Can A Poor Air Seal Cause Roof Failure?

Timothy A. Mills, P.E., LEED AP, CIT II

TAM Consultants Inc.

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Timothy A. Mills, P.E.

Tmills@tamconsultants.com

757-564-4434

www.tamconsultants.com

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BUT THIS FIRST

Timothy A. Mills, P.E., LEED AP, C.I.T.
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Hurricane Florence, N.C. – September 2018

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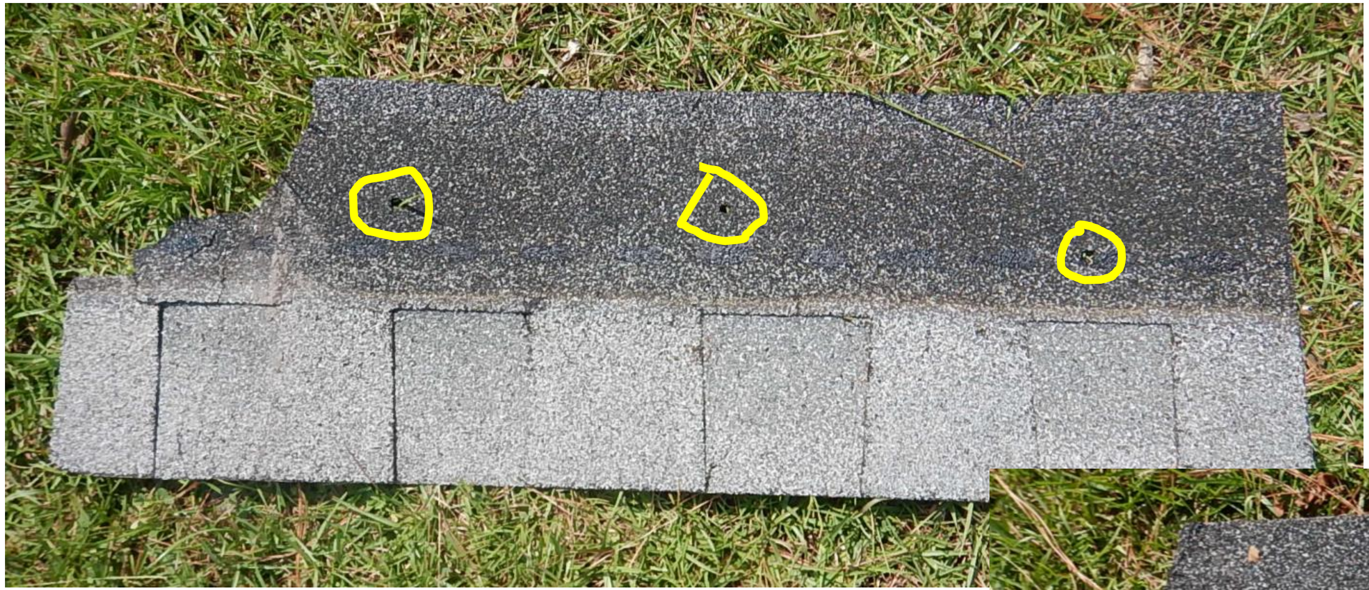

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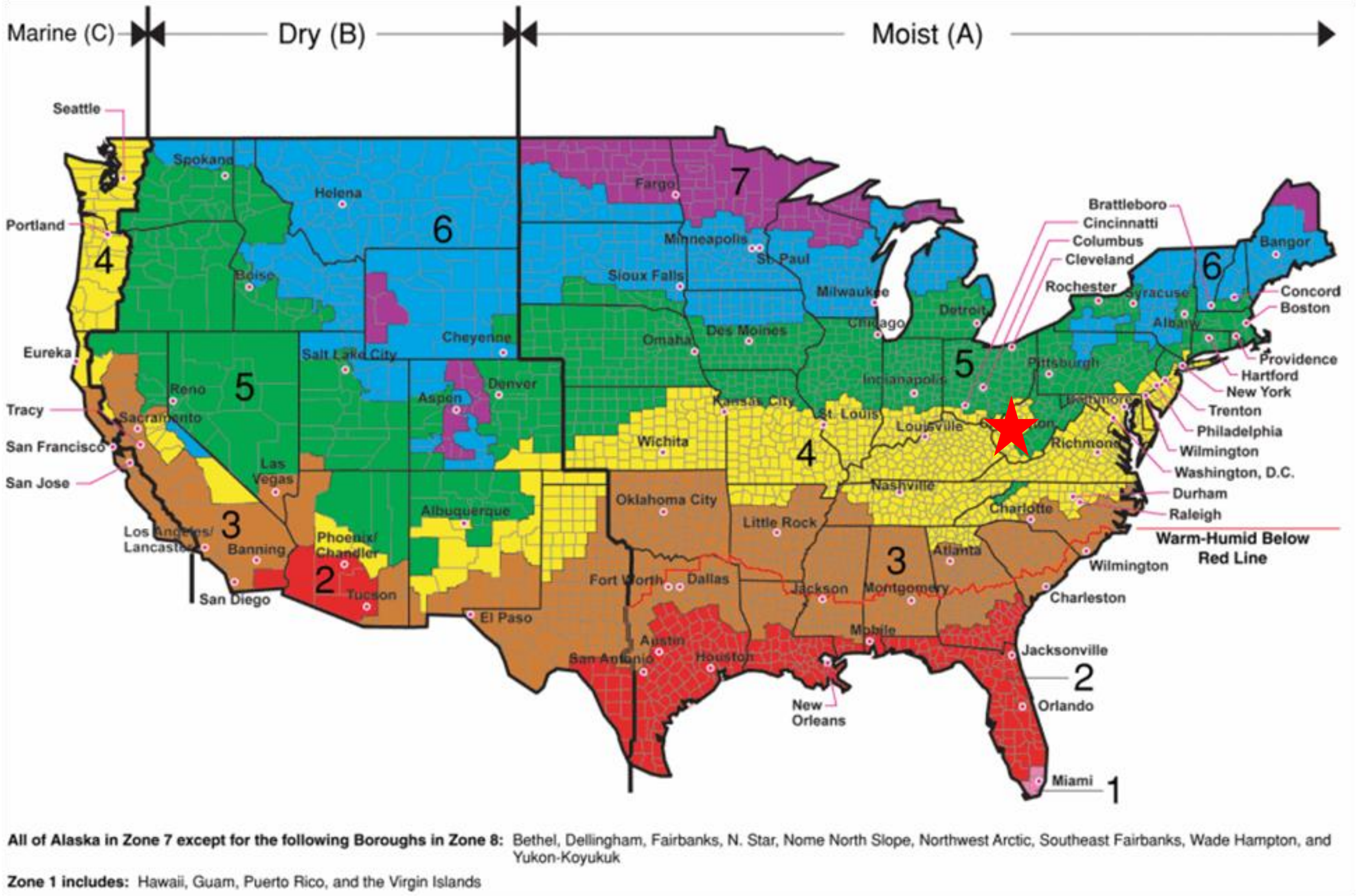
Learning Objectives

