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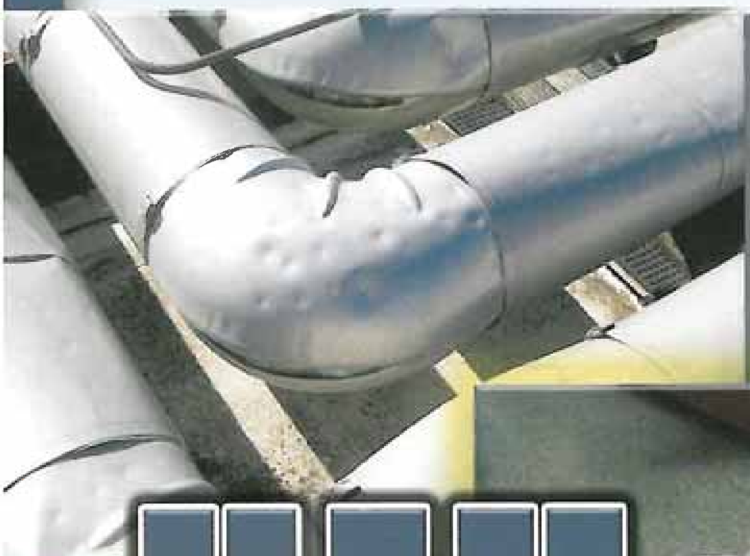

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FEATURES

SPECIAL INTEREST

DEPARTMENTS

On The Cover: Hail attacks all roof surfaces, but affects different materials in varying ways.

In This Issue: "Year in and year out, hail causes billions of dollars in losses to U.S. residential and commercial property. In 2005, Hurricane Katrina was the largest weather-related event of the year. The largest weather-related event of 2006, however, was an April 14 hailstorm that struck Indianapolis and generated 282,500 [insurance] claims."

— E. DeWayne Mitchell, page 31

THE DAY AFTER:

Documentation of Damage to Roofs from a Hailstorm and the Subsequent Restoration Efforts

By Karl A. Schaack, RRC, PE

On May 4, 2006, a hail-producing thunderstorm passed through the northwest portion of Harris County in the suburbs of Houston, Texas. The storm was relatively small in size–approximately five square miles–and was concentrated over an area predominantly populated by single- and multi-family residential dwellings, primary education facilities, and a few retail buildings.

The first reported hail (nickel- to quarter-sized)[1] occurred on this date at approximately 3:00 p.m. in northwest Harris County[2]. The storm moved in a westerly direction across Harris County, with the last reported hail at approximately 4:30 p.m. Central Standard Time being penny-sized particles. Penny- to teacup-sized hailstones[1] were reported at various times and locations within this storm. According to a HailTrax map from Weather Decision Technologies[3], the center linear portion of the storm was populated with hailstones 2 inches and greater in diameter, and the periphery of the storm was populated with hailstones 0.75 inch to 1.75 inches in diameter. Several homeowners located within the storm area confirmed reported hail sizes with photographic documentation of stones collected from accumulations on the grounds surrounding their homes (*Photos 1* and *2*). Heavy rains also accompanied the hail in this storm.

The purpose of this report is to provide observations compiled on the damages that

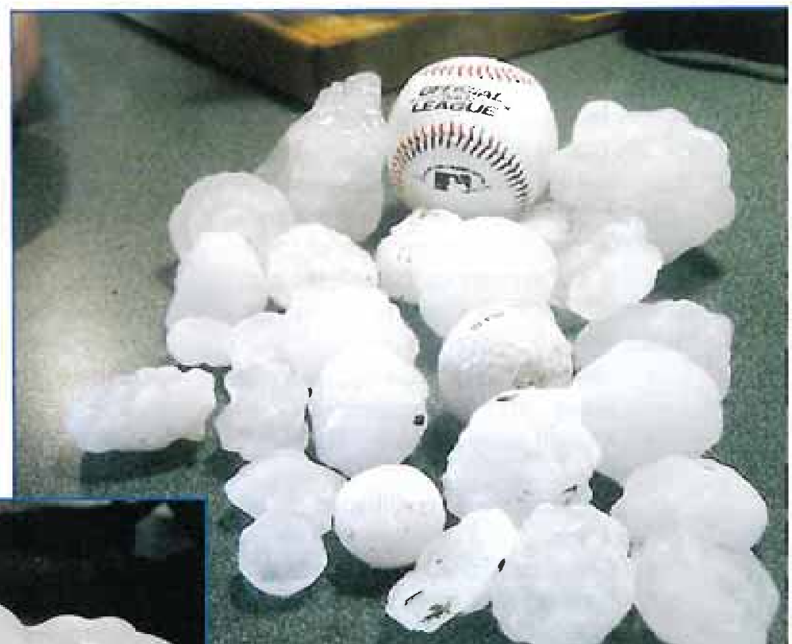


Photo 2 – Hailstones collected by homeowner on May 4, 2006[4].

Photo 1 – Hailstones collected by homeowner on May 4, 2006[4].

were documented on various roofs on several school facilities located within the subject area. A total of 15+ school facilities, including elementary, intermediate, and high schools, were situated within the subject zone that experienced the larger sized hail (2.0+ in), and an additional 10 facilities were located within the zone that experienced 0.75-in to 1.75-in sized hail.

The first signs of trouble occurred when school district maintenance personnel received calls from two adjacent schools (a high school and a middle school) about significant leakage through the roofs on the buildings. The day after the storm, the district asked Price Consulting, Inc. (PCI) personnel to visit the facilities that were experiencing water infiltration. Upon observing the physical damage that had occurred, PCI, together with the school district, performed roof inspections on the remaining schools within the district. These inspections were performed on the other schools that were close to the noted high school and then progressed to the other facilities located throughout the district. The roofs on 16 school campuses and surrounding administration/support buildings were determined to have been affected by the hailstorm.

The typical roof membrane/covering on these facilities consisted of thermoplastic single-ply membranes. Due to the relatively large size and the different ages of buildings, the roof systems on the affected high school consisted of a variety of systems, including:

- Gravel-surfaced built-up, thermoplastic single-ply membranes,
- Asphalt-composition laminated shingles,
- Standing-seam prefinished metal panels,
- Coated corrugated metal panels,
- Spray-applied polyurethane foam with both elastomeric coating and loose gravel, and
- Premanufactured aluminum panels (simulating wood shakes).

The single-ply membranes on the affected schools were typically installed with rigid insulation board over existing gravel-surfaced built-up systems. However, on newly constructed buildings (less than five years old) the single-ply membranes were installed over insulation board and the roof deck. The common insulation board that was installed under the single-ply membranes was extruded polystyrene and, to a lesser extent, polyisocyanurate. The single-ply membranes consisted of traditional PVC, PVC blends, CSPE (Hypalon), CPE, and TPO. At isolated locations, the single-ply membranes were installed directly over lightweight insulating concrete fill or plywood sheathing. The ages of these single-ply membranes ranged from 1 year to greater than 15 years. The single-ply roof systems were mostly mechanically attached assemblies and a few fully adhered assemblies.

Metal panel roof systems were installed over open framing systems and secured to structural steel purlins. Standing seam metal panel roof systems consisted of 16-in-wide, pre-finished, 24-gauge galvanized steel panels with a T-shaped seam. Corrugated metal panels were either 24-gauge or 26-gauge galvanized steel that was through-fastened into the underlying support structure. The corrugated metal panels had been coated with either an aluminum-pigmented, bituminous-based coating or an acrylic-based elastomeric coating. The standing seam metal roof was approximately 10 to 12 years old, and the corrugated metal roofs were 20+ years old.

The built-up roof system consisted of:

- Round river gravel embedded in an asphaltic flood coat,
- A membrane comprising four plies of fiberglass felts with asphalt interply moppings,
- Fiberglass rigid board insulation adhered with asphalt to a mechanically-attached base sheet over a lightweight insulating concrete fill, and
- Metal form deck.

