



ALLANA BUICK & BERS

Building solutions.
Engineering for life.

Critical Review of the Life Span of TPO and PVC

RCI Hawaii Seminar

January 20-21, 2010

**Karim P. Allana, P.E., RRC, RWC
Allana Buick & Bers, Inc.**

Copyright Materials

This presentation is protected by US and International copyright laws. Reproduction, distribution, display and use of the presentation without written permission of the speaker is prohibited.

Allana Buick & Bers, Inc. 2020



ALLANA BUICK & BERS
Making Buildings Perform Better

Best Practice

Allana Buick & Bers, Inc. (ABBAE) is a Registered Provider with the American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of completion for non-AIA members are available on request.

This program is registered with the AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.



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



Copyright 2020 Allana Buick & Bers, Inc.

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



Presentation Objectives

- ✓ Review the issues that impact the effectiveness and longevity of single ply PVC and TPO roofs
- ✓ Forensic evaluation of some of the oldest PVC (18 years old) and TPO (11 years old) roofs
- ✓ Deepen your understanding of how physical forces (water, sun, rain) affect TPO and PVC
- ✓ Deepen your understanding of how design and use affect the life of TPO and PVC
- ✓ Lay a base of information as to how single ply is manufactured
- ✓ Broaden your technical skills



History of PVC Roofing

- Vinyl gas discovered in the 1800's but with no commercial use
- Vinyl compound discovered in the laboratories of BF Goodrich in the 1920's.
- 1930's – some limited commercial uses for PVC were found.
- Mid 1960's, single ply roof covers are introduced.
- Early 1970's, vinyl roofing membranes are introduced to the roofing industry.
- Mid 1970's, as the oil shortage causes higher asphalt costs, single ply membranes become more cost effective.
- Early 1980's – PVC roofs are widely installed in the US.



PVC Chemistry

- Polyvinyl chloride (PVC) is a vinyl thermoplastic polymer constructed of repeating vinyl groups (ethenyls): through chemical reaction, hydrogen atoms are replaced with a chlorine in the form of chloride.
- Roughly half of the PVC compound is chlorine and half is vinyl and additives.
- Third most commonly used plastic (after polyethylene and polypropylene).
- Naturally stiff and light.
- Among the most widely used plastic in construction applications.



PVC Chemistry (Continued)

- **Some concerned citizens call for the cessation of PVC – production and incineration create dioxin, a toxic chemical.**
- **PVC inherently stiff – “Phthalate” plasticizer additives for softening.**
- **Some Phthalate plasticizers – low molecular weight variety – are water soluble and thus can possibly leach from PVC roofs, and other PVC products, washing into water supplies.**
- **Phthalates have been reported by some, to create health issues.**
- **Other additives: biocides to inhibit mold and algae growth, fire retardants, pigments, and to prevent Chlorine from leaving the molecules (loss of Chlorine leads to oxidation).**



PVC Chemistry (Continued)

- The industry reports replacing early phthalates with high molecular weight varieties that do not leach from roofs, such as changing from “711P” to 911P or DPHP.
- Earlier PVC roofs used compounds containing heavy metals, as fire inhibitors.
- The industry now reports the use of Antimony Trioxide (Sb_2O_3) as a fire inhibitor. Antimony is becoming more rare in the U.S.
- Some conversion to Magnesium Hydroxide as a fire inhibitor in PVC roofs.



ASTM Standard D4434 for PVC

- **Heat age testing: 176 degrees F for 56 days**
- **Physical properties**
 - Minimum thickness (45 mil for Type I and II, 91 mil for Type III)
 - Minimum thickness over scrim (16 mil over scrim for all Types)
- **D4434 also contains these standards**
 - Tensile strength at break
 - Elongation at break
 - Breaking Strength
 - Tear resistance
 - Static and dynamic puncture resistance
 - Weather testing
 - Content of reinforcing fiber



PVC Manufacturers, 2010

In alphabetical order:

- **Canadian General Tower (Mostly Manufactures Private Labels for Others)**
- **Cooley (Mostly Manufactures Private Label for Others)**
- **Duralast**
- **Flex Membrane**
- **Sarnafil**



PVC Raw Materials, 2010

In alphabetical order:

- **BASF (Additives)**
- **Exxon**
- **Formosa**
- **All have plants in the U.S.**



- Nearly all of the world's supply of antimony and antimony trioxide is in China.
- This has caused some instability in supply and pricing over the years.
- Antimony trioxide is possibly carcinogenic to humans.¹

¹ Source: World Health Organization, International Agency for Research on Cancer



TPO Chemistry

- **Thermoplastic Poly Olefin (TPO) is a trade name that refers to polymer blends usually consisting of some fraction of polypropylene, polyethylene, and additives.**
- **Additives: Fire retardants, UV protection agents, anti-oxidants, others.**
- **TPO tends to be stiffer than PVC.**
- **TPO does not contain halogens.**
- **TPO does not contain phthalates.**
- **Many of the very first TPO roofing membranes were black to mimic the look of EPDM.**
- **Soon failures occurred, caused by excessive heat.**



TPO Chemistry (Continued)

- **Early on, poly-brominated additives were added to TPO.**
- **The brominated compounds reacted with the UV stabilizers, decreasing the effectiveness of the stabilizers.**
- **This caused premature failures.**
- **Some manufacturers report having replaced these additives**



TPO Chemistry (Continued)

- Currently, most domestic TPO manufacturers use magnesium hydroxide flame retardant systems, according to the industry.
- Much higher levels of magnesium hydroxide are required compared to antimony systems.
- As a suspension in water, magnesium hydroxide is often called *milk of magnesia* because of its milk-like appearance.
- Magnesium hydroxide is produced domestically and the supply is stable.
- This has been driven, at least partially, by dwindling availability of Antimony.



History of TPO Roofing

- The TPO polymer developed in Italy by Montell (now LyondellBesseff).
- First applications as a waterproofing membrane were for below grade applications (pond liners) in Europe.
- TPO roofing membranes were introduced in the early 1990's in the U.S. with most major installations beginning in the early 1990's
- **Early 1990s:**
 - A couple of products introduced in America
- **2007:**
 - At least 5 major American companies offer TPO
- **Issues have been reported with TPO stiffness and durability**



TPO Standard - ASTM D6878

Heat Aging Testing: 240°F for 28 days

Physical Properties:

- Minimum thickness of 39 mils
- Minimum thickness over the scrim of 12 mils

ASTM D6878 also has these standards:

- Breaking Strength
- Elongation at Break
- Tearing Strength
- Brittleness Point
- Water Absorption
- Durability



Summary of D6878

- **Adopted in 2003**
- **In 2006, weathering requirement was doubled.**
- **2008 – Clarification was made on the Water Absorption test method.**
- **2010 – ASTM committee evaluated increase in Heat Aging requirements, resulting in no change.**



TPO Heat Aging Standard

- **New ASTM heat aging standard was proposed due to perceived problems with degradation caused by heat.**
- **Current Standard: Heat age for 28 days at 240 degrees Fahrenheit**
- **New Standard: Heat age for 56 days at 290 degrees Fahrenheit**
- **Sought to address some of the reported problems with TPO: Heat and reflected light most likely accelerate deterioration.**
- **New standard was voted down, in ASTM Committee.**



TPO Manufacturers, 2010

In alphabetical order:

- Carlisle
- Cooley
- Firestone
- GAF
- Johns Manville (Mostly sells materials made by others)



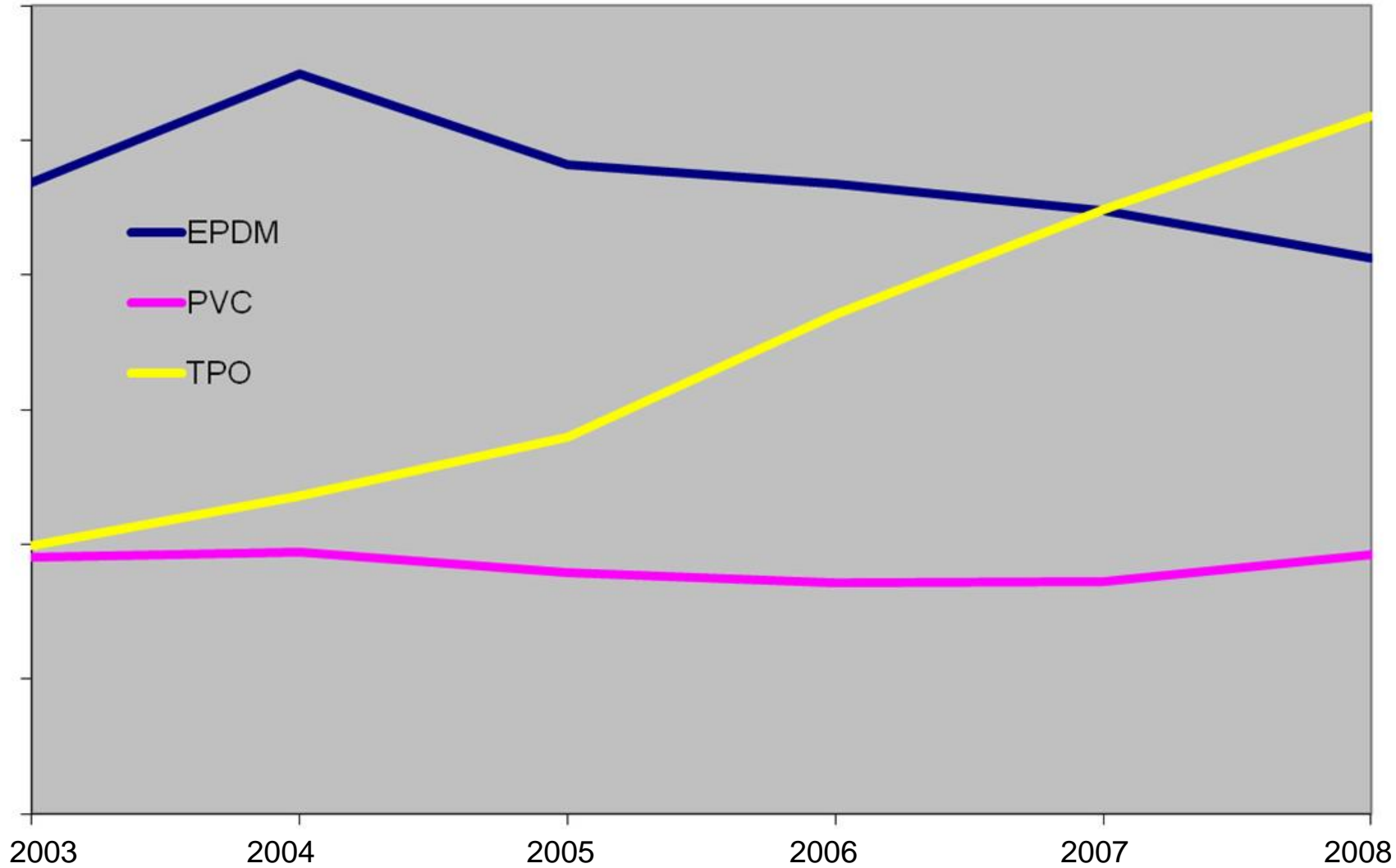
TPO Raw Material Suppliers

In alphabetical order:

- **Chevron Phillips**
- **Chroma Corporation**
- **LyondellBessell**
- **MRC Polymers Inc.**
- **All have plants in the U.S.**



Single Ply Sales Growth 2003 - 2008



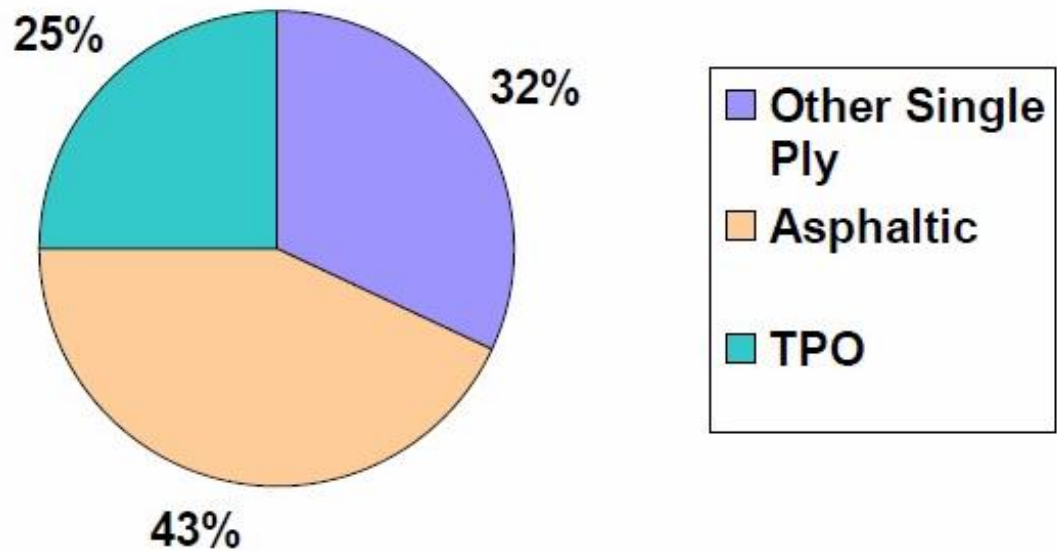
Source: Single Ply Industry

Copyright 2020 Allana Buick & Bers, Inc.