1. To gain an understanding regarding the importance of coordination of the various design disciplines and how building failures are not necessarily caused by the obvious issues.
2. To gain an understanding regarding the critical importance of airtightness in buildings and how to ensure that the roof wall interface is constructed air and water tight.
3. To demonstrate good detailing and design practices.
4. To review the steps in evaluating a failed roof system as part of an insurance claim.
5. To demonstrate how multiple failures either in design and construction work together to magnify and turn small problems into a major failure.

Background

- Medical facility
- located in Climate Zone 4
- Mid-Atlantic Region of the United States.
- The project is located in a mountainous region that experiences warm summers and cold winters.

Located in Climate Zone 4



Background

- Within a few years following installation of the roof on this medical facility the roof condition was such that it already required replacement as it was determined to be irreparable.
- This study came about as a result of an insurance and potential legal claim filed by the Owner with their property insurance company.

Background

- The results of a forensic engineering effort are often used by the insurance company to subrogate against a third party to allow the insurer to recover some or all of its costs associated with the claim.

Background

- Not too long after completion of construction the Owner began to have issues with the installed single ply low-slope roofing system.
- There were signs of excessive ponding, deformation, warping and cupping of the insulation boards under the roofing membrane.

Background

- After five years and filing numerous warranty claims and obtaining advice from various roofing companies and suppliers, the lawyers and insurance companies got involved.

- An assessment of the roof system was conducted in late summer.

Investigation

- A site visit to visually observe the roof during the daytime and evening
- Five large core cuts were made to review the construction and condition of the various roofing system components
- Roof seams were probed and inspected
- Moisture meters were used to verify the presence of wet insulation

Investigation

- Thermal imaging was utilized to check for the presence of saturated insulation in the top layer of insulation
- Differential building pressure measurements were also taken across the roof membrane at various locations.
- Various parties involved in the construction and management of the building were interviewed
- Construction related documents and warranty claim reports were reviewed.

Investigation

- The failed roofing system included:
  - 22,000 sf fully adhered
  - 0.060 black EPDM single ply roofing membrane
  - Adhered to tapered rigid board insulation
  - Multiple layers of polyisocyanurate insulation with organic facers bonded together with hot mopped asphalt.
  - The insulation is adhered to a composite concrete deck.
  - The roofing system turns up and over a short pre-cast concrete parapet wall on all sides and is topped with a pre-finished metal coping system.

Investigation

- Visual observations immediately indicated that there had been widespread bowing, cupping, delamination, or debonding in large areas of the roof insulation.
- This was readily visible on approximately 30 percent of the roof area.

View of roof area following a storm event, where ponding areas and insulation deformation is more evident.

Investigation

- The displacement of the insulation was severe enough that it created a series of many ponding areas across the roof and impeded water flow, preventing the roof from easily draining.

View of failed roof system, the photo does not convey the large amount of insulation deformation, note dirty spots where ponding frequently occurs.

Investigation

- In only a few areas the roof membrane had become debonded from the top layer of insulation,
- In the vast majority of locations, it appeared as though the insulation layers were either coming apart from each other or separating (debonding) from the roof deck.
- The areas where the roof membrane had debonded from the top layer of insulation primarily occurred at the roof access doorways and was due to foot traffic.

Investigation

- The Owner had reported that for the most part the roof system had remained leak-free with a few leaks noted over the years that were quickly repaired under the warranty.

Investigation

- During the course of the warranty repairs a significant portion of the roof membrane and insulation had been removed and reinstalled with a urethane adhesive rather than hot asphalt as the repairs would have been easier at the time for small areas in an occupied building.
- The portions of repaired roofing had also showed similar failures in the insulation.

Investigation

- During the inspection of the lap seams it was determined that in general the EPDM roof membrane seams appeared to be in serviceable condition with very few deficiencies noted and in need of perhaps a small amount of maintenance.
- The fully adhered roof membrane had separated from the pre-cast parapet walls in a large number of areas around the entire perimeter of the building.

Investigation

- Interior building air pressurization from the mechanical system was affecting the roofing system.
- The membrane was ballooning out due to internal building pressure.
- The membrane had also become debonded from the reinforced EPDM strip at the base of the wall.

View of a parapet wall where EPDM membrane has debonded from the wall surface.

Investigation

- As part of the insurance claim the installing roofing contractor, the general contractor as well as the roofing system manufacturer had claimed that the building HVAC system was positively pressurizing the roofing system with enough pressure to cause “structural damage” to the roof system including membrane and the insulation debonding, delamination and overall failure.

View of parapet wall where membrane is ballooning out and has deboned from the pre-cast concrete wall.