Base flashings at curbs consisted of composition felt with a bituminous coating. The subject roof also contained an elastomeric bellows expansion joint cover. The built-up roof system was believed to be 15 to 20 years old.

Both the laminated fiberglass shingles and the aluminum simulated-wood shingles were installed over a felt underlayment and plywood sheathing. The fiberglass shingles were approximately four to five years old, and the aluminum shingles were older than 12 years.

Various skylight structures were also present on several of the roofs. These included traditional acrylic-domed, individual curbed units, combined multiple-domed, acrylic units, and large structural skylight assemblies with composite panels. The structural skylights were either pyramidal-style, pitched-tent style, or flat panel, sloped in one direction. The composite panels were composed of either a fiberglass fabric or a fiberglass glazing. These panels were the same age as the roof and ranged from 10 to 20+ years old.

Other rooftop items that were the subject of documentation included exterior insulated ductwork, insulated waterlines, light-transmitting panels on greenhouses, and various equipment covers. The insulated duct consisted of faced-fiberglass insulation adhered to sheet metal and then coated with an elastomeric coating.

OBSERVATIONS

Single-ply Membranes

Damage observed on the single-ply membranes on the schools located within the area subjected to the hail greater than 2 inches in diameter included large punctures completely through the membrane, exposing the underlying insulation (*Photos*

Right: Photo 4 – Large puncture in single-ply membrane.

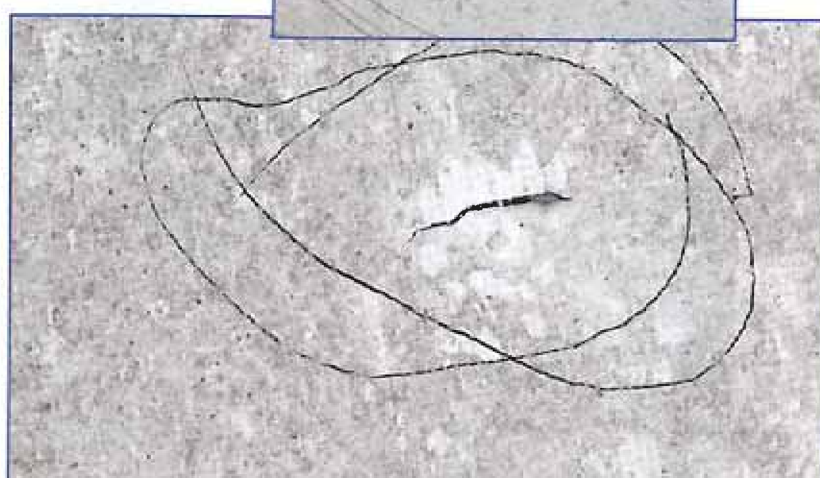
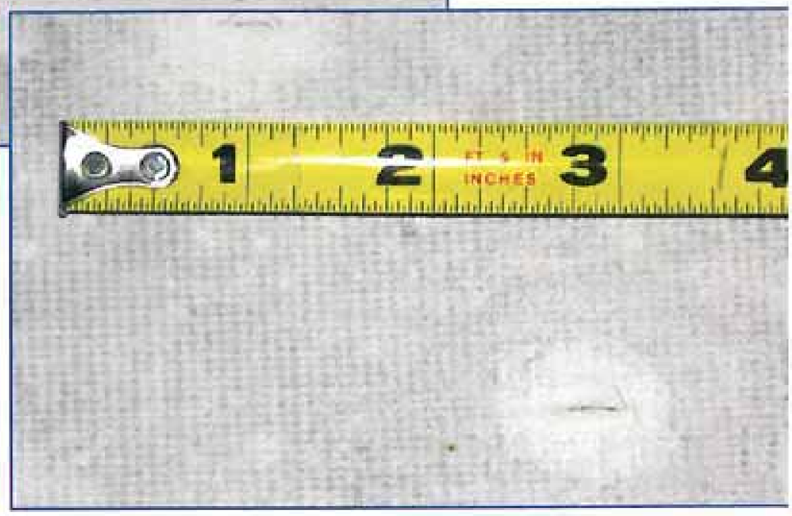


Photo 3 – Large puncture in single-ply membrane.

Photo 5 – Spiral fractures in single-ply membrane.

Below: Photo 6: – Spiral and linear fractures in single-ply membrane.



3 and *4*). This level of damage was widespread but sporadic, with no uniformity across the roofs. These punctures were found in approximately one to four locations within a 100-sq-ft area.

The more prominent damage that was observed on thermoplastic single-plies consisted of numerous cylindrical or spiral-shaped fractures in the membrane (*Photos 5* and *6*). Other, less obvious damage consisted of small linear cracks in the membrane. This type of damage was consistent on the various types of PVC single-ply membranes that were installed over rigid insulation. (Note: Separator sheets were installed between the PVC membranes and EPS.) The single-ply membranes that appeared to perform better were installed directly over plywood sheathing. Cylindrical fractures were not as widespread and numerous on the CSPE and CPE sheets, even though these membranes may have been older than other PVC membranes.

Spray-Applied Polyurethane Foam

Similar damage was also observed on the spray-applied polyurethane foam roofs on the high school. This damage ranged from spiral-shaped cracks in the elastomeric coating to punctures through the coating, exposing the underlying foam core (*Photos 7* and *8*). The foam was more readily damaged in areas containing blisters. However, physical damage was also observed where the foam was sound and intact.

Built-up Roof

There was no obvious evidence of any physical damage on the gravel-surfaced, built-up roof membrane. Physical damage did occur to an elastomeric bellows expansion joint cover. Many large punctures (approximately 2 inches in diameter) were observed throughout the length of the bel-

Photo 7 – Hail impact on SPUF.

Photo 8 – Hail impact on SPUF.

lows (*Photo 9*), which was somewhat brittle and weathered.

Metal Roofs

Observations of metal roofs indicated that damage was more cosmetic than damaging to the weatherproofing ability of the panel. Indentations were observed in prefinished metal panels, but the paint finish did not appear to have been affected. On the coated corrugated metal panels, chips were observed in the coating, which exposed the underlying metal core (*Photo 10*). Large indentations were observed in light-gauge corrugated metal panels that were installed over building entrances (*Photo 11*).

Photo 9 – Punctures in weathered expansion joint.

Photo 11 – Large dents in metal canopy.

Photo 10 – Fractures in coating on metal roof.

Photo 12 – Large impact on ridge shingle.

Photo 13 – Damage to edges of ridge shingles.

Shingles

Damage observed on asphalt shingles varied from granule loss and breakage at unsupported ends and sides to large abrasions and indentations (*Photo 12*). Physical damage was more prevalent along the ridges (*Photo 13*).

Skylights

Damage to skylights included fracturing of glazing material (i.e., fiberglass and acrylic). See *Photos 14* and *15*. Large punctures and holes completely penetrated the glazing material (*Photos 16* and

Photo 14 – Fracture in fiberglass skylight.

