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Critical Review of the Life Span of TPO and PVC

WSRCA

June 8, 2011

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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.
- ✓ Present a forensic evaluation of some of the oldest PVC roofs (18 years old) and TPO roofs (11-12 years old).
- ✓ Discuss how physical forces (water, sun, rain) affect TPO and PVC.
- ✓ Discuss how design and use affect the life of TPO and PVC.

History of PVC Roofing

- Vinyl gas discovered in 1800's but no commercial use.
- Vinyl compound discovered at BF Goodrich in1920's.
- 1930's – limited commercial uses found for PVC.
- Mid 1960's, single ply roof covers are introduced.
- Early 1970's, vinyl roofing membranes.
- Mid 1970's, 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 roughly 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 called for the cessation of PVC manufacture and use – production and incineration create dioxin, a toxic chemical.
- Additives such as Phthalate" plasticizer needed for softening.
- Some plasticizers are water soluble and thus can possibly leach from PVC roofs.
- Phthalates have been reported by some, to create health issues.
- Other additives: biocides, fire retardants, pigments, and to prevent oxidation

PVC Chemistry (Continued)

- The industry has reported to us the replacing of 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 also used compounds containing heavy metals, as fire inhibitors.
- The industry now reports the use of Antimony Trioxide (Sb_2O_3) as a fire inhibitor.
- Some conversion to Magnesium Hydroxide as a fire inhibitor in PVC roofs.

ASTM Standard D4434 for PVC

- **Last Updated: February 2009**
- **Heat age testing (Practice D3045): 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 retention after heat aging: 90% of original
  - Elongation at break: 220 to 250% Type I; ≤15% Type II, ≤25% Type III
  - Breaking Strength: None for Type I, 200 lbf Type II; 275 lbf Type III
  - Tear resistance or Tear Strength: 45lbf Type I; 45lbf Type II; 90lbf Type III;
  - Must pass static and dynamic puncture resistance test
  - Weather testing for 5000 hours – see D4434 for more information

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*

History of TPO Roofing

- **The TPO polymer was developed in Italy by Montell (now LyondellBasell).**
- **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 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 or phthalates.
- Some early TPO membranes were black to mimic the look of EPDM.
- Failures reported, possibly from excessive heat.

TPO Chemistry (Continued)

- Early on, poly-brominated additives were added to TPO.
- The brominated compounds reacted with the UV stabilizers, decreasing effectiveness.
- 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.

TPO Standard - ASTM D6878 – 08e*

Heat Aging Testing (test method D573):

240°F for 670 hours (28 days)

Physical Properties (test method D751):

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

ASTM D6878 – 08e also establishes these standards under test method D751:

- Breaking Strength, minimum - 220 lbf
- Elongation at Reinforcement Break, minimum 15%
- Tearing Strength, minimum - 55lbf

ASTM D6878 – 08e establishes these standards under test method D2137:

- Brittleness Point, maximum -40 degrees C and -40 degrees F

ASTM D6878 – 08e establishes these standards under test method D471:

- Water Absorption, maximum mass ±3.0% (top coating only)

* **This ASTM specification is under the jurisdiction of ASTM Committee D08 on Roofing and Waterproofing and is the direct responsibility of Subcommittee D08.18 on Nonbituminous Organic Roof Coverings. ASTM D6878 – 08e was last revised on July 1 2008. No changes since that date (as of 5-24-2011) .**

TPO Heat Aging Standard Under D6878 – 08e

- Test Method D573
- New ASTM heat aging standard was proposed due to perceived problems with degradation caused by heat.
- Current Standard: Heat age for 670 hours (27.92 days) at 240 degrees Fahrenheit (116 degrees C)
- Proposed new higher standard sought to address some of the reported problems with TPO.
- New standard was voted down, in ASTM Committee.

TPO Manufacturers, 2010

In alphabetical order:

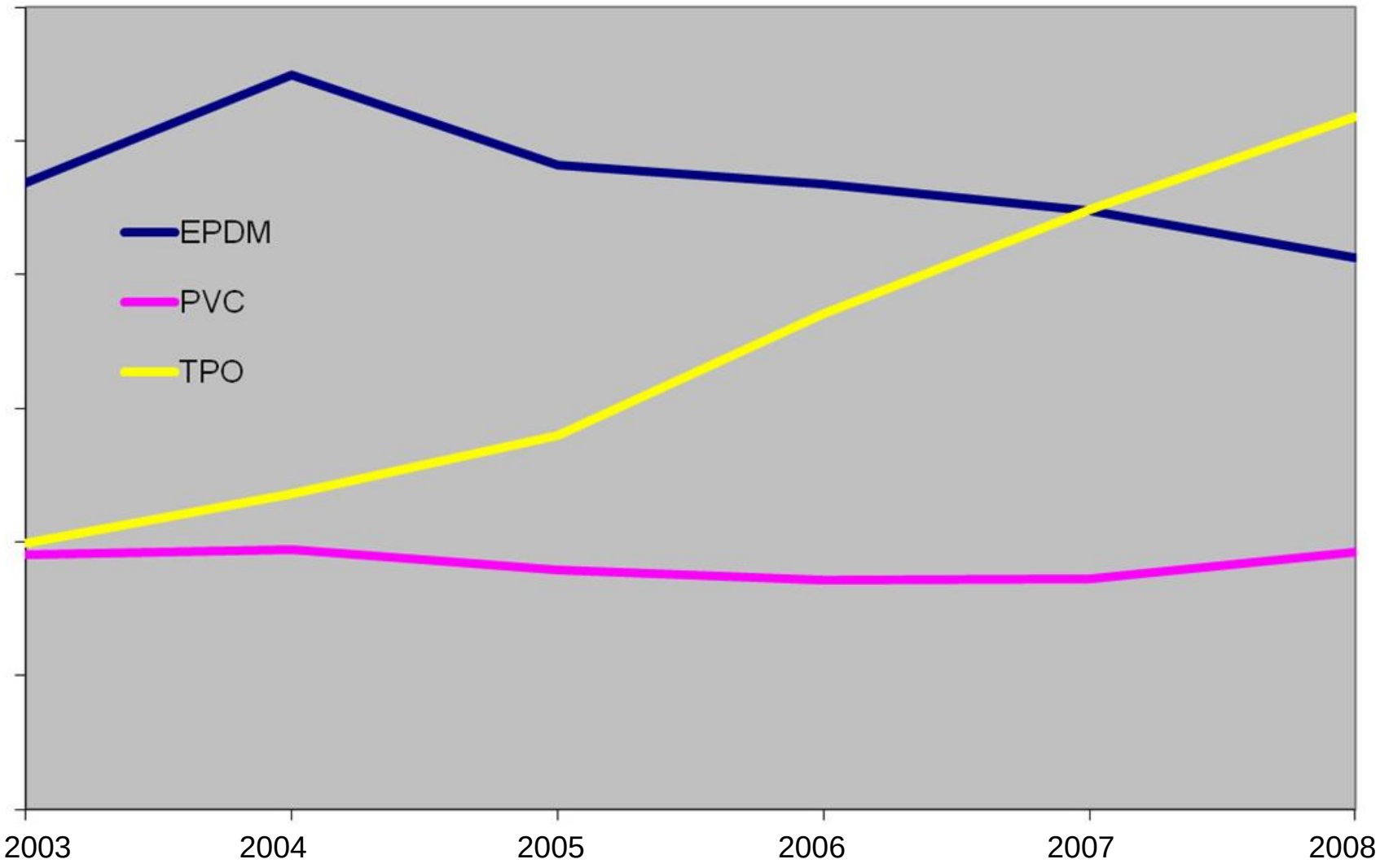
- **Carlisle**
- **Cooley**
- **Firestone**
- **GAF**
- **Johns Manville (Private label until recently)**

TPO Raw Material Suppliers

In alphabetical order:

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

Single Ply Sales Growth 2003 - 2008

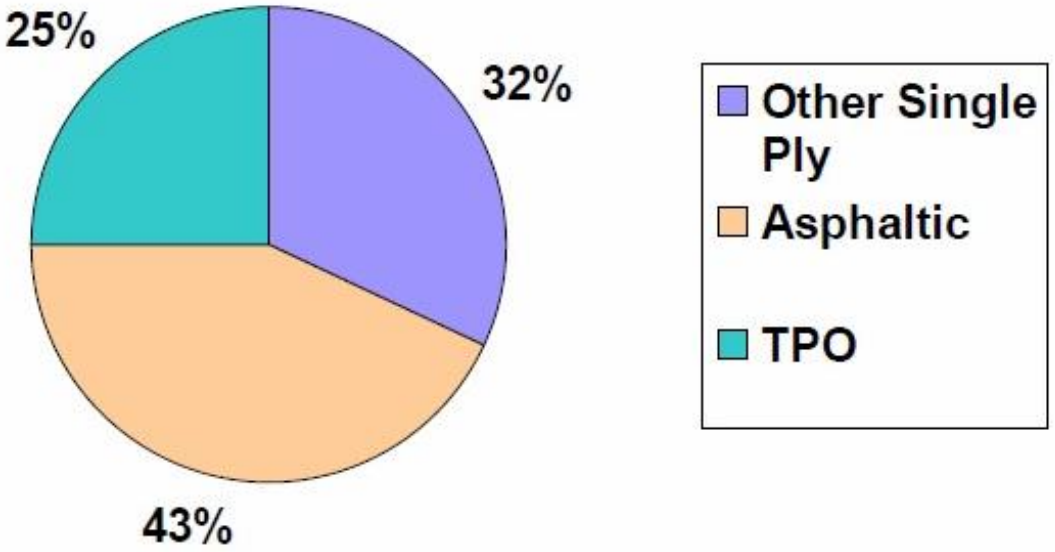


Source: Single Ply Industry

Market Share

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.