Investigation

- Therefore, using a micromanometer, pressure measurements were taken at various areas around the building to measure the differential pressure between the interior and the exterior of the building across the roof membrane.

Investigation

- The pressure measurements were taken on a windless day and represents the pressure induced by the HVAC system and pressure associated with the stack effect due to the height of the building. Wind effect, if measured, would have greatly increased the pressure readings.

View of the use of a micromanometer and pressure prove to measure the air pressure difference across the parapet wall roof membrane.

Investigation

- In nearly all building types it is desirable to have a pressurized interior environment relative to the exterior of the building.
- In an ideal world the amount of air that is exfiltrated can be completely controlled by mechanical means and unintended air leakage through the building envelope is reduced to near zero. The importance of an air tight envelope cannot be overemphasized.

Investigation

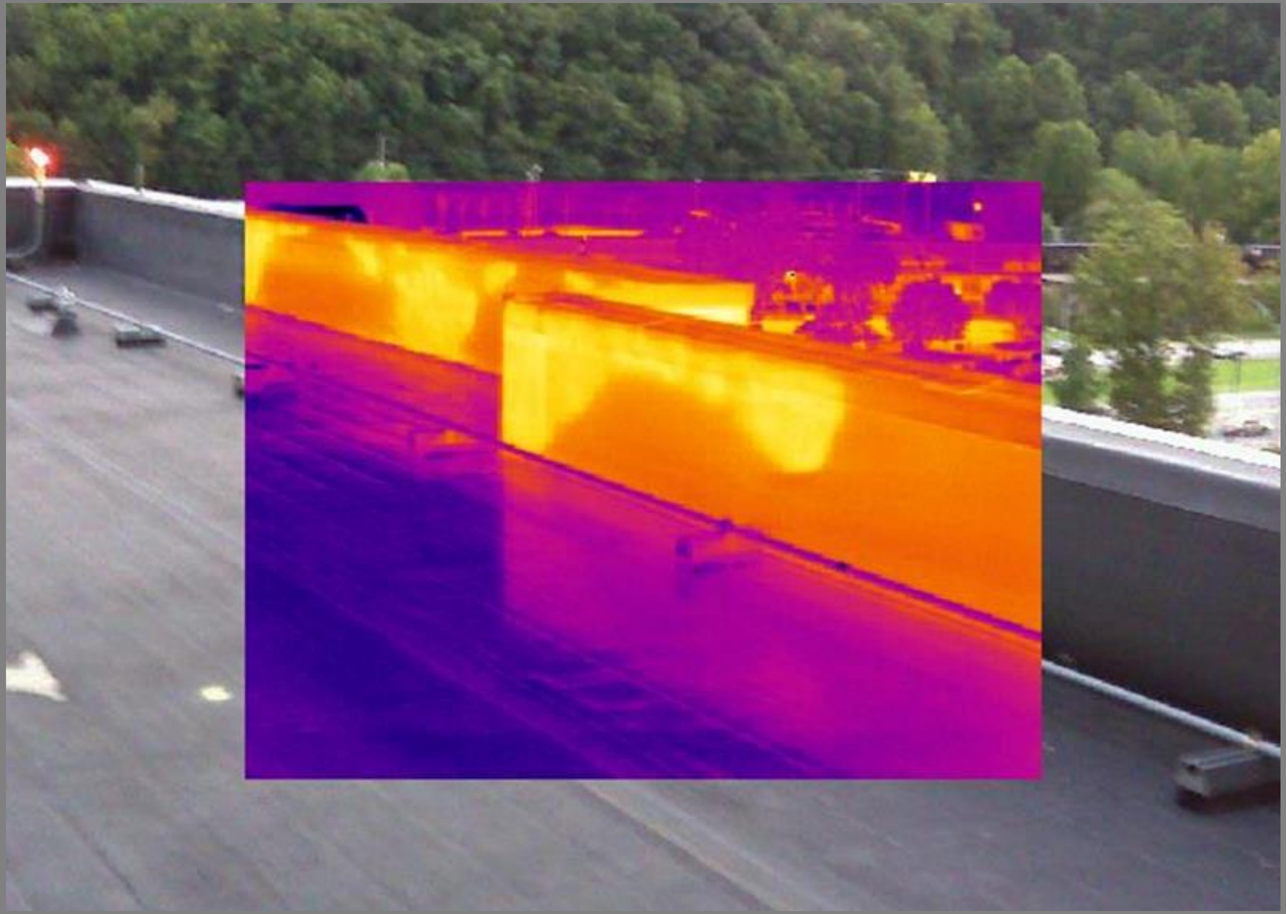
- Medical facilities are somewhat unique in that very often they rely on 100 percent outside air for the HVAC systems and don't return much if any air back to the air handlers via return ducts. This does have a tendency, depending on how the systems are operated, to create relatively moderate interior building pressures as measured in this case.

Investigation

- Pressures were measured between 10 and 15 pascals positive where the interior of the building was positively pressurized relative to the exterior at the roof level. Although elevated these pressures are not uncommon.
- The IR study found only four small areas of wet surface insulation and those areas were adjacent to penetrations and not located in areas where the failed and delaminated roof and insulation had occurred.

Investigation

- The thermal imaging survey also clearly revealed areas of debonded roofing membrane at the parapet walls around the entire roof area.
- It became clear that conditioned air from the interior of the building was easily finding its way to the roof level at the perimeter condition where the roof deck and parapet wall meet.



Thermal image of parapet wall where membrane separation is clearly visible.

Investigation

- Five roof core cuts were made.
- Four in the field and one at the parapet wall.
  - Interlayer adhesion for the various rigid board insulation layers was poor.
  - Poor adhesion occurred as a result of either:
    - too little asphalt,
    - the use of asphalt that was too cold,
    - insulation boards that are not stepped into place as they were placed into the hot asphalt.
- .