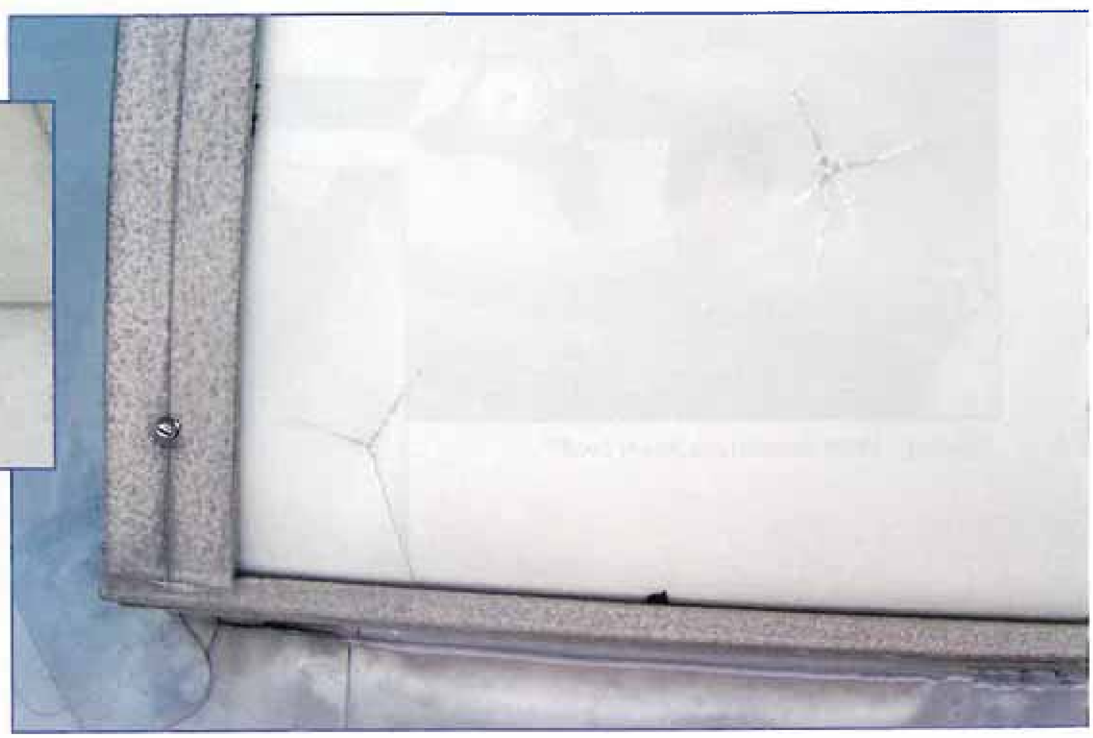


Photo 15 – Fracture in acrylic skylight.

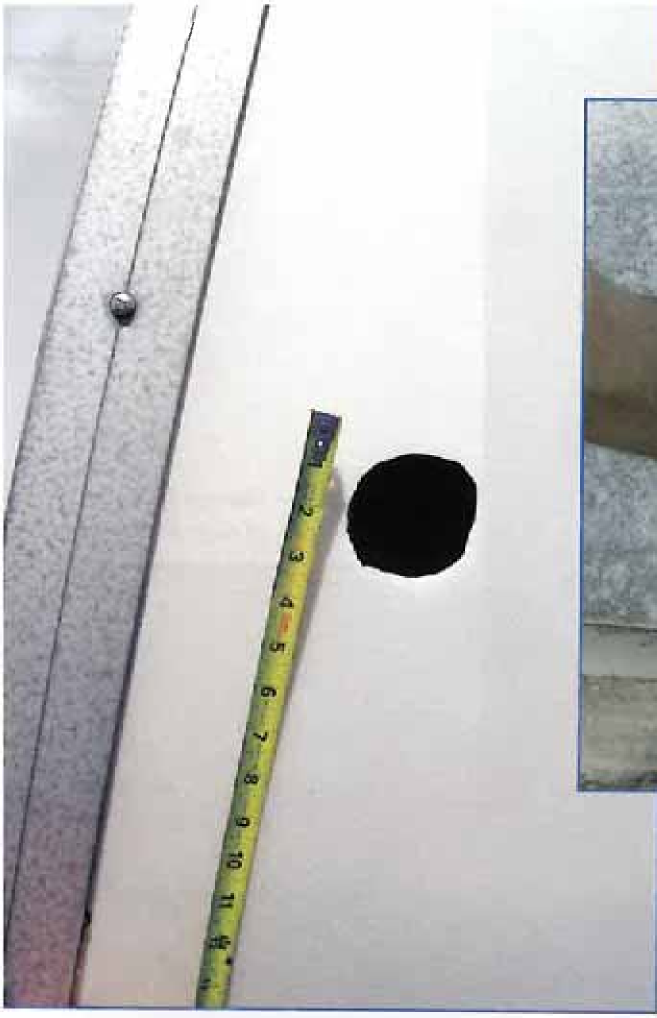


Photo 16 – Hole in barrel skylight.

Photo 17 – Puncture in fabric skylight.

17). Damage on the fiberglass sandwich panels occurred only on the top layer of fiberglass. Some domes did not exhibit any visible damage.

Miscellaneous Items

Indentations were observed on many light-gauge sheet-metal equipment hoods (*Photo 18*), as well as metal jackets on insulated water piping (*Photo 19*).

Both corrugated fiberglass-reinforced panels and flat-glass panels utilized as sloped glazing for greenhouses sustained damage. Punctures and isolated fractures were noted in fiberglass-reinforced panels (*Photo 20*). Glass panels sustained widespread breakage (*Photo 21*). Exterior insulated ductwork exhibited similar large punctures extending through the fabric covering and into the fiberglass insulation (*Photos 22* and *23*).

Photo 18 – Dents in metal equipment hood.[5]

Photo 19: Dents in metal jacket on insulated piping.

Photo 20 – Puncture in corrugated fiberglass panel.

Photo 21 – Significant damage to glass panels.

EMERGENCY REPAIRS

Immediately after the storm, school district personnel performed emergency repairs on damaged single plies until more permanent repairs could be implemented. This was to alleviate water infiltration into the buildings and to prevent subsequent damage to interior finishes and goods. Emergency repairs consisted of wiping the area of the membrane clean with a damp towel (to remove surface dirt), gunning a dollop of polyurethane sealant over the puncture, and troweling or tooling sealant to form a cap bead over the damaged area (*Photo 24*). This repair was performed in each area that exhibited an obvious puncture or fracture through the membrane. It was effective in stopping direct water infiltration during brief rain

Photo 22 – Punctures in exterior insulated duct.

Photo 23 – Punctures in exterior insulated duct.

Photo 24 – Applying sealant to damaged areas on single-ply.

events. However, during longer-lasting rainstorms, which resulted in water collecting on the surface of the roof, water infiltration was experienced through the small, spiral-shaped fractures and into the building interior. This was problematic on the affected single-ply systems that were installed directly over insulation board and a steel deck.

Those areas where the single-ply was installed over an existing built-up roof or over lightweight insulating concrete fill did not experience as widespread water infiltration into the buildings. Due to this problem, additional protection for the building occupants and goods was necessary, again until a more permanent solution could be initiated. On these subject roofs, an elastomeric coating was applied to the surface of the single-ply membranes (*Photo 25*). The surface of the single-ply membrane was initially swept clean of loose dirt, and then a wet rag, mop, or sponge was swept across the surface to collect additional dirt. Power washing was not performed, due to the chances of further introduction of moisture into the roof and building. After the surface preparation, a single layer of an elastomeric coating was applied with a roller to the roof membrane and flashings. This repair process was performed on a total of three schools and was found to be effective in alleviating further water infiltration until the roofs could be replaced.

Photo 25 – Applying coating to damaged single-ply membrane.

ADDITIONAL FINDINGS

During the roof-removal process of the damaged PVC single-ply membranes, unique observations related to physical damage that occurred to single-ply membranes were made. Pieces of the membrane, approximately 3 ft x 3 ft, were extracted from the roof after they were removed from the substrate by the contractor. Samples that were removed were considered to be representative of the overall membrane condition where actual physical damage was visible on the top surface of the membrane.

Upon initial review, physical damage was evident at approximately four to six random locations (*Photos 26* and *27*). However, after cleaning the top surface of

Photo 26 – Top view of typical sample.

Photo 27 – Close-up view of typical damage on top side.

the membrane and upon closer visual inspection, physical damage was observed at three to four locations, which were considered to be relatively small, at 1/4 in to 1/2 in long. This extent of damage was not readily visible when walking the roof or handling the uncleaned sample at arm's length, due to the small size of the actual damage (1/8 inch to 1/4 inch in length) and to dirt accumulation on the membrane top surface.

The more startling revelation occurred when the samples were turned over to gather further observations on the backside of the membrane. Damage was observed not only at the locations corresponding to the top surface spots but also at additional problem locations throughout the samples (*Photos 28* and *29*). Since the underside of the membrane was relatively clean, the damage was readily evident.