The U.S. Commercial Membrane Roofing Market

2009-2010 Estimate



Source: Consensus of Midwest Roofing Contractors Association Panel, 2010

Roofs Can, and Do, Last 30+ years

Traits of 30+ year roofs:

- **Good UV protection. Gravel surfacing, renewable acrylic coating, etc.**
- **Good Design. Details such as drains, sleepers, base flashings, all designed to last 30+ years, not just the membrane.**
- **Proper slope to drain.**
- **Proper securement of roof and insulation**
- **Stable substrate such as concrete, Lt Wt Insulating Concrete, or insulation over plywood or metal.**
- **Protection from physical damage, excessive traffic, hail, etc.**



Problem Areas to Be Discussed

- **Failings of the membrane above the scrim**
- **The scrim itself**
- **Impact of ponding water**
- **Repair issues**
- **Manufacturing issues**
- **Impact of other roof components**
- **Protection from physical damage, reflected sunlight, excessive traffic, hail, etc.**



WSRCA TPO Issues

- **WSRCA began a test in 2000: TPO Weathering Farm Project, a study of the same four manufacturers' products on four test buildings**
- **Participating companies that provided test membranes were:**
 - Carlisle
 - Firestone
 - Dow (formerly Stevens)
 - GenFlex (withdrew in 2007)
- **Test Roof Locations:**
 - Anchorage, Alaska
 - Seattle, Washington
 - Las Vegas, Nevada
 - San Antonio, Texas
- **Summary of Initial Report in 2007**
 - No significant issues found



■ Summary of WSRCA Findings in the Update:

- Seam integrity after seven years considered “normal”
- “Some tightening of the sheets”
- Some roof pads “have degraded significantly”
- Hard creases created during installation had cracked in the “top coating”
- Chalking test showed “minimal chalking or pickup”
- “Sealant applied at cut edges of some patches and flashings appears to be reaching the end of its useful service life and in a few locations it has separated and failed”
- Difference in color between sheets continues as does dirt accumulation, heavier on some sheets
- “All roofs are presently leak-free and these 60-mil white TPO membranes are so far showing good in-service performance.”





ALLANA BUICK & BERS

Building solutions.
Engineering for life.

Case Study: PVC

Bay Area, California

PVC Case Study: *Department Store*

- **Large department store in Northern California.**
- **Eighteen year old roof.**
- **No repairs, no leaks, no problem?**
- **Purpose of the investigation: Determine longevity of single ply after a long period of use.**
- **We were with a team of other skeptical consultants.**



Forensic Methodology

- **Visual inspection to observe performance of system for sustainability.**
- **Limited destructive testing.**
- **Laboratory testing of samples to compare between original membrane and aged membrane.**



Sustainability Checklist

- **Roof system's ability to handle foot traffic and impact damage.**
- **Membrane's ability to handle ponding water and condensate.**
- **Membrane's ability to be patched and repaired.**
- **Membrane's physical properties, tensile strength, thickness, bend test, etc.**



Sustainability Checklist (continued)

- **Was roof system sustainable for type of use (retail store)?**
- **Was original design of the roof system adequate for its intended use?**
- **Was original application (construction) installed per manufacturer's requirements?**
- **Could repairs be made to an 18 year old PVC membrane?**



*18 year old single ply roof on a
department store in Northern
California.*

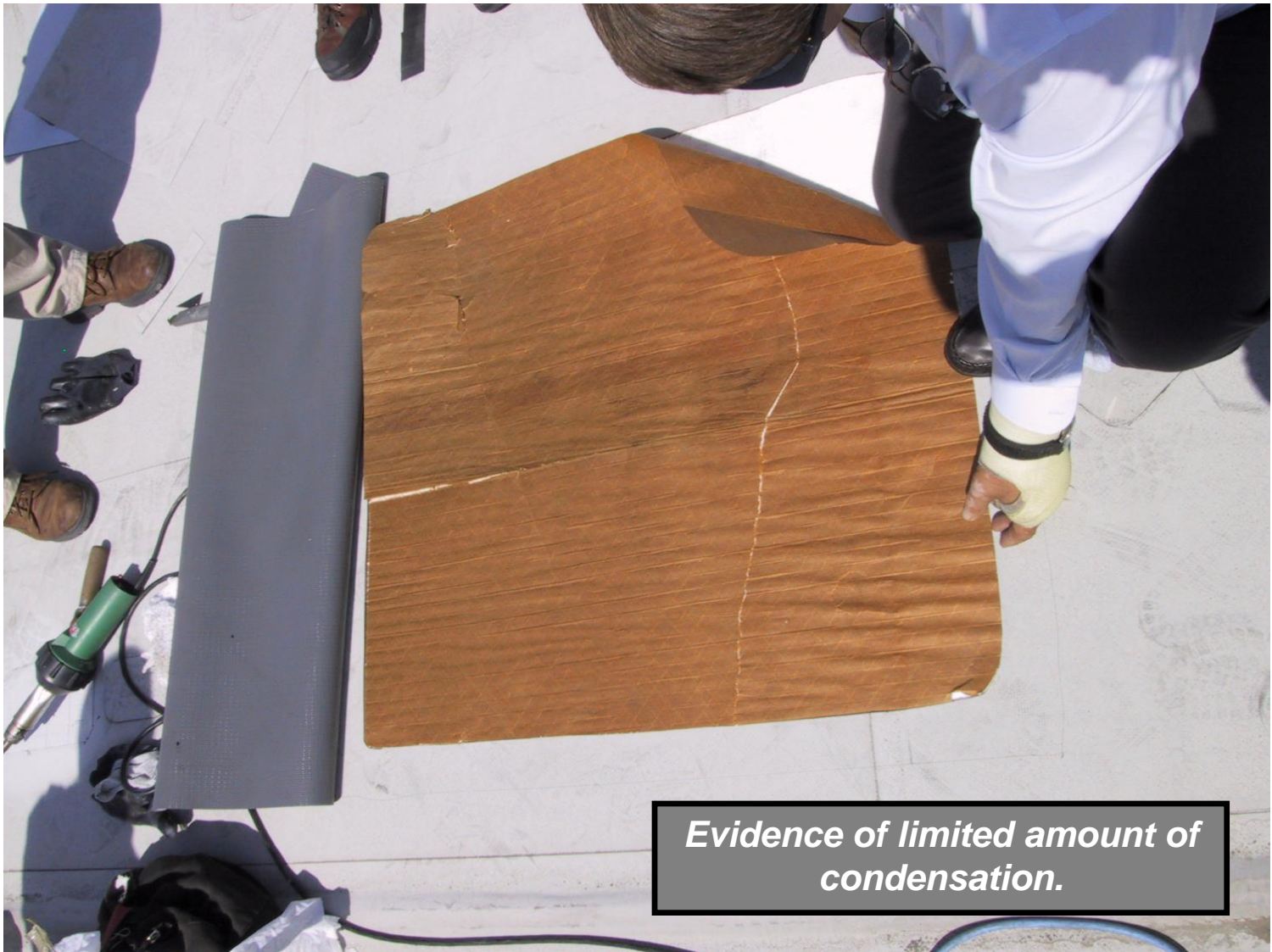


Test Cut Analysis



*Test cut exposing rosin paper
and insulation.*

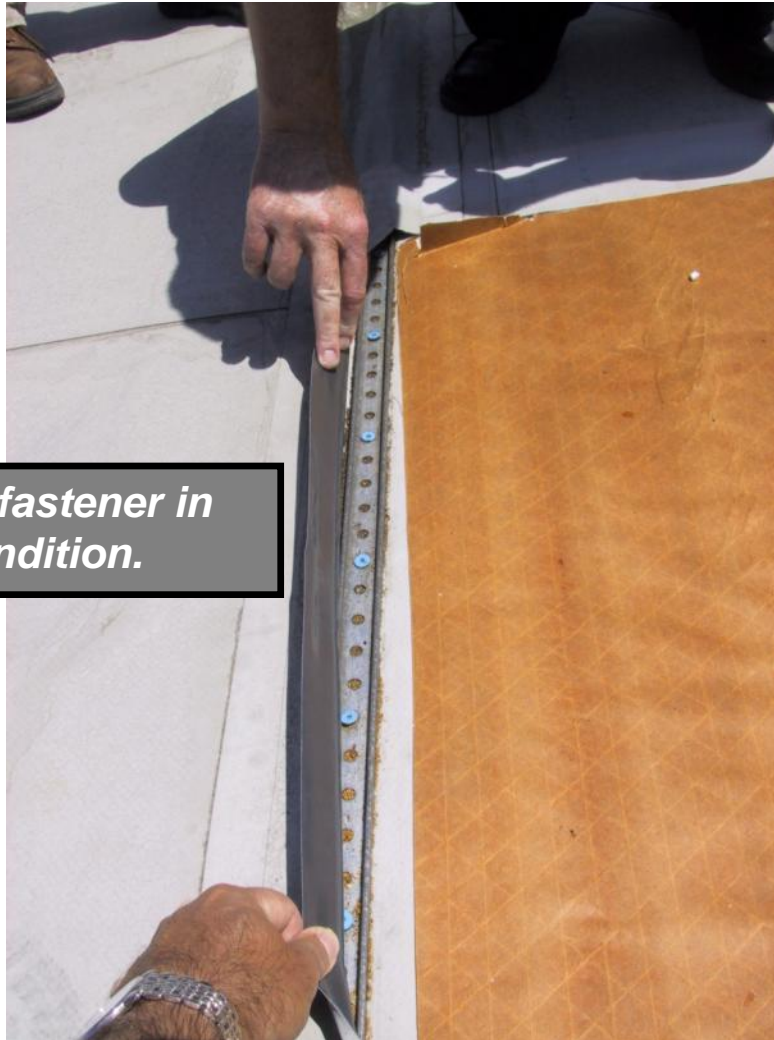




Evidence of limited amount of condensation.



*Mechanical bar fastener in
excellent condition.*





Membrane patching (Back of sheet) was no problem.



Visual Analysis



Construction debris was observed on roof.

Design Issue



Equipment supports not integrated and secured into roof. Design of pipe supports not sustainable.