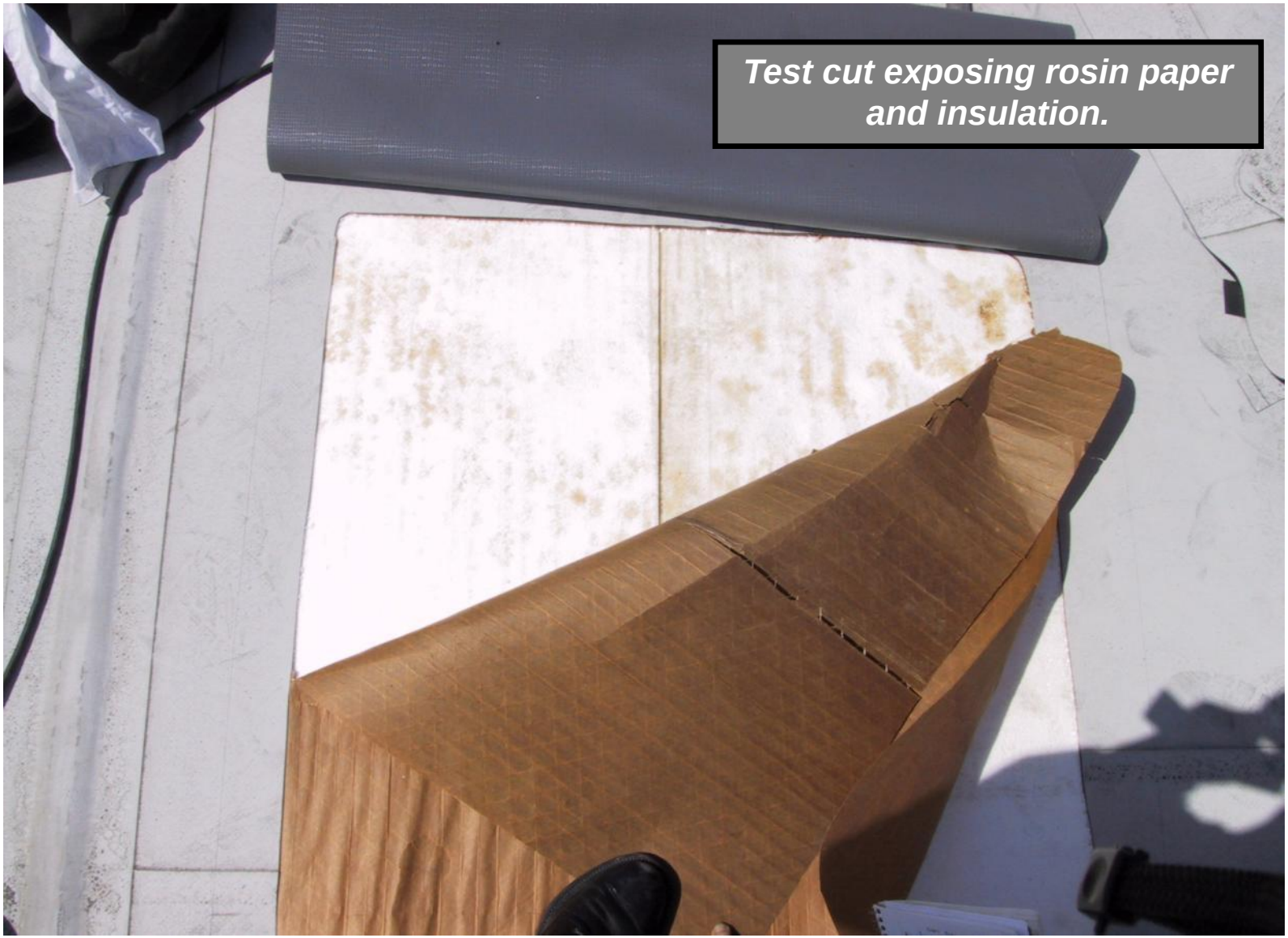
Sustainability Checklist

- 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?

Test Cut Analysis



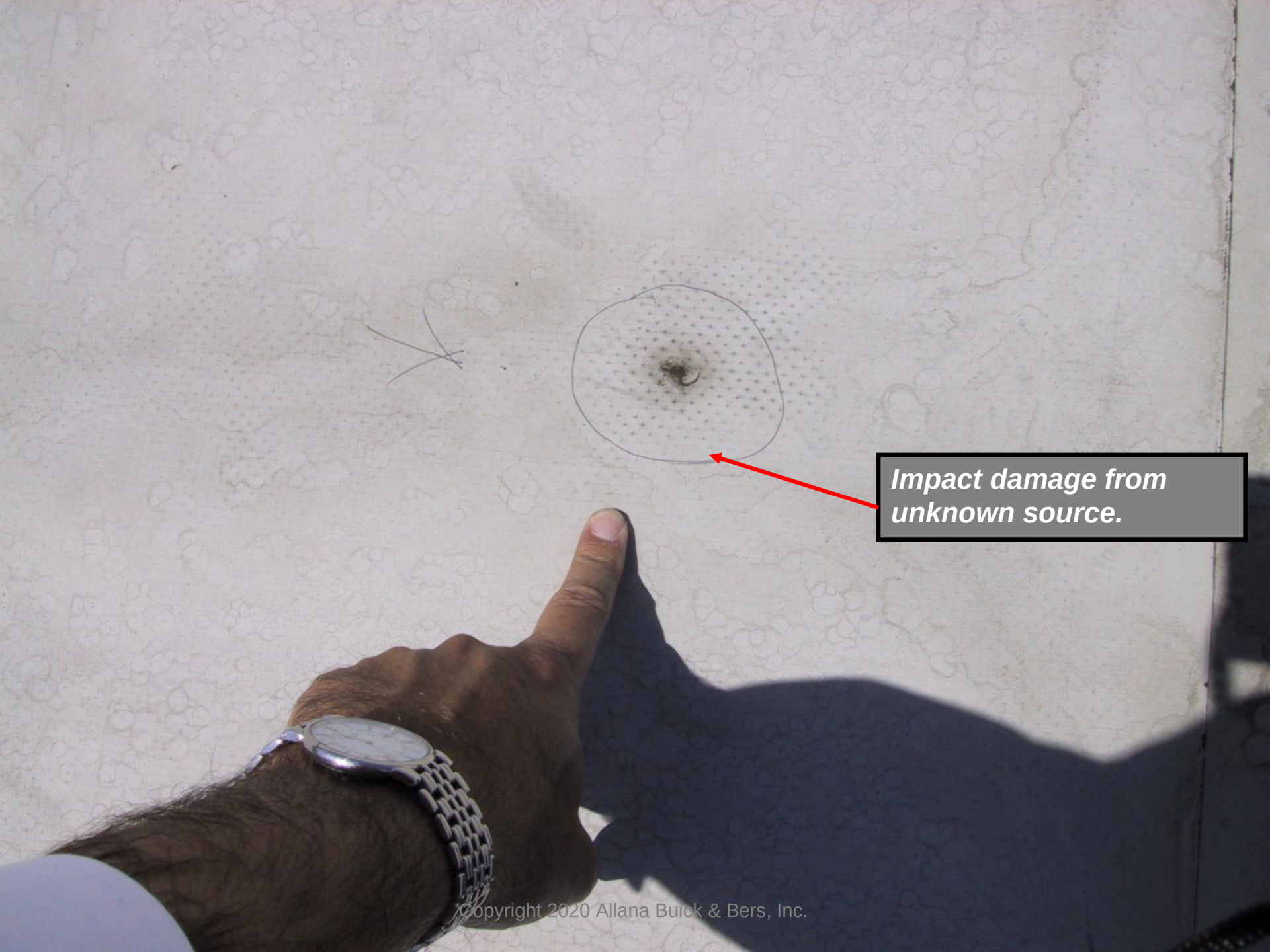
Evidence of limited amount of condensation.

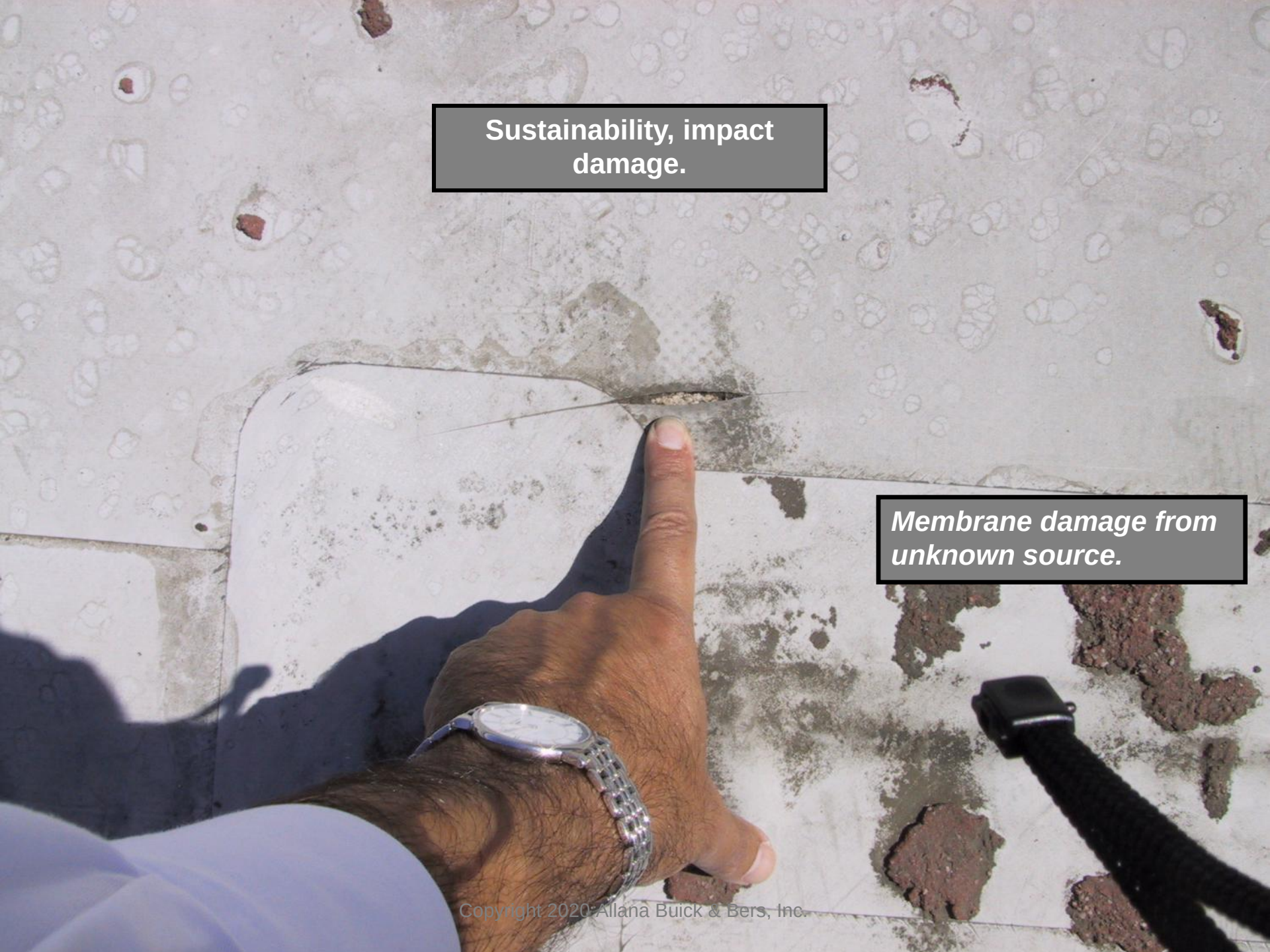
Mechanical bar fastener in excellent condition.

