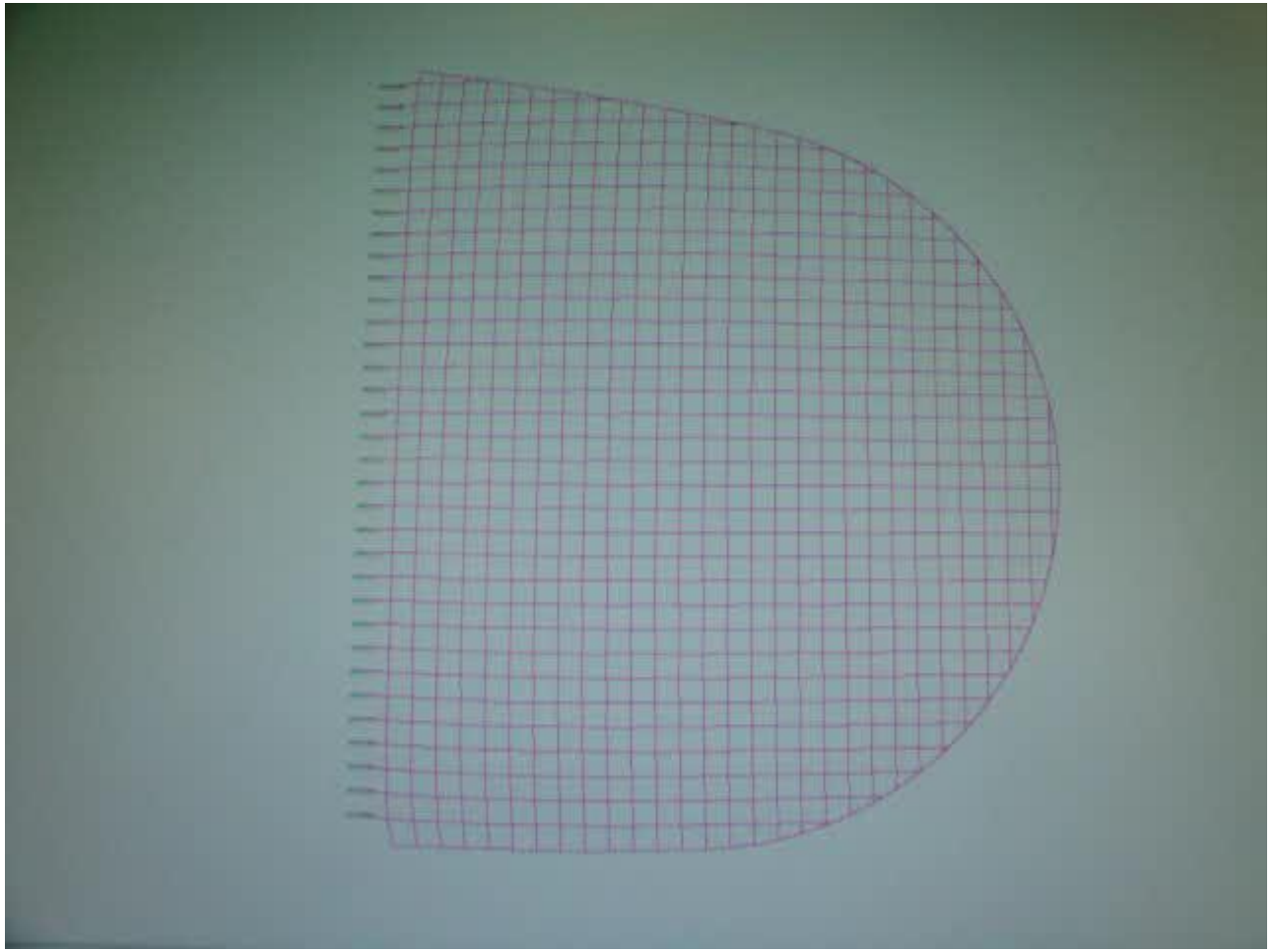
Moments (lb-in) for 50°F Decrease

Thermal Analysis (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)



50°F Temperature Increase (100°F to 150°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.

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.