Using a moisture meter for a quick check for moisture content at both the surface and deep layers of insulation.

Investigation

- In all of the roof cut areas, even though insulation had been badly deformed, only one roof cut yielded saturated insulation and only at the bottom of the assembly.
- In all locations there was a strong odor of mold and light to heavy mold growth

View of poor interlayer adhesion between insulation boards.

View of deformed polyisocyanurate insulation.

View of large deformation in the insulation, note evidence of water staining even though insulation was dry.

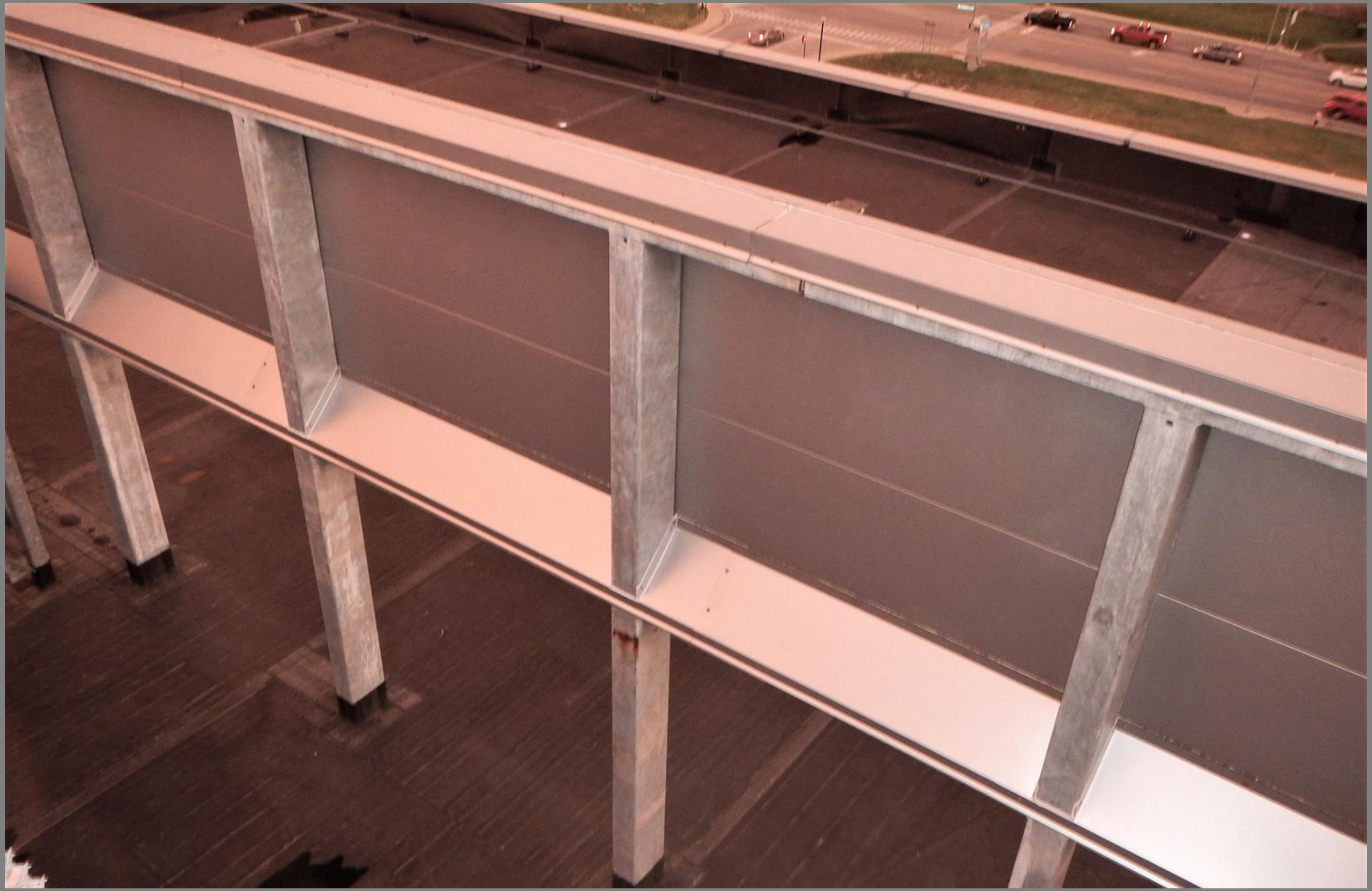
View of poor asphalt coverage on concrete deck

Investigation

- The project included a heliport and walkway located on a steel platform supported by tube steel columns well above the roof surface.
- The entire heliport, access stair and walkways were supported by galvanized structural steel tube sections which create square penetrations throughout the center portion of the roof area.

Investigation

- Additional structural steel tube sections are installed along certain portions of the roof as well for supporting screening from street views.



View of mechanical screen galvanized steel columns with exposed drain holes at the top of each column.