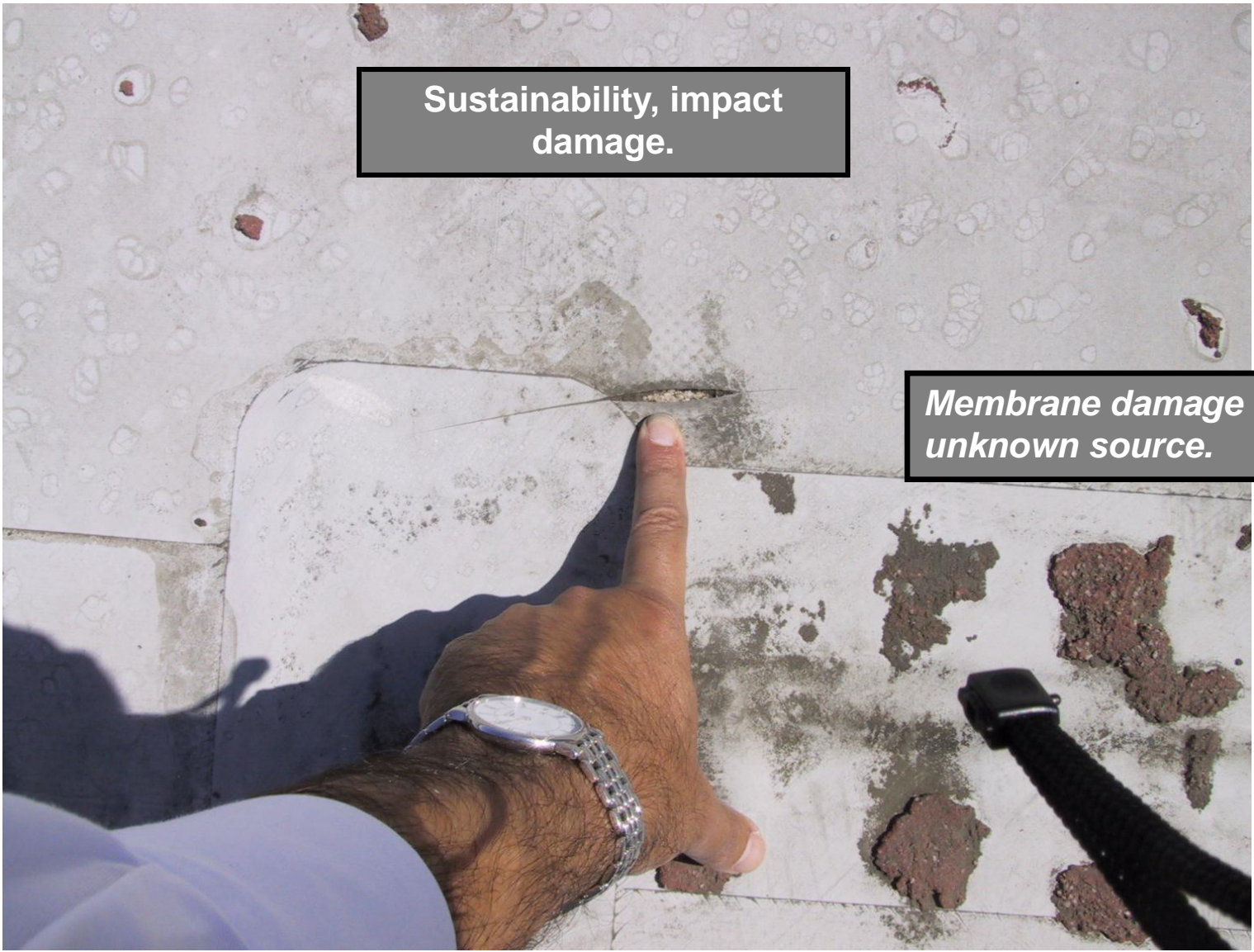




*Impact damage from
unknown source.*

Evidence of nail from
construction debris.





Sustainability, impact
damage.

*Membrane damage from
unknown source.*



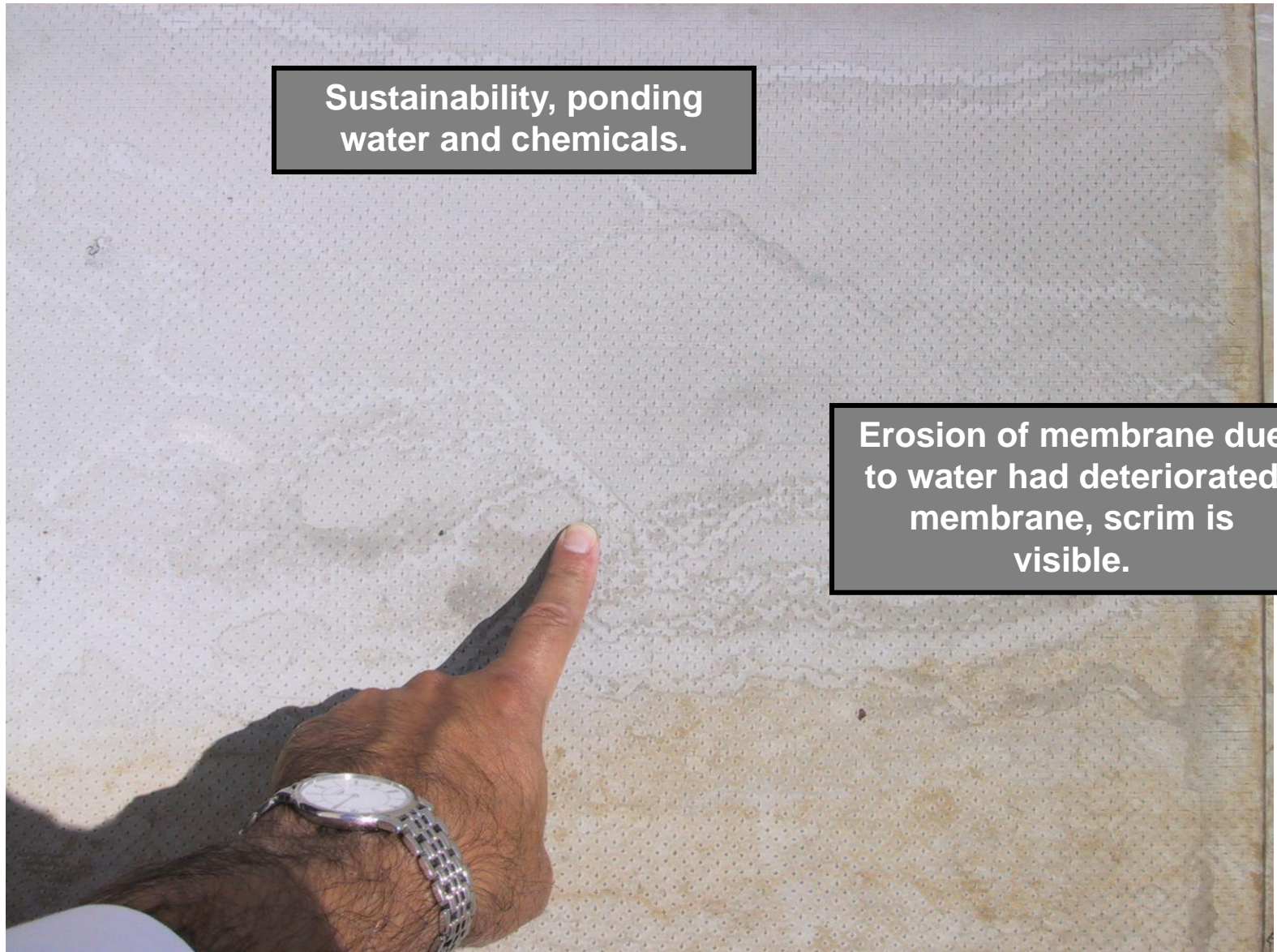
Visual signs of chalking and age were observed in areas of ponding water.

Cooling tower and
condensate water leaking
over roof.



**Sustainability, ponding
water and chemicals.**

**Erosion of membrane due
to water had deteriorated
membrane, scrim is
visible.**



PVC Sustainability Score

MEMBRANE MATERIAL

- Field areas of membrane performance good 20+ years for 40 mil membrane
- Easy to patch on back of sheet. Did not attempt to patch on front of sheet

TRAFFIC AND IMPACT DAMAGE

- Susceptible from impact damage
- Damage easy to identify and repair



Sustainability Score

DESIGN

- Original poor design of pipe supports caused damage
- Poor design of roof drainage caused ponding water and damage. Membrane susceptible to ponding water
- Poor design of condensation control mechanism caused damage





ALLANA BUICK & BERS

Building solutions.
Engineering for life.

Case Study: TPO

Las Vegas, Nevada

Reviewed Over 20 TPO Roofs in Vegas

- Reviewed several manufacturers in study:
 - Carlisle
 - GAF
 - Firestone
 - Johns Manville
 - JP Stevens (Dow)



7 Year Old TPO: *Large Warehouse*

- **Large beer distribution warehouse in Las Vegas.**
- **Carlisle/Stevens (Ask Bradley)**
- **Seven year old roof.**
- **Color difference in adjacent sheets**
- **Heat/UV damage adjacent to wall/base flashing areas**



Large Warehouse in Las Vegas, Nevada



Color Difference in Sheets



7 Years Old, Large Warehouse in Las Vegas

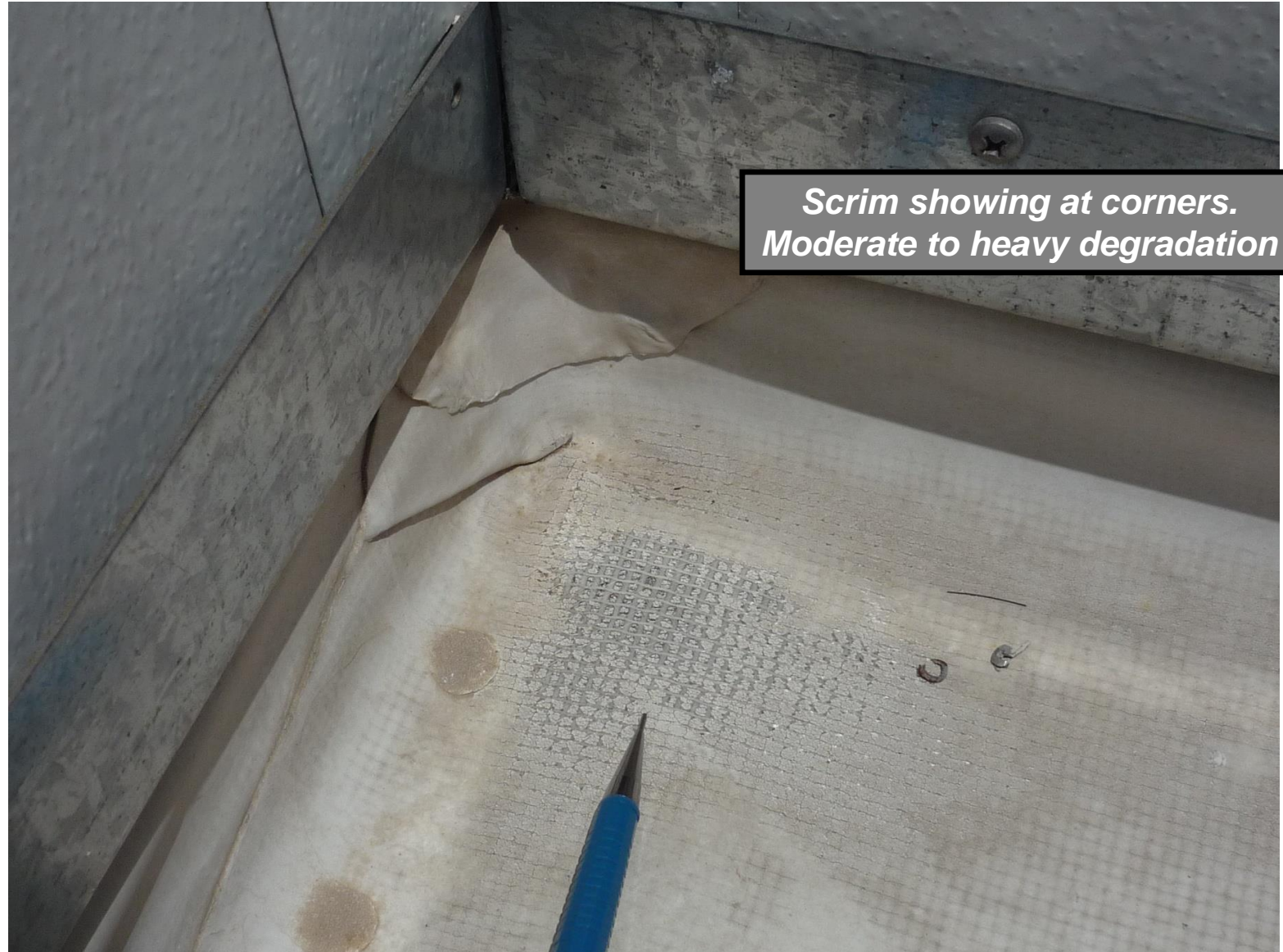


Typ. Equipment Well Area

7 Years Old, Large Warehouse in Las Vegas



Large Warehouse in Las Vegas, Nevada



Large Warehouse in Las Vegas, Nevada



The impact of ponding water.



