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Critical Review of the Life Span of TPO and PVC

RCI Hawaii Seminar

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EDUCATION: **B.S., Civil Engineering, Santa Clara University**

REGISTRATION: **P.E., Civil Engineering, Hawaii, California, and Nevada**

CERTIFICATION: **Registered Roof Consultant (RRC), Roof Consultants Institute (RCI); Registered Waterproofing Consultant (RWC), Roof Consultants Institute (RCI)**

OVERVIEW:

- Former Turner Construction Employee (Project Engineering and Superintendent).
- Over 20 years experience providing superior technical standards in all aspects of building technology.
- 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, and complex building envelope and mechanical assemblies**.**

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.**

Antimony Trioxide as a Fire Retardant – PVC and TPO

- **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 LyondellBesell).**
- **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:

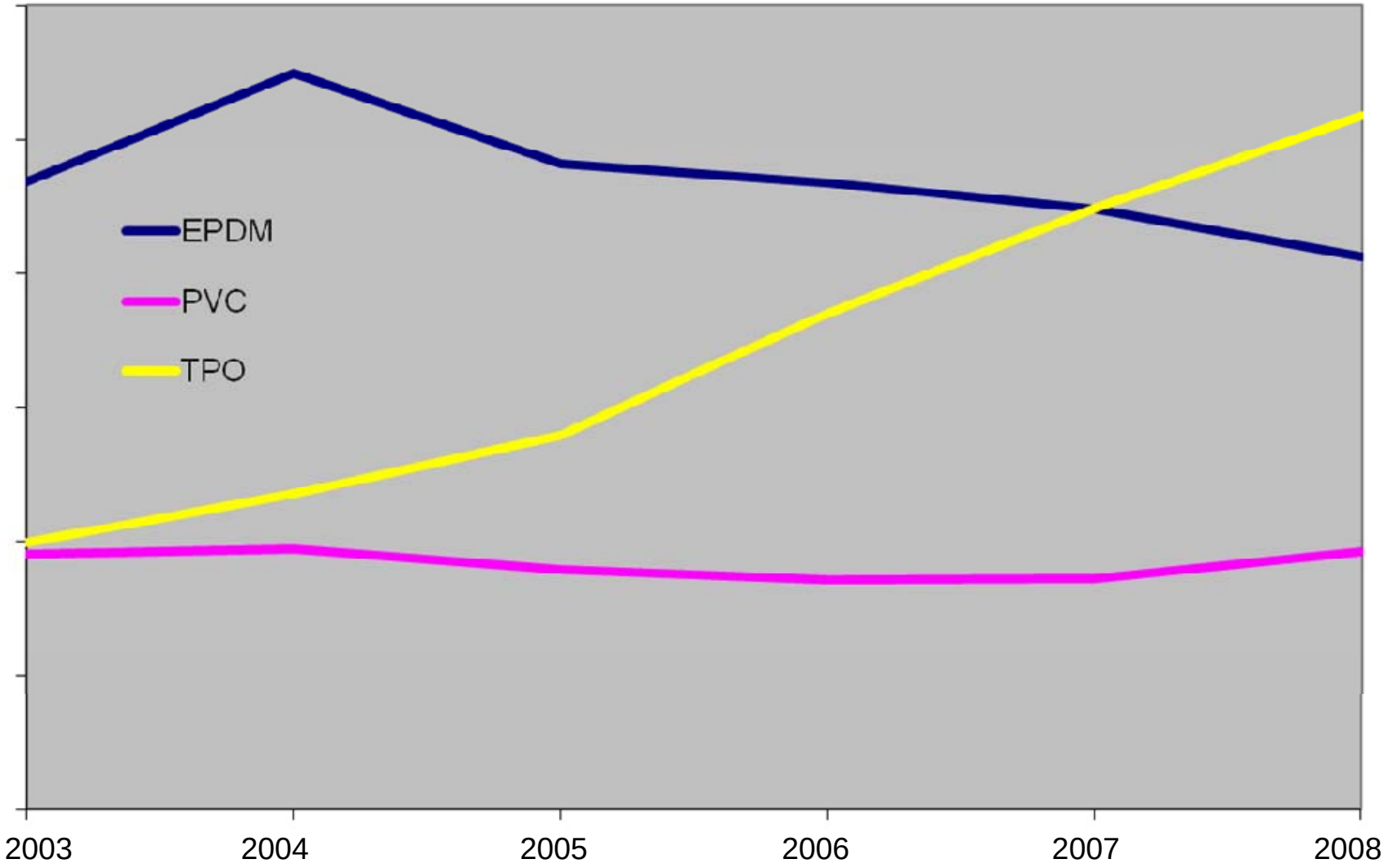
- **Carlisle**
- **Cooley**
- **Firestone**
- **GAF**
- **Johns Manville (Mostly sells materials made by others)**

TPO Raw Material Suppliers

In alphabetical order:

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

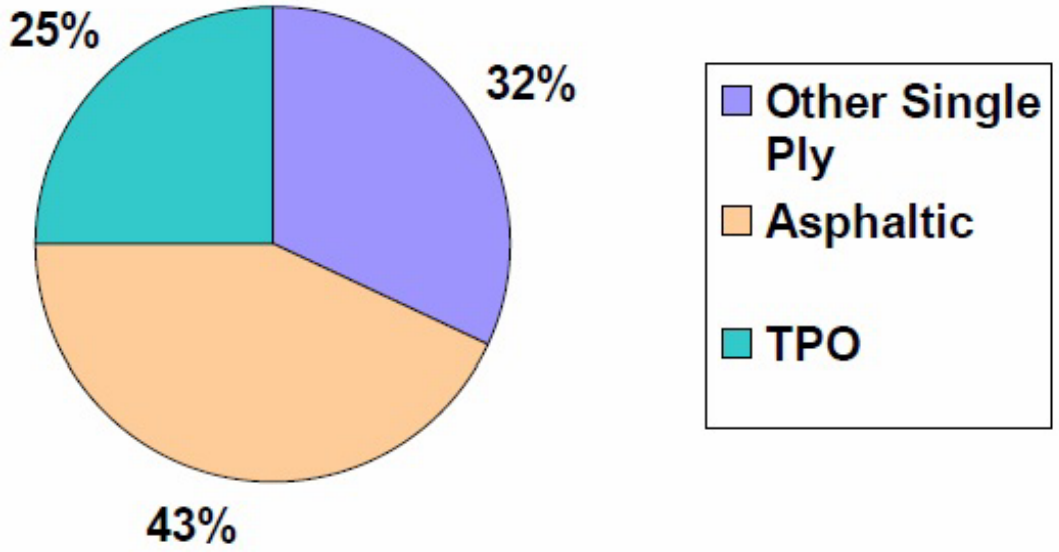
Single Ply Sales Growth 2003 - 2008



Source: Single Ply Industry

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

Updated Findings in May/June 2010

- **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.”

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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.