Membrane patching (Back of sheet) was no problem.

Visual Analysis

Design Issue





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 25 TPO Roofs in Vegas

- **Reviewed several manufacturers in study:**
  - Carlisle
  - GAF
  - Firestone
  - Johns Manville (by private label manufacturer)
  - JP Stevens (Dow)

7 Year Old TPO: *Large Warehouse*

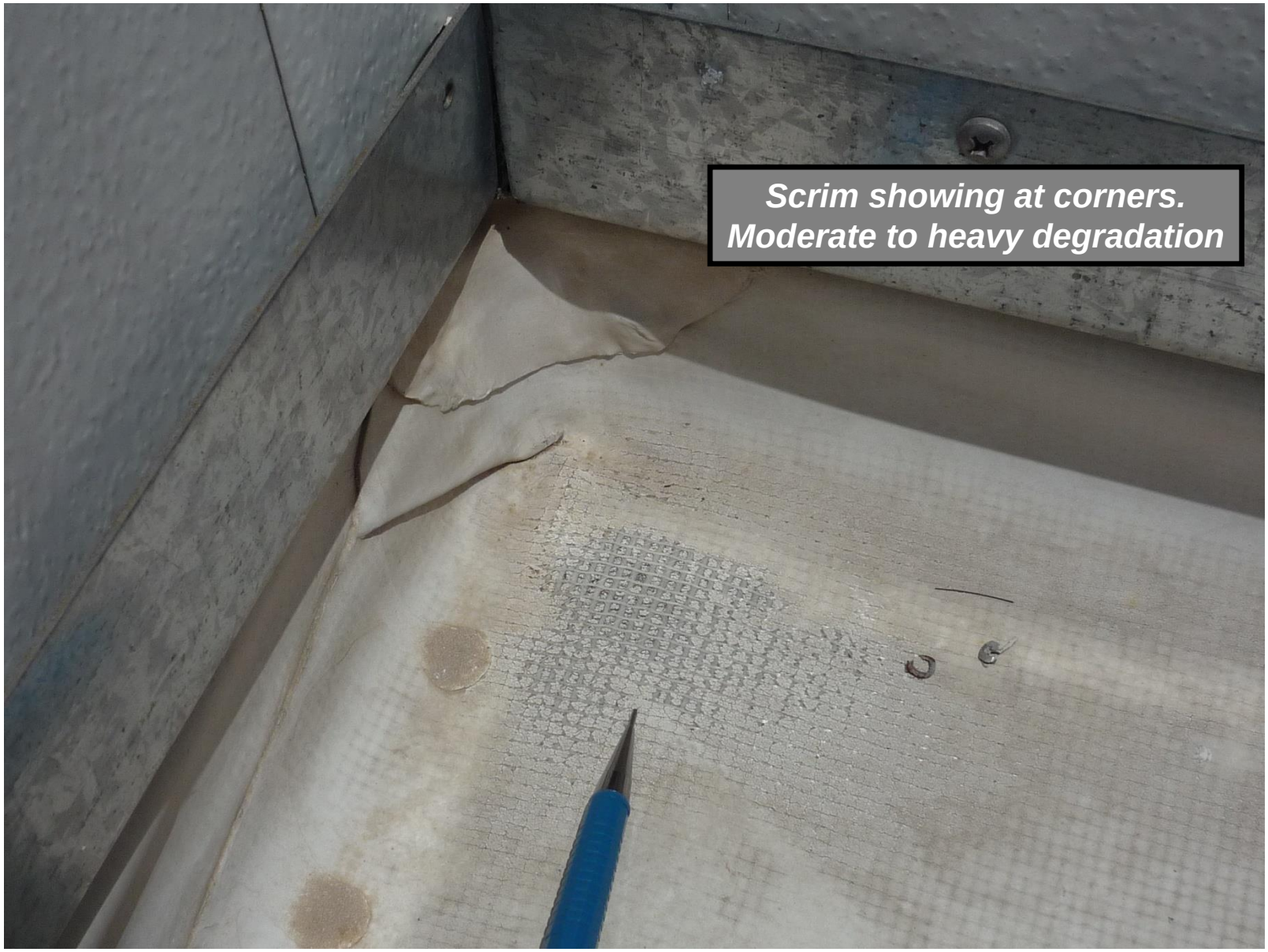
- Large beer distribution warehouse in Las Vegas.
- Carlisle/Stevens
- Seven year old roof.
- Color difference in adjacent sheets
- Heat/UV damage adjacent to wall/base flashing areas

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

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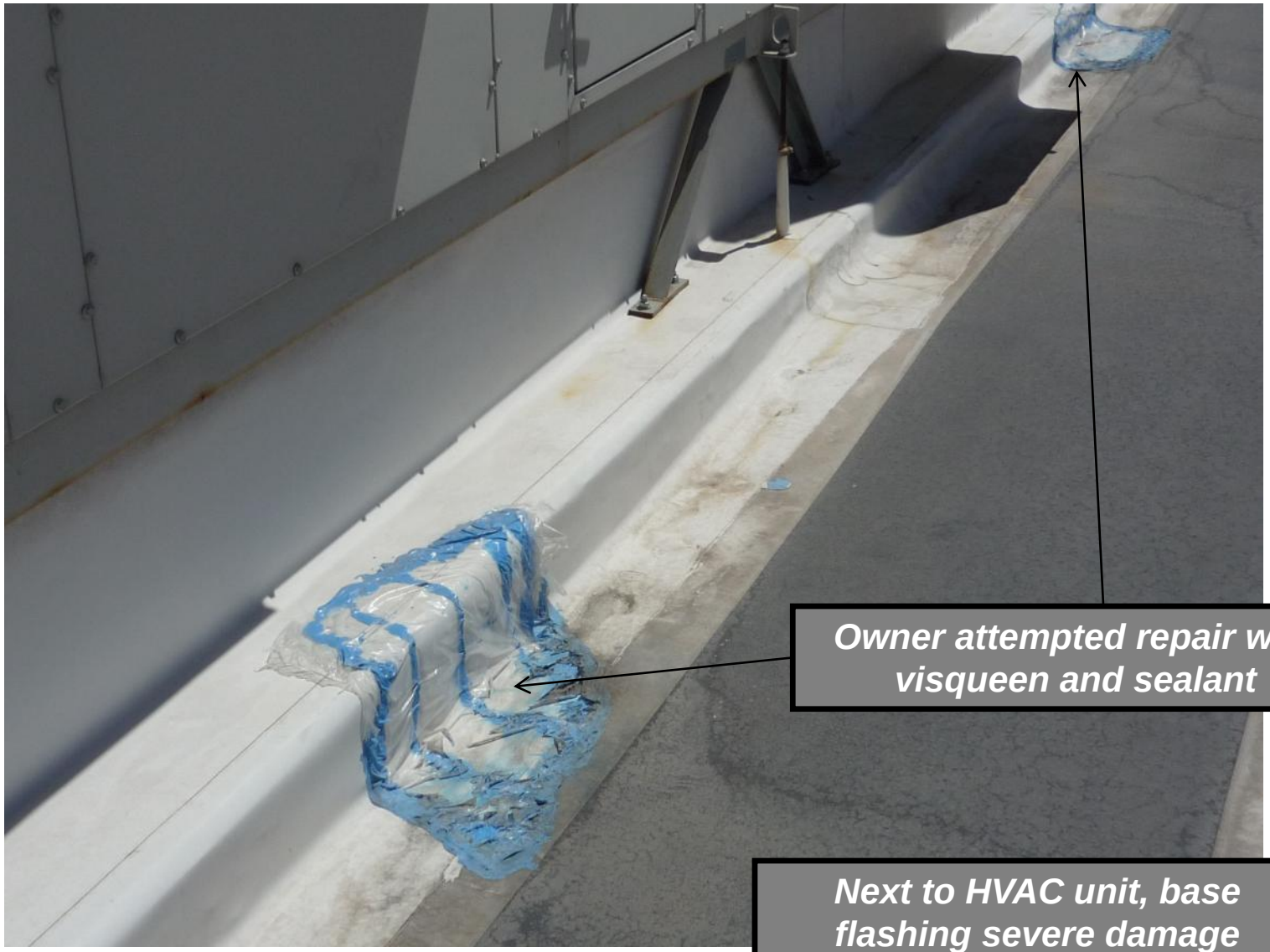
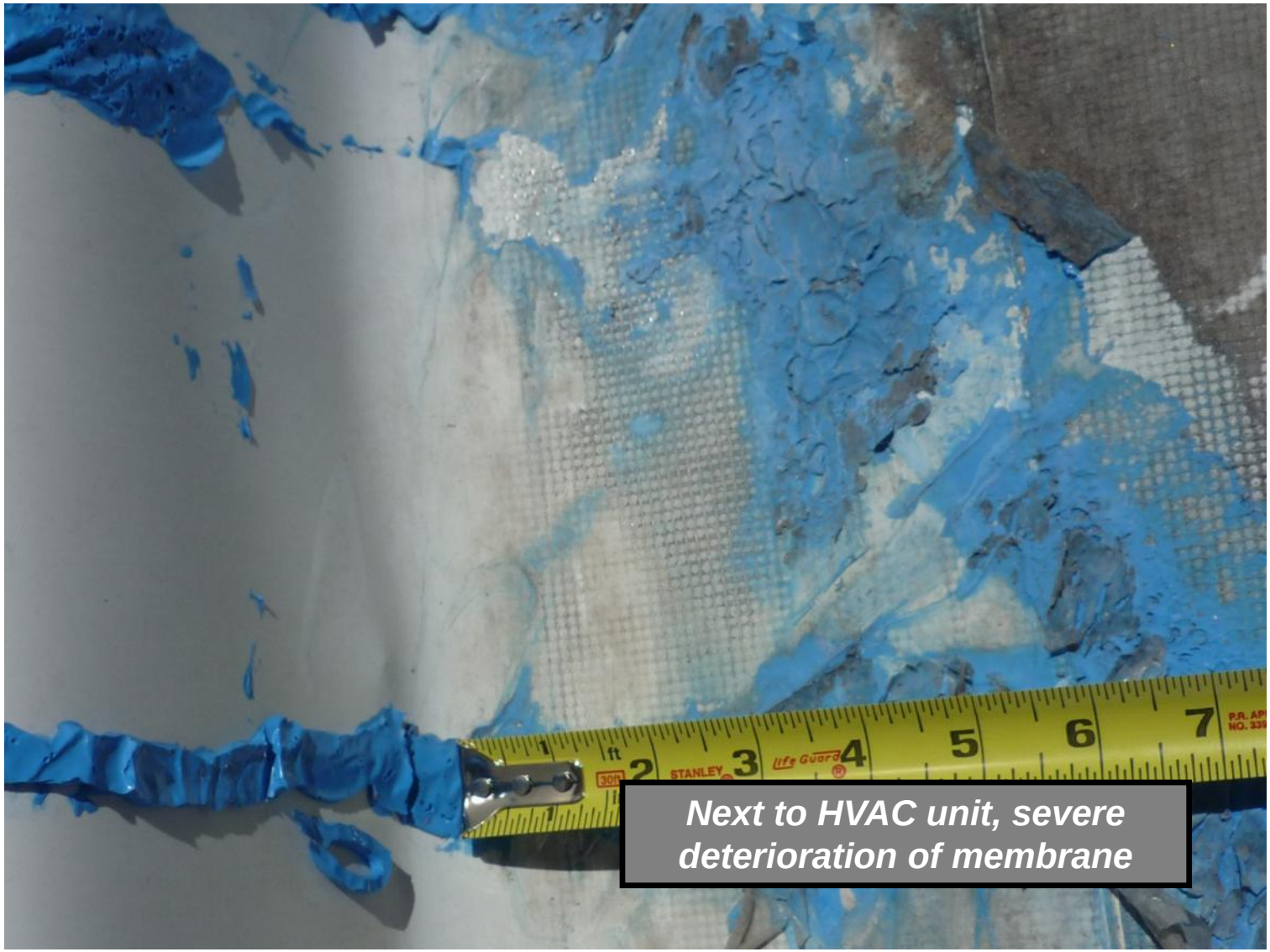
Corner of parapet wall, membrane completely gone, Severe Damage.