Large Warehouse in Las Vegas, Nevada



5 Years Old Carlisle, Hospital Building, Vegas



5 Years Old Carlisle, Hospital Building, Vegas



5 Years Old Carlisle, Hospital Building, Vegas

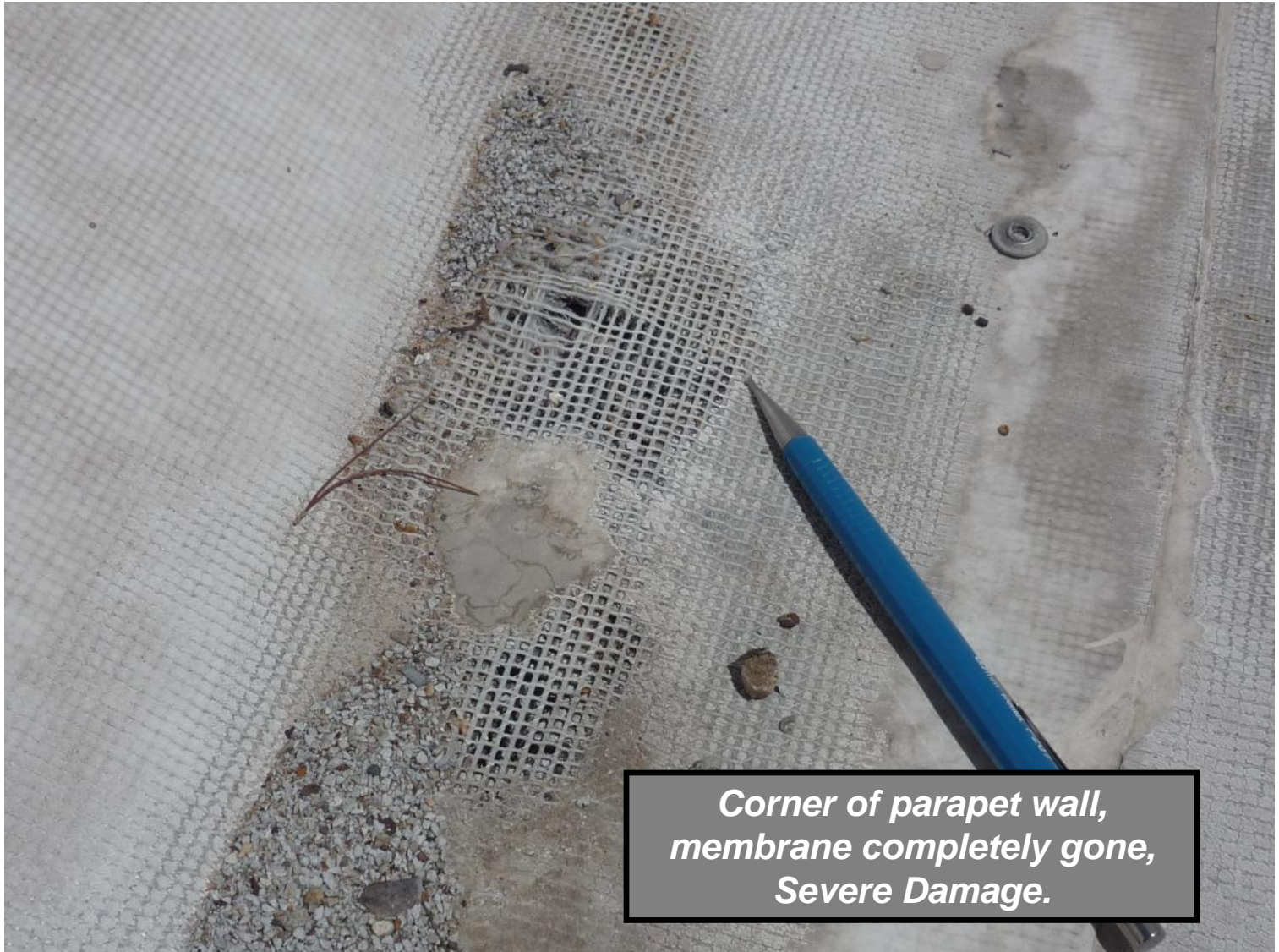


*Corner of parapet wall,
membrane completely gone,
Severe Damage.*

5 Years Old Carlisle, Hospital Building, Vegas



5 Years Old Carlisle, Hospital Building, Vegas



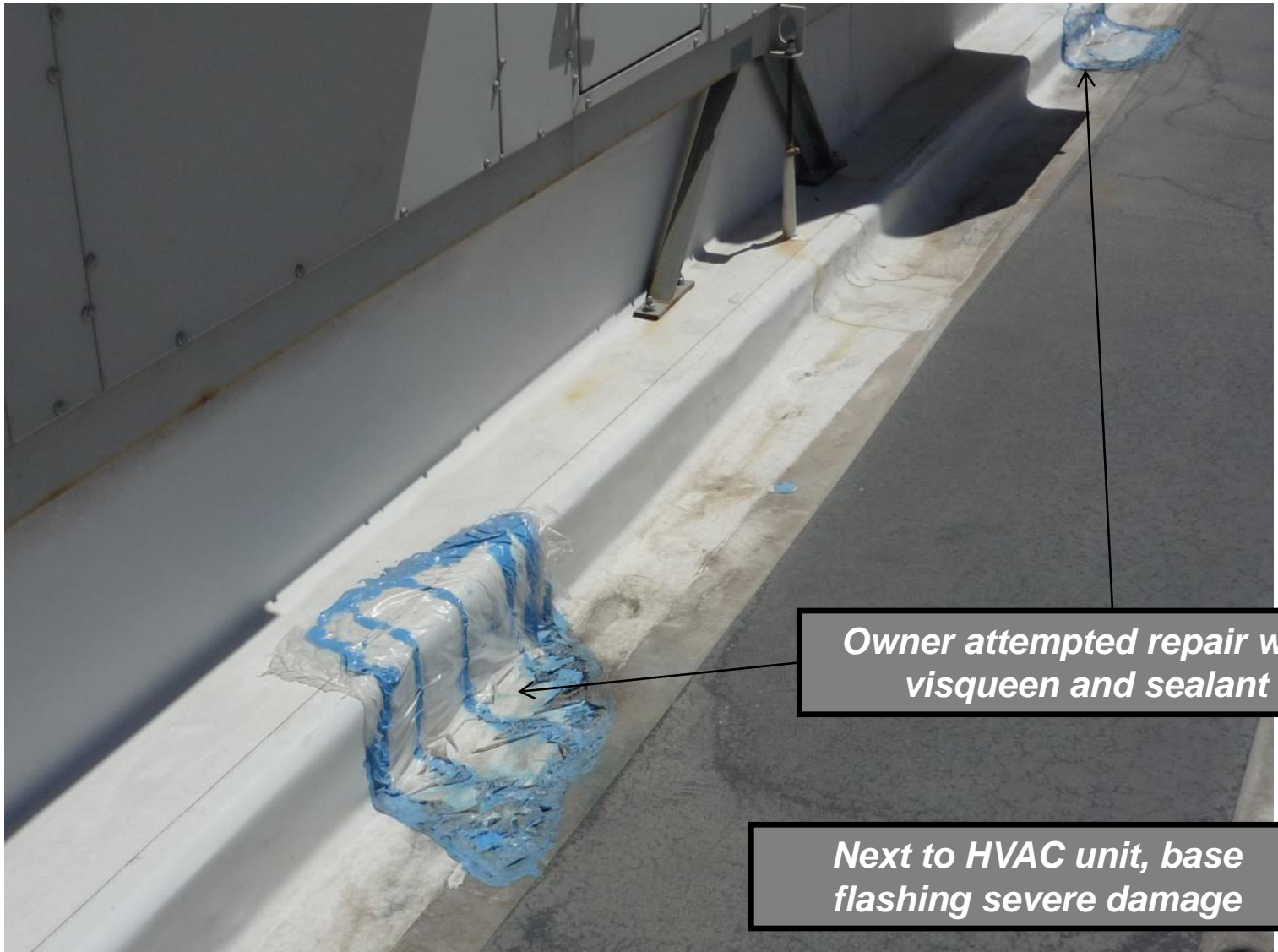
*Corner of parapet wall,
membrane completely gone,
Severe Damage.*