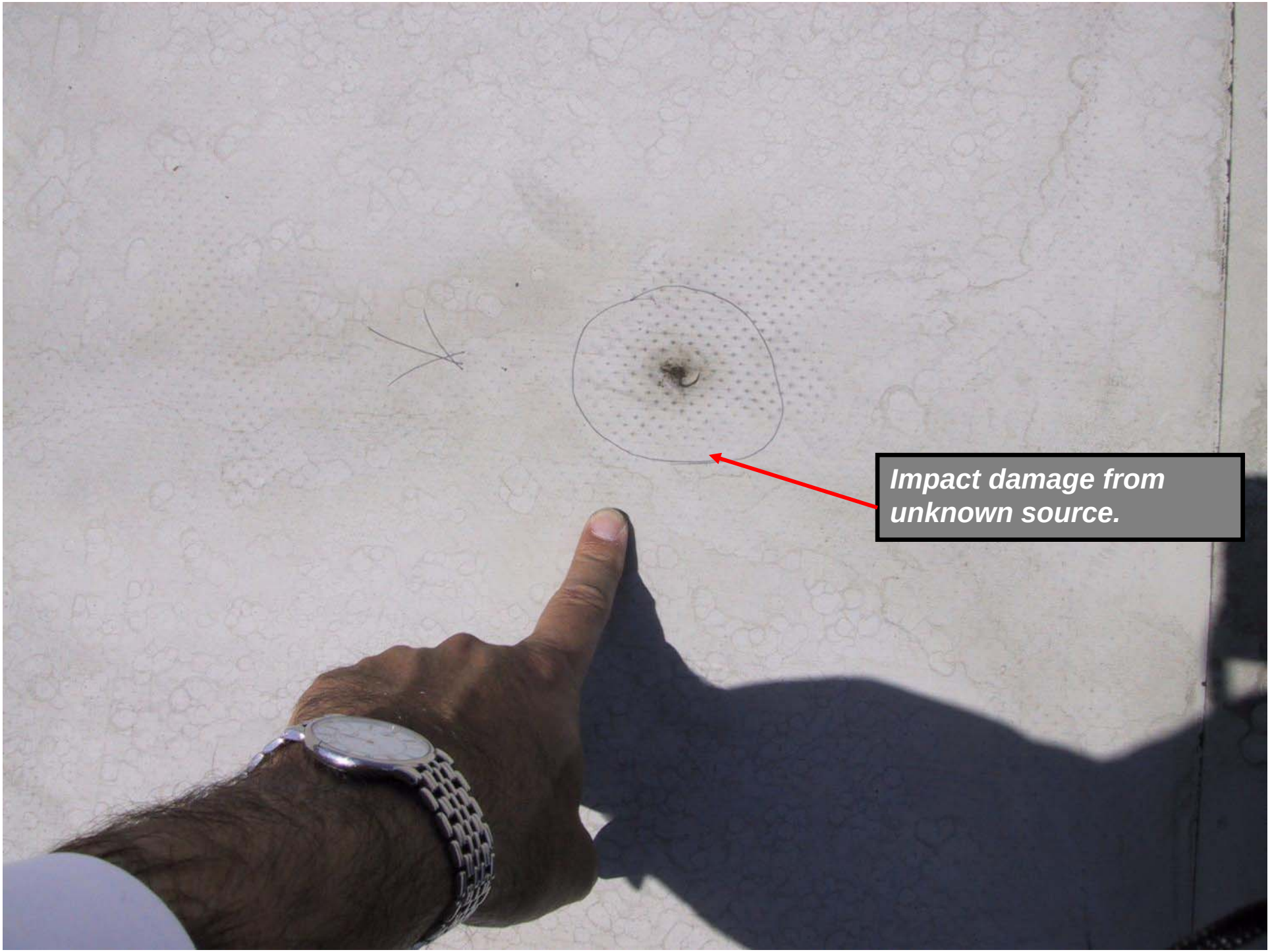

Evidence of limited amount of condensation.

Mechanical bar fastener in excellent condition.

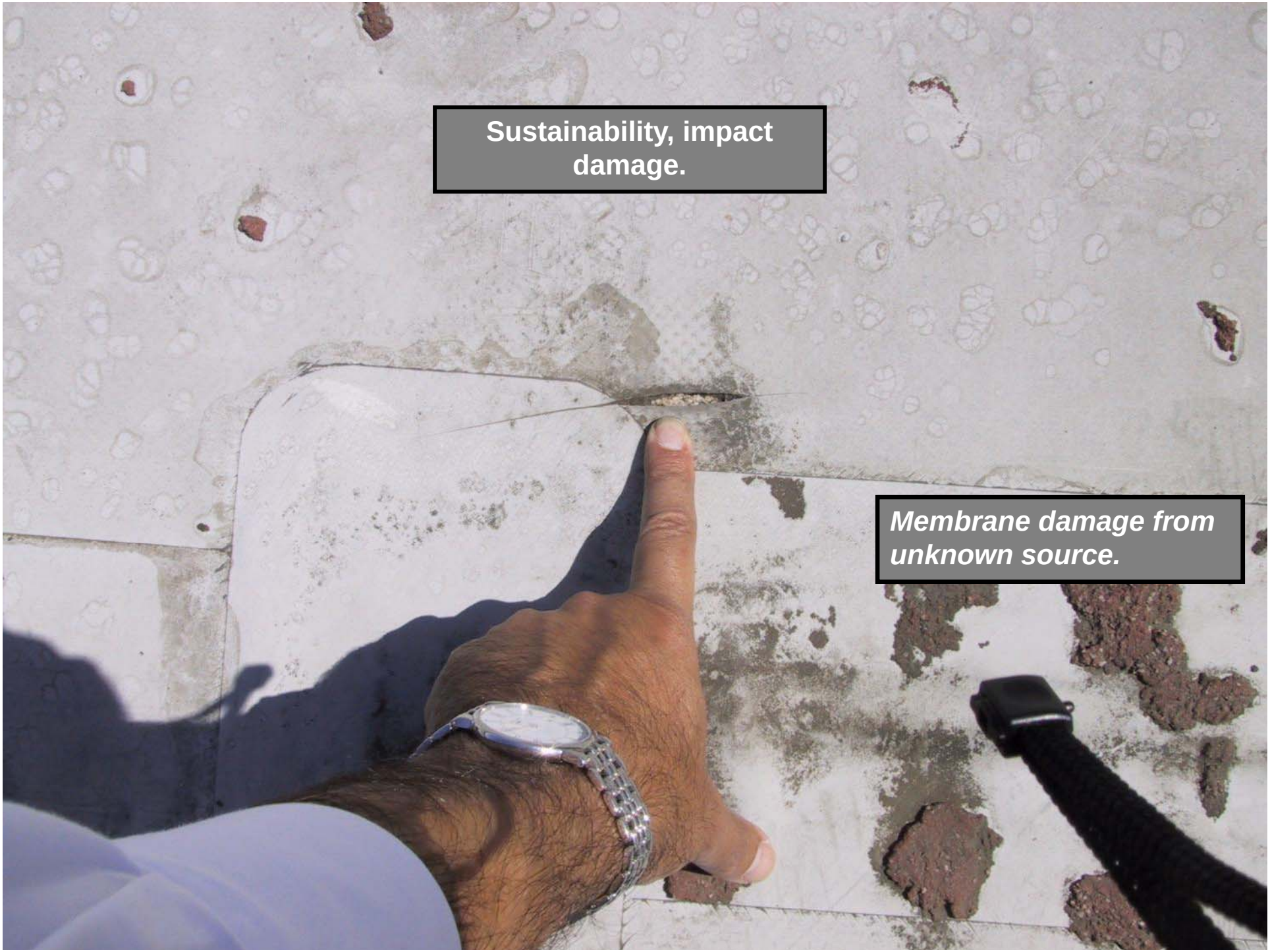

Membrane patching (Back of sheet) was no problem.