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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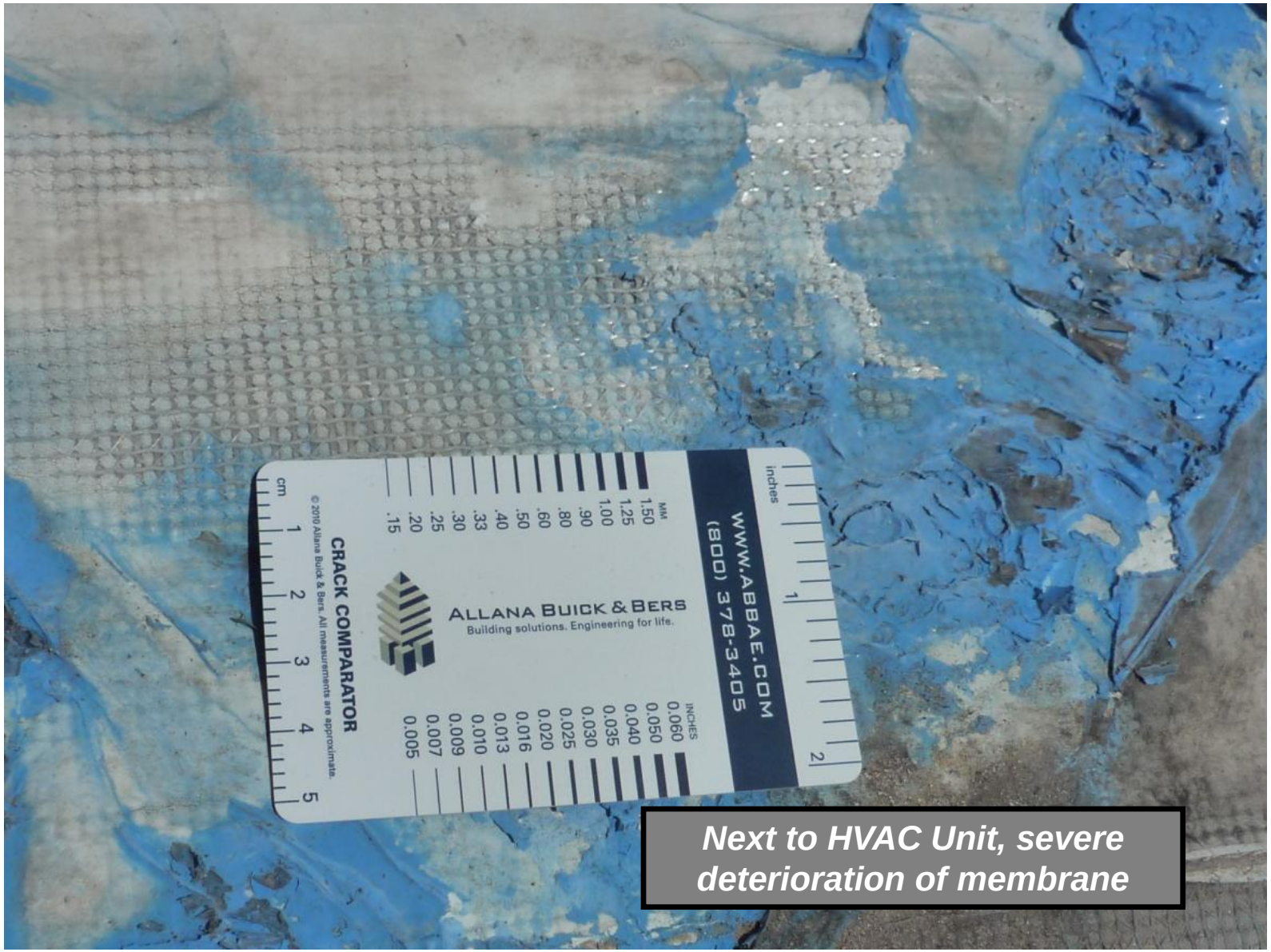