The damage, when viewed on the top surface (*Photo 30*), was circular- or spiral-shaped (or concentric rings). However, when viewed from the bottom, the damage typically appeared to be more "star-shaped," or composed of linear cracks intersecting at midpoint or propagating from a central focal point (*Photo 31*).

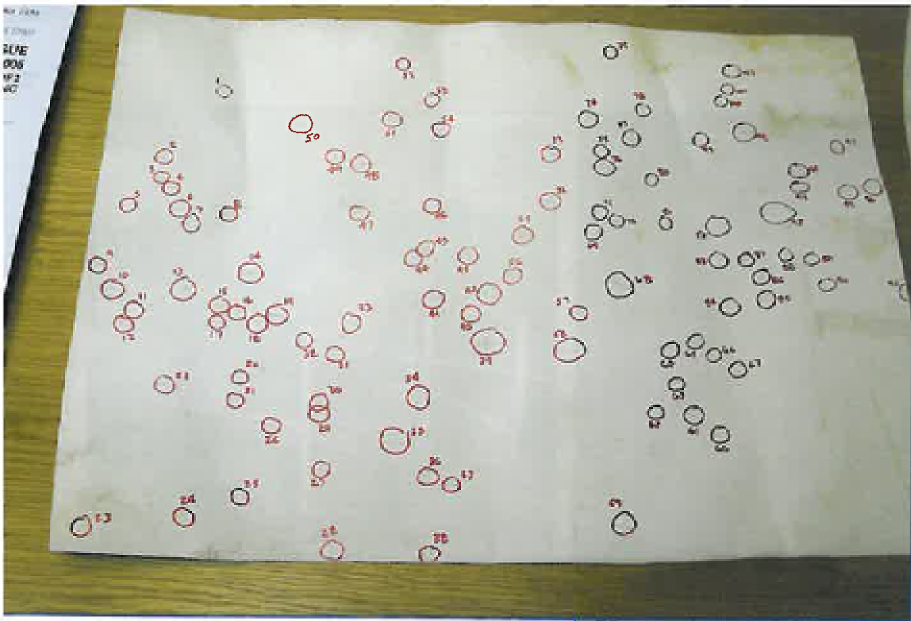
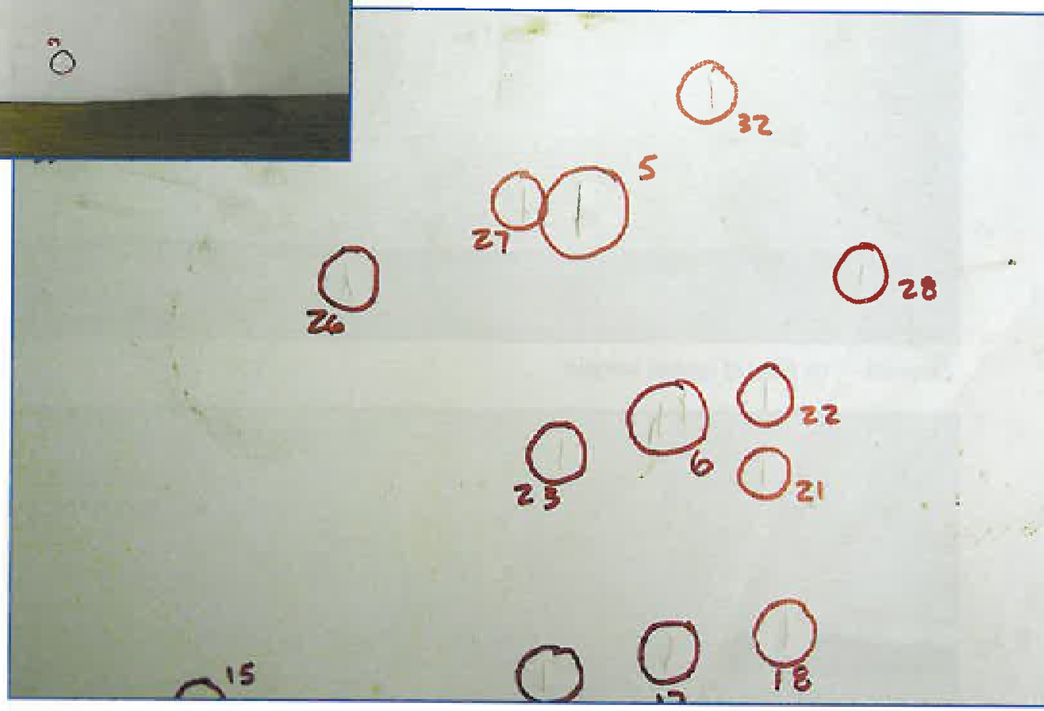


Photo 28 – View of damage from bottom of sample.

Photo 29 – Close-up view of damage on bottom side.



Observations gathered from these samples prompted PCI to perform further investigation of additional roofs where little damage had been reported from hail impact and the roofs were deemed repairable and not slated for replacement. These schools were located on the periphery of the storm containing the larger-sized hail. The school-district personnel, PCI personnel, and insurance representatives had initially inspected these roofs. Damage of the membrane that could be attributed to hail impact was observed at approximately four to eight locations at each school, with roofs ranging in size from 40,000 sf to 100,000+ sf.

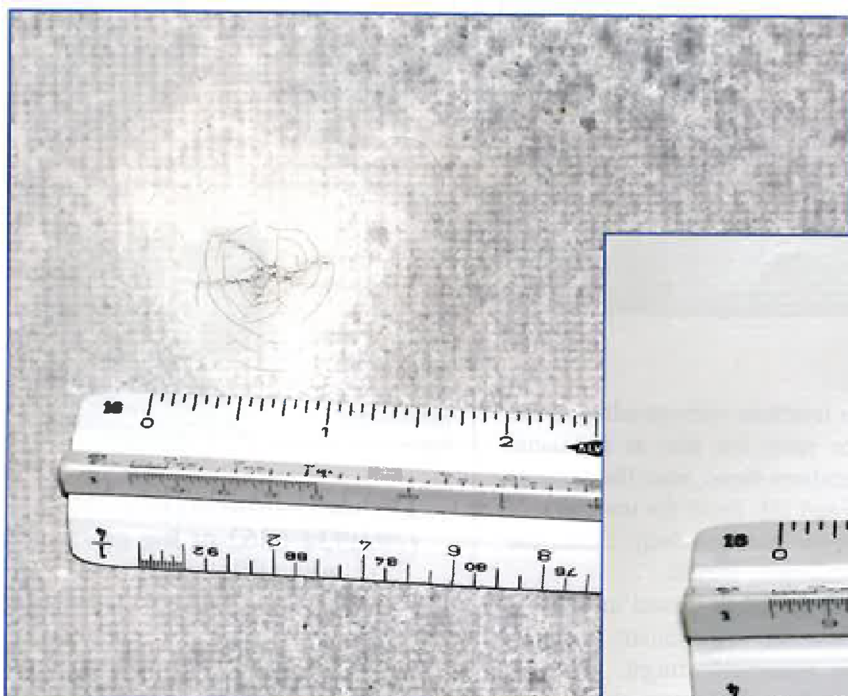
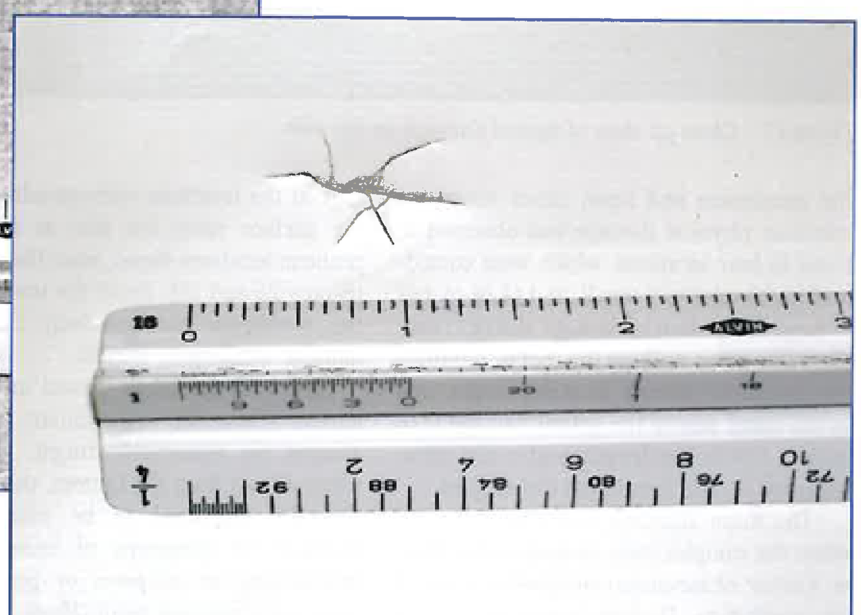


Photo 30 – Typical fracture in top side of membrane.