Visual Analysis

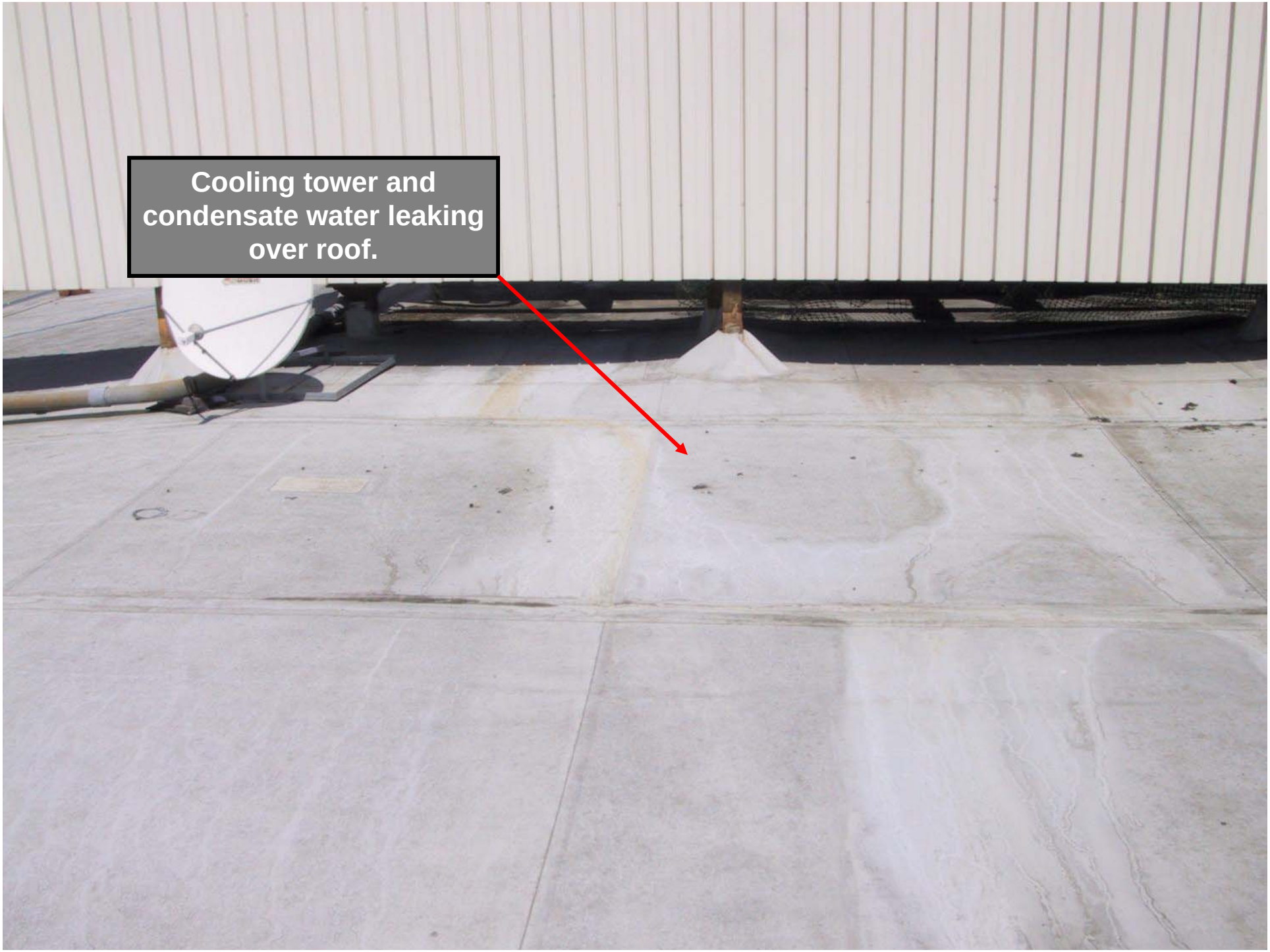
Design Issue

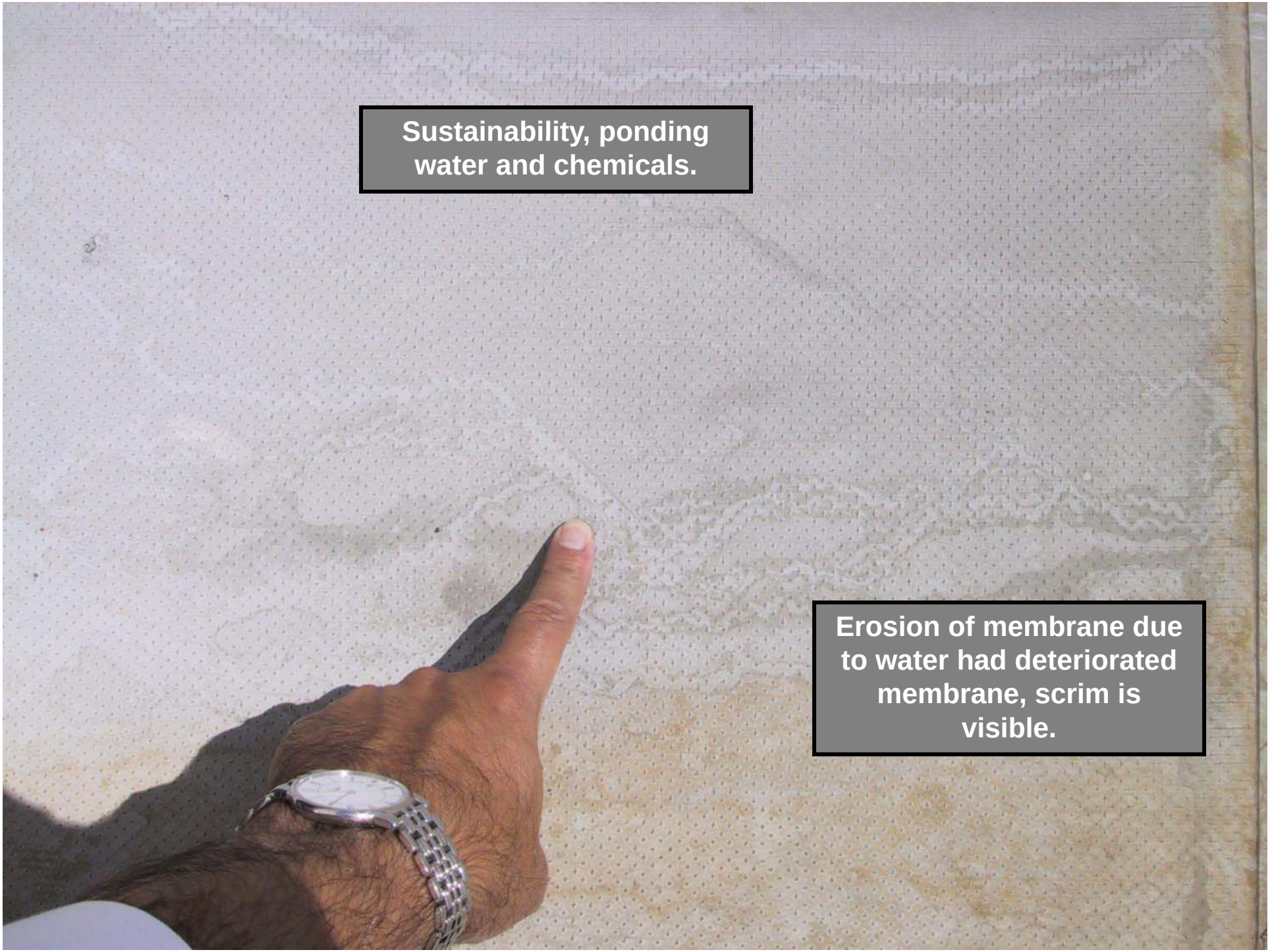

Impact damage from unknown source.


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

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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*

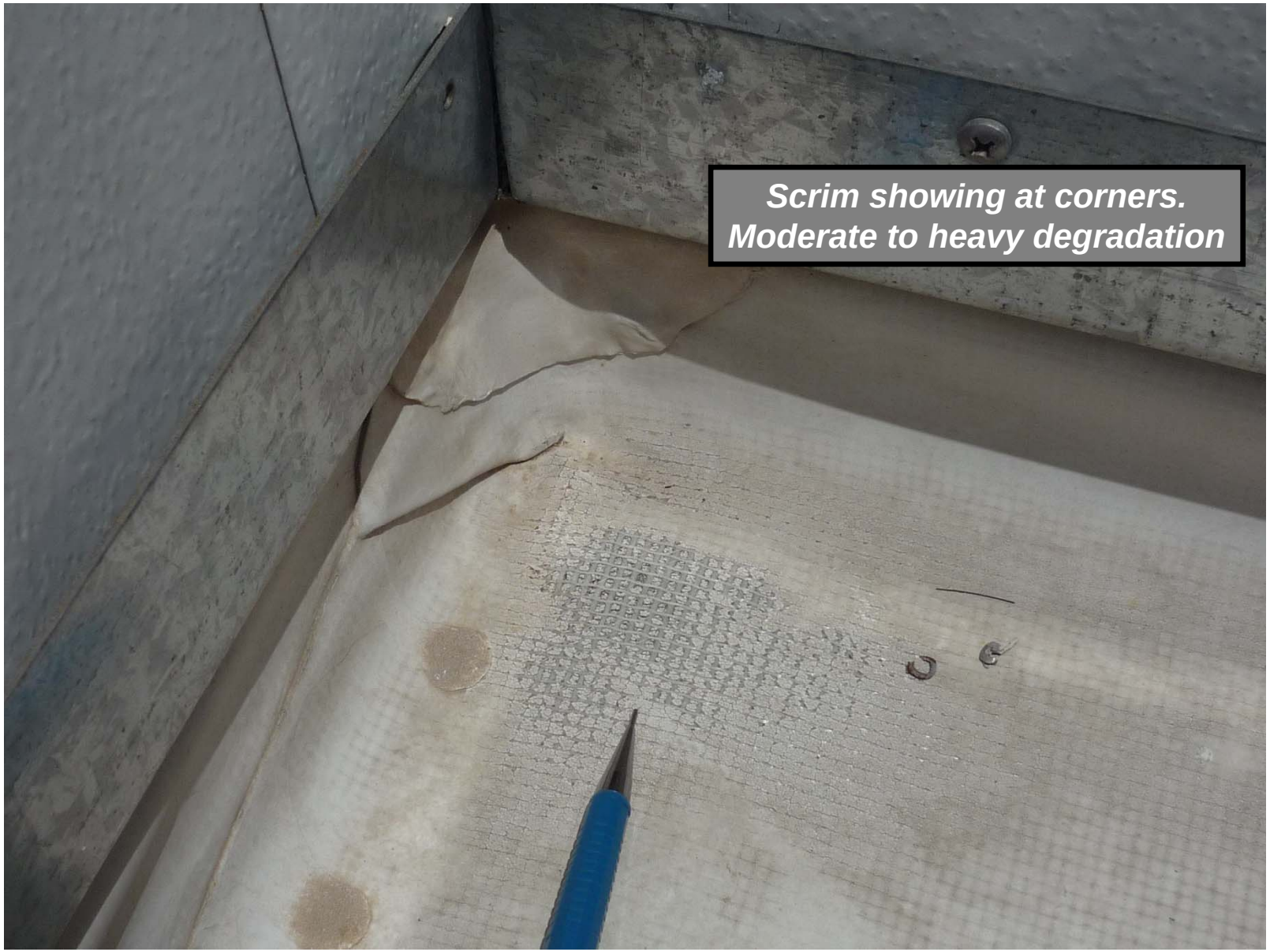
- **Large beer distribution warehouse in Las Vegas.**
- **Carlisle/Stevens (Ask Bradley)**
- **Seven year old roof.**
- **Color difference in adjacent sheets**
- **Heat/UV damage adjacent to wall/base flashing areas**