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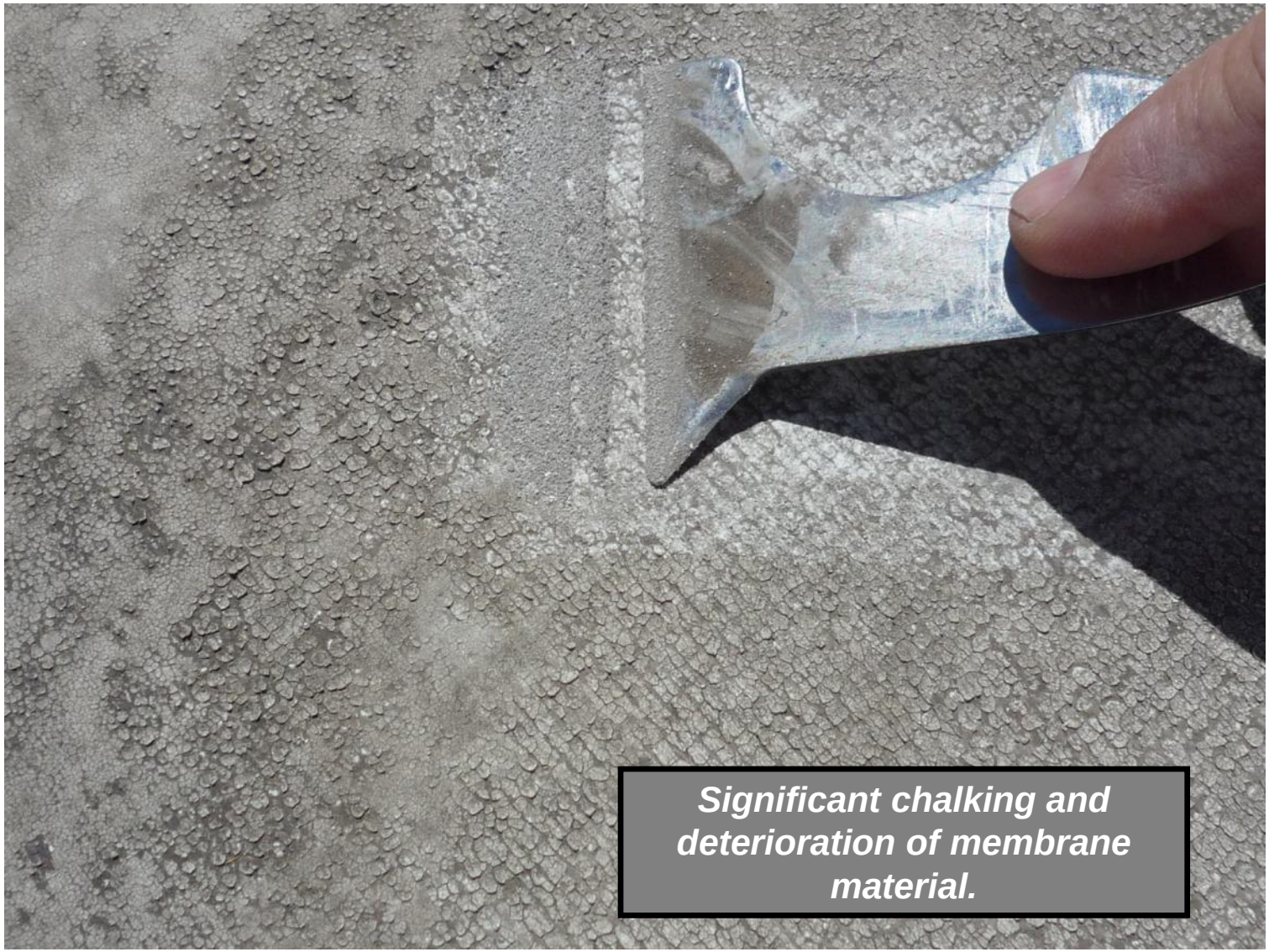
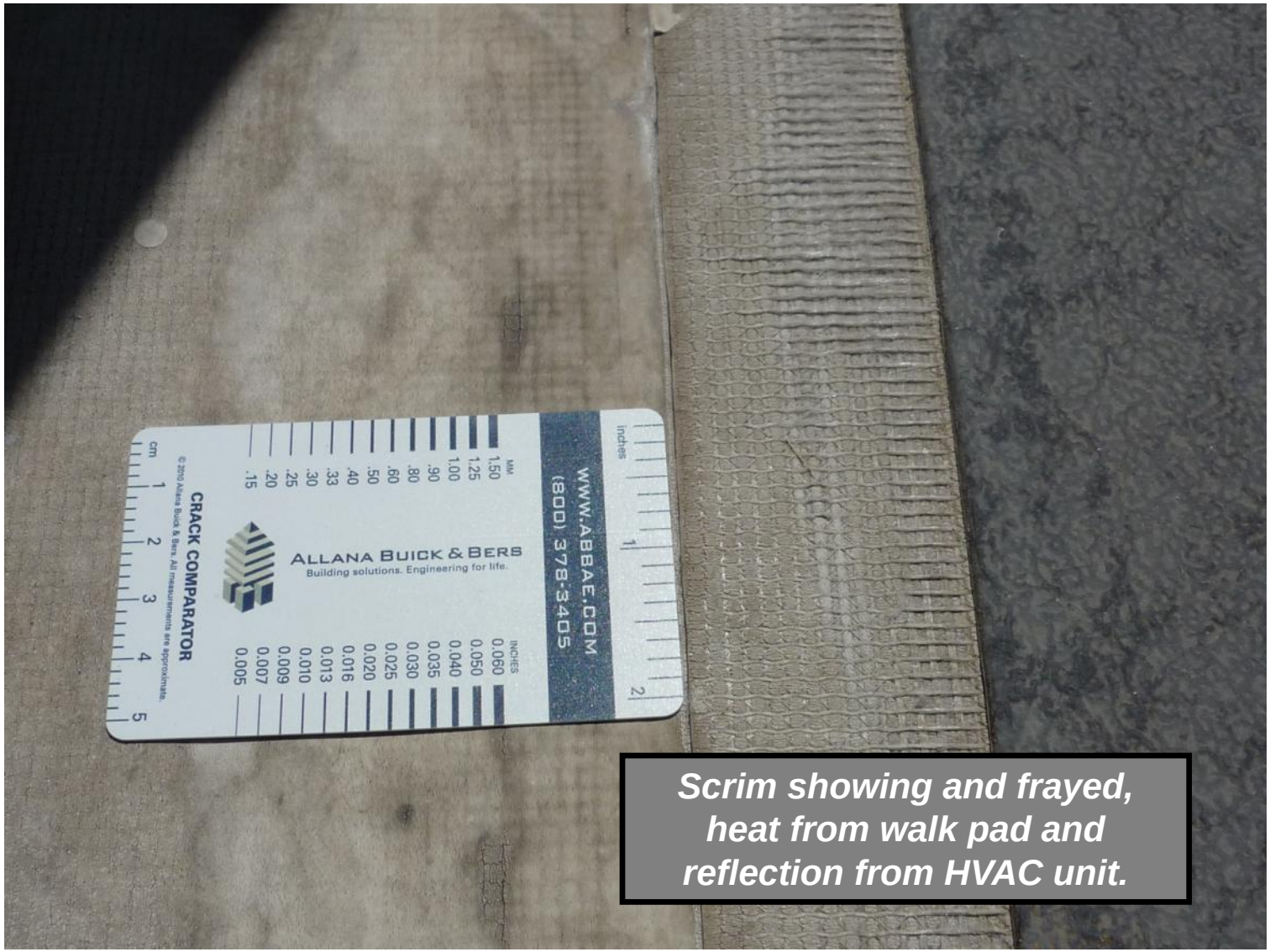
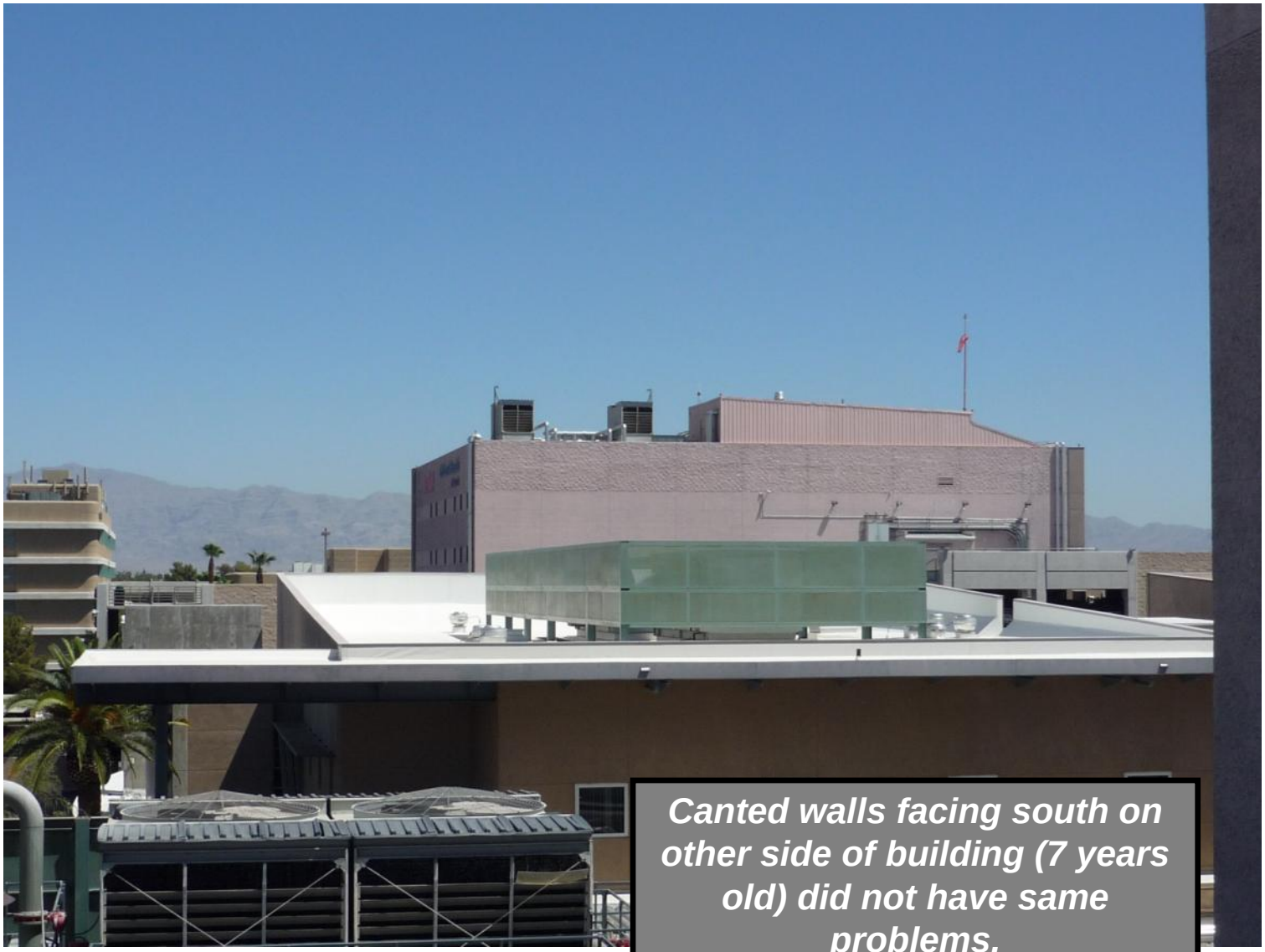


5 Years Old Carlisle, Hospital Building, Vegas



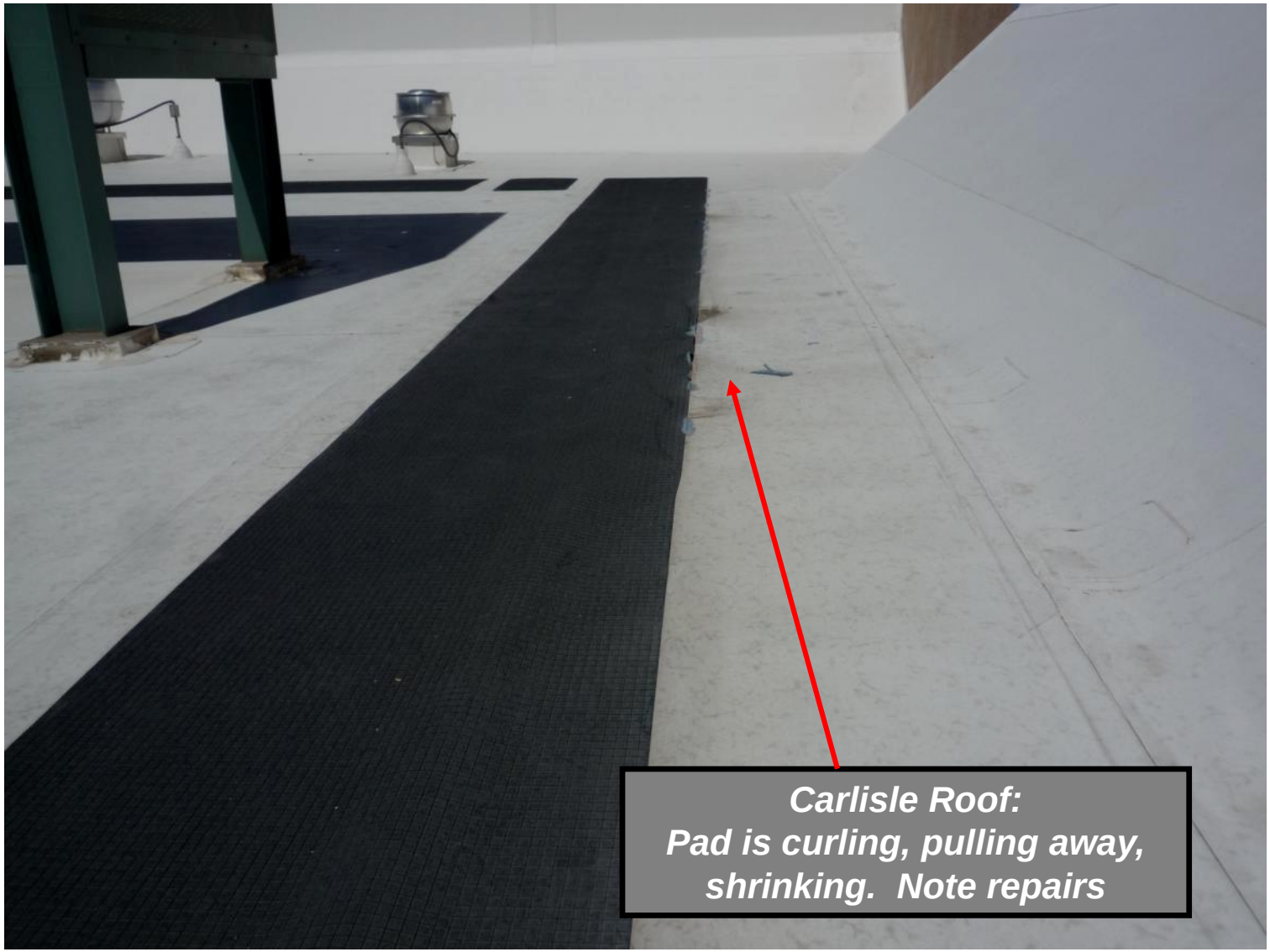
Scrim showing and frayed, heat from walk pad and reflection from HVAC unit.