Photo 31 – Typical view of fracture from bottom of membrane.



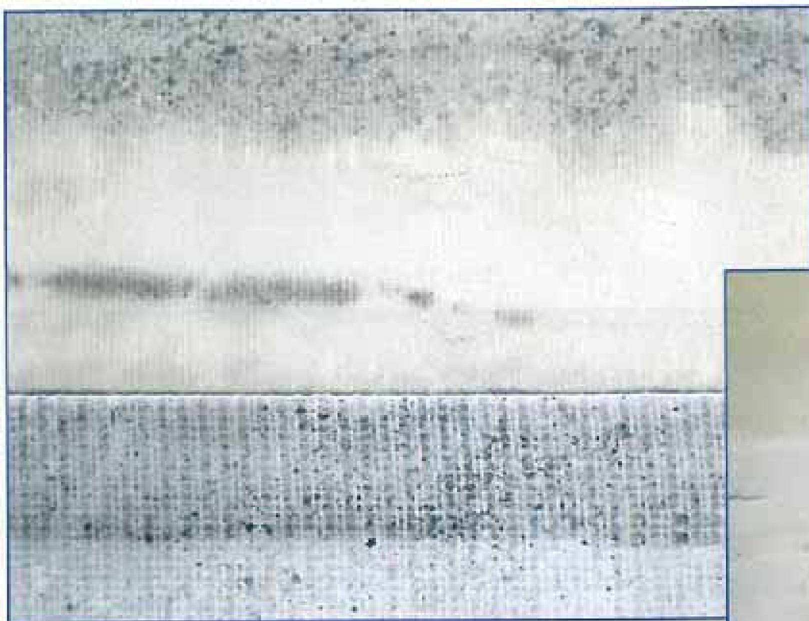


Photo 32 – View of top side of membrane (no damage visible).

Photo 33 – View of damage on bottom of membrane.

More detailed inspection consisted of peeling back a cut-section of the single-ply membrane at one of the previously identified locations that exhibited physical damage. Both the top surface and the underside of the membrane were inspected more closely. A magnifying eyepiece was utilized to visually inspect suspect areas. A total of three schools were reinspected in the aforementioned manner. At one of these schools, similar conditions were revealed when the underside of the membrane was inspected in a closer manner (*Photos 32* and *33*). Based on this more detailed inspection, an additional roof was identified as having sustained physical damage from the hail that otherwise might not have manifested until years

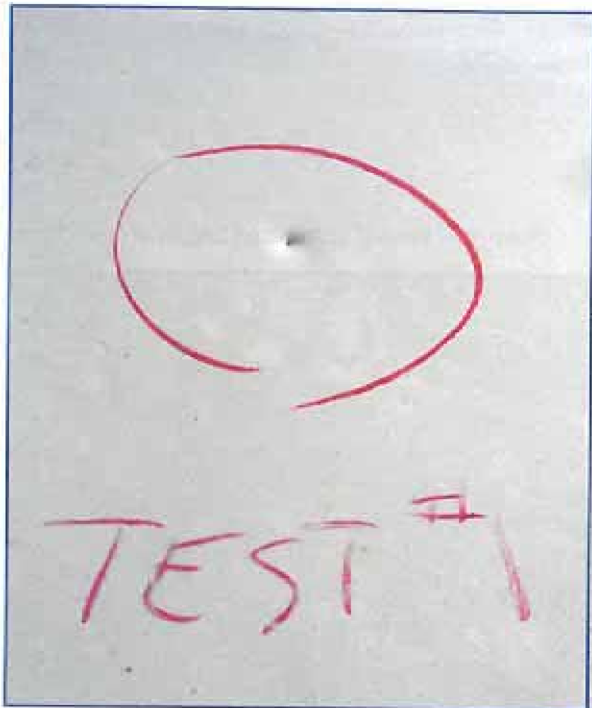
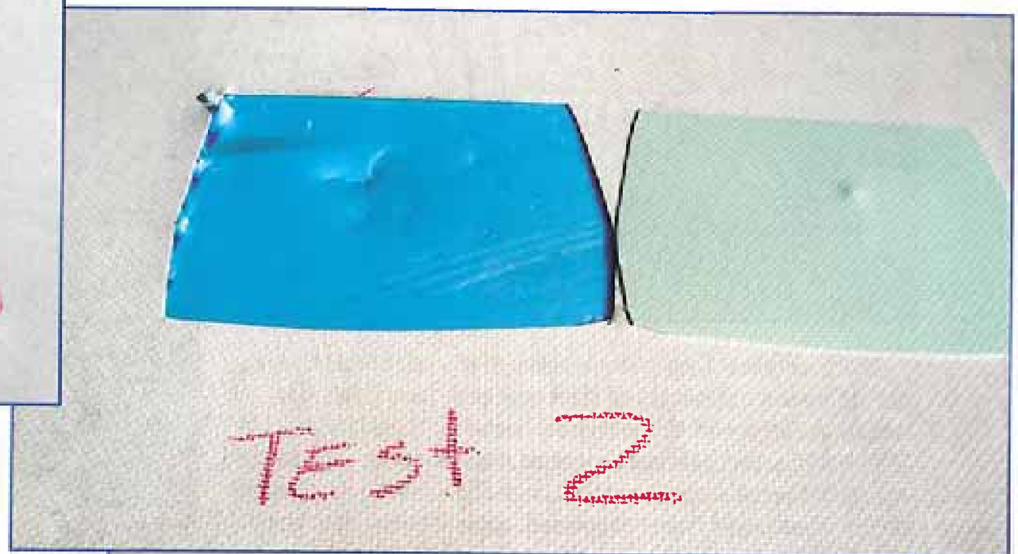


Photo 34 – Depression in membrane.

Photo 35 – Large depression in insulation board.



later, as the fractures enlarged and water intrusion resulted.

At two schools with relatively new roofs that were less than five years old (one Hypalon over extruded polystyrene and one TPO over expanded polystyrene), the original inspection did not reveal any obvious evidence of damage. However, upon further visual inspections at later dates, suspect areas were observed that indicated possible damage. These suspect areas typically resembled thumb-sized depressions in the membranes (*Photo 34*). Again, additional and more detailed inspections and analyses were performed. Upon removal of the membrane, relatively large depressions (over 2 inches in diameter) were observed in the top surface of the insulation board (*Photos 35* and *36*). These inspections included close-up, in-place visual inspections (with the aid of a magnifying eyepiece) and collection of membrane samples to perform photographic laboratory documentation.