Large Warehouse in Las Vegas, Nevada

7 Years Old, Large Warehouse in Las Vegas

7 Years Old, Large Warehouse in Las Vegas

Large Warehouse in Las Vegas, Nevada



Large Warehouse in Las Vegas, Nevada

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

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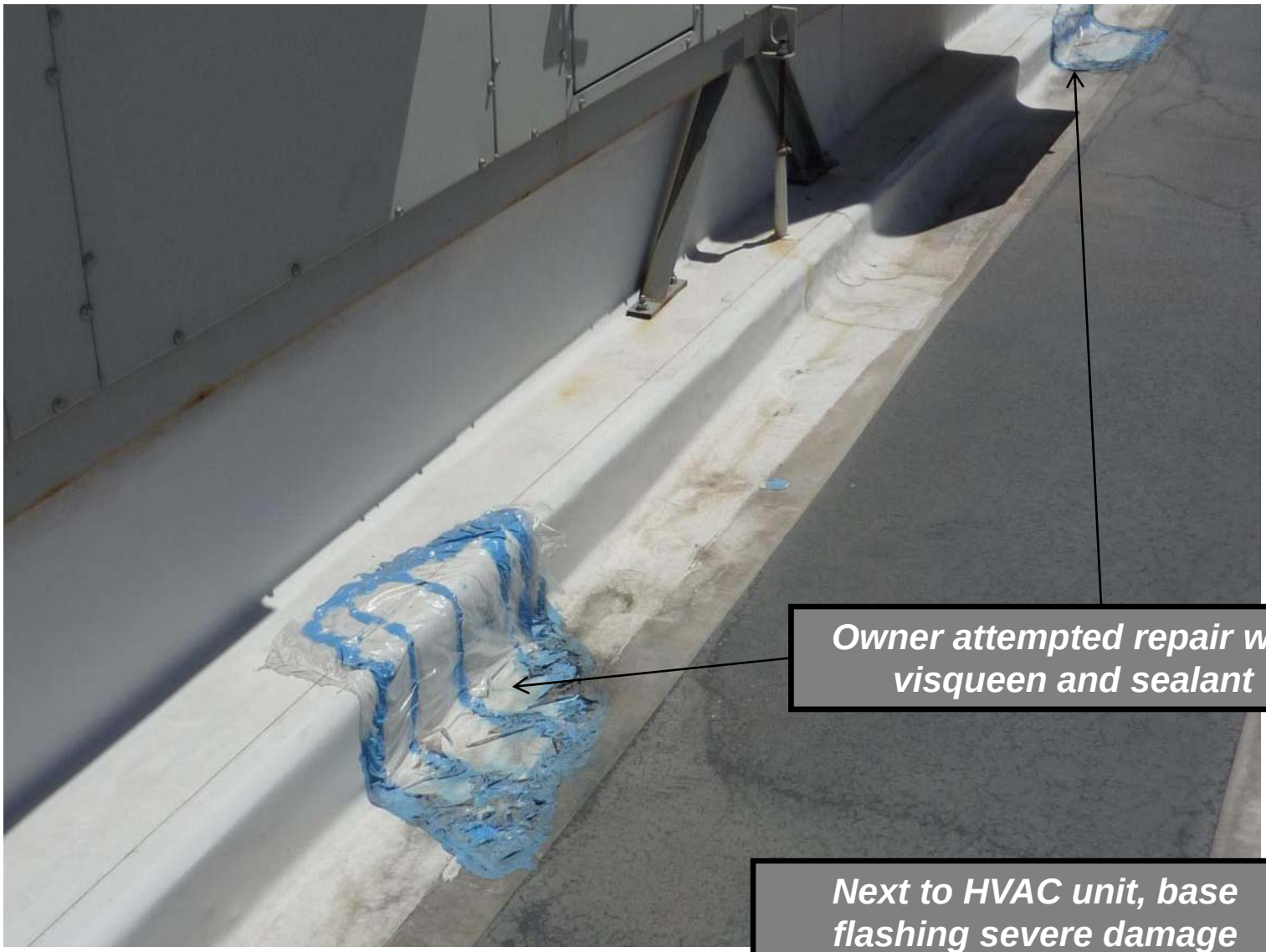
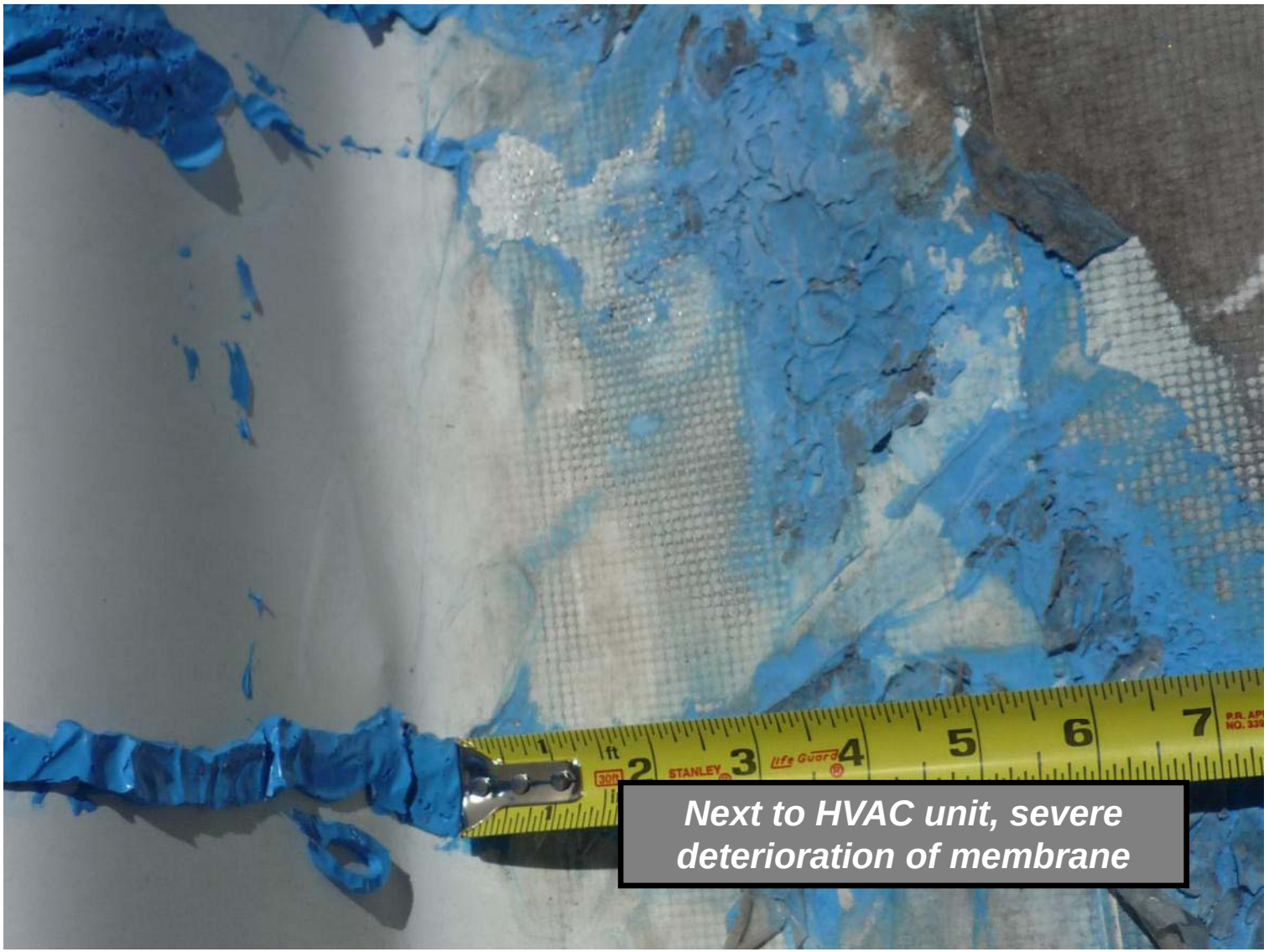
5 Years Old Carlisle, Hospital Building, Vegas



