Forensic Analysis of Roofing Systems Examples of Roof Performance Learn from Failures to Make Roofs More Sustainable!

International Roofing Expos

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

ABBAE Firm Overview

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

Staff & In-House Expertise

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

ABBAE Building Expertise

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

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

ABBAE Core Services

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

OVERVIEW

- Roofs can, and should, last 30 years or more – *but many do not even come close!*
- Today's presentation – analyze premature failures, either due to construction or design defect
- Provide lessons learned from forensic evaluation of roof performance
- Provide lessons learned about various roof types and their sustainability
- Serve the client by creative problem solving

Three Case Studies

- Failure of Metal Roof System
- Failure of Tile Roof Systems
- Study of Steep Roof's Shortened Life
- Study of Single Ply Long Term Sustainability
- Review of air barrier design Issues
- Overview of Foam Roof- Polyurea Coating

Specific Session Objectives

- Learn to look past the obvious cause of failure
- Learn from mistakes of designers and applicators
- Learn tips on performing forensic investigation
- Learn how to avoid common mistakes made during installation of roof assemblies
- Learn about design limitations and common design mistakes

Session Objectives Continued…

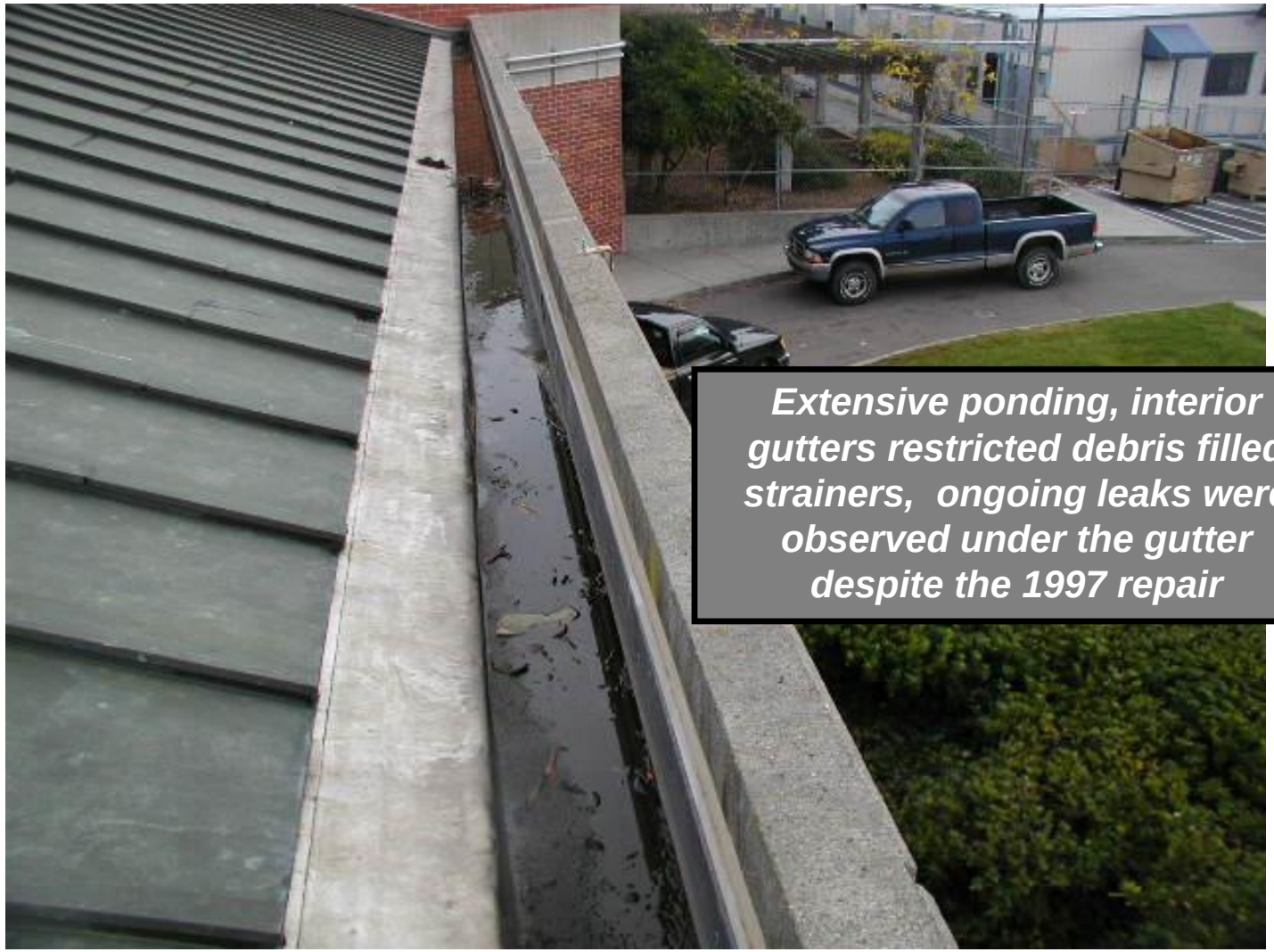
- Learn to evaluate the difference between improper roof design, improper installation and lack of maintenance
- Learn the difference between “express” warranty and “implied” warranty
- Recognize the Design-Build role assumed by roofing contractors
- Learn how the 10 year statute of limitation applies to defects in new construction and reroofing

Case 1: Forensic Investigation of Metal Roof Failure

CASE OVERVIEW

- Public Library in Northern California
- Multiple types of roofs 20 year old Building
- Been leaking since original construction
- In 1997 – Owner's original consultant believed the low sloped roof, gutters and equipment well was leaking
- Library replaced low sloped roof with single ply, new metal roof over equipment wells and new gutter liners.
- Later, building was gutted in 2003 for remodel and upgrade for new technology
- Extensive leaks were noticed on the walls, ceilings, along the wall to ceiling connection
- We were asked to investigate the source of leaks and recommend solutions