5 Years Old Carlisle, Hospital Building, Vegas



5 Years Old Carlisle, Hospital Building, Vegas

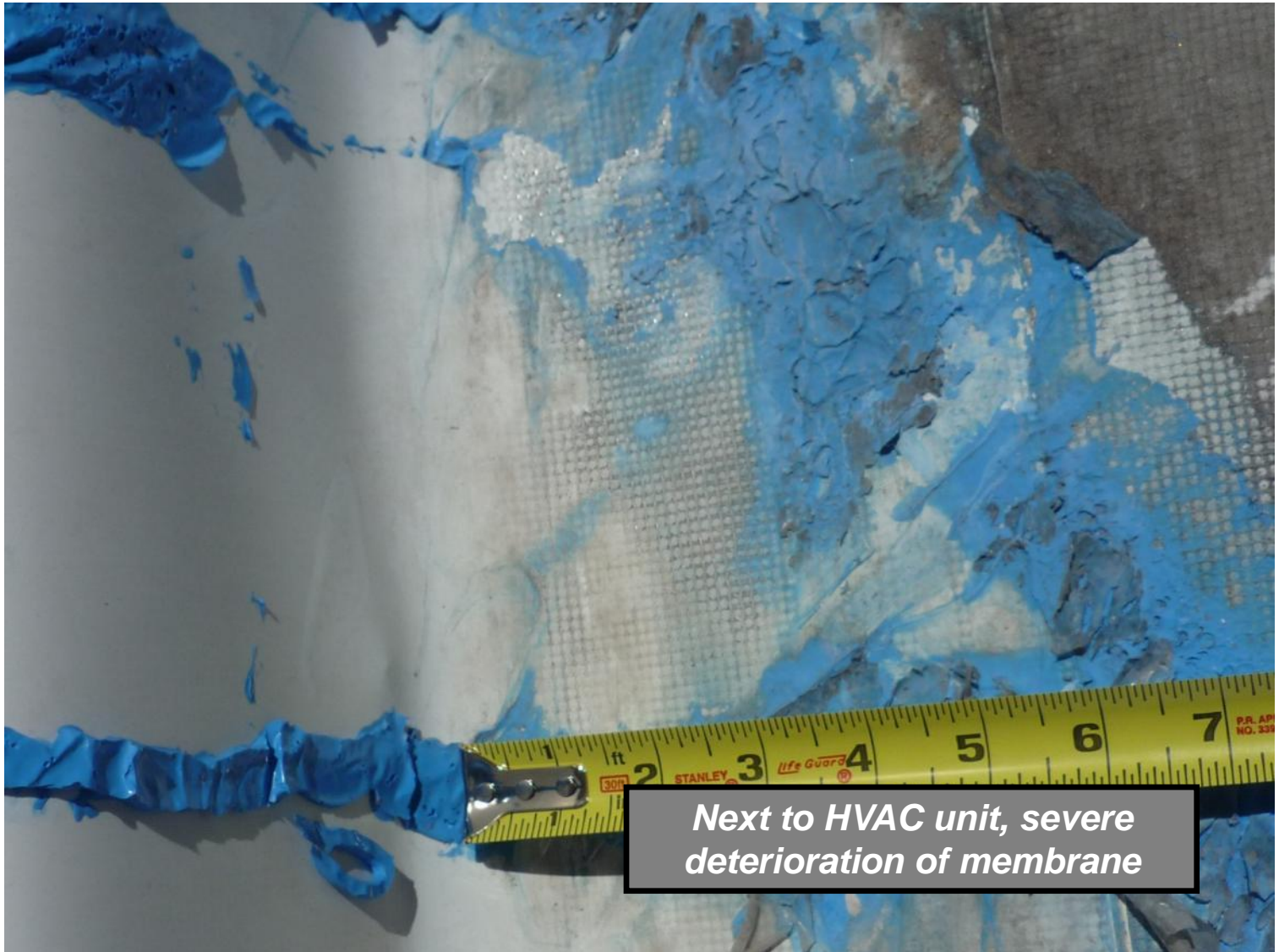


Owner attempted repair with visqueen and sealant

Next to HVAC unit, base flashing severe damage



5 Years Old Carlisle, Hospital Building, Vegas



Next to HVAC unit, severe deterioration of membrane



5 Years Old Carlisle, Hospital Building, Vegas

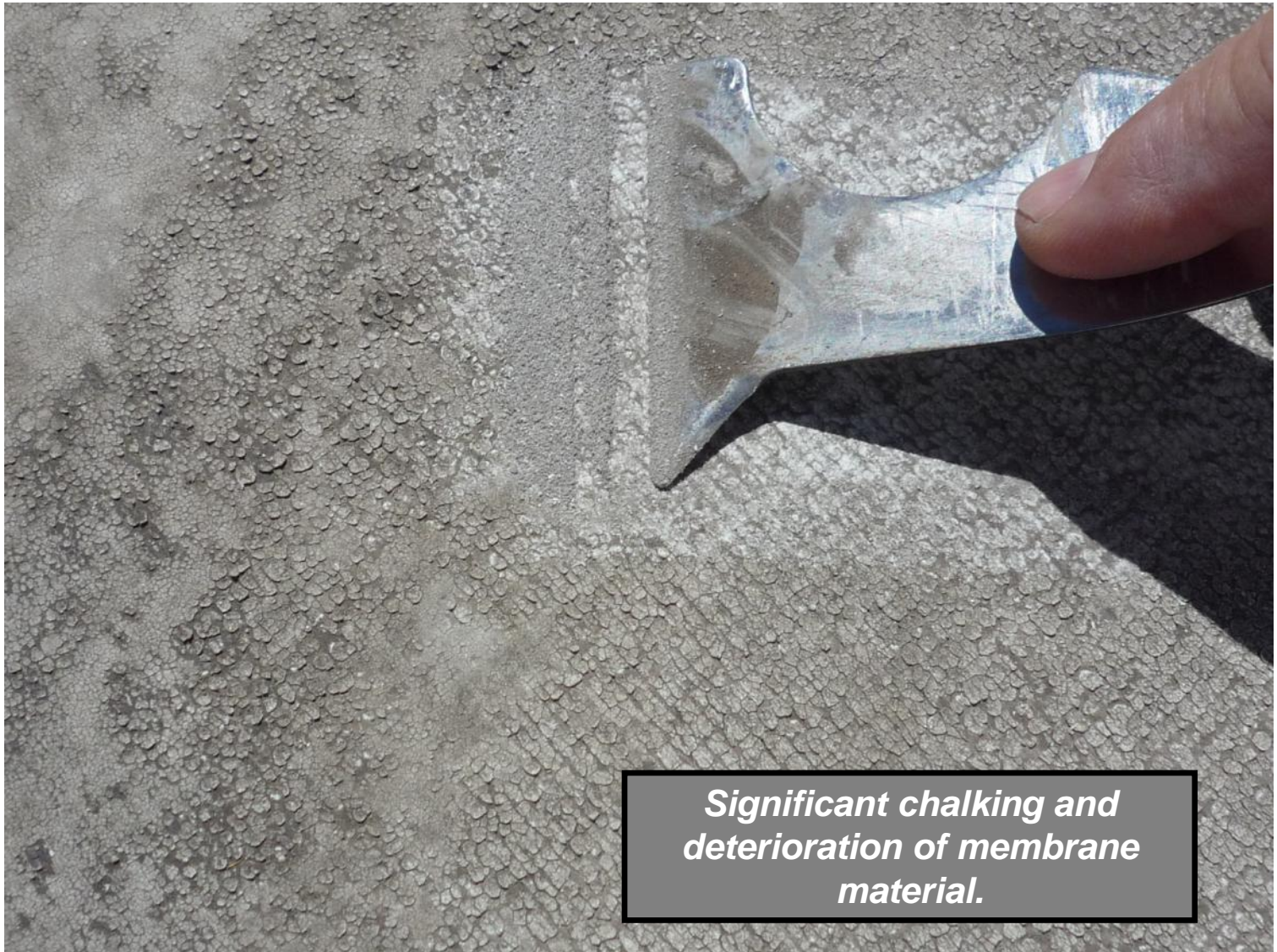


Copyright 2020 Allana Buick & Bers, Inc.

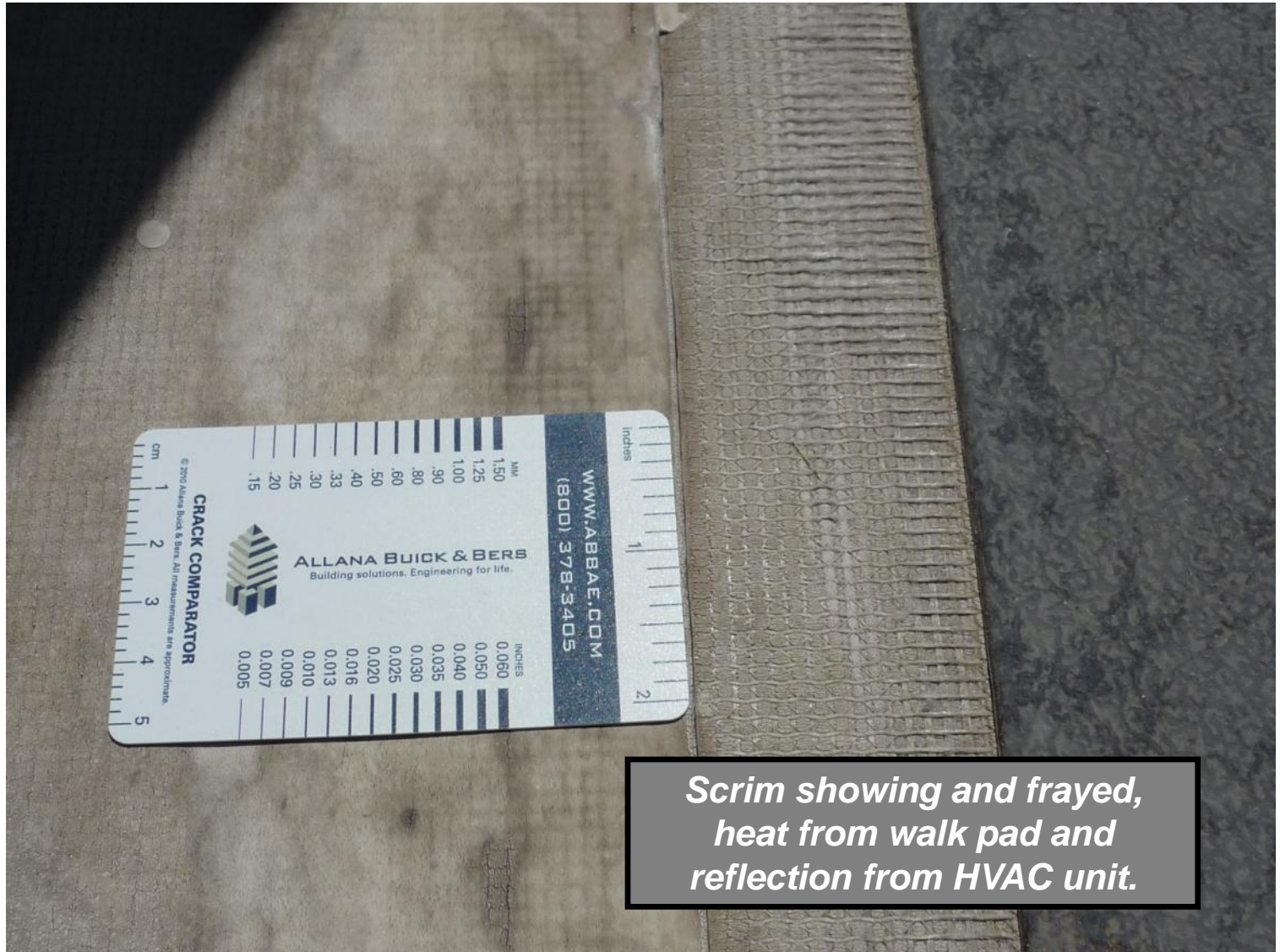
5 Years Old Carlisle, Hospital Building, Vegas



5 Years Old Carlisle, Hospital Building, Vegas



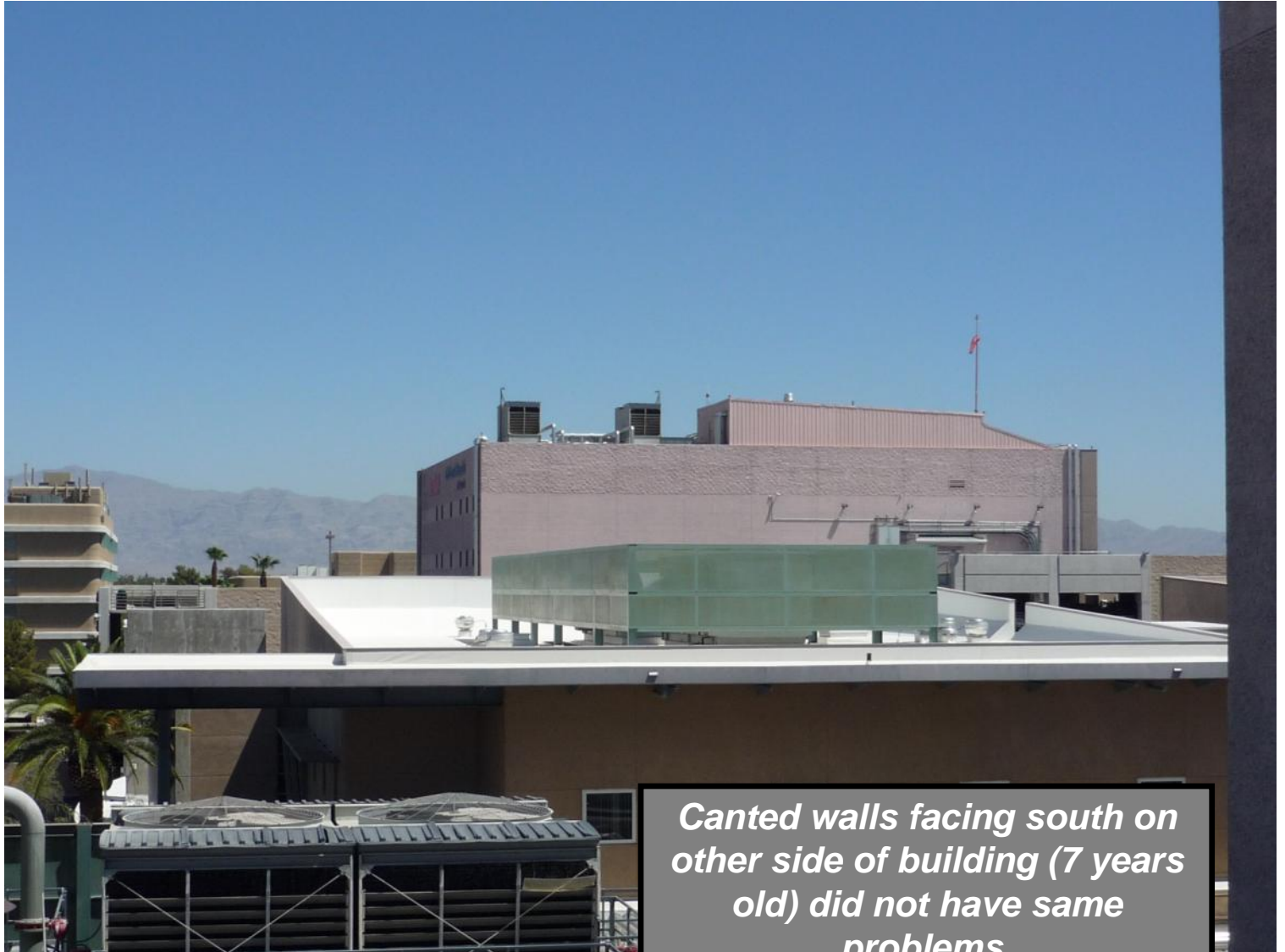
5 Years Old Carlisle, Hospital Building, Vegas



Copyright 2020 Allana Buick & Bers, Inc.