5 Years Old Carlisle, Hospital Building, Vegas



5 Years Old Carlisle, Hospital Building, Vegas

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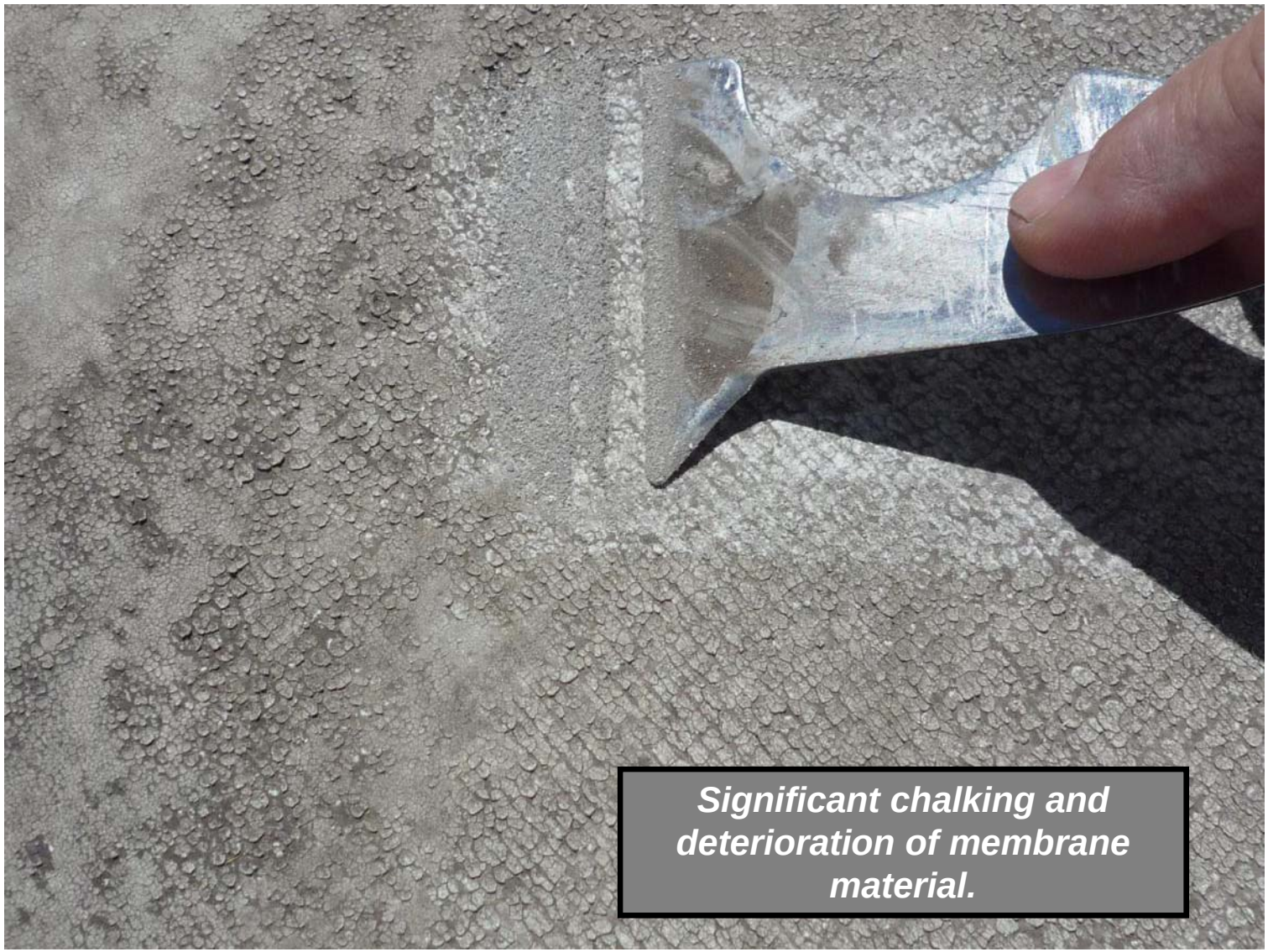
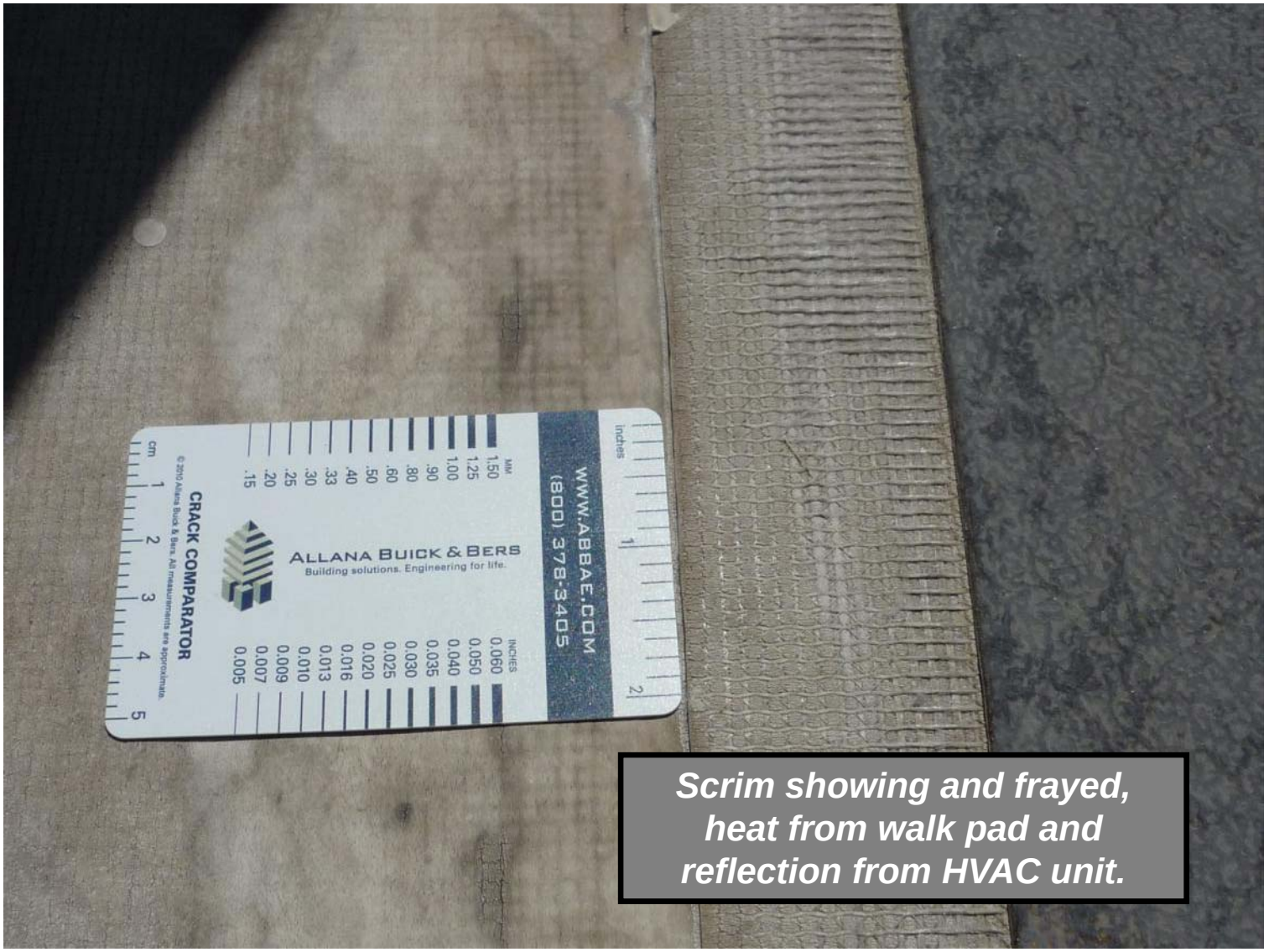
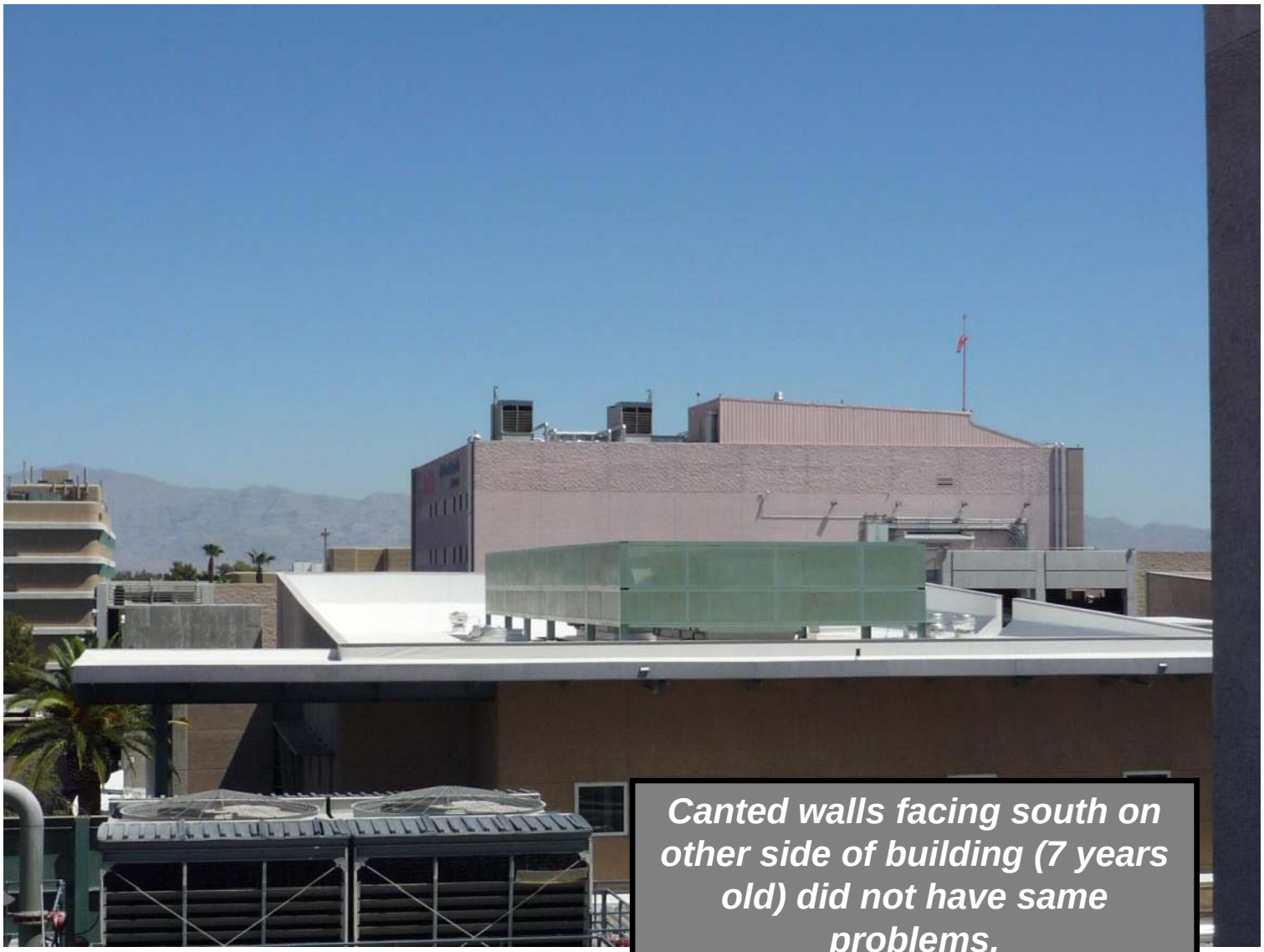