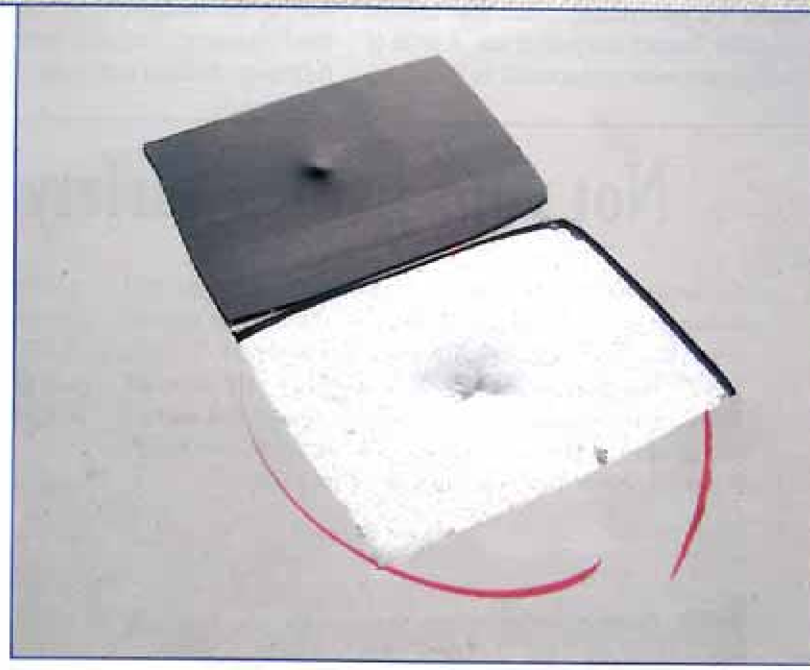


Photo 36 – Large depression in insulation board.

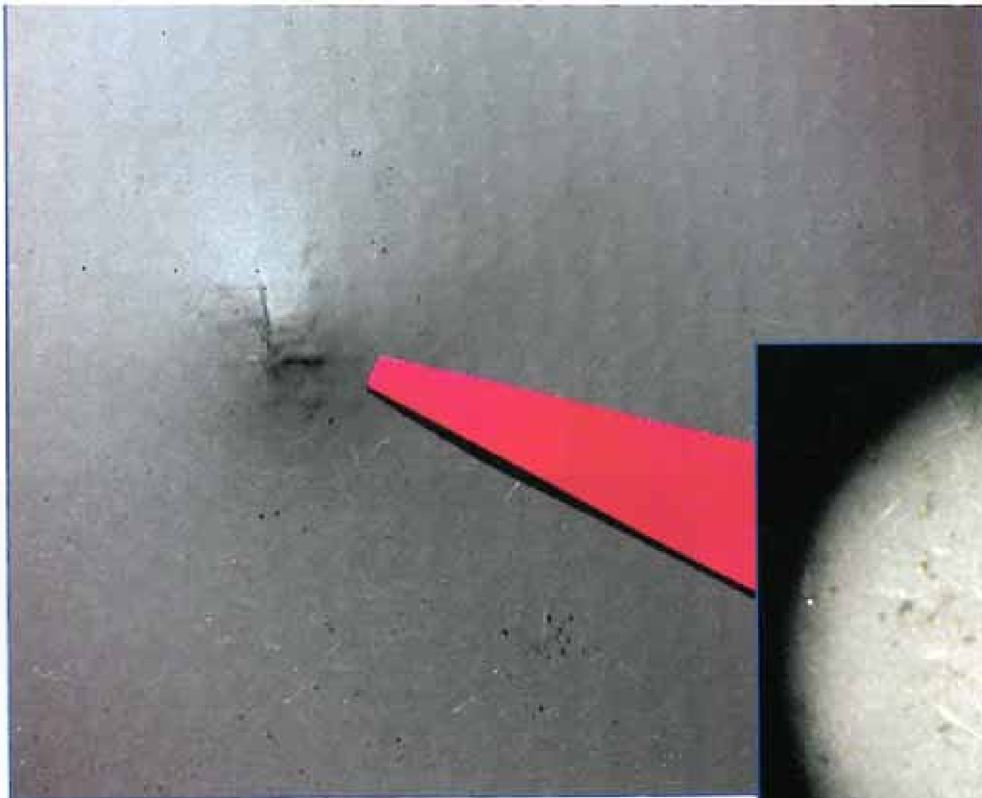


Photo 37 – Close-up view of underside of membrane at depression.[5]

Photo 38 – Magnified view (10x) of depression showing minor crease in membrane.[5]

These subsequent inspections revealed that both membranes had sustained damage at isolated locations.

The damage was small linear fractures in the membrane polymer coating, either on the top or bottom surface (*Photos 37 through 40*). Due to the isolated location and minimal frequency of this level of damage, the affected areas were repaired. This damage appears to have been caused by the larger-sized hailstones. These membranes also did not appear to have been affected by the smaller-sized hailstones.

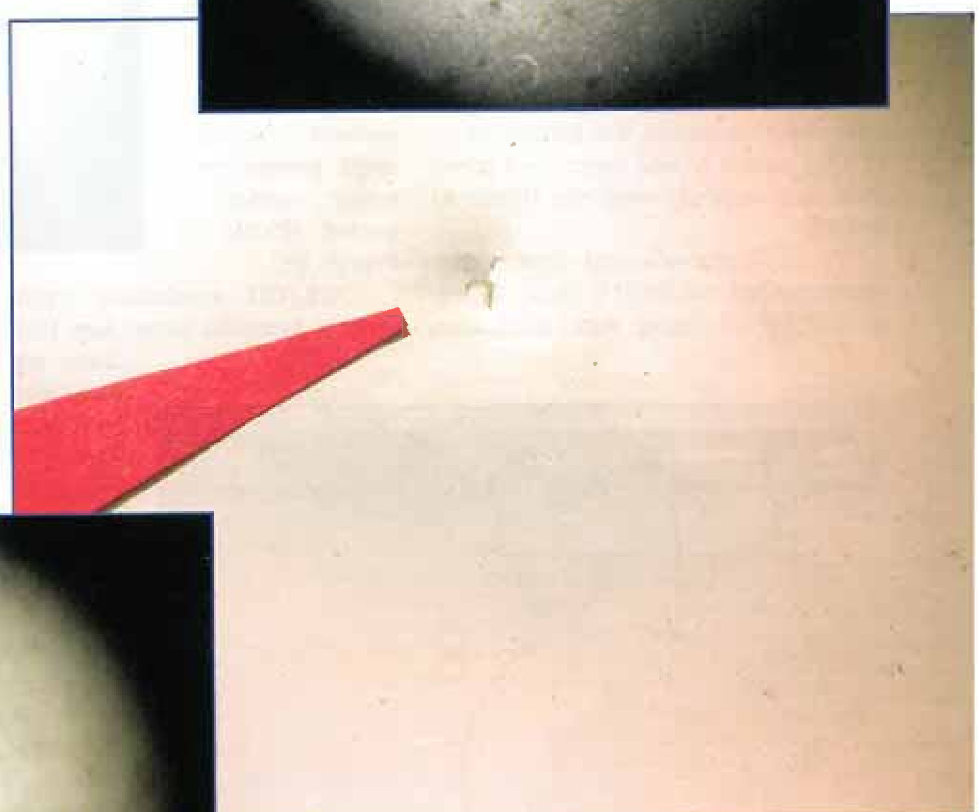


Photo 39 – Close-up view of top side of depression.[5]

Photo 40 – Magnified view (10x) of top side of depression showing minor crack in membrane coating.[5]