Roof Type: Batten metal roof on a 60,000 square foot public library

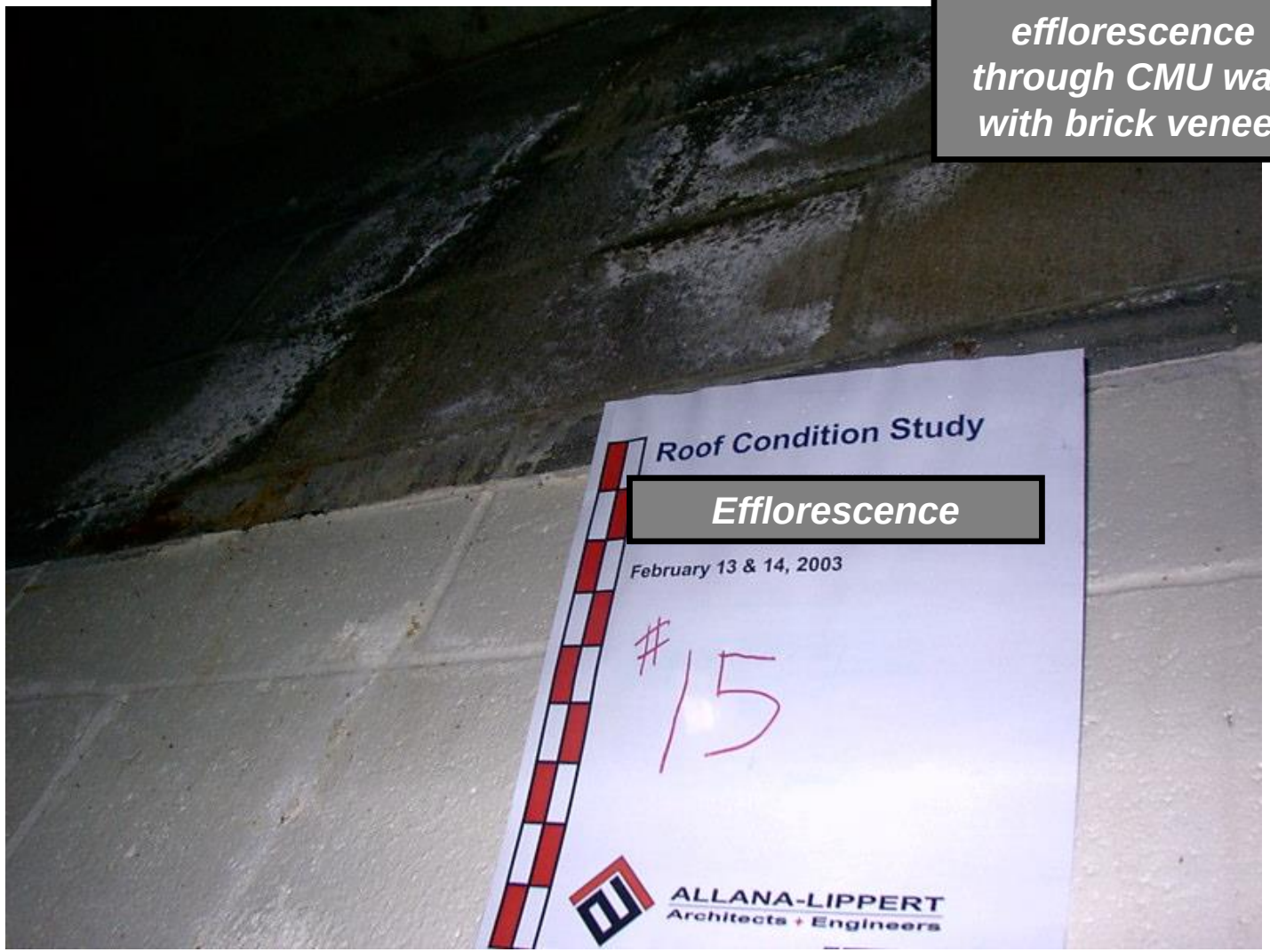


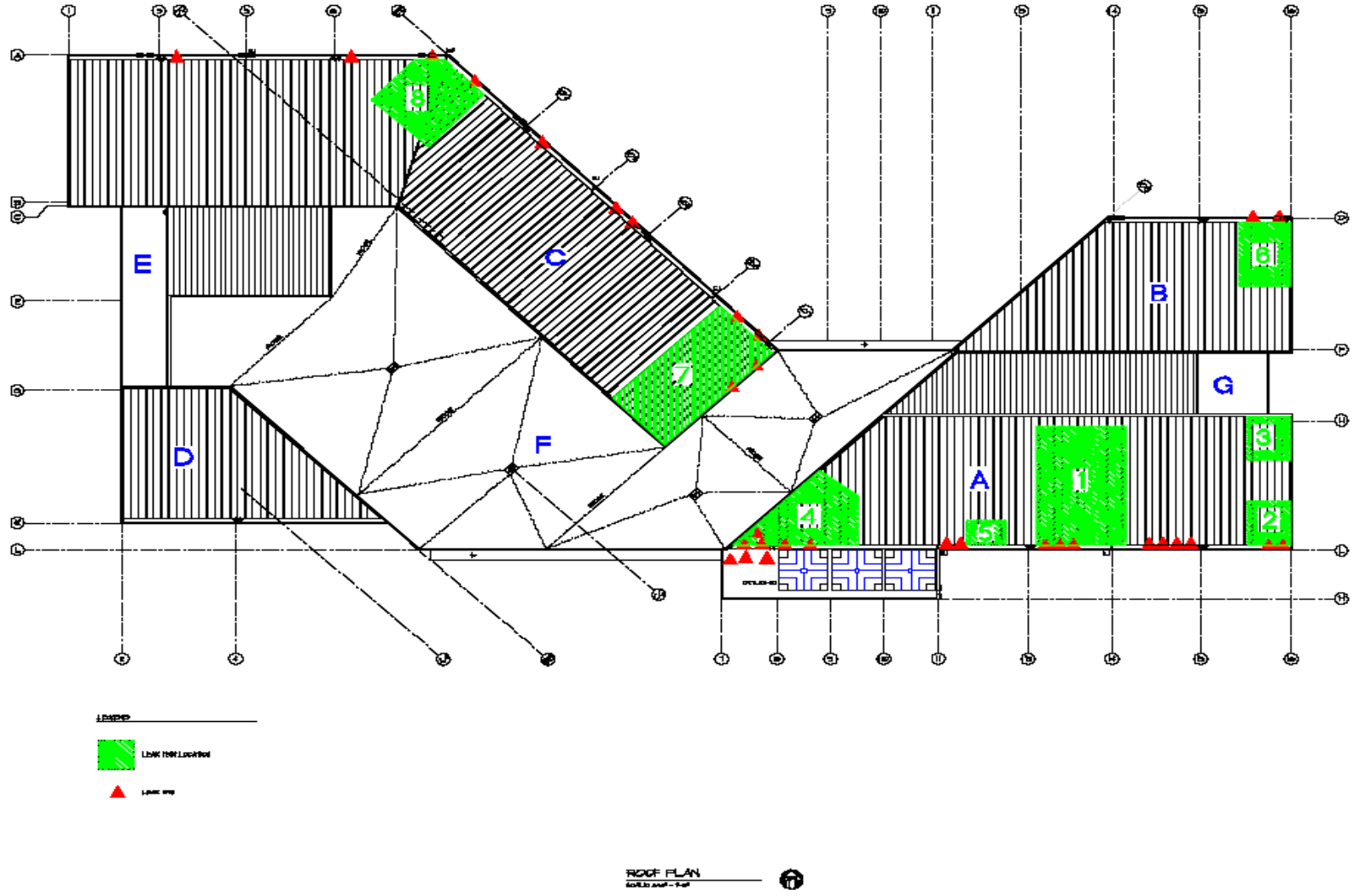
Extensive ponding, interior gutters restricted debris filled strainers, ongoing leaks were observed under the gutter despite the 1997 repair

Typical strainer clogged, and gutter filled with standing water

Evidence of significant leaks in the past, below the internal gutters and confined rake wall that already been repaired, once

Evidence of efflorescence through CMU wall with brick veneer

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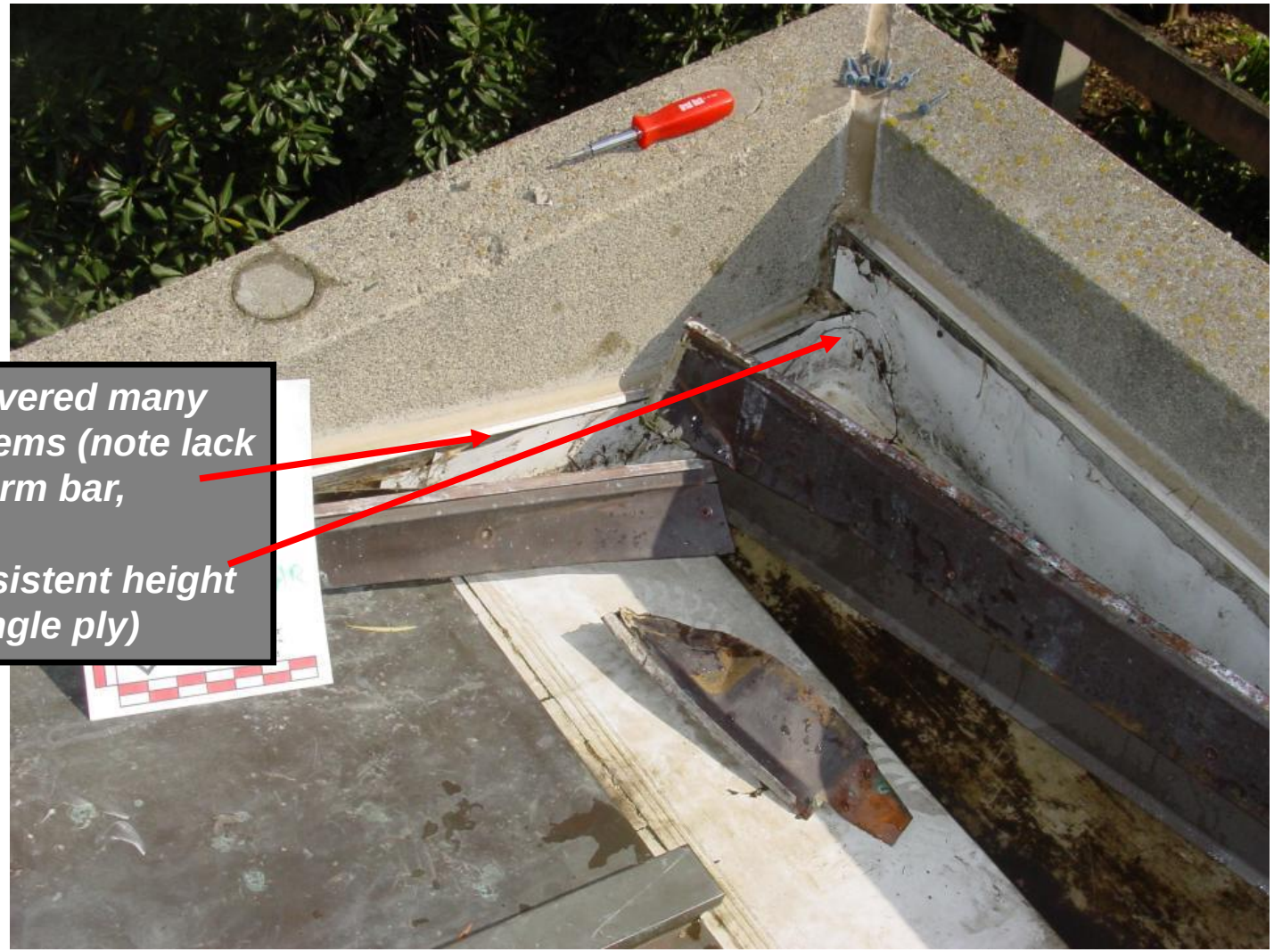
ROOF PLAN

FORENSIC METHODOLOGY

- Review plans and specifications
- Visual inspection
- Engineering analysis of materials
- Code compliance investigation
- Water testing
- Destructive testing
- Preparation of a defect report and budget