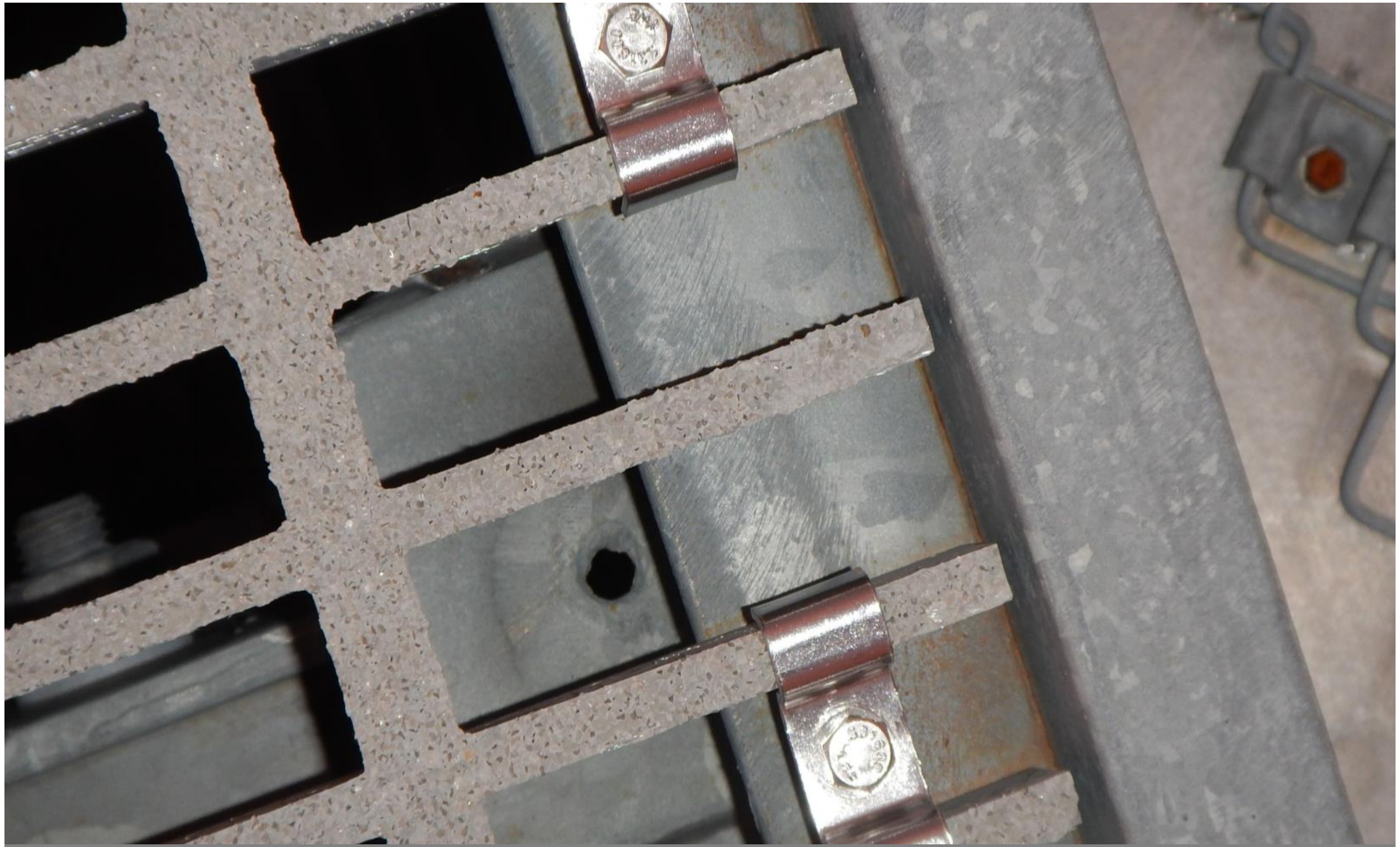
Investigation

- Evaluation of the steel structures revealed small three-quarter inch diameter drain holes in the tube steel members.
- As part of the galvanizing process, drain holes are installed at both ends of the tube steel assembly in order to allow the steel assemblies to drain once they are lifted from the galvanizing dip tanks. Some galvanizing shops will seal those holes with a plug, but often they are never sealed.