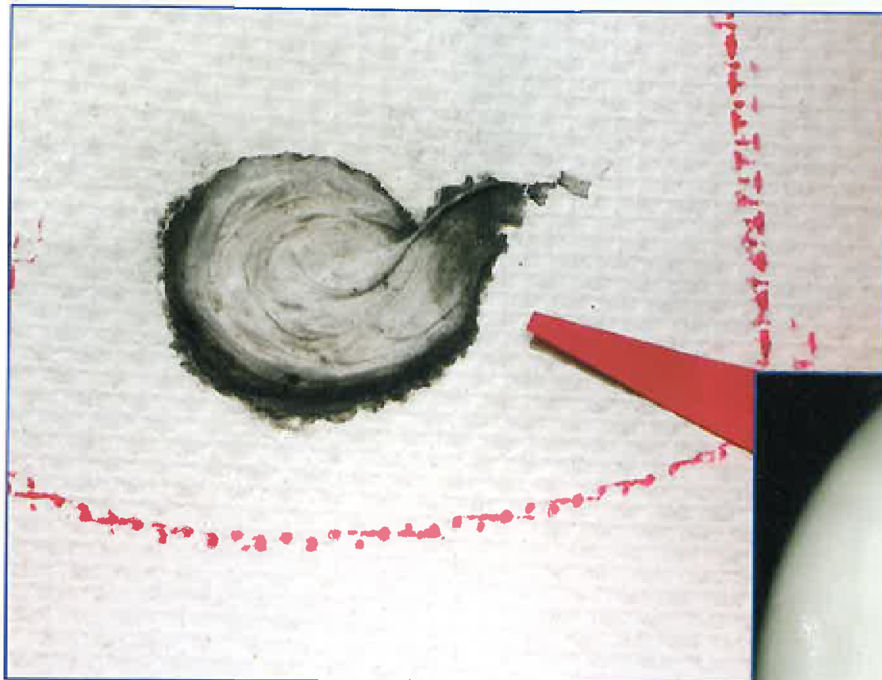
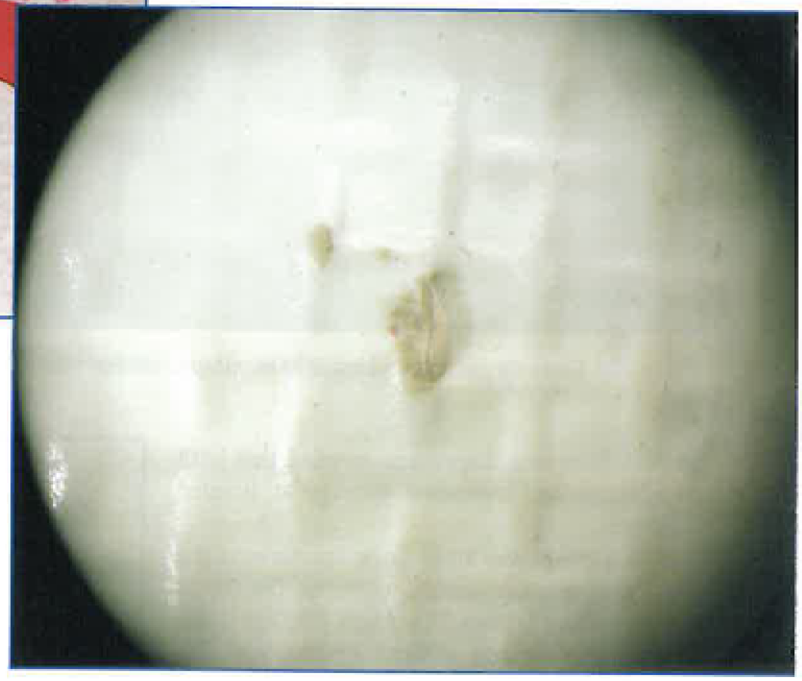


Photo 41 – Sealant applied over damaged area.[5]

Photo 42 – Close-up view (10x) of underside of membrane showing sealant permeating the fracture.[5]



SUMMARY

The author gathered important information from the observations made during the various inspections and subsequent repairs.

The "temporary" emergency repair, using urethane sealant, was found to be an effective means to seal larger-sized punctures on a single-ply membrane (*Photos 41* and *42*).

The application of a single layer of elastomeric coating was found to be an effective method for alleviating water infiltration through the numerous fractures in the single-ply membrane for a relatively effective time frame (six months) and, in the author's opinion, could provide even longer service if needed (*Photos 43 through 45*).

CSPE/CPE membranes appeared to perform somewhat better than PVC membrane types, or were less affected on a widespread basis (i.e., small fractures were not present; only large punctures were noted).

PVC membranes sustained considerably more damage than what was evident on the top surface. It also appeared that for specific sizes or forces of impact, no visible damage was initially evident on the top surface of the membrane, but the physical damage was evident initially on the underside of the membrane. However, damage or fracturing on the top surface at these locations will manifest at a later time, as the membrane experiences contraction, expansion, and differential movement. This condition appears to be a result of the underside of the membrane experiencing excessive tensile forces as it is depressed downward during hailstone impact. Yet the top side of the membrane is put into compression during the impact and is visibly unaffected at the time of impact.

Thermoplastic membranes appeared to have sustained dramatically more damage in areas that had been subjected to repeated, cyclic, or concentrated flow or ponding water on the roof surface. These areas were surrounding internal roof drains, below downspout discharge ports, or on lower roof areas where water drained directly over the edge of a higher roof elevation (i.e., steep-sloped roof). The author believes that the water has caused accelerated weathering of the membrane compared to other areas of the same roof.

Photo 43 – Sealant and coating applied over membrane.

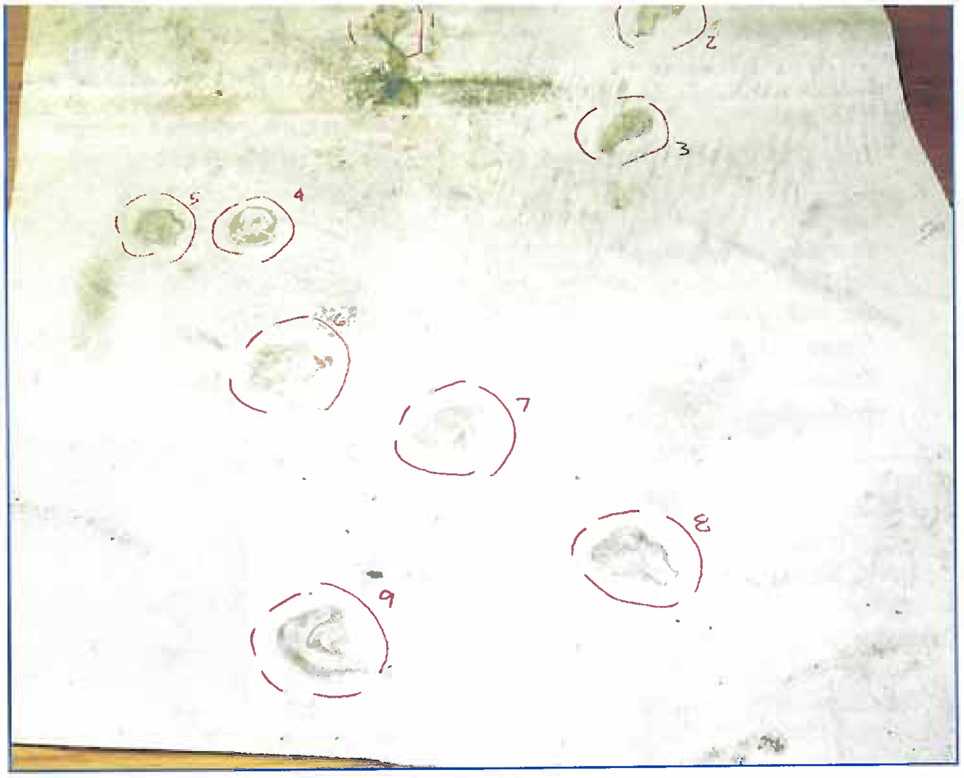


Photo 44 – Sealant and coating applied over membrane.

Other, more obvious findings were also confirmed:

1. The lone gravel-surfaced, built-up roof performed better than most other coverings, even though it was relatively older.
2. Single-ply membranes installed over a more dense substrate (i.e., plywood sheathing, lightweight insulating concrete fill, etc.) also appeared to perform better compared to membranes installed over insulation board.
3. Damage sustained by metal roof coverings was more cosmetic in nature and did not appear to affect the weatherproofing integrity of the metal unless the panels had been covered by a liquid-applied coating for protective purposes. In addition, the baked-on finish ("Kynar/Hylar") on metal roofs also appeared to perform well, with the panels becoming dimpled without any noticeable damage to the paint finish.