Testing at Gutter

- Destructive Testing
- Water Testing
- Visual Assessment
- Measurements



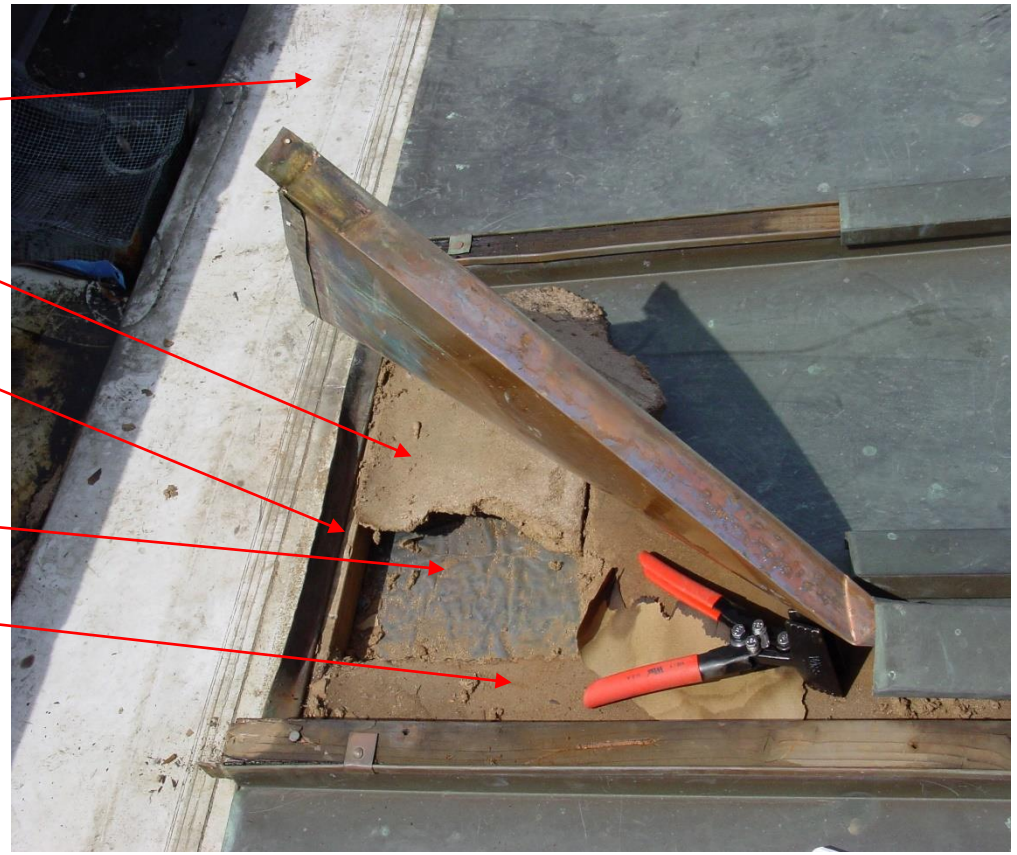
PVC gutter Liner

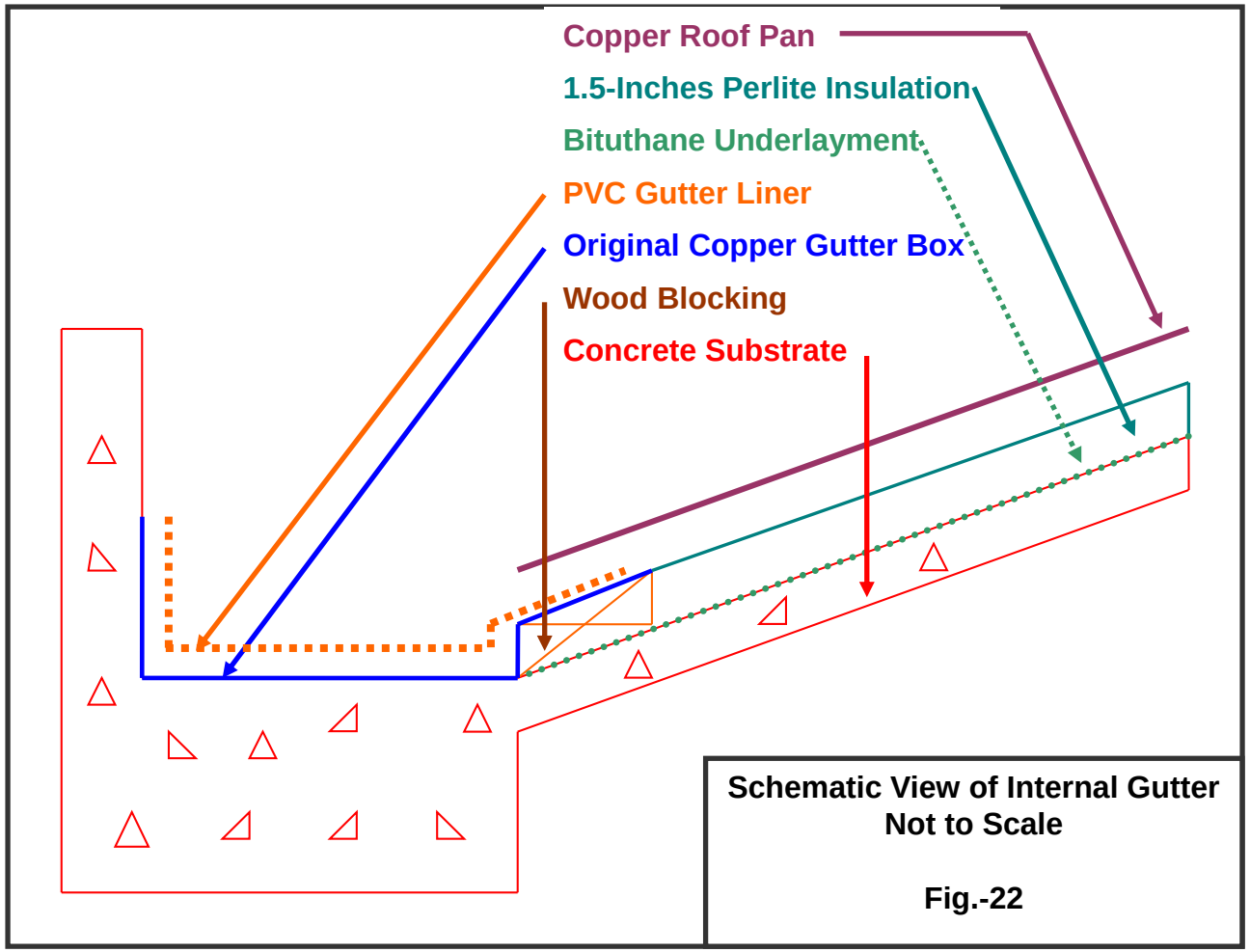
Original copper gutter liner

2x4 used to support copper gutter

Underlayment