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

Severe delaminating of under walk pad and upper membrane layer.

7 Years Old Carlisle, Hospital Building, Vegas

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7 Years Old Carlisle, Hospital Building, Vegas

5 Years Old, Firestone 40 Mil, Molasky Bldg.

5 Years Old, Firestone 40 Mil, Molasky Bldg.

7 Years Old Firestone, Agasi College, Vegas

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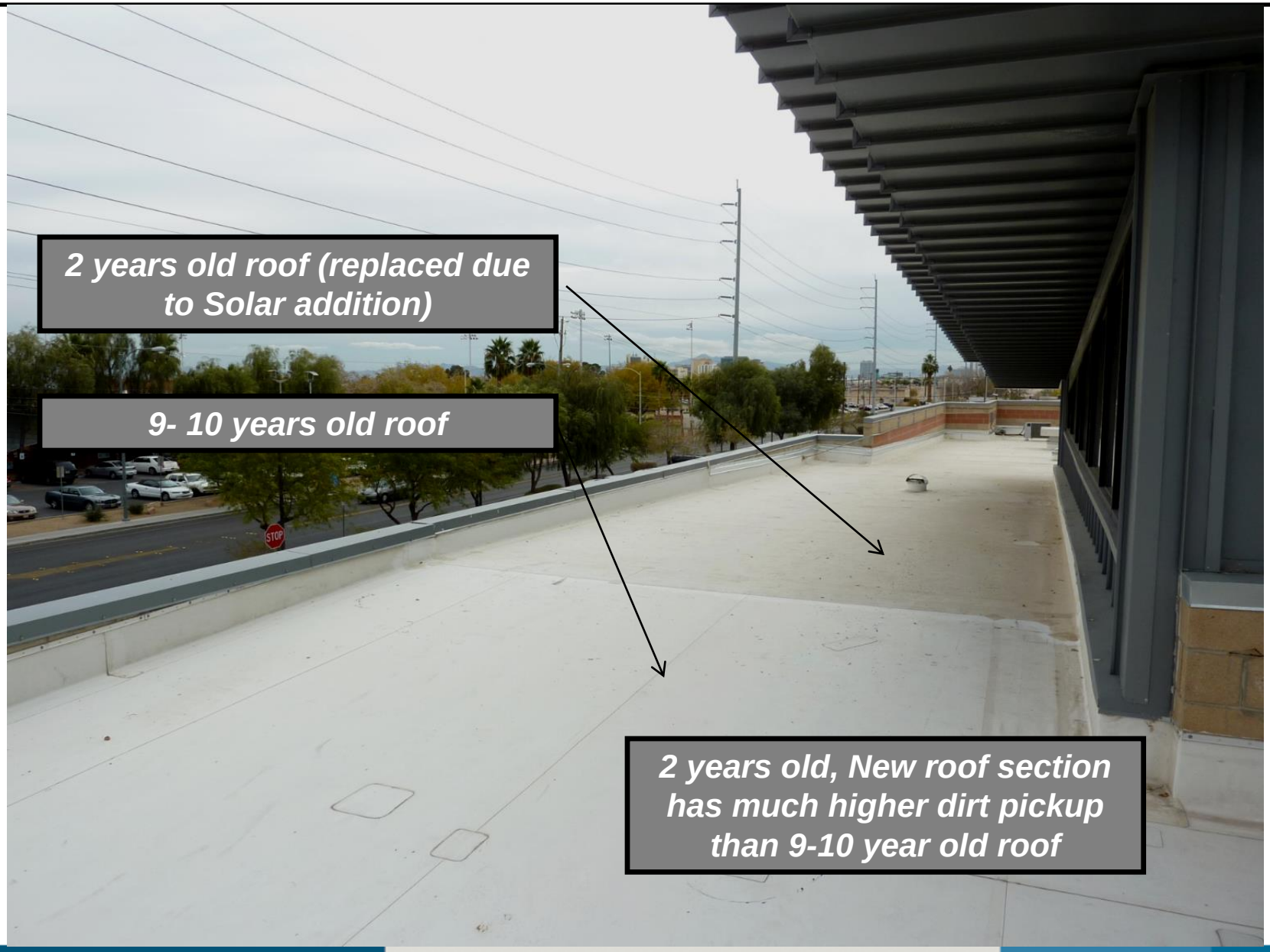
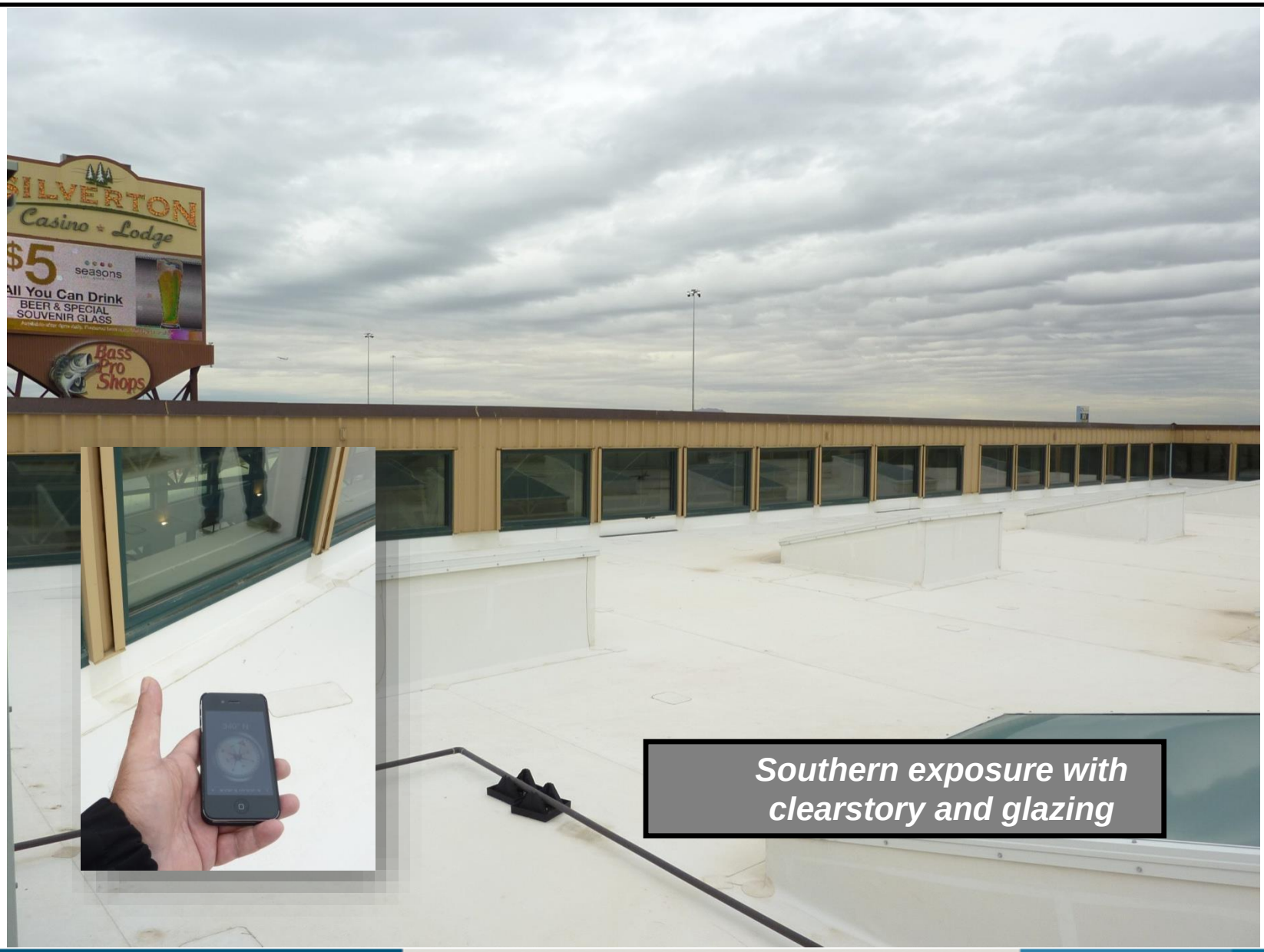
7 Years Old Firestone, Agasi College, Vegas



5 Years Old Firestone, Bass Sporting Goods

5 Years Old Firestone, Bass Sporting Goods



5 Years Old Firestone, Bass Sporting Goods

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 (Private label) – Cracks at seams
  - JP Stevens (Possibly Private Label) – 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.**