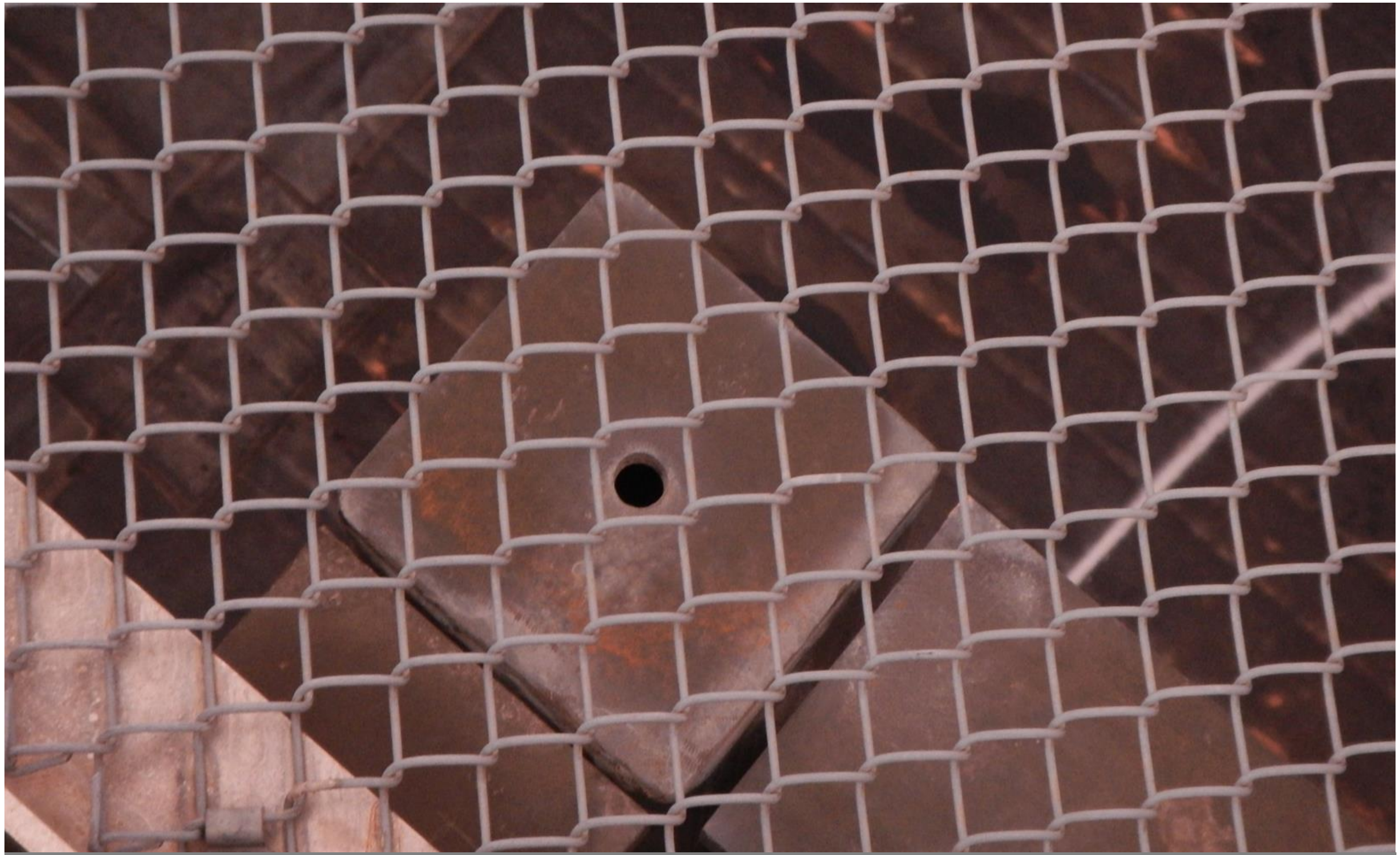
Investigation

- This observation yielded two conclusions including:
  - first; any water that got into the structural steel tube sections was directed to the bottom of the roof assembly directly to the concrete deck where the column base plates were attached to the deck.
  - second; each structural column was acting like a small, tiny chimney providing a direct air path from the roof assembly to the exterior, a highly undesirable condition.

Close-up view of exposed drain holes in the galvanized steel columns allowing direct water infiltration and air exfiltration. Note some holes are drilled and some are cut with a torch.



View of upward facing drain hole in a galvanized steel column.



View of upward facing drain hole in a galvanized steel column.

Findings

- In this matter:
  - the Owner claimed defective roof work as the cause of failure
  - the contractor and roof system manufacturer claimed building pressurization as the cause of failure.

- Both arguments failed to explain all of the observations that were made during the investigation.

Findings

- To be clear, the Owner's claim that the roofing system was defective due to defective workmanship was certainly a valid claim. The condition of the roof created somewhat of an emergency situation for the Owner as the roof was a potential candidate for a complete blow off should there be a high wind event.

Findings

- However; although the Owner’s claim was valid, it did not explain why the repaired areas were also failing and the water moisture at the bottom of the roof insulation and intermittent wetting of the insulation. Therefore, something else was also at play.

Findings

- The contractor, roofer and manufacturers' claim that the HVAC system was cause for the failures does not stand up.
  - 15 pascals at the parapet walls equals a differential pressure of a mere 0.3 PSF.
  - Compare this to even relatively low rating for an FM Global FMG 1-60 roof is designed for field pressures of 30 pounds per square foot and tested to pressures of 60 pounds per square foot
  - we are looking at orders of magnitude of 100 or more in the difference between what the mechanical system is capable of producing for internal building pressure versus what a properly installed roof system is capable of resisting.

Findings

- It can be seen that the contractor's and manufacturer's argument has no merit strictly from a "*the pressure caused the roof to fail*" argument. In fact, the internal building pressure is just barely capable of lifting just the self-weight of the EPDM membrane not including any other materials. Wind induced pressures on roofs are far, far greater than those created by the mechanical systems.

Findings

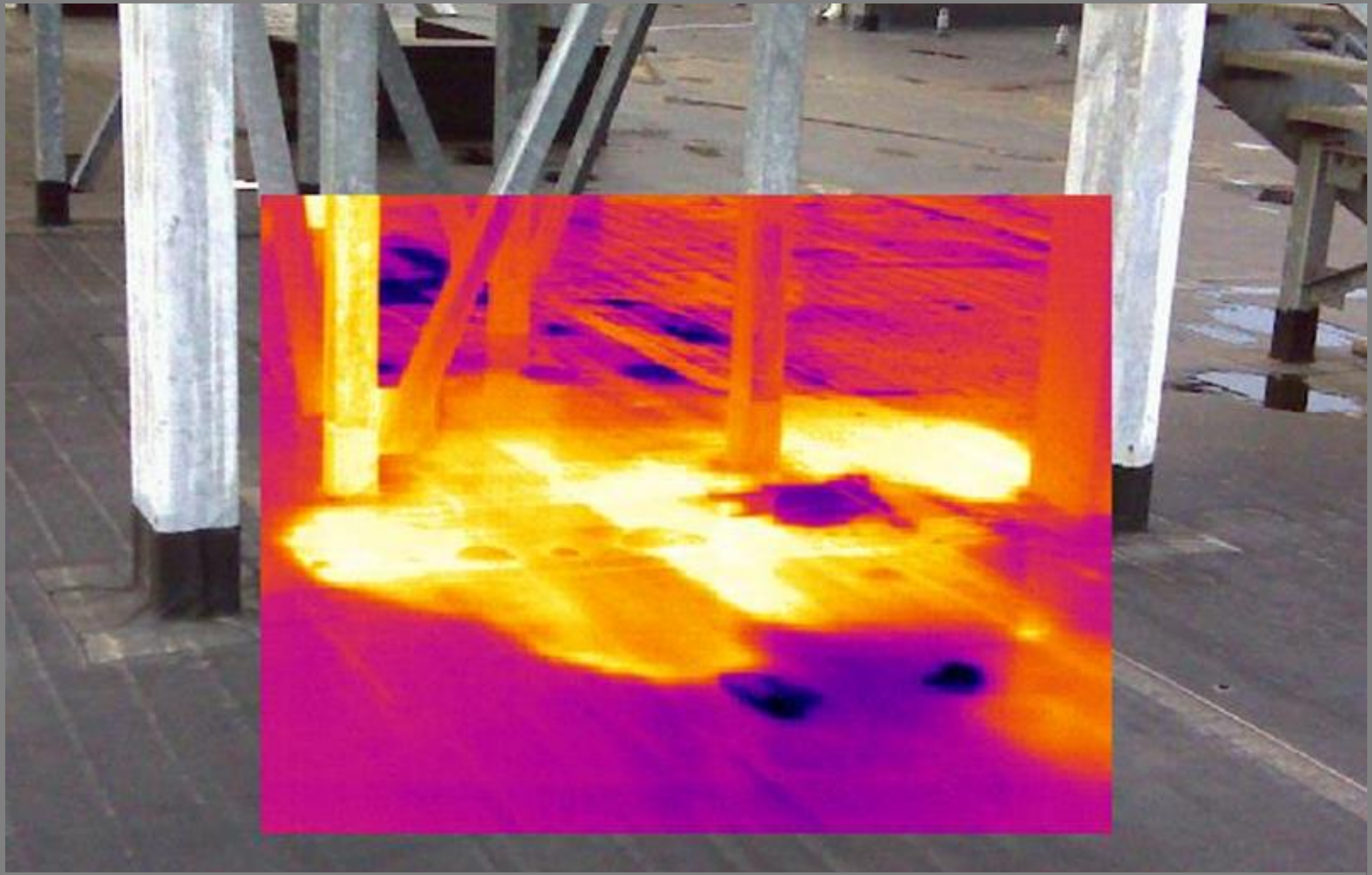
- The investigation continued to search for answers that explained what the observed conditions demonstrated.
  - Following a review of the construction documents and an under-deck inspection it became evident that the designer of record had failed to provide detailing to ensure that there was an adequate air seal between the roof deck and the adjacent pre-cast parapet walls, in fact, there was a large gap at the intersection.