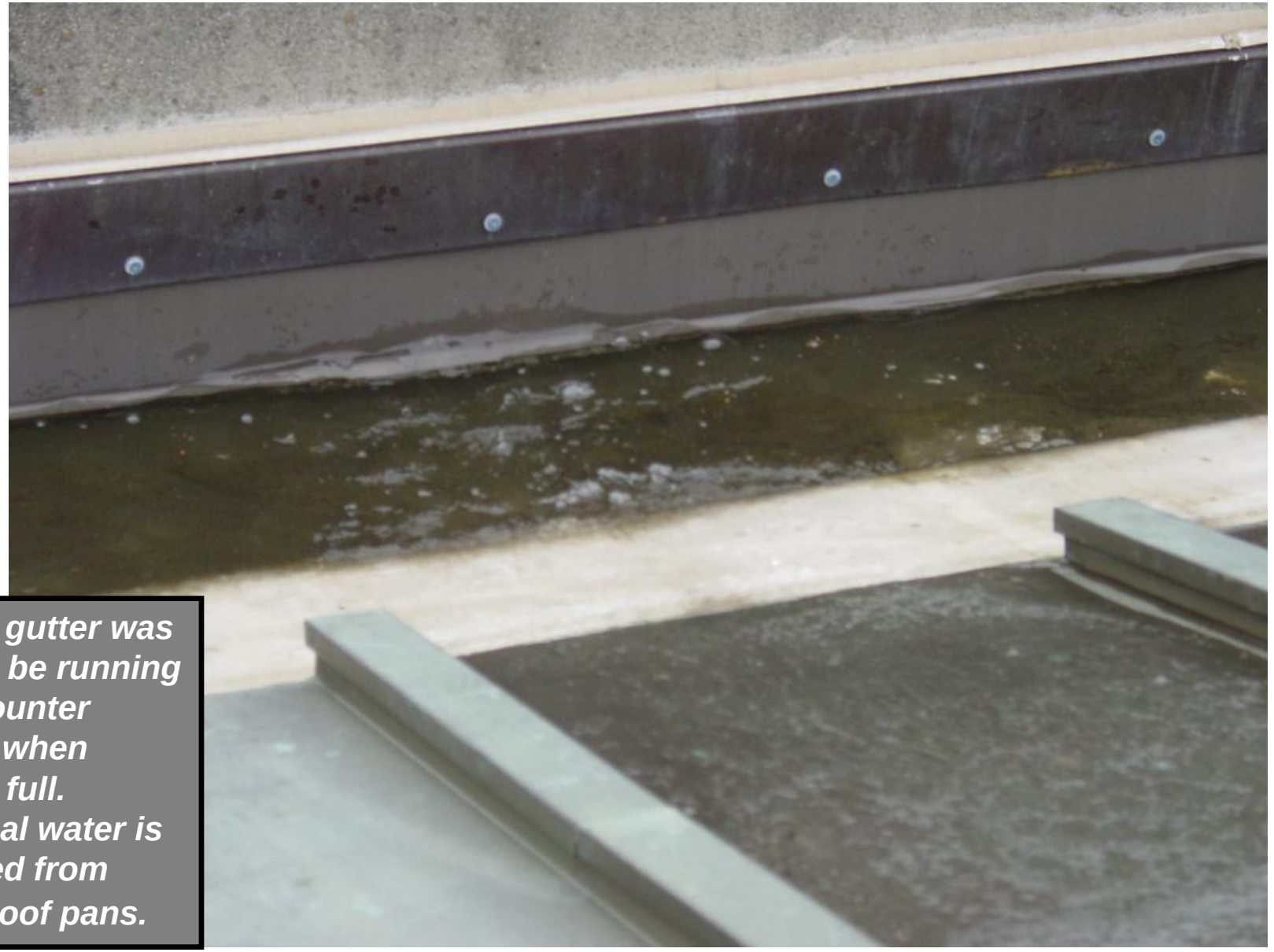
1.5-Inch perlite insulation





Schematic View of Internal Gutter
Not to Scale

Fig.-22

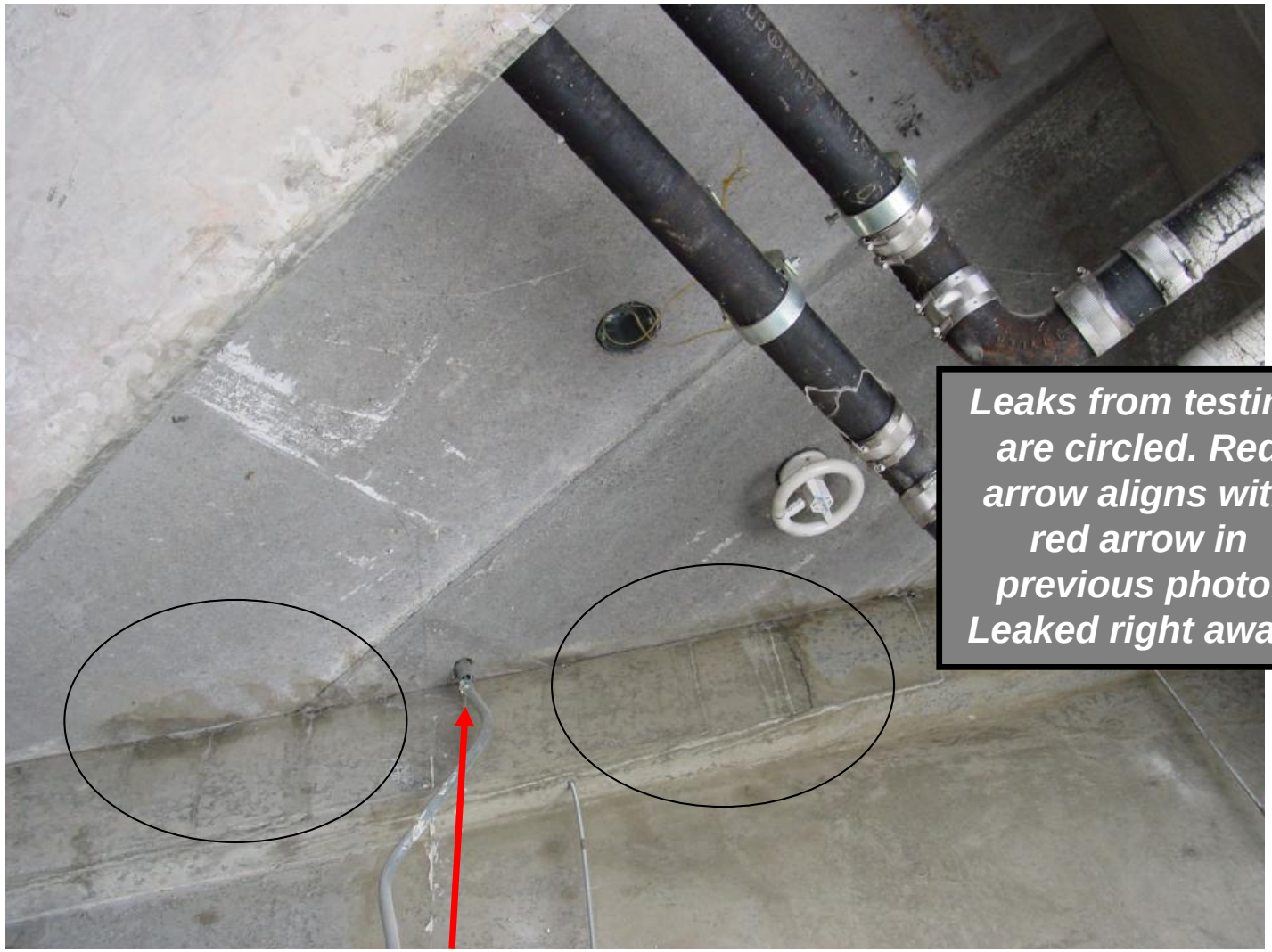


Water in gutter was found to be running under counter flashing when gutter is full. Additional water is presented from copper roof pans.