Less damage on 7 Years Old Carlisle

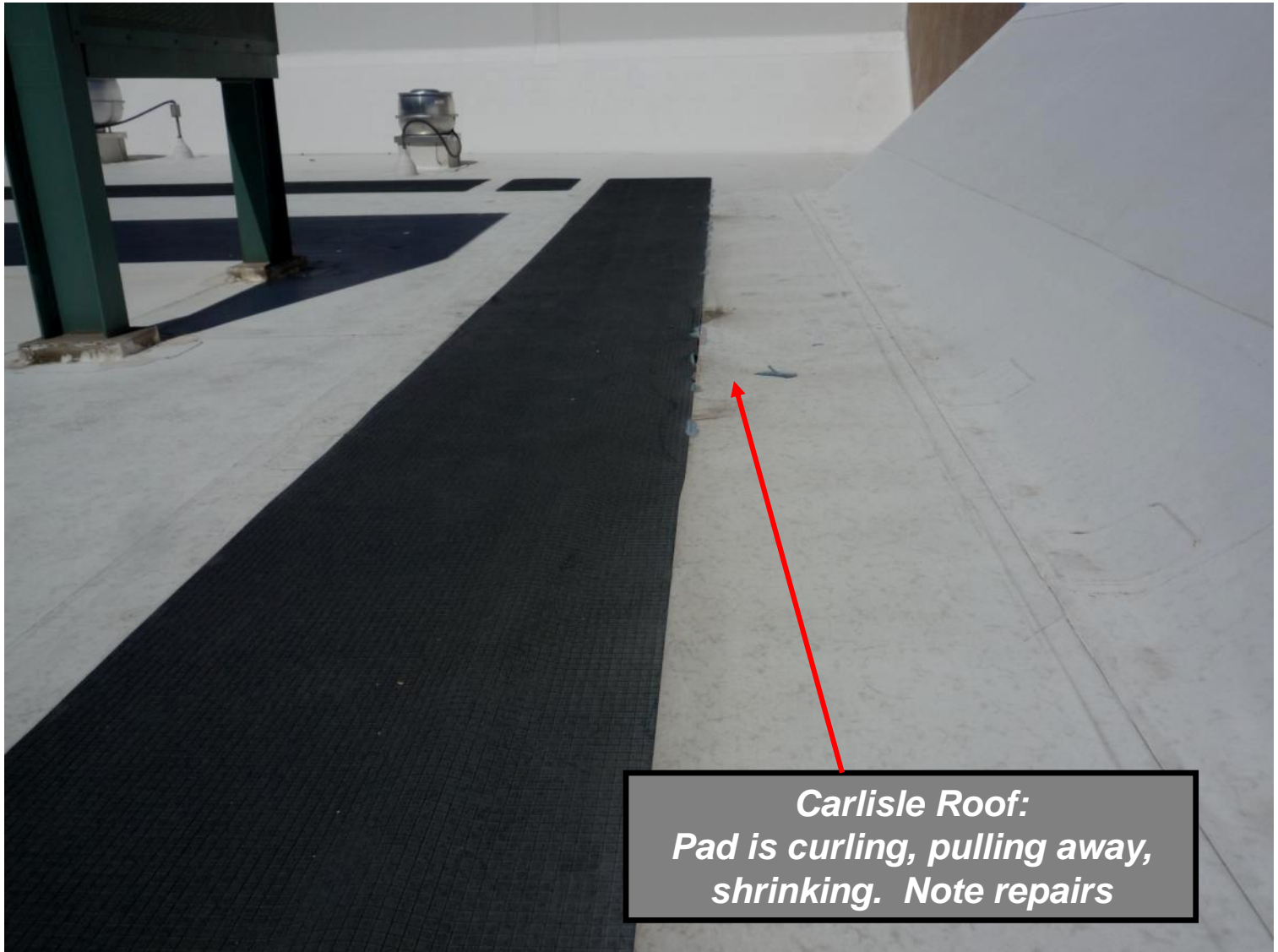


Canted walls facing south on other side of building (7 years old) did not have same problems.

Copyright 2020 Allana Buick & Bers, Inc.



7 Years Old Carlisle, Hospital Building, Vegas



*Carlisle Roof:
Pad is curling, pulling away,
shrinking. Note repairs*

7 Years Old Carlisle, Hospital Building, Vegas

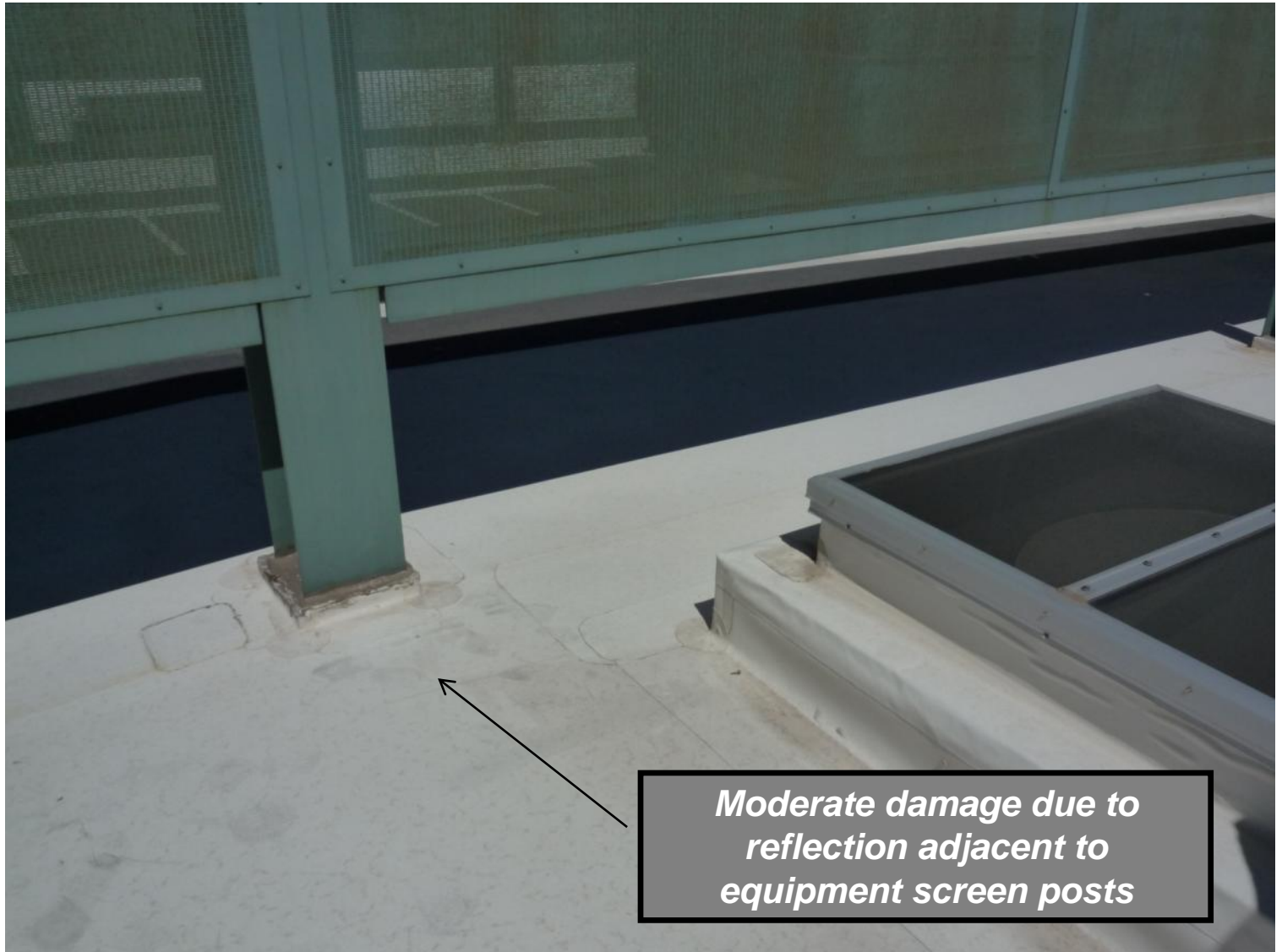


Severe delaminating under walk pad and upper membrane layer.

7 Years Old Carlisle, Hospital Building, Vegas



7 Years Old Carlisle, Hospital Building, Vegas



*Moderate damage due to
reflection adjacent to
equipment screen posts*

7 Years Old Carlisle, Hospital Building, Vegas



*Moderate damage due to
reflection adjacent to
equipment screen posts*



7 Years Old Carlisle, Hospital Building, Vegas



5 Years Old, Firestone 40 Mil, Molasky Bldg.



5 Years Old, Firestone 40 Mil, Molasky Bldg.



Copyright 2020 Allana Buick & Bers, Inc.



7 Years Old Firestone, Agasi College, Vegas



7 Years Old Firestone, Agasi College, Vegas

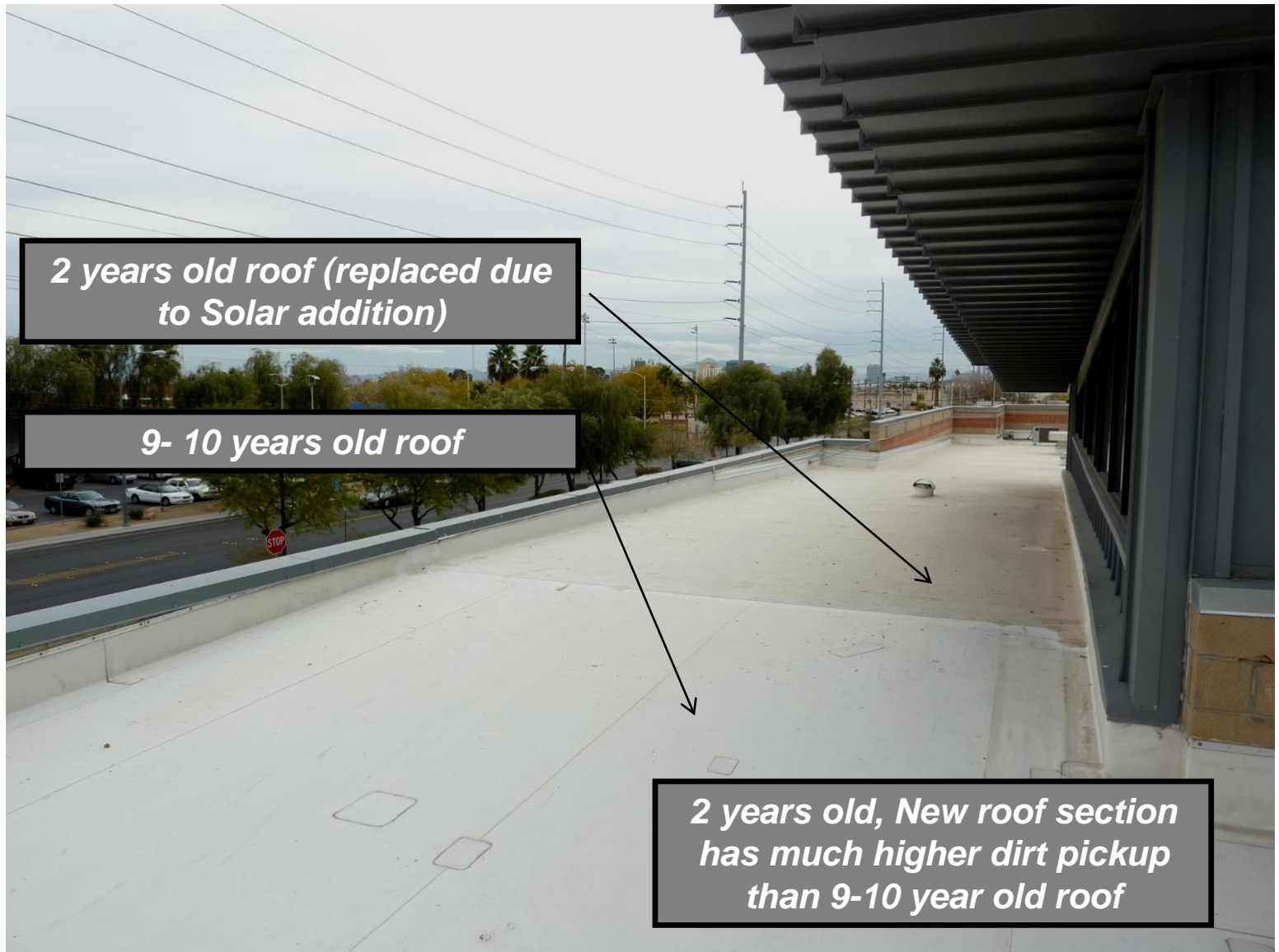


*Southern Exposure however,
no reflecting wall surfaces.
Observed no accelerated
deterioration.*

Copyright 2020 Allana Buick & Bers, Inc.



7 Years Old Firestone, Agasi College, Vegas



5 Years Old Firestone, Bass Sporting Goods



5 Years Old Firestone, Bass Sporting Goods



Copyright 2020 Allana Buick & Bers, Inc.



5 Years Old Firestone, Bass Sporting Goods



Corner exposure, no visible damage to membrane.