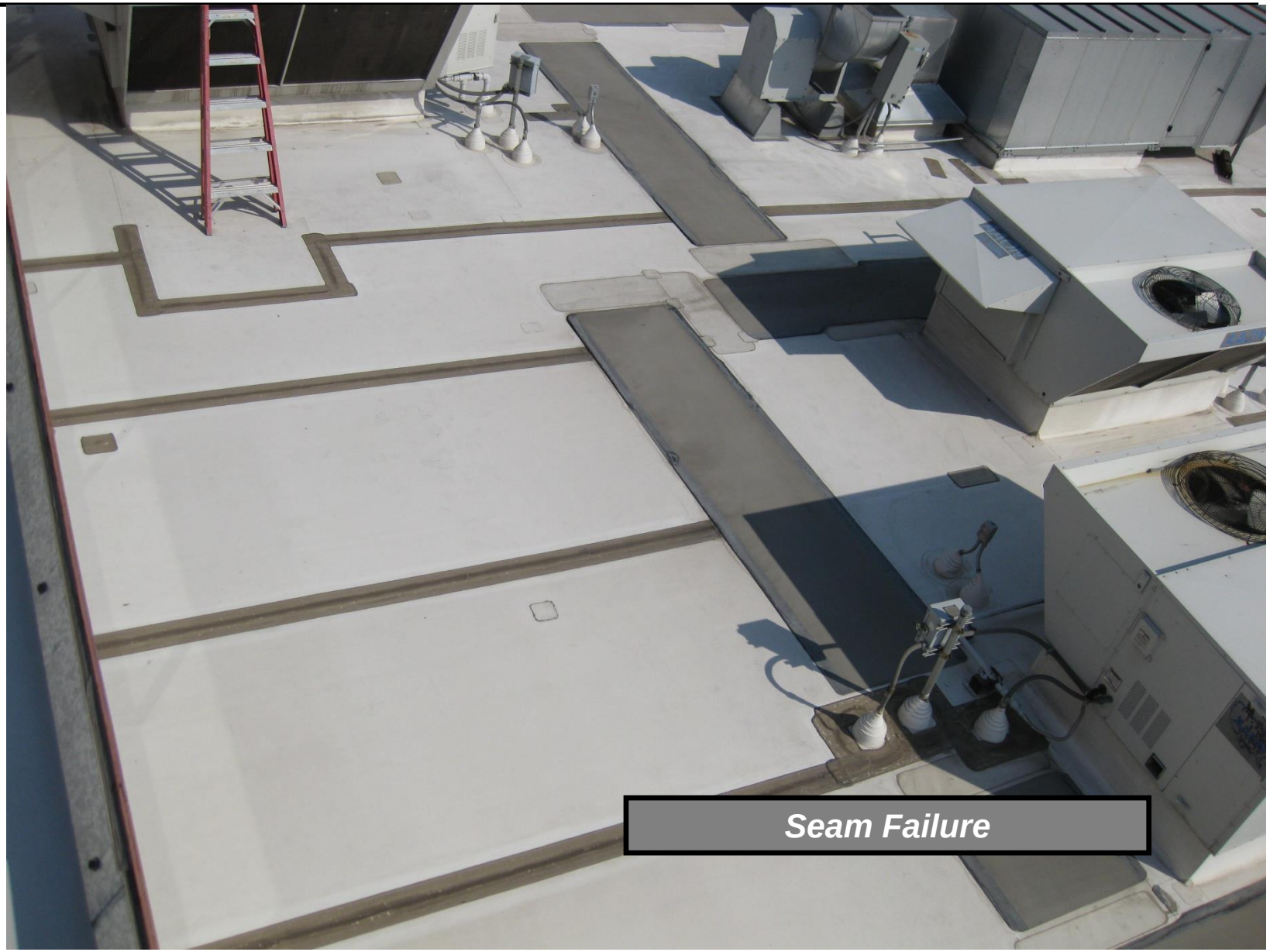
UNLV, LBC Building, GAF 7 years old

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

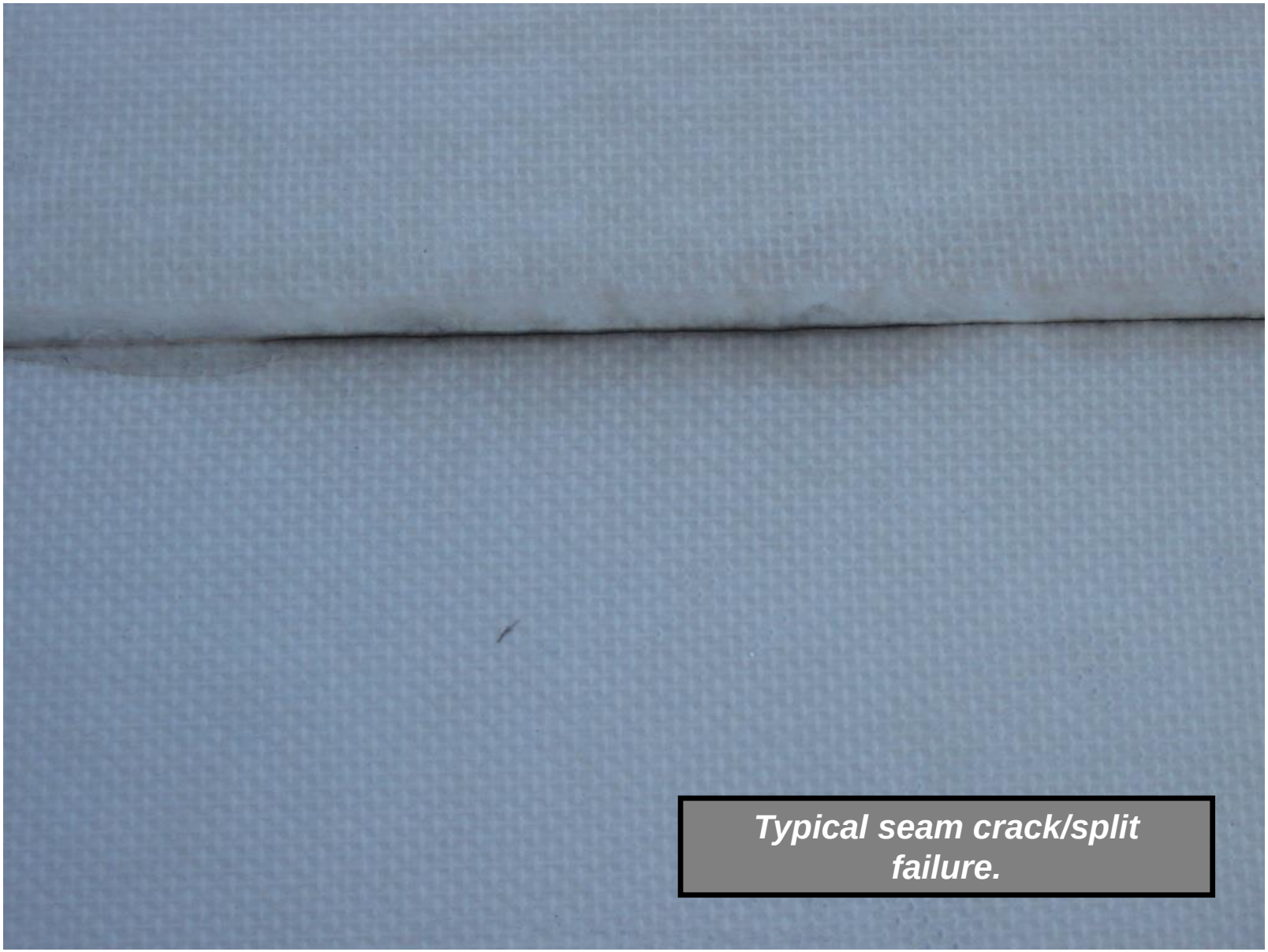
UNLV, LBC Building, GAF 7 years old

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



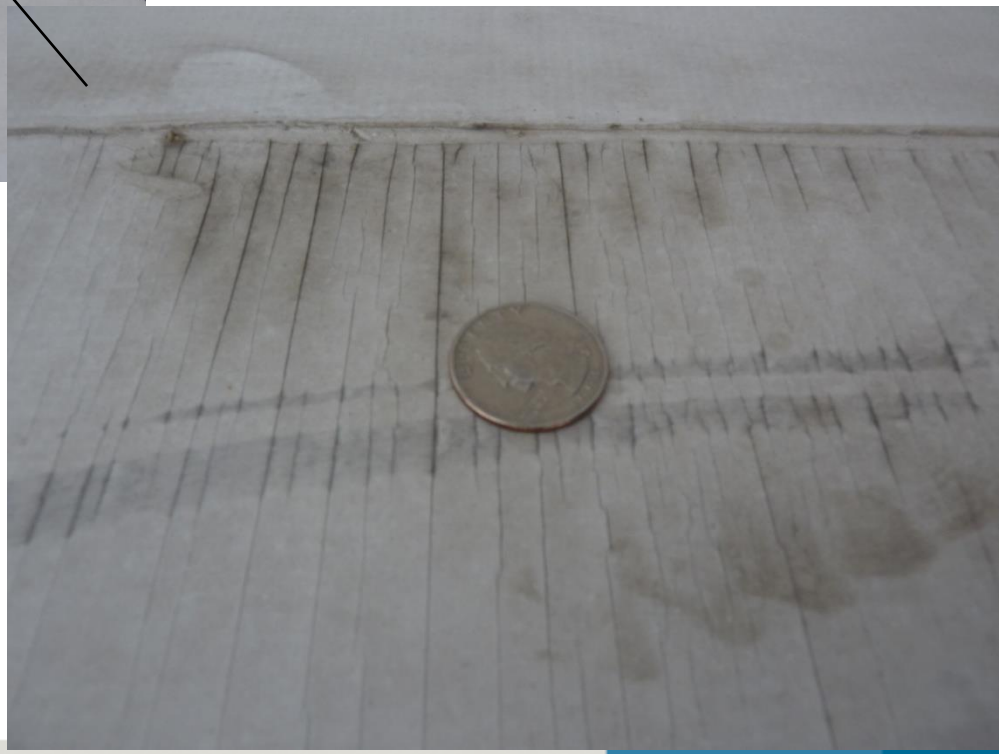
Typical seam crack/split failure.

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

UNLV, ARC Building, GAF TPO 2.5 years old

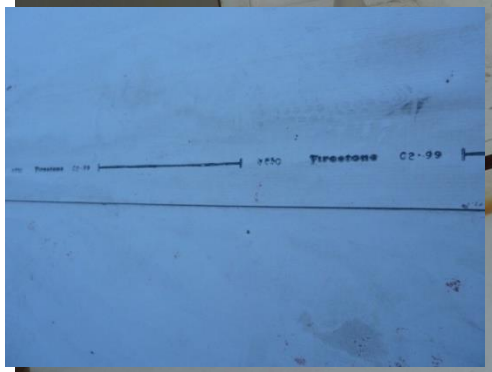


This replacement GAF roof is less than 3 years old!

UNLV Bookstore, Firestone 11 Years Old

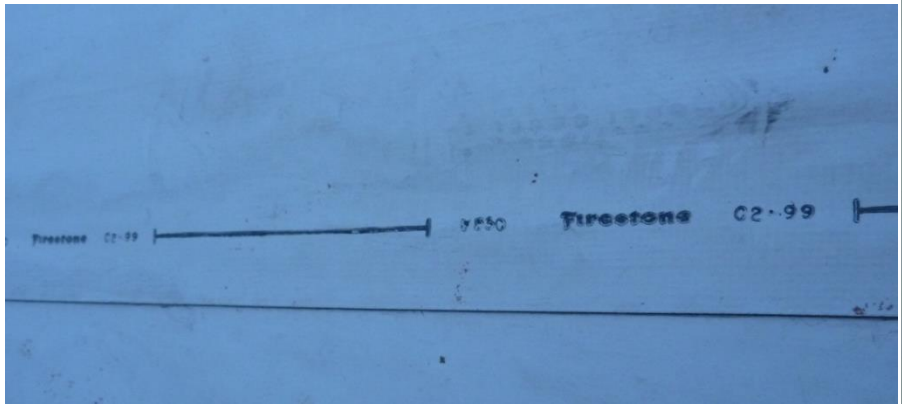
UNLV Bookstore, Firestone 11 Years Old

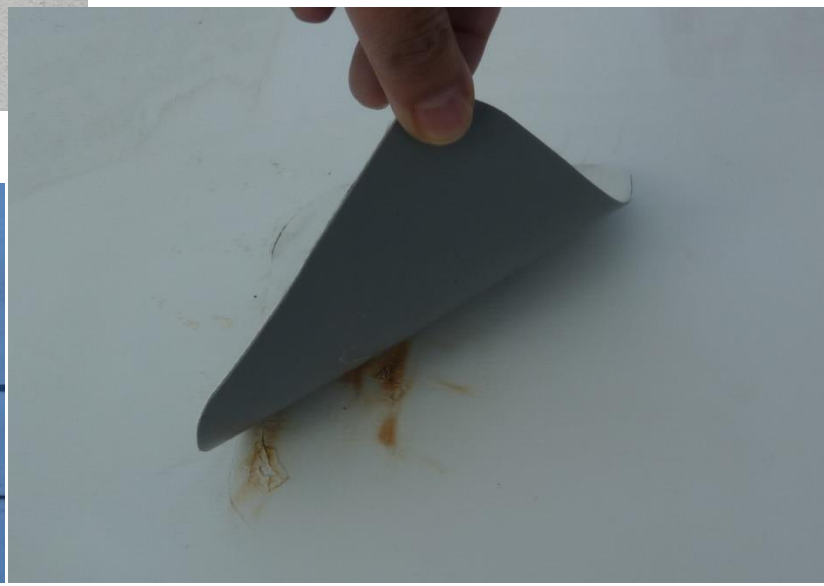
Roof has south facing stucco parapet. No heat related failures were observed