5 Years Old Carlisle, Hospital Building, Vegas

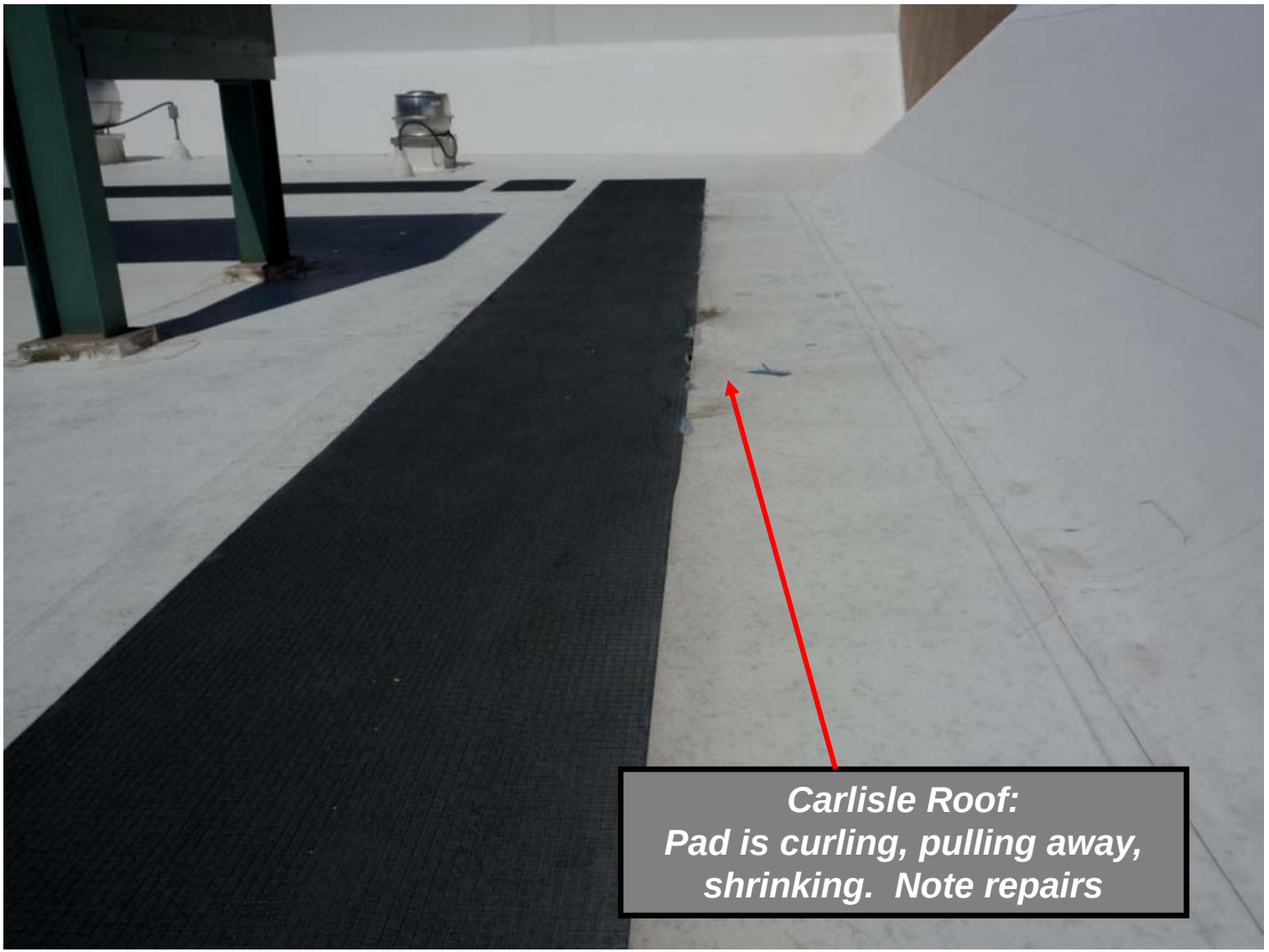


Less damage on 7 Years Old Carlisle



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

7 Years Old Carlisle, Hospital Building, Vegas



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

7 Years Old Carlisle, Hospital Building, Vegas

7 Years Old Carlisle, Hospital Building, Vegas

5 Years Old, Firestone 40 Mil, Molasky Bldg.

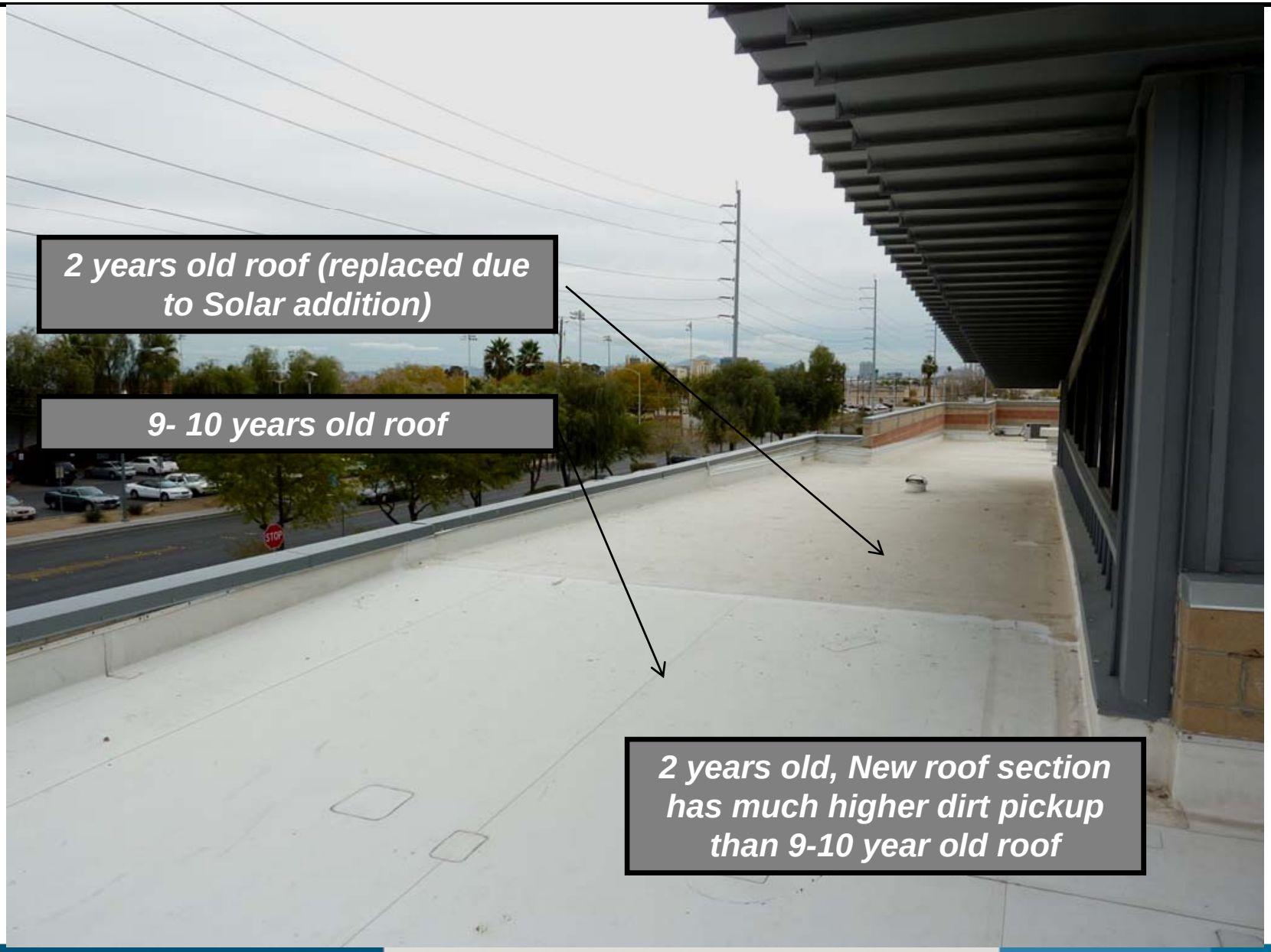
5 Years Old, Firestone 40 Mil, Molasky Bldg.