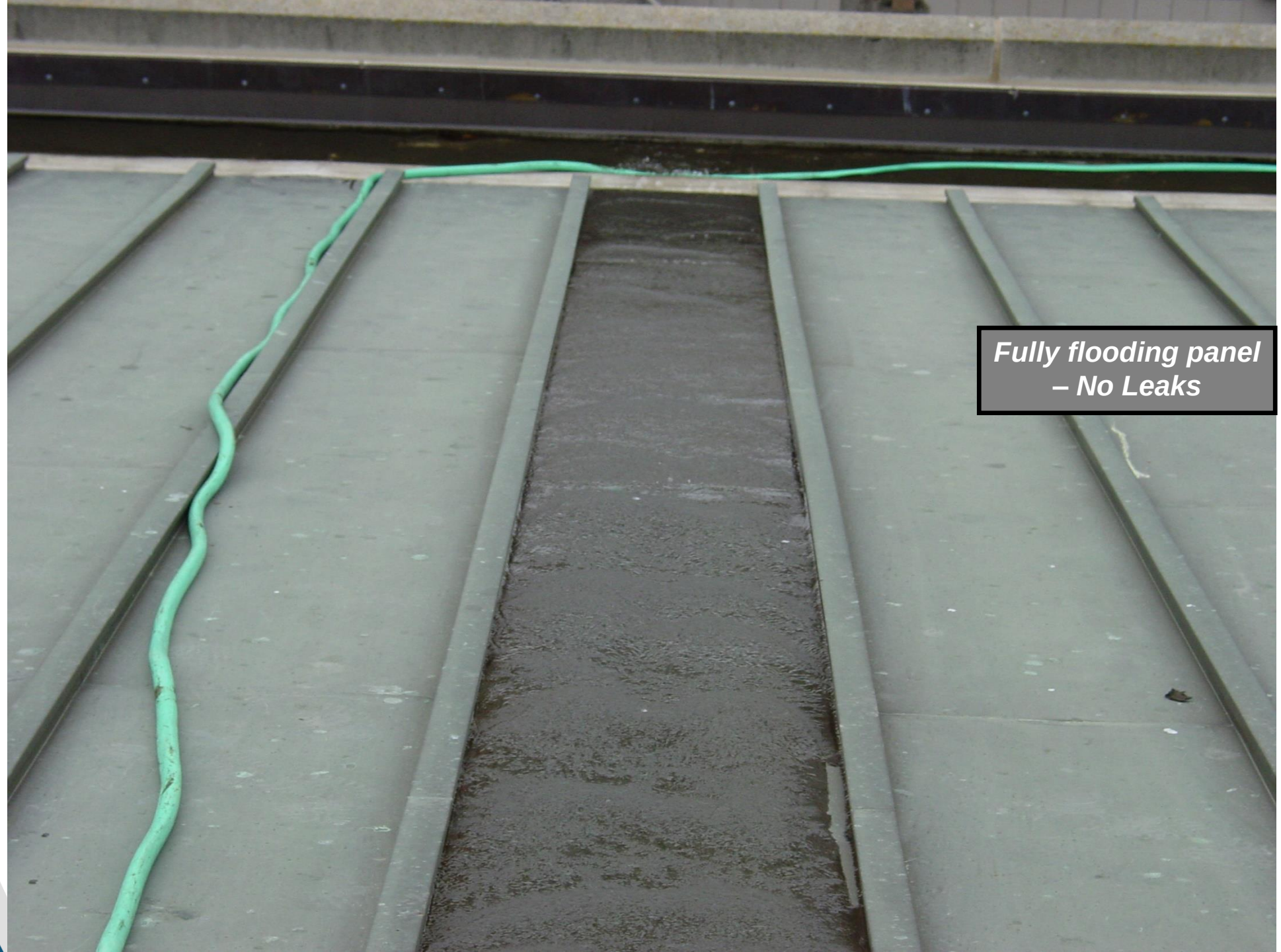
Testing at Confined Rake

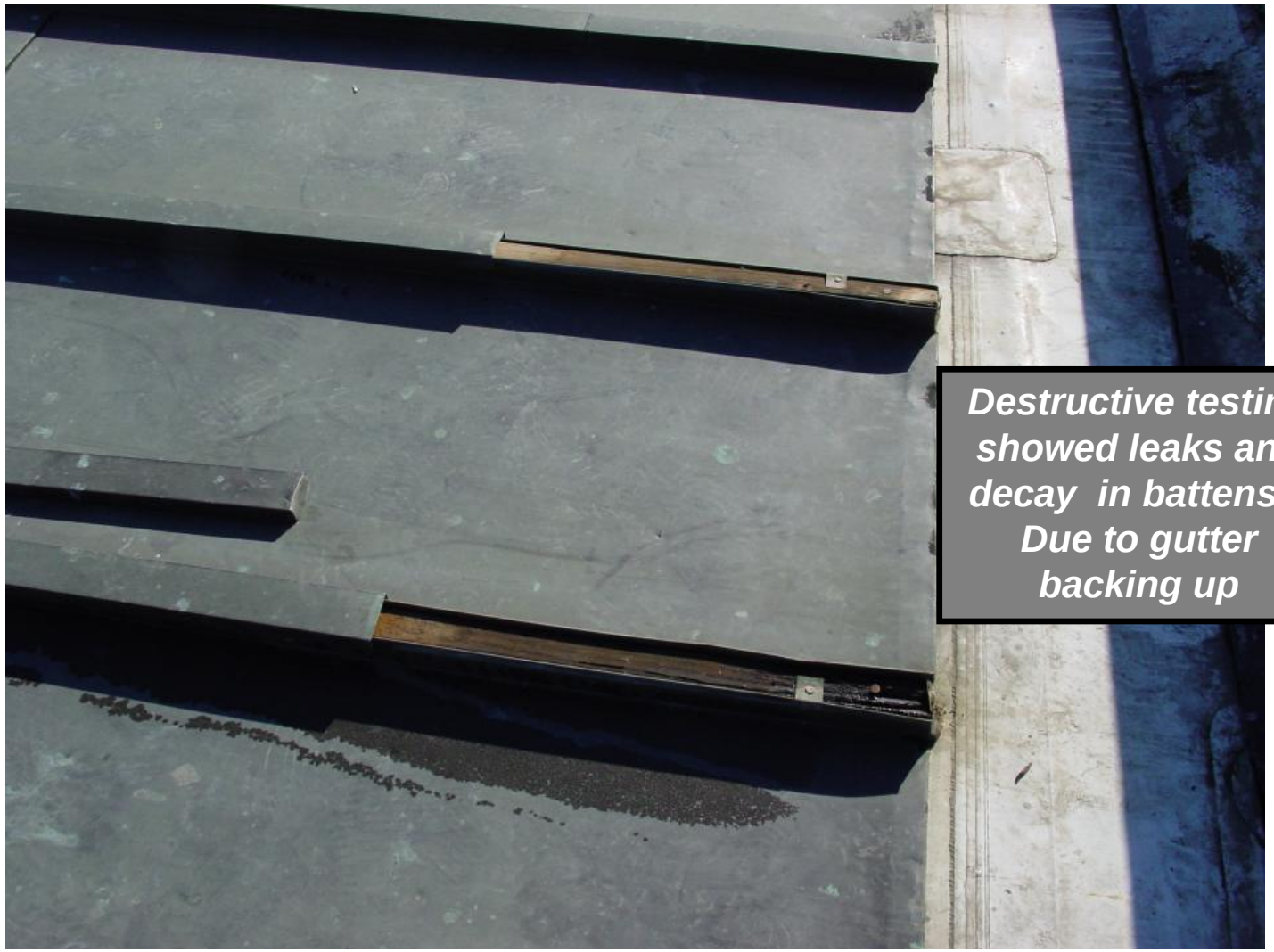
- Destructive Testing
- Water Testing
- Visual Assessment
- Measurements


Prepare for testing of one possible leak source - walls



Leaks from testing are circled. Red arrow aligns with red arrow in previous photo. Leaked right away!