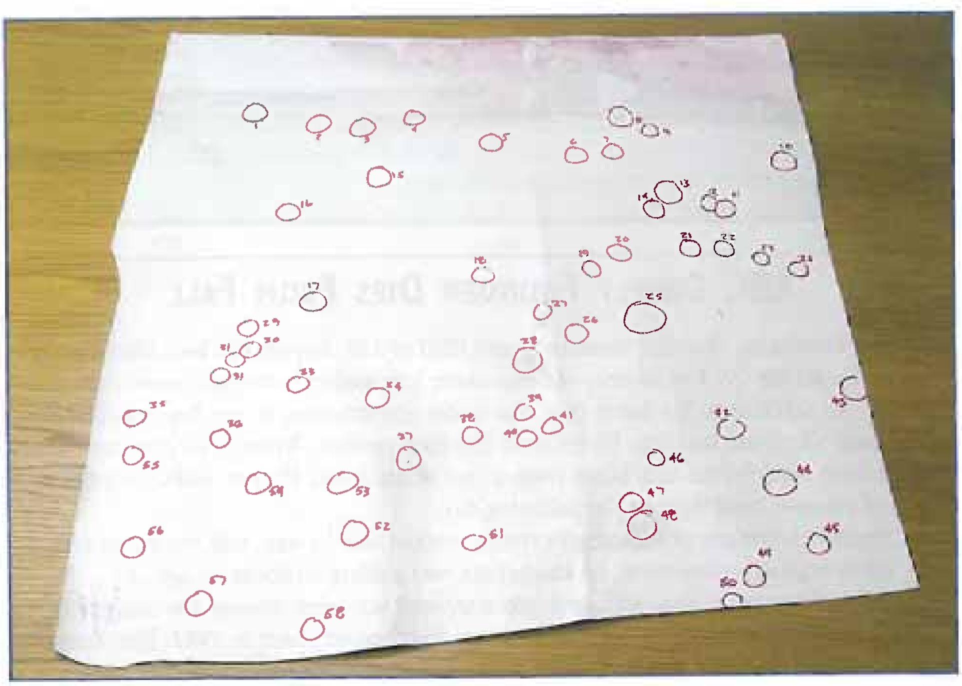


Photo 45 – View of underside of membrane showing numerous areas of damage.

BUILDING ENVELOPE KNOWLEDGE ASSESSMENT

Test your knowledge of building envelope consulting with the following questions developed by Donald E. Bush Sr., RRC, FRCI, PE, chairman of RCI's RRC Examination Development Subcommittee.

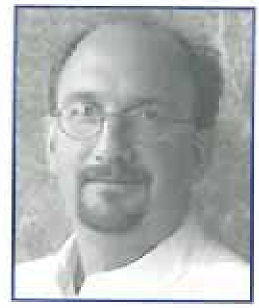
1. **How many climate zones are identified in the 2006 International Energy Conservation Code (IECC)?**
2. **What four criteria must be met to be classified as a marine zone?**
3. **What is the definition of a dry zone?**
4. **What is the definition of a moist zone?**
5. **What interior design conditions are required by the 2006 IECC?**

Answers on page 24

REFERENCES

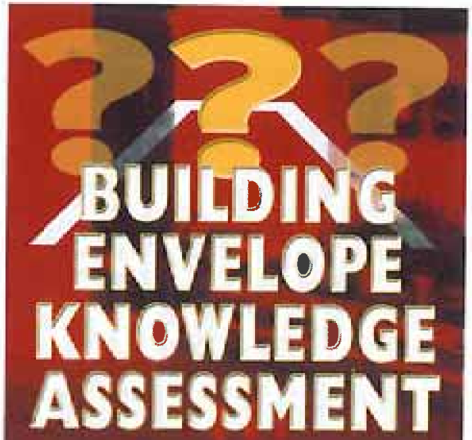
1. Crenshaw, Vickie and Jim D. Koontz, "Hail: Sizing it Up," Weather Decision Technologies Inc., www.weatherforensics.com.
2. National Weather Service and National Climatic Data Center, "Storm Data and Unusual Weather Phenomena."
3. Information produced by Weather Decision Technologies and provided by Steve Patterson with Roof Tech.
4. Photo courtesy of school district personnel.
5. Photo courtesy of Steve Patterson with Roof Tech.

Karl A. Schaack, RRC, PE



Karl A. Schaack, RRC, PE, is president of Price Consulting, Inc., a roofing and waterproofing consulting firm in Houston, Texas. Mr. Schaack has a bachelor's degree in civil engineering from Clemson University. He is a registered professional engineer in Texas, South Carolina, and North Carolina. Karl is a member of RCI, the Roofing Contractors Association of Texas, and the Gulf Coast Chapter of RCI. He is an RRC and a former director of RCI's original Region IV. In 2007, he won the Horowitz Award for best technical article in *Interface* for 2006.

Building Envelope Knowledge Assessment



Answers to questions from page 23:

1. **Eight.**
2. **A. Mean temperature of the coldest month between -3°C (27°F) and 18°C (65°F).**

   B. Warmest month mean temperature of <22°C (72°F).

   C. At least four months with mean temperatures over 10°C (50°F).

   D. Dry season in summer. The month with the heaviest precipitation in the cold season has at least three times as much precipitation as the month with the least precipitation in the rest of the year. The cold season is October through March in the northern hemisphere and April through September in the southern hemisphere.
3. **The zone is not marine, and the annual precipitation in inches is less than 0.44 times the annual mean temperature in °F.**
4. **Locations that are not marine and are not dry.**
5. **The interior design temperatures used for heating and cooling load calculations shall be a minimum of 72°F (24°C) for heating and a minimum of 75°F (24°C) for cooling.**

Reference: 2006 International Energy Conservation Code

Cash Posthumously Awarded Dudley and Cullen Awards

ASTM International has honored the late Carl G. Cash, PE, by posthumously awarding him the Dudley Medal and the Cullen Award, as well as establishing a new committee award in his name. Cash was a senior principal with Simpson Gumpertz & Heger Inc.

Cash received the Charles B. Dudley Medal Award for his paper, "Porosity of Glass Fiber Felts Used in Built-Up Roofing." In the paper, Cash discussed problems with built-up bituminous roofing using glass fiber felts for reinforcing. His proposed specification changes reduced the occurrence of membrane failures.

Cash also received the 2007 William C. Cullen Award from ASTM Committee D-08 on Roofing and Waterproofing for his contributions and commitment to the committee and the industry. In addition, D-08 established the Carl G. Cash Award, which will recognize ASTM Construction Committee members who provide outstanding research-oriented contributions that advance building envelope technology.

Cash was an ASTM member since 1975, working on D-08 and D-22 on Air Quality. A past D-08 chair, Cash led Subcommittee D-08.20 on Roofing Membrane Systems. He was an ASTM Fellow and past Award of Merit winner and received its Walter C. Voss Award in 1998. He was a member of the NRCA, the NSPE, RCI, and SPC. He earned a bachelor's degree from Wagner College and a master's from Fairleigh-Dickinson College.

ABC Supply Founder Dies From Fall

Ken Hendricks, founder, chairman, and CEO of ABC Supply Co. Inc., died from a fall on December 20. The 66-year-old billionaire had walked out of his house onto the floor of an addition to his home that was under construction to see how much work had been completed that day. He fell from this flooring deck. Widespread news services mistakenly reported he had fallen from a roof of his Rock, Illinois, home. Hendricks died of massive head injuries the following day.

Hendricks, the son of a Janesville roofer, worked side by side with his father growing up. A high school dropout, he started his own roofing business at age 21.

Tired of having to deal with multiple suppliers scattered around the country, he and his wife, Diane, started a national supply distribution chain in 1982. The company celebrated its 25th anniversary in 2007, with 6,000 employees in 390 locations nationwide.