Findings

- The results of the infrared survey, core cuts, and moisture meter readings suggest that portions of the lower layers of insulation were or had been saturated. The absence of significant leaks in the surface of the membrane suggests that water was getting into the system either at leak points (holes) that were noted at the structural steel columns where it was finding its way directly to the concrete deck or by other means.

Findings

- These holes, in combination with the presence of measured internal air leaks around the perimeter of the roof, can also serve as a means of interior air flow directly into the roof system at the perimeter. This condition of uncontrolled air flow via exfiltration through the roof assembly very likely caused condensation during the cold winter months.



Thermal image of saturated roof insulation adjacent to galvanized steel columns where drain holes are allowing water entry into the roof system.

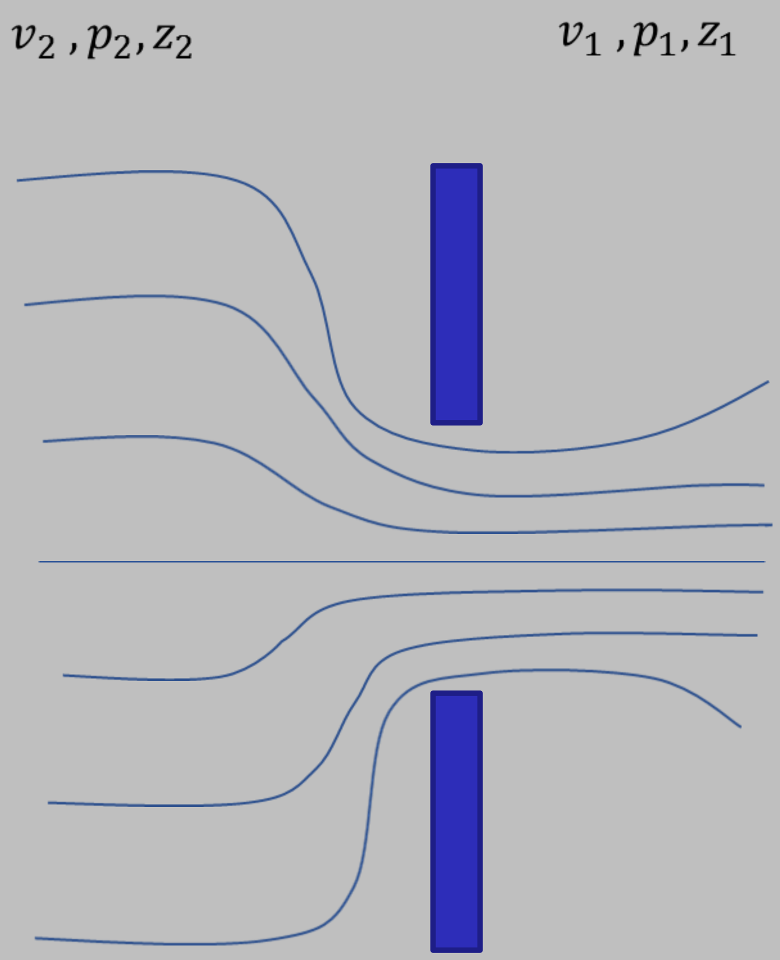
Findings

- If it is assumed a winter interior set point of 68 degrees Fahrenheit and 50 percent relative humidity and taking into account approximately 50 vent holes in the structural steel columns and the measured differential pressure, it can be calculated that approximately 10 gallons of water in vapor form is being transferred through the roof assembly via air flow alone every single day. This is not an insignificant amount for a 22,000 sf roof.