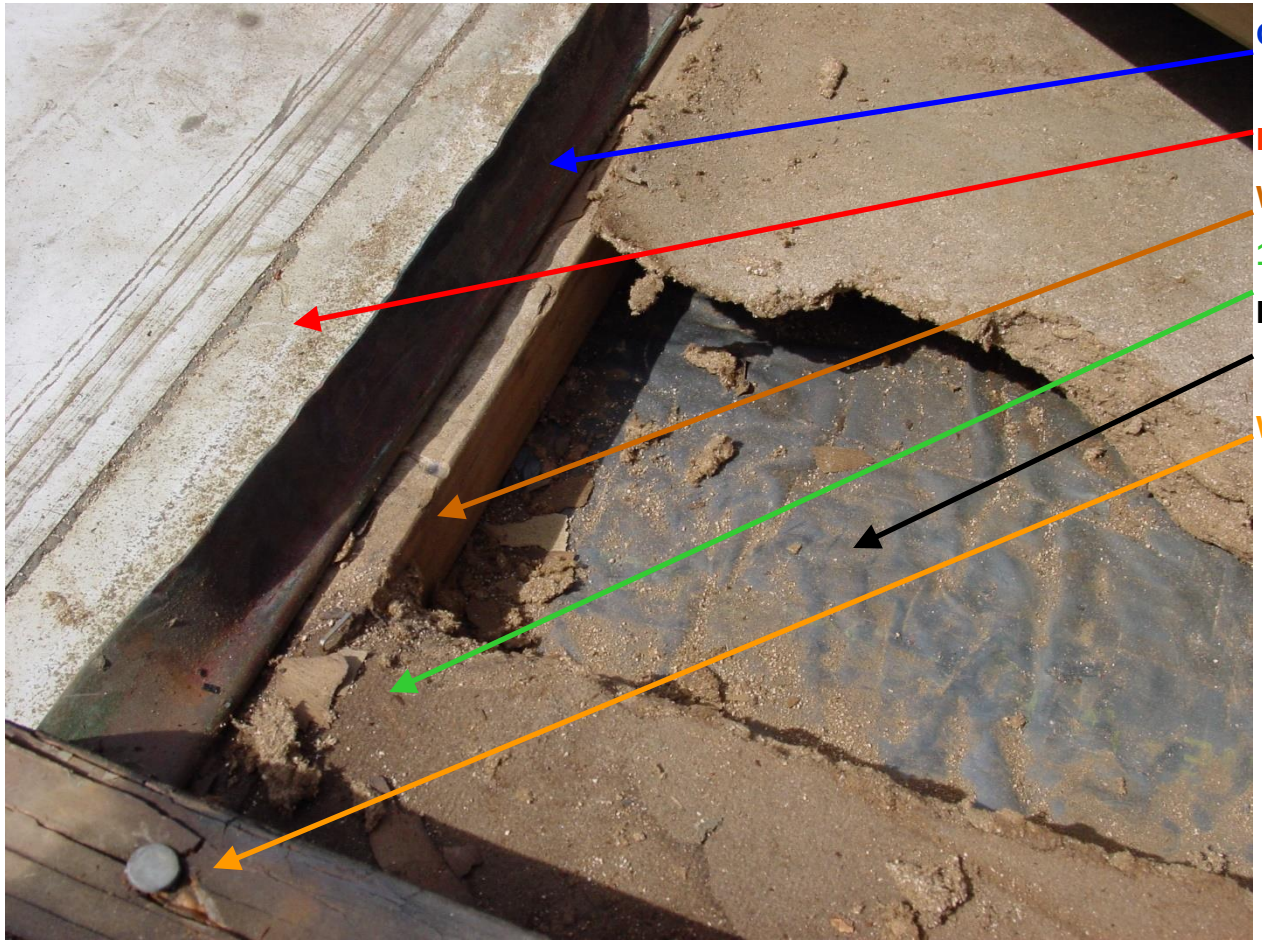

Fully flooding panel
– No Leaks



Destructive testing showed leaks and decay in battens – Due to gutter backing up

Batten end not properly constructed – did not allow water to weep out

Photograph of Conditions Found During Destructive Probing



Original Copper Gutter Liner

PVC Gutter Liner Added Later

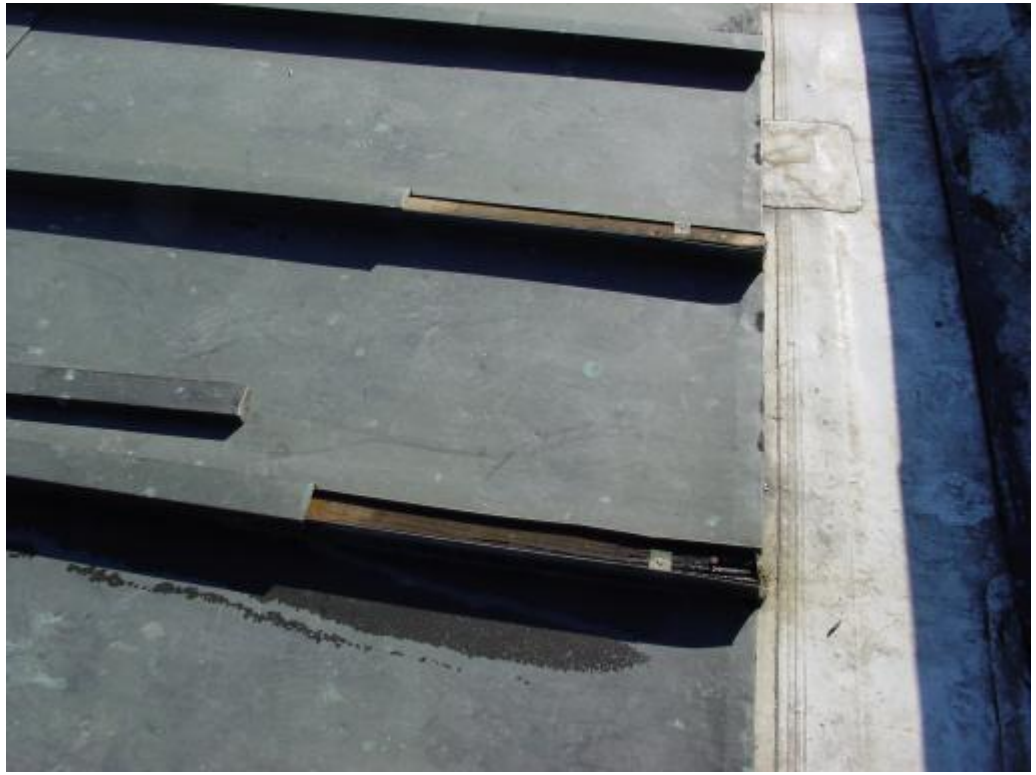
Wood Blocking

1.5-Inches Perlite

Bituthane Membrane

Wood Batten

Recommended Repair: Copper Roof



- Remove & Store Copper Roof
- Demolish Flashings
- Demolish Perlite Insulation
- Install Treated Wood Stringers
- Install Isocyanurate Insulation
- Apply 2 Layers of Underlayment
- Reinstall Copper (90% Reuse)
- Install New Copper Flashings
- Perform Concurrent Gutter Repairs
- 50 Year Life Expectancy

Recommended Repair: Internal Gutter

- Demo PVC and Copper Liner
- Demo Flashings
- Cut Large 8x12-inch Scuppers
- Cap Existing Outlet Drains
- Install Concrete Sloping Fill
- Install PVC Gutter Liner
- Install Flashings
- Provide Copper Collector Heads
- Install Copper Downspouts
- Provide Connection To Field Drains
- 50 Year Life Expectancy

Repair Costs: Recommended Repairs

Description	Cost	Life Expectancy
Restore Copper Roof	$ 488,000	50 Years
Rebuild Internal Gutters	$ 47,000	50 Years
Rebuild Rising Walls	$ 48,000	100 Years
Total Estimated Repair Cost (+/- 15%)	$ 583,000	

Lessons Learned

- Previous studies were visual only, did not identify all the problems
- Previous repairs were unsuccessful
- Isolating the building components was necessary to identify source of leakage
- The original design was also suspect (Gutter design, improper placement of roof underlayment, improper design and construction of brick cavity wall

Case 3: Investigation of Tile Roof Failures

CASE OVERVIEW

- Construction defect litigation case in Northern California
- 7 year old concrete tile roof
- Many leaks visible below, in living areas
- Visible cracks in tile
- There were some conditions of concern
  - Tile layout
  - Roof to wall conditions
  - Valley Flashing
- We were asked to investigate the source of leaks

Tile Roof Failure

FORENSIC METHODOLOGY

- Review of plans and specifications
- Visual inspection
- Water testing
- Destructive testing
- Review compliance with Manufacturer’s published literature
- Code compliance review
- Preparation of a defect report

Significant leaks in ceilings

Water tested the gable roof area above the confined rake

Water penetration but this was not the primary source of leak in unit below. Improper membrane was utilized as wind block. 30lb felt was used instead of 9” pressure sensitive adhesive membrane recommended by material manufacturer.

Exposed fastener. Ridge tile is not lapped properly.

Water had been leaking through the tiles however, could not reproduce the leak was because the owner's last attempt at repairs included replacing the deteriorated felt underlayment and mastic seal.

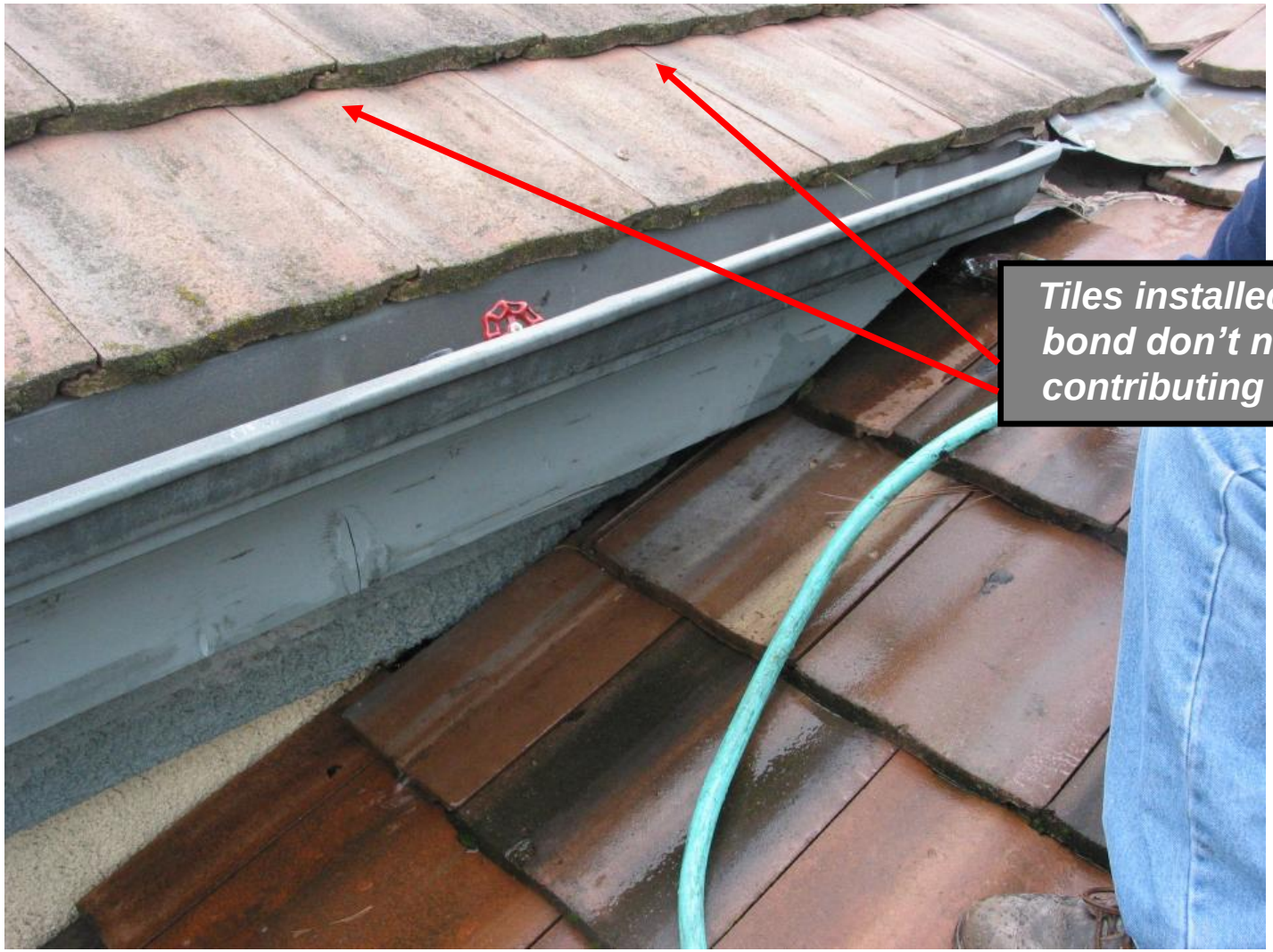
Much of the tile was installed with staggered joints. We observed a very high incidence of broken tile corners, which was primarily the source of leaks.