5 Years Old Firestone, Bass Sporting Goods



*Seam/edge sealant cracking
however, no visible damage to
membrane.*



UNLV TPO Failures

- **UNLV owns or manages over 120 buildings in Las Vegas**
- **UNLV replaced 11 TPO roofs over the past 3 years due to premature failure**
- **Premature failures included various TPO manufacturers and involved various modes of failures. Manufacturers included:**
 - JP Stevens (Dow) – Cracks at seams
 - Johns Manville – Cracks at seams
 - JP Stevens (Possibly made by Manville) – Cracks at seams
 - Carlisle – UV – Heat failure
 - GAF – UV – Heat failure
- **Only Firestone (10 year old) roof had no failures. All other TPO roofs at UNLV have been replaced.**



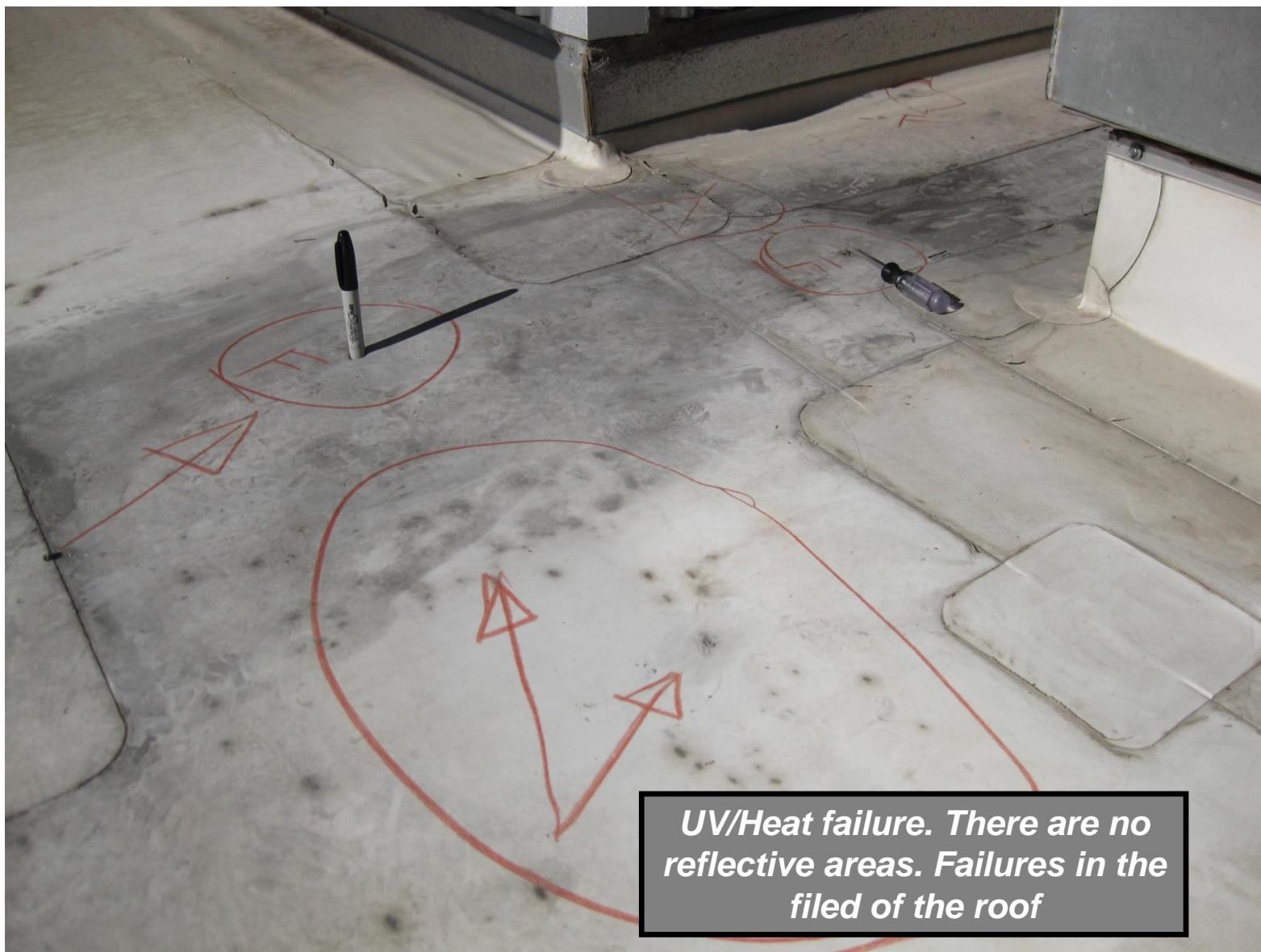
UNLV, LBC Building, GAF 7 years old



*Both seam and UV/Heat failure.
(Seam failure repairs)*



UNLV, LBC Building, GAF 7 years old



Copyright 2020 Allana Buick & Bers, Inc.

UNLV LLB Building, Dow/Stevens

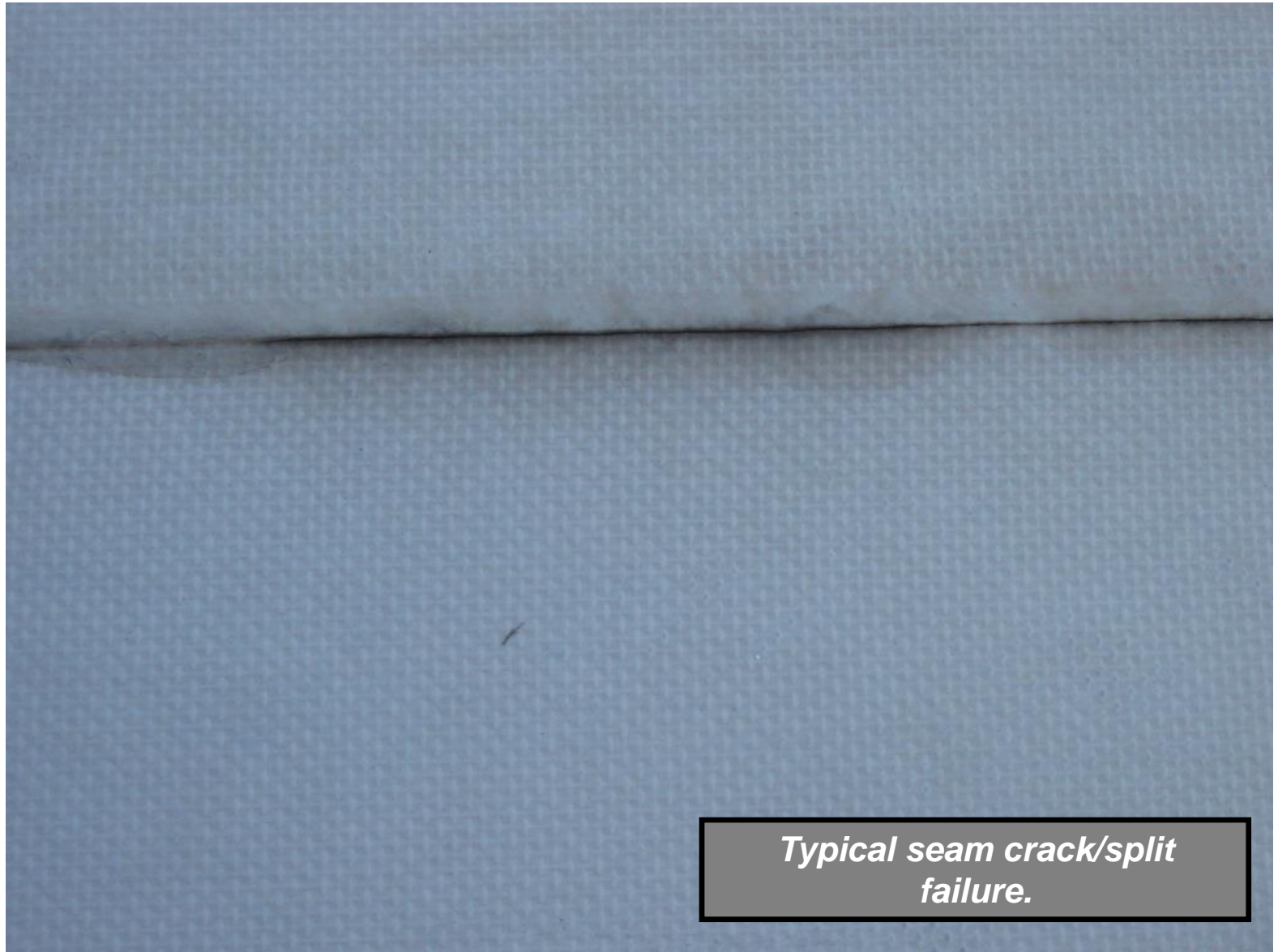


Seam Failure

Copyright 2020 Allana Buick & Bers, Inc.



UNLV LLB Building, Dow/Stevens



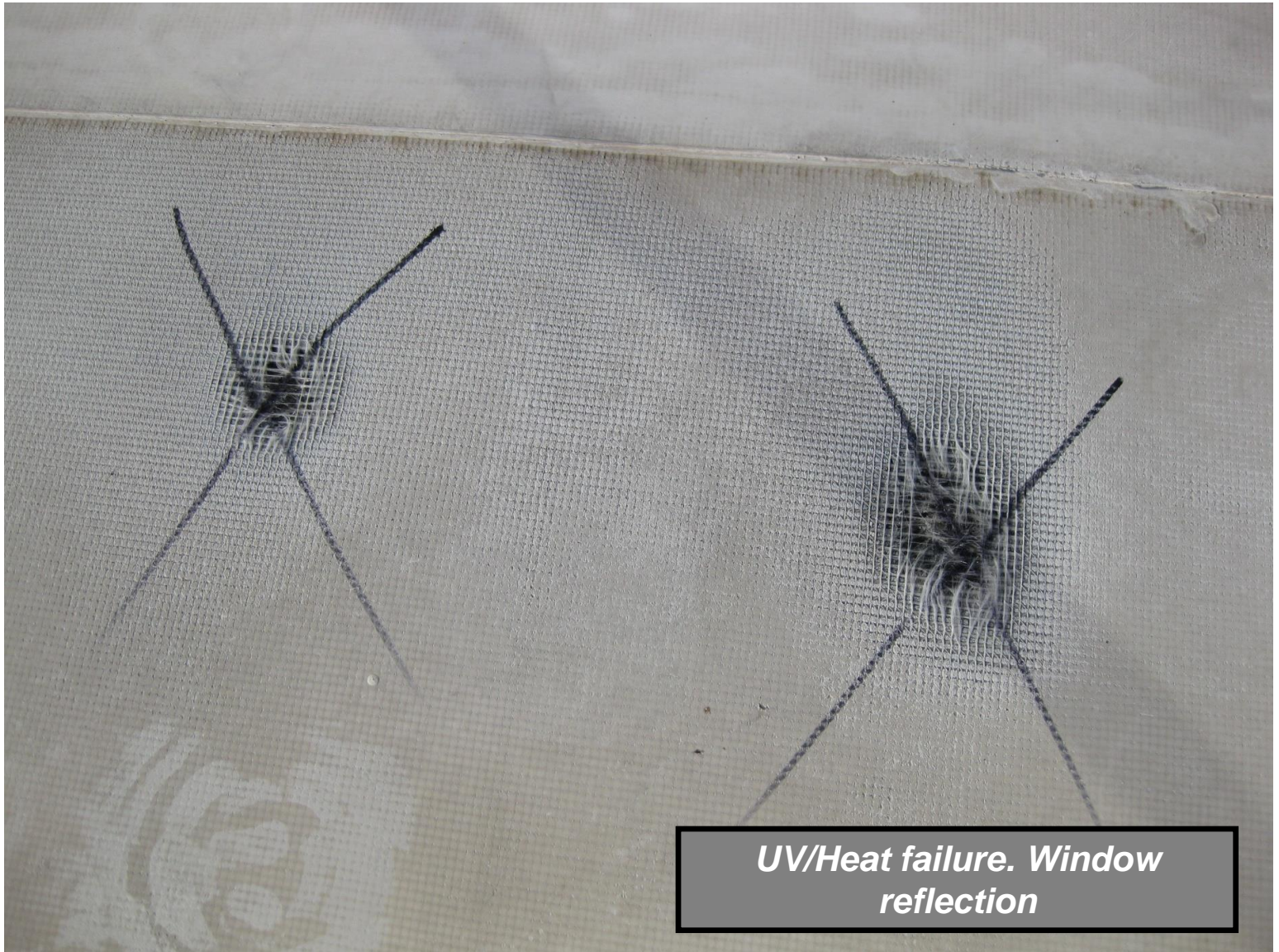
Typical seam crack/split failure.