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2$$

$$v_1 - v_2 = \sqrt{2g\left(\frac{p_2 - p_1}{\gamma} + z_2 - z_1\right)}$$

$$v_1 = \sqrt{2g\left(\frac{p_2 - p_1}{\gamma}\right)}$$



$$15\ pascals = 0.00218\ psi = 0.314\ lb/ft^2$$

$$\gamma_{air} = 0.0765\ lb/ft^3$$

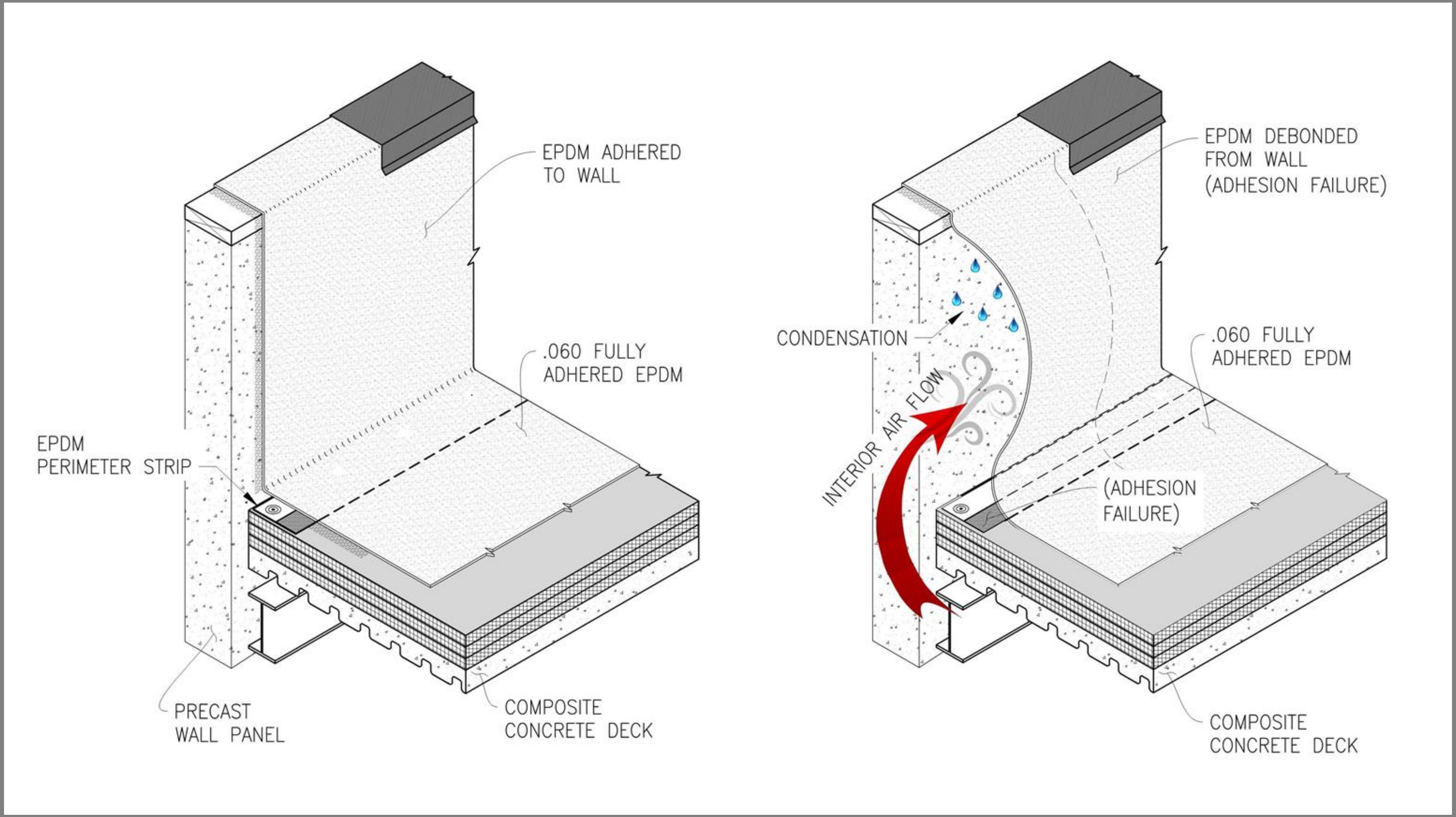
$$v_1 = \sqrt{2(32.2\ ft^3/s)\left(\frac{0.314\ lb/ft^2}{0.0765\ lb/ft^3}\right)} = 16.3\ ft/s$$

$$\frac{0.0075\ lb\ water}{1\ lb\ air}\left(\frac{0.0807\ lb\ air}{1\ ft^3\ air}\right)\left(\frac{1\ gal}{8.34\ lb\ water}\right) = 7.26\ x\ 10^{-5}\ gal/ft^3$$

$$\frac{3.0\ ft^3}{min}\left(\frac{60\ min}{1hr}\right)\left(\frac{24\ hr}{1day}\right)\left(\frac{7.26x10^{-50}\ gal}{ft^3}\right) = 0.314\ gal/day$$

Findings

- It can be assumed that a considerable amount of condensation might occur within the roof assembly during the cold winter months with a certain amount of drying occurring during the warmer seasons or warmer days. This amount of air flow and subsequent water vapor transfer combined with direct water leakage in a few of the steel columns that are exposed to the weather had a significant impact to the poorly installed insulation greatly exacerbating the failure condition that occurred.
-


EPDM ADHERED
TO WALL
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ADHERED EPDM
EPDM
PERIMETER STRIP
PRECAST
WALL PANEL
COMPOSITE
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EPDM DEBONDED
FROM WALL
(ADHESION FAILURE)
CONDENSATION
.060 FULLY
ADHERED EPDM
INTERIOR AIR FLOW
(ADHESION
FAILURE)
COMPOSITE
CONCRETE DECK

Conclusions

- In addition to the obvious workmanship issues.
  - The design allowed for air leaks into the roof assembly
  - The construction of the structural steel members allowed water infiltration to the deck AND air exfiltration to the exterior.
  - The HVAC system is incapable of causing structural failure of the roof system.
  - Air leaks, and by association, water vapor transfer, through a roof assembly will cause condensation issues and water damage.

THANK YOU!

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