Some roofs had tile laid in straight bond method, which had fewer broken tiles but instinctively seemed wrong

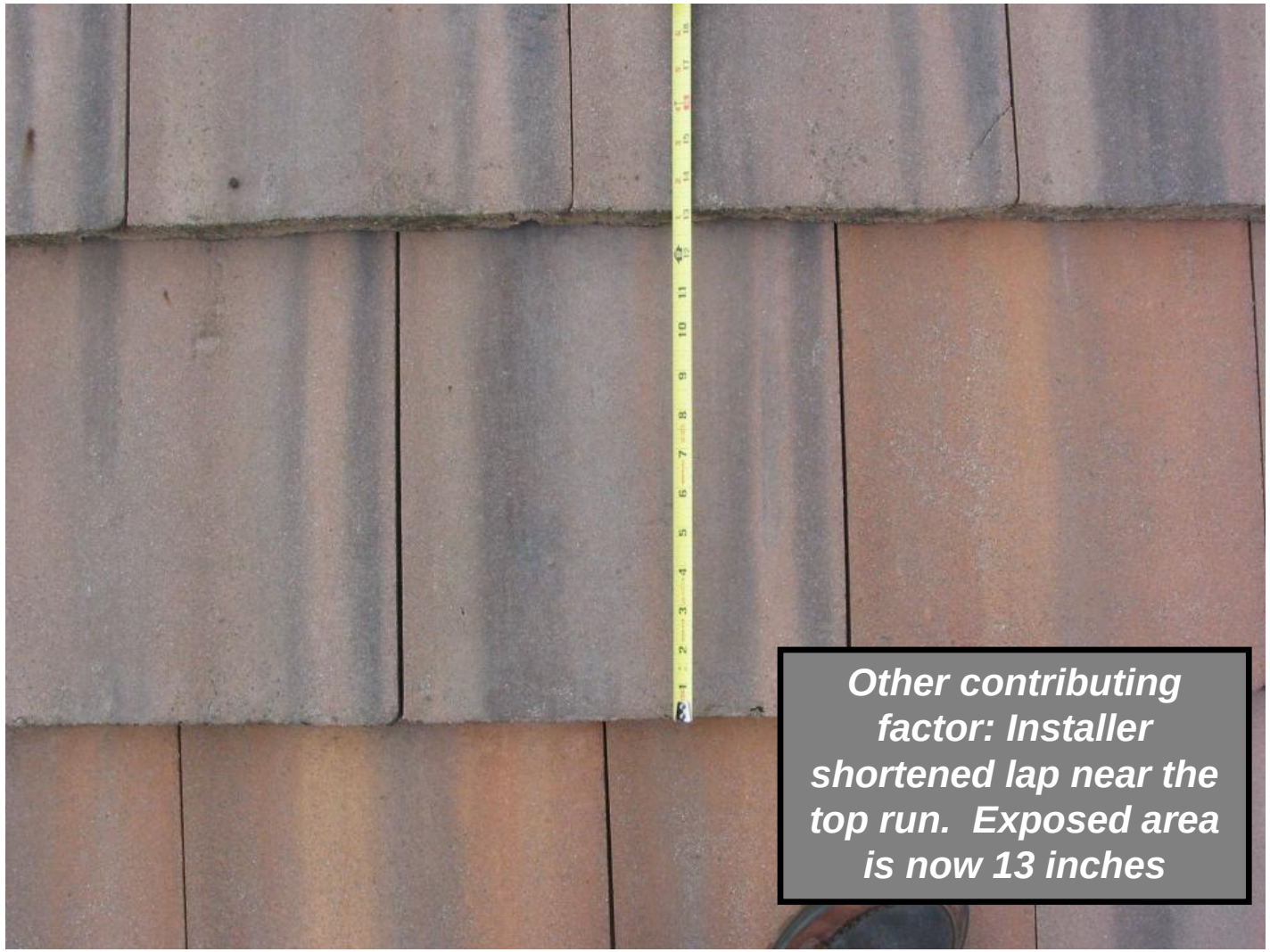
What is the correct way to install this tile, broken bond or straight bond?

ANSWER: The manufacturer of this time recommends the straight bond method.

ANOTHER DEFECT: Joints in tile not parallel and are too close, contributing to breakage



Tiles installed in a broken bond don't nest properly, contributing to breakage.



ANALYSIS OF LEAK TESTING

- We knew water was leaking under the tile at broken tile corners and ridge
- The amount of water leakage had deteriorated the felt underlayment.
- Approximately ½ the roof was installed in a straight bond and other ½ was installed in a running bond pattern.
- Adjacent courses of tile were not perfectly parallel and some tiles installed too close together, contributed to breakage.

Roof to wall flashing installed as an after thought, on top of felts

Battens were too short, causing tiles to fall in wrong direction

Lessons Learned

- Tiles, even in the best of conditions, shed only 95% to 99% of water
- Tile breakage, poor flashings and other problems, greatly increase incidental water under tile
- Study manufacturer’s recommended layout and design
- Poorly made tile, straight bond layout not natural or instinctive.
- Manufacturer pulled product off the market!

CASE OVERVIEW

- Large department store in Northern California
- Eighteen years old
- No repairs, no leaks, no problem?
- Purpose of the investigation: Determine longevity of single ply
- 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?

Test Cut Analysis

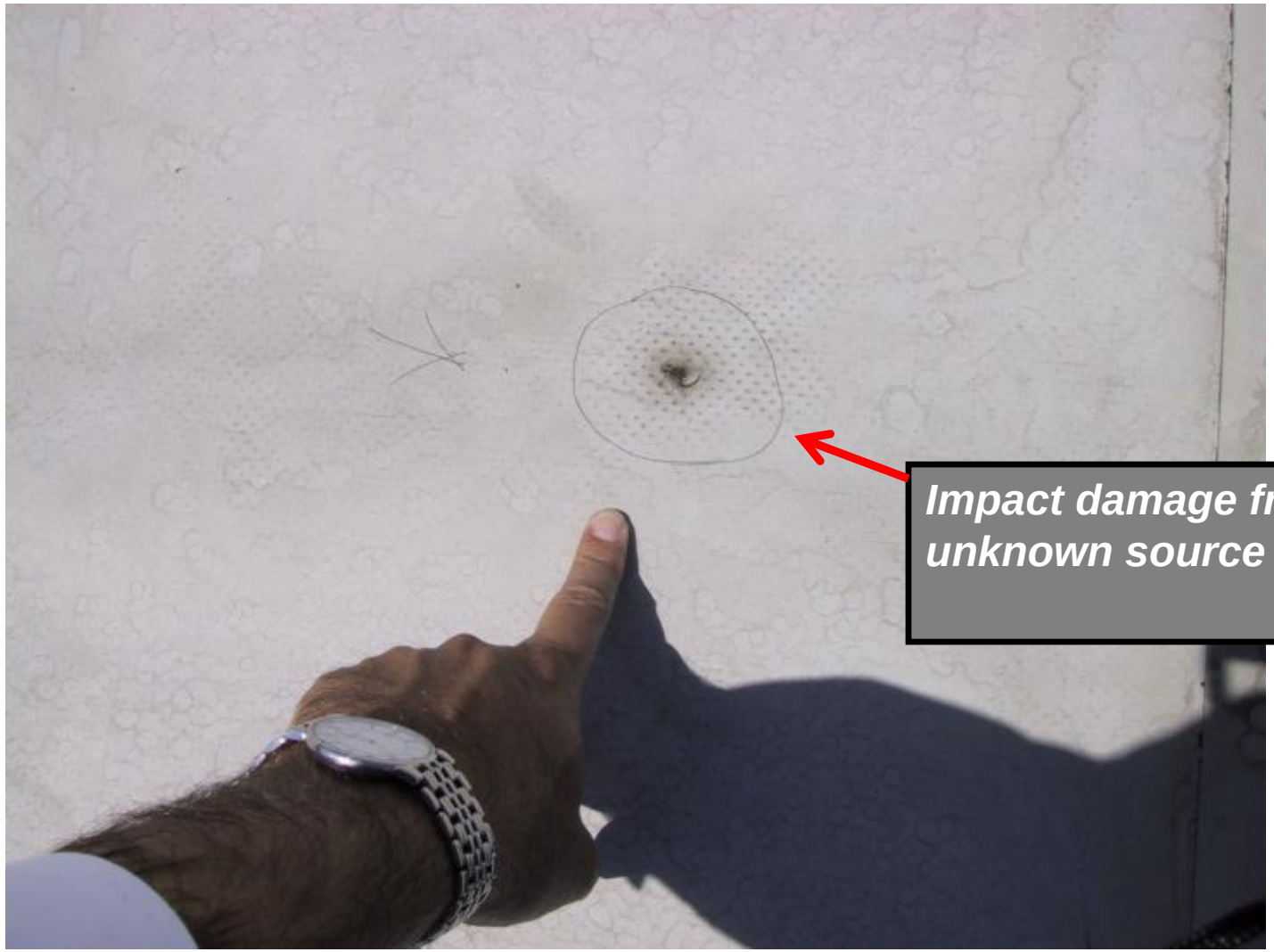
Test cut exposing paper and insulation

Mechanical bar fastener in excellent condition

Laboratory Test Results of this 18 year old single ply

Samples tested for thickness, tensile strength, elongation, dimensional change, seam strength. 95%+ samples met original membrane test results