South side exposure, reflection and walk pad, no significant damage

7 Years Old Firestone, Agasi College, Vegas

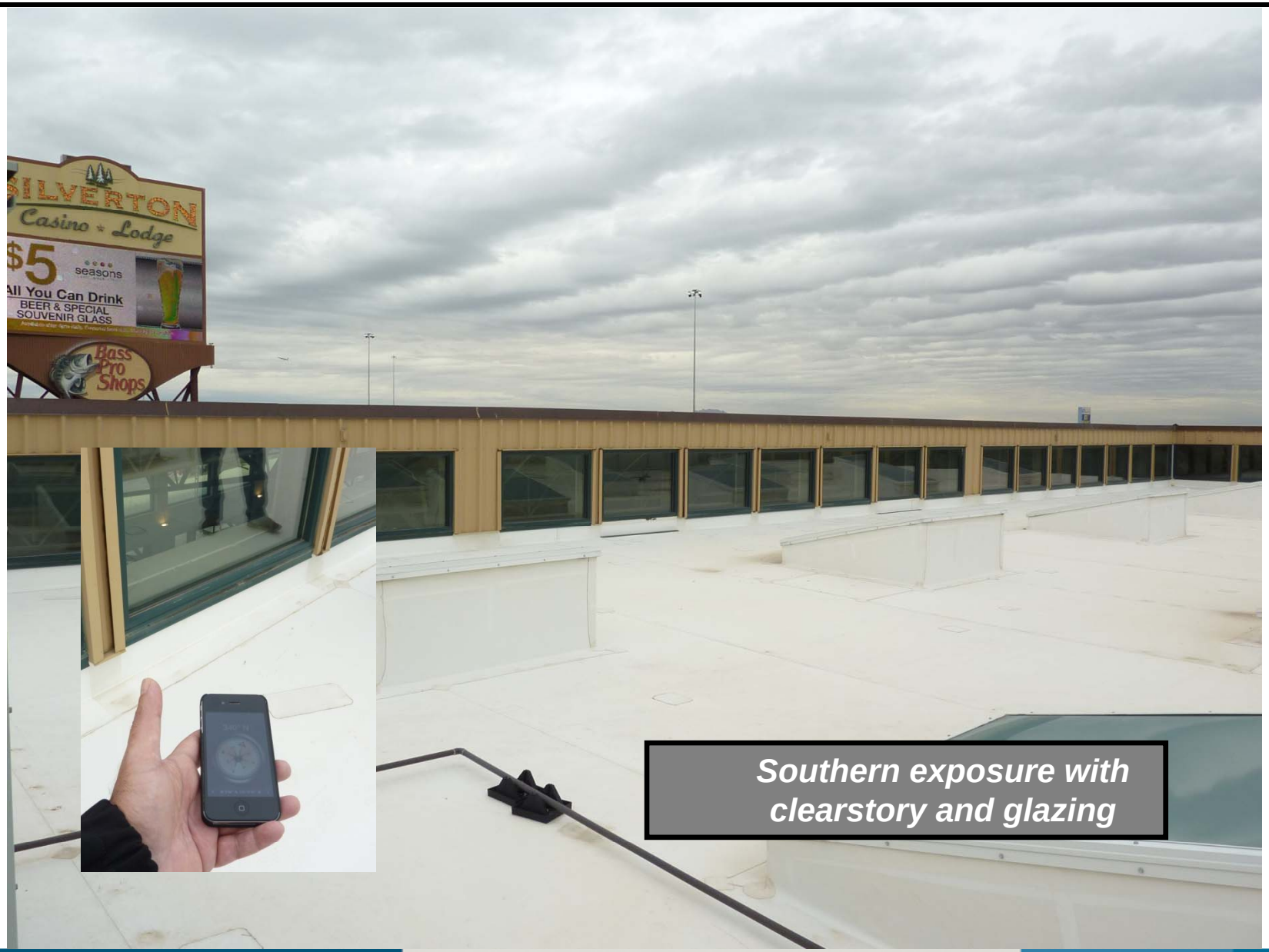
7 Years Old Firestone, Agasi College, Vegas

7 Years Old Firestone, Agasi College, Vegas



5 Years Old Firestone, Bass Sporting Goods

5 Years Old Firestone, Bass Sporting Goods



Southern exposure with clearstory and glazing

5 Years Old Firestone, Bass Sporting Goods

Corner exposure, no visible damage to membrane.

5 Years Old Firestone, Bass Sporting Goods

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

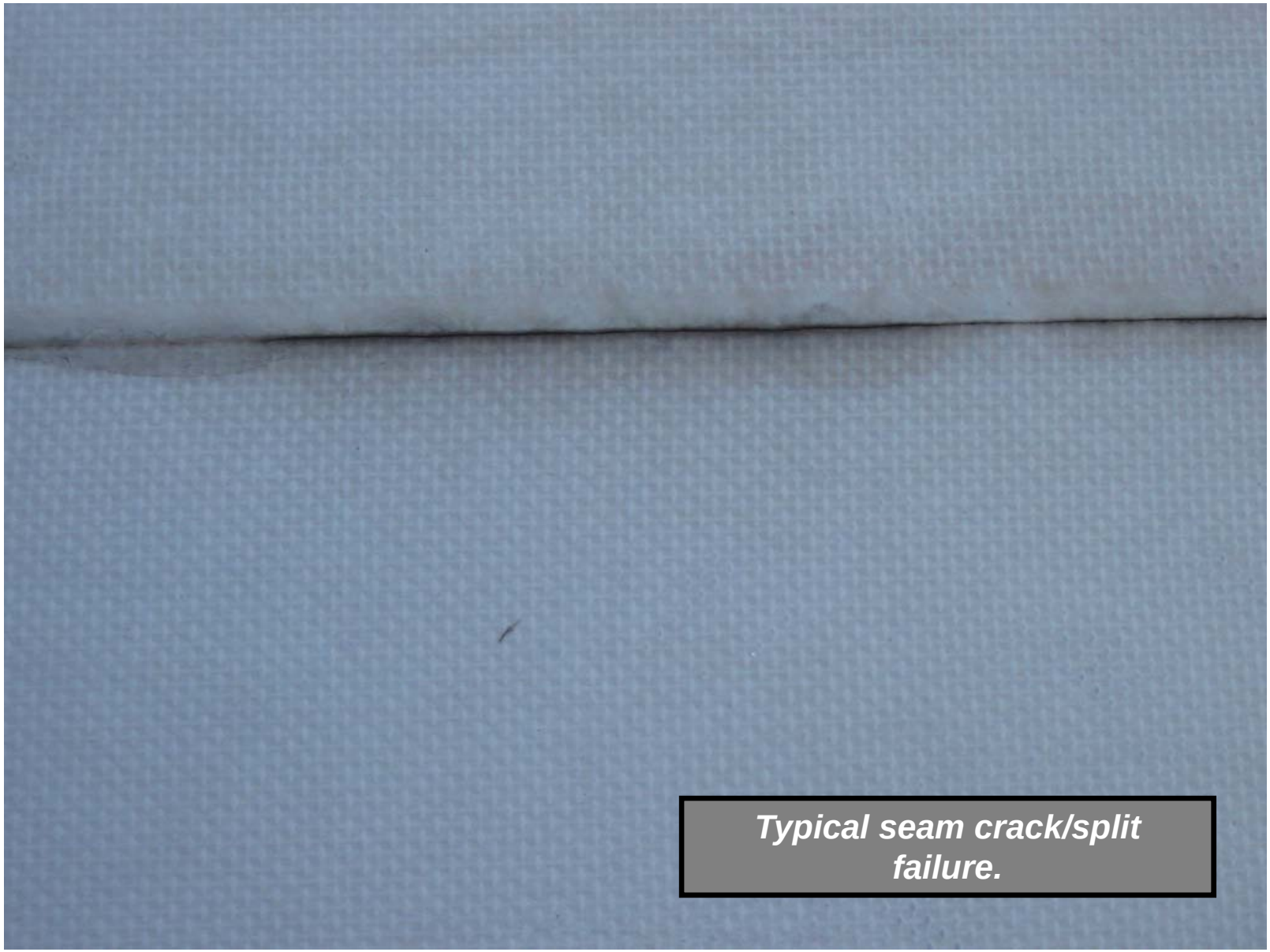
Both seam and UV/Heat failure. (Seam failure repairs)

UNLV, LBC Building, GAF 7 years old

UV/Heat failure. There are no reflective areas. Failures in the filed of the roof

UNLV LLB Building, Dow/Stevens

UNLV LLB Building, Dow/Stevens



Typical seam crack/split failure.

UNLV, BSL Bridge Way, Carlisle, 10 years old

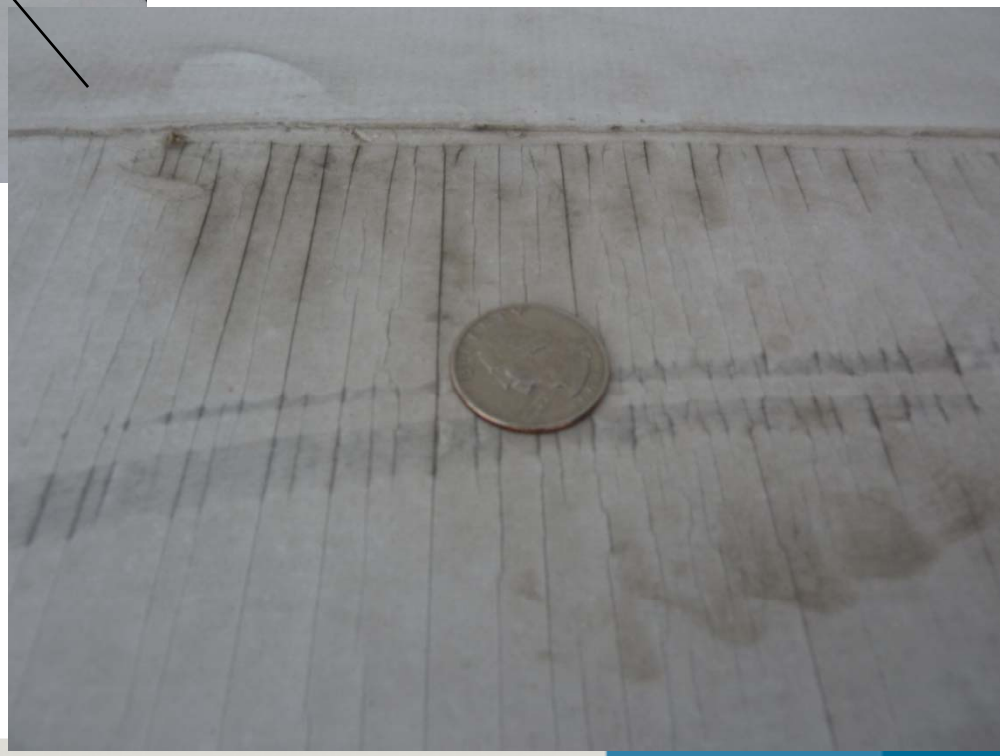
UNLV, BSL Bridge Way, Carlisle, 10 years old

UNLV, ARC Building, GAF TPO 2.5 years old

Original GAF roof failed in 3 years. GAF replaced it march 2008. New Roof also failing

UNLV, ARC Building, GAF TPO 2.5 years old

This replacement GAF roof is less than 3 years old!