UNLV, BSL Bridge Way, Carlisle, 10 years old



UNLV, BSL Bridge Way, Carlisle, 10 years old



UNLV, ARC Building, GAF TPO 2.5 years old



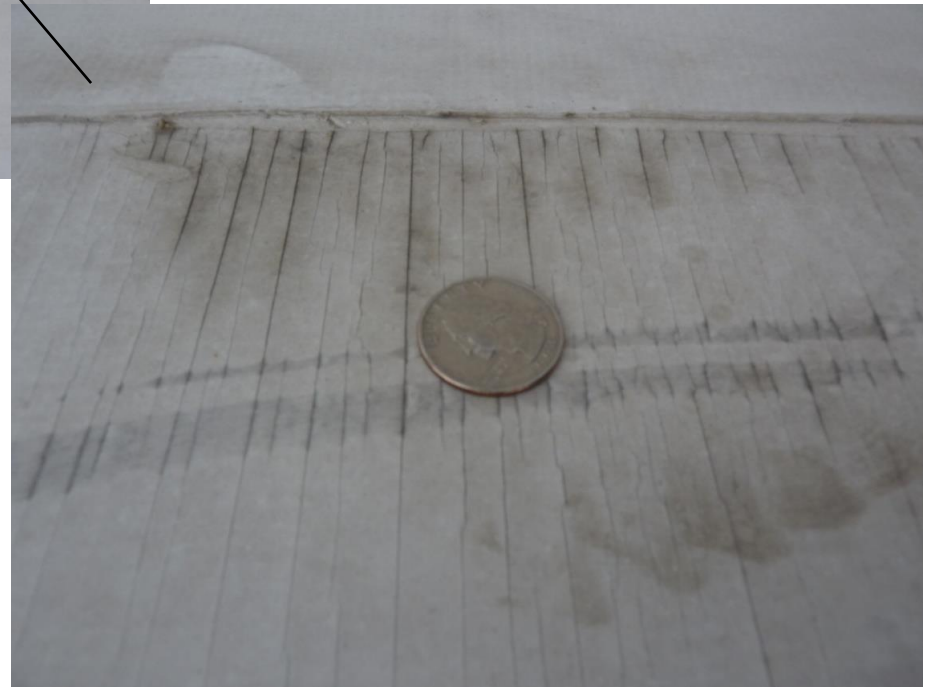
Copyright 2020 Allana Buick & Bers, Inc.



UNLV, ARC Building, GAF TPO 2.5 years old



This replacement GAF roof is less than 3 years old!



UNLV Bookstore, Firestone 11 Years Old

Roof has south facing stucco parapet. No heat related failures were observed



UNLV Bookstore, Firestone 11 Years Old

Roof has south facing stucco parapet. No heat related failures were observed



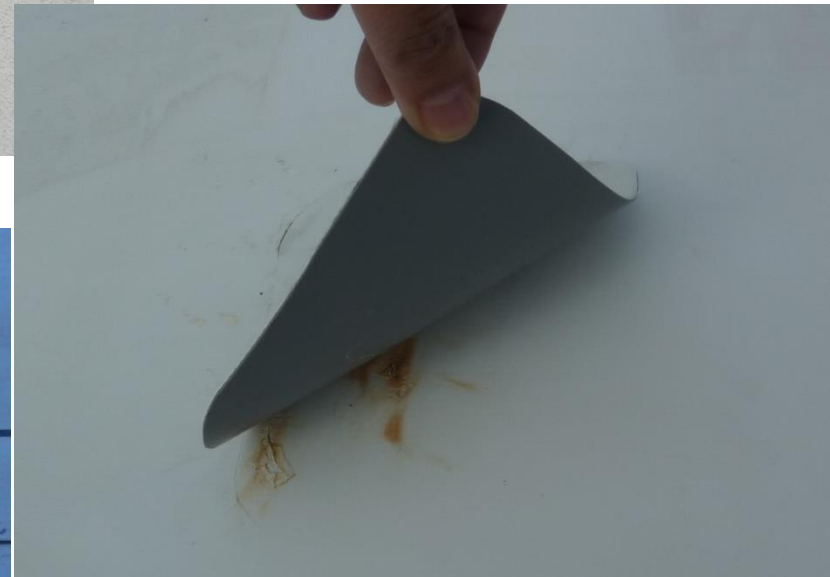
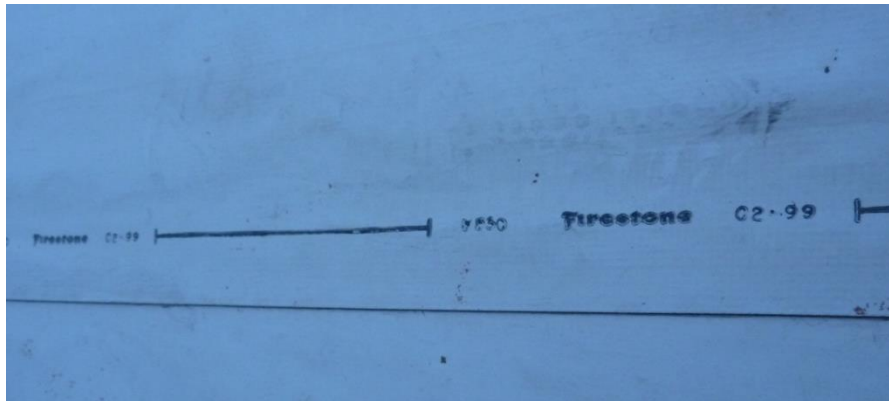
Copyright 2020 Allana Buick & Bers, Inc.



UNLV Bookstore, Firestone 11 Years Old



While there were no heat related failures, all attempts to heat weld/patch the roof were unsuccessful.



TPO Sample Thickness Test

UNLV Bookstore-Seam Sample (Exposed)

Sample #1
Sample #2
Sample #3
Average

Overall Thickness (m-in)

40.30
41.40
40.06
40.59

Thickness Over Scrim (m-in)

19.17
19.91
20.04
19.71

UNLV Bookstore-Seam Sample (Unexposed)

Sample #1
Sample #2
Sample #3
Average

42.98
42.63
43.73
43.11

23.07
22.11
23.46
22.88

UNLV Bookstore-Near South Facing Wall

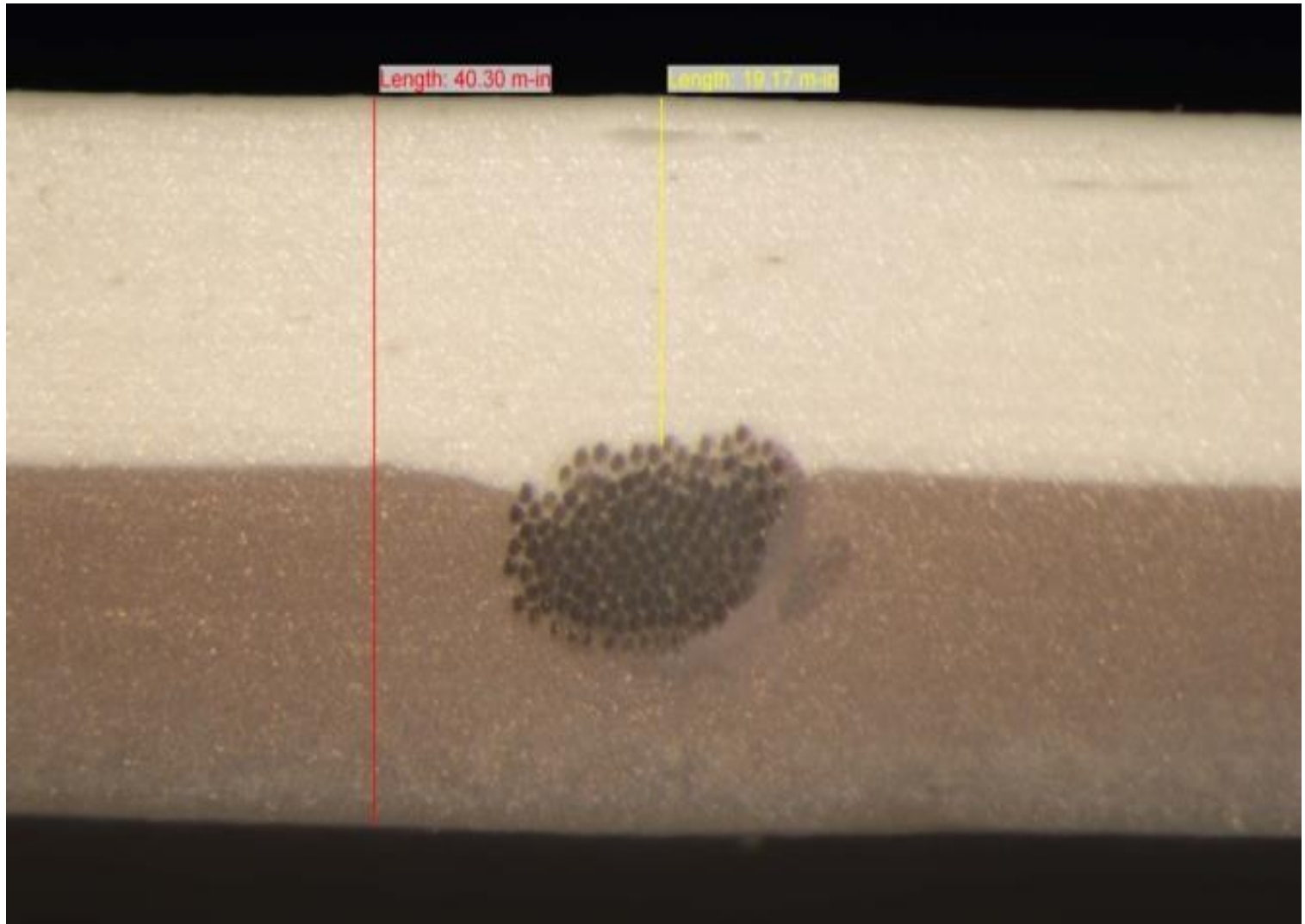
Sample #1
Sample #2
Sample #3
Average

41.07
40.80
42.73
41.53

19.95
20.54
20.89
20.46



TPO Material Thickness



Sysco, Las Vegas, Firestone 8 Years Old



Copyright 2020 Allana Buick & Bers, Inc.



Sysco, Las Vegas, Firestone 8 Years Old



*South side, next to HVAC and
black walk pads, no heat
related failures observed*



Sysco, Las Vegas, Firestone 8 Years Old



*Fully adhered section failed in
adhesion. Roof was
mechanically fastened and
seam tape repaired*



Sysco, Las Vegas, Firestone 8 Years Old



*White metal paneled clearstory
had some UV/heat damage*



Sysco, Las Vegas, Firestone 8 Years Old



*White metal paneled clearstory
had some UV/heat damage*



TPO Sustainability Score

UV – Heat Damage

- All membrane manufacturers suffered some level of damage
- GAF fared the worst. Firestone fared the best
- Failures appear to be mostly adjacent to parapet walls, reflection from clear story windows and metal panels
- More failures in hot climate zones like Las Vegas
- GAF failure was documented throughout the roof in UNLV case; started adjacent to clear story window but spread throughout the roof

Seam Crack/Split Issue

- Appears to be limited to some manufacturers
- Failures were observed in JP Stevens and Johns Manville



Cause of Failure?

- **Most TPO membranes are made from same or similar base polymers, Basell**
- **Formulations vary due to different additives (or packages) which are 2% to 3% of material volume but very costly.**
- **Packages include:**
 - UV Stabilizers and absorbers
 - Light stabilizers
 - Antioxidants
 - Fire retardants
- **Different manufactures use different chemistry and ratio for additives**
- **UV stabilizers and Antioxidants may need to be improved?**



Lessons Learned

- Sustainability depends on many factors, some of which could have been due to the manufacturing process.
- Membrane's ability to handle normal exposure to sun, especially reflected light, could be an issue
- Repairs may be necessary immediately
- Weldability of older TPO continues to be an issue
- Owners will need frequent inspections, timely repairs, and use of proper patching techniques.
- PVC appears to be performing better although Author did not conduct study of TPO performance in high heat/reflected areas in Las Vegas type climate. More study is needed to compare.
- Both PVC and TPO don't lose appreciable membrane thickness