UNLV Bookstore, Firestone 11 Years Old

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





Las Vegas TPO Round 2

- Six Carlisle Roofs, 10 - 15 Years Old.
- Planet Hollywood (Formerly the Aladdin)
- Town and Country Ford
- Sunset Station Casino
- Las Vegas Valley Water District
- Country Club Towers
- Southwest Medical Associates
- Similar issues:
  - Failures due to heat and reflected light
  - Walk Pads
  - Surface Deterioration and Chalking

Aladdin Hotel – Planet Hollywood

Carlisle Roofs – 12 years Old

Walk pad damage

Typical damage at walk pads

Seam and walk pad issues

Town & Country Ford Dealership

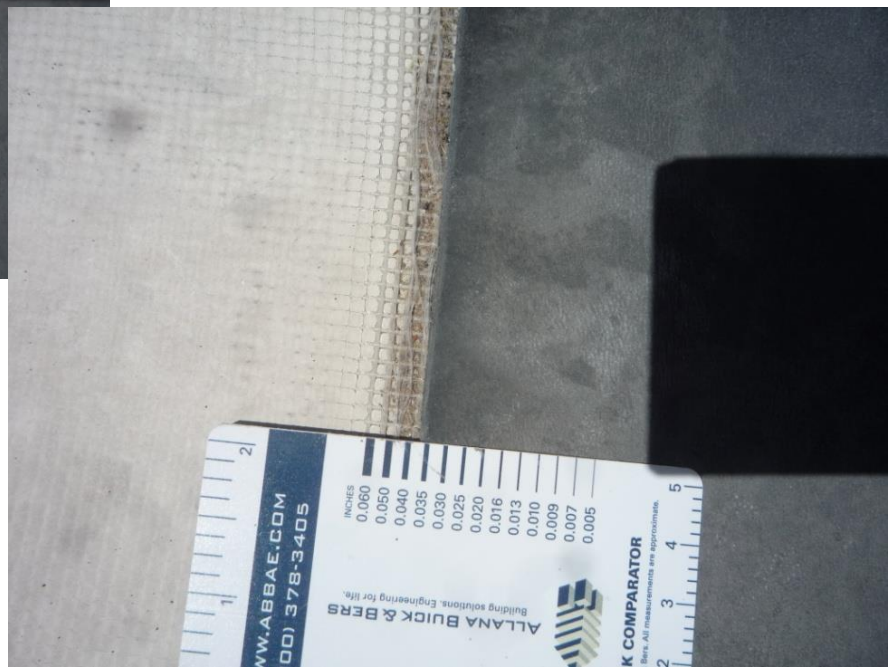
Carlisle Roof

Extensive Damage to Membrane Surrounding A/C Units

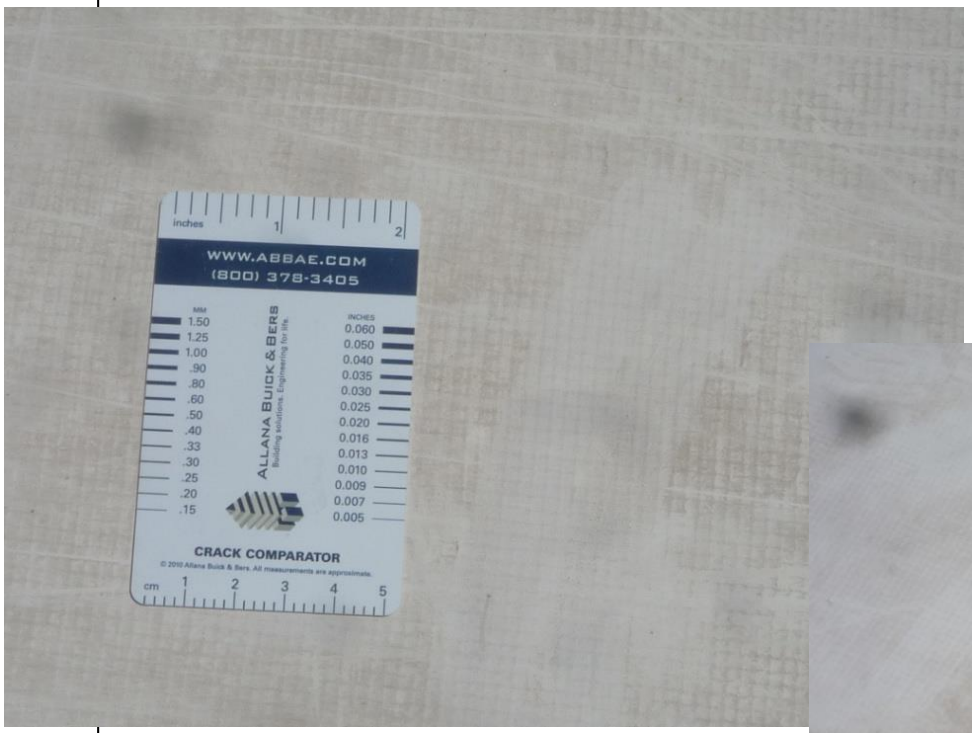
UV Damage at North Parapet

UV Damage at walk pad at the bottom of the transition ladder

UV Damage at Edge of Walk Pad



Chalking



Sunset Station Casino – Cinema Area

Oldest Roof in Group – 14 years old, in the best shape of all.

North Parapet Wall

North parapet wall shows minimal signs of change in the roof membrane.

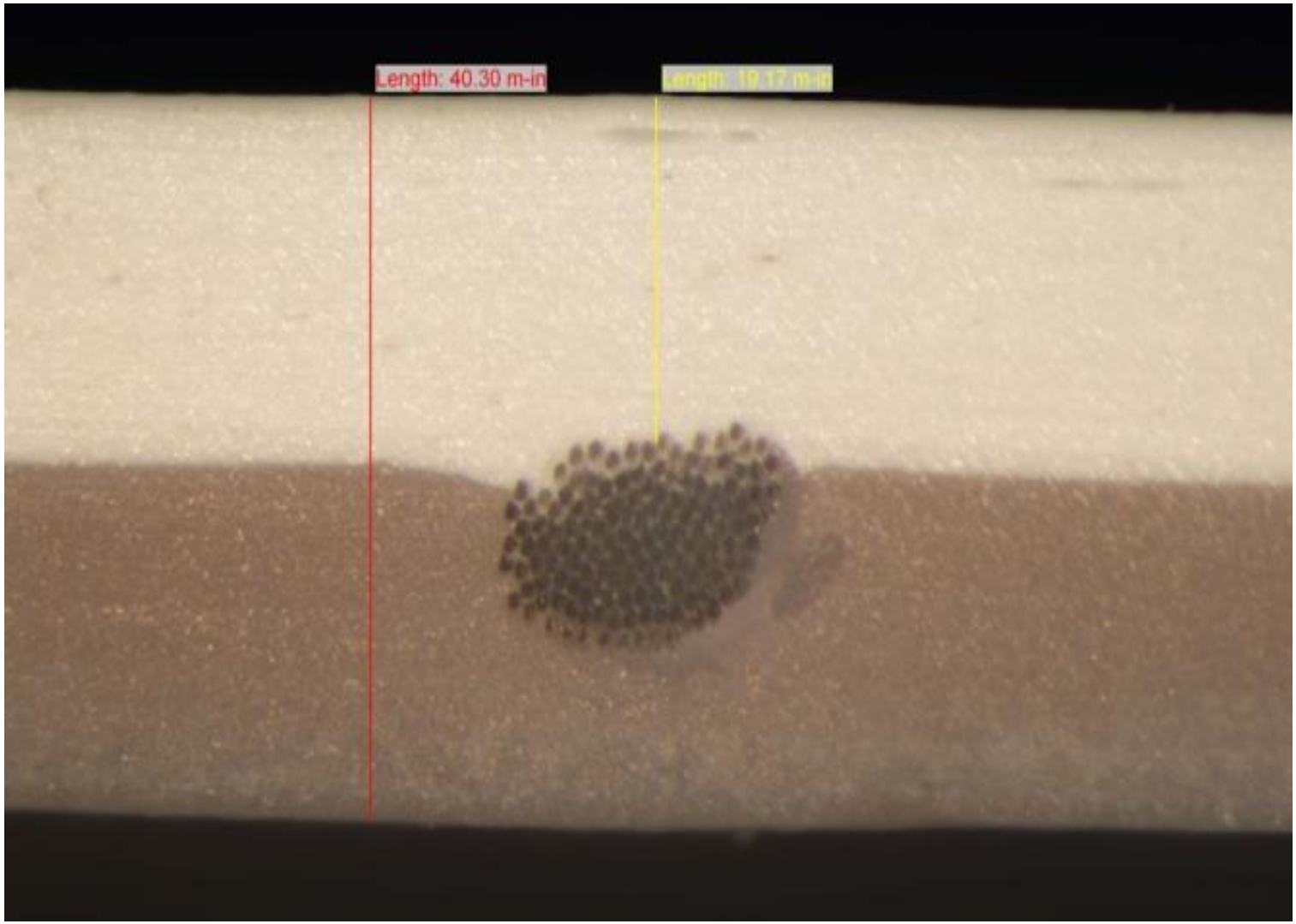
Grease Fan

Minimal damage, possibly due to type of vegetable oil used.

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

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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.
- Neither PVC or TPO lose appreciable membrane thickness.