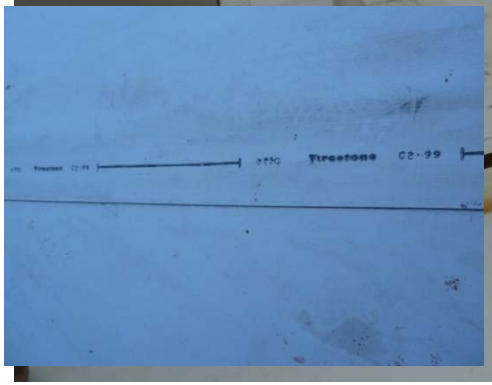


UNLV Bookstore, Firestone 11 Years Old

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

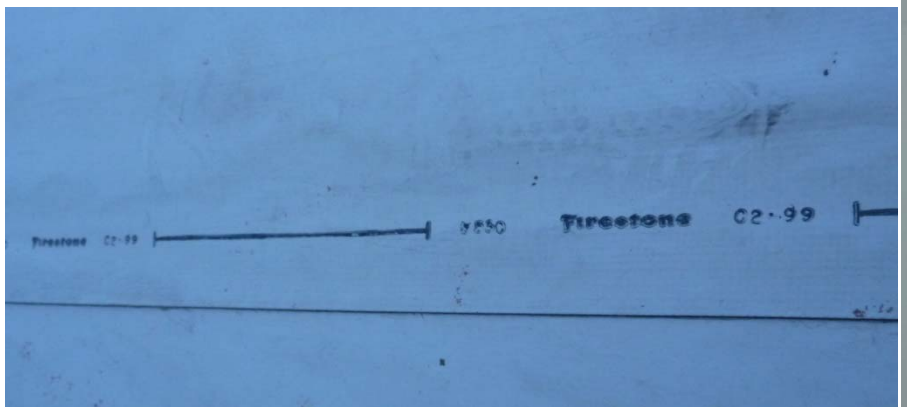
UNLV Bookstore, Firestone 11 Years Old

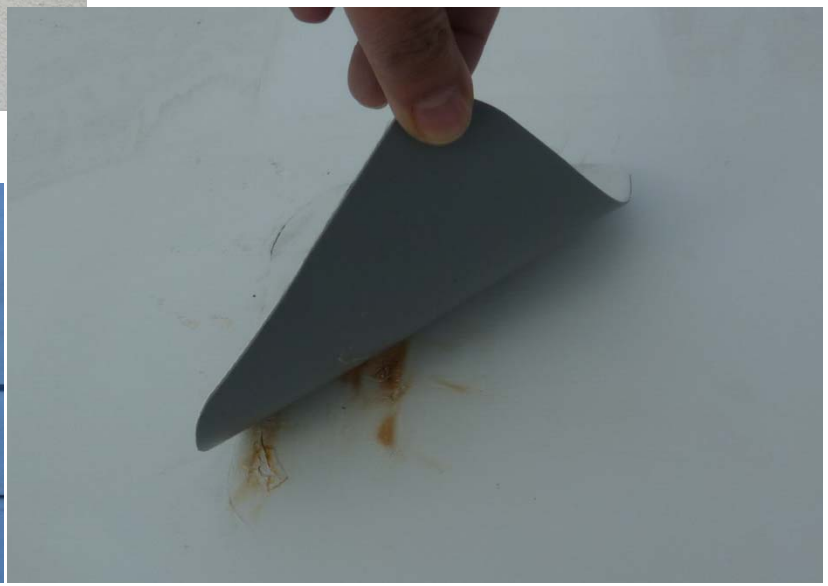
Roof has south facing stucco parapet. No heat related failures were observed



UNLV Bookstore, Firestone 11 Years Old

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

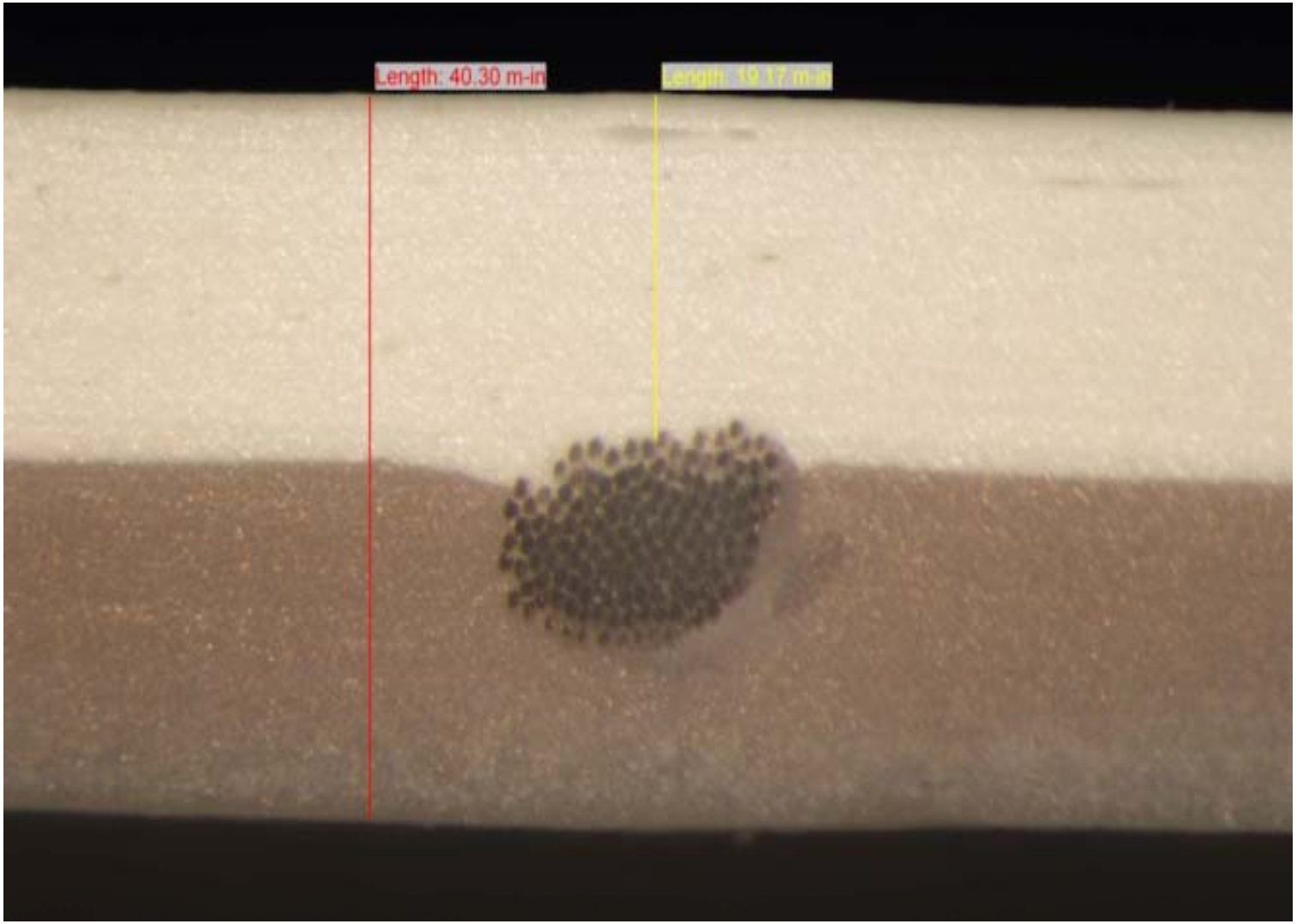




TPO Sample Thickness Test

UNLV Bookstore-Seam Sample (Exposed)	Overall Thickness (m-in)	Thickness Over Scrim (m-in)
Sample #1	40.30	19.17
Sample #2	41.40	19.91
Sample #3	40.06	20.04
Average	**40.59**	**19.71**
UNLV Bookstore-Seam Sample (Unexposed)		
Sample #1	42.98	23.07
Sample #2	42.63	22.11
Sample #3	43.73	23.46
Average	**43.11**	**22.88**
UNLV Bookstore-Near South Facing Wall		
Sample #1	41.07	19.95
Sample #2	40.80	20.54
Sample #3	42.73	20.89
Average	**41.53**	**20.46**

TPO Material Thickness



Sysco, Las Vegas, Firestone 8 Years Old

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

Sysco, Las Vegas, Firestone 8 Years Old

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**