Visual Analysis



Sustainability, impact damage

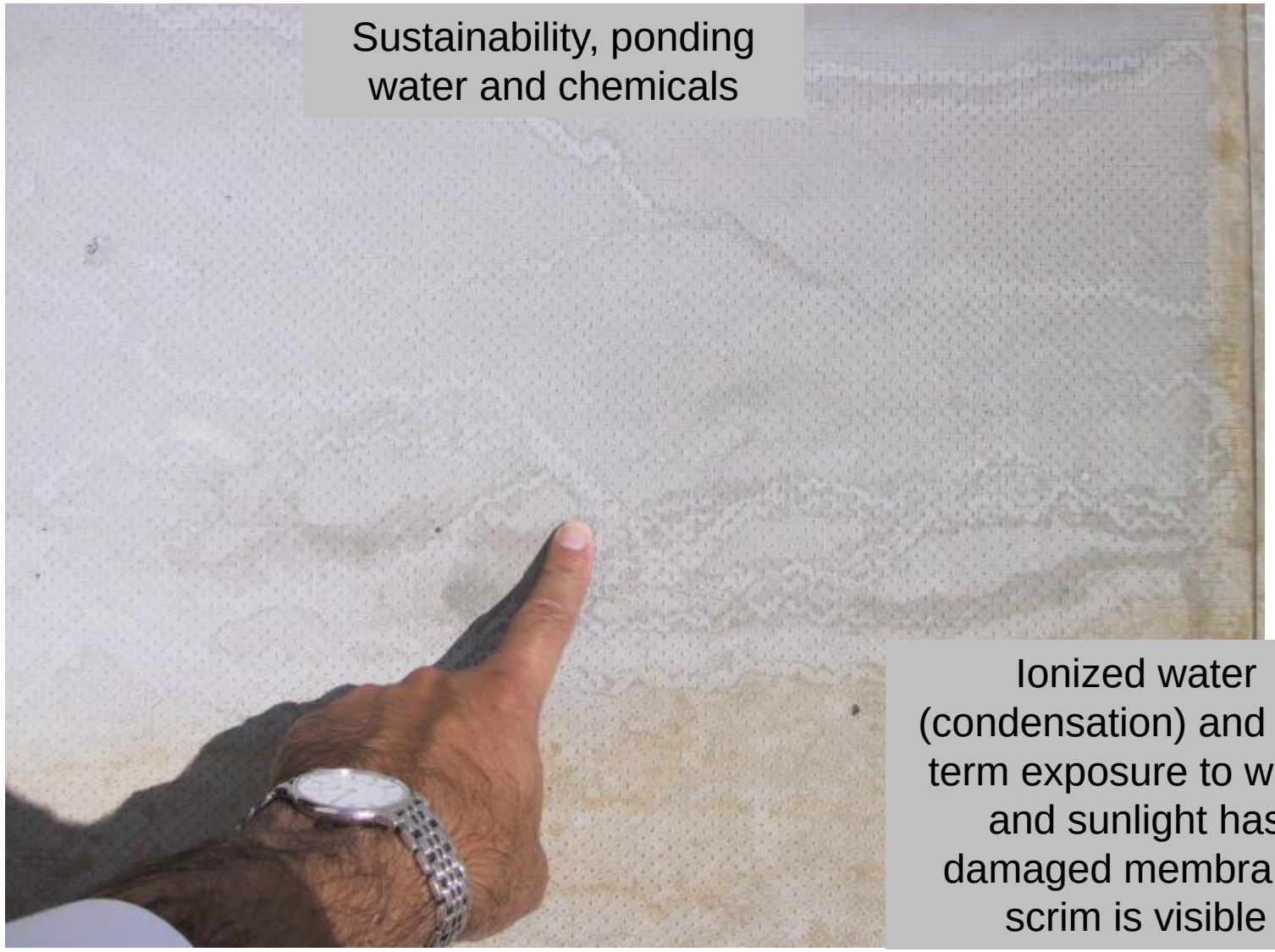
Membrane damage from unknown source

Tenant Improvement Work

New electrical pipe added, pipe jack set in mastic (not properly flashed with single ply) and wood block set in mastic (incompatible with PVC)

Cooling tower and condensate water leaking over roof

Sustainability, ponding water and chemicals



Ionized water (condensation) and long term exposure to water and sunlight has damaged membrane, scrim is visible

SUSTAINABILITY SCORE

1. MEMBRANE MATERIAL
   - Field areas of membrane performance good/excellent 20+ years
   - Easy to patch
2. TRAFFIC AND IMPACT DAMAGE
   - Susceptible from impact damage
   - Damage easy to identify and repair

SUSTAINABILITY SCORE

3. DESIGN
   - Original poor design of pipe supports caused damage
   - Poor design of roof drainage caused ponding water and damage
   - Poor design of condensation control mechanism caused damage

SUSTAINABILITY SCORE

4. MAINTENANCE
   - Lack of frequent inspection
   - Lack of proper roof protection during remodel construction
   - Lack of proper maintenance of HVAC equipment damaged the roof
   - New pipe penetrations not properly flashed (use of asphalt mastic)

LESSONS LEARNED (Single Ply)

Sustainability depends on many factors

- Membrane's ability to handle normal exposure to sun, rain and elements.
- In 20+ years, expect the roof to go through many different challenges
- When designing a roof, consider, building may undergo remodel, HVAC replacement, new electrical addition, etc.
- Impact of original design defects
- Owner's lack of frequent inspections, timely repairs, and use of proper patching techniques.

LEGAL ISSUES TO CONSIDER

- This section will include the following:
  - Maintenance vs. Repairs
  - Life expectancies
  - Express & Implied Warranties
  - Design-Build Role of a contractor
  - Statue of Limitations for defects/leak
  - How insurance pays for leak damage

Maintenance Vs. Repairs

- Inherent construction defects, requiring repairs, are not regular maintenance!
- Construction defects are the responsibility of the builder/contractor
- Properly designed and installed roof generally require very limited maintenance.
- Know what falls outside of regular maintenance

In Order To Define What is Maintenance and What is a Defect

1. Define life expectancy of roofing, sealants, windows, walls, waterproofing, painting, etc.
2. Define what is maintenance and what is repair
3. Leaks and repair of roofing, sealants, waterproofing, building exteriors, windows, within 10 years of completion = construction defect.

Life Expectancies…

- Sealants: 10 to 25 years
- Roofs: 10 to 40 years
- Below grade waterproofing: Life of the building
- Windows: Life of the building
- Window gaskets: 10 to 20 years
- Stucco: Life of the building
- Painting: 5 to 7 years
- Wood siding: 50 to 100 years

Owner Responsibility for Ongoing Maintenance

- Frequently Occurring Items Like:
  - Gutter cleaning.
  - Debris cleaning.
  - Annual inspection of roofs, sealants, windows, walls and exterior façade.
  - Tree trimming.
  - Low pressure power washing of roof and exteriors of building.

Owner Responsibility for Repairs on Occurrence

- Damage from trees and roots.
- Damage from cars and foot traffic.
- Damage from vandalism or abuse.
- Severe storm, earthquake, hail, hurricane, and other natural phenomena.
- Damage from oil and chemicals.

Defect – Not Maintenance

- Pipe jacks needing mastic repair because they are leaking
- Scupper needing repair due to failed solder joint
- Plies delaminating from edge flashing
- Mastic loose seams of capsheet
- Repair gravel not adhered to roof

Written Warranties, per RCI:

- Warranties can provide peace of mind
- They do not replace :
  - Sound design
  - Good materials
  - Quality workmanship
  - Proper maintenance

Express Warranty

- Words Warranty & Guarantee are generally interchangeable
- Term of warranty generally stated
- An agreement usually requiring owners signature
- Warranty generally requires that application meets material manufacturer's *published* requirements
- Does not include consequential damage
- May not include overburden cost
- May be limited to materials only
- May depreciate in value over time

Contractor Responsibility for Defective Construction

- If a 20 year type roofing system needs “repairs” other than true maintenance for repairs.
- If 10 year sealant types need replacement or fail in less than their life expectancy.
- If windows leak in fewer than 10 years.
- If other materials that do not last their normally expected lives, and fail within the first 10 years

Requirement of Owner, per RCI:

- Provide semi-annual inspection
- Provide roof maintenance
- Report leaks in writing immediately
- Use original contractor for repairs or addition to the roof system
- Keep records of leaks and repairs
- Store all documentation safely

DESIGN BUILD ROLE OF CONTRACTOR

- In the absence of a licensed architect or engineer of record, Contractor assumes role of Design professional.
- Roofing contractor can be held liable for code requirements
- Roofing contractor also has a responsibility to know when to call in a licensed professional

Statue of Limitation

- Most States allow for a 10 year statue of limitation for defective construction (even re-roofing)
- Most States have a 4 year statue for contractual liability
- Most States have a 4 year statue for obvious or “patent” defects
- Most States have a 3 year Statue for hidden or “latent” defects

Who Pays for Damage From Leaks

- If damage occurs within the statue of limitation, contractor's insurance company is generally liable for costs to fix damage.
- "Completed Operations" portion of the insurance coverage kicks-in.
- Even if contractor goes out of business, insurance company is on the hook.

Life Expectancies..

- Sealants: 10 to 25 years
- Painting: 5 to 7 years
- Hardboard siding: 25 years
- Roofs: 20 to 30 years
- Below Grade Waterproofing: Life of the building
- Windows: Life of the building
- Stucco: Life of the building

LIFE CYCLE COSTING

To obtain the equivalent annual cost
of a major expenditure, such as roof replacement,
you want to know the equivalent annual cost

Number of Years	Interest = 5%	Interest = 7%	Interest = 8%	Interest = 10%
4	0.2820	0.2952	0.3019	0.3155
15	0.0963	0.1095	0.1168	0.1315
20	0.0780	0.0944	0.1019	0.1175
30	0.0651	0.0806	0.0888	0.1061

Example: Assume a replacement cost for roof of $50,000
Assume Life Expectancy = 20 years
Assume Cost of money/interest = 5%
Life Cycle cost = $50,000 x .0780 = $3,900 per year
Compare that to: Yearly Maintenance Expense
Loss in Property Value
Cost of Continued Maintenance